Commissioning and Start-up of Alba Line 6 Project Using EGA DX+ Ultra Technology

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Abstract

"Success is where Preparation and Opportunity meet". This was a founding principle for the Aluminium Bahrain (Alba) team as it prepared and completed the commissioning and start-up of Alba Line 6 Smelter Project, which became the world's largest single site aluminium smelter outside China. From First Hot Metal achieved after a 24 months construction period (six months faster than industry standard) to Last Hot Metal, the commissioning and start-up of Line 6 Project required innovative ways to manage the interfaces between construction, the various equipment vendors and the operating plant in start-up. This paper presents the comprehensive start-up preparation framework employed by Alba, along with the coordination of the start-up of the DX+ Ultra Technology potline that allowed seizing each opportunity to maximize aluminium production.

Keywords: Aluminium smelter start-up preparation, change management, smelter commissioning and start-up, smelter operations readiness, workarounds, resilience.

1. Alba Line 6 Project

Aluminium Bahrain B.S.C. (Alba), one of the largest and modern aluminium smelters in the world, was established in 1971 as a 120 000 tonnes per annum smelter. With three successive expansions, the smelter capacity has grown to more than 1 million tonnes in 2018. Alba's Line 6 Expansion Project is one of the largest brownfield developments in the region. It will boost the smelter's per-annum production by 540 000 tonnes, bringing its total production capacity to 1.5 million tonnes per year in 2020.

With a CAPEX of approximately 3 billion US$, the Line 6 Expansion Project involves the construction of a new 1.4 kilometers long potline utilizing Emirates Global Aluminium's (EGA) proprietary DX+ Ultra Technology, a new Carbon plant, a new Casthouse, a 1 800 MW Power Station and other industrial services. The Line 6 Expansion Project makes Alba the world's largest single-site aluminium smelter outside of China and a significant economic boost for the Kingdom of Bahrain.

In June 2015, Alba Board approved the Line 6 Expansion Project. Bechtel was appointed as the engineering, procurement and construction management (EPCM) contractor in 2016 and work on the Front-End Engineering Design (FEED) study was initiated. The project Notice to Proceed (NTP) was received in January 2017. A number of Lump Sum Turn Key (LSTK) contracts were awarded early in the project to support the fast pace project schedule.

The construction site-works started in the second quarter of 2017. First Hot Metal (FHM) was successfully achieved on 13 December 2018, 24 months from NTP – six months faster than industry standard. Last Hot Metal was achieved on 31 July 2019, 31 months from NTP, making it the fastest aluminium smelter project in the GCC. This was accomplished with exemplary safety statistics making it also the safest start-up.

1.1. EGA DX+ Ultra Technology

The DX+ Ultra technology is an advancement of the DX+ Technology successfully implemented at EGA Al Taweelah Potline 3. In 2014, five DX+ Ultra demonstration cells were built and commissioned at EGA Jebel Ali. The DX+ Ultra cells have the same dimensions as the DX+ cells but incorporate amongst key changes, new cathode design, decreased cell-to-cell centerline and modified busbar thus savings on CAPEX and OPEX. The end-result is a best-in-class production per building surface area [1, 2].

Alba Potline 6 consists of 424 reduction cells arranged in two potroom buildings connected by one central passageway at the mid-point of the potrooms and a passageway at the north and the south end of the potlines. The central passage is equipped with a gantry crane for the transfer of the Pot Tending Machines (PTMs) between potrooms, the PTM maintenance shop, and the lining/ de-lining facility. The PTMs are supplied by Fives/ECL under LSTK contract. Two Gas Treatment Centers (GTC for north and south) and associated alumina and anode cover material handling systems were provided by Fives/Solios also under LSTK contract. Key target performance parameters for the DX+ Ultra in potline 6 are given in Table 1.

Table 1. DX+ Ultra target key performance parameters for ALBA Potline 6.

Parameter	Units	Value
Line current	kA	460
Current efficiency	%	94.5
Metal production	kg/pot-day	3501
Net cell voltage*	V	4.07
DC net specific energy consumption*	kWh/kg Al	12.83
Net carbon consumption	kg C/t Al	410

*Net voltage and net specific energy exclude contribution of busbar linkages.

