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INNOVATIVE SOLUTIONS TO SUSTAINABILITY IN HYDRO

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Abstract

Sustainability represents challenges for the Aluminium Industry and also opportunities.
Innovation is essential in meeting these challenges. By being innovative and by having a sustainability approach to the whole value chain, there are large potential for improvements both environmentally as well as financially. For Hydro this approach embodies the value chain from power production to the end user of aluminium products. Our aim is to improve Hydro's environmental footprint as well as generating value for the company Hydro. The two main challenges, the world as well as the industry, is facing today is climate change and energy consumption. In this paper we will show how Hydro systematically works to reduce energy consumption as well as share with you our main topics for future improvements.

Introduction

Global warming is today the "hottest" topic.
In September 2006 Sir Richard Branson announced[1] that he would pledge $3bn transport profit from his Virgin air and rail interest into fighting global warming. He claimed that if airlines, airport operators, engine manufacturers and governments worked together 25% of the aviation carbon consumption could be cut. Much of the announced investment will focus on bio-fuel. This is not only an opportunity for Branson to reduce CO_2 emission, but also a business opportunity to generate wealth for Branson, since the government has ordered petrol stations in the UK to source 5% of their fuel from renewable energy by 2010. OECD has estimated that the ecological industry will have an annual growth rate in the area of 5 - 20%[2]. Banks and investors have realized this and an increasing number of founds are now being allocated to sustainability because it makes business sense.

Sustainability

Yale Center for Environmental Law and Policy[3] have gathered empirical data providing first hand view on how American and European analytical communities value environmental factors in the process of analyzing the company. The dominating view is that environment represents a liability. Therefore Corporate spending on contaminated land and compliance are considered the most influential environmental factors influencing financial performance. Going beyond compliance is viewed as a cost and are not of benefit to the valuation process, even though it is acknowledged that it could have the potential to add to competitive advantage. Company history of spill, accidents etc, are viewed as a management performance indicator.

Many companies have been enjoying the benefit of sustainability for years, but others are struggling to understand just how to embrace it.
Esty and Winston[4] picked 50 Green companies calling them wave riders, companies which are riding the green wave, and compared their stock performance over the past ten years with SP-500 and FTSE100. The list of the 50 companies was developed from a group of 5000 companies by surveying the executives as well as using the environmental and sustainability scorecards generated by the analysts at Innovest Strategic Value Advisors, Sustainable Asset Management, also used by Dow Jones to produce its sustainability index. The list consists of 25 US companies and 25 none US companies.
These companies have easily outperformed the market over the last 10 years as shown in Figure 1. From the Aluminium Industry Alcoa, Alcan and Norsk Hydro[4] were qualified to be amongst the 50 wave rider companies.

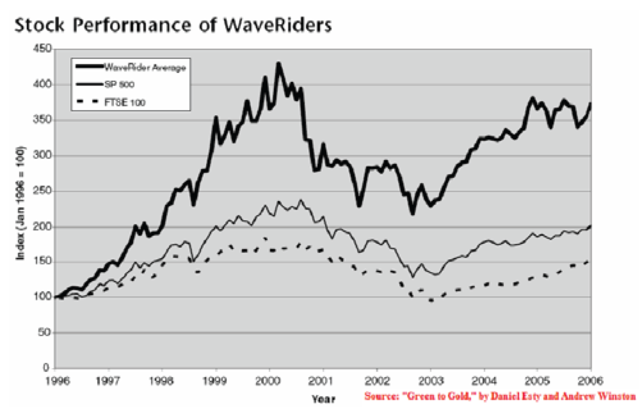

Figure 1. Stock performance of WaveRiders compared to SP500 and FTSE100[4]

Reinhardt[5] claimed that managers should look at environmental issues as business problems. The only reason to make investment should be expectations of delivering positive return or reduction of risk.

- *a.* Managing your competitor – legislation
- *b.* Saving cost – reduce waste
- *c.* Managing environmental risk – community relations
- *d.* Redefining markets – new business approach, from product to solution.

