

# Copper Refinery Modernisation, Mopani Copper Mines Plc, Mufulira, Zambia

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The electrolytic refining of copper has been conducted at Mufulira, Zambia, since 1939. The original refinery has been upgraded and expanded since then to match the output of anodes produced at the Mufulira, Luanshya, and Nkana smelters at various times; however, by the end of 2012, it was recognised that customer expectations regarding cathode physical quality and chemical purity have increased due to the introduction of new copper refining technologies. In June 2013, Mopani Copper Mines Plc (MCM) committed to the modernisation of the copper refinery that included the conversion of the existing refinery to the ISAPROCESS™ technology, installation of electrode handling equipment, upgraded electrolyte circulation systems, and upgraded process control systems. This paper describes the equipment, technologies and new operational practices that constitute the Mufulira Refinery Upgrade Project. All activities have been progressively completed since late 2014 and have culminated with the registration of a new London Metals Exchange cathode brand, MCM2, in July 2017. The MCM Refinery is the first copper electrorefining plant in Africa to utilise the ISAPROCESS™ technology.

## INTRODUCTION

Copper has been electrolytically refined in Mufulira, Zambia for over 75 years. The original refinery has been expanded several times and one part of the refinery was expanded to conduct commercial-scale electrowinning operations. These operations included in-situ leaching, vat leaching, and heap leaching of oxide ores. A dedicated solvent extraction plant was associated with each leach operation.

The primary objective of the Refinery Modernisation Project was to ensure that current and future customer expectations could be fully satisfied, and to implement productivity improvements, whilst allowing the refinery to have the flexibility to source anodes with higher impurity levels than currently received. This necessitated a change in the refining technology used by Mopani Copper Mines Plc (MCM).

MCM selected the ISAPROCESS™ technology due to its extensive record of converting starter-sheet refineries to permanent stainless steel cathode plates. At the same, MCM also took the opportunity to upgrade and modernise its electrode handling systems, electrolyte circulation systems and process control systems.

Owing to the requirement for the existing refinery to maintain copper production operations at full capacity, the upgrade activities were conducted progressively over a four-year period. The construction activities are described below in more detail. The operational improvements since completion of the project are also described in detail.

## PROCESS SELECTION

### **Layout**

Various combinations of cell house layout and design have been implemented in ISAPROCESS™ copper refineries. MCM was constrained in some cases due to the requirement to maintain full copper cathode production capacity during the modernisation activities. In particular, this meant that the new electrode handling machines had to be located in areas that were not being used for existing production activities. The location of anode receipt from the smelter was fixed by the existing transport infrastructure.

### **Design Criteria**

The principal design objectives for the project were:

- Long-term production forecasts;
- customer requirements;
- productivity improvement;
- upgrade of electrolyte circulation systems;
- future expansion options.

### ***Long-term production forecast***

MCM is upgrading the existing Mufulira Mine and expects to complete the new Synclinorium Mine and Concentrator Project in 2019. When combined with external concentrate feed treatment at the MCM smelter, this will enable the Mufulira Smelter to increase production to 225 000 tonnes per annum. The modernised refinery production capacity matches this requirement.

### ***Customer requirements***

MCM has been producing copper cathode marketed under the London Metal Exchange (LME) Registered Brand MCM. Cathode produced by the modernised refinery is now marketed under the LME Registered Brand MCM2. The cathode bundle being produced now has many advantages over the previous style. It is compact, easier to handle and transport and no longer has the protruding starter-sheet loops associated with starter-sheet cathode.

### ***Productivity improvement***

Using starter-sheet technology, MCM was operating four tank houses plus a starter-sheet production aisle with-in their refinery complex. Glencore Technologies experience with ISAPROCESS™ copper refinery conversions conducted over the past 30 years was that conversion to stainless steel cathode plate technology achieved direct productivity improvements of 25% to 30% when compared with starter-sheet technology. In the specific MCM case, this has allowed MCM to reduce the operational footprint to three tank houses, with an associated reduction in the number of operating overhead cranes, refining cells, and, importantly, copper inventory.