1.2. Carbon Plant

The carbon plant (Carbon 4) is composed of a 55 t/h anode paste plant using the Fives/Solios Rhodax technology. The paste plant was delivered under LSTK approach. It shares some installations with the paste plant built for the Line 5 expansion. The Xolios vacuum anode forming mould was sized for the anode dimensions required for potline operations at 460 kA.

The anode baking furnace (ABF) is a Riedhammer open top baking furnace with 8 pits per sections, 68 sections and four production fires designed to operate at 26 h fire cycle. The ABF was supplied under LSTK approach by Riedhammer, including the ABF ancillaries (furnace cranes NKM), fume treatment centre (Danieli) and firing ramps (Innovatherm).

The anode rodding shop (ARS) supplied by Outotec includes a casting station with 3 induction furnaces. The cold loop is designed to process cold butts and includes bath recycling plant using rotary breaker technology. The carbon recycling section is linked to the existing plant. The rodding shop was supplied under LSTK approach.

1.3. Casthouse

The casthouse (Casthouse 4), is composed of a 10 kg standard ingot chain (Befesa) for value added product (VAP), a sheet ingot vertical direct chill (VDC) facility producing slabs and tee ingots and a billet VDC producing various diameters and alloys (both VDC are from Wagstaff). The billet casting complex includes continuous and batch

homogenization furnaces. Six metal holding/remelting furnaces supply metal to the casting machines. Three furnaces have 165 tonnes capacity each and three furnaces have 85 tonnes capacity each. As part of an initiative to increase the overall casting resilience of Alba, a manual London Metal Exchange (LME) sow casting line was retrofitted to an existing building.

1.4. Start-up Strategy

The initial start-up strategy was based on the plan to have the first ½ of the potline up to central passage (Set-1) ready for energization and start-up (FHM) on 1 January 2019. This was supported by the start of anode production in the third quarter of 2018 and having the first casting complex (10 kg ingot chain) ready for FHM. The second half of the potline (Set-2) was to be ready for energization on 1 March 2019. With a baseline start-up rate of 2.3 pots per day, the Line 6 start-up was to be completed by 1 July 2019. Table 2 gives the key start-up milestones.

The project was a fast pace project with 24 months construction to FHM. The strategy to achieve these aggressive milestones included the award of numerous LSTK contracts upon NTP. Envisaged as well, were innovative construction methods for potline including extensive use of pre-fabricated elements. The preparation for the commissioning and start-up of the various production facilities also included preparing possible workarounds to allow for possible early start of the potline.

Table 2. Key start-up milestones.

Key Milestone	Actual Date	From NTP (months)
Notice to Proceed (NTP)	1 January 2017	0
First Hot Metal (FHM)	12 December 2018	24
10-kg Ingot Chain ready for FHM	18 December 2018	24
First Green Anode	23 December 2018	24
First Rodded Anode	23 January 2019	25
First Baked Anode	20 February 2019	26
1st Half ready for start-up	1 March 2019	26
2nd Half ready for start-up	1 June 2019	29
Last Hot Metal (LHM)	31 July 2019	31

2. Start-up Preparation Strategy

Although Alba had successfully executed three previous brownfield expansions and numerous major projects, the last major expansion (Line 5) had been done over 15 years ago and many of the skill sets required for the Line 6 start-up preparation efforts were not available in Alba anymore. The use of the EGA DX+ Ultra technology was new to Alba and the commitment of resources to the Line 5 recovery efforts led Alba management to secure external support to assist with the start-up preparation.

2.1. Start-up Preparation

In August 2017, Alba appointed STR Consultants (STR) to assist in the start-up preparation phase. STR is a Canadian based consultancy specialized in Operations Readiness, Commissioning and Start-up of large industrial projects. STR was involved in similar start-up preparation support mandate in the Middle East with Sohar Aluminium, Qatar Aluminium and

Emirates Global Aluminium (EMAL Phase 1 and Phase 2) where it developed good expertise with the EGA DX technology smelter configuration commissioning and start-up.

