

DECARBONISATION OPTIONS FOR THE DUTCH ZINC INDUSTRY

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Decarbonisation options for the Dutch zinc industry

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This report was reviewed by Nyrstar Budel B.V. PBL and ECN part of TNO remain responsible for the content. The decarbonisation options and parameters are explicitly not verified by the companies.

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FINDINGS

Summary

Zinc production in the Netherlands takes place at Nyrstar, in Budel. The company produces 250–290 kt zinc, annually, from zinc ore concentrate and zinc oxide recycling flows. The related CO₂ emissions mainly come from the roasting process and come to around 30 kt, per year. A significant part of these CO₂ emissions are process emissions from carbon in the concentrate. The fuel used consists of natural gas and diesel oil, and amounts to 0.13–0.3 PJ, per year. Electricity is the main source of energy used in the electrolysis process, and roughly amounts to 3.7 PJ, per year.

On-site decarbonisation options consist mainly of carbon-neutral fuels, such as biogas and hydrogen. Research on decreasing the share of zinc concentrate in the process is ongoing. Electricity efficiency improvements and the use of renewable electricity represent an important potential for indirect emission reduction, for this company.

FULL RESULTS

Introduction

This report describes the current situation for zinc production in the Netherlands and the options and preconditions for its decarbonisation. The study is part of the MIDDEN project (Manufacturing Industry Decarbonisation Data Exchange Network). The MIDDEN project aims to support industry, policymakers, analysts, and the energy sector in their common efforts to achieve deep decarbonisation. The MIDDEN project will update and elaborate further on options in the future, in close connection with the industry.

Scope

In the Netherlands, the zinc production location is Budel (at Nyrstar Budel B.V.). Production processes include roasting, leaching, purification, electrolysis, melting and casting; products include primary zinc ingots, sulphuric acid and other metal fractions. Carbon-neutral fuels and reducing primary input are the main options for decarbonisation.

Reading guide

Section 1 introduces the Dutch zinc industry. Section 2 describes the current situation for zinc production processes in the Netherlands, and Section 3 describes the relevant products of these processes, while options for decarbonisation are systematically quantified and evaluated in Section 4.

1 Zinc production in the Netherlands

Currently, there is one plant in the Netherlands that manufactures primary zinc under the European Union Emissions Trading System (EU ETS)—owned by Nyrstar Budel B.V., since 2007. It is a subsidiary of Nyrstar N.V., a mining and metals business operating multiple zinc plants around the world. The zinc plant is located in Budel-Dorplein, near Eindhoven and the Belgium border (see Figure 1). This location has been a zinc production site for more than 100 years and was formerly known as Budelco and Kempense Zinkmaatschappij.

In 2017, Nyrstar Budel B.V. employed 455 FTE and was responsible for the production of 248,000 tonnes of primary zinc products¹ (market metal) (Nyrstar, 2018a). As shown in Figure 2, this is lower than the production levels achieved in previous years. According to Nyrstar’s annual report (2017a), this lower production level was due to maintenance activities at its roasting section (16,000 tonnes), and a hydrogen explosion that occurred at its leaching section (11,500 tonnes). Nyrstar produces mainly special high-grade (SHG) zinc in the form of ingots of 25–2,000 kg, which have a purity of 99.995% zinc (Nyrstar, 2017b; Thole, 2015).



Figure 1. Geographical location of Nyrstar Budel B.V. in the Netherlands

¹ Nyrstar Budel B.V. is permitted to produce 320,000 tonnes of zinc (cathode zinc) per year (Nyrstar, 2016a).