Other research[6] has shown correlation between environmental performance and financial performance. Good environmental performance would give higher market gains by being a preferred product by customers, as well as good environmental performance would mean less pollution, less waste and reduced cost. So by reporting good environmental performance, investors will alter the evaluation of the firm's future perceived financial performance.

Value creation framework

Looking at creating sustainable value we will go in two dimensions. The first dimension is internal and external to the company. The second dimension is time, present and future. This creates a four window coral where different strategies are applied in order to generate value. These relationships are described by Hart and Milstein,[9] and are illustrated in Figure 2.

Pollution is an incomplete use of raw material or energy, which then is disposed into the environment; therefore, by reducing pollution you will reduce cost. [7]

By better controlling the process, companies can reduce usage of raw materials and cost at the same time as pollution is reduced.

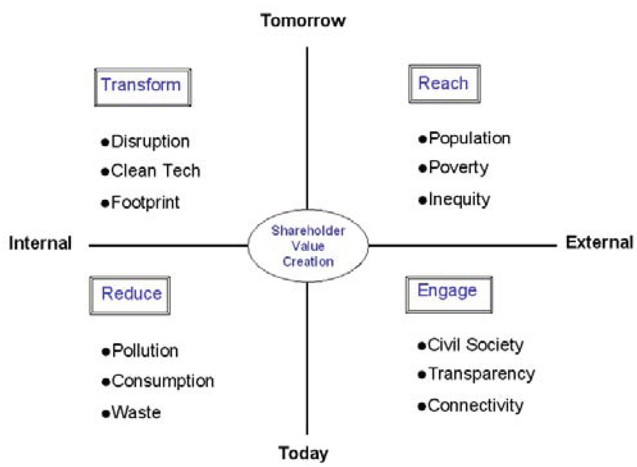

Figure 2: Shareholder value creation framework[9]

Better usage of resources will benefit the environment through less pollution. There would be a cost saving from the production process as well. In total this will improve the company's competitiveness[8] .

Pollution Prevention provides managers with the fastest way to increase shareholders value by growing the bottom line for existing business through reduction in cost and liability[9].

Look outside of the Firms boundaries. Look at the whole product life cycle from raw material through the different production processes and at the end the disposal of the product. Life-cycle management can be used as input for a new production line. This could lead to growing reputation for environmental sustainability as well as increased market share. [7] In Europe, take back laws are promoting these of solutions. [9]

Central in the future development is innovation of clean technology leading to a dramatic change, and not for an incremental improvement. New technology like genomics, bio-mimicry, IT, nano technology and renewable energy presents opportunities for firms. There are clear evidences that companies that fail to lead the development on innovation and the commercialization of such technologies are unlikely to be part of tomorrow's economy.[9]

One of he biggest challenges the world faces today is the difference in wealth between the developed and undeveloped countries. The extreme poverty that a waste majority of the people on this planet is living under, more then 4 billion people are surviving on less then $1.500 per annum, is not only a situation that needs to be solved. It is also a business opportunity for development and growth as the Nobel peace prize winner in 2006 is a good example of.[10]

Sustainability challenges for the Aluminium Industry

Esty[4] has put down a list of 10 environmental issues which the world is facing today.

1. Climate Change
2. Energy
3. Water
4. Biodiversity
5. Chemicals, toxics and heavy metal
6. Air pollution
7. Waste Management
8. Ozone layer depletion
9. Ocean and fisheries
10. Deforestation

From the list it is obvious that all 10 points, except maybe no 9, have relevance for the Aluminium Industry. In this paper we will have a special focus on what Hydro is doing to counteract climate change and to reduce energy consumption, as well as air pollution.

Reduced Specific Energy Consumption

Hydro Aluminium[11] has increased the primary metal production in its Norwegian smelters by 25 % over the last ten years by increasing the line amperage, all at low investment cost. In addition to increased production of primary metal, the capacity creep program has led to reduced specific energy consumption, and increased manning productivity. Both energy and manning costs are high in Norway, so the program has been an important contribution to improve the international competitiveness. The increased capacity has been achieved by utilizing technical slack in the existing system and by introducing new elements in cell technology.