Alba appointed a Line 6 Start-up Director to oversee the preparation of the operating smelter organization for the upcoming Line 6 Expansion. A dedicated Start-up Preparation organization was established to cover all areas of plant operations (see Figure 1). The area representatives in the start-up organization were called "Ambassadors" as they were the representatives of their "mother" organizations.

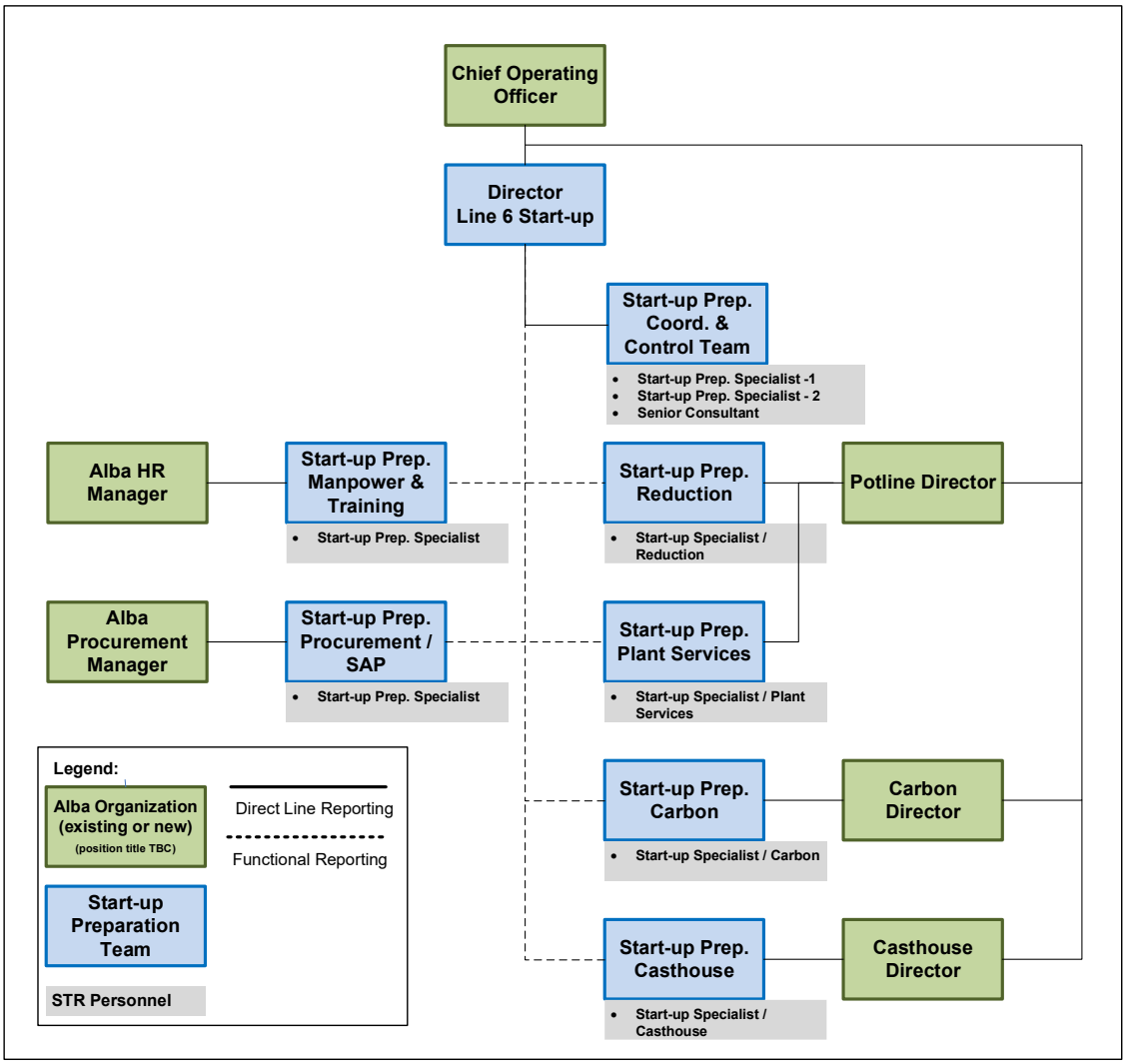

Figure 1. Line 6 start-up preparation organization.