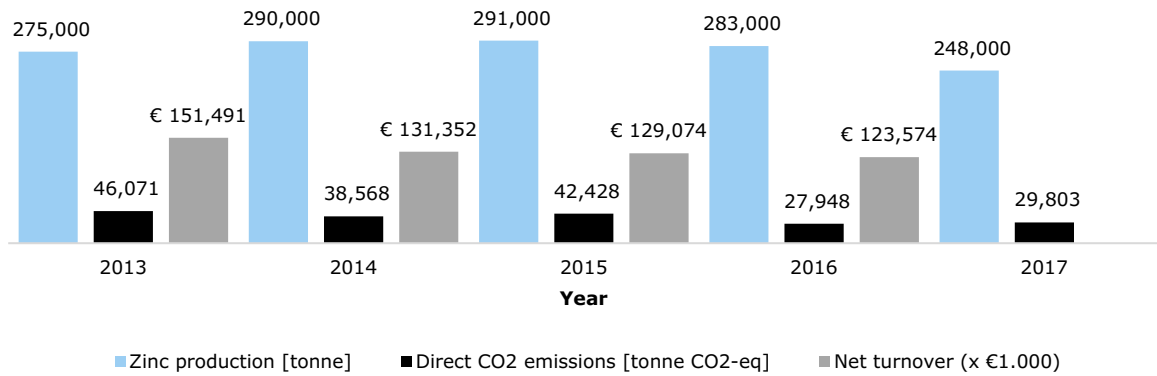


Figure 2. Nyrstar Budel B.V.: primary zinc production, direct CO₂ emissions and net turnover, over the 2013–2017 period (BGS, 2018; Nyrstar, 2014; Nyrstar, 2016; NEa, 2018)²

The remaining zinc production output consists of special alloys, such as continuous galvanizing grade (CGG) zinc that contains between 0.1% and 1% aluminium, to increase the flexibility and shine of galvanised metal (Nyrstar, 2018b). Other alloys contain Ni and Bi for the batch galvanising industry.



Figure 3. Blocks of 2000 kg (Jumbos) at Nyrstar

² Data about Nyrstar Budel B.V.'s net turnover in 2017 are not yet publicly available.

2 Zinc processes

The following subsections describe how primary zinc is produced, providing an overview of the main process inputs and outputs. In addition, where relevant, comparisons with international literature are made. Also, the processes that lead to direct CO₂ emissions are discussed.

2.1 Production of primary zinc ingots

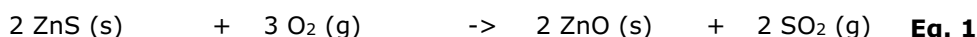
Traditionally, zinc is recovered from zinc concentrate by a hydrometallurgical or pyrometallurgical route. Nyrstar Budel B.V. produces zinc using a combination, the Roast-Leach-Electrowin (RLE) process. Globally, 95% of the refined zinc products is produced hydrometallurgically since this process results in a higher zinc purity, 99.995% compared to 98% (Van Genderen, Wildnauer, Santero and Sidi, 2016). Moreover, the pyrometallurgical process is an energy-intensive process, making it economically unattractive (Van Genderen, 2016).

2.1.1 General process

As shown in Figure 4, at Nyrstar Budel B.V., the zinc production process can be divided into five main steps: roasting, leaching, purification, electrolysis, and melting and casting. Each process step is briefly discussed, below. Table 1 gives an overview of the main process inputs and outputs involved.

Roasting

At the moment Nyrstar Budel B.V. operates two roasting furnaces in which zinc concentrate is heated up in the presence of air (Nyrstar, 2018c). When entering the furnaces, the concentrate consists mainly of zinc (Zn, 50%–55%) attached to sulfur (S, 25%–30%), together with iron (Fe, 8%), copper (Cu, 0.3%), and cadmium (Cd, 0.2%) (Thole, 2015; Vanhamel, 2014). At a furnace temperature of 950°C, the zinc sulphide reacts with oxygen, in an exothermal reaction (Equation 1). The exhaust heat is used to produce steam for the leaching plant (Vanhamel, 2014, p. 53).



To reduce the demand for virgin zinc concentrate, up to 30% of the material input mix consists already of zinc oxides (ZnO), processed from recycled zinc products. Together with the produced ZnO from Equation 1, these zinc oxides are cooled and moved to the leaching plant, while the hot sulfur dioxide (SO₂) gas is transported to a gas cleaner. There, the SO₂ gas is cooled with water, producing steam that is used in the leaching plant.

In addition, any chlorine and fluorine gases (resulting from roasting secondary zinc oxides) are removed by means of an electro filter (Vanhamel, 2014, p. 54). Waste water is drained to the wastewater treatment plant. The cooled and purified SO₂ gas is transported to the acid plant, where it is dried with sulfuric acid (H₂SO₄). Nitrogen compounds (formed during the

roasting process) are removed with ammonia, after which the SO₂ gas is eventually converted into H₂SO₄ by reacting with oxygen and water (see Figure 4).

