Galvanized Coatings on Power Equipment: Optimizing Life Cycle Costs

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SYNOPSIS

New Zealand's transmission and distribution system relies heavily on line and substation support structures constructed using millions of tonnes of hot dipped galvanized steel. It collectively represents an industry investment worth billions of dollars. All this investment has a finite life before rusting sets in. With the average asset age now exceeding 40 years and some structures over 80 years old, zinc protection applied decades ago is now heavily depleted in many locations.

Every day hundreds of kilograms of galvanising corrodes away (Note 1) and is not replaced. Obviously this cannot continue forever and eventually these assets will have to be maintained or, they will have to be replaced. Either way, maintenance is set to become a growing and costly issue for the industry and a ramping up of maintenance and/or capital replacement budgets to cope is already inevitable unless reliability is to decline.

In considering the maintenance of galvanised structures, the industry has essentially three choices: It can maintain proactively, it can maintain reactively or it can replace. Depending on the circumstances of particular assets, each option has its proper place. The challenge facing the industry is to ensure that its asset management selects the correct choice for each situation. Unfortunately this rarely happens and the outcome is usually higher long term costs; much higher in many cases.

The objective of this paper is to show that for most assets, the proactive maintenance option produces by far the lowest long term cost; yet this is the least adopted option. This paper will ask why that is and should the industry be adopting a more coordinated approach given the very large and growing sums involved.

Note 1: *If there are 28,000 towers in the national grid, with an average area of 300m² and the average zinc loss is 2µm per year, then this equates to a loss of about 14 kg of pure zinc per hour.*

