Diversified Usage of Renewable Energy in Iceland

Extract from an analysis of alternative energy intensive sectors

Investum

August 2009

Please note that the following document is an extract only. To get further information please contact Invest in Iceland
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Conclusions

- Several studies on chemical industries involving chlorine production have been done in Iceland the past 4 decades
- The process of producing chlorine and caustic soda is highly electrical energy intensive (>3,500 kWₜ / ton chlorine and >50% of cash cost) which makes Iceland an interesting site for such operation
- Furthermore some process implementations are also thermal energy heat intensive which makes direct use of geothermal steam attractive
- Chlor Alkali plant forms the backbone of most chemical parks as majority of chemical processes involves chlor handling in one way or another
- Due to shift in regulations, around 30% of European chlor alkali capacity have to be converted to new technology in the next 10 years
- The market consensus on growth in chlorine demand indicates 2%-3% YoY long term, but short term decline
- Stand alone chlor alkali plant in Iceland would have to ship the main product, chlorine gas in a liquid form (-35°C) to a European downstream user. Due to the high dependence of electricity such solution might be economically viable, but impractical as chlorine transport on sea has been abandoned in Europe due to safety reasons
- Production of organic chemicals would require import of ethylene or other types of intermediates which dilutes the percentage of electricity in the cash cost to less than 20% and makes Iceland as a location less attractive
Conclusions and Recommendations Cont.

**Conclusions cont.**
- However if oil prices surge again, the production of **acetylene from calcium carbide** as organic source could be attractive in Iceland.
- The ‘by-product’ caustic soda is easily shippable as a solution or dry to Europe. There remains an **undersupply** of the product in Europe.
- Modular small scale chlor alkali plants have become available on the market recently.
- This study reveals that **niche chlor derivatives** using materials available in Iceland such as aluminium and silica and even sulfur can be very attractive.
- If such plant will be build in Iceland export of chlorine in **cylinders and drums** in marginal quantities could become economically viable.

**Recommendations**
- Consider a industrial park concept having chlor alkali plant as backbone operation.
- Approach producers of niche chlorine derivatives such as:
  - Packaged chlorine
  - Aluminium chlorides
  - Silicones
- Co-operate with industrial experts like Prochemics to asses the feasibility of small scale modular chlor alkali plant in Iceland.
Production Cost & Prices

- Compared to production of metals via electrolysis the production of chlorine does not require much electric energy per weight, i.e. 2,500-3,500 kWh per ton chlorine or whereas aluminium electrolysis uses about 14,500 kWh per ton of product.
- But due to the low cost of raw material (salt) and rather simple process the cost of electricity as a percentage of total cash cost is higher than in any of the bigger chemical industries.
- Electricity is a significant cost element in chlor-alkali production, estimated to account for 60% of the variable costs of production and approximately 40% of total production cost.
- Due to the high electrical prices in Europe, Prochemics, a chemical industry consulting company states that there will be no incentive to build new plants in Europe or to invest in the conversion from mercury cell plant to membrane plant technology, as well as conduct major expensive modernizations.
- The collapse of caustic soda prices over the past few months has impelled chlor-alkali producers to idle plants and reduce production capacity, and downstream industries such as polyvinyl chloride (PVC) have reported shortages of chlorine as a result.

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1) Source: “The viability of importing packaged chlorine from Europe”, UK competition Commission, 2008
3) Bank of America & Merrill Lynch, 08.06.2009, Dow Chemical analysis
The Chlorine Production Cost in Different Regions

- Production cost varies greatly from region to region mainly due to the cost of electrical energy.

<table>
<thead>
<tr>
<th>REGION</th>
<th>EUROPE</th>
<th>US GULF COAST</th>
<th>SAUDI ARABIA</th>
<th>CHINA</th>
<th>RUSSIA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw Materials:</td>
<td>€/MT</td>
<td>€/MT</td>
<td>€/MT</td>
<td>€/MT</td>
<td>€/MT</td>
</tr>
<tr>
<td>Net Raw Materials</td>
<td>81.3</td>
<td>73.9</td>
<td>83.9</td>
<td>77.9</td>
<td>83.9</td>
</tr>
<tr>
<td>Utility Costs:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Net Utility Costs</td>
<td>253.7</td>
<td>183.9</td>
<td>66.7</td>
<td>129.8</td>
<td>72.5</td>
</tr>
<tr>
<td>Net Variable Costs</td>
<td>335.0</td>
<td>257.8</td>
<td>150.5</td>
<td>207.6</td>
<td>156.4</td>
</tr>
<tr>
<td>Operations &amp; Maint. Costs:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Net Operations &amp; Maintenance</td>
<td>37.2</td>
<td>31.1</td>
<td>31.9</td>
<td>19.1</td>
<td>38.3</td>
</tr>
<tr>
<td>Plant Gate Cost</td>
<td>528.1</td>
<td>418.9</td>
<td>324.1</td>
<td>319.6</td>
<td>368.1</td>
</tr>
<tr>
<td>Corp. G&amp;A</td>
<td>13.8</td>
<td>13.8</td>
<td>13.8</td>
<td>13.8</td>
<td>13.8</td>
</tr>
<tr>
<td>Total Production Cost (ECU)</td>
<td><strong>541.9</strong></td>
<td><strong>432.7</strong></td>
<td><strong>337.9</strong></td>
<td><strong>333.4</strong></td>
<td><strong>381.9</strong></td>
</tr>
<tr>
<td>Total Cash Cost (ECU)</td>
<td>421.2</td>
<td>332.2</td>
<td>227.3</td>
<td>260.0</td>
<td>246.1</td>
</tr>
<tr>
<td>Cl₂ Production Cost (excl. NaOH)</td>
<td>239.3</td>
<td>130.2</td>
<td>35.3</td>
<td>30.8</td>
<td>79.3</td>
</tr>
</tbody>
</table>