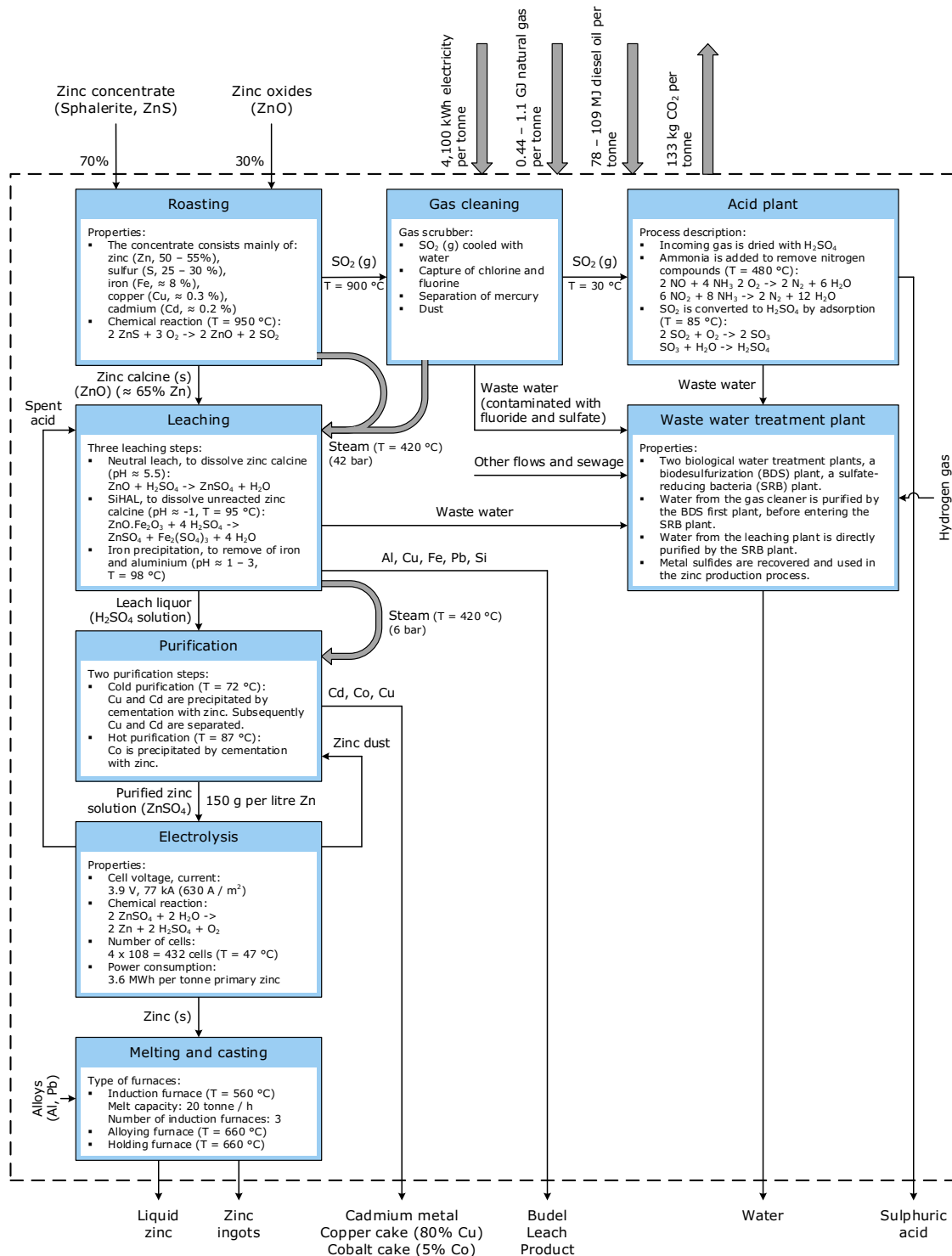


Figure 4. Overview of the hydrometallurgical production of primary zinc at Nyrstar Budel B.V., numbers are per average tonne of zinc ingot (Dijkhuis, 2009; Serrano, 2017; Nyrstar, 2018c; Thole, 2015; Vanhamel, 2014; Verrijt, 2018)