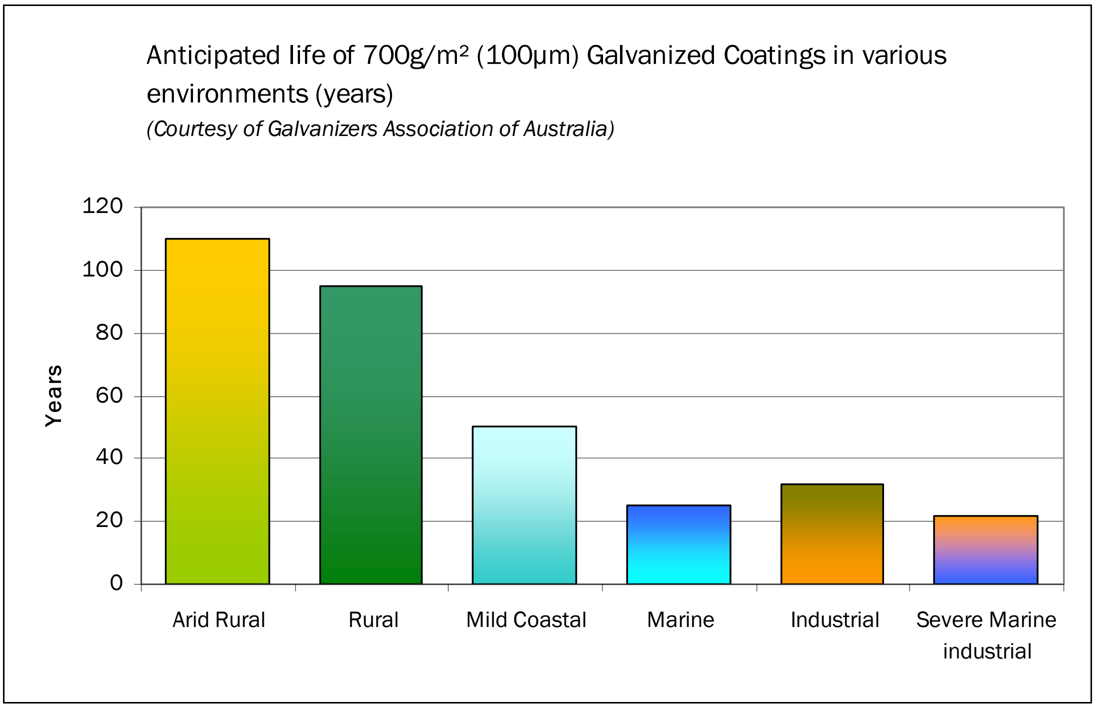
ZINC LOSS RATES

Bare zinc is a sacrificial coating…it is not designed to last forever. Environmental forces are at work on the zinc surface from the moment it emerges from the galvanising bath. When zinc is exposed to the atmosphere a thin protective layer of complex oxides and carbonates are formed. However atmospheric pollutants such as marine salts and repeated wetting and drying cycles help to accelerate the breakdown of the outer protective layer and therefore increase the rate of consumption of the zinc. A summary of the influencing factors include:-

- Time of wetness
- Sulphate levels in the atmosphere
- Chloride levels in the atmosphere
- Ambient temperature
- pH of moisture
- Contact with other chemicals
- Contact with dissimilar metals
- Orientation of exposure (vertical, horizontal)
- Nature of exposure (sheltered, open)
- Ventilation conditions

Graph 1 shows the relationship between galvanizing "life" and various environments.

Graph 1



It can be seen that in the non-aggressive environments of "arid rural" and "rural", zinc has a "life" of around 100 years; however when the marine and industrial influences become a factor the "life" drops considerably. It should also be noted that the "arid rural" environmental classification may only exist in New Zealand in Central Otago. What are not included are the New Zealand geothermal and high rainfall sub-alpine environment classifications which can be very aggressive.

PROTECTING GALVANISING

Having determined that hot dipped galvanised (HDG) steelwork will have a predictable corrosion rate and therefore economic life, there is a simple choice: either accept the design life for the structure based on the longevity of the HDG, or extend it by applying additional protection. Given that the design life criteria for many power system assets is considered indefinite, then the critical issue is, if a coating is to be applied, at what point in the life of the galvanizing should the additional protection be applied.

If a protective coating is applied too early, then the protection or exposure time of the zinc layer is not utilized to the optimum. If the decision to protect the remaining zinc is left to the point where rusting has occurred, then significant additional costs associated with rust removal are incurred.

Extensive international research, fully supported by local experience, has shown that the following criteria can be used to help make the decision for long life power industry equipment: (Table 1)

