Chapter Twelve

Industrial Development

12.1

Steel from Ironsand

by
Sir John Ingram

Introduction

The story of New Zealand Steel Limited is one of developing an internationally competitive process for utilising the country's previously useless but vast ironsand deposits and indigenous low ranking coal. It is the story of establishing a highly successful domestic and export steel industry based on unique raw materials and a unique process developed by New Zealand engineers and technologists. The Glenbrook process and project received an IPENZ plaque in 1990 for engineering excellence.

Aerial view of New Zealand Steel Plant, 2009.

NZ Steel CIMG0080c

Early History

Some two and a half million years ago Mt Taranaki and its old volcanic relations disgorged vast quantities of titanomagnetite material which was ground by the action of the sea and wind and deposited in sand dunes behind headlands up and down the North Island west coast.

These black magnetic sands attracted interest from the time of the first European explorers. Captain Cook had noted the deposits on his first visit in 1769, and later the material's accessibility, its density, magnetic properties, colour and metallic appearance excited the interest of the Pakeha settlers.

The early attempts to smelt the material marked the beginning of a series of unsuccessful trials, tribulations and bankruptcies that unfolded over the next 120 years. From 1840 to the end of the 19th century there were literally scores of attempts to smelt ironsand, some by small companies, others by provincial or national governments and some by public companies.

In 1857 the Taranaki Provincial Government offered a reward of £1000 to the first person who could produce 100 tons of merchantable iron from ironsand. The prize was not claimed!

The Waihi Gold Mining Company built a blast furnace in New Plymouth in 1914. Under the direction of Mr J. A. Heskett, using briquettes of ironsand and finely pulverised coal, five tons per day of iron were initially produced but the furnace kept clogging and the process stopped.

It was about this time that the cause of the problem was identified. The reduction of the titanium dioxide in the ore at high temperature resulted in the formation of carbides and nitrides, a viscous slag which blocked the draught of the furnace and stopped the process. It was later recognised that to avoid this problem the reduction (conversion of oxide to metal) had to take place at a lower temperature without melting the material.

During this time three patents were granted on the processing of ironsand but none had an impact on the challenge. Their significance lay in the growing interest in direct reduction and the growing influence of science and engineering in resolving problems, instead of trial and error. Two of the patents were in the name of university graduates, Galbraith and Cull.

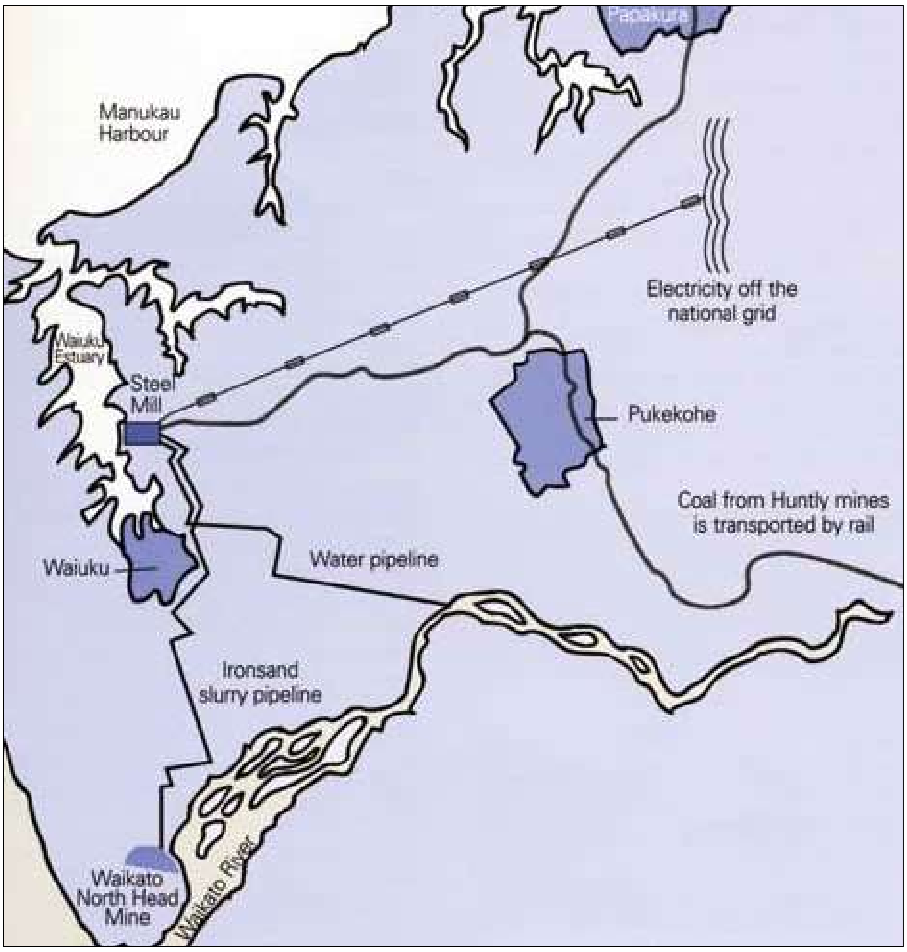
Cull, after graduating in engineering from Canterbury University College in 1906, undertook some ironsand research there, and his patent was granted in 1908. It comprised a preheater and reduction chamber directly discharging partly reduced ironsand concentrate into an electric arc furnace. His trials were unsuccessful.

Cull left the Engineering School and had a distinguished engineering career in Auckland before returning to Christchurch as professor of civil engineering.