2.2. Start-up Preparation Framework

Alba and STR developed a standardized and systematic approach to the development and execution of start-up preparation (often referred to Operational Readiness) based on ensuring that all preparatory work in the key departments of the business were effectively completed in time for the start-up activities in each area. The five areas of focus are presented in Figure 2. The sections below describe the key work performed during the preparation phase.

2.2.1. Manpower Readiness

Operations of the new Line 6 smelter is based on a workforce of 507 permanent employees supplemented by contract labor for "low skills" positions. The general approach for the manning of Line 6 operations was to assign 50 % of the workforce from the existing smelter (experienced employees) and 50 % from the newly recruited workforce.

Onboarding and training of the new employees was done in four waves, with the various positions aligned with the smelter commissioning schedule. Following basic internal training, new employees underwent dedicated training profile in their assigned area. This training was a combination of theoretical and on-job training. Specific Vendor training for new Line 6 equipment was also organized and synchronized with the commissioning of the plant.

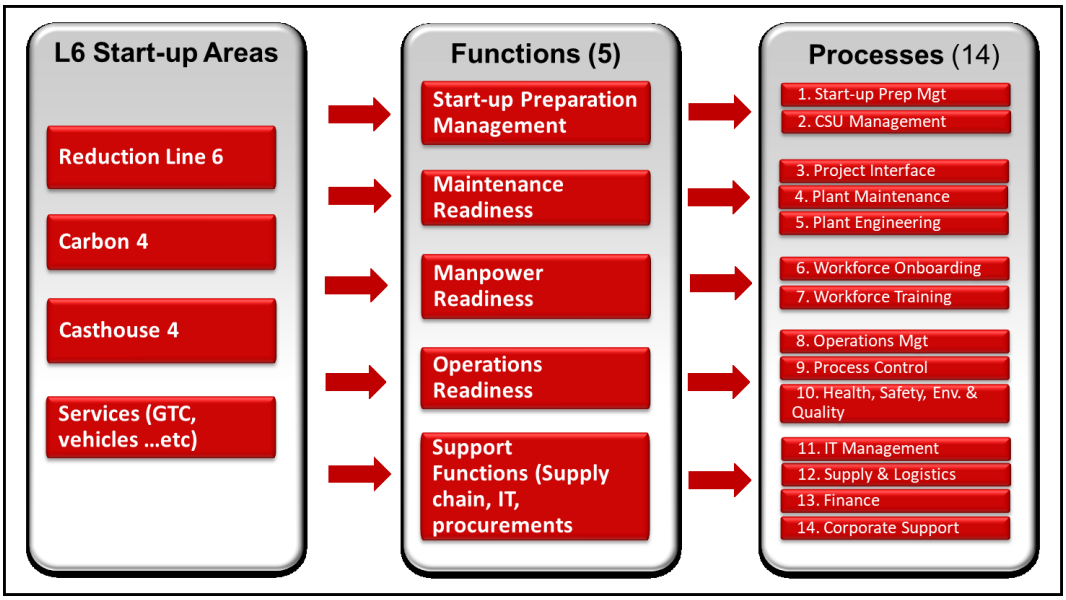

Figure 2. Line 6 start-up preparation structure.

2.2.2. Operations Readiness

The main focus of this was to ensure that the standard operating procedures (SOP), job safe practices (JSP) and other safety, health and environment requirements, tools and equipment for operations, process control and monitoring systems, the automation and information technology systems that support operations and generate the data necessary for the overall "business" management were in place for start-up.

STR has observed in most of the projects that the EPCMs have difficulty to properly expedite the various vendor Operations and Maintenance (O&M) documentations required by the operations team during the preparation phase. Late availability of this documentation resulted in numerous re-writes of SOP and JSP. This also impacted the ordering of the various tools and equipment.

Fresh from the Line 5 recovery efforts, Alba team also included extensive work to develop "resilience" action plan for Line 6 facilities. Failure mode effect and criticality analysis (FMECA) were conducted on the critical plant systems in order to identify the "resilience" requirements. These ranged from additional training, purchase of extra spare parts and development of specific contingency plans for manual workarounds. A specific budget was allocated for the resilience action plan and the implementation was included in the overall start-up preparation plan.