- It can be seen that European cash costs (assuming old, fully depreciated plants) will be still higher than the production costs in other regions (which take into account the capital costs of new plants), there will be no incentive to build new membrane plant technology, as well as conduct major expensive modernizations.
- Due to high electricity prices in Europe the industry faces tough competition from low electricity price regions of the world.
- Chlor Alkali producers in Europe have pointed out that this can lead to carbon leakage i.e. relocation to countries without capped CO₂ emission.

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Product Sectors

- Chlorine chemistry is used in over 50% of all industrial chemical processes
- Including 90% of pharmaceuticals and 96% of crop protection chemicals
- It is a basic manufacturing chemical and thus affects numerous other industries

Chlorine Chemistry's Product Sectors *

<table>
<thead>
<tr>
<th>Sector</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vinyl</td>
<td>36%</td>
</tr>
<tr>
<td>Phosgene</td>
<td>9%</td>
</tr>
<tr>
<td>HCl</td>
<td>8%</td>
</tr>
<tr>
<td>Porpylene oxide</td>
<td>7%</td>
</tr>
<tr>
<td>Chlorometh &amp; chlorophth solvents</td>
<td>6%</td>
</tr>
<tr>
<td>Water treatment</td>
<td>5%</td>
</tr>
<tr>
<td>Allyics</td>
<td>4%</td>
</tr>
<tr>
<td>Pulp &amp; paper</td>
<td>4%</td>
</tr>
<tr>
<td>Other organics</td>
<td>7%</td>
</tr>
<tr>
<td>Other inorganics</td>
<td>14%</td>
</tr>
</tbody>
</table>

Caustic Soda's Product Sectors *

<table>
<thead>
<tr>
<th>Sector</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic chemicals</td>
<td>16%</td>
</tr>
<tr>
<td>Pulp &amp; paper</td>
<td>12%</td>
</tr>
<tr>
<td>Inorganic chemicals</td>
<td>12%</td>
</tr>
<tr>
<td>Alumina</td>
<td>10%</td>
</tr>
<tr>
<td>Soaps &amp; detergents</td>
<td>8%</td>
</tr>
<tr>
<td>Textile industry</td>
<td>8%</td>
</tr>
<tr>
<td>Sodium hypochlorite (bleach)</td>
<td>3%</td>
</tr>
<tr>
<td>Water treatment</td>
<td>2%</td>
</tr>
<tr>
<td>Food industry</td>
<td>1%</td>
</tr>
<tr>
<td>Other uses</td>
<td>21%</td>
</tr>
</tbody>
</table>

- Chlorine chemistry is not only important for today's economy, but also plays a key role in enabling future innovations, thus contributing to economic growth. Innovative uses of chlorine chemistry include producing:
  - ultra-pure silicon, the basic material of the photovoltaic cell
  - super-strength polyaramide fibers, used to replace asbestos in brake linings and to reinforce fiber optic cables
  - silicon chips, essential to microprocessors that drive computers
  - titanium metal and aluminum for lightweight aircraft fuselages
  - epoxy resins used in satellites, cars and planes

Source: [www.worldchlorine.com](http://www.worldchlorine.com)

* Based on 2005 consumption data
Chlor Alkali Plant Output – where does it go?

European chlorine applications in 2007 (10.71 million tonnes)

- **Inorganics 13.2%**
  - Disinfectants, water treatment, paint pigments, silicon chips

- **Other organics 7.1%**
  - Detergents, ship & bridge paints, lubricants, wallpaper adhesives, insecticides

- **PVC 33.8%**
  - Pipes, flooring, medical supplies, clothing, windows

- **Isocyanates & oxygenates 30.9%**
  - Upholstery, insulation, footwear, plastics, pesticides, car parts

- **Solvents 3.4%**
  - Pipes, flooring, medical supplies, clothing, windows

- **Epichlorohydrin 5.5%**
  - Pesticides, epoxy resins, printed circuits, sports boats, fishing rods

- **Chloromethanes 6.1%**
  - Silicon rubbers, decaffeinators, PTFE, paint strippers, cosmetics

Source: www.eurochlor.org
Production Cost of Chlorine

- Electricity is estimated to account for 60% of the variable costs of production and appr. 40% of total production cost 1)

- In a study done for Eurochlor in October 2007 by the Swiss consultant company Prochemics concluded that due to high electricity prices in Europe: 2)
  
  "there will be no incentive to build new plants in Europe or to invest in the conversion for mercury cell plant technology to membrane plant technology..."

