NICKEL

THE MAGAZINE DEVOTED TO NICKEL AND ITS APPLICATIONS

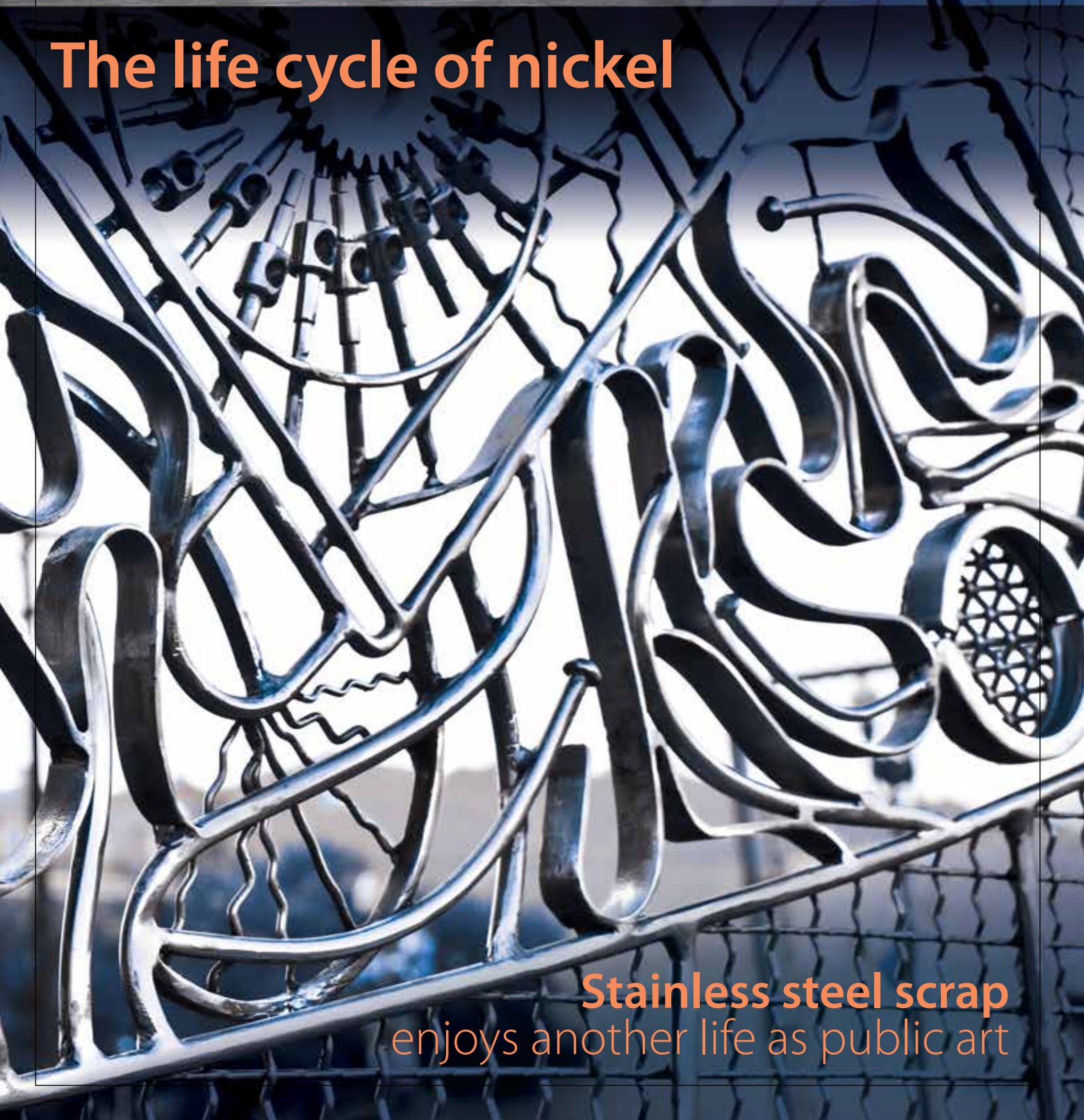
Progreso Pier: advantages of stainless rebar

Yale University research explains where the nickel goes

New environmental nickel data

March 2014 Vol. 29, Nº 1

The life cycle of nickel



Stainless steel scrap enjoys another life as public art

△ *Stonecutters Bridge at night* ▷ *Tapered mono tower*

NIGHT PHOTO: STONECUTTERS BRIDGE, HONG KONG © MARCEL LAM PHOTOGRAPHY COURTESY OF ARUP

TOWER PHOTO: STONECUTTERS BRIDGE, HONG KONG © JOHN NYE COURTESY OF ARUP

CASE STUDY 01
STONECUTTERS BRIDGE TOWERS

Imposing and important, Stonecutters Bridge in Hong Kong provides a vital commercial link in an environmentally demanding setting. It also depends on nickel-containing stainless steel to ensure safe and continuous service over its 120 year design life to cope with salt water, industrial pollution and frequent typhoon events.

The most striking features of the bridge are the twin tapered mono towers at each end which rise to 295m above sea level and support the 50m wide deck. While the lower sections are reinforced concrete, the upper 115m are composite sections with an outer stainless steel skin and a reinforced concrete core.

Circular towers are known to be susceptible to vortex shedding vibration. To avoid it, the upper part of the tower was designed as a composite structure with a stainless steel skin around a reinforced concrete annular core enclosing the steel cable anchor boxes. Its greater mass, stiffness and damping gave the bridge an improved response to vortex shedding.

In addition, the height of the towers and the busy traffic beneath means that maintenance needs to be kept to a minimum. Nickel-containing stainless steel was chosen to clad the upper part of the tower because of its durability and attractive appearance. The alternative, carbon steel, would have required replacement after an estimated 25-30 years with repeated additional costs and disruption of traffic over the 120 year service life. Duplex stainless steel 2205 (S32205) was the material of choice, thanks to its high yield strength (460 MPa) and superior corrosion resistance. Ni

STABLE AND STRONG

The tower skin is made up of 32 stainless steel segments each of 20mm thick hot rolled plate. The diameter of the circular tower section tapers from 10.9m to 7.2m with the concrete wall thickness decreasing from 1.4m to 0.8m. The lower three sets of stay cables are anchored into the reinforced concrete lower tower section. Above this there are 25 steel anchor boxes into which the remaining 25 sets of stay cables are installed. The structural capacity of the upper tower section relies on the interaction of the stainless steel skin, the concrete core and the anchor boxes. High strength duplex stainless steel shear connectors, 16mm in diameter and up to 300mm long, transfer the load between the concrete and the skin or anchor box.

