

**MEASURING RESIDUAL SALT AT ROAD SPEED -  
"THE MAMMOTH IN THE ROOM".**

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**ABSTRACT**

Over the 4300km of the principle road network maintained by Highways England, approximately £7.5M is spent annually in spreading in the region of 197,000 tonnes of salt for winter service. It has been estimated that for each tonne of salt spread, approximately £0.50 of environmental damage is caused, however in excess of £100 worth of corrosion damage to vehicles and structures is thought to be caused by the same tonne of salt. There is also the environmental impact of salt extraction, transport and loss on the surrounding ecosystem to take into consideration. Extensive research and development has already been undertaken to understand how residual salt on the network can be determined, since unnecessary salt on the road surface contributes to infrastructure deterioration, however all methodologies to date have been found wanting, e.g. the accurate determinations gained in the use of wet-and-dry vacuum cleaners (requiring the road to be closed) or, in the case of the possible use of laser-induced fluorescence (LIF) for road-speed residual salt determination, where other organic materials deliver a false positive.

No attempt has been made to date to embrace the advances in bio-engineering to combine the genes responsible for fluorescence in proteins, characteristics of salt-loving (halophilic) organisms and ion transport proteins known to move sodium within multi-cellular organisms.

Investment in research to investigate this new direction for the development will be high risk, but when you could spend £75M on salt over a ten year period, and this almost certainly including additional treatments made with no accurate method of determining whether such treatments were really required, only £750,000 spent on research to deliver a 10% saving in salt costs in the first year would break even!

## 1. INTRODUCTION

Salt (Sodium Chloride, NaCl) has a definite place in the armoury of the winter service practitioner, we are highly unlikely ever to be able to abandon our love-hate relationship with this most fundamental of compounds whether on the personal level, as a flavour-enhancing table condiment, or something to sprinkle to taste on our road networks.

Regardless of the degree to which we dose our winter networks, every gramme of salt and every litre of brine comes along with its own health and wealth warnings: the environmental and financial costs associated with getting the salt to the point of application and each step of the journey from salt mine to brine spreader has an energy and financial cost.

## 2. THE ECONOMIC COSTS OF ROAD SALT APPLICATION

The financial costs encompass the energy needed to extract the salt from the ground (either as crushed rock salt or as dissolved brine), the energy expended in the haulage of the salt, by road rail or ship, to the winter depot and the diesel burned by the gritter or spreader used to finally dose the road with the saline end-product.

The Highways England network in the UK extends to approximately 4,300 miles. While this network represents only 2 per cent of all roads in England by length, these roads carry a third of all traffic by mileage and two thirds of all heavy goods traffic.

Though only approximate the following costs may be considered for salt for use on the roads in the UK (for high tonnage users). These figures were provided by Highways England in 2017. A cost of £38/tonne has been assumed for the purposes of this exercise.

Summer prices for UK rock salt £34-38 per tonne

Winter rates for UK rock salt £36 -£45 per tonne

Marine salt £52 - £58 per tonne.

Figure 1 below illustrates the actual tonnage of salt used each winter to treat the Highways England network along with an estimated annual cost based on the salt costs above.

- What can be seen is that over a typical winter, Highways England spend £7.5M spreading 197,000 tonnes of salt over their network.
- A ten percent saving in salt use would reduce this annual salt expenditure by £750,000.
- If such a saving was realised as a result of a prior investment in novel research of £250,000 per annum for 3 years it would represent a 100% first year rate of return (FYRR).