Direct Reduction Development

The development of direct reduction processes in the 1950s caused the government to sponsor an investigation into the resources and processes available, forming the New Zealand Steel Investigating Company under the chairmanship of Mr Woolf Fisher (later Sir Woolf Fisher). With the help of Department of Scientific and Industrial Research scientists and the Battelle Memorial Institute in Ohio, New Zealand ironsand and coal were shipped to the northern hemisphere over the next five years and trialled in various pilot plants.

Finally the investigating company considered that the resources, a process and a market existed for the establishment of an economic domestic steel industry. The press announcement in 1962 caused considerable excitement, particularly in the industrial/manufacturing sector. At last New Zealand was to get its own integrated flat products steel works, after more than 120 years of failure in the attempt.

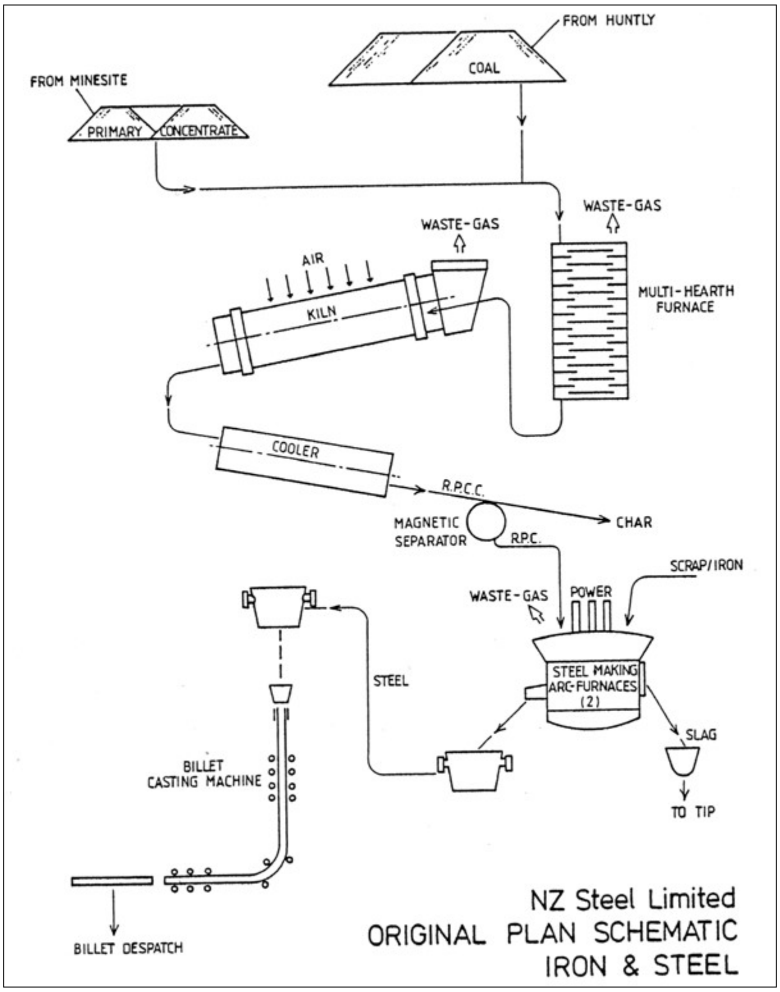


Above: Map showing Glenbrook, Port Waikato, Huntly, Taharoa and Mt Taranaki.

S. La Roche composition

Left: Map showing the Glenbrook Steel Mill, the ironsand mine, slurry and water supply pipeline to the steel mill.

NZ Steel leaflet, Natural Resources and Energy



NZ Steel Ltd Original Plan Schematic Iron & Steel.

J. H. Ingram paper, Fig. 1

Investigations into the extent of ironsand available at Waikato North Head revealed a reserve of about 150 million tonnes of primary concentrate (57 per cent iron) which at current usage, 1.2 million tonnes per year, is enough to last over 100 years. It was decided to build the plant at Glenbrook, close to the ironsand mine, Huntly coal, and available land with good foundations, and in close proximity to the bulk of the domestic market in Auckland and to export shipping.

The plan was to build a prototype iron and steel plant of 150,000 tonnes per year capacity of continuously cast billets, together progressively with finishing plants (galvanising plant, paint line, pipe plant and hot rolled coil finishing equipment), all operating initially on imported semi-finished steel. Later, when the iron and steel process was optimised, additional capacity would be installed, together with rolling mills to substitute the imported semi-finished steel with local product.

The government underwrote the floating of a new public limited liability company and New Zealand Steel Ltd was born. At this point the government owned about half of the company and was in effect a joint venture partner, but later sold all of its shares to the public at a substantial premium.

The Prototype Plant

The process selected for the iron and steel plant utilised the SLRN (Stelco-Lurgi-Republic Steel-National Lead) direct reduction kiln, 75 metres long and 4 metres in diameter, which was fed with ironsand pellets. The coal, providing the carbon as a reductant and the energy for the process, was blown into the kiln at the discharge end and the pellets reduced to sponge iron during their passage down the kiln. After cooling to ambient temperature to avoid reoxidation and allow magnetic separation from the surplus carbon and ash, the sponge iron pellets were stored before being refined into steel in the steel plant.