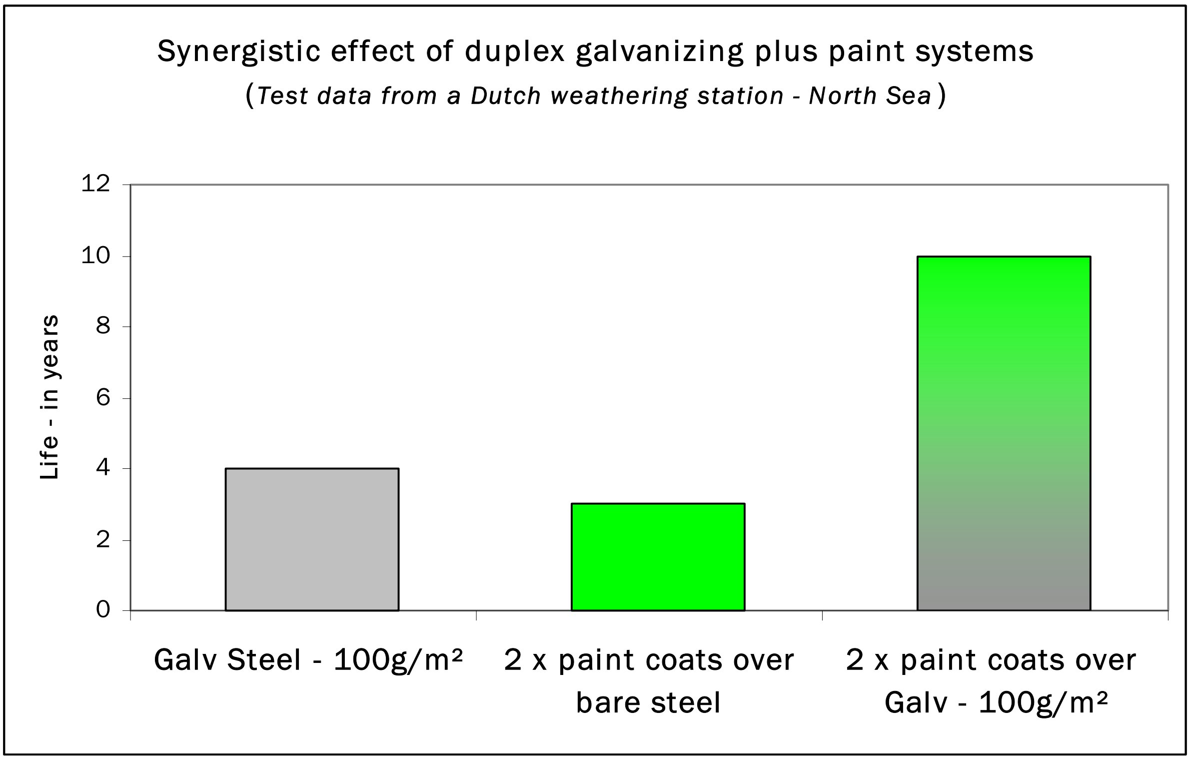
Table 1

	Option	**Use when:**
1	**Painting new:** (or near new) Extends the total coating life by as much as twice the life of the two coatings (paint + zinc) when exposed individually (Synergistic effect – see explanation below).	The synergistic effect makes this option ideal for moderate to **extreme corrosivity areas** where galvanising life is otherwise very short. Further, the cost of painting is the lowest it will ever be (no or minimal surface preparation) and the quality control possible is the best it will ever be. Very robust corrosion protection can be obtained for least cost.
2	**Painting before the galvanising fails:** Preserves the synergistic effect to a large degree, but surface preparation is required and costs may be significant especially in marine areas where surface crusting and contamination may be very difficult and costly to remove.	Applicable to many existing structures in moderate to **mild corrosivity areas**: Obtains the greatest life from the initial galvanising investment, incurs least painting cost due to minimal surface preparation and preserves the synergistic effect for long paint coating life. Recoating is also low cost
3	**Painting after the galvanising fails** (and rusting has begun). Destroys the synergistic effect, whilst removal of rust and repairing the galvanising using costly zinc primers, adds enormously to painting costs.	**Very rarely an optimum economic choice**. Highest recovery and painting costs due to blasting and priming. If the structure has deteriorated extensively complete replacement may be more economic in some cases.
4	**Complete Replacement.** Because structures rarely deteriorate uniformly, extensive ongoing patching and replacing of bolts and lighter members is usually required before replacement of the total structure is economic.	Usually **economic only if the structure is already extensively rusted** and/or structurally unsound, yet must remain in service.

As indicated in Table 1, there is a synergistic effect with painting over galvanised steel, where the "life" of the combination of the two methods of protection is greater than the sum of either protection alone. The synergy factor varies according to the environment.

In the example below (Graph 2) the environment was a "very high" corrosivity classification and gives a factor of 1.5. For less aggressive environments such as the mild marine and industrial classification C3 (see Table 2) the synergy factor improves to the order of 1.9 to 2.3.