Further productivity improvements have been made in the electrode handling task. The elimination of starter sheets has removed all aspects of starter-sheet production – starter-sheet production cells, manual stripping, sorting, and preparation activities, loop production, hanger bar assembly, manual cell loading, alignment activities and replacement of falling cathode due to broken loops. The introduction of the ISAPROCESS™ permanent stainless steel cathode system requires a dedicated cathode stripping machine (CSM) to perform cathode stripping operations. The CSMs selected at MCM are capable of fully automatic operation and eliminate all steps that were performed manually. At the same time, MCM elected to introduce a fully automated anode preparation machine (APM), anode scrap washing machine (ASWM), and upgraded its overhead refinery cranes to suit the new electrode handling machines.

### ***Upgrade of electrolyte circulation systems***

With the expected increases in copper production intensity, it was determined that the existing circulation systems required additional circulation capacity and improved process control. At the same

time the refinery circulation equipment configuration was changed so that each tank house now has its own, independent circulation system. All piping associated with the refining cells has been upgraded and the ability to collect decant solution from each refining cell during anode change operations has been implemented. The reagent dosing system was replaced for each tank house with a system that has the ability to prepare and dose thiourea, glue and salt. Automated process control has been implemented for all circulation system equipment via the introduction of a SCADA PLC-based system.

#### ***Future expansion options***

The current MCM refinery building has five individual tank houses plus a dedicated starter-sheet section. The design, specification and placement of all electrode handling equipment will allow MCM to expand its refinery production to five tank houses without the need to purchase additional anode handling equipment.

#### **Final Process Selection**

The modernisation of the MCM copper refinery was implemented with the following items:

- introduction of the ISAPROCESS permanent cathode plate technology;
- replacement of starter-sheet preparation machines with automated cathode stripping machines;
- introduction of automated anode scrap washing machine and automated anode preparation machine;
- introduction of automated anode and anode scrap transfer system;
- anode mould design was upgraded to match new anode dimensions;
- total replacement of electrolyte circulation system piping;
- installation of dedicated cell decant electrolyte piping system;
- replacement of fixed-speed circulation pumps with variable-speed drives;
- replacement of all reagent dosing equipment;
- partial replacement of overhead cranes;
- upgrade of anode and cathode lifting bales on the refinery overhead crane;
- installation of a SCADA PLC-based process control;
- installation of cell voltage monitoring system;
- implementation of an intermediate bar-based cell top furniture system;
- installation of new electrolyte circulation system tanks in Tank house Five;
- replacement of 336 refining cells in Tank House Five.

## **PROCESS DESCRIPTION**

#### **Modernised Refinery Operating Statistics**

Table I shows the key operational statistics for the modernised refinery.

*Table I. Operating statistics for new refinery.*

Capacity	225 000 t per annum
Cells	1320
Electrodes per cell	36 cathode / 37 anode
Electrode pitch	100 mm
Cathode deposition area, per side	0.82 m <sup>2</sup>
Maximum anode mass	320 kg
Maximum cathode mass	60 kg
Anode cycle	18 days nominal
Cathode cycle	2 crop or 3 crop
Current density	305 A/m <sup>2</sup>
Electrolyte circuits	3
Number of cranes	6

#### **Refinery Layout**

The existing MCM Refinery design is typical for the era in which it was built. Overhead refinery cranes from that era had very slow operating speeds hence the design objective was to minimise the length of crane runs. Crane rail heights were also set as low as possible to reduce lifting and lowering times for electrodes. This led to refineries being built with multiple aisles, short crane runs with a low operating height over the electrolysis cells. Movement of material was best managed by having a common centrally located aisle running the length of the refinery building. Industrial standard forklifts were also not common at the time so rail was used as a method for moving anodes, anode scrap and copper cathodes.