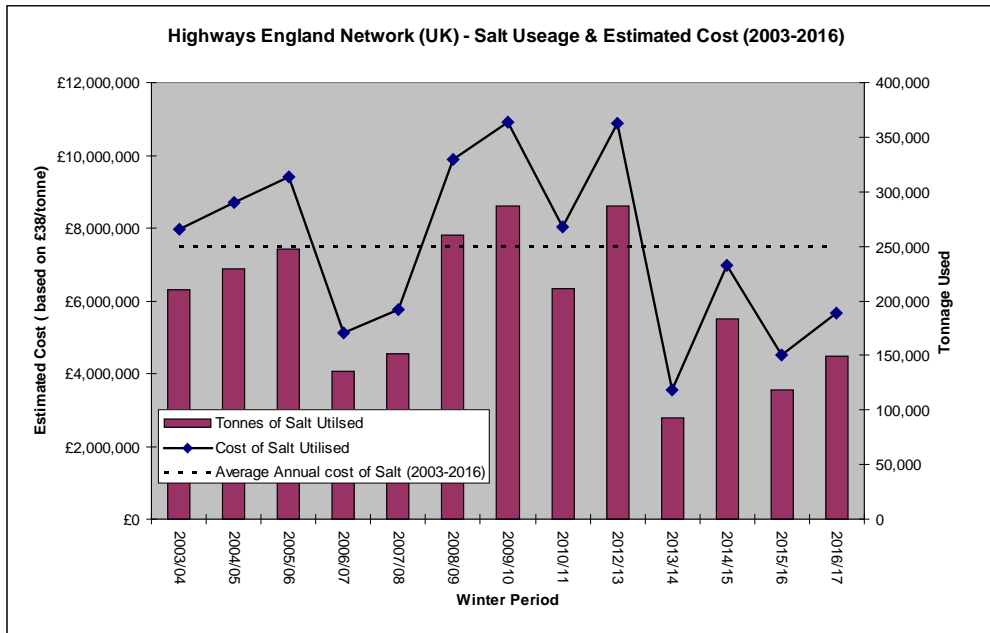


Figure 1 - Highways England (UK) Annual Salt Usage and Estimated Cost of Salt Used

Similarly, the extraction and transport processes have environmental impacts, the removal of the raw salt from the ground may result in surface subsidence and the passage of transport may impact on local pollution levels, whether this is at the point of extraction or at the point of delivery.

Table 1 below provides a measure of the environmental impact of transporting a tonne of salt for a kilometre with respect to atmospheric pollution (OECD, 1997 [1]), more up to date figures may exist.

Table 1 - Truck Air Pollution Emission Factors, in grams/tonne-km OECD, 1997 [1]

	Kürer <sup>a</sup> (Germany)		Schoemaker & Bouman <sup>b</sup> (Netherlands)				White- legg <sup>c</sup> (Europe)	Befäh <sup>d</sup> (Belgium)	OECD <sup>e</sup> (Europe)
	Local	Long-haul	Trucks	Trucks & Trailers	Truck-tractors & semi-trailers	Road freight overall	Road freight overall	Trucks and semi-trailers > 10 tonnes	Long-distance trucks
CO	1.86	0.25	2.24	0.54	0.34	0.90	2.4	2.10	0.25
CO <sub>2</sub>	255	140	451	109	127	211	207		140
HC	1.25	0.32	1.57	0.38	0.34	0.68	0.3 <sup>e</sup>	0.92	0.32
NO <sub>x</sub>	4.1	3.0	5.65	1.37	2.30	2.97	3.6	1.85	3.0
SO <sub>2</sub>	0.32	0.18	0.43	0.10	0.11	0.20	n.a.	n.a.	0.18
Particulates	0.30	0.17	0.90	0.22	0.19	0.39		0.04	0.17
VOC							1.1		

When one then considers the impact of the salt applied to the road as part of a reasoned winter service strategy, the introduction of sodium chloride into an environment where it does

not naturally occur can have very detrimental effects both on the built and the natural environment.

### 3. THE ENVIRONMENTAL IMPACT OF ROAD SALT APPLICATION

The environmental impact of Road Salt Application comprises the environmental burdens associated with the extraction of salt from our environment, the energy expended in processing and transporting the salt to the point of application and the environmental impacts that arise from the widespread application of salt to road surfaces.

Longitudinal studies conducted over 47 years (Godwin, Hafner & Buff, 2003 [2]) have shown a significant increase in the concentration of NaCl in the Mohawk River due to the application of road de-icing salt.

Furthermore, compounds used as “anti-caking” agents in road salt, for example Iron Cyanide, (Paschka, Ghosh & Dzombak, 1999 [3]) also present their own environmental challenges. Reduction of the use of road salts will further diminish these effects accordingly.