This article has been adapted from a series of Structural Stainless Steel case studies produced on behalf of Team Stainless by SCI and available for download from ***www.nickelinstitute.org***

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NICKEL

The Magazine Devoted to Nickel and its Applications

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ALL ABOUT LIFE CYCLE

The phrase "life cycle" is in danger of joining "sustainability" as exhausted of meaning because of overuse. Yet as this issue of Nickel will show, "life cycle" and "sustainability" are still powerful concepts in society, economics and commerce.

With full life cycle thinking we can show the real environmental and economic performance of nickel and nickel-containing products as it allows us to balance the impacts from production against the benefits of use (and recycling).

Turn to page 5 for a special feature devoted to exploring the life cycle of nickel. We start with an introduction to the newly completed Life Cycle Inventory of metallic nickel and ferronickel, both key ingredients for many grades of stainless steels and nickel alloys. This inventory provides current, representative and peer-reviewed quantification of all the material and environmental resources that go into making a unit of nickel.

With this baseline information it is possible to draw up a balance sheet showing the net benefits the use of nickel brings to society and the environment. And it provides information to help political, regulatory and industrial stakeholders within the nickel value chain take the best – sustainable – decisions.

We go on to examine the question of net benefits – the degree to which the service provided by a material outweighs the physical and environmental resources required to create it – in a Life Cycle Analysis of the Progreso Pier in the Gulf of Mexico. This simple concrete pier, built using nickel-containing stainless steel rebar, is still standing, still functioning after more than 70 years in a hostile marine environment.

Next, for over a decade the Yale University Centre for Industrial Ecology has been examining the flows and stockbuilding of metals from "cradle to grave". What this independent research, supported by Nickel Institute, has shown and measured with a precision not previously attempted, is that the journey is a long one and that enormous resources for future generations are accumulating "in use" in society.

And to come full circle, on page 11, read how nickel-containing stainless steels are collected and recycled – a very practical demonstration of what the Yale University research shows: the qualities of nickel are such that society values and works hard to hold on to nickel-containing materials for the good of today and tomorrow.

There is more, as always, and for a combination of beauty and utility, see what nickel is doing for Stonecutters Bridge in Hong Kong and how scrap stainless steel becomes public art in the hands of sculptor Bruce Taylor. Both practical examples of what nickel brings to society and sustainability.

Clare Richardson
Editor, *Nickel* magazine

ISTOCK PHOTO © STEVEN JOHNSON

STAINLESS REBAR

Past, present and future

Stainless steel rebar prevents damage to structures caused by rebar corrosion

No matter where you live, you have read about "the crumbling infrastructure" in our regions, whether it be Europe, North America, Asia or elsewhere. Most of us can point to examples of roads and bridges that have deteriorated, some to the point where structural failure is imminent. Yet lack of funds means repairs are delayed and ultimately need to be more comprehensive.

Most of the deteriorating concrete in our bridges is due to the corrosion of the carbon steel rebar, whether coated or not, in the concrete. The worst corrosion occurs in regions where road salt is heavily used or in areas near to salt water, but stainless steel rebar prevents damage to structures caused by rebar corrosion. In our story starting on page 7, Pier Review, the Life Cycle Assessment of a pier in the Gulf of Mexico constructed around 1941 which used stainless steel rebar is featured. It would have been considered an odd choice at the time, but today looks to have been a very wise one. Stainless steel rebar is used in ever increasing amounts today both in North America and around the world. The Stonecutters Bridge shown on the inside front cover used stainless rebar in Type 2205 (UNS S32205) as well as plate. While stainless steel is more expensive than carbon steel rebar, its selective use can be justified financially when all the costs of maintaining the structure over its life are considered.

In Edmonton, the provincial capital of Alberta, Canada, with a metropolitan population of over one million, a new ring road around the city is in the final stages of completion, with the Northeast Anthony Henday Drive portion being 27km of 6 or 8 lane highway. Winter is especially hard on the roads in Edmonton. The average daily temperature in January is -10.4°C, with an annual snowfall of about 124cm. Large amounts of salt, both sodium and the more corrosive calcium chloride, are applied to keep the roads as free from ice as possible. In 2011, Type 2304 (S32304) stainless steel was specified for a trial for one highway interchange on the ring road. The success of that venture led to the specification of Type 2304 rebar for a major portion of this new section, reported to being the region of 6,000 tonnes. Perhaps in 75 years of so, a Life Cycle Assessment will be done of one of these Edmonton bridges, leaving no doubt that the engineers in charge made the right decision. Ni

ISTOCK PHOTO © WONGANAN

Life of Ni

A SPECIAL FEATURE ON THE LIFE CYCLE OF NICKEL

Life cycle deconstructed

Life cycle *is a common phrase but there are important distinctions to be made between* life cycle *in economic terms (**Life Cycle Cost Analysis**) and* life cycle *in environmental terms.*

*It is the environmental aspect of the life cycle of products and processes that has received the greatest academic, political, marketing and regulatory attention in recent decades. This embraces terms such as **Life Cycle Thinking, Life Cycle Management** and the family of **Life Cycle Assessment** (LCA) acronyms: LCA itself plus its sub-elements of **Life Cycle Inventory** (LCI) and **Life Cycle Impact Assessment** (LCIA). These have been formalized into the widely followed ISO (International Organization for Standardization) 14040 series.*

Life Cycle Inventory

The keystone for any LCA exercise is the existence of data. This is the Life Cycle Inventory. It represents the investment of energy, materials and environmental resources needed to produce a unit of something.

The existence of an LCI allows the development of a Life Cycle Impact Assessment. As the title implies, an LCIA takes the metrics of the LCI and attempts to calculate environmental impacts such as Ozone Depletion, Eutrophication Potential (the ecosystem response to the addition of artificial or natural substances to an aquatic system) and Global Warming Potential. Unlike an LCI where the metrics are derived from actual measurements, LCIA calculations come from models.

Life Cycle Assessment

When the metrics of an LCI and the modelling of an LCIA are combined to compare two similar products the result is a product Life Cycle Assessment.

In the LCA example of the Progreso Pier on page 7, even though there is no equivalent structure to which it can be compared, it is possible and legitimate to construct a "what if" scenario using different parameters. That was done in this case and the only parameter changed was the substitution of modelled carbon steel rebar for the actual stainless steel rebar used in the construction of the pier. Ni

Transparent Nickel –

Knowledge of nickel updated and improved

Every issue of *Nickel* magazine provides examples of how the use of nickel contributes strength, durability, ductility and corrosion resistance to materials and technologies through its electrical, magnetic, shape-memory, catalytic and other still-being-explored properties. In every instance nickel is making a difference: reducing emissions, increasing energy efficiency, prolonging product life and being recycled without loss of basic properties.

However, governments and consumers are increasingly asking industries to show the complete environmental profile of their goods and services. The benefits of those goods and services are well communicated but what about the environmental resources – land, water, air, biodiversity – that are impacted by their production, use and final disposal?