Owing to the existing layout, all of the new electrode handling machines can only be located in the central common aisle. This led to the situation where anodes and anode scrap need to be conveyed up to 120 m if only one APM and one ASWM unit are installed. By working with the supplier of the APM and ASWM, an innovative ground-running transfer car system for carrying anodes and anode scrap was specially developed for each machine. All of the electrode handling machines are designed to be serviced by forklifts.



*Figure 1. New overhead crane with drip tray carrying cathode plates.*

## **Electrode Handling Equipment**

### ***Anode preparation machine***

Anodes are received from MCM's copper smelter via rail and forklift. Anodes are loaded to the APM by forklift for weighing, blade pressing, lug-offset pressing and contact milling. Contact milling is used to ensure that anodes hang vertically in the cell and ensure best possible current distribution in the refining cells. The anodes are then transported in loads of 36 anodes to the appropriate tank house using the anode transfer car system. The APM was supplied by MESCO, Japan.

### ***Anode transfer cars***

A transfer car system is used to move anodes and anode scrap within the refinery building. Each transfer car runs at ground level and carries 36 pieces of anode or anode scrap to or from the respective APM or ASWM. Each transfer car services nine fixed set-down or pick-up positions located across the length of the refinery building. The Anode transfer car system was supplied by MESCO, Japan.

### ***Cathode stripping machines***

Three medium speed CSMs have been installed at MCM. One CSM is installed in each operating tank house; however, each CSM has the capacity to service the electrodes from the two bays in each tank house. The CSMs have been specially designed to interact with manually operated and low clearance overhead cranes. This means that conveyors are used to transfer cathode plates instead of fast-moving trolleys. This eliminates the possibility of a crane bale to trolley collision. A forklift is used to remove the finished cathode bundles to the product despatch area. The wash water used to remove electrolyte

from the cathode deposits is heated using electric heaters. The wash water system is designed for future conversion to steam heating. The CSMs were supplied by MESCO, Japan.

#### ***Anode scrap washing machine***

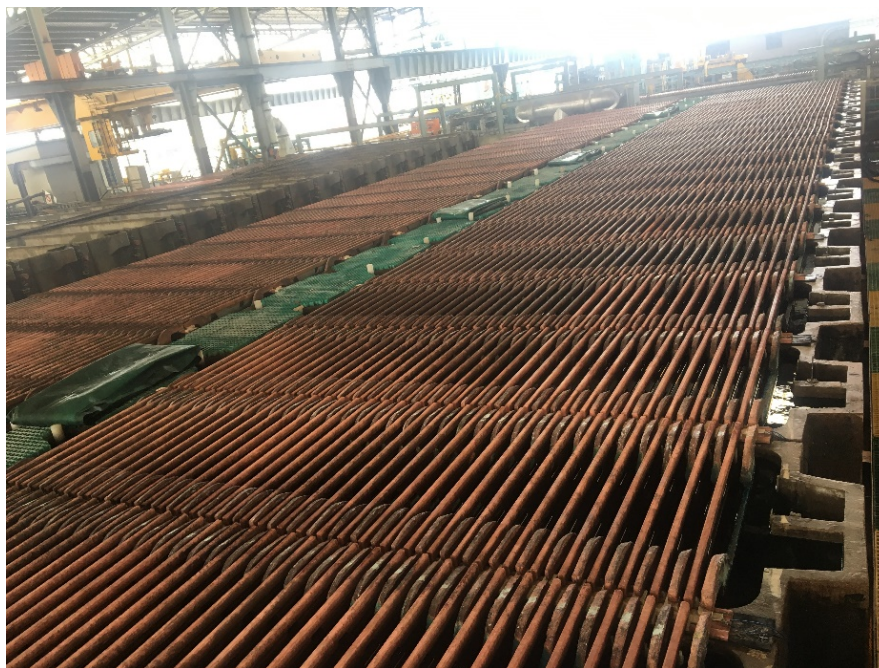
Anode scrap is moved from the refining cells by overhead crane and then conveyed to the ASWM via the transfer car system. In the ASWM, the scrap is washed to remove any adherent slimes and then formed into bundles for forklift removal. Anode scrap is returned to the copper smelter. The ASWM was supplied by MESCO, Japan.