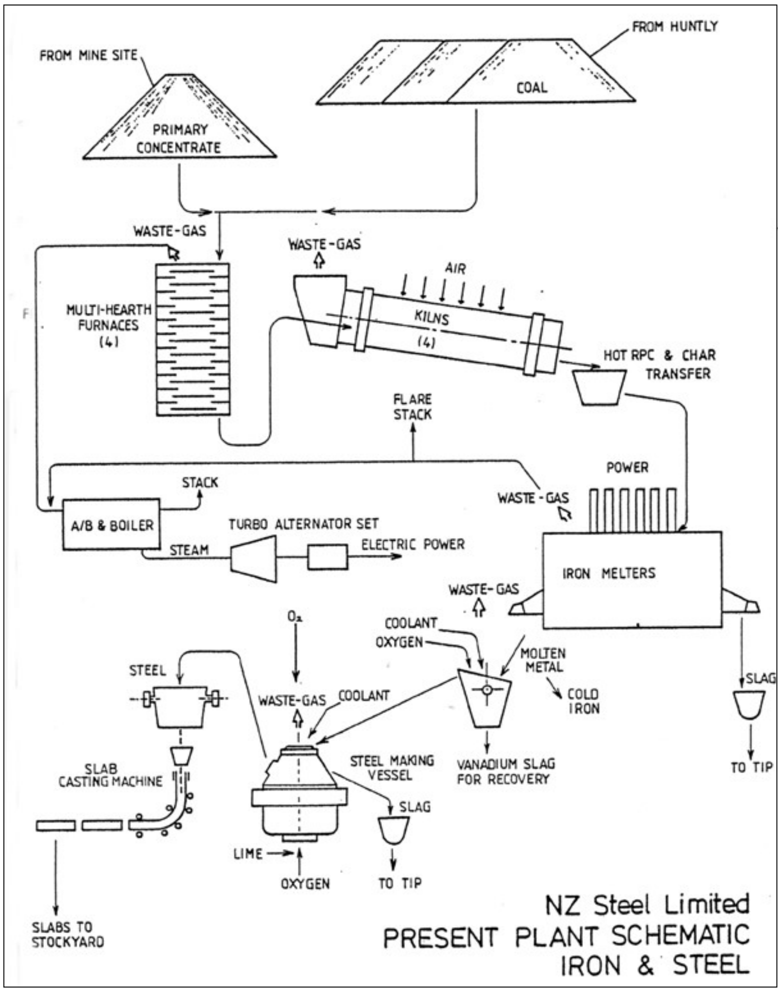
All very well in theory and in the pilot plant trials, but in practice an absolute disaster. The process as bought and designed did not work!

Prototype Problems

First the pellets broke down in the kiln, reverting to the black talcum powder-sized grains from which they were made, and were either picked up by the waste gas and distributed far and wide over the countryside or accreted as massive iron lumps on the walls of the kiln.

Secondly, there were nine process steps between the receipt of the ground ironsand concentrate from the mine and the reduced sponge iron pellet storage, each with a discrete item of plant and with no intermediate storage. The not infrequent breakdown of any item would interrupt the process, causing instability, which made consistent operation impossible.

Operating campaigns were a few days or weeks instead of the planned 10 months, each followed by the heartbreaking job of breaking and removing stubborn accretions, including, on one occasion, repairing a split in the kiln shell caused by the excessive use of explosives during accretion removal.



NZ Steel Ltd Present Plant Schematic Iron and Steel.

J. H. Ingram paper, Fig. 2

The process designers, plant manufacturers and engineering consultants provided experts aplenty who tendered advice and apportioned blame, pointing to each in turn. There was an enormous conflict between the demands of the arc furnaces for sponge iron, the market for steel billets and the bank for cash on the one hand, and the need to slow down, think, experiment and learn on the other.

During this period and up to 1973 the company made big losses, cushioned by the profitability of the galvanising plant and profits from the export of ironsand concentrate from Taharoa. Sir Woolf Fisher, the then chairman, remained confident throughout and was wonderfully supportive of the company management. The government provided five million dollars of new capital as preference shares, subsequently repaid.

Prototype Innovations

Dr Nigel Evans.

Courtesy Bryce Williamson and NZ Institute of Chemistry

Peter Bates.

Courtesy Bryce Williamson and NZ Institute of Chemistry

Dr Richard Cooper.

Courtesy Bryce Williamson and NZ Institute of Chemistry

At the time of its founding the company recruited several postgraduate engineers and technologists who were sent overseas for steel industry experience. On their return they, particularly Dr Nigel Evans, Dr Richard Cooper and Peter Bates, became the core of the company's technical services department. It was their analytical ability, innovation and determination that played a major role in the ultimate development of the extremely efficient iron and steel making process.

In spite of strong protests from the overseas experts, on the recommendation of its technical services department the company decided to trial-feed the kiln with unground primary concentrate. It had been observed in the laboratory that these grains, unlike the fine grains of secondary concentrate, did not grow biddybid-like whiskers, obviously a major cause of accretion growth, during the reduction process.

The tests were successful, plant availability greatly improved and accretion growth was much reduced. Other changes were necessary to cope with feeding concentrate instead of pellets. The evolution of carbon monoxide fluidised the bed so it acted like thick slurry and the resulting surges caused problems, including variations in the degree of metallisation. Brick dams were built in the kiln to reduce, in effect, the kiln slope. After trials, surplus dams were removed on the run with the army sharpshooters shooting out the relevant key bricks.

For the first time the plant operated smoothly, but design output was not achieved. One third of the kiln length was used for drying and heating the burden and devolatilising the coal so it was decided to install a multiple hearth preheating furnace ahead of the kiln. The evolving gases were burnt to provide the works' steam requirements and the output was increased to 150,000 tonnes per year.

At last an efficient process was developed for converting New Zealand ironsand to iron as reduced primary concentrate (RPC), but the cost of converting this to steel was not viable. First, the discharge from the kiln had to be cooled before exposure to air to avoid re-oxidation and to allow magnetic separation of the iron grains and surplus carbon. Thus the heat of about 200 kilowatt hours per tonne was lost. Secondly, the relatively high slag volumes meant long arc furnace tap to tap (cycle) times with high energy costs. Thirdly, the alternative acid and basic slags during the melting and then refining cycle shortened refractory life, incurring high costs in both refractories and furnace downtime.

