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Economic Assessment of Potassium Chloride Fertiliser Production in Laos

Erfurt
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Economic Assessment of Potassium Chloride Fertiliser Production in Laos

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Economic Assessment of Potassium Chloride Fertiliser Production in Laos

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Introduction

The report “Analysis and Assessment of a Feasibility Study Report” was compiled within the scope of the technical cooperation project “Support for a Sustainable Development of the Mining Sector” for the Department of Mines (DOM), Lao People’s Democratic Republic (Lao PDR), and the Federal Institute for Geosciences and Natural Resources (BGR)1, Federal Republic of Germany. The project is financed by the Federal Ministry for Economic Cooperation and Development of Germany (BMZ).

On behalf of the BMZ, the Federal Institute for Geosciences and Natural Resources (BGR) implements the project “Support for a Sustainable Development of the Mining Sector” jointly with the Department of Mines (DOM), which has been put in charge of the implementation of the project by the government of Lao PDR.

As part of this technical cooperation, the BGR has commissioned ERCOSPLAN Ingenieurge sellschaft Geotechnik und Bergbau mbH (ERCOSPLAN), a member of the ERCOSPLAN Group of Companies, to complete several tasks. ERCOSPLAN, which has its headquarters in Erfurt, Germany, is a consulting firm with over 60 years of experience in the potash and mineral salt industry. ERCOSPLAN’s services include, among others, exploration, surveying, consulting and planning, supervision of installation and start-up as well as project management.

One of the tasks commissioned by the BGR is the economic assessment of potassium chloride fertiliser production in Laos, which is contained in this report.

1 Potash Demand and Potash Supply

The focus of this report is the production of potash fertilisers from Lao deposits. Section 1.1 will provide a brief introduction to fertilisers and potash as one of the important macro-nutrients. Section 1.2 will discuss recent trends in the consumption of potash fertilisers, followed by a look at the supply of potash fertilisers in Section 1.3. The Asian potash market will briefly be introduced in Section 1.4 and, finally, the driving forces behind potash prices described and a price forecast is provided in Section 1.5.

1.1 Brief Introduction to Fertilisers and Potash as a Nutrient

Fertilisers are “(…) any solid, liquid or gaseous substances containing one or more plant nutrients in known amount, that is applied to the soil, directly on the plant (foliage) or added to aqueous solutions (as in fertigation) to maintain soil fertility, improve crop development, yield and/or crop quality” (IFA2, 2014, /34/). As such, fertilisers are used to supplement those nutrients that are already contained in the soil or to replace those nutrients that were lost due to agricultural activities and therefore enhance the fertility of the soil.

Global consumption of fertilisers reached 173 million metric tonnes of nutrients in 2010/2011 and is expected to continue increasing in the future (Figure 1).

---

1 German name: Bundesanstalt für Geowissenschaften und Rohstoffe.
2 International Fertilizer Association
Fertilisers are characterised by containing at least 5% of one or more of the macronutrients nitrogen (N), phosphorous (P) and potassium (K) (IFA, 2014, /34/). Each of these 3 macronutrients (also called primary nutrients) is essential for plant growth. Thus, a lack of one of the nutrients will result in decreased plant resistance and eventually in lower crop yields:

- **Nitrogen** is essential for plant growth, plant development and yield formation as it provides the necessary proteins to the plant.
- **Phosphorus** is essential for photosynthesis and is required by the plant for developing its tissue.
- **Potassium** is essential for activating plant enzymes and helps to improve a plant’s water regime as well as develop an increased tolerance to drought, salinity and frost.

In addition to these primary nutrients, plants also require so-called micronutrients or trace elements for optimal growth.

Since soils deplete over time and the nutrients cannot be substituted, farmers need to fertilise with products based on either organic or industrial sources. Fertilisers that are industrially produced are often also referred to as mineral fertilisers.

Common fertiliser products are

- **Nitrogen fertilisers:**
  - Ammonia
  - Ammonium sulphate (AS)
  - Ammonium nitrate (AN)
• Calcium ammonium nitrate (CAN)
• Urea

Phosphate fertilisers
• Single superphosphate (SSP)
• Triple superphosphate (TSP)
• Diammonium phosphate (DAP)
• Monoammonium phosphate (MAP)
• Ground phosphate rock

Potash fertilisers
• Muriate of potash (MOP\(^3\)), also called potassium chloride
• Sulphate of potash (SOP\(^4\)), also called potassium sulphate
• Sulphate of potash magnesia (SOPM)

Magnesium fertilisers
• Kieserite
• Epsom salts

Complex fertilisers
• NPK fertilisers
• NP fertilisers
• NK fertilisers
• PK fertilisers

The majority of agricultural potash fertilisers are applied as potassium chloride (KCl) and traded as MOP with a standard grade of 95% KCl, which is equivalent to 60% \(\text{K}_2\text{O}\)\(^5\). Smaller amounts are applied as potassium sulphate, traded as SOP, or mixed with other nutrients to obtain NPK, KMg and other fertiliser cocktails. Both product lines, MOP and SOP are traded as standard material, which is a crystal-grained product, or granular, which is a compacted and crushed coarser product (Figure 2).

Besides this agricultural application, there are many industrial applications (shown as industrial in Figure 2), which usually require a higher \(\text{K}_2\text{O}\) content of the final products, e.g. KCl98 and KCl99 for caustic potash production.

---
\(^3\) Muriate of Potash (MOP): trading term for a potassium chloride-based fertiliser product with a minimum KCl content of 95%.
\(^4\) Sulphate of Potash (SOP): trading term for a potassium sulphate-based fertiliser product.
\(^5\) \(\text{K}_2\text{O}\): Chemical formula for potassium oxide. Traditionally, the international potash industry measures its production in terms of KCl or \(\text{K}_2\text{O}\): 1 metric tonne of KCl is equivalent to 0.632 metric tonne of \(\text{K}_2\text{O}\).
Only a few producers are able to produce K/Mg sulphates and SOP to make premium products. Sodium chloride (NaCl) and magnesium chloride (MgCl₂) are possible by-products of potash production.

In 2013, potash fertilisers were produced at a total of 71 production sites worldwide. At a total of 65 production sites, both extraction and processing of potash are carried out in the immediate vicinity of each other in specially coordinated facilities. In contrast, at 4 production sites, only the mining of solid potash ore is carried out, while the processing occurs elsewhere, together with ore extracted from stand-alone mines. At 2 production sites, solid potash ore, which has been mined elsewhere and transported to these sites, are only processed.

A total of 35 of the 69 potash mining facilities in operation all over the world today use conventional underground mining methods for the extraction of solid potash ore from geological formations. They supply the raw material for more than 75% of worldwide potash fertiliser production. Merely 5 of the mining facilities in operation today use solution mining methods for extracting solid potash ore from geological formations. At least 29 of the mining operations for potash use natural brines that have a low mineral content, which can be found in surface waters, so-called salt lakes, or are stored as pore waters in aquifers near the surface. They supply the raw material for 20% of worldwide potash fertiliser production.

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6 Only production sites that produced saleable final products in 2013 were counted, of which 20 are partly very small producers in Western China.
1.2 Potash Consumption

Worldwide consumption of potash increased by two-thirds between 1990 and 2007, reaching a maximum of 58 million t KCl\text{equ}. Five developing countries, namely Brazil, China, Indonesia, India and Malaysia contributed to most of the growth in consumption.

Global potash consumption fell significantly in 2008 and 2009, after reaching its peak in 2007. This was due to exploding potash prices and was compounded by the global financial crisis. As a result, in 2009, the global sales of potash were slightly more than half of that in 2007.

For the medium term, continuing growth with an average annual growth rate of more than 5.5% is expected. For the 5-year period after 2015, the growth of potash consumption worldwide will probably decrease to less than 3% and by the end of the forecast period, global potash consumption will be close to 70 million t KCl\text{equ}.

1.3 Potash Supply

In 2009, the potash industry worldwide had an annual production capacity of 64.1 million metric tonnes KCl\text{equ}, produced by 32 conventional mining operations, 5 solution-based operations, 6 brine-based mines as well as some smaller, mostly brine-based mining operations located in China. North America and the FSU\textsuperscript{7} countries each account for approximately one-third of potash demand worldwide, while the other third is accounted for by Asia, Europe as well as South and Central America. During recent years, the largest share of growth in capacity has come from North America, owing to Canada’s introduction of more favorable mining legislation, especially with regard to taxation and the rise in potash prices. Between 2005 and 2009, the North American market raised its capacity by 4.9 million metric tonnes of KCl\text{equ}.

The producers in Russia, Belarus, Brazil, China, Israel, Jordan and Iran also increased their capacity between 2004 and 2009, contributing an additional 3.6 million metric tonnes of KCl\text{equ} to total capacity. Between 2009 and 2019, 20.4 million metric tonnes of capacity are expected to be added to the worldwide total. The greatest positive growth in capacity up to the end of the forecast period is expected in North America (46.1%) and the FSU states: Belarus, Russia and Uzbekistan (22.5%).

Since the 1980s, no drastic changes in global potash capacity have taken place due to new mine/plant commissioning. The bulk of the expansions in capacity during this period can be attributed to the upgrading and/or debottlenecking of existing operations, since the construction of new mines is an undertaking that requires a period of several years.

Over the next 10 years, more than 15 million metric tonnes of additional capacity is forecast to come on-stream at existing production plants, especially in North America and FSU and also in the Middle East (Israel, Jordan).

The advantages of the brownfield projects are follows:

- Existing experience in infrastructure and transport
- Long-term relationships with the customers
- Ability to add operational capability quickly
- Lower capital cost per t compared to greenfield projects.

\textsuperscript{7} FSU - Former Soviet Union
As shown in Table 1, the largest shares of expansion in existing operations are located in Canada and USA. The producers PCS, AGRIUM and MOSAIC are planning to add to their capacity not only in Saskatchewan, but also in New Mexico and New Brunswick. The forecast shows an addition of more than 10 mtpy over the next ten years.

The capacity of the potash producers in the FSU will not increase as greatly: URALKALI’s brownfield projects “include 1.5 million tonnes of additional capacity at Berezniki 4, efficiency increase and debottlenecking at Berezniki-2 and 3, as well as Solikamsk-2 and -3 which will add 1.0 million tonnes in total…”. BELARUSKALI’s investment in new capacities is focused on opening new parts of the Soligorsk deposit.