Table 1. Average characteristics of the primary zinc production process at Nyrstar Budel B.V., compared to data given in the BREF (Cusano et al., 2017)

| Type | Value per tonne of primary zinc (market metal) | Source |
|---|--|---|
| Raw materials | | |
| Zinc concentrate | Nyrstar Budel B.V.: 70%–100% BREF: 75%–100% | (VNMI, 2018) (Cusano et al., 2017, p. 607) |
| Zinc oxides | Nyrstar Budel B.V.: 0%–30% BREF: 0%–25% | (VNMI, 2018) (Cusano et al., 2017, p. 607) |
| Energy inputs | | |
| Electricity consumption | Nyrstar Budel B.V.: 4,100 kWh ³ (14.8 GJ) BREF: 3,850–4,905 kWh ⁴ (13.9–17.7 GJ) | (Serrano, 2017) (Cusano et al., 2017, p. 637) |
| Thermal energy consumption | Nyrstar Budel B.V.: 14–36 Nm ³ (0.44–1.1 GJ ⁵) natural gas ⁶ 1.80–2.52 kg (78–109 MJ ⁷) diesel oil ⁸ BREF: 0.48 GJ coke ⁹ | (Nyrstar, 2018c) (Cusano et al., 2017, p. 637) |
| By-products | | |
| Cadmium metal | Nyrstar Budel B.V.: 3.23 kg BREF: 3.69 kg | (Nyrstar, 2018c) (Cusano et al., 2017, p. 634) |
| Copper cake (80% Cu) | Nyrstar Budel B.V.: 16.1 kg | (Nyrstar, 2018c) |
| Cobalt cake (5% Co) | Nyrstar Budel B.V.: 1.61 kg | (Nyrstar, 2018c) |
| Budel Leach Product | Nyrstar Budel B.V.: 565 kg | (Nyrstar, 2018c) |
| Sulfuric acid | Nyrstar Budel B.V.: 1.51 tonnes BREF: 1.73 tonnes | (Nyrstar, 2018c) (Cusano et al., 2017, p. 634) |
| Gas emissions | | |
| Carbon dioxide (CO₂) (direct) | Nyrstar Budel B.V.: 133.3 kg | (Nyrstar, 2018a) (NEa, 2018) |

Leaching

In the second process step, the mix of zinc oxides and concentrate impurities¹⁰ (i.e. zinc calcine) coming from the roasting division is transported to the leach division. The function of this division is to remove impurities from the zinc calcine. In general, the leaching process

⁴ Aluminium, cadmium, cobalt, copper, iron, and lead.

⁴ According to the BREF this concerns only the RLE process, implying that energy required for melting and casting zinc is not included.

⁵ Based on a caloric heating value of 31.65 MJ per Nm³ (NEa, 2014, p. 48).

⁶ Based on 5-year average natural gas consumption and zinc production. This includes natural gas used for: steam production in case one of the roasting furnaces is out of use due to maintenance, hydrogen gas production in the wastewater treatment plant, and controllable cooling of zinc ingots in the casting department (Nyrstar, 2018c).

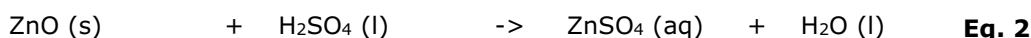
⁷ Based on a caloric heating value of 43 GJ per tonne (NEa, 2014, p. 96).

⁸ Based on 5-year average diesel oil consumption and zinc production. This includes diesel oil used for: starting up the roasting and acid plants after maintenance (Nyrstar, 2018c).

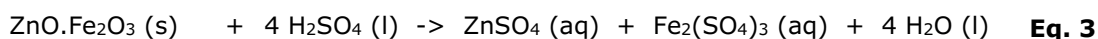
⁹ Average of energy required for other processes than electrolysis.

¹⁰ Aluminium, cadmium, cobalt, copper, iron, and lead.

has three stages (Dijkhuis, 2004). In the first stage, the neutral leach, most of the zinc calcine (including cadmium, cobalt and copper impurities) is dissolved in sulfuric acid¹¹ at an acidity of pH 5.5 (Dijkhuis, 2004) (see Equation 2). From the neutral leach stage, the solution is transported to the purification division.



However, zinc ferrite ($\text{ZnO}\cdot\text{Fe}_2\text{O}_3$), aluminium hydroxides, lead sulfate, and a part of zinc silicates present in the zinc calcine, do not dissolve in the neutral leach stage and are removed by means of thickeners. The unsolved elements are moved to the second leach stage, the Silica Hot Acid Leach (SiHAL), having a negative pH of ≈ -1 . In this stage the zinc ferrite is dissolved as shown in Equation 3 (Dijkhuis, 2004). The components that remain insoluble in the SiHAL, such as lead sulfate, form the Budel Leach Product (BLP). A part of the BLP is sent to Nyrstar's fumer and multi-metals recovery plant in Høyanger (Norway) and Port Pirie (Australia) respectively, in which the majority of materials is recovered (Nyrstar, 2018c).