Academic research has been undertaken to investigate the migration of salt-loving (halophyllic) species, a masters thesis (NigFhloinn, 2011 [4]) included a study of the salinity levels of the soil with distance from the road, Figure 2 below reproduces one key figure from this study showing that salinity decreases with increasing distance from the edge of the road.

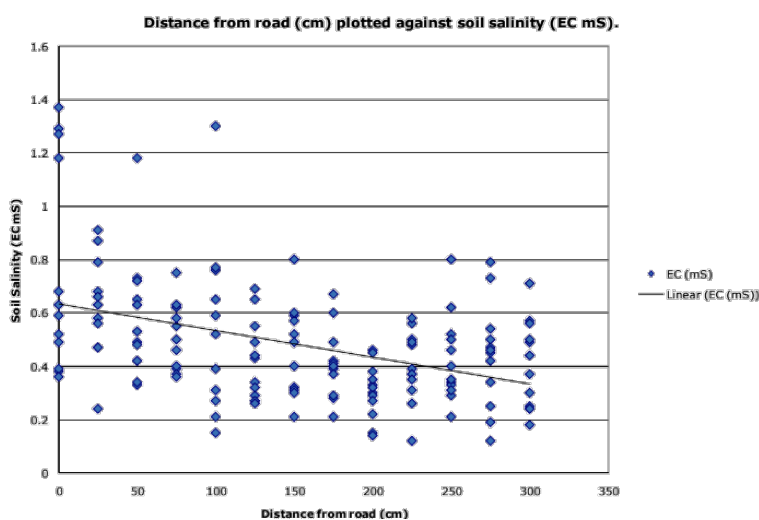


Figure 2 - Distance from road (cm) plotted against soil salinity (NigFhloinn, 2011 [4]).

However, Findlay & Kelly (2011) [5], noted that whilst research has focused on near-road short term impacts of salt spreading, the ecological damage resulting from the practice can have longer lived, further reaching impacts than previously thought.

Burtwell, Jordan & Ofori-Darko (2004) [6], provides an estimated cost for the environmental damage of 500,000 tonnes of salt applied to the highway network, this was estimated as £250,000 for dry salt and £192,000 for pre-wetted salt respectively. These figures equate to £0.50 and £0.39 per tonne of salt laid. See Table 2 below.

Table 2 - Annual Indirect Cost for 500,000 tonnes of salt. Figure reproduced from Burtwell, Jordan & Ofori-Darko (2004) [6].

Indirect cost	Value
Vehicle corrosion associated with dry salting	£47,440,000
Structural corrosion/damage associated with dry salting	£20,000,000
Environmental damage associated with dry salting	£250,000
Vehicle corrosion associated with pre-wetted salting	£36,530,000
Structural corrosion/damage associated with pre-wetted salting	£15,400,000
Environmental damage associated with pre-wetted salting	£192,500

Furthermore, the impact on the natural environment and ecosystem services is hard to quantify, multi-dimensional and context specific. The run off from road salt results in significant environmental damage. Findlay & Kelly (2011) [5] and Trombulak & Frissell (2000) [8] have conducted reviews, which includes significant examination of the effects of road de-icing salts (NaCl but also CaCl<sub>2</sub>, KCl, and MgCl<sub>2</sub>) on both terrestrial and aquatic ecosystems.

Whilst alternative organic formulations to traditional road salt exist, their cost is hitherto largely considered prohibitive (Findlay & Kelly, 2011 [7]), and in turn these products may come with their own poorly understood environmental consequences.

The impacts on flora and fauna by the kerbside are manifold. Road salts cause 'salt stress' in plants growing near to roadways,

Paerl & Huisman (2008) [9] have discussed how nutrient over-enrichment of waters, combined with increased salinity (partly an effect of the application of road salt) has resulted in toxic blooms of cyano-bacteria in lakes and water courses. In turn, these algal blooms can have knock-on effects for other elements of the marine ecosystem, killing other plant life and depleting oxygen killing fish.