One of the key elements of making this a success has been the target of constant heat input to the cell. This has allowed an amperage increase with a simultaneous reduction in the energy consumption. This is illustrated in Figure 3.

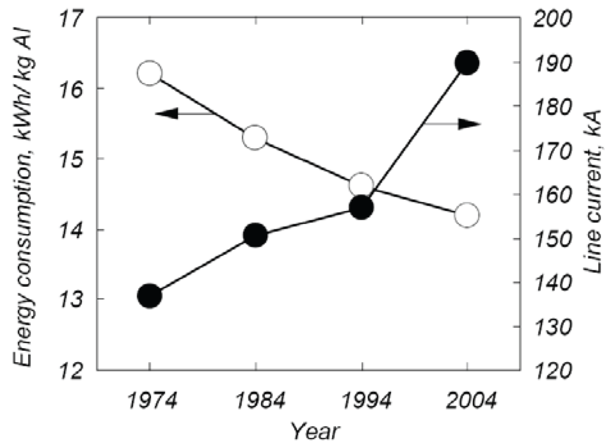

Figure 3. Development of the specific energy consumption with increasing amperage for end-to-end Prebake cells at SU III, Sunndal.[11]

Using data from the Årdal smelter, there has been an amperage increase from 151 kA in 1984 to 201 kA in 2006 with a parallel reduction in the specific energy consumption of 1,5 kWh/kg Al for the ÅI series. Additional metal produced would then have a specific energy consumption of 10,4 kWh/kg Al.
The same goes for line ÅII which increased amperage from 157 kA to 217 kA, reduced specific energy consumption by 1,7 kWh/kg giving a specific energy consumption of the additional metal of 11.6 kWh/kg Al.
This shows how extremely favorable this amperage increase program has been. The investment cost is typically well below 50% of what you will expect for a new installation.
Amperage increase can be obtained keeping the ACD constant. This leads, however, to increased energy consumption often with specific energy consumption in the area of 16 – 18 kWh/kg Al, which is comparable to the worst Soederberg technology nowadays. With continuously increasing price of power this is an element of consideration when boosting amperage.
Hydro has phased out Søderberg capacity with high energy consumption and replaced this with modern Prebake technology with energy consumption in the area of 13.0 kWh/kgAl.

High current density operation

Through introduction of novel, innovative technology elements, combined with holistic cell redesign and a more advanced understanding of the Hall-Heroult process, the aim is now a step change in the anodic current densities of the potlines from today (0.8-0.9 A/cm2) into the range well above 1.0 A/cm2. This is a new approach to productivity increase with an inherently large potential, but at a larger technological risk.

A project uniting researchers from academia, research institutions, and the industrial R&D community in Hydro Aluminium, is undertaken to address this challenge. Main focus are anode quality, transport in the electrolyte, fracture mechanics, cathode lining and cathode lifetime.

At high current densities (>0.9 A/cm2) experience shows that the carbon anode may represent a severe limitation to stable, high performance cell operation. Accumulation of carbon dust in the cells and an increased occurrence of anode deformations (spikes) may constitute a serious obstacle.

Fundamental studies will be undertaken of mass transport in the electrolyte under high current density and low interpolar distance. Improved prediction of the turbulent electrolyte flow, under the influence of both electromagnetic forces and drag forces from gas bubbles, is crucial for better prediction of mass transfer mechanisms. This includes both the side ledge dynamics and the distribution of alumina in the cell.

In order to understand failure due to fracture, it is important to understand the generation of tension by thermal gradients and thermal mismatch of materials as well as the materials resistance to fracture (fracture toughness).

A main reason for disengagement of aluminium reduction cells is the chemical/mechanical wear of the graphitic and graphitized carbon cathode bottom blocks. These materials are necessary at high current densities, due to its improved electrical conductivity. The aim is to clarify the wear mechanisms.