Furthermore, there are expansion projects in the Middle East on a small level. In spite of a small increase in the capacities in China, China’s domestic production will not be able to cover the potash demand of Chinese agriculture.

As a result of the high prices of potash over the last 10 years, many new projects are in development around the world. ERCOSPLAN’s database includes more than 90 projects at various stages of development.

<table>
<thead>
<tr>
<th>Producer</th>
<th>KCl Capacities ['000 t']</th>
<th>2012</th>
<th>2017*</th>
<th>2025*</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCS (Canada)</td>
<td>12,400</td>
<td>18,900</td>
<td>21,800</td>
<td></td>
</tr>
<tr>
<td>MOSAIC (US, Canada)</td>
<td>9,800</td>
<td>12,600</td>
<td>14,700</td>
<td></td>
</tr>
<tr>
<td>AGRIUM (Canada)</td>
<td>1,900</td>
<td>2,900</td>
<td>2,900</td>
<td></td>
</tr>
<tr>
<td>INTREPID POTASH INC. (US)</td>
<td>1,000</td>
<td>1,300</td>
<td>1,300</td>
<td></td>
</tr>
<tr>
<td>BELARUSKALI (Belarus)</td>
<td>9,100</td>
<td>10,800</td>
<td>10,800</td>
<td></td>
</tr>
<tr>
<td>K+S (Germany)</td>
<td>6,700</td>
<td>7,900</td>
<td>8,900</td>
<td></td>
</tr>
<tr>
<td>URALKALI (Russia)</td>
<td>13,500</td>
<td>15,000</td>
<td>21,000</td>
<td></td>
</tr>
<tr>
<td>SQM (Chile)</td>
<td>1,600</td>
<td>1,800</td>
<td>1,800</td>
<td></td>
</tr>
<tr>
<td>ICL* (Israel, GB, Spain)</td>
<td>6,300</td>
<td>6,700</td>
<td>6,700</td>
<td></td>
</tr>
<tr>
<td>APC+ (Jordan)</td>
<td>2,400</td>
<td>2,400</td>
<td>2,400</td>
<td></td>
</tr>
<tr>
<td>China (more than 20 producers)</td>
<td>8,300</td>
<td>12,700</td>
<td>12,800</td>
<td></td>
</tr>
</tbody>
</table>

* Forecast

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8 Potash Corporation of Saskatchewan Inc., also known as PotashCorp or PCS.
9 Source: http://www.uralkali.com
10 Israel Chemicals Limited
11 Arab Potash Corp.
ERCOSPLAN’s description of greenfield projects therefore focuses on upcoming projects that probably will result in potash production in the near future (cf. Table 2). A great amount of them are located in Saskatchewan, with an increasing proportion of solution mining projects.

The largest effect on the potash market will be achieved with the potential entry of BHP Billiton (BHPB) and other well-respected companies onto the market with properties in Saskatchewan. All of these projects are not close to their target markets, but would increase the global supply. Another important point of these Saskatchewan greenfield projects is related to the rail infrastructure to potential terminals. CANPOTEX handles all transports with Canadian Pacific (CP) rail network, which has become crowded in recent years with the handling of products from brownfield projects.

Other greenfield projects are located in Russia, for example. URALKALI is planning 2 new projects and has the advantages of long-term potash experience and a well-developed infrastructure.

<table>
<thead>
<tr>
<th>Potash Project</th>
<th>Description</th>
<th>Project Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>EUROCHEM Volgakali12</td>
<td>Phase I: Capacity of 2.3 mtpy MOP. Production to start in 2014, full capacity to be reached in 2015</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Phase II: Additional capacity of 2.3 mtpy MOP (total capacity doubled to 4.6 mtpy. Production to start in 2015, full capacity to be reached in 2018</td>
<td></td>
</tr>
<tr>
<td>Usolye-Project (Perm)</td>
<td>Start of production of 2 mtpy of MOP in 2017, increasing of capacity to 3.4 mtpy in 2020</td>
<td>SS</td>
</tr>
<tr>
<td>VALE Saskatchewan Project</td>
<td>Production of 2.9 mtpy MOP will not start before 2017</td>
<td>PFS</td>
</tr>
<tr>
<td>BHP Billiton Jansen Lake Potash Project</td>
<td>Ramp up to production of 8.0 mtpy MOP between 2015 and 2026</td>
<td>SS, EIS</td>
</tr>
<tr>
<td>K+S Kali Potash One Project</td>
<td>Phase I: Capacity of 2.0 mtpy MOP in 2017, production start in 2015, Phase II: Additional capacity of 0.86 mtpy MOP in 2023</td>
<td>FS, EIS</td>
</tr>
<tr>
<td>WESTERN POTASH CORP. Milestone Project</td>
<td>Planned capacity of 2.5 mtpy MOP, start up in 2015</td>
<td>SS</td>
</tr>
<tr>
<td>AGRIUM Triton Project</td>
<td>Planned capacity 2.0 mtpy MOP, which could then be expanded to a total of 4 mtpy at a later date.</td>
<td>EIA</td>
</tr>
<tr>
<td>MAGMINERALS INC. Kouilou Project</td>
<td>Phase I: Capacity of 0.6 mtpy MOP in 2017, Phase II: Additional capacity of 0.6 mtpy MOP in 2023</td>
<td>BFS</td>
</tr>
</tbody>
</table>

1.4 Brief Introduction to the Asian Potash Market

The potash market in Asia is the fastest growing market in recent times, together with South America led by Brazil.

In the whole of Asia, potash demand is mainly driven by India and China. However, the ASEAN countries, in particular Indonesia and Malaysia, are also important importers in the region (Figure 3).

![Composition of Global Potash Consumption](image)

**Figure 3** Composition of Global Potash Consumption
The forecast of potash demand in Asia is closely linked to fertiliser consumption and depends on plantation crops, most of them having high potash requirements. How much fertiliser the farmers will purchase and at what price is based on the economic cost to benefit ratio that farmers expect.

A balanced fertilisation program that considers both crop demand and the nutrient status of its soils usually improves economic returns and yields as well as mitigating the impact of negative climatic factors such as inadequate rainfall or higher and lower than normal temperatures.

Fertiliser use according to the type of crop in the various SE Asia countries is very different (Figure 4). Furthermore, different crops and soils contain different amounts of potassium per unit weight. An intensive cultivation uses more fertiliser and a higher application rate of fertilisers increases the yields.

![Figure 4: Percentage of K₂O Fertiliser Use by Crop (Southeast Asia)](image-url)
1.4.1 Potash Market in China

China is the largest consumer of potash in the world. Potash consumption in China during the last few years is shown in Figure 5.

Half of all K₂O fertiliser consumption in China is used in the growing of fruits and vegetables. China is by far the world’s largest producer of fruits and vegetables. Accordingly, the consumption of potash will rise from 5.2 million tonnes K₂O to 10.8 million tonnes in 2020.

The demand for potash is covered both by China’s own production and by imports. The import shares have shown an upward trend since 2009 (Figure 6).

Over half of the imports in 2010 were delivered from Russia and Belarus. Other suppliers include Canada, Israel and Jordan.

China is the sixth largest potash producer in the world. The production is based on natural brines with solar evaporation. The KCl production capacity in China is expected to increase by 1.3 million tonnes KCl<sub>equ</sub> by 2019, following recent trends. It is estimated that China will have a capacity of 5.0 million tonnes KCl<sub>equ</sub> by the end of the forecast period. China’s increase in capacity is assumed to be essentially brine-based and will probably come from QINGHAI SALT LAKE POTASH CO. (QSL GROUP), which is China’s largest potash producer, as well as some other minor producers.

Based on the present understanding of China’s potash deposits, it is not expected that the local potash industry will undergo expansion because reserves are not enough to sustain further growth in capacity and production.
Thus, China will continue being a net importer of potash in future and, therefore, potash deposits in the vicinity, such as those in Laos, the Kingdom of Thailand and Uzbekistan, are of strategic importance for China’s continuing growth.

China, which has an annual demand of about 10 mtpy, is now attempting to break the monopoly power in the potash market by seeking development of potash projects to settle its own demand by:

- Carrying out enhanced exploration works on potash in non-marine basins
- Combining petroleum and potash exploration as about 85% of the world’s petroleum reserves are situated in evaporite basins
- Combining exploration and exploitation of potassium, lithium, boron and sodium salt to improve economic recovery
- Investing in promising greenfield potash projects abroad, e.g. the greenfield projects in Laos (cf. Table 6), offtake agreements with Sirius Minerals Plc’s York Potash Project, strategic investment in Western Potash Corp.’s Milestone Project.

If these efforts lead in the long-term to China being independent of third countries’ potash producers, the international potash fertiliser price will decrease.

Laos’ potash production could account for about 60% of Chinese imports in the long-run.
Traditionally, China makes contracts of approx. 1 year with BPC\textsuperscript{13} and CANPOTEX. In future, the delivery contracts will become biannual contracts or spot purchases in order to smoothen the flow of imports. The potash products are imported by ocean transport and railway transport from Russia. The imports by railway have a share of more than 30\% of the total MOP imports in China.

The main importers in China, which are authorised for potash imports, are shown in Figure 7. Standard potash has been the primary product but the use of granular product is gradually increasing as farming practices improve. Both are bagged at the port and transported to the consuming regions to be applied directly or manufactured into a compound NPK product.

![Figure 7 Estimated Shares of MOP Imports in China by Main Importers](image)

\textbf{1.4.2 Potash Market in Southeast Asia}

As described above, Southeast Asia is a very important region for the future increase in potash demand. While the potash application in Indonesia and Malaysia is focused on oil crops, and in Vietnam on cereals (mainly rice), Thailand and the Philippines have an equilibrated and non-mono-structured agricultural use (Figure 4).

Based on future population growth as well as the available arable land, forecasts for the Southeast Asian region underline not only the strong increase of fertiliser demand in general, but also for potash in particular (Figure 8).