#### ***Overhead crane upgrade***

The change in refinery electrodes, electrode pitch and cell-top furniture necessitated that new anode and cathode plate bales were required for the overhead cranes. At the same time, MCM decided to replace four of the six existing refinery cranes. MCM utilises crane transfer cars located at the end of each tank house. This allows the overhead cranes to be moved to another aisle when needed, thus reducing the overall number of cranes required in the refinery. The new cranes and lifting bales were designed and supplied by DEMAG, South Africa.

#### **Electrolyte Circulation**

Many parts of the existing circulation systems were not suitable for the increased operating intensity associated with the ISAPROCESS™ technology. A higher and more consistent cell electrolyte flowrate was the major change required. This meant that all electrolyte piping was upgraded, together with the associated circulation pumps. The use of variable-speed pumps was required so that a responsive flow control scheme could be implemented. The electrolyte is distributed to the cells by direct pumping without an intermediate head tank. Owing to the introduction of the thiourea reagent to replace Tembind, the existing reagent dosing systems were also replaced.



*Figure 2. ISAPROCESS™ permanent stainless steel cathode plates in service.*

#### **Process Control and Monitoring**

To ensure the correct electrolyte conditions for electrolysis at the higher operating intensities, improved process control of the operation was required. This has been achieved by implementation of a SCADA-based PLC system for the electrolyte circulation. The Siemens PLC-7 system was used for the SCADA configuration.

## Refinery Cells

As most of the existing refining cells were retained, the dimensions of the new stainless steel cathode plates were matched to the internal cell dimensions. The dimensional design of the anode was changed to match the new cathode plate dimensions. Owing to the inherent straightness of the stainless steel cathodes, the electrode pitch in the cell was able to be reduced to 100 mm, which provides reduced power consumption when compared with the starter-sheet design. The cathode plates were designed and supplied by Glencore Technology, Australia.

The upgrade of the electrolyte circulation system required changes to the electrolyte feedpipe for each cell. At the same time, an individual cell flow-control device was included in the new piping design. New cells were installed in Tank house Five to allow for full implementation of the decant collection system.

It was necessary to change all cell-top furniture to an intermediate bar design. The end cell busbars on all sections required modification to suit the ISAPROCESS™ system. The additional busbar elements and intermediate bars were designed and supplied by Copalcor, South Africa.

## CONSTRUCTION

In all cases, the scheduling of construction activities was dictated by cathode production requirements. With four tank houses still available for production, each of the three modernised tank houses was consecutively taken off-line for refurbishment over a two-year period. At the same time, MCM was forced to curtail production during 2016 due to power supply restrictions in place in Zambia.

The major construction milestones are listed below:

Jan-May 2014	New end cell busbars designed and installed
July-Dec 2014	Preparation of electrode handling machine areas
Oct-Dec 2014	Installation of electrode handling machines – TH1 & TH4 CSM's
Feb-March 2015	Installation of electrode handling machines – APM, ATS
May 2015	Installation of electrode handling machines - TH5 CSM
June-Aug 2015	Replacement of reagent system, piping and pumps – TH4
May-Aug 2016	Installation of new overhead cranes
Feb- July 2016	SCADA and cell voltage monitoring installed
Mar-Dec 2016	New circulation system for TH5 installed
May-Oct 2017	Installation of new cells – TH5
May-Nov 2017	Replacement of piping and pumps – TH 1
November 2017	Replacement of piping TH5

## COMMISSIONING

MCM formed a dedicated commissioning team to ensure that the transition between the two operating systems was performed safely and in step with the completion of construction/installation activities. A major emphasis was placed on training across all disciplines: metallurgy, operations and maintenance. At the same time, the operational requirements and testing to obtain LME registration for the new cathode were completed.