- Since then power prices in Europe have risen even further

**Assumptions:**

- Membrane cell technology
- Plant Capacity: 500 kt/a Cl
- Operating rate: 100%
- Salt Price: 30 €/t
- Caustic soda price: 275 €/t

1) Source: "BOC and Ineos Chlor", UK Competition Commission, December 2008

2) Source: "Impact of Electricity on the Competitiveness of the European Chlor-Alkali Industry", PROCHEMICS Ltd., October 2007
Chlorine Derivatives from Project in Iceland

What will we do with the chlorine?

A: Ship bulk chlorine to Europe
   - Chlorine (Cl₂) is a hazardous gas at standard temperature and pressure (STP)
   - It can be stored and transported in pressurized vessel or liquefied by cooling below -35°C
   - Transportation of chlorine is done widely in the US but has been reduced significantly in Europe due to safety reasons

B: Chlorine as an Intermediate to manufacture non chlorinated products
   - Lithium
   - Polysilicon

C: Inorganic chlorine derivatives
   - Silicones
   - Aluminium chloride (AlCl₃)

D: Organic chemistry - PVC (Polyvinyl Chloride)
   - Ethylene route
   - Acetylene through Calcium Carbide

1) Source: www.worldchlorine.com
   * Based on 2005 consumption data
A: Ship Bulk Chlorine to Europe

Transportation of Chlorine in Europe ¹)

- In 2007 about 6% of the 10.7 million tones of Chlorine in Europe where transported from producers
- This is significantly less than 1996 when 15% of western European chlorine production was transported
- A large proportion of the chlorine transported, by rail or road tanker, goes to small users who do not require sufficient quantities to make on-site chlorine production feasible
- In almost 60 years, there has not been a single fatal accident in Europe involving bulk transport of chlorine

Several factors are leading towards the elimination of storage and transportation of liquid chlorine. Chief among these are: ²)

- Regulatory and legislative pressures regarding the control of major accident scenarios for chlorine storage and shipment
- Economic pressures to eliminate, if possible, the high energy consumption needed to liquefy chlorine

¹) Source: Eurochlor Website www.eurochlor.org/transportation
²) Source: www.pvc.org
A: Ship bulk chlorine to Europe Cont.

The industry has taken practical steps to minimise chlorine transport such as:

- Encouraging new industrial users to locate facilities close to chlorine production plants
- Using sodium hypochlorite, rather than chlorine, in applications such as swimming pool disinfection
- Converting chlorine into ethylene dichloride (EDC) for shipment to PVC producer

Brief cost / benefit analysis

- As an example, would it be viable to produce Chlorine in Iceland and ship it in liquefied form to the PVC plant in Stenungsund in Sweden and thus replace the mercury chlorine plant there?
- Size of plant 210,000 t/a Chlorine
- The shipping cost is derived from very old data and compared with cost of ammonia transportation cost

<table>
<thead>
<tr>
<th>Advantage of produce in Iceland</th>
<th>Disadvantage of produce in Iceland</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power cost saving: 18.4 m USD/a</td>
<td>Capital at 10% RoI: 0.6 m USD/a</td>
</tr>
<tr>
<td></td>
<td>Liquefacation energy: 1.0 m USD/a</td>
</tr>
<tr>
<td></td>
<td>‘Lost’ Production: 0.8 m USD/a</td>
</tr>
<tr>
<td></td>
<td>Revaporisation energy: 0.3 m USD/a</td>
</tr>
<tr>
<td></td>
<td>Transportation: 11.6 m USD/a</td>
</tr>
<tr>
<td></td>
<td>Total: 14.3 m USD/a</td>
</tr>
</tbody>
</table>

- Notably the power cost savings would hardly justify the transportation cost

1) Difference in electrical power prices: 25 USD/MWh, Specific electrical consumption: 3.5 MWh per ton chloride
2) Source: “Modern Chlor Alkali Technology”, Vol 8, Chapter 21
A: Ship Bulk Chlorine to Europe Cont.

Transportation of chlorine by sea

- The last regular bulk chlorine transport on sea in Europe was to the DuPont’s plant at Maydown, Northern Ireland from a chlorine plant in Spain and from ICI’s chlorine plant in Runcorn, near Liverpool ¹)
- This transport discontinued when DuPont closed down its chlorine consuming plant in Maydown in the 90’s
- Shipping bulk chlorine from Iceland to Europe is therefore not considered viable given the opposition to chlorine transport
- In a recent study the UK Competition Commission did not examine bulk chlorine imports from Europe as evidence suggested that this would face considerable regulatory barriers ²)
- According to Eurochlor there is one company shipping 22 ton ISO containers with liquefied chlorine on seawater in Europe, but in marginal quantities ³)

¹) Source: Telephone talks with Ian White, Otpimax Consulting
²) Source: The UK Competition Commission, 2008, “BOC and Ineos Chlor”, page 79
³) Source: Telephone call with Jean Dubel, Eurochlor
B: Chlorine as an Intermediate to Manufacture non-Chlorinated Products