Southeast Asia is one of the growth hotspots for potash products and potash deliveries rose more than 100\% between 1998 and 2008. The demand in Southeast Asia in 2011 was ex-

\textsuperscript{13} Belarusian Potash Company
tremely strong. The largest share of growth in demand in the past 10 years is attributed to the rapid spread of palm oil plantations. The palm oil plantations have one of the highest potassium requirements of any crops, with an application rate of 330 kg/ha of potash product. The largest land areas used for palm oil plantations are in Malaysia and Indonesia. According to data from IFA and FAO\textsuperscript{14}, oil palm accounts for

- Approx. 60% of cultivated land and 85% of potash consumption in Malaysia
- Approx. 13% of cultivated land and 50% of potash consumption in Indonesia.

The growth in demand for potash in Indonesia and to a lesser extent in Malaysia is only for a small part independent of the expansion of cultivated land for palm oil plantations.

In the region, Thailand shows the most advanced fertiliser use in general. Thailand uses a relatively large amount of MOP granular in comparison to other Asian countries (Table 3).

\begin{figure}[ht]
\centering
\includegraphics[width=\textwidth]{figure8.png}
\caption{Recent MOP Deliveries to SE Asia and Forecast Until 2025}
\end{figure}

\textsuperscript{14} Food and Agriculture Organization of the United Nations
In the past few decades, chemical fertilisers have come into widespread use throughout Asia. Especially in South Asia, farmers rely heavily on nitrogenous fertilisers (Figure 9) and poorly manage the nutrition of soils with complementary inputs. Thus, the soil fertility is declining. Weak marketing and distributions systems are further hindering the effectiveness of fertiliser use in the region.

Figure 9 Share of Nutrients in Fertilisation in Southeast Asia (GDN, 2012, /28/)

Considering the central role that agriculture plays, especially in the rural economies of the Southeast Asian countries, promoting efficient and effective fertiliser use has emerged as an important target of policies and programs in recent decades. The privatisation and liberalisa-
tion of the fertiliser sector over the years have improved the availability of fertiliser in Southeast Asia. However, it has not succeeded in eliminating supply bottlenecks and ensuring fair prices of fertilisers at the farm level. The current distribution systems are still not adequate to supply fertilisers on time or provide fertilisers in remote areas. Furthermore, the fertiliser subsidy policies are putting heavy pressure on government budgets and have not guaranteed the low proportionate benefits to the farmers. The policies have also led to serious distortions in fertiliser consumption toward nitrogenous nutrients, reducing the efficiency and effectiveness of fertiliser use, which have been compounded by the low and unbalanced use of fertiliser, creating deficiency in organic matters and seriously threatening the sustainability of fertiliser use in Southeast Asia (GDN, 2012, /28/).

It is often argued that continuous higher application of nitrogen in relation to phosphate and potash has adverse effects on soil fertility, crop productivity and sustainability of agriculture in the long-term. The ideal ratio of 4:2:1 of NPK is recommended for optimal soil conditions. In Southeast Asia, fertiliser use has been forecasted to grow annually at a high rate of 2.8% over the medium term with corresponding increases for N at 2.2%, P at 3.5% and K at 4.2%. The need for rebalancing fertiliser application points to stronger growth for P and K than for N. In any case, the intensity of fertiliser use is still low in Southeast Asia compared with other regions. The average application rate was 86 kg/ha in 2006, compared with 118 kg/ha in Latin America and 179 kg/ha in developing countries in general (GDN, 2012, /28/).

The promotion of fertiliser use and the improvement of the fertiliser distribution systems are tasks that can only be realised and coordinated by the public sector, but should not be underestimated in its benefits to the agricultural industry of the Southeast Asian countries.

1.4.3  Potash Market in Laos

Less than 4% of Laos’s total area suitable for cultivation is used for agricultural purposes (FAOSTAT\textsuperscript{15}, 2014, /23/). Most of this area is used for growing rice. Although the Lao government is supportive of crop diversification, Figure 10 shows that the shares of different crops have not changed significantly during the past years. The use of fertilisers is increasing, with greater areas being cultivated and higher incomes generated from agricultural production. Laos’s gross production value from agricultural production has more than tripled since 1996 (Figure 11), indicating that the demand for fertilisers has risen.

\textsuperscript{15} The Statistics Division of the FAO.
If all the projects come into production as planned, Laos will produce 8.5 million metric tonnes of potash product in 2025.
Exploration and development of these potash projects have progressed faster than other greenfield projects worldwide, mainly due to the relatively shallowness of the deposits in Laos. Production from these projects will most likely be transported by road to China via Vietnam or Thailand. Currently, a railway line, which will ultimately lead from Singapore to Southwest China, is under construction. This will allow product transport via rail from Laos to China from 2018 onwards (Telegraph, 2014, /59/). Further product markets will likely be Malaysia and Indonesia.

1.5 Potash Prices

Historically, potassium product prices were rather stable, with two peaks in the middle of the 1970s and early 1980s due to the commodity price shocks at international trading places. The few potash producers, however, started to cut back production to meet the demand for minimising the costs of storage. Hence, prices steadily increased in the late 1980s and remained at a level of 100 to 115 USD FOB\(^{16}\) per tonne MOP for the next 10 years. In 2003, increasing freight costs caused the potash producers to raise their prices by about 100 USD per tonne in order to cover freight cost volatility in CFR\(^{17}\) sales. This increase had no significant impact on demand. On the contrary, demand rose during the following years, as countries such as Brazil and China were heavily demanding fertiliser products. When agricultural commodity prices greatly increased in 2008, potash prices were at a new peak of over 1,000 USD per metric tonne of MOP on spot markets.

The recent trends in potash prices from 2003 to 2009 were dependent on:

- Increasing international demand for potash
- Increasing prices for crops
- Increasing costs of ocean freight cost
- No availability of larger production capacities within a short time
- Increasing operating costs due to the expansion of existing capacities.

Still, MOP prices were on an exceptional level in 2009. Since then, the price for MOP has fallen even below the level it was at the beginning of 2008. It can be expected that the price will fall slightly or will persist on the current level in the next few years. It can be assumed that the price will climb significantly to reach a level similar to that of 2008/2009 in 2020 because the consumption of MOP will rise approx. 40% by the year 2020. Indeed, supply will increase as well, but nevertheless, the price will grow. Furthermore, potash prices will be influenced in future by the supply/demand balance, the state of world agriculture, the fertiliser prices, the ocean freight costs and last but not least, also by the dollar exchange rate.

The recent development of potash product prices is given in comparison to the value of the US Dollar in Figure 12.

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\(^{16}\) FOB: Free on Board. For a definition, see http://www.iccwbo.org/products-and-services/trade-facilitation/incoterms-2010/the-incoterms-rules/

\(^{17}\) CFR: Cost and Freight. For a definition, see http://www.iccwbo.org/products-and-services/trade-facilitation/incoterms-2010/the-incoterms-rules/
Since 2012, the forecast rise in global potash consumption has been revised slightly downwards. The first half of 2013 had still been relatively strong in terms of demand, but after the break-up of BPC in July 2013 and the resulting events in Belarus and Russia, demand for potash fertilisers came to a hold as market participants were waiting for prices to drop.

Potash fertiliser prices have decreased by more than 20% since January 2013 and are currently ranging at a level of 310 USD/t MOP standard CFR. In the long-term, potash prices will not remain at their current levels and the projections made by URALKALI of prices at or lower than 280 USD/t will most probably not prevail. Although they are reasonable from a potash producer's point of view, they do not reflect the standpoint of traders and consumers who are increas-

---

18 Average Market Price from FERTILISER WEEK
19 22 December 2012: Decree of the Belarusian President (Decree No. 566) and suspension of the exclusivity agreement between BELARUSKALI and BPC. BELARUSKALI is entitled to sell its potash products through other export organisations to be named by the Belarusian president.
20 26 August 2013: Vladislav Baumgertner, CEO of URALKALI, is invited to Minsk by the Belarusian prime minister. After the meeting he is arrested at the airport in Minsk. He is accused of abuse of power and personal gain. According to Belarusian media, Interpol has issued a warrant against further board members as well as a major shareholder of URALKALI (Reuters, 2013a, /56/). Furthermore URALKALI's decision is understood by Belarusian media to have caused a financial harm of about 100 million USD to Belarus.
30 August 2013: The conflict between Russia and Belarus escalates. Russia cuts oil exports to Belarus and prohibits the import of pork from the neighbouring country. A possible stop of imports of Belarusian dairy products is considered (FAZ, 2013, /24/).
02 September 2013: Interpol announces in a press release that no warrants were issued but only a request of the Belarusian government was filed (RiaNovosti, 2013, /58/)
ingly interested in greater competition on the potash market not only for monetary reasons but for ensuring shorter transport distances and thus quicker reply times. This will ultimately lead to a need for *greenfield* potash projects closer to the main potash markets.

Since July 2013 and until recently, competition in the market was strongly influenced by the break-up of BPC. However, Figure 12 also shows that the potash prices did not just fall since the break-up of BPC but have steadily been declining over the last couple of months. A further mid-term drop in potash prices is likely. URALKALI announced on 20 January 2014 that a contract for potash deliveries to China in the first quarter of 2014 was closed on basis of 305 USD/t CFR (Fertilizer Week, 2014a, /26/). The first delivery out of this contract was made in early March 2014 and other producers seem to follow this negotiated price, i.e. CANPOTEX, APC, ICL and BPC are said to have signed delivery contracts with Chinese importers at the same price level or 20 USD/t lower (Fertilizer Week, 2014b, /27/).

CANPOTEX furthermore announced in April 2014 that a contract with Indian customers was signed at 322 USD/t of MOP for a total sales volume of 1 million metric tonnes.

Analysts now expect that prices for potash fertilisers have reached their mid-term low and will stabilise or even slightly increase over the next months.

## 2 Potash Deposits in Southeast Asia

Based on the results of the geological exploration, the distribution of the evaporites was deduced to be within a large, originally connectedly evaporite basin (Hite & Japakesr, 1979, /54/). The total size of the basin area is 170,000 km². The result of the sea water inflow during the Maha Sarakham Formation period was a gradual uplift of the western edge of the basin and sea water transgression from the east (Sattayarak & Polachan, 1990, /61/).

At present, this formerly connected basin can be divided into the southern Khorat Basin and the northern Sakon Nakhon Basin (Suwanich, 1986, /67/). These larger basins are separated by the Phu Phan Uplift (Figure 13).