> Governments and consumers are increasingly asking industries to show the complete environmental profile of their goods and services

While the nickel industry continuously seeks to reduce emissions and improve energy efficiency, metals production is highly visible and attracts political and societal attention.

To respond to that attention and to make the best choice between competing materials or products requires that all the inputs along the way be taken into account and measured. This is the task of the life cycle inventory (LCI) and this information for the production of metallic nickel and ferronickel has recently been updated and improved.

Second life cycle inventory for nickel

Nickel Institute completed the first comprehensive life cycle inventory in 2000. The study, conducted by PwC/Ecobilan, examined the material flows and environmental and energy requirements to take nickel from the ground to the point where, in various forms, it became usable in other industrial processes. Then, as now, that was primarily as an alloying element in the making of stainless steels.

Time has passed and what is being mined and how it is being processed in the second decade of the 21st century has changed. (See page 6 for the process routes.) The study just completed by PE International shows that the change has been for the better in terms of the environmental impacts associated with the two principal nickel products: elemental nickel and ferronickel.

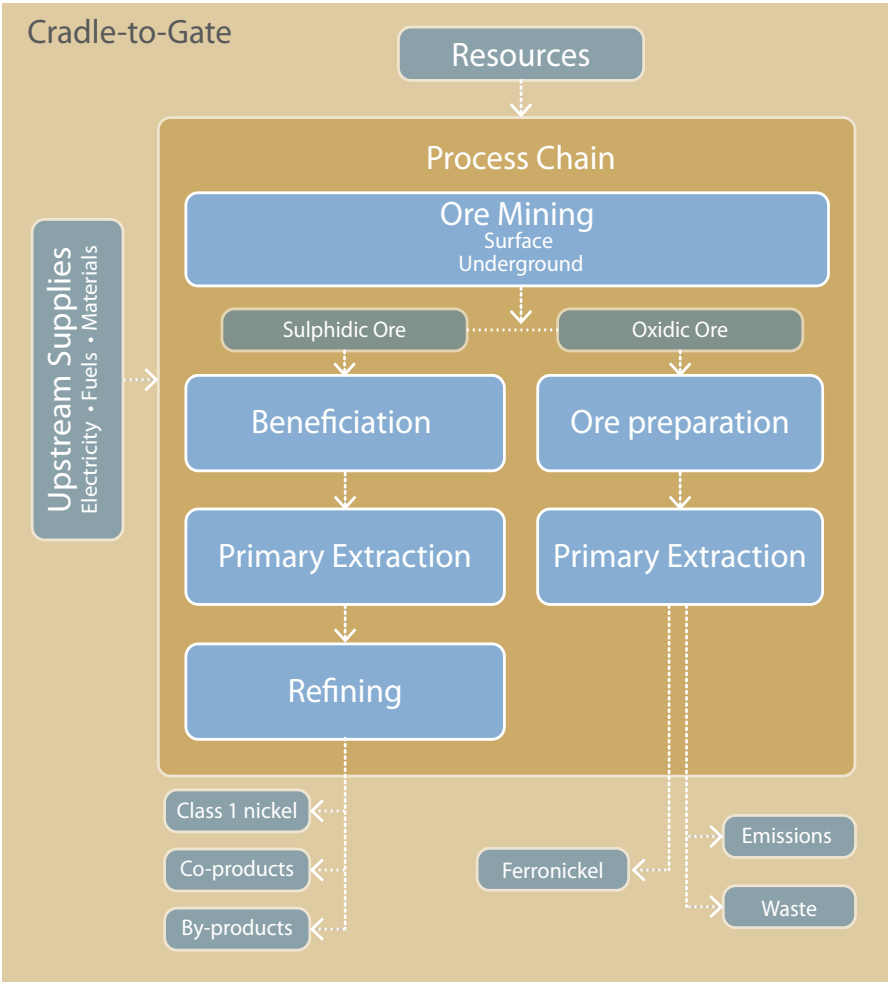
The Life Cycle Inventory was a complex and challenging project. Unlike most other metals, nickel ores are found in diverse geological formations, in different mineralogical forms, at different depths, with varying percentages of nickel content and

often with different metals present. Depending on these variables, different processing techniques are used which will yield different rates of metal recovery. The abundance or scarcity of water can have an effect. The presence or absence of by-products (such as sulphuric acid and fertilizer) have to be accounted for. And the power that makes it all happen comes from widely different sources such as thermal, nuclear and water.

Putting the LCI to work

There is now an up-to-date and robust understanding of what it takes to produce nickel. This gives nickel producers insights that they can use as they continuously seek to reduce emissions, and improve recoveries and energy efficiencies. Downstream users can do their own LCAs with greater confidence in the base data of nickel materials. Governments and all stakeholders can have greater confidence in the merits of nickel-containing materials and products in society.

The LCI has passed its peer review and additional information about it and how to access the complete report is available on the Nickel Institute website. Ni



PE INTERNATIONAL

Why life cycle thinking matters

For governments and civil society the links between the supply of raw materials and the quality of life and the environment are not clear. It is easy to see the impacts of production, less easy to understand the contributions which that production makes possible.

Here is where life cycle thinking helps by expanding, understanding and providing context. It ensures that the full picture is taken into consideration and helps governments, industries and consumers achieve the regulatory, material selection and design choices most supportive of sustainability.

Why it's complicated

Nickel ores may be oxidic or sulphidic. They may come from underground or open-cast mines. Then there are a variety of hydrometallurgical and pyrometallurgical process routes that will be selected and adjusted to optimize the metallurgical and economic efficiency of extraction from different ores.

Primary extraction

DON flash (Direct Nickel Flash) smelting
EAF (Electric Arc Furnace)
HPAL (High Pressure Acid Leach)
Flash furnace

Refining

Ammonia HPAL reduction
Chloride and sulphide electrowining
Hydrosulphidic refining
Pyro refining
Natural gas reforming
Volatisation
Leaching (biological or acid)

What was measured (group headings only)

Nickel containing ores
Energy (electricity)
Energy (fuels)
Nickel concentrates
Metallic emissions to air
Inorganic emissions to air
Organic emissions to air
Particles to air
Metallic emissions to water
Inorganic emission to water

What was calculated

Global Warming Potential
Acidification
Eutrophication
Photochemical Ozone Creation
Primary Energy Demand

FROM WIKIMEDIA COMMONS

PIER REVIEW

A new ISO-consistent peer-reviewed LCA compares the existing Progreso Pier constructed with stainless steel rebar with a modeled alternative design that is identical in every way except for the substitution of carbon steel rebar.

The modeling and comparison of the piers shows both the environmental and economic benefits of using stainless steel rebar throughout the entire life cycle.