Given the aggressive milestones for FHM and the start of production activities in all areas, contingency plans to allow commissioning and start-up to begin without all the required systems available were developed. These "workarounds" proved instrumental in achieving the project milestones.

2.2.3. Maintenance Readiness

The maintenance readiness key activities included the development of the "SAP" maintenance structure and loading the associated Master Data, the selection and ordering of spare parts and organizing the maintenance training.

Although the O&M documentation and spare parts list from vendor were received late, considerable work was done by the area maintenance teams to review the vendors' recommended spare parts lists and to rationalize the ordering. Efforts were made to identify alternative suppliers for non-vendor specific parts to promote local supply sources. This resulted in substantial savings to Alba as well as securing local alternatives as shown in Table 3.

Table 3. Data on spare parts.

Description	Data
Spares parts items recommended by vendors	+ 40 000
Material already in Alba stocks or duplicates	+ 20 000
Spares added in SAP	+ 16 000
Spares ordered from OEM	45 %
Spares ordered from local suppliers	55 %

2.3. Start-up Preparation Management

A Start-up Preparation Master Plan was developed for the start-up preparation activities of each areas. Progress was monitored through twice-weekly "stand-up" meetings where each area's progress KPIs were reviewed and weekly formal coordination meetings where the "Ambassadors" would report to the Line 6 Start-up Director. Weekly interface coordination between the operations and maintenance teams and the project team (at area level) were also initiated in the fourth quarter of 2017.

It was clear in everybody's mind that the Alba Line 6 Project would be a fast pace execution and would require detailed coordination between the construction/project and operations and maintenance teams in order to achieve or surpass the target milestones.

A "Master Steering Committee" (MSC) to review progress of both the project/construction and operations start-up preparation work as initiated. The MSC also provided an escalation and issues resolutions process. Starting three months before FHM, a series of workshops were held between EPCM and Start-up Preparation team to develop the "Go/No-Go" criterion for FHM and subsequent milestones and to prepare the various workarounds necessary to achieve the milestones.

During the start-up period itself, regular "Command Center" meetings were held to coordinate the construction and start-up activities. A detailed mass balance tool was developed to monitor the progress of the start-up in all areas and conduct simulations on possible start-up scenarios. This was an important tool for the planning of the various workarounds and contingencies.

2.4. Change Management

In addition to the start-up preparation described above, another crucial element for the success of the Line 6 project involved some cultural changes in the Alba organization. Alba was moving from a 1 million tonnes smelter to a greater than1.5 million tonnes in the space of less than a year of operational ramp-up.

To be successful, this transformation required the involvement of all levels of Alba leadership. Starting in early 2017 with Project NTP, Alba's management began a number of initiatives to prepare the organization for Line 6. The first initiative was related to increasing the leadership training for shop floor supervisory levels positions. Another initiative involved the roll-out of a series of "Word of Wisdom" (WoW) cards containing leadership advices and motivational quotes. It is in the first WoW card that the slogan "Success is where Preparation and Opportunity meet" was introduced to drive Line 6 preparation work.

A series of "recommended readings" covering themes related to preparation, hard work and determination was also implemented. The key reference books were further analyzed in dedicated workshops for the leadership team. The favorite of the Alba team and the driver of the final campaign to promote the Line 6 start-up was "Extreme Ownership: How U.S. Navy SEALs Lead and Win" [3]. In anticipation of the hard work required for making Line 6 a success, the quote associated with the book *"The Only easy day was yesterday"* became part of the Alba colloquial language.

To increase awareness to the safety and risk associated with the start-up, a campaign using the orange color to promote "stop and think" before all actions was launched. A "Line 6 Safe Start-up" pledge from all leadership team was also taken.

There is no doubt in Alba's management that these organizational culture changes and the Extreme Ownership theme were key to the success of the Line 6 start-up.