Furthermore, several smaller sub-basins were detected southeast and northeast of the Sakon Nakhon Basin.

### 2.1 Geological Setting

The Khorat Plateau of Northeast Thailand and Western Laos comprises widespread, exposed Mesozoic rocks which are formed by non-marine and marine sedimentation processes. The development of the Mesozoic strata began during Late Triassic after extension release of the Indonesian Orogeny (Cooper et al., 1989, /37/).

Sediments were deposited during the Late Triassic – Late Cretaceous, followed by Himalayan Orogeny in Early Tertiary caused uplifted of the Khorat Plateau and Phu Phan Uplift.

The Mesozoic rocks of the Khorat Plateau (Thailand) are grouped as the Khorat Group, which contains the following formations in ascending age (Manop and Denchok, 2007, /57/)

- Huai Hin Lat, Nam Phong (Triassic)
- Phu Krading, Phra Wiharn (Jurassic)
• Sao Khua, Phu Phan, Khok Kruat, Maha Sarakhan and Phu Thok (Cretaceous-Tertiary).

Only the Maha Sarakham Formation contains thick marine evaporites, which are deposited by the cyclical evaporation of saline lakes and ponds in an arid paleoclimate (Meesook, 2000, /49/).
In Laos, a different stratigraphic order described by Phommakayson (2001, /54/) exists. The correlation between the stratigraphic order in the Khorat Plateau and the Vientiane Basin is shown in Table 4.

### Table 4  Stratigraphy of the Khorat Plateau (Thailand) and the Vientiane Basin (Laos)

<table>
<thead>
<tr>
<th>Khorat Plateau, Thailand</th>
<th>Vientiane Basin, Laos</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>System</strong></td>
<td><strong>Formation</strong></td>
</tr>
<tr>
<td>Quaternary</td>
<td>Sediments (Qa)</td>
</tr>
<tr>
<td>Cretaceous-Tertiary</td>
<td>Phu Thok (KTpt)</td>
</tr>
<tr>
<td></td>
<td>Maha Sarakham (KTms)</td>
</tr>
<tr>
<td>Cretaceous</td>
<td>Khok Kruat (Kkk)</td>
</tr>
<tr>
<td></td>
<td>Phu Phan (Kpp)</td>
</tr>
<tr>
<td></td>
<td>Sao Khua (Ksk)</td>
</tr>
<tr>
<td>Jurassic-Cretaceous</td>
<td>Pra Wiharn (JKpw)</td>
</tr>
<tr>
<td>Jurassic</td>
<td>Phu Kradung (Jpk)</td>
</tr>
<tr>
<td>Triassic</td>
<td>Nam Phong (Trnp)</td>
</tr>
</tbody>
</table>

| **System**               | **Formation**          | **Thickness [m]** |
| Quaternary               | Sediments (Q II-III)   | 70                 |
| Cretaceous               | Tha Ngon (K2tn)        | >500               |
|                         | Upper Champhon         |                    |
| Cretaceous               | Champhon (K2cp)        | 400                |
| Jurassic-Cretaceous      | Phu Pha Nang (J-Kpn)   | 350                |

The Maha Sarakham Formation (Thailand) and the Upper Champhon Formation (Laos) consist of sequenced strata of evaporites with intercalated and clastic rocks. The reported thickness of the formations is approx. 150 m to approx. 1,400 m.

### Table 5  Evaporite Section with Subdivisions in Thailand and Laos

<table>
<thead>
<tr>
<th>Thailand</th>
<th>Laos</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Clastics</td>
<td>Member 6 (Upper Mudstone)</td>
</tr>
<tr>
<td>Upper Salt</td>
<td>Member 5 (Upper Rock Salt)</td>
</tr>
<tr>
<td>Middle Clastics</td>
<td>Member 4 (Middle Clay-Siltstone)</td>
</tr>
<tr>
<td>Middle Salt</td>
<td>Member 3 (Middle Salt)</td>
</tr>
<tr>
<td>Lower Clastics</td>
<td>Member 2 (Lower Clay-Siltstone)</td>
</tr>
<tr>
<td>Lower Salt</td>
<td>Member 1 (Lower Salt)</td>
</tr>
</tbody>
</table>
The whole evaporite section is sub-divided into the following evaporite members/units (Suwanich, 1986, /63/, c.f. Figure 14).

2.2 State of Exploration

In 1963, it was reported for the first time that there were large evaporite deposits beneath the Khorat Plateau in Northeastern Thailand. Prior to that, in 1958, the THAI DEPARTMENT OF MINERAL RESOURCES (DMR) launched a drilling programme that was intended to search for a potable groundwater supply. The drilling of thick salt bed horizons was carried out in 1962 in order to find rock salt intervals that were potentially suitable for soda ash production. A mineral exploration programme that included the drilling and coring of rock salt was carried out by the DMR in 1965, during which time evaporite horizons containing potash minerals were identified. It was reported that these potash-bearing horizons were closely linked to the crests of very shallow, dome-like or anticline salt structures.
The DMR then started a potash and rock salt exploration programme across the Khorat Plateau both in 1973 and 1982, during which 194 exploration drill holes were drilled in the Khorat and Sakon Nakhon Basins.

The extension of the Sakon Nakhon Basin in Laos was discovered in 1974 by an exploration drill hole north of Vientiane. With further exploration during the 1970s and early 1980s, the distribution of the salt basin was explored more in detail. Based on these exploration programmes, the distribution of the Vientiane Sub-Basin in northern part of the Sakon Nakhon Basin and the Thakhek Khammouane Sub-Basin in the western part of the Sakon Nakhon Basin was deduced.

Based on the exploration results, potash mineralisation was identified in the following regions:

**Sakon Nakhon Basin**
- Udon North Area (Thailand) – detailed exploration
- Udon South Area (Thailand) – detailed exploration
- Wanonniwat Area (Thailand) – search exploration
- Dong Tai (Laos) – detailed exploration
- Nong Phur Area (Laos)
- Nonglom Area (Laos) – detailed exploration
- Tha Ngon Area (Laos)
- Na Tan Area (Laos)
- Thongmang Area (Laos)

**Khorat Basin:**
- Bament Narong Area (Thailand) – detailed exploration
- Chakarat Area (Thailand) – search exploration
- Ban Thum Area (Thailand) – search exploration
- Ban Prakham Area (Thailand) – search exploration
- Khon Kaen Area (Thailand) – search exploration
- Nachuak Area (Thailand) – search exploration

**Kengkok Basin:**
- Kengkok Area (Laos) – search exploration

Based on the exploration results, some commercial potash projects have been developed in Thailand and Laos during the last 25 years. The following table shows the known projects and their planned MOP capacity as well as the current status of their development.
Table 6  Potash Projects and Exploration Areas in Thailand and in Laos

<table>
<thead>
<tr>
<th>COMPANY</th>
<th>Project/Country</th>
<th>Status</th>
<th>Planned MOP Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASIA PACIFIC POTASH CORPORATION LTD.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Udon South/Thailand</td>
<td>Mining Lease Application</td>
<td>2.0 mtpy</td>
<td></td>
</tr>
<tr>
<td>Udon North/Thailand</td>
<td>Mining Lease Application</td>
<td>2.0 mtpy</td>
<td></td>
</tr>
<tr>
<td>FYI RESOURCES LTD.</td>
<td>Special Prospecting Licenses</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>ASEAN POTASH MINING PUBLIC COMPANY LTD.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bamnet Narong/Thailand</td>
<td>Mining Lease Application</td>
<td>1.1 mtpy</td>
<td></td>
</tr>
<tr>
<td>SINO-LAO POTASH MINING CO.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thongmang Potash Project, Vientiane Province/Laos</td>
<td>Mining Concession, (Production On-Stream)</td>
<td>0.05 mtpy</td>
<td></td>
</tr>
<tr>
<td>Natan Potash Deposit, Vientiane Province/Laos</td>
<td>Exploration License</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>SINOHYDRO MINING (LAO) CO LTD.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thangone Potash Project, Vientiane Province/Laos</td>
<td>Mining Concession</td>
<td>0.20 mtpy</td>
<td></td>
</tr>
<tr>
<td>Thoulakhom Potash Deposit/Extension</td>
<td>Exploration License</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Ban Keun (Nongphong) Potash Project, Vientiane Province/Laos</td>
<td>Exploration License</td>
<td>0.12 mtpy</td>
<td></td>
</tr>
<tr>
<td>Ban Keun (Nongphong) Potash Deposit/Extension</td>
<td>Exploration License</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Ban Hai Potash Deposit, Vientiane Province/Laos</td>
<td>Exploration License</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Pak-Ngum Potash Deposit, Vientiane Province/Laos</td>
<td>Exploration License</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>JIAXI LAO POTASH DEVELOPMENT CO LTD. (SINO-AGRI)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dong-Tai Potash Project, Khammouane Province/Laos</td>
<td>Mining Concession, (Production On-Stream)</td>
<td>0.10 mtpy</td>
<td></td>
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<tr>
<td>Dong-Tai Potash Project/Extension</td>
<td>Exploration License</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>LAO KAIYUAN MINING CO LTD.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nongphu Potash Project, Khammouane Province/Laos</td>
<td>Mining Concession, (Production On-Stream)</td>
<td>0.50 mtpy</td>
<td></td>
</tr>
</tbody>
</table>
### 2.3 Potash Mineralisation and Potash Ore Characteristics

According to the drilling and assay results, the potash deposits contain mainly two potash-bearing minerals:

- Carnallite, chemical formula: KMgCl₃ x 6H₂O (~17% K₂O)
- Sylvite, chemical formula: KCl (63.2% K₂O)

A potash rock, which contains mainly Sylvite with exploitable potash grades, is called sylvinite. A potash rock, which contains mainly Carnallite with exploitable potash grades, is called carnallitite.