While the alternative design has to undergo periodic rehabilitation and reconstruction, the Progreso Pier experiences only minor maintenance, is still functioning, and is expected to continue to serve well beyond the 2020 cut-off date of the study.

Significant environmental benefits are achieved at, depending on the discount rate chosen, similar or significantly lower costs.

THE DIFFERENCE STAINLESS STEEL MAKES

The decision in the late 1930s to use nickel-containing stainless steel rebar (Type 304, UNS S30400) in the construction of an oceanic pier was rare and the structure unusual in its size and length. Both the decision and the pier have stood the test of time.

The engineering reasons were, even then, fairly well understood. It was an environment where the entire surface area would be exposed to chlorides – by virtue of being submerged, in splash zones or subject to wind-borne spray. Chlorides would over time penetrate the concrete. Carbon steel rebar would begin to corrode and rust would crack the concrete and increase the depth of chloride penetration and speed of corrosion. Nickel-containing stainless steel, on the other hand, would provide enhanced strength while greatly slowing the rate of corrosion.

Given the anticipated service life of the structure – literally open-ended as the need for a pier was not going to disappear – the designers clearly felt that a stainless rebar choice was justified. Now, after 73 years of service, the economic and environmental advantages can be quantified.

A comparative LCA

There is only one Progreso Pier and thus not another existing structure to which its economic and environmental performance can be compared. It is, however, legitimate to compare the real Progreso Pier to a modeled Progreso Pier, the only difference being the substitution of carbon steel rebar for the stainless steel rebar.

This was the approach taken by consultants, PE International. It allowed standard engineering design protocols to be applied with confidence because all the key parameters for the structure – age, location, usage, climatic environment – are exactly the same except for a single material substitution for one structural component. This removes all peripheral considerations and allows a focused comparison of the performance of the as-built pier with the well understood and familiar carbon steel alternative.

The LCA itself conforms to the ISO 14040 series of standards that govern the conduct of LCAs. The full report is available on www.nickelinstitute.org

Over the 79 year period covered by the LCA (to 2020), the life-time cost of the "cheap" alternative structure is now 44% higher than the actual Progreso Pier costs

Charting the economic differences

Material costs would have been approximately 14% less to build Progreso Pier in 1941 using carbon steel rebar instead of using stainless steel. Once the maintenance, refurbishment and rebuilding costs begin, however, the balance of advantage shifts.

Table 1: Alternative design life cycle costs

Year		Activity	Net present cost (1941$)
0	1941	Initial material cost	$467,377
10	1951	Maintenance #1	$1,611
25	1966	Maintenance #2	$2,413
40	1981	Maintenance #3	$3,213
50	1991	Reconstruction	$465,046
60	2001	Maintenance #1	$1,603
75	2016	Maintenance #2	$2,401
79	2020	Residual value	-$194,754
		Total	**$748,912**

Table 2: As-built Progreso Pier life cycle costs

Year		Activity	Net present cost (1941$)
0	1941	Initial material cost	$544,989
44	1985	Maintenance #1	$1,606
59	2000	Maintenance #2	$2,405
74	2015	Maintenance #3	$3,202
79	2020	Residual value	-$32,185
		Total	**$520,018**

△ *The timing of repairs and life-time costs strongly favour stainless steel. "Residual value" reflects the conservative nature of the assumptions for the "as-built" pier and an additional 23 years of service (to 2041) for the alternative design as a consequence of the modeled total rebuild in 1991. All dollar amounts are 1941 values and reflect adjustments for inflation and discount rates that can be found in the full report.*

Charting the environmental differences

Putting metrics on environmental impacts is more difficult than accounting for inflation. The methodology has progressed over time, however and Life Cycle Impact Assessment (LCIA) is the usual end product of the LCA methodology.

For the as-built Progreso Pier and the alternative design, the environmental benefits associated with nickel-containing stainless steel rebar show up sooner and are larger than in the case of the economic benefits. Chart 1 shows the as-built Progreso Pier as "100" and illustrates the degrees to which the alternative design exceeds the environmental impacts by amounts varying from 18% (ozone depletion) to 71% (primary energy demand).

But over the 79 year period covered by the LCA (to 2020), the life-time cost of the "cheap" alternative structure is $748,912, compared to $520,018 for the actual Progreso Pier – 44% higher. And the economic advantage of the as-built design is already established and will only grow over time.

Chart 1: Impact relative to as-built design

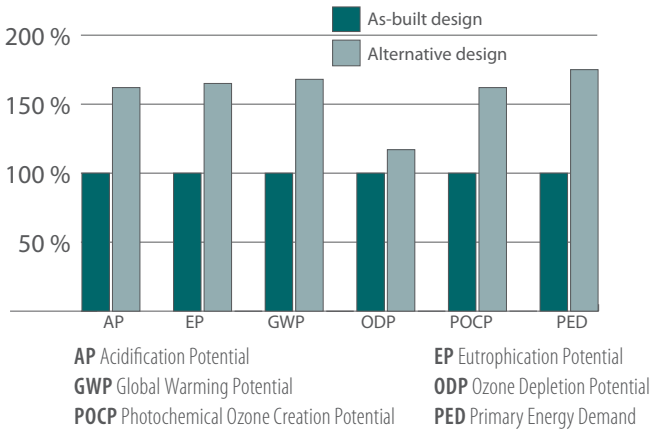
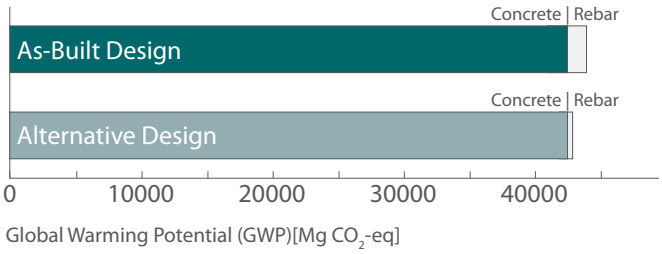


Chart 2 below shows two important things for Global Warming Potential: firstly, the overwhelming importance of cement/concrete to the overall impact and secondly, the small – approximately 3% – difference the choice of stainless steel over carbon steel makes to the total. This difference disappears with the first 10 year maintenance requirement of the alternative structure after which the benefits accumulate.

Chart 2: Global Warming Potential



△ *The two piers in 1941. The GWP gap between the two structures disappears with the first 10 year maintenance of the alternative structure. The benefits of the "as built" Progreso Pier then grow.*

A pier for the ages

The LCA of Progreso Pier points to very significant financial and environmental advantages flowing from a decision more than 75 years ago to use nickel-containing stainless steel.