Polysilicon production

- The electronic industry demands silicon with extremely high purity. The so called Siemens process uses trichlorosilane (HSiCl₃) as intermediate to purify silicon by distillation to an impurity level less than $10^{-9}$ whereas other similar processes use silicon tetrachloride (SiCl₄).
- The growth in solar industry has increased polysilicon demand in recent years and couple of companies have seen Iceland as a potential site.
- Last February Wacker Polysilicon one of the world’s most established polysilicon producers introduced its plan to build its next production facility in Tennessee on the basis of several advantages the site is offering including “over the fence supply of chlorine” ¹)

Manufacturing
- Anhydrous aluminium chloride (AlCl₃) - is produced primarily by the gaseous chlorination of molten aluminum, there are several slightly different processes
- Hydrous aluminium chloride - Commercial-purity hydrous AlCl₃ is produced by dissolving anhydrous AlCl₃ in dilute hydrochloric acid
- Polyaluminum chloride - Aluminum chloride solutions can be used to make polyaluminum chloride (PAC), also known as aluminum chloride hydroxide, basic aluminum chloride, polybasic aluminum chloride, aluminum hydroxychloride, aluminum oxychloride and aluminum chlorohydrate

Uses
- Anhydrous aluminum chloride: Most widely used as a Friedel-Crafts catalyst in numerous reactions, particularly in the manufacture of petrochemicals
- Hydrous aluminum chloride: A significant part was consumed in the production of antiperspirants, with smaller volumes consumed for the production of alumina trihydrate gels for antacid use
- Polyalumimnium chloride: Major uses are in water treatment and in internal sizing in paper production. In water treatment, PAC is used for purifying surface water, sewage and wastewater from chemical industries; in backwater purification in the steel industry; in effluent purification in the pulp and paper industry; and for water purification in swimming pools. A smaller use of PAC is in oil separation in refineries. The consumption of PAC has increased significantly since the early 90's

Source: Prochemics Ltd, “Iceland’s objectives in the Chemical Industry”, letter to Investum dated April 17th 2009
C: Inorganic Chlorine Derivatives – Silicones

Manufacturing
- Silicon metal is reacted with methyl chloride to form a mixture of methylchlorosilanes. These products are then separated by distillation and used for the manufacturing of silicone fluids, elastomers or resins; as well as organosilanes, which are high value specialties.

Uses
- Silicone fluids are used in a broad variety of applications, such as in the electrical and electronics industries, in the building industry, in cosmetics, paints and coatings and others.
- Silicone elastomers are mainly used as general purpose and special purpose sealants and rubbers.
- Silicone resins are mainly used in protective coatings, in electrical and electronic applications and for insulation applications.

Source: Prochemics Ltd, “Iceland’s objectives in the Chemical Industry”, letter to Investum dated April 17th 2009
C: Smaller Chlor-Alkali Solutions – Packaged Chlorine

Chlorine gas for end users
- Packaged chlorine is sold in drums (1,000 Kg) and cylinders (70 Kg)
- Main users are water treatment services and swimming pools
- At least two companies import and distribute packaged chlorine in Iceland

Packaged chlorine business in the UK ¹)
- In 2008 the UK Competition Commission issued a report on the anticipated acquisition by BOC Ltd of the packaged chlorine business of Ineos Chlor Ltd.
- The reason was the potential risk of monopoly situation if imported chlorine from Europe would not be competitive due to transportation cost
- In the study BOC and Ineos Chlor stated that the major input cost in the manufacture of chlorine was energy, which was cheaper in Europe than in the UK
- The main parties stated that ‘production cost advantages associated with the manufacture of packaged chlorine in Western Europe offset additional transport costs and make this activity economically viable’ and, further that the ‘transportation of packaged chlorine presents no particularly difficulty’

Some suppliers of package chlorine in Europe:

<table>
<thead>
<tr>
<th>Supplier</th>
<th>Website(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brenntag GmbH</td>
<td><a href="http://www.brenntag.de">www.brenntag.de</a></td>
</tr>
<tr>
<td>C&amp;S Chlorgas GmbH</td>
<td><a href="http://www.chlorgas.de">www.chlorgas.de</a></td>
</tr>
<tr>
<td>Air Products &amp; Chem.Inc.</td>
<td><a href="http://www.airproducts.com">www.airproducts.com</a></td>
</tr>
<tr>
<td>MSSA S.A.S.</td>
<td><a href="http://www.metauxspeciaux.fr">www.metauxspeciaux.fr</a></td>
</tr>
<tr>
<td>Gerling Holz</td>
<td><a href="http://www.ghc.com">www.ghc.com</a></td>
</tr>
<tr>
<td>BOC Ltd</td>
<td><a href="http://www.boc-gases.com">www.boc-gases.com</a></td>
</tr>
</tbody>
</table>

¹) Source: UK Competition Commission, 2008, “BOC and Ineos Chlor”
D: Use of Chlorine in Organic Chemistry

**Ethylene** ¹)
- Using Chlorine in organic chemistry processes requires hydrocarbon input in one way or another
- Most common is the introduction of ethylene (C₂H₄) gas in the downstream process, such as VCM / PVC production
- Ethylene is produced in the petrochemical industry by steam cracking and would therefore have to be shipped into Iceland with pressurized vessels or liquid gas tankers and stored as cooled liquid