Considering the lithology and structural characteristics of the evaporite strata (mainly the Lower Salt) obtained during exploration and widespread experience in the field of evaporite basin development, the following general statements regarding the deposit type can be made:

- The majority of the evaporitic basin is composed of rock salt with interbeds of Anhydrite (gypsum). Commercial quantities of potash ore only exist in the Lower Salt Member. A second potash horizon was found in the Middle Salt Member only in a few places.
- The distribution of the potash-bearing horizon in the Lower Salt is stable within the different basins.
- Carnallitite is the most widely distributed potash rock within the basins and forms the basis of several potash projects. Thin layers of sylvinite caused by a secondary crystallisation phase were detected mostly on top of the thick carnallitite horizons. Sometimes, larger areas with sylvinite were also found within tectonically overprinted parts of the deposit. The carnallitite is composed of Carnallite together with Halite and Anhydrite and small amounts of Tachyhydrite, Bischofite and Mirabilite.
- As an exception, larger amounts of sylvinite were found in the Udon Thani area (Udon North Project, Udon South Project). Here, the sylvinite is underlain by a thick carnallitite horizon. The sylvinite is composed of Sylvite, Halite and Anhydrite.
- The exploration results so far do not indicate any exploitable amounts of sulphate minerals combined with the potash mineralisation. Therefore, a production of potash fertilisers based on the in-situ potash ore is limited to MOP.
- The thickness of the carnallitite horizon ranges from approx. 5 m to approx. 200 m. The average thickness is approx. 50 m in the Sakon Nakhon Basin and little less in the Kho-
The KCl grade ranges from 9.7% to 30.76%, while the average grade is 15.63% KCl.

- The thickness of the sylvinite horizon within the Udon North Deposit ranges from 1.0 m to more than 25 m. The average thickness is 2.3 m for the Udon South deposit and 12 m for the Udon North Deposit. The average KCl grade is 35.8% and 27.8% respectively (Crosby, 2007, /16/)

- The depth of the potash deposits ranges from 200 m to 500 m

- During the genesis of the potash deposits, evaporite rocks were relocated on a small scale under the influence of a proceeding diagenesis (mostly compaction) and limited impact of the stress field.

- It was assumed that the primary mineralisation of the Middle and Upper Salt consists of Halite (rock salt) and Anhydrite (gypsum). Local dissolution of Middle and Upper Salt Members usually led to the formation of residual anhydritic clay layers. Within the Middle Salt Member, secondary Sylvite spots rarely exist, due to the alteration of the deposit (migration of highly concentrated brine). The rock salt horizons of the Middle and Upper Salt form the hydrogeological protection layer against the inflow of unsaturated groundwater to the mining horizon.

2.4 Impacts of the Deposit Geology on the Economics of Potash Production in Laos

As described in Section 2.3, potash mineralisation, which can feed an industrial-scale production of potash fertilisers for several decades, is available in Laos.

Exploration and development of the potash in Laos have progressed well in recent years. At present, there are 5 approved Mining Licenses and 9 Exploration Licenses. Most of the owners of licenses explored the deposits according to the “Russian Model”, which could lead to the deposit being over-drilled.

The grade of up to 30% KCl of the potash horizons in Laos offers highly favourable conditions for the economic feasibility of potash production.

The potash mineralisation is located at a depth of 80 m to 520 m in the Vientiane Basin and at a depth of 120 m to 360 m in the Khanmmouane Basin respectively.

The relatively shallow depth of these deposits in comparison with other potash deposits in the world (cf. Figure 15) offers favourable conditions for a low-cost development of the deposit.
A shallow depth of the deposit may, however, pose certain risks. These risks mainly consist of the missing or reduced thickness of a suitable hydrogeological protection layer (salt back) for the selected mining method. The absence of these hydrogeological protection layers could lead to a reduction of the mineable reserves.

Figure 16 shows the reduced thickness of a hydrogeological protection layer in a potash deposit in Laos.
3 Goals of Industrial-Scale Potassium Chloride and NPK Fertiliser Production in Laos

The Lao economy is estimated to have grown 8.1% in 2013 by the World Bank (2014, /68/) (Figure 17), fuelled by the resource sector and continued Foreign Direct Investment (FDI). Exports from the mining sector are forecast to bring more than 2 billion USD of foreign exchange into Laos in 2014. These figures alone demonstrate how important the mining industry is for the country’s economic balance.
In Laos, 5 *greenfield* potash projects are currently in development. All of these projects will contribute to the macroeconomic development of the country but also to the regional development of the provinces that the projects are located in.

The main contributions of these projects and thus the herein implied goals of the Lao government when authorising them are:

- Creation of jobs at the mine site and in supporting industries
- Support of local communities by the raised demand for goods and services
- Support of local education programmes by the increased need for skilled labour
- Revenues from taxes and royalties and foreign exchange coming into the country

Apart from these remarkable benefits from future potash production in Laos, the following chapter will take a closer look at the efforts that will be necessary to realise industrial-scale potash fertiliser production from Lao potash deposits and the possible negative effects of such operations if no professional management and mitigation is in place right from the project start.

### 4 Requirements for Industrial-Scale Potassium Chloride and NPK Production in Laos

The following sections describe the principle requirements of potash processing in terms of processing methods, equipment and infrastructure.
4.1 Typical Determining Factors for a Potash Processing Plant

There are several factors that influence the design and the operation of a potash plant. A first important issue is the targeted annual production. Usually, this value ranges from 350,000 tpy of MOP up to 1 mtpy of MOP, but e.g. in Russia or Canada, there are also plants in operation that have a production capacity with more than 2 mtpy of MOP. This parameter directly influences the investment costs for the plant and also for the mining section because when more product is to be produced, more raw material has to be hauled from underground. Within this context, the mine lifetime has to be considered. Based on the available mineral resources within the explored area and the annual raw material demand of the production site, the mine lifetime can be estimated. The mine lifetime should be at least 20 to 30 years. Otherwise, the plant cannot produce economically.

Another important issue for a potash plant is the annual operating hours. Usually, about 7,500 hours per year of operation or less are envisaged. The rest of the time is reserved for routine maintenance services. The planned operating hours should not exceed 7,800 hours per year, as a sufficient maintenance service cannot be ensured for the plant otherwise.

The targeted product quality is also an important influencing factor for the whole production site. MOP can be either produced using flotation or hot leaching/crystallisation processes (see Section 5.2), but a product in higher quality (e.g. KCl98) can only be achieved by the latter. The most common potash product is MOP of standard quality. The specifications of this material are listed in Table 7. In principle, it is also possible to subject the standard product to a granulation section in the plant. This produces granulated MOP.

| Table 7 Specifications of an MOP Product in Standard Quality |
|-----------------|-----------------|
| **K₂O-Content** | 60.0% min.      |
| **Moisture**    | 0.2% max.       |
| **Physical Properties** |        |
| Form            | crystalline solid |
| Colour          | white/pink      |
| Odour           | odourless       |
| Melting Point   | 770°C           |
| Specific Gravity| 2.0 g/cm³       |
| Water Solubility (25°C) | 357 g/1,000 g |
4.2 Processing Methods for Potash Ores

The most adequate processing method depends on several factors. First of all, the mining method, which for its part depends on the quality of the raw material as well as the availability of water and energy, is of crucial importance.

In general, potash ore can be extracted via conventional underground mining and solution mining, which account for different processing methods.

Processing of Potash Ore Extracted by Conventional Mining:

A sylvinite ore extracted by conventional mining is processed by flotation. If the potash ore contains critical amounts of Anhydrite and/or insoluble material like clay or silicates, a hot leaching/crystallisation may be required in order to obtain the required product quality.

For the processing of conventionally mined carnallitite ore, there are several reliable processing methods available. In each case, the contained Carnallite is decomposed with water or an adequate brine to yield solid KCl and MgCl₂-rich brine. On the one hand, a primary NaCl
flotation (reverse flotation) can be performed in order to remove most of the NaCl. This is usually followed by Carnallite decomposition and a cold leaching of the KCl. On the other hand, Carnallite decomposition may also be the first process step, which is followed by hot leaching of the KCl/NaCl mixture and subsequent KCl crystallisation. In order to minimise KCl losses, the KCl-bearing MgCl₂-rich disposal brine is evaporated, whereupon synthetic Carnallite is obtained and transferred back to decomposition.

The process flow sheet of a typical processing method for a solid sylvinitite ore is depicted in Figure 18, in which the single process steps are shown.

**Processing of Brine Extracted by Solution Mining**

During the solution mining process of a sylvinitite ore, the production brine has a relatively low MgCl₂-content. Evaporation results in the precipitation of solid NaCl. The hot brine is subjected to cold crystallisation in order to obtain a saleable potash product.

The brine from a carnallitite ore is basically processed in the same manner. Due to the high MgCl₂-content of the brine, the evaporation yields solid Carnallite instead of KCl/NaCl. After decomposition of the Carnallite, the KCl/NaCl mixture can either be subjected to hot leaching/crystallisation or cold leaching. The MgCl₂-rich disposal brine can also be further evaporated in order to recover certain amounts of KCl as synthetic Carnallite and is transferred back to decomposition.

The process flow sheet of a typical processing method for carnallitite mining brine is depicted in Figure 19, in which the single process steps are shown.
Figure 18  Process Flow Sheet for a Typical Processing Method for Sylvinitite Ore Yielding MOP
Figure 19 Process Flow Sheet for a Typical Processing Method for Carnallite Mining Brine Yielding MOP
4.3 Sub-Structures of a Potash Processing Plant

The whole potash producing facility is fenced and several gates with checkpoints are installed. Typical plant site dimensions range from 500 m x 500 m to 500 m x 1,000 m. Several sub-areas of the plant area are listed below and are briefly described.

- **Mining Equipment on the Surface**
  Depending on the mining method, either several shafts (hoisting shafts, ventilation shafts) or several caverns on the brine field have to be developed.
  The solid potash ore is hauled out of the hoisting shaft and transported by conveyer belts to the potash ore storage.
  The production brine is extracted from several caverns and transferred via pumping through pipelines to the brine storage.

- **Potash Ore Storage/Brine Storage**
  In the raw material storages (potash ore or brine), a certain amount of raw material can be stored temporarily. Usually, the capacity is designed to cover 2-3 days of plant production.
  The potash ore storage is a simple roofed storage, which is fed with potash ore by a belt conveyor system or by trucks. From here, the raw material is sent continuously to the process building e.g. via a belt conveyor.
  The brine storage consists of simple tanks. From here the processing plant is continuously fed with the required amount of production brine.

- **Process Building**
  All equipment that is required to produce the targeted product from the appropriate raw material is located in the process building. Depending on the climatic conditions on processing site, it could be a closed building or only a roofed steel structure. Some of the equipment, e.g. large thickeners, may be placed directly next to the process building.