There has been and continues to be less limestone being mined, less stone being crushed to make aggregate; less carbon steel diverted from other uses; fewer chemicals used in concrete mixes to defend carbon rebar from the inevitable chloride attack; and less disruption of the service function because of the reduced need to repair, refurbish or replace.

Capital, labour and materials that would have been required to keep a single piece of infrastructure in operation over the decades have been available for other domestic and industrial development.

And the full story remains to be told as the pier remains in service despite constant industrial use and extremes of climate and environment. Progreso Pier has been an economic and environmental bargain for the people of the Yucatán Peninsula. Ni

FROM WIKIMEDIA COMMONS

NICKEL INSTITUTE

△ *Top: In 1969 a much smaller pier (left) was built using carbon steel rebar alongside the enduring 1941 Progreso Pier (right). The 1969 pier did not stand the test of time.*

△ *Bottom: Even though they were conveniently located beside each other and shared the same aggressive environment of saline waters, high humidity and extremes of temperature (and occasional hurricane-force winds and waves), differences in design and function made this smaller unnamed pier an inappropriate basis for comparison with Progreso Pier. The "alternative design" approach allowed total control of form and function with only a single – and essential – variable: the presence or absence of nickel-containing stainless steel.*

Gross Domestic Product (GDP) and efficiency

Imagine if Progreso Pier has used carbon steel instead of stainless steel rebar

The Gross Domestic Product (GDP) of Mexico would have recorded the repeated construction and repair of a carbon steel rebar pier as positive economic activity. There would be additional mining, cement and rebar manufacture, transportation, landfilling of rubble and all the employment and wages that go with such activities, all contributing to the growth of Mexico's GDP.

This peculiarity of how GDP measures corrosion damage as an economic positive does not mean that the financial and environmental choice of stainless steel rebar in 1941 restrained the economy of Mexico. Rather it means that the resources of all kinds that would have been needed to sustain a pier built using carbon steel rebar have been available for other projects such as the 1980's 4.4km extension of the Pier.

SATELITE IMAGES COURESY OF GOOGLE MAPS

Finding Progreso

Progreso is the port city of the Mexican state of Yucatán and its pier, visible from orbit, is the longest in the world. The need for length is determined by the geology. The limestone shelf that forms the Yucatán peninsula transitions from land to sea at such a slight angle of decline that it is literally kilometres before the water is deep enough to accommodate cargo vessels.

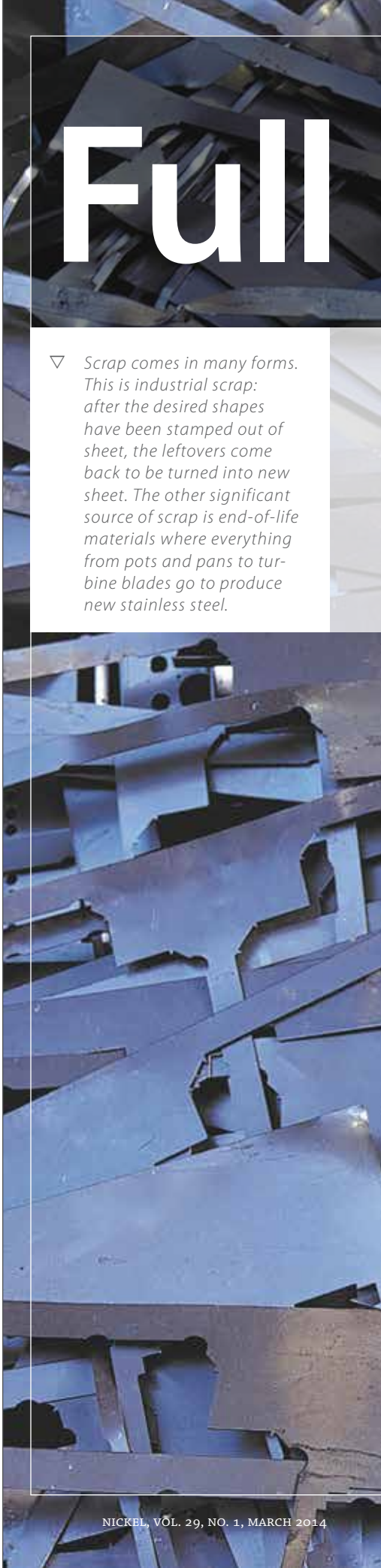
In 1941 the original structure was completed with a length of 2.1 kilometres. It is that structure that was the subject of the life cycle assessment.

With the rise of commercial activity (including large cruise ships) and the increasing draft of cargo and container vessels, the pier was extended in the 1980s to its current length of 6.5km. Ni

△ *Left: The Campeche Bank that makes the Progreso Pier necessary.*

△ *Right: The pier today with the original 1941 pier circled.*

Full



▽ *Scrap comes in many forms. This is industrial scrap: after the desired shapes have been stamped out of sheet, the leftovers come back to be turned into new sheet. The other significant source of scrap is end-of-life materials where everything from pots and pans to turbine blades go to produce new stainless steel.*

Circle

How nickel comes back to serve

PHOTOS COURTESY OF OUTOKUMPU

△ *The material for the next "heat" of stainless steel in is the foreground. It is mainly scrap but with various additions to balance the ingredients and ensure that the resulting stainless steel meets specifications.*

There are many ways nickel can be recycled. Nickel in batteries – historically nickel cadmium (NiCd) but increasingly nickel metal hydride (NiMH) and nickel-containing lithium ion (Li-ion) batteries – are making their contributions. Also, some nickel-containing materials such as spent nickel catalysts make their way back to nickel smelters.

Overwhelmingly however, the vital recycling of nickel does not involve the recovery of nickel as nickel. Environmentally and commercially the melting of scrap stainless steel to make new stainless steel with undiminished properties is by far the most common way to recycle nickel.

The Outokumpu example

Stainless steel production is a global industry. And whilst there are differences in how it is done, the starting point – melting ingredients in electric arc furnaces – is universal.

One of the largest producers of austenitic (nickel-containing) stainless steels is the Finnish Outokumpu Group with production in China, Finland, Germany, Mexico, Sweden, the UK and US. It produced 2.2 million tonnes (roughly 10% of the world's nickel-containing stainless steel) in 2012 and those steels account for over 80% of Outokumpu's total production. It is, therefore, an excellent example of a recycler of nickel.

The ability of any stainless steel producer to recycle nickel depends on the availability (and cost) of obtaining appropriate feed for their furnaces. There are significant geographic differences. For producers in Europe or North America where there is a long history of stainless steel use there is a ready supply of end-of-life scrap. For Outokumpu this means that approximately 80% of the material that goes into the furnace is stainless steel and carbon steel scrap.

Recycled content

In other parts of the world, where there is not the same inventory of scrap becoming available, this figure can be considerably less. The global average, therefore, is closer to 60% recycled content.