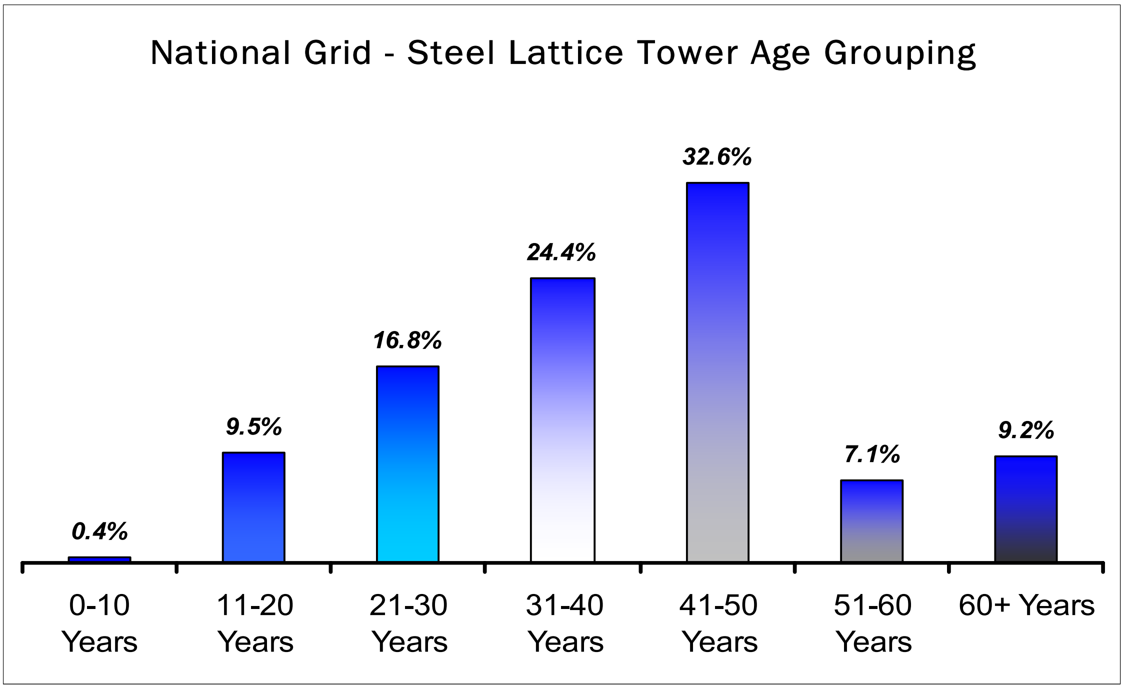
Graph 2



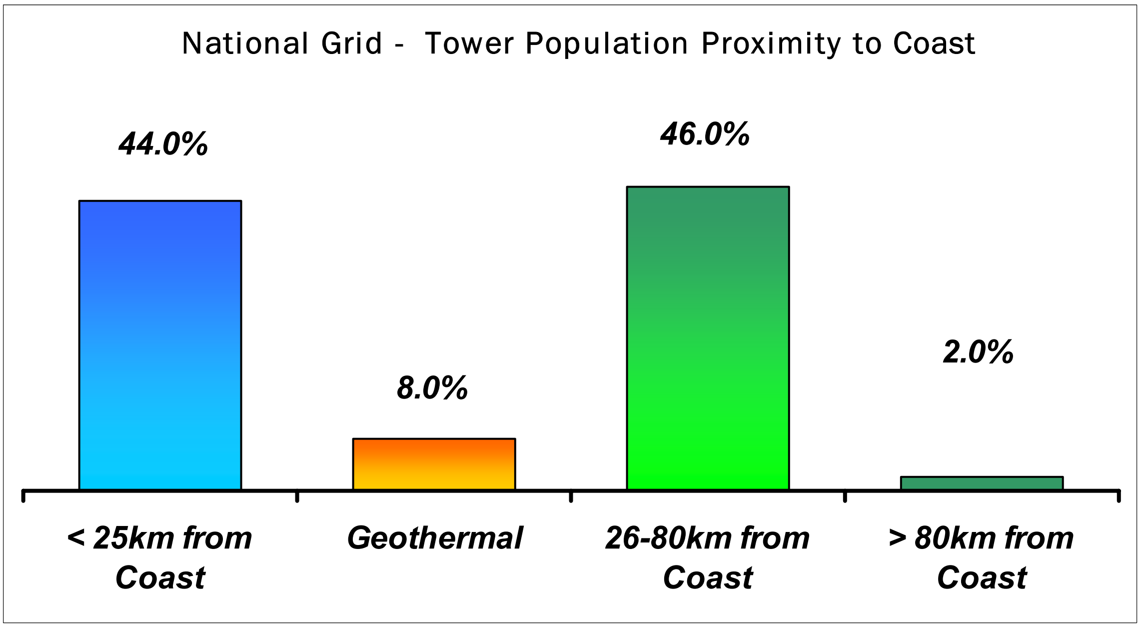
ASSET AGE & LOCATION

Graph 3, below gives some indication of the age issue. Nearly half of our national grid transmission towers are over 40 years old. This is exacerbated by the fact that 50% of the towers are located within 25 km of the coast or within geothermal regions (Graph 4)