Pressing the performance of reduction cells makes control of the cell's heat balance of utmost importance. Correct thermal and mechanical properties for aged bricks are crucial to be able to do reliable design calculations for new linings. Understanding the degradation mechanisms is necessary to design cells in such a way that the risk for unnecessary degradation is minimized, without sacrificing the energy consumption.

GHG Management

Hydro has entered voluntary agreements with Norwegian and German authorities regarding reduction of greenhouse gas emissions from aluminium production. The Norwegian agreement was signed in 1997, and the industry committed to a 55% reduction in specific emissions of climate gases (baseline 1990) by 2005. Target was achieved well ahead of schedule. In Germany the agreement was signed in 1997 and the objective was a 50 % reduction in specific perfluorcarbon (PFC) emissions (baseline 1990) by 2005. The German smelters also achieved this target well ahead of schedule. The reductions have been linked to investments in technology, improving the efficiency of the operations. These investments are in the order of NOK 200 million. Since 2000 Hydro has closed down the Soederberg plant in Sunndal and invested close to one billion USD (NOK 6 billion) in new, efficient technology. The total emission reduction, as a consequence of the Norwegian agreement, has been 1 million tonnes CO_2e.
In 2006 Hydro closed the Soederberg potline in Høyanger and the Soederberg line in Årdal was closed during the first half of 2007. The only remaining Soederberg potline still in operation in the Hydro production system is the line at Karmøy, scheduled to close at the end of 2009. This will further reduce the GHG emission from our operations.
Hydro is now a part of an agreement that covers the process industry in Norway, as a part of the industry association Norsk Industri (Federation of Norwegian Industries). This agreement aims to reduce total CO_2 emissions by 20 percent compared to 1990 within 2007.

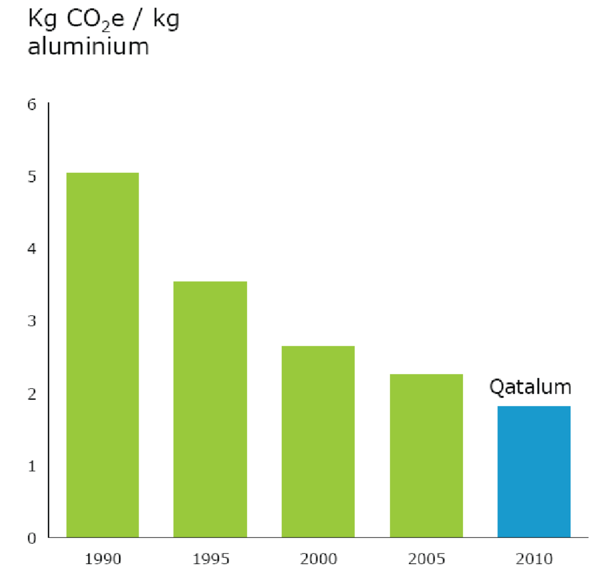

Figure 4. Development of specific GHG emission from the Norwegian Hydro Smelters from 1990 to 2006, also showing the effect of closing down the reminding Soederberg capacity and Qatalum.

UN's intergovernmental panel on climate change, IPCC, has estimated that the world emission of GHG would have to be reduced by up to 80% from the level we are seeing today[14]. In order to reach this target IPCC suggests that 15 – 55% of the CO_2 mitigation would have to come from Carbon Capture and Storage (CCS). In 1990 PFC's represented 70 % of the total CO_2e from aluminum production. Today it represents 25% of the total CO_2e from the smelter. At Sunndal this level is in the area of 5%, with an AEF of 0.05. In that respect Hydro has started trials of carbon capture from the electrolysis cells. A test cell is now in operation, and the results so far are promising. The principle for the carbon capture is shown in Figure 5.