Process Optimisation

Because of the high cost of steel production, the cost of the end product – steel billets – was not internationally competitive. Without cross-subsidy and domestic protection the iron and steel plants would have to be closed with big redundancies and the end of using indigenous materials.

It was decided therefore to research an optimum process and then test if it was feasible to fulfil the original proposal of expanding the plant into an integrated flat products works, replacing the imported steel for the paint line, the galvanising line, the pipe mill and ultimately the hot and cold rolled sheet and plate for the domestic market.

It was recognised that producing pig iron as an intermediate product between the kiln and steel making would result in three major benefits. First, the hot kiln product (RPC and un-used carbon) could be fed directly to a melting furnace and the wasted heat saved. Secondly, a modern, highly productive oxygen steel-making process could be utilised using carbon and oxygen as the energy source in lieu of electricity as in the arc furnaces. This greatly reduced electricity demand and refractory costs. Thirdly, the vanadium present in the ore and reduced in the kiln to vanadium metal would be soluble in the pig iron. Its subsequent recovery as vanadium-rich slag and sale would subsidise the steel making costs by an average of $30 per tonne.

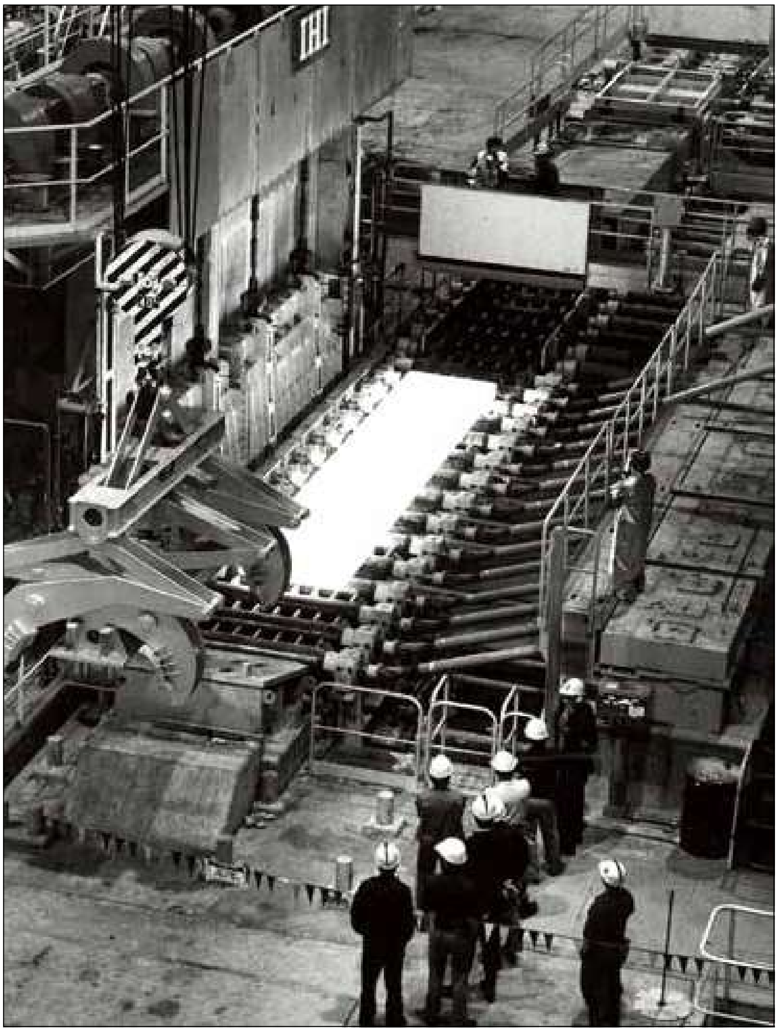
Although plants existed in South Africa and Scandinavia using submerged arc melters for making pig iron from ore or partly metallised ore, it had not previously been achieved using sponge iron (RPC), the product of the Glenbrook kilns. The problem was to make a pig iron of high enough carbon content, more than three per cent, to enable the extraction of the vanadium-rich slag and to provide the energy to operate the basic oxygen steel furnace.

A pilot plant comprising a batch pilot kiln and small 500 kilovolt ampere furnace was built at Glenbrook. After lengthy trials it was established that a suitable quality pig iron could be obtained if certain operating parameters were adopted.

The Expansion Project

Having established that the new process would work, a feasibility study was undertaken which indicated that an integrated works could be built and provide a good rate of return to both the shareholders and the nation.

It was, however, recognised at the time that to ensure an economic capital cost per tonne of production, the rolling mill complex would have to include a number of state of the art innovations such as a coil box. A description of these is outside the scope of this writing but may be seen in the paper 'Pioneering



IHI Hot Strip Mill with management watching.

Courtesy NZ Steel, Scan0030

a Process' described under 'References and further reading' at the end of this section.

The project, comprising an increase in steel production of five times to 700,000 tonnes per year, and the installation of hot and cold rolling mills, was far too big for the company to undertake alone and the government would be invited to participate in a form of joint venture, just as it did when the company started.

The choice for the company was simple. It had to either persuade the government to agree to and participate in the expansion, or in a few years face the closure of the existing iron plant, steel plant and mine site with massive redundancies and become merely an importer and processor of imported steel. There was a firm determination to avoid the latter.

The government agreed to consider an involvement and negotiations began with representatives of Treasury, Trade and Industry and supplier departments. At first the officials were sceptical that the company's forecasts could be achieved but with an intensive interchange of financial and technical information and visits, their doubts were mollified. Through this extensive period ministers and cabinet committees were kept informed of progress.