3. Potline 6 Start-up

In order to "de-risk" the start-up of the potline and provide an opportunity for early start-up, in May 2018, the project decided to build a "temporary cross over bridge" (TCOB) allowing energizing a group of 48 pots and to proceed with pot start-up activities in December 2018. In addition to allow early start of metal production, the "48 pots" (actually 40 pots started to avoid disturbance from the magnetic field of the nearby TCOB) provided a vital "test bed" for training and to refine the various start-up procedures ahead of the remaining 376 pots.

The central passage cross over bridge was energized on the 1st of March 2019. Pot start-up in the remaining of Set-1 achieved start-up rate of 3.77 pots per day (with peak at 6 pots per day) and was completed on 17 April 2019.

In order to minimize the pause of start-up activities between Set-1 and Set-2, construction work on Set-2 prioritized the welding of the DC busbar circuit and potlining. The approach was to energize Set-2 and continue construction work (such as structural steel, pot superstructure and other) in magnetic field environment. Construction work was adapted for the magnetic field and innovative approaches were developed. It also required extensive coordination of construction activities within the energized potline and a strict "Permit to Work" process (PTW) as the operations team became the controlling authority following the energization of Set-2. Last Hot Metal (LHM) was achieved on 31 July 2019. The average start-up rate in Set-2 was 4.5 pots per day (with peak at 8 pots per day) and the overall start-up rate was 3.88 pots per day. Figure 3 presents potline 6 start-up rate.
EGA mobilized a Technology Transfer team to Alba to support the start-up. Extra EGA resources were also requested by Alba to support the accelerated start-up. At the time of this article, most

potline KPI were settling down within the design criteria targets or surpassing them. These are good signs to confirm the first commercial application of the DX+ Ultra technology will be delivering on its performance guarantees.

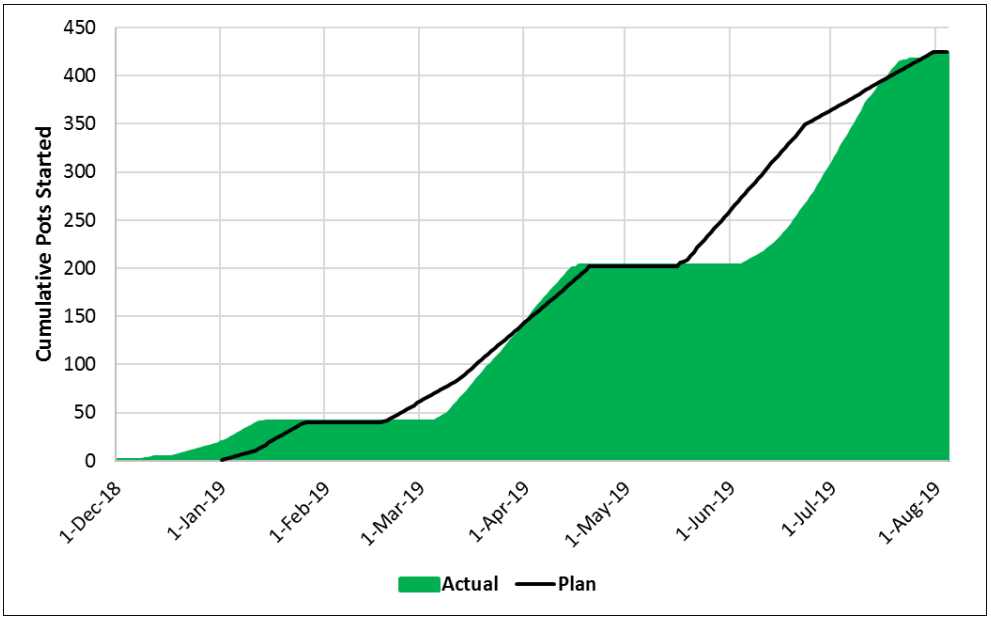

Figure 3. Line 6 start-up rate.

4. Carbon Plant Start-up

One of the resilience capabilities was the ability to manually seal Line 6 anodes at a rate sufficient to support operations of Line 6. It was decided to test this capability using purchased baked anodes and provide sealed anodes to begin pot preparation activities. The first manual sealed anode was produced on 24 July 2018 and over 5000 anodes were sealed to provide support the preparation and operations of the 48 pots and mitigate the delays in the construction of the new rodding shop.