Graph 3



Graph 4



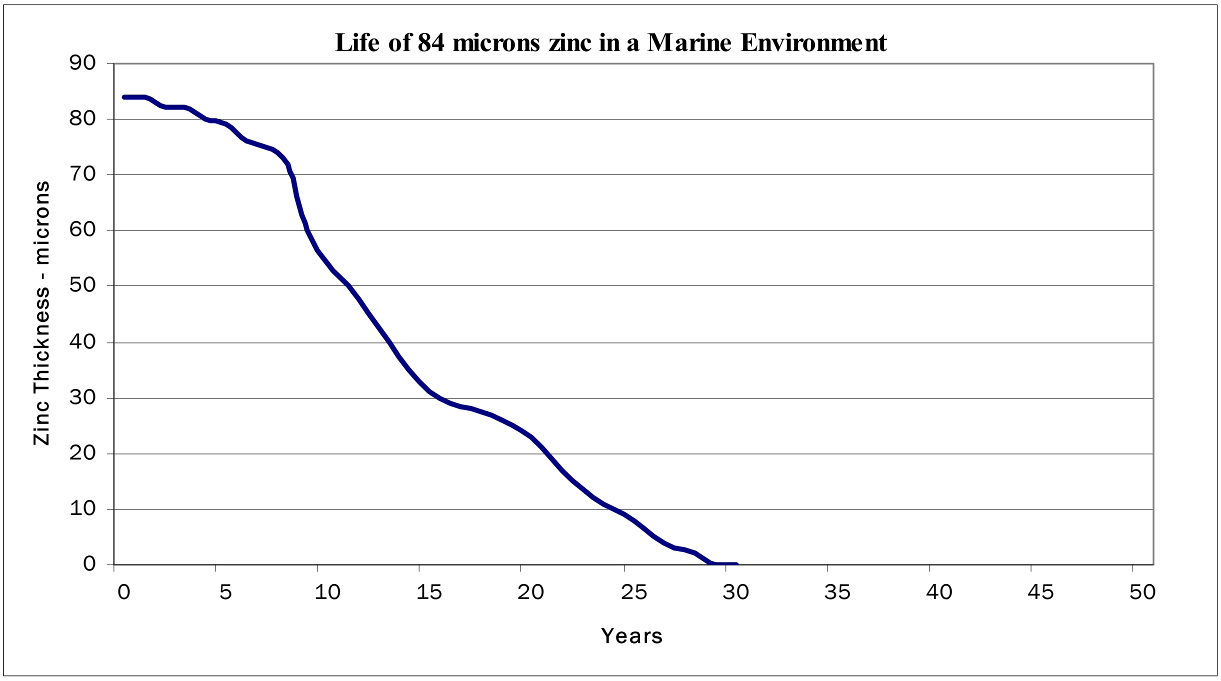
MAINTENANCE STRATEGY

Important factors that need consideration when developing a maintenance strategy include:-

- Asset design life?
- Zinc loss rate for the asset location?
- When does the corrosion clock start?

If for example an asset is in a marine environment with a zinc loss rate of 3µm/year and the design life is 50 years, then if the HDG has an average thickness of 84µm[1], the zinc will be exhausted about half way through its service life. (Graph 5). For most power industry assets the required life is indefinite, so this makes the judgement process relatively simple.

Graph 5



There are a number of ways that the zinc loss rate can be measured for a particular location. A simple categorisation of the location is possible purely by its proximity to the coast or geothermal influences, annual rainfall, prevailing weather and adjacent land contours conditions etc.

Organisations such as BRANZ have zinc loss rate maps of New Zealand which can be used as a guide, or scientific methods such exposure panels using zinc coupons can be used.

Indicative zinc loss rates are in Table 2.