#### **4. IMPACT ON VEHICLES, AND THE BUILT ENVIRONMENT OF ROAD SALT APPLICATION**

As drivers we are aware well of the toll that winter can have on the metalwork of our motor vehicles

As asset managers of highway infrastructure, we are also well aware of the accelerated corrosion of embedded ironwork that can result from salt ingress.

Penetration of concrete by chloride ions from de-icing salts and marine environments is the primary cause of reinforcement corrosion in highway structures. Burtwell, Jordan & Ofori-Darko (2004) [6], calculated vehicle and structural corrosion associated with dry salting per 500,000 tonnes of salt was £67,440,000, whereas for the same weight of pre-wetted salt the figure was £51,930,000: this equates to an estimated corrosion cost of £135 and £104 per tonne of salt applied, respectively.

What can be seen from the above research is that the corrosion damage costs estimated for the action of salt is over 250 times that of the estimated cost of the environmental damage.

## **5. CONTROLLING AND LIMITING THE APPLICATION OF ROAD SALT**

We may never be able to stop applying salt to our road networks, however what we can aim to do is to mitigate for all or some of the negative impacts of this use by improving the efficiency of its application. This will decrease the environmental burden associated with the continual extraction of salt, the energy used in salt transportation may be reduced, and the impact on ecosystems from saline run-off can be minimised. To put it bluntly, the efficiency of application will improve by actually knowing how much we are applying and how much we need to re-apply.

A wealth of research drives the development of ever more accurate weather forecasting and technological advances to improve the accuracy of the delivery devices that dose the highway, but regardless of how well we apply the salt, one of the most difficult decisions for any network operator is in deciding exactly how much salt or brine is needed when repeated treatments are considered, that is when a residue of earlier treatments remains on the network

If a prediction of precipitation was factored into an earlier treatment and the road subsequently remained dry during that shift, the road surface may have retained a significant proportion of the earlier treatment, but just how much is still left on the road?

This paper does not attempt to provide chapter and verse for the development of a perfect method of measuring residual salt at road speed, rather it provides a catalyst for thought and a road map for funding research and development, to take residual salt measurement out of The Dark Ages by the application of 21st century technology learned outside of the highways realm: to take the Mammoth in the room, play around with it, make it glow and then measure it, tusks and all!

Before we go any further, let's give the whole methodology to measure residual salt at road speed a name: RSRS??? or better still let's use RS<sup>2</sup>

## **6. MEASURING RESIDUAL SALT ON THE LOCAL (MACRO) SCALE**

On the macro scale, without an accurate method of determining residual salt on the road network, subsequent treatments cannot be optimised ( i.e. minimised) to allow for this residue and the environment and the operators purse carries the costs of the common response of ignoring what is already there to err on the side of caution.

Similarly, without an accurate method of determining residual salt on the road network at any given time, the network operator cannot provide documentary evidence that they were doing their job.

Without a documentary measure of residual salt at a given time on the network, legal challenges from personal injury and accident lawyers may not be addressed to their, or indeed your, satisfaction.

## 7. MEASURING RESIDUAL SALT ON THE MICRO SCALE

At the micro-scale, being able to precisely map the distribution of residual salt or brine across the any linear metre of the road section could improve our understanding of spreading mechanisms (optimising their development), and the influence of wind shear.

But, can we measure residual salt on the road network and at road speed, now?

Yes, we can measure it but no, not over the whole network or at road speed: a number of technologies and methodologies already exist for the measurement of salt on the road network but, broadly speaking, their accuracy (a pre-requisite in a safety-critical arena) appears in inverse proportion to their practicality (which means if it can't be used to quickly survey a whole network it has the value of a chocolate screwdriver).