A major concern for the company was to ensure that profits and dividends could be maintained throughout the construction period. This could be achieved only if the project was undertaken off the company's balance sheet. Therefore a new company would be established to undertake the project, New Zealand Steel Development Ltd (NZSD), 60 per cent owned by the government and 40 per cent by New Zealand Steel. The capital of the company would be nominal but the government would guarantee the loan finance if necessary. New Zealand Steel Ltd would progressively take over NZSD once production had reached certain levels.

Hot Coil Box in rolling mill.

NZ Steel, Hot Coil

A heads of agreement document was drawn up to include these points, and others concerning limited market protection for a period following the completion of the project, an obligation by the company to maximise local content of plant and machinery and the availability of coal and electricity. The New Zealand Steel board considered that this agreement, although not enforceable on successive governments, provided sufficient protection for the shareholders. It agreed that the project should proceed, following final government approval.

Prior to the 1981 election two other substantial capital intensive projects were proposed as a part of the government's 'Think Big' policy: the aluminium smelter at Aramoana and a synthetic gasoline plant at Motunui. There was no official comment but it was suggested these projects would take precedence over the expansion of New Zealand Steel (which, originally proposed by the New Zealand Steel Investigating Company in 1962, was never a part of 'Think Big') either because they had a better net national benefit or because they required no government input or risk. However, neither project materialised at that time and New Zealand Steel got the go-ahead in November 1981.

The company was ready to go and earth moving contracts were let by NZSD almost immediately, the prime minister turning the 'first sod' a few weeks later.

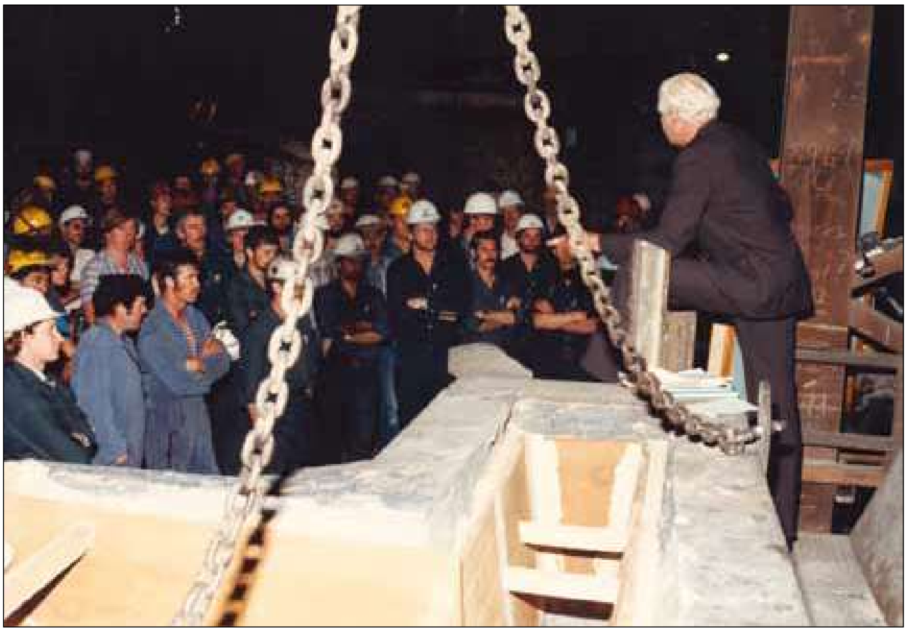
The project was run by NZSD, at arm's length from New Zealand Steel Ltd. However, because of the physical linking of the project and the existing works and the ultimate responsibility belonging to New Zealand Steel, a number of the directors and executives, including the managing director, had dual responsibilities. Sir Alan Hellaby chaired both boards, being joined by three New Zealand Steel directors and four government appointees, including resident director Mr A. G. Stirrat, previously chief design engineer of the Ministry of Works. He made a major contribution to the project.

As construction work reached a peak, demarcation problems between various unions reached massive proportions. Inter-union disputes, sometimes violent, broke out pitting welders and engineers against boilermakers; riggers and labourers against engineers; roofing plumbers against carpenters against boilermakers, and so on. The inter-union nature of the disputes left contractor management helpless and many work hours were lost. Similar problems at the Marsden Point Refinery were solved by special government legislation but similar measures were declined for the NZSD project.

Significant additional costs were incurred by the company in meeting the very high local content target, much of the work being on the limit of the local works capacity. Requests to the government for some relief in this area were declined.

Double digit inflation added to cost overruns but project reviews confirmed the project was viable.

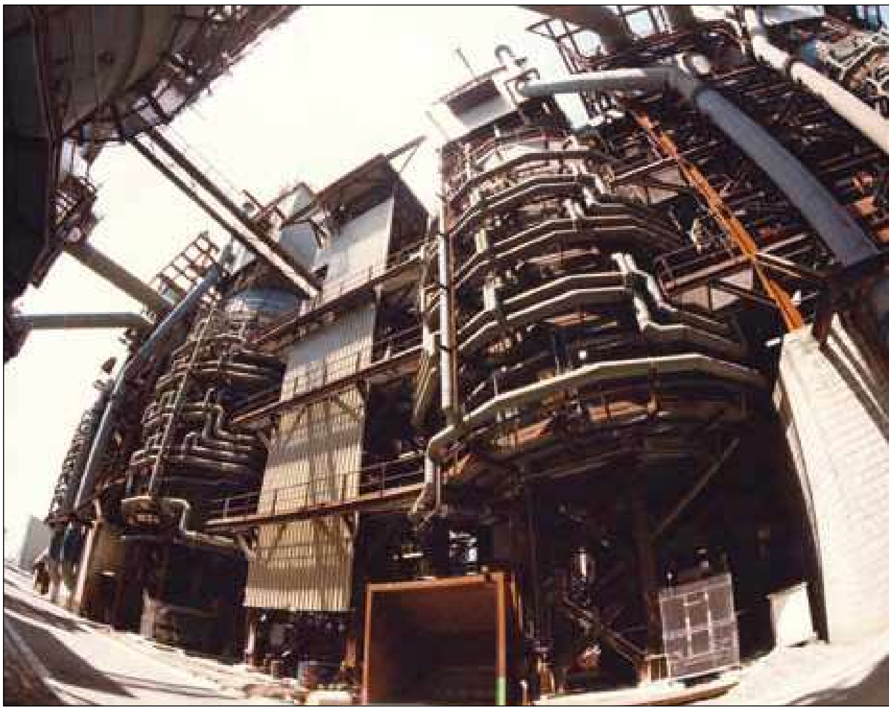
In 1984 Labour won the snap election and Mr Roger Douglas (later Sir Roger Douglas) was made minister of finance. He did not accept the heads of agreement signed by the previous government and indicated he would not continue to guarantee the NZSD loans. Prolonged negotiations ensued during which overseas consultants examined the company's feasibility study and process. The government finally proposed that it would absorb the NZSD loans