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1 AS/NZS 4680:1999 article thickness >6mm thick

Table 2

Comparison of corrosion rates for steel and zinc (in µm/year) in various locations (extract from ISO 9223)						
ISO Cat	**Corrosivity**	**Carbon Steel**		**Zinc**		**Typical Environment**
		First Year	**Steady State**	**First Year**	**Steady State**	
C1	Very Low	< 1.3	< 0.1	<0.1	<0.05	Dry Indoors
C2	Low	1.3 -2.5	0.1 – 1.5	0.1 – 0.7	0.05 – 0.5	Desert to Non-polluted urban
C3	Medium	25-50	1.5 - 6	0.7 -2.1	0.5 -2	Mild marine or mild industrial
C4	High	50-80	6 -20	2.1 – 4.2	2 - 4	Marine (calm sea)
C5	Very High	80-200	20 - 90	4.2 – 8.4	4 -10	Marine (surf Beach)

Tracking and recording the condition of existing HDG structures over time can be a relatively simple and reliable method of monitoring condition and environment, using either visual references or agreed condition descriptions. Management of assets such as a switchyard gantry is a comparatively easy task, but when multiple sites are considered such as a whole network of galvanized pylons, with differing ages and each with their own micro-climates, the task becomes much more complex.

MAINTENANCE START POINT

Given the type of location, the rate of degradation of the zinc protection can be predicted. If there is an acknowledged need for an indefinite service life, it should be a simple matter to selecting the maintenance start point. Unfortunately what should be a simple engineering decision, is often compromised by various other influences.

Any accountant will determine, that investment in maintenance should only be carried out the day before all the zinc protection is lost, therefore maximising the initial investment of having the asset galvanized in the first place. But it is not that simple in reality. A HDG steel structure does not depreciate (in corrosivity terms), at a uniform rate. It consists of complex shapes with varying orientation and altitude resulting in some parts of the structure deteriorating much quicker than others. It could then be argued that if this was a universal condition, then selective protection to high risk areas can be carried out leaving the remainder to catch up. Unfortunately this is just not practical or cost effective in most instances.

The Engineer will determine that it is always a good idea to have some form of back-up protection and therefore maintenance action will hopefully be considered well before the onset of rusting. However if the timing is wrong or lack of finance or resources forces maintenance delays allowing rusting to develop, it then becomes a costly exercise to remediate this prior to painting.

SAFETY QUALITY AND THE ENVIRONMENT

There are a number of other factors should be taken into consideration and the most important is worker safety. The less time spent working on a live asset – at height, the lower the exposure to accidents. Also, when crews have to spend additional time carrying out abrasive blasting operations (secondary preparation) with all its inherent risks, there is a greater opportunity for things to go wrong. Anecdotally, the majority of incidents on tower painting work have taken place during secondary preparation work.