The key commissioning milestones are listed below:

Jan-Feb 2015	Operations and maintenance training program completed at CRL Australia and PASAR, Philippines
March 2015	Full commissioning of CSM TH4, APM, ATS, ASWM and TH4 circulation systems



Apr–July 2015	Full conversion of TH4 for first LME registration testing program
Jan–Dec 2016	Second LME registration testing period – TH4
June 2016	Full conversion of TH1 and commissioning of CSM TH1, CSM TH5
June–Nov 2016	Progressive commissioning of new refinery overhead cranes
June 2017	LME registration granted for MCM2 brand
October 2017	Central control room operational for SCADA and cell voltage monitoring systems
October 2017	Full conversion of TH5 and commissioning of TH5 circulation system
October 2017	Starter-sheet oOperations ceased

Commissioning engineers were supplied from MESCO, DEMAG and Glencore Technology for the electrode handling equipment. Specific ISAPROCESS™ training services and process engineers were also provided by Glencore Technology. MCM also retained the services of two expatriate electrode handling machine specialists to provide on-site training.

## PRODUCTION AND OPERATIONAL IMPROVEMENTS

Table II details the improvements in several refinery production performance indicators since the conversion of the refinery to the ISAPROCESS™. The level of improvement achieved is consistent with the levels foreseen during the feasibility study phase of the project.

*Table II. Cathode purity improvement – ISAPROCESS vs conventional.*

Impurity (ppm)	Conventional			Full ISAPROCESS	Note
	2014 average	2015 average	2016 average	2017/8 average	
S	3.74	6.29	4.93	4.43	Similar
Pb	1.50	1.81	1.42	0.53	Improved
Ni	1.19	1.27	0.70	0.58	Improved
As	1.24	1.48	1.27	0.50	Improved
Bi	0.43	0.41	0.26	0.20	Improved
Sb	0.36	0.51	0.54	0.47	Similar
Se	1.07	1.24	0.84	0.28	Improved
Ag	6.48	6.20	5.35	5.95	Similar
Sn	0.28	0.24	0.31	0.25	Similar
Te	0.45	0.43	0.46	0.31	Improved
Zn	0.56	0.46	0.48	0.418	Similar
Fe	<2	<2	0.48	0.35	Similar

Table I shows the long-term improvement in copper cathode impurity levels for the common cathode copper impurities. These levels easily comply with the requirements for LME Grade A copper cathode. At least four different mechanisms for cathode impurity exist in an industrial-scale copper electrolytic refinery. Each mechanism and the associated impurities are briefly described below with reference to Mopani's specific anode impurities:

- inclusion of slimes in cathode deposit: indicators are lead, selenium, arsenic, bismuth, tellurium and antimony;
- occlusion of electrolyte in cathode deposit: indicators are nickel, iron and arsenic;
- electrolytic codeposition: indicator is silver;
- precipitation on cathode deposit surface: bismuth, antimony, tellurium and arsenic.

Impurities associated with slimes inclusion have shown the greatest improvement. The inherent straightness of the permanent stainless steel cathode plate means the probability of a slimes particle making contact with the cathode deposit during electrolysis is significantly lower than for a starter

sheet. In addition, permanent stainless steel cathode plate technology allows for shorter crop ages, which reduces the probability of slimes inclusion occurring.

The level of impurity associated with electrolyte occlusion has also improved noticeably. This is attributed to the improved cathode deposit smoothness achieved by MCM since introducing the thiourea reagent. MCM upgraded its electrolyte circulation system to ensure that all refining cells are now receiving the correct flowrate of electrolyte, and thus reagents are always available at the cathode deposit surface during electrolysis operations. The inherent flatness of a permanent stainless steel cathode plate and the shorter crop ages also contributes to the cathode deposit smoothness.