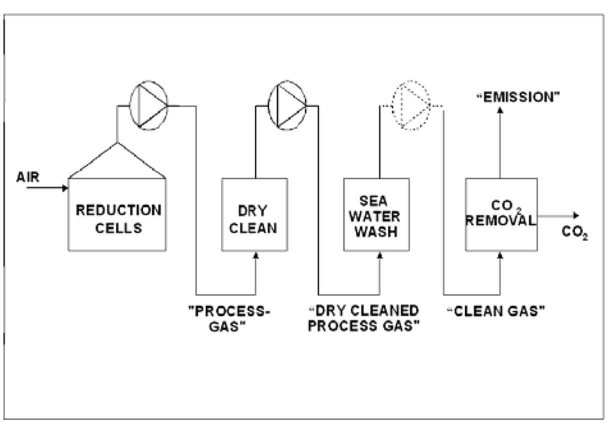

Figure 5. Principle setup for carbon capture from electrolysis cells.

Hydro has over 10 years experience on research for carbon capture. The target is to be able to reduce the CO_2 by at least 50% from the reduction process. This will be a major contributor to a viable future.

Heat recovery

Hydro has since the startup of the HAL230 in Høyanger in 1980 used heat exchangers on "clean process gas" that produces warm water. This system has later been introduced at all the Norwegian plants. This was also a part of the Sunndal modernization program. A principle sketch is shown in Figure 6 below.

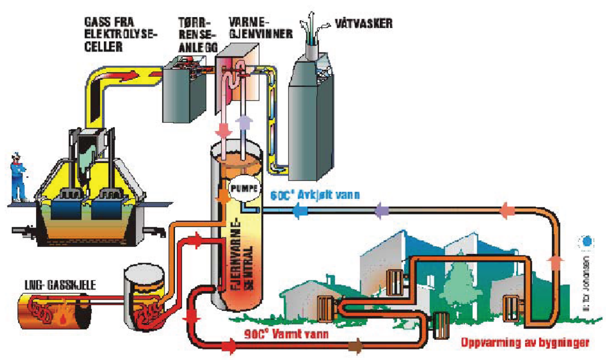

Figure 6. Heat recovery system at the Sunndal smelter showing a heat exchanger in combination with an LNG heater to provide constant 90 °C water to the end user.

There is a potential to recover a larger part of the heat loss from the process then we are doing today. One option is to move the heat recovery closer to the pot. The heat exchanger will then be working on the uncleaned process gas, in challenging dusty environment. This has the potential to increase energy recovered from the gas due to higher gas temperature. It will also allow for reduced gas scrubber systems, due to reduced gas volumes. The savings here can be quite significant. This is relevant when constructing new green field smelters. In combination with amperage increase programs this could avoid investment on new scrubbers.

Another area, which Hydro is actively pursuing, is the heat recovery directly from the sidewall. The first test cell is due for installation.

Totally the ambition is to recover energy in the area of 3 – 6 % of the cells total energy consumption.

One challenge is to find use of the energy. Traditionally central heating is not a common system in Norway, and therefore we cannot find sufficient users of the energy from the hot water.

Process and equipment for utilizing high temperature heat for power production is partly available. However, with the present production process, the larger part of the heat is available at lower temperatures, typically around 120 °C. Hydro is now participating in a project that will study the fundamentals for producing electric power from low temperature heat.

Fluoride emission

The expression "nature's critical load" is of particular relevance in connection with international agreements regarding the reduction of emission that caused acid precipitation. The target for reductions in acid emissions are being based on such "critical loads". This was also the basis for the effect study performed by the Norwegian aluminum industry in the 1990's[13]. One of the elements, which were of key importance in a negative manner, was the effect of the fluoride emission on nature and wildlife in the narrow Norwegian fjords and valleys where most smelters were placed. This together with a strong regulatory focus on Fluoride emission has influenced the technological development of the Hydro technology. Several innovative solutions like additional suction during operation as well as optimized anode butt handling have been focusing on minimizing the emission, leading to benchmark performance as well as benchmark technology. This is illustrated in Figure 7.