- **Product Storage and Product Loading Facilities**
  The final product (MOP) is transferred from the process building to the product storage e.g. via belt conveyor. The product storage is usually a closed building and enables the storage of the targeted amount of product. From the product storage, the product can be loaded onto trucks or trains. This can be either done by an automatic belt conveyor system or by wheel loaders. Connections at the plant site to transport ways (roads/railways) have to be established.

- **Administration and Social Buildings**
  Social buildings such as a canteen and quarters for the staff as well as administration buildings are also located within the facility area.

- **Reagent and Spare Part Storage**
  Here, the required spare parts for the plant equipment (e.g. spare pumps) and consumables, such as process chemicals or lubricants for several workshops can be stored in the appropriate amounts.

- **Garages and Workshops**
  The required maintenance services of some equipment from the process building and vehicles are conducted here.
- **Fire Station and First Aid Room**

  The potash plant has its own fire station and a first aid room in the case of emergency. Both buildings are included in the plant structure.

  An example of a potash plant with the main facilities at the surface is shown in Figure 20.

![Figure 20 Typical Facilities of a Potash Plant for a Conventional Underground Mine](image)

### 4.4 Infrastructure Needs of Potash Production

The geographical location of the deposit and of the production site nearby are important in terms of their distance to the potential markets, but also, on a smaller, regional scale, to the existing infrastructure, such as water, gas and power supply, transport links, especially railways, waterways and ports. The general availability of land, usually determined by the population density, is another important criterion.

The main infrastructure facilities that are needed for producing potash products in international standard on an industrial scale will be described in the following chapters.

The main potash projects in Laos are located in 2 provinces of Laos:

- Khammouane Province
- Vientiane Province
The names and the owners of these projects are listed in Table 6.

4.4.1 Logistics

For the economic operation of a potash project on an industrial scale, it is necessary to consider infrastructure that is required for project logistics and for the transport of final product. Large potash producers should be capable of transporting their products based on agreements and delivery schedules to the international market. This target can be achieved when sufficient roads for truck transport, railway tracks for train transport and well-equipped ports for ocean transport are available.

For potash production on an industrial scale, well-operating logistics services for a timely delivery of equipment and construction materials during the construction period and logistics services for importing coal, fuel and spare parts during the production period are very important. Insufficient logistics infrastructure has both a direct and an indirect effect on production cost. If the logistic services are disrupted during plant operation, production could need to be stopped and this would directly affect production capacity and consequently affect production cost. The main logistics services in a potash production plant are as follows:

- Logistics services for coal
- Logistics services for fuel and consumable materials
- Transportation of equipment, construction materials and spare parts
- Transportation of personnel
- Transportation of final product

If the logistics infrastructure is insufficient, producers have to consider bigger storage areas to store enough fuel, consumable materials and spare parts to avoid disruptions of production, which would indirectly lead to an increase in operating costs.

4.4.2 Transportation of Final Product

More than 50% of potash fertiliser production worldwide is produced in a mid-continent position in the Northern Hemisphere and the majority of this is transported to export markets via sea ports. Both in the Perm Region, where the centre of the Russian potash industry is located, and in Saskatchewan, where most of the Canadian potash products are produced, considerable distances have to be covered by rail before the products reach the export ports in St Petersburg or in Vancouver, British Columbia. Essential logistical pre-requisites for the potash production sites are, therefore, the connection to the national railway network and/or waterways that are navigable all year round as well as the availability of transport capacities along these routes. Naturally, there are great differences in the logistical frame conditions among individual production sites.
Figure 21 Main Potash Producers and Transportation Routes

Table 8 Land Transport Distances of Final Product to the Port Sites for Main Potash Producers

<table>
<thead>
<tr>
<th>Potash Producer</th>
<th>Port Site</th>
<th>Distance [km]</th>
</tr>
</thead>
<tbody>
<tr>
<td>APC, Jordan</td>
<td>Aquaba</td>
<td>225</td>
</tr>
<tr>
<td>Belaruski, Belarus</td>
<td>Baltic Sea or Black Sea</td>
<td>620-940</td>
</tr>
<tr>
<td>ICL – Dead Sea Works, Israel</td>
<td>Eilat and Ashdod</td>
<td>180-200</td>
</tr>
<tr>
<td>ICL – Iberpotash, Spain</td>
<td>Barcelona</td>
<td>80</td>
</tr>
<tr>
<td>K+S, Germany</td>
<td>Hamburg</td>
<td>170-420</td>
</tr>
<tr>
<td>MOSAIC, Canada</td>
<td>Vancouver</td>
<td>&gt;1,200</td>
</tr>
<tr>
<td>PCS, Saskatchewan, Canada</td>
<td>Vancouver</td>
<td>&gt;1,200</td>
</tr>
<tr>
<td>PCS, New Brunswick, Canada</td>
<td>Port Saint John</td>
<td>85</td>
</tr>
<tr>
<td>SQM, Chile</td>
<td>Tocopila</td>
<td>370</td>
</tr>
<tr>
<td>URALKALI, Russian Federation</td>
<td>St Petersburg</td>
<td>2,100</td>
</tr>
</tbody>
</table>
Based on the location of potash projects in Laos in the Vientiane and Khammouane Provinces, transportation infrastructure for the delivery of final products to capable ports is still necessary for each region.

Laos does not have direct access to the sea and is a landlocked country bordered to the south and east by the Mekong River, to the west by the Annamite Mountains separating Laos from Vietnam and a mountainous landscape, which extends across much of the north of Laos to the border with China.

Most of the companies that have applied for licenses for potash production are Chinese companies. China and Southeast Asian countries are possible target markets for potash producers in Laos.

Most practical seaports for the export of final products are located in Vietnam. Two main transit transport corridors could be used:

- Road No. 8 from Paksane (Laos) to Cua Lo Port Vinh (Vietnam), 257 km
- Road No. 9 from Vientiane (Laos) to Danang Port (Vietnam), 944 km.

**Transport of Final Product from Potash Production Sites in Vientiane Province**

The current transportation infrastructure in Laos is not sufficient for access to the international markets. Potash exports to China could be transported by road via Vietnam, or possibly to Bangkok, where it can be shipped to China. It has been announced that there is a plan to build a 420 km high-speed railway line between Boten on the Laos border with Yunnan Province (China) and Vientiane, and when this comes into operation, it could well be the critical factor in encouraging an expansion of potash output, especially in the Vientiane area so that potash can be transported directly into China (cf. Figure 22). This rail construction project is currently scheduled to be completed in 2018. Before the completion of the rail connection, practical options to access the Chinese market will be shipping from Vietnam or Thailand, which are also the only possibility to access the Southeast Asian market.

The rail connection in Thailand is an alternative option for possible rail transport to the ports in the south of Thailand, especially for potash projects in the Vientiane Basin. There is a rail link from Nong Khai in Thailand across the Friendship Bridge to Thanalaeng, 20 km east of Vientiane and would be an economical and practical option for the transport of MOP products from the Vientiane Basin to ports in the south of Thailand near Pattaya. Currently, Laos has no railway system, but 2 railway projects that are planned will connect to the Vietnamese railway system as follows:

- Thakek via Mu Gia Pass to Tan Ap (Vietnam)
- Savannakhet to Lao Bao (border to Vietnam)

There is also a plan to connect the railway of Thailand to China, which would pass through Vientiane and Luang Prabang in Laos (cf. Figure 22).

The detailed design of a 3.5 km section from the middle of the Friendship Bridge to Thanaleng has been completed.
Transport of Final Product from Potash Production Sites in Khammouane Province

For the mines in Khammouane Province, the preferred export route will probably be via Highway 12 into Vietnam: Road No. 12 starting from Thakek in Laos through Vung Ang Port in Vietnam (cf. Figure 23). The road has 1 lane in each direction. The construction of the Road No. 12 was planned and processed based on the agreement between Laos and Vietnam, which stated Vietnam’s intention of cooperating with Laos for it to have access to the South China Sea. In terms of road construction, compared to the steady progress in Laos, the construction in Vietnam took a while. All of the highways crossing the mountains are at risk of closure due to landslides, especially in the rainy season, but Highway 9 to the south and Highway 8 to the north have sections where there are bridges with a 20-tonne limit. These bridges can be bypassed in the dry season but will create a transport bottleneck in the rainy season. Similar problems affect the road north of the SINO-AGRI Mine towards Thakek. It is necessary to build a new hard-surface road linking the mines to Highway No. 13 to solve truck size limitation. Truck transport capacity of 30 tonnes would be more economic and a size limitation to 20-tonne trucks would increase transport costs.
Planned railway projects from Thakhek via Mu Gia Pass to Tan Ap and from Savannakhet to Lao Bao, which would connect Laos to the Vietnamese railway system after construction, could be an alternative option for potash transport to Vietnam (cf. Figure 22).

4.4.3 Power Generation

For potash production, 2 types of energy supply are required:

- Electrical energy
- Steam

Electrical energy could be obtained from the local network or produced at the plant site. It is necessary to note that the required electrical power for a potash project is usually about 20 to 30 MW and in this range, electrical power stations are not at an economical capacity. This technology is used for coal power stations with more than 100 MW. Potash production usually requires between 200 – 450 KWh/t of MOP product and varies depending on the mining and processing technology used. Energy for drying or steam generation is not included. Steam is required for technical evaporation processes and hot leaching steps in processing, which can amount to around 1.0 t of steam per t of MOP product.

In Laos, no natural resources for gas are available.
There are several projects for the construction of hydropower plants in Laos. These are shown in Figure 24. If there is a possibility to obtain electrical energy from a hydropower plant and electrical network, it would be more economic in comparison with producing electricity at the project site.

In case a power plant is necessary, it has to be designed and constructed within the project schedule. As an energy source for this plant, hard coal from local deposits or imported coal could be used.

Steam required for processing is produced via steam generators. Electrical energy is generated via a combination of a mixed pressure turbine and a 3-phase alternator.

The following criteria have to be considered during the capacity dimensioning of a power plant:

- Requirements for the production process
- Requirements for infrastructure
- Reserve capacities for periodic, partial maintenance works
- Reserve capacities for future expansions

Near to the power plant, a medium voltage main switchgear (e.g. 6 kV/generator main switchgear) that is supplied by 3-phase alternators should be built.