No change in the silver assay at MCM indicates that the level of silver codeposition is not influenced by the conversion to permanent cathode plates. MCM does not have sufficient quantities of bismuth, antimony and tellurium in its anode and electrolyte for the surface precipitation impurity mechanism to be noticeable.

### Customer Acceptance

Figure 3 shows the percentage of copper cathode production that was suitable for direct despatch to customers as LME Grade A cathode. The long-term trend for starter-sheet production was 86.6%, with significant variability in conformance. This indicator has improved to 97.7% since the conversion of the refinery to the ISAPROCESS™, with a vast reduction in variability. Figure 4 shows a photograph of typical cathodes.

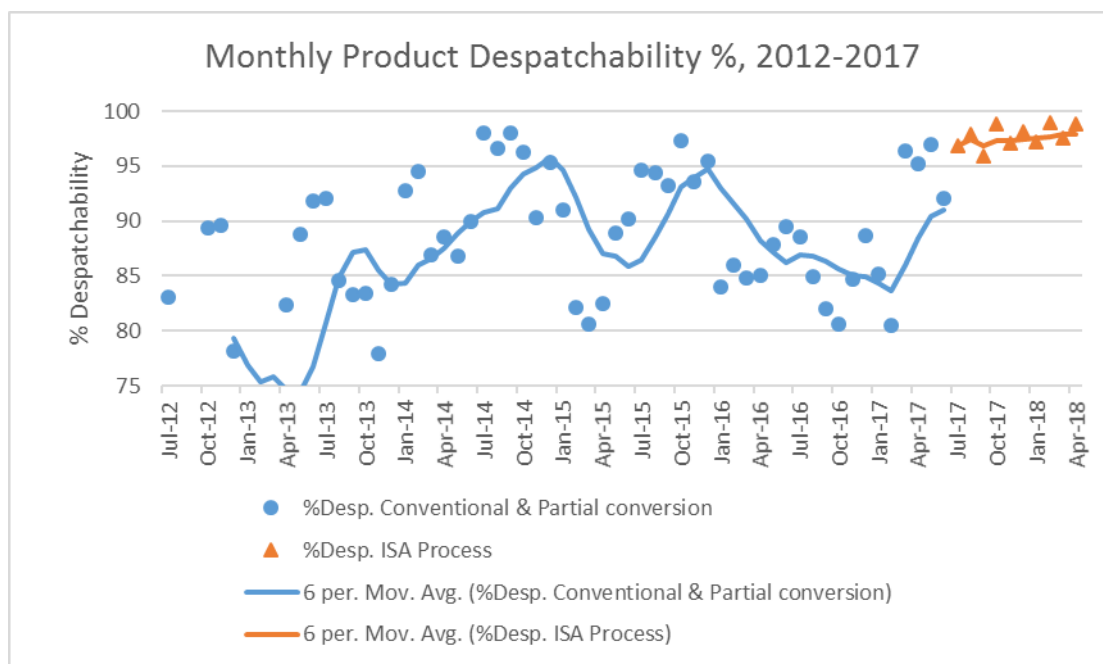


Figure 3. Cathode product despatchability.





Figure 4. Copper cathode at CSM and existing trolley system.

### Current Efficiency

Figure 5 shows the long-term trend for refinery current efficiency (CE). The long-term trend for CE was 85.9%. This indicator has improved to 97.5% since the conversion to the ISAPROCESS™, due to significant reduction in the number of short circuits. The variability in month-to-month performance has also reduced significantly.