It is important to understand that the constraint to recycled content is the availability of scrap. While an aluminium beverage can might have a life cycle of 6 months, a product of stainless steel might have a service life of 60 years. The material will come back but the wait time can be measured in decades while the stainless steel remains in service. In the meantime, the need for more stainless steel is increasing because of its material and environmental qualities.

It is expected that the recycled content of stainless steels will rise over time but it is important to understand that the constraint is not environmental or technical. It is lack of supply.

The interplay of demand for stainless steel and the availability of scrap is shown by the work of the Yale University "Stocks and Flows" research (featured on page 12). Ni

The Road to Recovery

From the smallest towns and villages to the largest cities, collecting, sorting, consolidating and preparing metallic materials for recycling is a profitable business that employs millions globally. And nickel-containing stainless steel is valuable and highly sought after: approximately 90% of stainless steel that becomes available for recycling is collected and recycled.

Sorting is key to value. Most nickel-containing stainless steels are not ferromagnetic and thus easily separated from the other stainless and carbon steels.

Further along there are larger companies that consolidate all the small lots, do further sorting, and sell to global businesses.

Shearing and baling takes large or unwieldy shapes and puts them into forms that can be easily transported. The scrap stainless steel is melted and cast into "new" stainless steel.

"New" stainless steel is composed of approximately 60% recycled material.

The savings per tonne of stainless steel:

- *1100kg of iron ore*
- *55kg of limestone*
- *100kg of chromium*
- *45kg of nickel*

Energy demand reduced by one-third

TODAY'S USE TOMORROW'S RESOURCE

bringing knowledge to the "future resources" debate

Where are tomorrow's resources? Where are the materials needed to ensure the food and shelter of future generations? Or will technology provide all the answers and make worries about the limits to resources unnecessary?

There is speculation and exaggeration on both sides of the debate. This is where effectively presented comprehensive life cycle data can challenge misplaced fears or complacency. It allows informed examinations of metal availability and the development of measurable targets for metal recovery. It will also, of course, draw attention to the challenges but will do so in a data-rich environment.

And progress is being made.

A strong contribution comes from the "Stocks and Flows" (STAF) initiative at Yale's Center for Industrial Ecology. Since 2000, STAF researchers, supported by governments and industry including the nickel industry, have designed, built and refined methodologies related to the movement of metals from their geological resource base (mining) to their use in society, their fate at end-of-life and their eventual reuse through recycling.

Most importantly, STAF research is measuring not just how metals move but also how much metal flows, how long it stays in use (i.e. the stock of metals in society) and how much returns to use (by being collected and recycled). At the same time, it shows where and to what extent metal is being lost and no longer available to be used again.

The example of nickel

We know that nickel is a vital component of a healthy and productive society. It offers strength, ductility (formability), toughness, and resistance to corrosion: the better grades of stainless steel are the best known nickel-containing products. Of increasing importance are the catalytic and electro-chemical properties of nickel. Different varieties of batteries, including many of the lithium-ion type, have nickel as an essential component.

But nickel is a non-renewable resource. It is not however consumed during its use, so the total amount of available nickel will not vary. What changes, because of human activity, is where the nickel is located, what form it is in, and how easy or difficult it will be to reclaim it for future use.

So where is all this nickel coming from? Where is it going? When will it be available for collection and reprocessing? To what extent is that happening? STAF provides a framework that brings discipline and metrics to address these questions.

The figures opposite quantify the global flow of nickel through society, from mining to recycling. It summarizes the underlying nickel cycles of all major world economies, illustrating sometimes striking differences. For example, the USA has historically been an insignificant miner of nickel. Yet because large stocks of nickel-containing materials have accumulated in this advanced economy, it is now a significant contributor to the annual global requirement for nickel. By contrast, China is just entering its period of accumulation.

As societies become ever more aware of the importance of efficiency and of the finite nature of our resource base, the attributes of nickel will be more and more in demand. The analytical tools provided by STAF help to measure and track where we will be looking for tomorrow's nickel to satisfy that demand. And increasingly it will be the accumulated stocks in society that will be the "mines" of tomorrow.

More information on STAF and all the metals that have been examined:
http://cie.research.yale.edu/research/stocks-and-flows-project-staf

For over a decade Dr. Barbara Reck has been associated with Yale University's Stocks and Flows research and is the principle researcher on nickel. Nickel magazine asked her some key questions:

DR. BARBARA RECK

Ni: *Why is the "Stocks and Flows" work important?*

Barbara Reck: Our work is quantifying what most people understand intuitively: that recovering valuable materials such as metals at the end of life of products is a vital source of future metal supplies.

Ni: *You say it is important but to whom?*

BR: Governments, businesses, communities: they all need to understand why they are doing things and how it will make a difference. How do you act on something you intuitively understand? How do you communicate the importance to societies? How, if you are a government or regulator, do you justify regulations that will encourage or force more conservation of metals? And importantly, how do you develop a business case to exploit these very large accumulations of metals in society? Questions like these need metrics and now we are providing methodologies and numbers that support and give confidence to decision-making.

Ni: *So the job is done?*

BR: The job is very well started and others outside Yale are taking up and applying the lessons learned. The job is not finished but there is an enormous base of knowledge that didn't previously exist in usable form.

Ni: *Why are we talking to Barbara Reck about nickel and not someone else?*

BR: I've just been lucky. The funding commitment from Nickel Institute was made shortly after I arrived at Yale and I was available to take on the work. It was a steep learning curve but it has been very rewarding from both personal and professional points of view.

Explaining "Stocks and Flows"

The outer ring establishes the boundary of the system within which nickel is mined, refined, fabricated, used and recycled. The boundary does not include in-the-ground resources that are not actively being exploited (or, perhaps, even discovered).

There is always movement within the system: nickel being extracted, traded, lost and recycled. Arrows show nickel entering or leaving the system. The size of the arrow gives an indication of the relative size of the flow. The nickel is usually in the form of alloys – mainly stainless steels – but includes nickel in catalysts, batteries, plated surfaces and a host of minor (in terms of volume) products.

With a clear understanding of where the nickel we use comes from – and where it goes – the challenge is to be able to put numbers on the flows.

For policy makers and businesses, STAF research tells you where to start your search for tomorrow's nickel.