'Big John' addressing NZ Steel staff.

NZ Steel, Scan 0116

and that New Zealand Steel should take over the government's 60 per cent share of NZSD by issuing New Zealand Steel shares to the government. This would cause considerable loss of value to the shareholders. The board considered this proposal against the possibility of withdrawing from the project and continuing to operate the company's other assets. Considering the interlinking of the project with common services and operating with an antagonistic government, this was not a practical proposition.



Exterior view of multi-hearth furnaces.

NZ Steel, Scan 0126

With the transaction complete, the government became the 90 per cent majority owner of New Zealand Steel Ltd. Newspaper headlines claimed the move as a 'bail-out'. New Zealand Steel, however, considered that the absorption of the NZSD loans by the government was an appropriate compensation for the new government's abrogation of the heads of agreement and acquisition of the company.

The expanded iron and steel plants began operating in 1986 and the rolling mills complex and associated plant in 1987.

In October 1987 the government, unlike its predecessors, was so desperate to divest itself of the company that it sold New Zealand Steel to Equiticorp Ltd, a merchant bank-type company remote from the steel industry. Further, because the plant was still commissioning, the sale price was far from optimum.

In early 1989, Equiticorp was placed under statutory management. Negotiations between the statutory manager and China Minmetals Corporation to buy New Zealand Steel were disrupted by the Tiananmen Square massacre in June and not resumed.

The company was later sold to a consortium led by BHP, which later became 100 per cent BHP owned. The company is now owned by BHP Steel's

KOBM vessel for converting iron to steel.

NZ Steel, Davy

Above: Molten Iron being charged into the steelmaking vessel.

NZ Steel, Charging

Above: Steel Slab emerging from the casting machine.

NZ Steel, High Res Slab

successor, Bluescope Steel Ltd, but the name has reverted to New Zealand Steel Ltd.

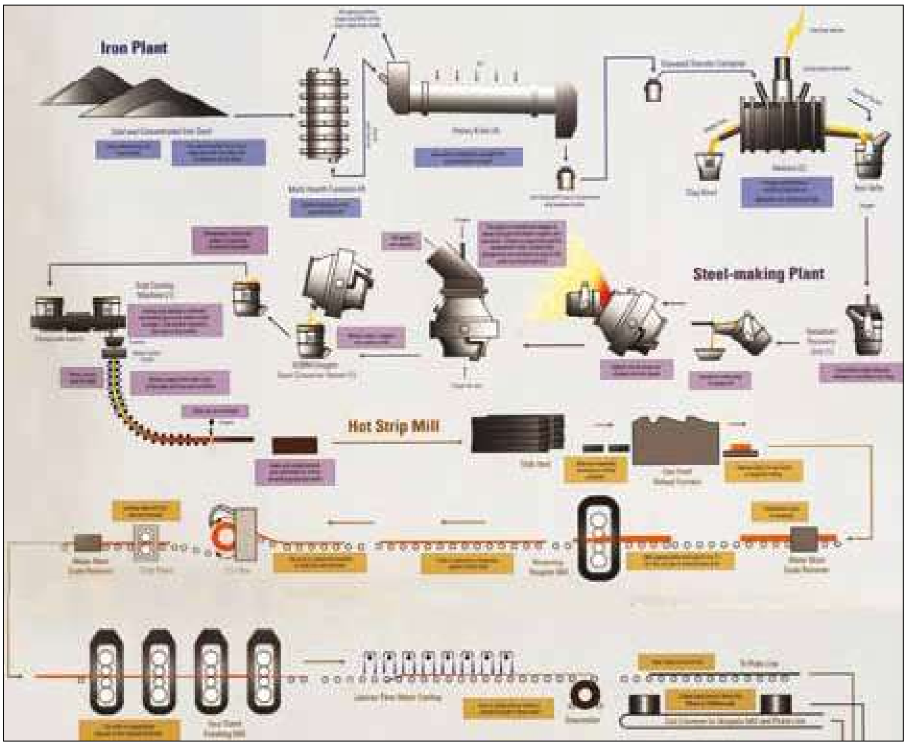
It is perhaps ironic that the Equiticorp statutory manager subsequently took action against the government in connection with Equiticorp's payment package. Substantial damages in favour of the statutory manager resulted.

Progress Under New Owners

The control of the company changed to the new owners in late 1989. Significant capital expenditure was undertaken, and the design level of productivity achieved. In 2009 the company operated for a full year without one lost time accident, an exceptional achievement. Glenbrook is one of the cleanest integrated flat products steelworks in the world. The company's largest capital investment in environmental control is in gas cleaning equipment to ensure that the quality of gases leaving their stacks betters the levels agreed in the Air Permit issued under the Resource Management Act.