Past research (Highways Agency 2007a [10] & 2007b [11]) into the measurement of residual salt on the road network has included:

- the use of wet-and-dry vacuum cleaners on a closed road to recover the salt on the road surface for residual salinity determination following extraction. This approach also has the corollary effect of removing salt from the road surface, rendering it redundant. Whilst this forms a tool for monitoring, it is less useful for in-service applications
- the development of several hand-held devices capable of precisely measuring residual salt on a micro scale (these devices are very sensitive to user error and contamination as well as being incapable of measuring large areas at road speeds). These require operatives to manually sample the road surface. This is uneconomical and impractical at a network level.
- embedded sensors that perform a similar function for a fixed reference point on the network (these devices are reliant on regular inspections to remain operational). Furthermore, they only provide a “point” reading, so cannot validate the condition of the broader road network.
- remote sensors typically mounted on poles by the side of the carriageway (these typically infer road surface friction/characteristics from image analysis),
- vehicle mounted devices that use refraction measurement devices to estimate residual salt from its effect on the refractive index of liquid water on the road surface (such devices are reliant on the presence of liquid water on the road or the ability to produce sample brine on-the-fly from the salt on the road, such devices require constant monitoring to ensure they are not clogged with precipitate from the material recovered from the road surface),
- the use of laser-induced fluorescence (LIF) to measure the presence of a molasses-based salt additive has been used in the laboratory, however this method is rendered inaccurate in practice as organic material on the road surface was shown to fluoresce in the same manner as the molasses,

and

- The use of a higher energy laser-induced breakdown (LIB) method to directly stimulate the salt to generate a plasma that could be detected using spectrophotometry (in a manner akin to that used to detect the sodium line in the light observed from distant stars in astronomy for the last hundred years).

Unfortunately for the highway engineer, the dynamic nature of the interface between the moving road and the measuring vehicle is not conducive to easy or accurate measurement of residual salt.

A presentation to be made at the 15th International Winter Road Congress (Rufino, Ruiz et. al, 2018 [12]) should also describe some of the latest applications of LIF to residual salt measurement.

## **8. A CASE FOR FUNDING THE DEVELOPMENT OF RS<sup>2</sup>**

Road administrations and local network operators are under increasing pressure to make smaller budgets go further, not to spend large chunks of these budgets on groundbreaking research.

To progress this idea to the point of commercial adoption, funding is required to progress the basic science, with a view to increasing the Technology Readiness Level (TRL) of this idea. Concurrently, as a manufactured product, the chemical engineering approach needs to be developed to improve the Manufacturing Readiness Level (MRL) to a stage where the product can be used in pre-commercial demonstrations, with a view to construction of a commercial scale plant.

Highways England have long seen the value of a road speed residual salt measurement device and have already funded novel research in this area [10,11] however the far greater risk associated with "blue sky" funding of work as is proposed in this paper has, to date, generated interest rather than real investment.

## **9. THE RS<sup>2</sup> WISHLIST**

LIB/ LIF? Attempting to get salt to fluoresce in its own right requires very high energies, pointing lower energy lasers at molasses added to salt for improved adhesion also accurately tells us where the manure is!

Refractive Index? Using devices based around the refractive index of brine greatly limits the sample area.

Beating, Sweeping and Cleaning? Measuring residual salt precisely using wet and dry vacuum cleaners takes the road speed down to nil while you close the road for room service.

Thus a new additive to salt and a matched detection device (that enables the treated salt to be subsequently detected following spreading) is urgently needed.

In order to deliver a practical network wide measurement of residual salt on the road network at traffic speed we can draw up an RS<sup>2</sup> wish list, that, if all boxes were ticked, the



RS<sup>2</sup> package would deliver one of the best Christmas presents that a winter service practitioner could (possibly) wish for. It would:

- Have no impact on the efficacy of the salt
- Have minimal impact on the ecosphere
- Enable measurement at road speed
- Easily & rapidly deliver lane-wide measurements of residual salt
- Give accurate measurement in wet and dry conditions regardless of the salt delivery process.
- Be free from false positives

So where could a new salt additive be found and what do we want it to do?

If we look to the natural world for the component needed to deliver RS<sup>2</sup>, we can fabricate the building blocks we need, the following sections describe THREE individual components from nature that if combined would give the functionality we need in a new salt additive:

#### *9.1 RS<sup>2</sup> COMPONENT 1: THE ABILITY TO BIND TO SALT*

Salt in the natural environment is a problem, a big problem, for every fish, whether in salt or fresh water: and there is continuous migration of sodium and chloride ions to maintain the correct level of salts concentration in the body of the fish.