Key for all diagrams:

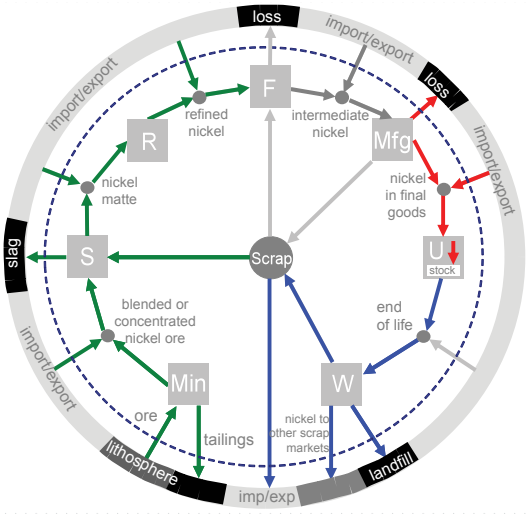
- ➡: Nickel production
- ➡: Manufacture and fabrication
- ➡: Use
- ➡: End-of-life/recycling

Min: Mining & Beneficiation
S: Smelter
R: Refinery
F: Fabrication
Mfg: Manufacturing
U: Use
W: Waste Management & Recycling

All amounts in gigagrams (1 gigagram = 1000 tonnes) Scale of arrows approximate

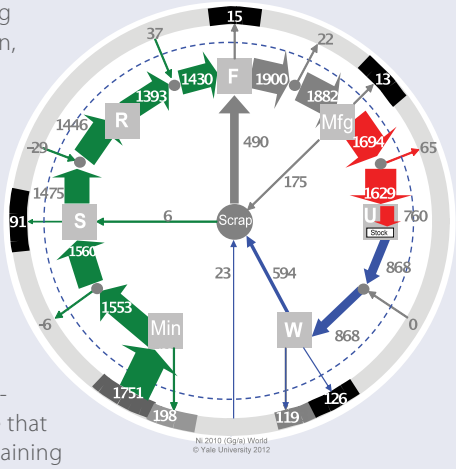
The nickel life cycle

The life cycle of nickel as seen by Yale University's Stocks and Flows methodology



Global nickel flows: 2010

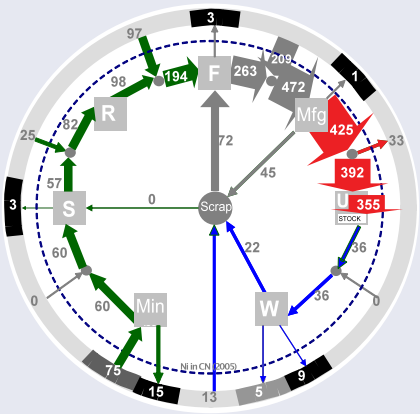
There are many numbers and behind those numbers, much painstaking research. Even a brief examination, however, shows where the nickel is being lost (opportunities for increased recoveries/decreased losses) and where it is accumulating (where an increasing percentage of the future nickel supply will be found). This figure is just the big picture. There is a growing technical literature that drills down into the detail. From those details will come the design choices and collection strategies that will ensure that larger percentages of nickel-containing materials return to productive use.



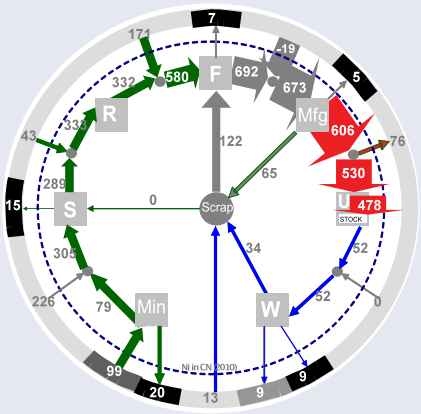
China: Nickel flows in 2005 and 2010

These two snapshots of nickel use (in stainless steels, super alloys, catalysts, etc.) in China look remarkably similar. When the time period of five years is combined with the 43% increase (472,000 tonnes to 673,000 tonnes) in the use of nickel, the extraordinary transformation of China is starkly revealed.

The existing stock of nickel in use in China is not shown. It is, however, still smaller than in Europe and North America. This is a reflection of the industrial history of China and the newness of the growth of nickel use in China as Chinese citizens are increasingly able to purchase the quality goods that use higher amounts of nickel.



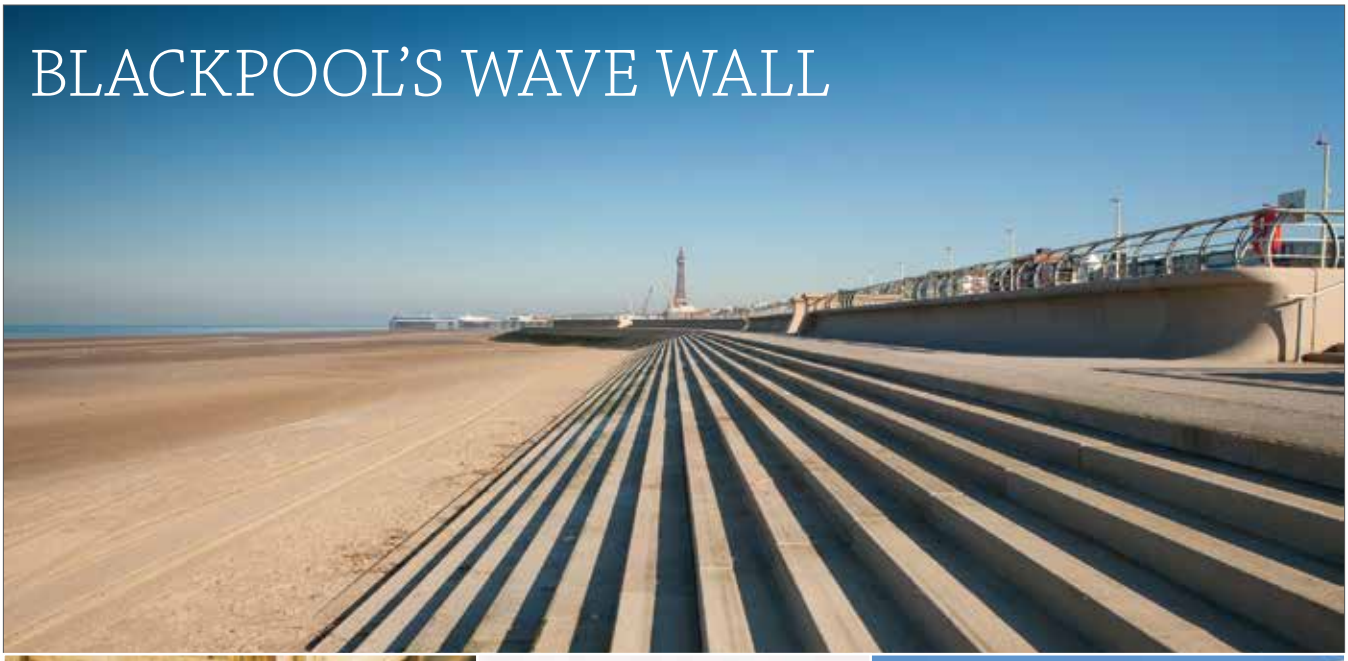
2005



2005 2010

YALE UNIVERSITY

BLACKPOOL'S WAVE WALL



BLACKPOOL COUNCIL

STAN TAYLOR, VALBRUNA UK LTD

In many parts of the world coastlines require improved fortifications against bad weather damage. One example is the three kilometre sea defence wall constructed by Birse Coastal in the popular seaside town of Blackpool on the north west coast of England. Nickel-containing stainless steel played an integral role.