The “hot loop” of the new rodding shop was commissioned in January 2019 with manual load/unload of anodes. Manual slot cutting was also implemented using concrete sawing equipment. Over 20 000 anodes were prepared using the manual slot cutting system before the rodding shop became reliable.

Manual workarounds were implemented to clean butts and remove carbon and thimbles. Bath from the manual butt cleaning was recycled in the existing facilities. This imposed heavy strain on the existing facilities but with proper planning and mitigations, the full potline bath recycling was possible. Carbon recovered from manual butt stripping was only partially recycled. A significant inventory of carbon has been accumulated before the new carbon recycling was operational. An aggressive carbon recycling plan has been developed to minimize the impacts of this large “inactive” carbon inventory (operational, environmental and financial). The ramp-up of the rodding shop (including the bath cleaning and treatment plant) is expected to be completed sometime in Q4 2019.

In order to start the baked anode production in line with green anode availability, workarounds were also implemented for the anode handling and cleaning systems. Manual load/unload of anodes in the ABF as well as manual cleaning were necessary up to the time when four

production fires were in operation. The baking furnace performance has been meeting design parameters since the end of Q2 2019.

The anode paste plant was commissioned in November 2018 and required only minimal workarounds for green anode handling from paste plant to storage. Some initial problems that resulted in vertical cracks in the baked anodes were resolved within 6 weeks from start-up. However, the baked anode reject rate peaked at more than 25 % and this affected the potline operations. The paste plant performance has been meeting the design parameters since the end of Q1 2019.

The various workarounds for anode handling in Carbon represented a massive operational and logistic challenge. The intensive use of forklift and transport trucks for anode handling created enormous mobile equipment and people interface challenges with corresponding safety risks, but zero incident resulting in injury occurred. This was achievable only by keeping "Safe Start-up" mindset and dedicated coordination and collaboration between the project, operations and EPCM.

Figure 4 presents the ramp-up in anode production of the permanent facilities (excludes production by workarounds).

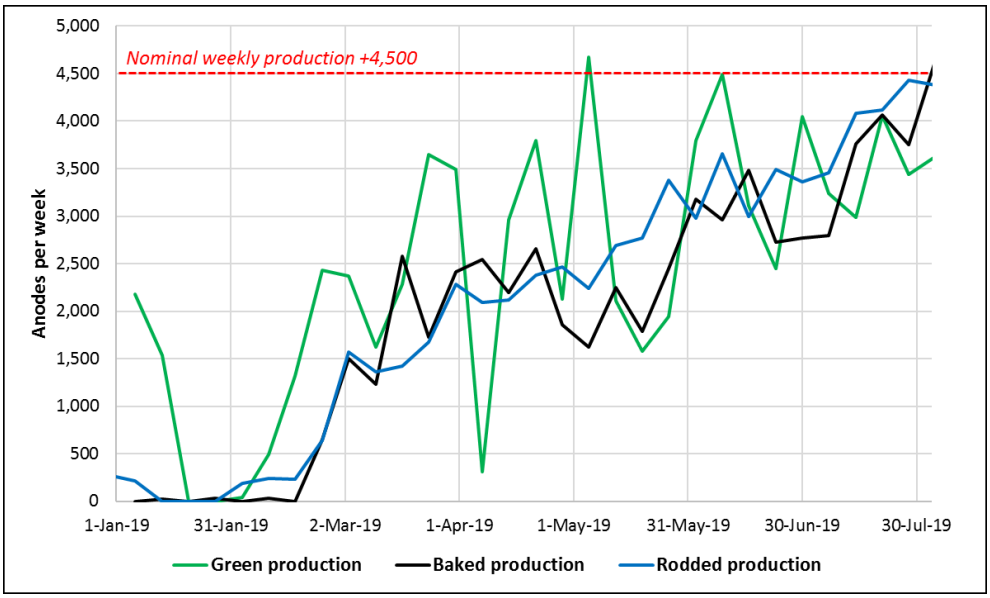

Figure 4. Anode production ramp-up.