Major ion transport proteins include Na<sup>+</sup>/K<sup>+</sup>-ATPase (NKA), Na<sup>+</sup>-K<sup>+</sup>-2Cl<sup>-</sup> cotransporter 1 (NKCC1), Na<sup>+</sup>/Cl<sup>-</sup> cotransporter 2 (NCC2), Na<sup>+</sup>/H<sup>+</sup> exchanger 3 (NHE3), and the cystic fibrosis transmembrane conductance regulator (CFTR) .

Online reference: [https://en.wikipedia.org/wiki/Membrane\\_transport\\_protein](https://en.wikipedia.org/wiki/Membrane_transport_protein)

#### *9.2 RS<sup>2</sup> COMPONENT 2: THE ABILITY TO FLUORESCENCE*

We need a 'fluorescent something'.

The use of fluorescence to tag cells is now relatively common place, Green Fluorescent Protein (GFP), is a protein produced by a jellyfish *Aequorea victoria* which produces glowing points of light around the margin of it's umbrella. The light arises from yellow tissue masses that each consist of about 6000-7000 photogenic cells.

Scientists Roger Y. Tsien, Osamu Shimomura, and Martin Chalfie were awarded the 2008 Nobel Prize in Chemistry on 10 October 2008 for their discovery and development of the green fluorescent protein (GFP), see Figure 3 below.

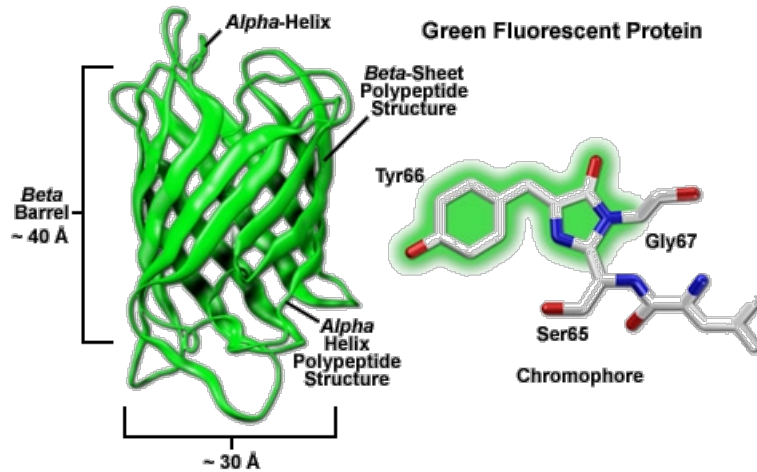


Figure 3 - The Structure of the Green Fluorescent Protein (GFP), from Piston, Campbell et. al. (n.d.) [13]

Wild type GFP has two excitation peaks, a major one at 395nm (long wave UV, causes rapid quenching of the fluorescence) and a smaller one at 475nm (blue) and an emission peak at 509nm (green). This emission peak compares with the peak emission for molasses of 420nm

The highest profile applications of GFP have been:

- Alba, a green-fluorescent rabbit, created by a French laboratory and commissioned by Eduardo Kac) [14]. See Figure 4 below.



Figure 4 - Alba, the fluorescent rabbit, New Scientist (2000) [15].

- Green fluorescent zebrafish (GloFish) that were initially developed by the US company Yorktown Technologies to detect pollution in waterways, Neal Stewart, Jr (2006) [16].
- Green fluorescent mice developed by NeonPets, a US-based company (Hadjantonakisa et. al., 1998) [17].
- Green fluorescent pigs, known as Noels, were bred by a group of researchers at the Department of Animal Science and Technology at National Taiwan University (Miles et. al., 2013) [18].

- Green-fluorescent cats created by a Japanese-American team as proof of concept to use them potentially as model organisms for diseases (Wongsrikeao et. al., 2011) [19].
- Transgenic beagles that give off a red fluorescent light were bred In 2009 by a South Korean team from Seoul National University to allow scientists to study the genes that cause human diseases like narcolepsy and blindness. (So Gun Hong et. al., 2009 [20]).