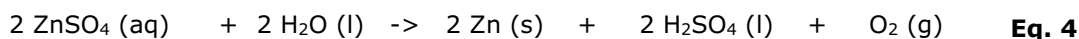
Finally, in the third leach stage, the zinc solution formed in the SiHAL is gradually neutralised, resulting in the precipitation and capturing of iron and aluminium impurities. The zinc solution leaving this leach stage is added to the neutral leach. In this way the zinc that was trapped in zinc ferrite is recovered (Dijkhuis, 2004).

Purification

Although the zinc solution is already purified from aluminium, iron and lead, the solution still contains cadmium, cobalt and copper. In the purification plant cadmium and copper are removed in the cold purification step ($T = 72^\circ\text{C}$) by cementation¹² with zinc dust (Dijkhuis, 2014; Thole, 2015). Subsequently the temperature of the solution is increased to 87°C in order to extract cobalt (Dijkhuis, 2014; Thole, 2015). The cadmium, cobalt and copper are sold to third parties (Vanhamel, 2014).

Electrolysis

When entering the electrolysis department with a flow of $350 \text{ m}^3/\text{h}$, the purified zinc solution has a zinc concentration of 145 g/l (Serrano, 2017, p. 62). The department consists of four circuits of 108 in series connected electrolysis cells. Each cell has 45 lead anodes and 44 aluminium cathodes, placed vertically in alternation order in the bath of ZnSO_4 (Serrano, 2017, p. 43; Vanhamel, 2014). During the electro winning process the zinc solution (electrolyte) flows through the cells, leading to the following net reaction taking place, in which zinc deposits on the aluminium cathodes ($T = 47^\circ\text{C}$):



It takes approximately 32 hours to grow a layer of 3 mm zinc on each cathode¹³ (Vanhamel, 2014, p. 58). As soon as a layer of 3 mm is created, the cathodes are lifted out of the bath in order to collect the solid zinc by means of a stripping machine (Thole; 2015). After this the cathodes are putted back in the cells. When leaving the electrolysis cells, the concentration of zinc in the electrolyte has dropped from 145 to 45 g/l (Serrano, 2017, p. 62). The spent electrolyte is fed back to the leaching plant, where it is used to dissolve zinc calcine in the neutral leach stage.

¹¹ Spent acid coming from the electrolysis cell house.

¹² Described by Dijkhuis (2004) as "the precipitation mechanism in which one metal in ion form is precipitated in its metallic form by the reaction with a less noble metal." (p. xvii).

¹³ At a current density of 630 A / m^2 .

By contrast to the electrolysis of aluminium oxide, during the electro winning of zinc, the anodes and cathodes are not consumed. The energy needed to produce the anodes and cathodes are not included in this study.

Melting and casting

Per hour, 36.5 tonnes of zinc is sent from the electrolysis cell house to the melting and casting department. Here, Nyrstar uses three induction melting furnaces to melt the solid zinc (Vanhamel, 2014, p.59). Depending on the product requirements, liquid zinc is directly casted or goes to an electric alloying furnace where alloy metals, such as aluminium, are added first (Vanhamel, 2014, p. 59). A small part of the liquid zinc is used to produce zinc dust, consumed by the purification plant. Once the liquid zinc is casted into ingots, gas-fired burners are used to cool down the ingots gradually to prevent it from breaking.

2.1.2 Raw materials

Zinc concentrate

A large part of the zinc concentrate consumed at Nyrstar Budel B.V. used to come from the Australian Century mine, until its closure at the end of 2015 (Nyrstar, 2017c). Although the Century mine reopened in 2018, currently, Nyrstar Budel B.V. buys zinc concentrates from suppliers located in Bolivia, Botswana, Chili, Ireland, Finland, Peru, Sweden and Turkey (Nyrstar, 2018c). At the mine locations, ore with a percentage of 3%–10% zinc is concentrated. The share of zinc in the concentrate varies between 50%–55%, which corresponds the common 54% given by the BREF (Cusano et al., 2017, p. 635).