This main switchgear will supply the operational departments of the project with power. A medium voltage system (usually e.g. 6 kV) should be used as supply voltage. Separate transformer stations that will be supplied from the generator main switchgear have to be installed. Low voltage switchgears of the operational department are supplied via 6 kV switch gears and 6 kV/0.4 kV and 6 kV/0.69 kV transformers respectively.
4.4.4 Water Supply

Usually a potash production plant requires different amounts of water, depending on the mining method and type of ore and processing technology involved. Examples of estimated water consumption for 4 types of projects are as follows:

- Carnallite solution mining project 7.5 m³/t of MOP
- Carnallitite conventional mining project 2.5 m³/t of MOP
- Sylvinite solution mining project 1.0 m³/t of MOP
- Sylvinite conventional mining project 0.5 m³/t of MOP

Most of the water is required for processing and steam generation.
For processing, water could be sourced from rivers, depending on the distance and possibility of obtaining the water. A problem of using river water could be the seasonal variations of the water level of the river. The complexity for the technical implementation is very high and expensive.

Generally, river water has to be filtered and cleaned in a water treatment plant for use in processing. River water contains suspended sediments, which would pollute brines and the refinery in general. These sediments have to be detached by filtration. Filtration is a physical process where solid particles in fluids can be detached with filtration material. In this case filtration in gravel-packed filters is useful. Apart from this, water has also to be used for sanitary purposes, which means that biological treatment of the water is required as well.

Rinsing water is used for cleaning in the refinery. Rinsing water can be collected rainwater or also river water. A rinsing water network distributes rinsing water to appropriate locations in the refinery.

Small amounts of drinking water are supplied by the local drinking water network. A drinking water network distributes drinking water to appropriate places in the refinery.

### 4.4.5 Education

The personnel of the processing plant comprise approx. between 350 and 600 employees. Approximately 15% are upper-level employees, 60% skilled workers and 25% non-skilled workers.

Education plays an important role in industrial production. Potash industrial production requires manpower in several specialist categories during the construction and production periods. Well-educated engineers and technicians who understand the process and are able to solve production problems and manage the maintenance programme are necessary for the smooth operation of a production plant that fulfils international standards.

There should be education programmes for personnel during the construction period as well as during the operation period.

The marketing of potash products in the domestic market in Laos also requires an education programme at several levels of the agricultural industry. Fertilisers’ specifications and effectiveness of using the fertilisers in terms of quantity and quality of agriculture products should be taught to farmers and decision-makers.

### 5 Environmental Impact and Sustainability

During the production of potash fertilisers from solid potash ore and natural brines, solid as well as liquid residues inevitably accumulate. An utilisation of these residues is not technically possible, not ecologically sustainable and/or not economically feasible.

The problem with these residues is not the toxicity of their substances but their large mass alone. The composition of the residues naturally depends on the source of the ore.

The solid residues from the processing of sylvinitic and carnallitite ores mainly consist of Halite. During the processing of sylvinitic and carnallitite, small and large amounts respectively of liquid processing residues arise in the form of aqueous brines.
The main environmental impacts caused by the handling of residues are land use, brine leakage into the ground and also dust emission. Moreover, attention should be paid to the stability of residues that are stored on the surface and the maintenance of protective measures. The basis for a successful handling of production residues are a thorough characterisation of the residue material, including predictions about its long-term behaviour that are as accurate as possible, as well as the choice of a suitable location for residue storage or disposal.

5.1 Solid Residues

Solid residues mostly consist of approx. 90% NaCl, while other components often include among other things, Anhydrite and clay. The management of the processing residues is dependent on many factors, e.g. geographical location, ore composition, industrial infrastructure and development, the political situation as well as public opinion regarding environmental protection.

The following disposal methods are used worldwide:

1. Backfilling operations: the solid residues from mining and processing are transported back into mined out galleries. A benefit of this is that the backfill operation supports the stability of these mined out galleries and can minimise surface subsidence.

2. Dissolving and disposal to sea: if the residue material is mostly water soluble, it can be dissolved in water. The resulting brine can be disposed of in a sea nearby. This method often causes problems, since environmental regulations often prohibit this procedure.

3. Permanent stockpiling on the surface: the solid mining and processing residues can be stockpiled permanently on the surface. Special attention has to be paid to environmental regulations.

5.2 Liquid Residues

Liquid residues comprise processing residues as well as brines, which result from the effect of precipitation on surface tailings piles.

The following disposal methods for liquid waste (brines) can be considered:

1. Disposal to sea: discharge of liquid processing residues or brines into receiving waters with the objective of transporting the salt to seawater or directly into seawater.

2. Deep well injection: injection of liquid processing residues or waste brines into suitable underground pores or fissured rocks

3. Backfilling operations: the disposal brine can be used as backfill material for exhausted galleries or caverns. The resistance of the underground cavities against the brine has to be ensured.
The methods to be used for the disposal of residues from potash production in Laos in future should be carefully selected according to the abovementioned criteria and applied and monitored according to the regulations and laws for environmental protection. In doing so, there needs to be a state-accepted balance between economic and ecological interests, and not a one-sided emphasis on ecology or economy.

Figure 25  Percentage Shares of the Disposal Methods Used Worldwide for Solid Residues from the Processing of Solid Potash Ores from Conventional Underground Mining

6  Investment Appraisal

Investment appraisal of a mining project differs from other investment subjects due to the specific characteristics of a mining venture, such as:

- Lengthy exploration period with no revenue
- High capital investment during development
- Specialised equipment
- Large environmental/social/infrastructure costs
- Large costs at the end of the project for reclamation
- The mining project is a major foreign exchange earner for the country
Due to these features of a mining project, the appraisal of its economic value requires knowledge and understanding of the geological, mining, processing and environmental parameters of the mineral project, paired with the skills of an experienced economic valuator.

Currently, there are several standards and guidelines for the valuation of mineral projects. The most commonly used is the CIMVal Standards & Guidelines for Valuation of Mineral Properties from February 2003 (CIMVal, 2003, /1/). For appraising a mineral project, CIMVal differentiates between the following approaches:

- **Income approach**: net present value and internal rate of return estimates
- **Market approach**: analyses of comparable transactions
- **Cost approach**: plant and equipment value and replacement value

These 3 general methods are conceptually straightforward and have (some) proven track records for *greenfield* and *brownfield* potash mining projects. The most widely applied and accepted approach for investment appraisal is the income approach, which offsets the costs for mine and plant construction, operation and closure against the anticipated income from product sales. The assumptions that are the basis for calculation start with geological exploration results such as mineral reserves and are then followed by engineering advice regarding time and costs for extraction and processing as well as efforts for closure and mine site reclamation. The risks that are inherent to the mining project are then reflected in the discount factor, which is used to convert future cash flows to a present value.

Thus, the main input data for potash project appraisal with the help of the income approach are:

- Production rate and ramp-up
- Potash product and possible by-product price
- Capital expenditures (CAPEX)
- Operating expenditures (OPEX)
- Taxes and royalties
- Depreciation

The potash price was briefly discussed and forecast in Section 1.5. Section 6.1 will give an overview about CAPEX and OPEX accuracy at the different project stages that will possibly influence the accuracy of the results of investment appraisal. In Section 6.2, some general risks of potash production are discussed, which should serve to complement the specific risks of potash production from the Lao deposits that were already discussed in Chapter 4.

### 6.1 Capital and Operating Cost Estimates

Sensitivity analyses of potash projects typically show that the projects are highly sensitive to changing CAPEX and OPEX. With ongoing exploration and investigation, further geological information becomes available and the technical concepts for mining and processing are designed with a higher certainty. Thus, the accuracy of the cost estimate increases. Typical accuracy ranges and the contingencies that are included in such cost estimates are shown in Table 9.
Table 9 Minimum Requirements on Cost Accuracy and Contingency at the Different Project Stages

<table>
<thead>
<tr>
<th>Cost Accuracy</th>
<th>Scoping Study</th>
<th>Pre-Feasibility Study</th>
<th>Definitive/Bankable Feasibility Study</th>
<th>Project Execution</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>+/-25%</td>
<td>+/-15% to 25%</td>
<td>+/-10% to 15%</td>
<td>+/-5% to 10%</td>
</tr>
<tr>
<td>Cost Contingency</td>
<td>30% to 50%</td>
<td>15% to 30%</td>
<td>less than 15%</td>
<td>less than 15%</td>
</tr>
</tbody>
</table>

Table 9 illustrates that the results of investment appraisal will become more reliable the further the project is developed. To provide BGR with some benchmark costs of potash production, Table 10 compares the costs of selected greenfield potash projects at different project stages and with different mining methods.

Table 10 shows that conventional mining projects have higher OPEX/t of final product, mainly due to the higher demand for labour. However, the OPEX of a solution mining project are highly sensitive to energy prices. A comparison of 11 potash mines in Saskatchewan showed that the average energy consumption of a solution mining operation was about 1,300 kWh/t of final product\(^{21}\), while that of conventional mining was close to 400 kWh/t of final product (Gen-source, 2014, /33/).