**Other possible sources of hydrocarbons**
- Gas mining and export of LNG started in the Snöhvit area in N-Norway in 2007, LNG tankers pass Icelandic waters on their way to N-America ²)
- Using this gas would require high investments in terminal construction that would hardly be justified
- Yet due to the current development in “Biomass to liquid” cracking Iceland could have opportunity in providing hydrocarbon for downstream chlorine industry with this new method using fat from seafood

¹) Source: Harriman Chemsult, *Outlook for the international PVC Market*, June 2005
²) Source: Snöhvit homepage
Acetylene
➢ Another source of hydrocarbon is Acetylene (HC₂H) a colorless gas
➢ Until 1950 Acetylene was the main source of organic chemicals in the chemical industry but has since then be replaced by Ethylene due to lower cost
➢ Acetylene is normally prepared by the hydrolysis of calcium carbide (CaC₂)
➢ Calcium carbide is produced from limestone with high temperatures in electric arc furnaces, a process that has already come to question in Iceland due to its power intensity 3,500 kWh/ton CaC₂
➢ Producing organic chlor derivatives from acetylene could be an option in Iceland if oil prices surge again

China and Acetylene
➢ One of the misinterpretations of the development of the Chinese industry has been the belief that the acetylene route is a) an old technology and b) that is places limitations on plant capacity
➢ Both these myths have been dispelled. The majority of new expansions in China are acetylene-based and the size of new acetylene plants is now well into the 200,000 -300,000 ton/year scale
➢ The Western model of integrated cracker-vinyl plants has not really evolved in China because of the success of the acetylene route and the reluctance of olefin producers to get involved with chlor-alkali
➢ Harriman Chemsult estimates that China cost of PVC from carbide was RMB 5,695/t (688 USD/t)
➢ Benchmark PVC import prices in Asia in May 2009 are 710 USD/t CFR

1) Source: Harriman Chemsult Outlook for the international PVC Market, June 2005
2) Source: ICIS.com, "(PVC) Prices and Pricing Information", May 2009
Acetylene - are there Lessons to be learned for Iceland

PVC production from Acetylene

- The specific el. energy consumption of the Acetylene route is around 5,300 kWh/ton PVC
- Based on power el. energy prices of 65 USD/MWh in China the el. cost of one ton PVC is around 340 USD if the acetylene route is used
- This is in line with production cost in NW-China according to Tecnon Orbichem

Iceland and Acetylene

- Icelandic Chlor Alkali project could source hydrocarbons through the acetylene route by importing limestone or using 90% calcium carbonate rich shell sand
- Such sand is currently used as calcium originator by Icelandic Cement and earlier by fertilizer plant
- The cost would be considerably lower than China and competitive with Ethylene if Oil prices remain high
- According to Tecnon Orbichem such acetylene has break even point with Ethylene at 35 USD/bbl

1) Source: CBI China, Higher production prices due to electricity price increase, 22.07.2008
2) Source: Tecnon Orbichem, The world chemical Industry Focuses on Asia, 2008
3) Source: Icelandic Cement, homepage
A fully integrated Icelandic VCM or PVC Project

**Ethylene**
- A fully integrated chlor-alkali VCM or PVC project in Iceland would either have to rely on imported Ethylene or produce Acetylene via Calcium Carbide production.
- Instead of importing salt it could be feasible to prepare the brine from seawater with evaporation.
- For smaller projects a production of caustic soda in dry form could be attractive.
Smaller Chlor-Alkali Solutions for Iceland ¹)

- Chemical industry which combine intensive use of electricity /steam with raw materials which may already be available in Iceland or which can be easily imported
- A key to develop these industries would be the use of smaller electrolysis plants which can operate economically with lower production capacities
- Prochemics Ltd. understands that such technologies, based on standard modular plants, have recently become available, and could supply some of the more special industries that are suggested here, and which to not require large quantities of chlorine
- A further advantage of these modular plants, is that capacity can be expanded as needed by adding modules

**Products which could meet the specification for a production plant in Iceland are:**
- Caustic soda
- Aluminium Chlorides ¹)
- Silicons ¹)
- Packaged Chlorine*

¹) Source: Prochemics Ltd, “Iceland’s objectives in the Chemical Industry”, letter to Investum dated April 17th 2009

* Investum
Investum | August 2009

Sodium Chlorate
Conclusions and Recommendations

Conclusions

- The pulp and paper industry has chosen Sodium Chlorate instead of elementary chlorine for better quality paper.
- Sodium Chlorate is highly electricity intensive process, both in terms of specific energy consumption (5,200 kWh/ton) and especially in terms of energy cost as % of cash cost (>60%).
- The industry is moving production from places where electricity prices have surged.
- The product is easily shippable in containers.
- Without any doubt a Sodium Chlorate production in Iceland would be very compatible on the international market.
- Salt is the main raw material which can be shipped in or sourced locally (evaporation of sea water).
- The European and N-American market are saturated and no project under development.
- European producers are currently curbing production due to difficult market.
- It is unlikely that the main producers or new entrants start to look for new sites.