GFP had been widely used in labelling the spermatozoa of various organisms for identification purposes as in *Drosophila melanogaster*, where expression of GFP can be used as a marker for a particular characteristic (Plautz et. al., 1996 [21]).

Another powerful use of GFP is to express the protein in small sets of specific cells. This allows researchers to optically detect specific types of cells in vitro (in a dish), or even in vivo (in the living organism). Genetically combining several spectral variants of GFP is a useful trick for the analysis of brain circuitry. Other interesting uses of fluorescent proteins in the literature include using FPs as sensors of neuron membrane potential, and the infection of individual influenza viruses and lentiviral viruses (Day & Davidson, 2009 [22]).

A large array of fluorescent proteins exist, indeed an interactive selector can be found online here: <http://www.fpvis.org/PSFP.html>

Other fluorescent mutations include:

- BFP: Blue fluorescent proteins (EBFP, EBFP2, Azurite, mKalama1), BFP derivatives (except mKalama1) contain the Y66H substitution. They exhibit a broad absorption band in the ultraviolet centered close to 380 nanometers and an emission maximum at 448 nanometers.
- Cyan fluorescent protein (ECFP, Cerulean, CyPet, mTurquoise2),
- smURF: A new class of fluorescent protein was evolved from a cyanobacterial (*Trichodesmium erythraeum*) phycobiliprotein,  $\alpha$ -allophycocyanin, and named small ultra red fluorescent protein (smURFP) in 2016.
- Yellow fluorescent protein derivatives (YFP, Citrine, Venus, YPet).

### 9.3 RS<sup>2</sup> COMPONENT 3: THE ABILITY TO TURN ON FLUORESCENCE IN THE PRESENCE OF SALT

If, and this is a big if, it were possible to combine GFP, or another suitable fluorescent protein, with an ion transport protein, we may then be able to "tag" salt with fluorescence, however these spliced proteins (if that is what would be created) would have an intrinsic fluorescence regardless of whether they were bonded to salt or not, so how do we turn on the fluorescence only when the protein is bonded to salt?

A number of organisms exist that rely on the presence salt to grow.

One example of such an organism is *Chromohalobacter beijerinckii*, a motile, rod-like, salt-loving, soil bacterium, isolated in 1935 by T. Hof. The bacterium thrives in media with salt (NaCl) concentrations ranging from 0.35% to 25%; the optimum growth occurs at 8 to 10% NaCl (Beutling, Peçonek & Stan-Lotter, 2009 [23]).

Another example is *Wallemia ichthyophaga*, a fungus which requires 1.5 M NaCl (a concentration of 87.66 g NaCl/litre) for in-vitro growth (or some other osmolyte for an equivalent water activity), and it thrives even in saturated NaCl solution. This makes it the most halophilic fungus known! (Zajca et. al., 2014 [24]).

Thus, with a wide choice of fluorescent proteins, a number of organisms identified that require salt to grow, and the identification of major ion transport proteins there may be the building blocks to develop an additive to salt that turns on the fluorescent when it binds to salt, and only then.

We would also want the additive RS<sup>2</sup> to leave no fluorescent if the salt was removed by runoff or rain

#### *9.4 RS<sup>2</sup> COMPONENT 4: MEASURING FLUORESCENCE OVER A NETWORK AT ROAD SPEED*

Network wide survey tools already exist to record road surface characteristics using GIS mapping to precisely locate measurements, this technology is easily harnessed to record the results of road surface fluorescence measurements to determine residual salt.

Live residual salt surveys from gritter mounted measurement equipment have already been used to modify treatment rates. The limited success of this process was attributed to the use of refractometers to determine residual salt (Highways Agency, 2007b [11]).

The use of live measurements "on the fly" of surface fluorescence to feed back to the treatment rate as the vehicle passes over the road surface would deliver an immediate benefit in reducing the level of subsequent treatments as well as recording a residual salinity map for the network.

A post-treatment measure of residual salt would require a second pass of the network or a measurement array located on the rear of the treatment vehicle.

### **10. SANITY CHECK: RELEASING A BIOENGINEERED PRODUCT INTO THE WILD.**

Should the RS<sup>2</sup> "wonderstuff" be developed in the laboratory, it would need to be assessed for safety in a similar manner to a GM crop or GM treatment for agricultural use (but appropriate for the intended end use).