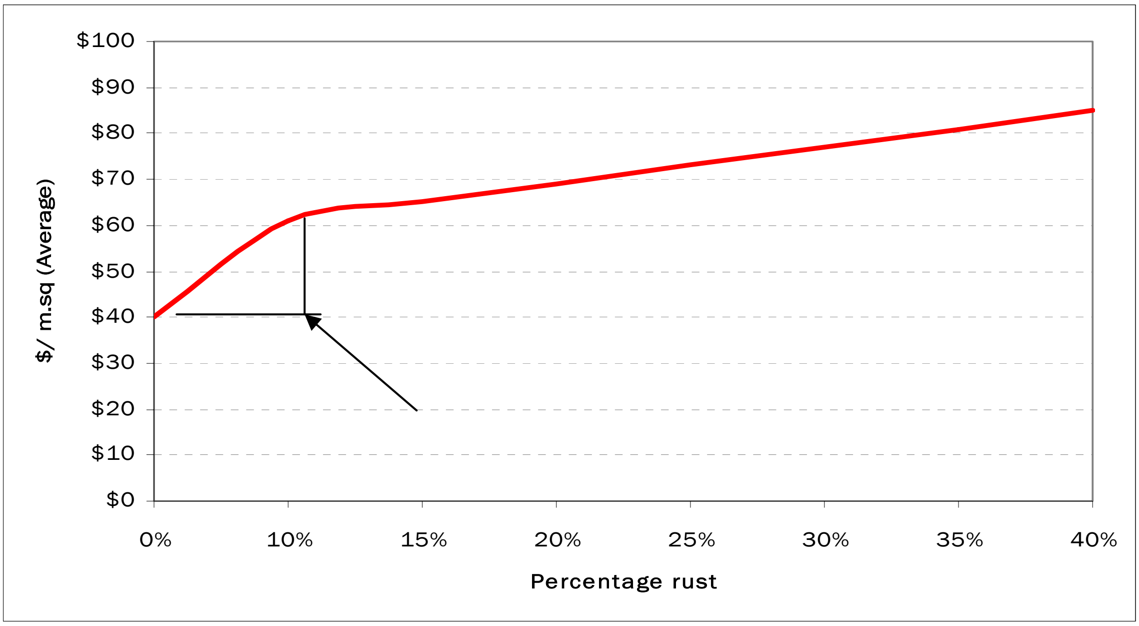
Despite a contractor's best intentions it is sometimes difficult to find every last square inch of rust and remove it. Whilst defect inspections can often pick up these problems; they can also remain concealed for several years before resulting in costly coating failure. Whilst this should be the Contractor's responsibility to correct, the cost eventually falls back onto the asset owner because prudent Contractors will always make an allowance in the bid price.

From an environmental view point, it makes good sense to maintain rather than replace. Whilst it can be argued that discarded, rusting assets can be recycled, additional resources such as energy and zinc need to be incorporated into the equation. There is also a school of thought that says there are environmentally harmful effects from concentrated zinc ablation. There are many millions of square metres of HDG in power equipment assets, but these are actually insignificant when compared to run-off from domestic and industrial galvanised roofing and car tyres. However, while the power industry contribution may be small, painting does arrest zinc ablation and so it should be considered a benefit.

MAINTENANCE COSTS

Current average costs for preparation and painting a double circuit 220 kV transmission tower is in the order of $\$40/m^2$. This includes establishment, surface washing and the application of two paint coats. The cost of rust removal is (currently) in the order of $\$60/m^2$, added to this is an application of a zinc rich primer increasing the cost by a further $\$20/m^2$.
It can be seen from Graph 6 that as soon as rust removal is required there is a 50% increase in the cost/m^2.

Graph 6



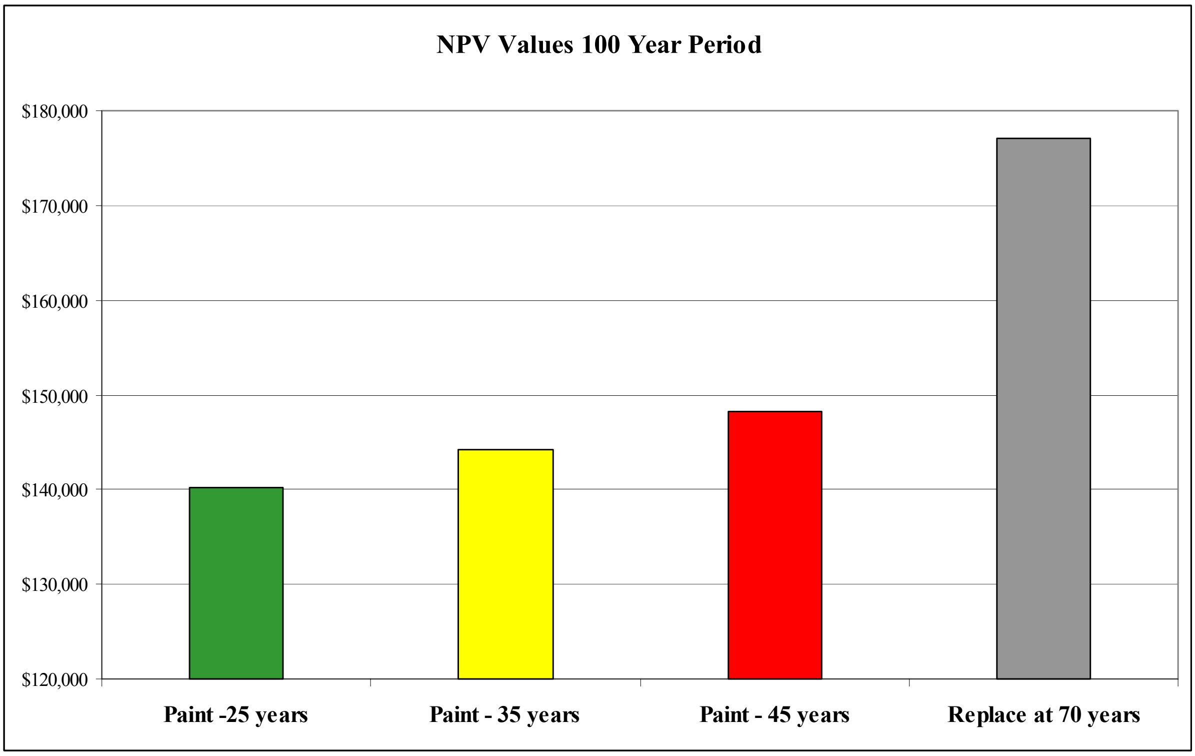
Graph 7 shows a number of Net Present Value (NPV) costs for a pylon located in a mild coastal environment.