Recommendations

- Keep in contact with the main producers and have them informed about development of a chemical park if that starts to evolve.
# Potential Sodium Chlorate Project in Iceland

- **Plant size:** 50,000 t/a  
- **Investment:** 70 m USD  
- **Power needs:** 30 MW  
- **Revenue:** 20 m USD/a  
- **Employees:** 20-30  
- **By-product:** hydrogen, appr. 3,000 t/a  

Such plant could benefit from being located close to the Reykjanes geothermal power plant for these two main reasons:

- Available process heat and steam  
- Potential salt production in later stages
Lithium
Conclusions and Recommendations

Conclusions

- World lithium demand is expected to grow around three fold in ten years
- Lithium Metal Production is a small niche and an interesting option for Iceland
- The production of Lithium Metal from Lithium Chloride requires much electrical energy per weight, i.e. 35,000 kWh/ton Lithium whereas aluminium electrolysis uses about 14,500 kWh/ton of product
- Some of the raw material needed for Lithium Metal production could be produced in Iceland
- Lithium exist in geothermal brine and volcanic rocks in Iceland
- The raw material Potassium Chloride (KCl) used in the electrolysis appears in geothermal brines in Reykjanes containing 41% KCl
- With the existence of a Chlor-Alkali plant, Lithium Chloride (LiCl) could be produced locally from imported Lithium Carbonate by using chlorine
- Production of Lithium-aluminium alloy containing up to 7.5% lithium could be an interesting end product to produce
Conclusions and Recommendations Cont.

**Recommendations**
- Compare a project in Iceland to key projects coming up
- Look into the feasibility of mining KCl salt from Reykjanes
- Introduce Iceland to potential producers of Lithium
- Contact Rio Tinto as they are exploring Lithium mining in Serbia

**Recommended Reports**
- Up to date market and industry information is not available freely as the Lithium market is small and not publicly traded. Investum recommends the following reports for in deep detailed information
  - The Lithium Industry, Metal Bulletin research, 2009, Price $5,995
  - Roskill, The Economics of Lithium, 11th edition 2009; Price $5,000
Lithium Metal Production in Iceland

Feasible production size in Iceland ¹)

- A preliminary estimate for a feasible project size would be a 3 stage expansion plan of 250 ton of lithium metal annually each stage
- The power required is 8-24 MW
- The production facility would need 50-75 employees ²)

Production possibilities

- Lithium Metal with high Purity as:
  - Lithium Ingots
  - Pellets
  - Foils
- Lithium Alloys with:
  - aluminium
  - cadmium
  - copper
  - manganese
- Huge development possibilities

¹) Source: Peter Ehren, May 2009
²) Source: Investum estimate
Lithium Metal Production in Iceland Cont.

- The raw material needed are: 1)
  - Lithium Chloride (LiCl)
  - Potassium Chloride (KCl), to lower the melting point.
  - Caustic Soda (NaOH) or Calcium Carbonate (CaCO₃) is required to neutralize the chlorine gas produced during the lithium production
  - Electricity
- With the existence of a Chlor Alkali plant in Iceland it could be feasible to import Lithium Carbonate (Li₂CO₃) and produce Lithium Chloride (LiCl) and Caustic Soda on site 1)
- The market price for Lithium Carbonate was USD 5-6,000/ton in 2008
- Potassium Chloride (KCl) appears in geothermal brines in Reykjanes. Salt with 41% KCl content was produced there in the nineties 2)

**Environmental and Transport Issues:**

- There are no restrictions regarding shipment of raw material needed for the production
- Lithium Carbonates and Lithium Chloride are shipped in containers
- The only way to transport Lithium Metal from Iceland is by sea as air transport of Lithium is restricted to small amounts
- The lithium metal production does not produce waste products. The by-products are:
  - Chlorine gas
  - Sodium hypochlorite also known as bleach (NaClO)
  - Calcium hypochlorite also known as bleaching powder (Ca(ClO)₂)
  - Calcium Chlorite (Ca(ClO₂)₂)

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1) Source: Peter Ehren, Emails, May-June 2009
2) Source: Skýrsla: Framleiðsla á natriumskertum matvælum, page 6, Matvælarannsóknir, Keldnaholi, December 1999
Lithium Metal Production in Iceland Cont.

**Production cost and feasibility:**
- Cost of Lithium Carbonate is USD 5/kg
- The cost of 6 kg Lithium Carbonate is USD 30 but about 6 kg of Lithium Carbonate is needed to produce 1 kg Lithium
- The market price of Lithium is USD 58/kg for industrial grade or USD 64-70/kg for battery grade
- The added value is about USD 30/kg without taking into account the production cost, other raw material needed and electricity

1) Source: Asian Metal, 12 January 2009; www.asianmetal.com
Extract Lithium from Geothermal

- Today, while brine deposits remain the most cost effective means of extracting lithium reserves, there is a vast amount of research into developing technologies that could exploit lithium from other types of deposits such as geothermal brines. Should they succeed, they could seriously compete with the brine producers.

- Geothermal waters have had intimate and lengthy contact with the layers of the earth’s crust that they flow through, resulting in dissolution of minerals and metals from the rocks, and solution into the hot water.

- Suitable sites need to have a high concentration of lithium in the brine stream to be efficient.

- Simbol Mining, a Texas based company, focuses on mining lithium from the brine streams of natural and artificial geothermal hotspots.