For example, In the USA, the Environmental Protection Agency (EPA) Regulation of Biotechnology for Use in Pest Management include

1. Identification of new genetic material and all new proteins.
2. Mammalian toxicity testing of all new proteins.
3. Comparison of new proteins to known toxins and allergens.

4. Toxicity testing on birds, fish, earthworms, and representative insects such as bees, ladybird beetles, and lacewings.
5. Toxicity testing on insects related to target insect pests.
6. Length of time required for the new proteins to degrade in the environment.

Toxicity testing would be conducted with a range of doses and concentrations 10 to 100 times higher than those expected in environmental conditions. EPA also consults literature and other sources of supporting information related to any aspect of the proteins and the organisms from which they are derived.

Refer to the EPA online resource for more information on the above regulations:

<https://www.epa.gov/regulation-biotechnology-under-tsca-and-fifra/epas-regulation-biotechnology-use-pest-management>

The tests necessary for RS<sup>2</sup> to "comply" would need to be specifically established based on the nature of its use. Regardless of the approval process time and significant expense are highly likely before it would be approved for use. Multiple parallel approvals via equivalent organisations to the EPA would be required for the global application of the technology.

## **11. DISCUSSION**

### *11.1 TURNING THE WISH LIST INTO A PRODUCT INTO A DELIVERABLE SOLUTION*

It is all very well to have a concept or an idea, it is another matter to turn it into from a product "RS<sup>2</sup>" to getting it out on the network.

We need to be practical about the approval of a methodology for use on the road once it has been approved to be used in the natural environment.

As at example, GFP has been used for a multitude of applications within the biological sciences since it was discovered (Zimmer, 2015 [25]), but these have all been "in vitro" (in the laboratory) and not released into the natural world (in vivo).

Laboratory-based simulations of the road environment will be required, at this point the volume of the RS<sup>2</sup> marker to be added to the bulk salt can be determined and the detection method formalised

Exhaustive laboratory tests would provide the building blocks for controlled full-scale track testing to proof-test the final configuration for use on the live network.

Once on the live network, monitored trials would precede the routine use of RS<sup>2</sup>-powered residual salt measurement.

### *11.2 WHAT ARE THE NEXT STEPS FOR THE RS<sup>2</sup> PROJECT?*

Funding is now needed to kickstart the investigation of a workable combination of salt affinity and of fluorescence switched by the presence of salt.

The costs to identify the organic combination required to deliver the RS<sup>2</sup> magic bullet will be dwarfed by the cost of approval to use the material in the natural environment and the

development of the manufacture, delivery and detection components the RS<sup>2</sup> magic ingredient will need.

The combination of molecular biology, biological engineering, bio-manufacture, sensor technology and winter service expertise that the RS<sup>2</sup> project needs is unlikely to be serviced by a single entity, whether network operator, academic institution or national transport research establishment, a joint venture between centres of excellence, maybe an international exercise?

## 12. CONCLUSIONS

Where we stand in 2018 is with the RS<sup>2</sup> balance sheet in surplus, we can see all the positives with no measure of the negatives, the "you just can't do that's", and the "do you know how much that will cost's", investment in a major multi-disciplinary research programme may bring deliver a high-(bio)tech solution to a low-tech problem!

The Authors would relish the opportunity to continue to be part of this unique journey of discovery around highway- and bio-engineering, wherever it takes them! Hopefully this journey would be down Quality Street and not down a salt-encrusted cul-de-sac!

## 13. ACKNOWLEDGEMENTS

The author would like to thank Mr Jim Doxford, (Project Sponsor, Highways England), David Batchelor (Operational Capability Team - Safety, Engineering and Standards, Highways England), and Samantha Clark, Darren Clark & Helen Jordan (all of Highways England) for their kind assistance and support in the preparation of this paper.

They would also like to thank Marta Ruiz LLata (Profesora Titular, Dpt. Tecnología Electrónica, Universidad Carlos III de Madrid) for information regarding their residual salt measurement research.

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