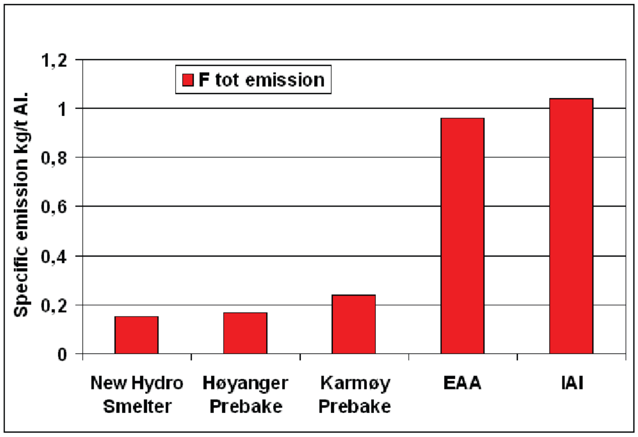

Figure 7. Fluoride emission from some Hydro smelters compared with European and World average. (Data from IAI, EAA 2005, and internal Hydro 2006. New Hydro reflects target level for new Hydro technology, with Fluoride emission below 0.15 kg/tAl.)

Environmental impact studies which regularly are being performed by Hydro in future potential growth projects strongly indicates that new large smelters above 1 million tpy capacity, demands Fluoride emission level down below 0.2 kgF/ tonne Al, which today only is achieved by the Hydro technology.
So what seemed to be a comparative disadvantage due to unfavorable geographical conditions, as well as strong regulatory focus, has led to a competitive advantage placing the Hydro technology in a favorable position for future large smelter projects.

Biomaterial to replace coke

Globally, production of aluminum is experiencing strong growth, and the industry experiences shortage of adequate quality petroleum coke for anode production. Petroleum refineries operate their cokers to maximize profitability (increase sales of light gasoline products) and current refining economics often dictate the use of lower grade crude oils with high sulfur (low cost crude). Anodes made of low quality coke may result in dusting cracking, increased environmental and metal problems, as well as increased anode overpotential resulting in higher power needs. At the same time the producers are trying to increase the amperage in the pot lines in order to achieve higher aluminum productivity. Both these trends require anodes that can maintain stable and predictable operations. A novel approach would be to replace petroleum coke and coal tar pitch with alternative carbon sources, as it is renewable and has low content of sulfur and ash (trace elements). A possible approach could be to use an anode aggregate of charcoal and bio-pitch as binder, producing CO_2 neutral anodes. New and robust strategies for using different petroleum coke qualities, as well as understanding how to use new and less environmental harmful products (wood coal/coke and wood tar pitch) in anode manufacturing in the electrolysis cells are currently being pursued.

Regenerative Thermal Oxidation, RTO

In the mid 1990s, Årdal plant produced anodes in four baking furnaces of vertical flue design, with an annual production capacity of about 150 000 tons. Since 1998 retrofit of two baking furnaces using the latest technology of the Hydro Aluminium baking design has increased the annual production capacity to about 235 00 tons in three baking furnaces. The latest expansion was made in 2004 with the retrofit of Furnace #3.

In 2004 the technique of regenerative thermal oxidation (RTO) was introduced for treatment of the fumes from the baking furnaces. Two identical flue gas treatment lines were constructed, each consisting of two pre-filters and one RTO. Results was presented in TMS 2007. [12] The design capacity of each line is 90 000 Nm3/h.

From the RTO the flue gas enters four parallel seawater wet scrubbing systems. Each line consists of a quenching and a washing tower. In 2007 wet electrostatic precipitators (WESP) were introduced as an additional scrubber step. Four identical lines were constructed, each with a nominal capacity of 45 000 Nm3/h.

By the combination of scrubber steps the following were achieved:

- The RTO will incinerate almost any organic matter with a high efficiency. Dry scrubbers and electrostatic precipitators loose efficiency for substances with low boiling point.
- Seawater wet scrubbers are used for fluoride and SO_2 removal. The flue gas is cooled to approx. 10°C, transforming gaseous pollutions (sulfuric acid, PAH) to condensed or aerosol state.
- As the last scrubber step in the line, the WESPs gives an efficient cleaning of inert particles and aerosols/condensates formed in the wet scrubber.