5. Casthouse Start-up

The commissioning plan for the new Casthouse was based on a conservative ramp-up period to full capacity of four to six months for each casting complex. The commissioning of the 10 kg Ingot line started in December 2018 with first cast on 16 January 2019. Only one furnace was initially available. By early February 2019, a second holding/remelt furnace was available and ingot production reached more than 250t per day. The ingot casting complex reached nominal capacity within four months.

The commissioning of the sheet ingot VDC started in April 2019 with first cast on 28 April. To support line 6 metal production, the initial focus for the sheet VDC was on remelt T-ingot. Qualification work for sheet production was postponed to after the completion of the Casthouse start-up. The production ramp-up of the sheet VDC on T-ingot is well underway and should be at

nominal capacity by end of Q3 2019. At the time of the writing, the VDC billet had just achieved its first cast on 24 July 2019. Full capacity is planned for end of year.

In order to optimize metal product orders across Alba casting complex, line 6 metal was also sent to the existing Casthouse. This casting capacity was also utilized to cover the new Casthouse capacity gap during the ramp-up. This casting resilience capacity was instrumental for the success of the line 6 start-up. Figure 5 presents the new Casthouse ramp-up.

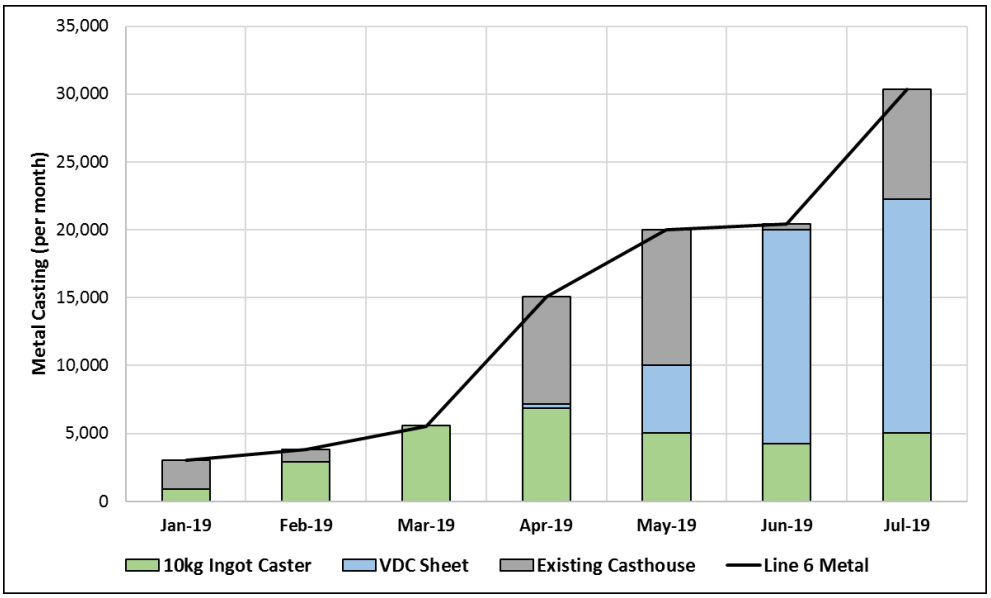

Figure 5. New Casthouse production ramp-up.

6. Safety

The Line 6 start-up team, contractors and sub-contractors took "Extreme Ownership" on safety in all of the start-up activities. Potline 6 was built and commissioned without any single lost time injury (LTI) throughout the project period. This is one of the greatest achievement for Alba.

7. Conclusions

Line 6 Project Expansion increased Alba's capacity to more than 1.5 million tonnes making it one of the largest single site smelter in the world and a significant contributor to Bahrain's economic growth. To ensure the success of the start-up, a comprehensive start-up preparation action plan was executed over an 18-month period before FHM. A key component of the preparation was the development of contingency plans and workarounds to allow starting production activities and FHM without all the support facilities operational. The potline start-up was initiated ahead of schedule and benchmark start-up rate was achieved in the second half of the start-up. The highest safety standards were maintained during the project with the resulting zero LTI performance. The DX+ Ultra technology KPIs are now settling within the design criteria targets and confirming the expected performance of the technology.

Figure 6. Line 6 safe start-up LHM celebration.

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