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\(^{21}\) Including gas consumption.
### Table 10: Comparison of Cost Figures per Tonne of Final Product of Selected Greenfield Potash Projects

<table>
<thead>
<tr>
<th>Project Owner and Project</th>
<th>Project Status</th>
<th>Report Date</th>
<th>Production Capacity</th>
<th>Cost/Tonne of Final Product</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Solution Mining Projects</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Encanto Potash Corp.</td>
<td>Preliminary Feasibility Study</td>
<td>02/2013</td>
<td>2.8 mtpy MOP</td>
<td>CAPEX: 23.73 USD/t MOP</td>
</tr>
<tr>
<td>Muskowekwan First Nations Home Reserve Project, Saskatchewan, Canada</td>
<td></td>
<td></td>
<td></td>
<td>OPEX: 54.32 USD/t MOP</td>
</tr>
<tr>
<td>Western Potash Corp.</td>
<td>Feasibility Study</td>
<td>11/2013</td>
<td>2.8 mtpy MOP</td>
<td>CAPEX: 58.84 USD/t MOP</td>
</tr>
<tr>
<td>Milestone Project, Saskatchewan, Canada</td>
<td></td>
<td></td>
<td></td>
<td>OPEX: 62.28 USD/t MOP</td>
</tr>
<tr>
<td>Allana Potash Corp.</td>
<td>Bankable Feasibility Study</td>
<td>02/2013</td>
<td>1 mtpy MOP</td>
<td>CAPEX: 66.61 USD/t MOP</td>
</tr>
<tr>
<td>Danakhil Potash Project, Ethiopia</td>
<td></td>
<td></td>
<td></td>
<td>OPEX: 161.51 USD/t MOP</td>
</tr>
<tr>
<td><strong>Conventional Mining Projects</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Passport Potash Inc.</td>
<td>Preliminary Economic Assessment</td>
<td>02/2013</td>
<td>2.5 mtpy MOP</td>
<td>CAPEX: 43.52 USD/t MOP</td>
</tr>
<tr>
<td>Sylvinite/Carnallitite Mining in the Holbrook Basin, Arizona, USA</td>
<td></td>
<td></td>
<td></td>
<td>OPEX: 75.75 USD/t MOP</td>
</tr>
<tr>
<td>Potash Ridge Corporation</td>
<td>Preliminary Economic Assessment</td>
<td>10/2012</td>
<td>0.75 mtpy SOP</td>
<td>CAPEX: 66.09 USD/t SOP</td>
</tr>
<tr>
<td>Blawn Mountain Project, Beaver Country, Utah, USA</td>
<td></td>
<td></td>
<td>1.8 mtpy sulphuric acid</td>
<td>OPEX: 308.65 USD/t SOP</td>
</tr>
<tr>
<td><strong>Open Pit Mining Projects</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Verde Potash Plc</td>
<td>Preliminary Feasibility Study</td>
<td>03/2014</td>
<td>0.33 mtpy ThermoPotash(^2)</td>
<td>CAPEX: 14.64 USD/t</td>
</tr>
<tr>
<td>Cerrado Verde Project, Minas Gerais State, Brazil</td>
<td></td>
<td></td>
<td></td>
<td>OPEX: 54.92 USD/t</td>
</tr>
<tr>
<td>South Boulder Mines Ltd.</td>
<td>Scoping Study</td>
<td>11/2012</td>
<td>2 mtpy MOP</td>
<td>CAPEX: 66.89 USD/t</td>
</tr>
<tr>
<td>Colluli Potash Project, Eritrea</td>
<td></td>
<td></td>
<td></td>
<td>OPEX: 187.00 USD/t</td>
</tr>
</tbody>
</table>

\(^2\) ThermoPotash (TK) is a multi-nutrient fertiliser that contains no chloride and is supposed to provide the soil with more potassium than regular MOP fertilisers. TK was approved by the Brazilian Ministry of Agriculture in June 2013.
6.2 Risk Evaluation

Ernst & Young annually compiles a list of risks to which mining companies are subject. This list is based on the perceived risks and their effects on mine operators and is based on input from operating producers. Table 11 shows the risks associated with a mining project. Risks that are closely connected to the location of the mining project are highlighted in orange.

Table 11 Comparison of the Top Ten Risks Associated with a Mining Project (Ernst & Young, 2013, /20/)

<table>
<thead>
<tr>
<th>2008</th>
<th>2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>01 Skills Shortage</td>
<td>01 Capital Dilemmas (Capital Allocation and Access)</td>
</tr>
<tr>
<td>02 Industry Consolidation</td>
<td>02 Margin Protection and Productivity Improvement</td>
</tr>
<tr>
<td>03 Infrastructure Access</td>
<td>03 Resource Nationalism</td>
</tr>
<tr>
<td>04 Maintaining a Social License to Operate</td>
<td>04 Social License to Operate</td>
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<tr>
<td>05 Climate Change Concerns</td>
<td>05 Skills Shortage</td>
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<tr>
<td>06 Rising Costs (Cost Inflation)</td>
<td>06 Price and Currency Volatility</td>
</tr>
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<td>07 Pipeline Shrinkage</td>
<td>07 Capital Project Execution</td>
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<td>08 Resource Nationalism</td>
<td>08 Sharing the Benefits</td>
</tr>
<tr>
<td>09 Access to secure Energy</td>
<td>09 Infrastructure Access</td>
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<tr>
<td>10 Increased Regulation</td>
<td>10 Threat of Substitutes</td>
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</tbody>
</table>

The table shows that risks that are connected to project financing and maintaining a competitive cost structure as well as risks that are associated with the project location are of major concern for all mine operators in general. For potash mine operators, 3 of these risks were a major cause for concern in 2013. These are, in the order of their influence:

1. Capital Dilemmas
2. Price Volatility
3. Resource Nationalism

Since these risks will also affect potash production from Lao deposits, they are discussed in more detail below:

- Capital Dilemmas

For junior mining companies, it has been increasingly difficult to obtain the necessary project funding in the last 18 months. Investors are seeking a rapid on their investments, which is – due to the specifics of a greenfield mining project (cf. Section 6.1) – not to be found in a mining company.

However, also for operating mine producers, capital allocation has proven to be difficult under the current market conditions. One recent example of the potash industry is Vale S.A. (VALE) and its Rio Colorado Potash Project in Argentina: VALE suspended the
project in March 2013 due to escalating capital investment costs that were no longer in line with VALE’s commitment to discipline in capital allocation.

For the potash projects that are currently developed in Laos, capital access does not seem to be of a major concern since the investors are clearly interested in a long-term commitment to the projects.

This risk is therefore only has a marginal impact on potash production in Laos.

- **Price Volatility**

  Both CAPEX and OPEX of a potash mining project are dependent on foreign prices and currencies. Depending on the level of imported goods and equipment, CAPEX and OPEX volatility could ultimately decide the level of profitability of the operation. Therefore, Figure 26 shows the exchange rates of selected currencies in which purchases of equipment and machinery are highly likely for the potash projects in Laos.

  Hedging is an option to protect against volatile prices. A sufficient cash “cushion” could also help to increase flexibility. Furthermore, a constant assessment of the market situation, including forecasts of price trends should be used as a basis for decision-making.

![Figure 26 Development of Selected Currency Exchange Rates Compared to the USD over the Last 5 Years](image)

However, not only expenditures are affected by volatile prices and currencies. Fluctuations in the potash product price will also affect the project’s profitability. A potash price forecast was included in Section 1.5. Since most of the potash projects in Laos are backed by Chinese investors with the clear intention to satisfy the Chinese demand for potash products through these projects, the dependence on product prices is not as high as for projects that have no offtake agreements.
Price volatility is often worsened by actions of resource nationalism such as taxes or controls on the export (see the following point).  
**This risk is considered have a medium impact on potash production in Laos.**

- **Resource Nationalism**

  Resource nationalism has always been a threat to mine operators, but has gained increasing significance over the last few years. There is hardly any mitigation measure against resource nationalism and every mining project is subject to it to a certain degree.

  Resource nationalism might benefit a country’s development and eventually also a mine operator, e.g. if revenues raised by taxation on mining production are invested in a country’s infrastructure, education or social system.

  The fiscal obligations of a mine developer in Laos are related to a rental fee for general survey and exploration of 0.5 USD to 1.0 USD per hectare per year and a preparatory fee of 3.0 USD to 12.0 USD per hectare per year for the Feasibility and Construction Phase (CMCPL, /13/). For mineral production, a royalty of 2% on the gross sales value of the potash minerals is due. Privileged income taxes between 20% and 35% seem to be generally possible in the mining sector (CMCPL, /13/). Further taxes on import and re-export as well as a tax levy on dividends and retained earnings are imposed. Although a definite calculation basis for the taxes due on the mining operation cannot be made at the moment, Laos has established a mining law that allows existing mine operators to exploit the country’s resources at a reasonable tax level (PanAust, 2011, /51/).

  **This risk is considered to have a medium impact on potash production in Laos.**

### 7 Conclusions and Recommendations of Possible Solutions for the Production of Potassium Chloride Fertilisers

The exploration data available to date show that there is a large potential for MOP production, which would make an important contribution to an independent supply of potash fertilisers for the Southeast Asian region. Sylvinite resources appear to be in the minority and carnallitite resources dominate in terms of quantity. This does not necessarily have to be a major drawback, but it requires in particular an intelligent concept for (i) an Mg-line by-product production and (ii) waste disposal management. For this, there needs to be a state-accepted balance between economic and ecological interests, and not a one-sided emphasis on ecology or economy.

As the deposits in Laos are chloride-type deposits, there is no deposit basis for SOP production.

Compared with established producers in Canada and the Russian Federation, the following advantages exist: the proximity to the booming Asian market and the shallow depth.

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23 Not only in developing countries but also in developed countries such as in 2012 in Australia or Britain (Economist, 2012, /7/)
However, shallow depth is not only positive. It also means that the mining-induced subsidence will reach the surface more quickly and with a relatively large total subsidence as a result of the mining process. This can only be countered by a low extraction ratio (high mining losses) or also by the backfilling of large amounts of backfill material (hydraulic backfill) soon after extraction. Surface subsidence cannot be absolutely avoided in this way, especially if solution mining is used.

The disadvantages are the hitherto undeveloped industrial infrastructure, the lack of railway and highway connections, no availability of high-grade fuel in the country, especially gas, and the limited level of technical training of broad segments of the population at the moment.

In view of the Mg-line by-products, the state-controlled power generation using hydropower and the resulting lower energy prices in comparison to other countries with carnallite deposits appears to offer a great advantage, as economically feasible options for the electrolytic synthesis of Mg metal are opened up. However, these have to be investigated in detail.
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LIST OF ABBREVIATIONS

Abbreviations of physical units/constants used throughout this study are as follows:

- cm³: cubic centimetre
- H₂O: water
- ha: hectare
- K: potassium
- K₂O: potassium oxide
- KCl: potassium chloride
- kg: kilogram
- km: kilometre
- km²: square kilometre
- kV: kilovolt
- kWh: kilowatt hour
- m: metre
- m%: percentage by mass
- Mg: magnesium
- MgCl₂: magnesium chloride
- mtpy: million metric tonne(s) per year
- MW: megawatt
- N: nitrogen
- NaCl: sodium chloride
- P: phosphate
- t: metric tonne(s)
- tpy: metric tonne(s) per year
- %: percent