No bi-products are formed which needs to be processed in other process steps.

Concluding remarks

Hydro has since the beginning of 1980's worked hard to improve their environmental, and financial performance, leading to an improved competitive position and has for the second year been rated top of Dow Jones Sustainability Index list.
Now Hydro has just started the next generation cell technology, where several of the features mentioned in this paper has been implemented resulting in a high amperage cell, well above 400 kA. Through innovative cell design this will give a lowered energy consumption, as well as low specific investment cost, and continued leading environmental performance.

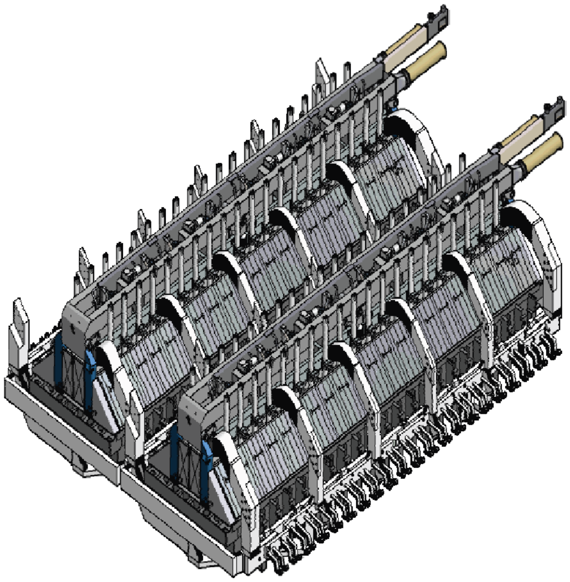

Figure 8. Next Generation Cell technology in Hydro.

Six cells will be in full operation in early 2008 at the Årdal test facilities and will become the basis for the next generation of global competitive smelters with leading financial, operational and environmental performance.

References

1. Guardian Unlimited, Friday September 22, 2006. "*Branson pledges $3bn transport profits to fight global warming.* ". http://environment.guardian.co.uk/climatechange/story/0,,1878492,00.html,
2. SFT: 25.06.2007 "*Miljøteknologi kan gi bærekraftig utvikling*" http://www.sft.no/artikkel____41268.aspx,
3. L. Descano and B.S. Gentry "*Communicating Environmental Performance to the Capital Market*" Corporate Environmental Strategy, 1998
4. D.C Esty and A.S. Winston, "*Green to Gold ; How smart companies use environmental Strategy to Innovate, Create Value, and build Competitive Advantage"* Yale University Press, 2006
5. F.L. Reinhardt, "*Bringing the environment Down to Earth*" Harvard Business Review, Jul – Aug, 1999
6. R.D. Klassen and K.P. McLaughlin, "*The Impact of Environmental Management on Firm Performance*" Management Science/Vol.42, No. 8, August, 1996
7. A.B. Lovins, L.H. Lovins and P. Hawken, "*A road map for Natural Capitalism*" Harvard Business Review, May – Jun. 1999
8. M. Porter and C. van der Linde, "*Green and Competitive Ending the Stalemate*". Harvard Business Review, Sep – Oct, 1995
9. S.L Hart and M.B. Milstein, "*Creating Sustainable Value*" Academy of Management Executive, Vol. 17, No. 2, 2003
10. The Nobel Peace center, October 13, 2006, "*The Nobel Peace Prize for 2006.*" http://www.nobelpeacecenter.org/index.php?page=news&id=121
11. B.P. Moxnes, H. Kvande and A. Solheim, "*Experience and challenges with amperage increase in Hydro Alumnium potlines*" Light Metals 2007
12. C. Behrens, O. Espeland and B. Nenseter, "*Emission of dioxins and VOC's from the Årdal Carbon Plant*". Light Metals 2007
13. Aluminiumsindustriens Miljøsekriteriat, AMS *"The Norwegian Aluminium Industry and the Local Environment"*, Summary report, November 1994
14. N. Stern, The Stern Rèview. "*The Economics of Climate change*". Cambridge University Press 2007

Recommended Reading

Banker, J., and A. Nobili. Aluminum-steel electric transition joints, effects of temperature and time upon mechanical properties (2002, pp. 439–445).