Zinc oxides

As mentioned in Section 3.1.1, currently, Nyrstar Budel B.V. produces primary zinc out of 70% zinc concentrate and 30% zinc oxides. The zinc oxides are bought from recycling companies that recover zinc oxide from galvanised steel scrap. Another common type of secondary zinc feed are the so-called Waelz oxides, produced using a rotary kiln (Waelz kiln).

2.1.3 Energy input

Electricity

The required electricity for the production of zinc is coming from a 150 MW connection to the national 150 kV power grid (Nyrstar, 2016c). On average, it takes 4,100 kWh of electricity to produce one tonne of zinc, leading to an annual electricity consumption in the order of 1.1 TWh (Serrano, 2017, p. 4). Approximately 15% of the electricity is needed for the electric furnaces in the melting and casting house. The majority (85%), however, is consumed in the electrolysis department (Serrano, 2017, p. 4). By having a cell voltage of 3.9 V and a cell current of 77 kA, the power rate per cell amounts to 0.3 MW, resulting in a power rate of 130 MW for the whole cell house (Serrano, 2017, p. 45). The cells operate under a current efficiency of 93%, meaning that it takes 3.6 MWh of electricity to produce one tonne of primary zinc (Nyrstar, 2009; Serrano, 2017, p. 43). Compared to the range given in the BREF (see Table 1), Nyrstar Budel B.V. scores high, in terms of energy efficiency. The minimum theoretical energy requirement for producing one tonne of zinc, however, is ≈ 2.3 MWh per tonne of zinc, which leaves some room for improvement (Ettel and Tilak, 1981).

Recently, Nyrstar Budel B.V. and the province of North Brabant have announced their plans to build a solar park (60 hectares) of 170,000 solar panels, producing 48 GWh of electricity, per year, at an investment of EUR 36 million (Krekels, 2018). The solar panels will be installed on the closed basins in which, currently, environmentally harmful rest products are stored. The solar park will be connected to the national power grid.

Thermal energy

Next to electricity, on average, the zinc plant uses 4,000,000–10,000,000 Nm³ of natural gas and 500–700 tonnes of diesel oil, per year (see Table 1). Natural gas is used for 1) producing hydrogen gas that is required for the wastewater treatment plant, 2) controllable cooling of zinc ingots in the casting department, and 3) for producing steam in case one of the roasting furnaces is not being used due to maintenance (Nyrstar, 2018c). Currently, Nyrstar Budel B.V. operates two roasting furnaces, which receive maintenance every year. After maintenance, diesel oil is used to reignite the roasting furnaces. To same goes for the acid division, which is shut down every five years for maintenance, after which it is restarted using diesel oil.

2.1.4 Greenhouse gas emissions

CO₂ emissions

Since the consumption of both natural gas and diesel oil are mostly related to the maintenance intervals at the roasting and acid divisions, direct CO₂ emissions have fluctuated significantly, over the years (see Figure 2), and so has the content of carbon in the zinc concentrates. To compensate for this, in Table 1, the direct CO₂ emission factor is based on the average CO₂ emission and zinc production over the last five years (see Figure 2).

3 Zinc products and application

Overall, zinc find its application in galvanisation (60%), zinc alloys (15%), brass and bronze (14%), zinc compounds (8%), and other (3%) (Nyrstar, 2018d). A share of the zinc produced by Nyrstar Budel B.V. is delivered to the Trafigura Group, a multinational commodity trading company. The offtake is part of a large offtake agreement between Nyrstar N.V. and Trafigura that entered into force on 1 January 2016 for a fixed term of five years (Nyrstar, 2018e). Regarding the Dutch market, a part of the Nyrstar's zinc is sold to Nedzink, a manufacturer of rolled zinc products located on the same business park (De Bruyn et al., 2014).

Trading prices of semi-finished zinc products are mainly based on the London Metal Exchange (LME) for primary zinc. Internationally, the LME price serves as a reference price, and determines for a large share the market price for zinc products. The remaining part of the market price is based on regional market premiums, which depend on the desired type of alloy, and physical and chemical properties of the product for instance.