The wall consists of revetments, a series of steps which are designed to break up waves as they come inshore. Behind this, a shaped wave wall curls and pushes incoming waves back into the sea. As this is a busy beach area, it was important to come up with an accessible and aesthetically pleasing design, where people could sit on the revetments at low tide and use the wave wall as a wind break. A dye was added to the concrete to create a warmer colour in harmony with the seaside environment.

Over a five year period, 720 wave wall units, along with revetments were produced, using over 1000 tonnes of stainless steel in the form of 340,000 cut and bent pieces, ranging in diameter from 6mm to 32mm. The units were pre-cast close to the site and then brought to the beach.

Stainless steel was selected for the areas of the structure most exposed to seawater, with normal carbon steel rebar used for the more deeply embedded areas. This created a cost effective design with less concrete cover, but still retaining a long life expectancy for the structures, with low on-going maintenance costs. Grade 1.4301 (Type 304, UNS S30400) stainless steel was used, produced to the BS 6744 standard.

As well as protecting Blackpool from flood damage, the wave wall has enhanced the appearance of the whole beach area. Ni

UNS details

Chemical compositions (in percent by weight) of the alloys and stainless steels mentioned in this issue of *Nickel*.

UNS No.	C	Co	Cr	Cu	Fe	Mn	Mo	N	Nb	Ni	P	S	Si	V
S30400 p. 7, 14, 16	0.08 max.	-	18.00-20.00	-	bal.	2.00 max.	-	-	-	8.00-10.50	0.045 max.	0.030 max.	1.00 max.	-
S31600 p. 15	0.08 max.	-	16.00-18.00	-	bal.	2.00 max.	2.00-3.00	-	-	10.00-14.00	0.045 max.	0.030 max.	1.00 max.	-
S32205 p. 2, 4	0.030 max.	-	22.0-23.0	-	bal.	2.00 max.	3.00-3.50	0.14-0.20	-	4.50-6.50	0.030 max.	0.020 max.	1.00 max.	-
S32304 p. 4	0.03 max.	-	21.5-24.5	0.05-0.60	bal.	2.50 max.	0.05-0.60	0.05-0.20	-	3.0-5.5	0.040 max.	0.040 max.	1.00 max.	-

Drinking water in Tokyo

the right pipes reduce water losses by 90%

Safe, clean, palatable water costs money. Leaks incur additional costs as even more water must be found and treated. Dealing with leakage is a universal challenge for cities but none have responded more effectively than Tokyo.

Starting in the 1980s the Tokyo Metropolitan Government Waterworks Bureau turned to nickel-containing stainless steel pipe Type 316 (UNS S31600) for the distribution systems that take water from the sub-mains to final destinations in homes, offices and industrial plants. It was a gradual process that took 24 years to complete, but now after two decades of service it is possible to calculate the benefits.

Leakage and its costs

Lead was the preferred material for water connections because it is soft and malleable and easy to work with, especially for the last few meters from sub-mains to offices and residences. Once lead pipe is in the ground, however, various forces can act on it. Combinations of human activity – heavy traffic and vibration or construction work – and natural forces such as unequal ground subsidence and earthquakes can cause the soft lead pipes to deform, become detached or even break.

The result was that in the early 1960s over 20% of all of the water suitable for human consumption in the Tokyo distribution system was lost to leakage. Water shortages were chronic and rationing was occasionally required for about one million Tokyo households.

Historically approximately 3% of the leakage repairs of the Waterworks Bureau was on water mains, with 97% on the distribution lines of 50mm or less that take the water from the public system to internal systems in buildings.

△ *Easy-to-bend corrugated stainless steel pipes are a key part of the system that has reduced leakage in Tokyo's distribution system by 90%*

ISTOCK PHOTO © PEETER VISIMAA

Health and financial benefits

In switching to stainless steel pipes the Tokyo Government has made a significant investment in the health of its citizens. The reliability of the water supply has increased and the leakage rate has been reduced from 20% to 2% (2012) and is perhaps the lowest of any metropolitan area in the world.

Supplying and distributing water in Tokyo will always be a challenge because of the limited water resource base. The dramatic reduction in leakage from the system allows the most efficient management and use of a scarce resource as the per capita amount of water that has to come from reservoirs and pass through treatment plants has been reduced. And while not a formal objective of the campaign against leakage, there is the additional benefit of reducing the potential exposure to lead.

This achievement of long-term planning and implementation has led to many engineering and institutional awards but the greatest benefits have been for the citizens of Tokyo. Ni

RECLAIM, REUSE, RECYCLE, REVITALIZE

A second life for nickel-containing stainless steel

Bruce Taylor likes nothing more than rummaging around a scrap yard. It's where he finds inspiration for the unique sculptures he makes from recycled stainless steel. "My niche is readily accessible public art and outdoor sculpture. I always carry a magnet to separate out the non-magnetic nickel-containing stainless steel to make sure the materials I use can withstand the rigours of harsh exterior environments."

Taylor hails from Denver, Colorado in the USA and now lives in Texas. He started out as a painter and then got involved in sculpture, coming to prominence in the mid 1980s after winning a commission for an installation at the Denver Concert Hall.

Over recent years he has focused on stainless steel. "Durability is one of the main reasons for choosing stainless steel. It's easy to weld and withstands outdoor conditions. It has a rich contemporary feel – it can be highly reflective, have a basic mill finish or occasionally be coated. Much of my work is public art, so minimal maintenance is essential. It's also an aesthetic decision – if it lasted a long time but didn't look good it wouldn't do anything for my reputation as an artist!"

In his recent work, Taylor takes reclaimed stainless steel – Type 304 for preference – and fabricates it into new forms. The observer can recognize the interesting shapes which the artist has incorporated. "The reclaimed objects I use are part of a guessing game – what are they and what were they originally used for?"

In 2013 Bruce Taylor created a piece of sculpture for one of five railroad bridges in El Paso, Texas. He found his inspiration for this original urban art piece from recycled elements. "It's about low environmental impact design utilizing recycled materials. I feel good about that. I'm conveying how materials can be recycled. While recycling is not the predominant goal of my works, it's an important component to my aesthetic process." Ni

△▽ *El Paso Bataan Bridge Project http://brucetaylorsculpture.blogspot.be/*

▷ *Artist Bruce Taylor*

PHOTOS COURTESY OF BRUCE TAYLOR