Manufacturing Success

The domestic availability of high quality competitive flat steel products, with shorter lead times, an increased range of specifications and small order item sizes,



'The New Zealand Steel Production Process'.

NZ Steel Brochure BH821124 W3885 P6

together with skilled technical advice, has greatly benefited the very diverse local manufacturing industry. A 'boutique steel company' is an apt description.

Economic Success

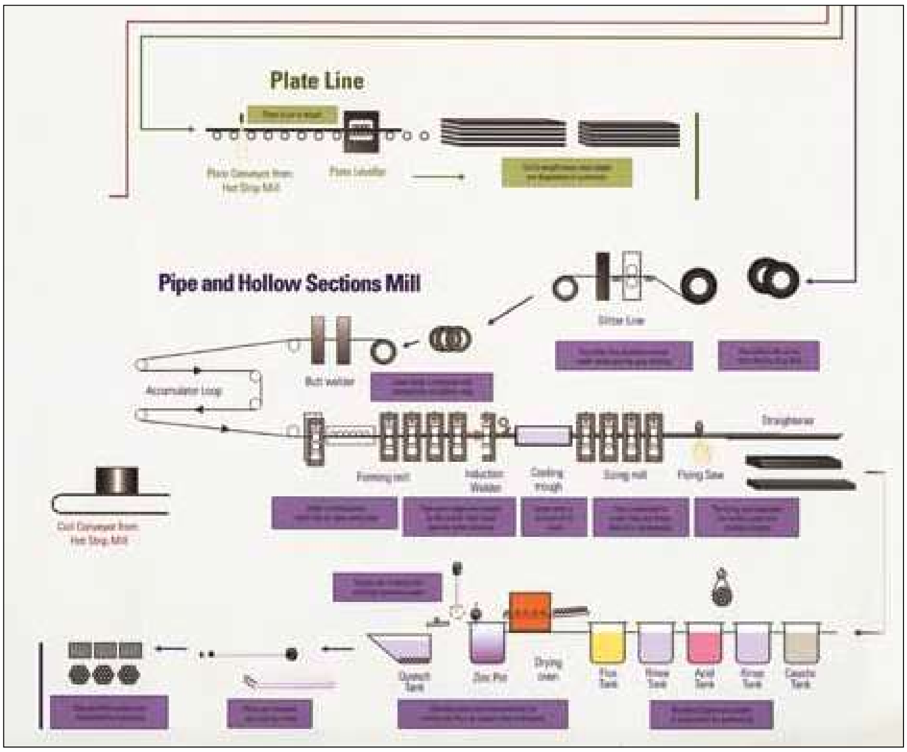
In year 2000 figures, if New Zealand Steel had not existed the current account deficit would have risen by about 600 million dollars per year, or about 0.6 per cent of gross domestic product.

Environmental Care

Although the company's record of contribution to the environment started with a stutter, mostly in self defence, with the early formation of an environmental committee chaired by the managing director to keep local people and their representatives informed of progress (or lack of it), it has grown into one that is nationally acclaimed as excellent.

Since the change in ownership of the company in 1989, BHP directed all their businesses to establish an environmental system based on international standard ISO 140001. The company therefore uses this formal system to monitor and improve its environmental performance.

In 1994 the company received a Green Ribbon Award from the Ministry



'Skin Pass Mill, Plate Line and Pipe and Hollow Sections Mill'.

NZ Steel Brochure BH821124 W3885 P6

of the Environment for a major environmental and economic achievement: that some 550,000 tonnes of slag per year, previously discarded to land fill, are now recycled, reused or sold profitably – the latter replacing materials previously quarried.

Further, the hot gas from the iron plant multi-hearth furnaces, kilns and melters is burnt in a cogeneration plant to produce about 60 per cent of the 1,000 gigawatt hours of electricity consumed annually on the Glenbrook site. This has led to a decrease in carbon dioxide emissions at thermal stations by some 300,000 tonnes per year. The company was recognised for this outstanding contribution to the environment by being awarded the Energy-Wise Companies Campaign Award in November 1998.

Contribution to Society

The arrival and expansion of New Zealand Steel has changed Waiuku and to a lesser extent Pukekohe into thriving local towns, no longer solely dependent on dairying and horticulture. Furthermore the company policy to subcontract many of the services at the mill has led to a strong growth in the range of small local engineering businesses. The variety and strength of sports, service, cultural and leisure clubs has increased significantly and it is interesting to note the high percentage that now have New Zealand Steel employees as office bearers.

Relationships have greatly improved with the Tainui hapu Ngaati Te Ata, the guardians for Waiuku, the mine site and Glenbrook. The company can point to many areas of agreement where it has been able to contribute to the welfare of the hapu following agreement on certain problems at the mine site.

The changes at Taharoa for the Maori community, Ngati Mahuta, also a hapu of Tainui, have been far more dramatic: the arrival of New Zealand Steel literally thrust a small community with no electricity and access except by horseback into the 20th century. Taharoa C, the Maori shareholders with whom the mining lease had been negotiated, have invested their royalties wisely in successful commercial enterprises, farms, but importantly in providing scholarships, both secondary and tertiary, for the education of their young people.

The words of Prime Minister Norman Kirk at the opening ceremony in November 1972 have been truly vindicated: 'The development of these ironsands will transform the lives of the owners, their children and their grandchildren for generations ahead. It has provided a future.'

Recognition by the Engineering Profession

The achievements of BHP New Zealand Steel Ltd were recognised in 2000 by IPENZ in presenting one of its Millennium Awards to the company for its contribution to manufacturing, to the economy, to the environment and to society.