On the LME various types of contracts are offered for buying or selling LME futures, providing the option to hedge prices for up to 63 months (LME, 2018a). In this, LME contracts for three-months deliveries are typically the most actively traded contracts (LME, 2018a). Therefore, the prices of three-months seller contracts are commonly used as reference prices for zinc products. Figure 5 presents the trends in prices of three-months seller contracts for primary zinc over the period 2007–2018. As shown in Figure 5, in 2009 zinc prices dropped significantly, which can be related to the financial crisis started in 2008. Currently, LME prices fluctuate around USD 2,500 per tonne of primary zinc.



Figure 5. Trends in the prices of LME three-months seller contracts for primary zinc over the period 2007–2018 (LME, 2018b).

As a by-product of producing primary zinc, in 2017 Nyrstar Budel B.V. produced an additional 375,000 tonnes of sulphuric acid, 140,000 tonnes of Budel Leach Product¹⁴, 4,000 tonnes of

¹⁴ Solid residues coming from Nyrstar's leaching plant, consisting mainly of lead (Thole, 2015).

copper cake (80% cu), 800 tonnes of cadmium and 400 tonnes of cobalt cake (5% Co) (Nyrstar, 2018c). Approximately 95% of the produced H₂ SO₄ is sold at EUR 10 to 30 per tonne, 5% is used for own consumption (Nyrstar, 2018c).

4 Options for decarbonisation

Based on the company input, the following decarbonisation options can be distinguished (Nyrstar, 2018c):

- Substitution of diesel oil by renewable energy fuels such as bio oil or green gas. At present, 4% to 6%¹⁵ of direct emissions are related to diesel oil; these emissions can be avoided by switching to renewable energy.
- Substitution of natural gas by green gas or hydrogen. Direct CO₂ emissions related to natural gas, currently, represent 19% to 48%¹⁶ of total on-site CO₂ emissions. Although the technologies, currently, are only being tested on a small scale, Gasunie (2018) published an exploratory study on a CO₂-neutral national energy supply by 2050, in which green gas and hydrogen play a promising role in the replacement of natural gas.
- Electrification of the gas-fired burners in the melting and casting department. At the moment, burners are used to slowly cool down zinc ingots to prevent them from breaking.
- Energy efficiency improvements in the electrolysis winning process. According to Nyrstar-Budel, small energy efficiency improvements can be made in the electrolysis cells. The electrolysis process consumes only electricity, meaning that this option will reduce indirect CO₂ emissions. Since it is an energy intensive process, small energy efficiency improvements can already have a significant impact.
- Direct input in the leaching step of zinc oxide from recycling of galvanised steel is investigated by Nyrstar and TATA. This requires zinc oxide with lowered Cl and F content.

Further research will help to determine what the costs and additional preconditions are of engineering and implementing the above mentioned decarbonisation options. The plant would need specific decarbonisation research on process emissions, since 46% to 77%¹⁷ of the direct CO₂ emissions are related to the carbon embodied in the zinc concentrates. For this reason, the potential of, for instance, carbon capture and storage could be investigated, but the concentration level and volume of CO₂ in the exhaust gas are relatively small. Furthermore, there is no known underground storage capacity in the area. Using alternative zinc concentrates with a lower carbon content can have only limited effect. Currently, the share of secondary zinc oxide in the input for the roasting plants cannot be further increased (Nyrstar, 2018c).

Finally it is worth noticing that Nyrstar-Budel's acid plant produces an excess of 30 MW low-grade heat (T = 60–80°C) (Nyrstar, 2018c). At this moment this heat is emitted into the atmosphere (Thole, 2015). Since Nyrstar-Budel is located in a rural area, using the waste heat for district heating seems not a promising option. Weert is the nearest urban area at 7 km.

¹⁵ Based on the 5-year average diesel oil consumption given in Table 1 and a CO₂ emission factor of 74.1 kg per GJ (NEa, 2014, p. 96). Average annual zinc production and CO₂ emission over the last 5 years are 277,400 tonnes of zinc and 36,963.6 tonnes of CO₂ (see Figure 2).

¹⁶ Based on the 5-year average natural gas consumption given in Table 1 and a CO₂ emission factor of 56.1 kg per GJ (NEa, 2014, p. 98). Average annual zinc production and CO₂ emission over the last 5 years are 277,400 tonnes of zinc and 36,963.6 tonnes of CO₂ (see Figure 2).

¹⁷ Calculated by subtracting the 5-year average annual CO₂ emissions related to diesel oil and natural gas, from the total 5-year average annual CO₂ emissions. With the ore used presently, the share is nearer to the lower bound.

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