- According to Simbol Mining their brine steam technology to extract lithium is more cost effective than other mining options.

2) Source: http://www.ioes.saga-u.ac.jp/ioes-study/l/lithium/occurence.html
Case Study - Extract Lithium in Iceland

Test samples in Geothermal waters: 1)
- About 20 geothermal waters were sampled in Iceland in October 2007 and June 2008 for measurement of lithium isotopes
- The samples came from Svartsengi, Reykjanes, Nesjavellir, Krafla and Námufjall
- These studies showed Li concentrations of 0.085-5.8 ppm whereas Reykjanes and Svartsengi had the highest concentration
- For comparison:
  - The usual lithium concentration in the common surface water is about 0.010 ppm
  - The geothermal field in Salton Sea, southern California, has shown concentrations of 200 ppm 2)

Test samples in Hekla in 2008: 2)
- Seventeen lava eruption samples were investigated from the Hekla central volcano
- Lithium concentrations in the analyzed samples range from 2.9 to 42 ppm Lithium

<table>
<thead>
<tr>
<th>Water source</th>
<th>Concentration range in ppm</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drinking (surface)</td>
<td>0.002 - 0.017</td>
<td>Czech Republic</td>
</tr>
<tr>
<td>Drinking (groundwater)</td>
<td>0.0047 - 0.020</td>
<td>Czech Republic</td>
</tr>
<tr>
<td>Geothermal</td>
<td>0.085-5.8</td>
<td>Iceland</td>
</tr>
<tr>
<td>Drinking (mineral)</td>
<td>0.1 – 13</td>
<td>Czech Republic</td>
</tr>
<tr>
<td>Mineral</td>
<td>3-6</td>
<td>Romania</td>
</tr>
<tr>
<td>Mineral</td>
<td>4.87-8.00</td>
<td>USA</td>
</tr>
<tr>
<td>Volcanic</td>
<td>10-46</td>
<td>Turkey</td>
</tr>
<tr>
<td>Volcanic</td>
<td>2.9-42</td>
<td>Hekla, Iceland</td>
</tr>
<tr>
<td>Volcanic</td>
<td>0.1-44.2</td>
<td>Mexico</td>
</tr>
<tr>
<td>Geothermal</td>
<td>200</td>
<td>Salton Sea, USA</td>
</tr>
</tbody>
</table>

It remains to be seen if Lithium mining in Iceland could be feasible although these tests do not indicate a high Lithium brine or rock concentration in Iceland

1) Source: Lithium isotopes in Geothermal Fluids in Iceland; Research done by BRGM, France and ISOR, Iceland
2) Source: Jan A. Schuessler, Ronny Schoenberg and Olgeir Sigmarsson; Iron and lithium isotope systematics of the Hekla volcano, Iceland, July 2008
Pros and Cons of Producing Lithium in Iceland

Pros:
- Very electrical energy intensive
- Possible mining of raw material needed
- Suitable project size and a growing market
- Possibility to produce Aluminium-Lithium alloys
- Being part of European Economical Area could attract Investors
- Due to small scale size transportation to and from Iceland would be done by containers and is not a problem

Cons:
- No Chlor-Alkali plant in Iceland
- Lack of local off takers
- Little chemical knowledge locally

Source: Peter Ehren, May 2009
Chemical Clusters
Conclusions and Recommendations

Conclusions
- The chemical industry in Europe is suffering from high cost
- To increase its competitiveness, the industry has deliberately taken steps toward clustering
- Most chemical clusters are based on raw material supply, including hydrocarbons
- Electricity and steam are one of the most important raw materials in the chemical industry
- A potential Icelandic cluster based on green electricity and steam at competitive prices and located close to good port facilities is likely to attract inorganic chemical industries
- In recent years, companies specialized in owning and operating chemical parks have emerged
- Such a company in a public-private partnership with Icelandic authorities could be key to a successful FDI policy for Iceland

Recommendations
- Get advised by ECSPP on what cluster operators in Europe are most likely to be interested in a potential Icelandic development
- Put together information package on potential cluster possibilities (i.e., sites, energy, country, people, industry sectors viewing Iceland already) and present to cluster operators in Europe/USA
- Present a ‘green chemical park project’ to selected group of operators
- Do further research on possible EU support schemes and eventually prepare an application to fund a full blown feasibility study
The Concept and Players

- Investors develop their business model and outsource all other business processes
- In chemical parks investors can focus on their core business

**Management processes**
- Capital, financial management
- Controlling, HR, resources

**Core processes**
- Research/Development
- Raw materials
- Production
- Marketing
- Sales

**Support processes**
- Analytics
- Energies
- Technical services
- Logistics
- PR
- Planning
- Real estate
- Infrastructure
- Safety
- Environmental Protection

**Operators:**
- Currenta
- InfraServ Höchst
- ChemSite
- NUON Industriepark management
- ValuePark
- Emmtec
- Nepic

**Website:**
- www.currenta.de
- www.infraserv.com
- www.chemsite.de
- www.nuon-ipm.de
- www.dow.com/valuepark/index_e.htm
- www.emmtec.nl
- www.nepic.co.uk