Bardal, A., et al. HAL4e - Hydro's new generation cell technology (2009, pp. 371–375).

Bearne, G., D. Gadd, and S. Lix. The impact of slots on reduction cell individual anode current variation (2007, pp. 305–310).

Bernhauser, E., O. Knaisch, and U. Heinzmann. Experience in retrofitting sidework pots to centerwork pots for environmental reasons (1979, pp. 971–978).

Bygstad, L., et al. Modification of an old Soederberg plant to meet new requirements as to environmental conditions and general performance (1987, pp. 171–182).

Canming, X. Overview of high-efficiency energy saving for aluminium reduction cell (2011, pp. 591–598).

Champagne, D., et al. Busbar circuit design and installation for boosting already boosted pots (2010, pp. 479–484).

Dhameja, R., and G.S. Sachan. Pot retrofit with larger anodes (1990, pp. 459–462).

Eika, K., and R. Skjeggstad. Heat recovery and dynamic process studies (1993, pp. 277–289).

Farsi,Y.A., A. Meghlaoui, and N. Aljabri. CD20 reduction cell upgrade for DUBAL's expansion project (2005, pp. 297–302).

Givry, J.P. Considerations on modern Soderberg cells with vertical studs (1963, pp. 185–196).

Givry, J.P. Technical and economic aspects of aluminum cell conductors (1963, pp. 115–130).

Jiaming, Z., Y. Xiaodong, and L. Yafeng. The continuous development of SAMI's SY300 technology (2008, pp. 275–280).

Johnson, A.R., and G.R. Gualfo. Applying new technology in plant retrofit programs (1988, pp. 617–621).

Jordal, P., et al. Modernization of Høyanger works: Economical advantage of large reduction pots (1983, pp. 587–594).

Keinborg, M., and J.P. Cuny. Aluminium Pechiney 180 kA prebake pot from prototype to potline (1982, pp. 449–460).

Lavoie, P., et al. Increasing the power modulation window of aluminium smelter pots with shell heat exchanger technology (2011, pp. 369–374).

Lu, D., et al. New progress on application of NEUI 400kA family high energy efficiency aluminum reduction pot ("HEEP") Technology (2011, pp. 443–448).

Martin, O., et al. The FECRI approach and the latest development of AP3X technology (2008, pp. 255–260).

Moxnes, B.P., B.E. Aga, and J.H. Skaar. How to obtain open feeder holes by installing anodes with tracks (1998, pp. 247–255).

Nasipuri, T.K., H.L. Stephen, and H.O. Bohner. Pilot plant operation of Russian VSS pots in excess of 160 kA following magnetic improvements, installation of point feeders and process control systems (2001, pp. 497–503).

Pedersen, T.B., et al. Results from implementation of point feeders and complete hooding on vs Søderberg pots (1998, pp. 221–226).

Pedersen, T.B. The Søderberg cell technology -- present performance, challenges, and possibilities (2001, pp. 489–495).

Richard, C., et al. The Alcan's P155 smelters now operating at 195 kA: A successful assets optimization strategy (2008, pp. 267–270).

Scholemann, B.A., and S. Wilkening. Reduction cell with continuous prebaked anodes -- a new approach (2001, pp. 167–172).

Skornyakov, V.I., et al. SUAL 300 kA pre-baked cells (2006, pp. 307–311).

Tonheim, J., et al. Experience with booster pots in the prebake line at Hydro Aluminium Karmøy (2004, pp. 191–196).

Tschopp, T. Modern conceptional design of aluminum smelters (1977, Vol.1, pp. 51–67).

Vogelsang, D., et al. Development of a 300-kA reduction cell: Application of simulation tools for the conceptual design (1994, pp. 245–251).

Zarouni, A., et al. DX pot technology powers green field expansion (2010, pp. 339–343).