- Painting after 25 years exposure at a cost of $16,000
- Painting after 35 years exposure at a cost of $24,000
- Painting after 45 years exposure at a cost of $32,000
- Replace structure after 70 years at a cost of $85,000

The following values are used:

- Initial asset value $60,000
- Discount rate 7.5%
- Period 100 years
- Annual (patrol) cost $100
- 5 yearly condition assessment $250
- 10 yearly routine maintenance $2000
- Painting maintenance after 15 years $8000
- Similar condition at the end of the period

Graph 7



The 25 year option shows the lowest NPV despite having additional repeat maintenance painting operations. This is because surface preparation costs are small. At the other end of the scale, the replacement option has an indicated cost increase of about 40% over the original. This is somewhat arbitrary but must include the additional impact of resource consents, landowner issues and increased material costs since the initial construction, as well as removal of the old structure and foundations. Most importantly, it shows that a proportional amount of preventive maintenance can eliminate the need for major costs later.

PRIORITY

The dilemma facing owners with existing assets already suffering advanced corrosion is the issue of maintenance priorities. Do you preserve those assets that are currently in good condition, at a lower cost per m^2 (and let the rest deteriorate to complete replacement)? Or, do you concentrate on the backlog of assets that are already rusting, meanwhile allowing others in good condition to deteriorate to the extent that in future higher costs will be incurred to recover them.

As a simple principle, assets that are in a non-rusted condition but located in high corrosivity zones should be the first priority for painting. After that, assets can usually be prioritized by corrosivity location, condition, age and proximity to public scrutiny.

The matrix below, (Table 3) shows how a priority list can be developed based on the optimum time for painting being before the onset of rusting, with 100 being the highest priority.

Table 3

	Age - Range							
Corrosivity	<10	10-20	20-30	30-40	40-50	50-60	60-70	70+
Very high	**85**	**100**						
High	**65**	**80**	**95**					
Medium	**45**	**50**	**60**	**75**	**90**			
Low	**15**	**20**	**25**	**30**	**35**	**40**	**55**	**70**

CONCLUSIONS

- Application of "fit for purpose" protective coatings over well prepared galvanised surfaces will provide a synergistic protection, greatly extending total coating life.
- For severe environments over-coating galvanising when new provides the most cost effective method of extending its economic life.
- For moderate environments painting the aged galvanized steel, before the onset of rusting is the most economic maintenance action available.
- Painting before the onset of rusting also reduces worker exposure to OSH risks and is environmentally prudent.
- Where structures have begun to rust, removal of corrosion using abrasive blasting followed by rehabilitation with specialised zinc based primers and coatings is the optimum maintenance method for in-situ structures.

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