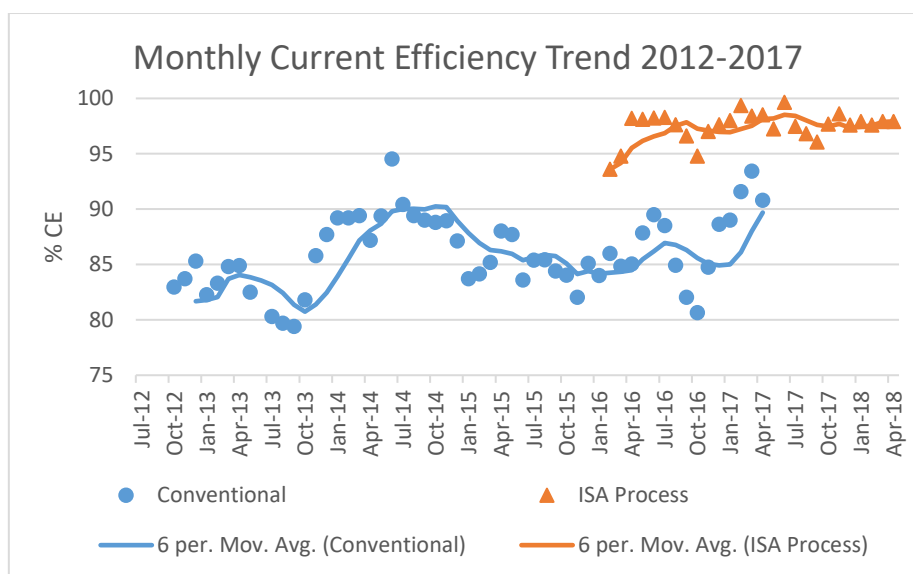


Figure 5. Current efficiency improvement after conversion.

### Productivity

Figure 6 shows the long-term trend in labour productivity for the refinery. It is important to correlate this measure against the actual production level at the time. Refinery output was constrained significantly for two years between August 2015 and September 2017 due to the countrywide power shortages and MCM's business response to the crisis. Thus, to make a valid comparison, only months with production above 12 500 t are compared.

The long-term productivity trend for the starter-sheet refinery was 30 t cathode production per person-month. Since full conversion to the ISAPROCESS™, the productivity measure has averaged 41 t cathode production per person-month. This is a 37% improvement in labour productivity. As MCM returns to previous production levels, the productivity improvement achieved will continue to improve.

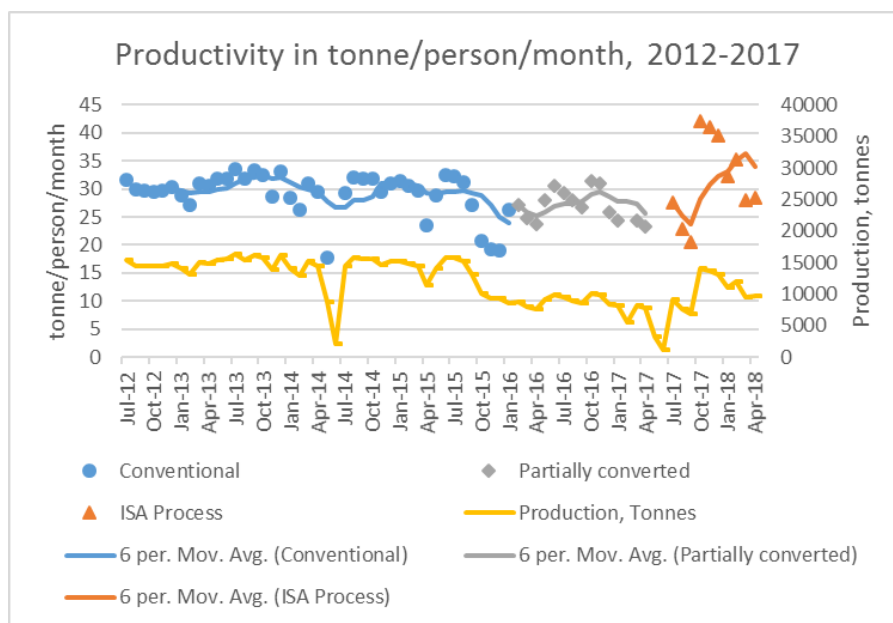


Figure 6. Productivity in tonne/person-month

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