In responding to the award Dr Norm Clark, finishing plants manager of BHP NZ Steel as it was then known, and a work colleague of the three engineers mentioned below, said,

> Many people over many years have contributed to this achievement. However, at a time when the country is celebrating the success of Team New Zealand, I would especially like to acknowledge a small group of Team NZ Steel, who took overseas technology, which quite frankly did not work, and transformed it into the elegant iron-making process which is still the heart of the company thirty years on.
>
> There was a knight at the top, Sir Woolf Fisher, an entrepreneur who strongly supported his young engineers against the conventional wisdom of many overseas experts and who held together the financial backers through desperate months.
>
> There was John Ingram, later Sir John, an engineer and past president of this institution, who made pivotal recommendations based on a sound technical understanding of the problems and the proposed solutions. Then there was a team of three young NZ engineers: Dr Nigel Evans, Peter Bates and the late Dr Richard Cooper. Their great achievement was to put in place a technology for making steel from ironsand and Waikato coal which was simple in concept, and which has proved capable of delivering continual financial and environmental improvements at BHP NZ Steel.
>
> The process was not entirely novel. In fact it can now be seen as the logical end-point of a series of experiments on ironsand which started as soon as the first European settlers arrived. And of course many engineers have worked improvements since the time of Evans, Bates and Cooper. So in accepting this award we look across nearly 150 years of engineering endeavour and commensurate financial courage. It makes one feel very humble.

Conclusion

There is at Glenbrook a highly efficient, and low cost, flat products integrated steel plant which uses ironsand ore and low-ranking Waikato coal. Although a very small integrated works by world standards, it is the largest industrial site in New Zealand by far and contributes greatly to the national economy. Around half of the company's production is exported and the balance sold on the domestic market. The company is very profitable and competes against imported steel with no tariff protection. It is probably one of the very few steel works which continued to operate at full capacity throughout the recession that began in 2009.

The success of the company vindicates the board's confidence in the young engineers and technologists who developed the new process, in the management who recommended the development should proceed and in the brave pioneering decision of the board, particularly Chairman Sir Alan Hellaby, to enter the commitment.

Appendix

Expansion Project Main Contractors and Plant Suppliers

Stage I. Iron and Steel Plants

Project Principal – NZS Development Ltd
Managers and Engineers – Davy McKee (Stockton) Ltd
Multi Hearth Furnace & Rotary Kilns – Lurgi Gmbh
MHF Waste Gas Scrubber – Flakt Australia Ltd
Co-generation plant – NEI Pacific Ltd
Iron Melter – Elkem a/s Engineering
KOBM – Davy McKee (Stockton) Ltd
Slab Caster – Sack Stranggiesstechnic
Billet Caster – Concast Standard AG
Air Separation Plant – Cryoplants Ltd and NZ Industrial Gases Ltd

Stage II

Project Manager – NZ Steel Development Ltd
Project Engineers – Nippon Kokan KK
Main Contractors – Ishikawajima-Harima Heavy Industries Ltd (IHI)

Sub Contractors

Preheat furnace – IHI
Hot strip mill – IHI
Pickle line – Sumitomo Heavy Industries
Reversing cold mill – Hitachi
Combination mill – IHI
Uniflow Annealing Plant – Chugai-Ro
Water treatment – Ebara Infilco

Mine site

Concentration plant Managers and Engineers – Beca Carter Hollings and Ferner
Bucket Wheel Excavators – Orenstein & Koppel
Slurry Pipeline – McConnell Dowell Construction Ltd

References and further reading

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12.2

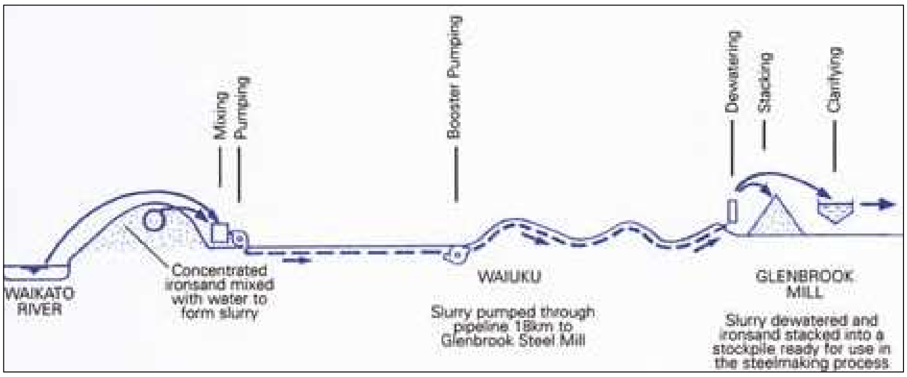
Slurry Transportation Ironsand Concentrate – Mine Site to Glenbrook

by
Sir John Ingram

Slurry transportation from the mine site to Glenbrook began in 1986. This was the world's first polyurethane-lined high pressure underground pipe line with welded flanges transporting dense abrasive coarse material by positive displacement pumps. The project extended the known bounds of slurry pumping technology and was awarded an IPENZ plaque for engineering excellence.

The increase in usage of primary concentrate due to the iron and steel plant expansion (from about 250,000 tonnes per year to over 1.2 million tonnes) meant continuing use of road transport for the 18-kilometre journey was neither economic nor practical. Other options had to be considered. These were: slurry transportation, aerial ropeway, conveyors, pneumatic capsules and railway.

Slurry transportation was initially ruled out, as no slurry systems longer than a few kilometres existed for such abrasive material with its combination of grain size and density. There was reluctance to risk extending the bounds of technology to such an extent for such a vital service.



Diagrammatic illustration of slurry transport system.

NZ Steel leaflet 'Water and Essential Resource', Fig 1