**Operating in:**
- DE
- DE
- DE
- NL, DE
- DE
- NL
- UK

Source: Invest in Germany, Chemical Parks in Germany, 2007
Key Attributes and Performance Criteria of Successful Clusters ¹)

- Investment environment; role and support of the authorities in providing incentives and support in the development of infrastructure or attracting investment
- Availability of land
- Raw material and feedstock supplies at competitive prices
- Energy and utilities at competitive prices
- Relative proximity and easy access to most important customers
- Availability of efficient services (logistics, finance, IT, packaging, security, marketing, promotion etc.)
- Availability of labour (skilled and unskilled) at competitive prices
- Efficient logistics infrastructure
- Low-risk and stable business climate and stable regulatory environment
- Good schooling and educational facilities
- Co-siting & partnering opportunities

¹) Source: ECSPP and CEFIC, Improving Competitiveness of European Chemical Industry Clusters

²) Source: Festel Capital, Zukunftsaussichten für Industrieparks und infrastrukturdienstleister in Deutschland, May 2006
Power Supply and Prices

- Bilateral contracts for large consumers: 1)
  - Long term contracts, typically 20 years
  - Fixed prices with US CPI indexing
  - ...or prices linked to product prices, such as LME – i.e. risk sharing
- Price estimation: 20 to 35 USD/MWh

1) Source: PPA: Power Purchase Agreement
2) Source: European Electricity Exchange, Investum estimates
3) Source: National Energy Authority
Steam Supply and Prices

Industrial steam supply
- Steam is widely used as an energy transport medium, distributing heat and power in many industrial applications.
- The amount of money spent generating steam is very large; equaling to about 40% of the fuel burned by the process industry ¹)
- One of the key attributes in chemical clusters is the supply of industrial steam.
- Steam is often delivered at various temperatures depending on customer’s demand and the suppliers capability.
- Typically industrial steam is delivered in three different forms:
  - Low pressure  3 Barg
  - Medium pressure  12 Barg
  - High pressure  20 Barg

Steam cost and prices in different places in the world
- According to Morgan Stanley equity research the GCL-Poly Energy Holding Ltd average revenue from steam sales in China in 2008 was 21 USD/ton ¹)
- The cost of raising steam using different fuel sources is presented in the graph below.

²) Source: Process Engineering, Jan/Feb 2007, “Steam: not a free ride”
Steam Supply and Prices Cont.

Steam prices in Iceland
- No transparent market for geothermal steam has evolved in Iceland so far
- There are though some indicators towards steam price that could be expected in a bilateral contract with the Icelandic geothermal energy suppliers:
  - The diatomite plant at Myvatn that was in operation until 2004 paid 1 USD/ton steam
  - The national Energy Authority issued prices in 1992: 2.5 USD/ton as shown in the bar chart below 1)
- The power company Hitaveita Sudurnesja offered following prices in a leaflet from 1995:
  - Steam at 20 barg: 4 USD/ton
  - Steam at 6 barg: 3 USD/ton
- Investum's calculation derived from cost of electricity from geothermal power plant indicate cost of 2.5 USD/ton

Types of steam in Iceland
- Geothermal steam fields in Iceland are typically operated at 10-12 Barg pressure
- Some wells, especially in the Reykjanes field deliver higher pressure or up to 18 barg
- This is sufficient to meet requirements of customers demanding both LP and MP class of steam
- The possibility of boosting this steam with a MP steam driven turbine has been studied 3)

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2) Source: Process Engineering, Jan/Feb, “Steam: not a free ride”
3) Source: Teitur Gunnarsson, Mannvit, verbal
Industrial Park in Iceland – next steps

- Based on a petrochemical free processes
- Electricity and steam intensive industries
- Small scale chlor-alkali plant as back bone plant

<table>
<thead>
<tr>
<th>Other industries:</th>
<th>Power needs [MW]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>from</td>
</tr>
<tr>
<td>Chlor Alkali</td>
<td>8</td>
</tr>
<tr>
<td>Sodium Chlorate</td>
<td>8</td>
</tr>
<tr>
<td>Fertilizers</td>
<td>20</td>
</tr>
<tr>
<td>Polysilicon</td>
<td>20</td>
</tr>
<tr>
<td>Lithium metal</td>
<td>8</td>
</tr>
<tr>
<td>Carbon Fiber</td>
<td>5</td>
</tr>
<tr>
<td>Methanol</td>
<td>10</td>
</tr>
<tr>
<td>Aluminium foils</td>
<td>20</td>
</tr>
<tr>
<td>Dimethly Ether</td>
<td>10</td>
</tr>
<tr>
<td><strong>Total:</strong></td>
<td><strong>109</strong></td>
</tr>
</tbody>
</table>

Technon Orbichem suggest the first steps in development of a chemical park in Iceland would be: 1)

- Define Chemical park philosophy
- Define Production of the cluster etc. to take the best combined advantage of limitless local energy and power, sea going access (for feedstock), feedstock supplies
- Identify potential producers and investors
- Supply and price of feedstock and bioalternatives - i.e. bio ethanol
- Identify trading partners - i.e. Europe, Americas, Asia

1) Source: Technon Orbichem, email 4.6.2009