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Development and implementation of novel cryogenic railhead cleaning technology

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The Problem

A complex and persistent problem faced by the GB rail industry is that of low adhesion at the rail/wheel interface. This is often caused by a third body "contaminant" between the wheel and rail that does not support high shear stresses. The stopping distance of a train is mainly determined by the friction between the wheel and the rail (adhesion). When low adhesion is present, there is a detrimental effect to the braking performance of trains, resulting in increased stopping distances, platform overruns [1], Signals Passed At Danger (SPAD's)[2] or collisions [3]. Wheel slides also cause considerable damage to wheels and rails which may mean that trains have to be taken out of service or rails replaced, both of which lead to disruption of service. Wheel slides can cause squat formation (a track defect). Squats are hard to identify in their initial stages and can affect track safety if not removed by preventative maintenance. Reduced adhesion also leads to driving wheels spinning, thus reducing vehicle acceleration and maximum speed. This can even lead to heavy freight trains 'slipping' to a stand-still on a gradient or rail burns.

Although the low adhesion causing contaminant can arise from a variety of sources such as leaves, dust, oxides and moisture, much of the focus is during the autumn season tackling slippery leaf layers. These leaf layers arise through leaf mulch on the rail-head being compressed in the specific conditions of the wheel rail contact and forms a black Teflon like layer. Speed limits are typically imposed during the Autumn season to maintain confidence in train deceleration rates, which results in the "Autumn timetable".

Contrary to widespread public perception, it is **not just a UK problem**, it occurs worldwide. For example, in North Rhine-Westphalia (Germany), in one week in October 2003, only 56% of trains arrived on time and ten thousand delay minutes were accumulated due to low adhesion caused by leaves on the line [4]. However, problems can occur all year round due to the "wet-rail" phenomenon (caused by oxides and water) [5] which is prevalent at dew point in the morning and evening, when environmental conditions lead to the formation of a thin film of condensation on the track.

The annual cost of the leaf problem is reported to be **£354 million** in the United Kingdom [6] and 100 million SEK in Sweden [7]. Problems also lead to customer dissatisfaction, especially when measures to reduce the problems include timetable changes and shorter trains. **This dissatisfaction can cause a reduction in train use,** reducing the clear societal benefits of rail travel.

Presently, the method utilised for **cleaning the lines** during the autumn season is **high-pressure water jetting. These jetting systems are mounted to a** specialist fleet of Rail-head Treatment Trains (RHTTs) operated by infrastructure operators throughout the autumn season in an attempt to remove low adhesion layers. Currently this high pressure water jetting is operating at 1500 bar. To enable jetting at this pressure, a vast 130,000,000 litres of water, equivalent to 52 Olympic sized swimming pools, are required for the 11-week autumn period in the UK alone [8]. With the UK Environment Agency forecasting water shortages within 25 years, it is necessary for alternative technologies to be fully explored. Treatment train lengths and the advanced route planning prevent flexibility of the system, and therefore treatment is typically restricted to high priority lines, which may result in heavy freight trains 'slipping' to a stand-still on a gradient.

The method used for addressing adhesion loss in **braking and traction** is **train-borne sanding**. Sand is applied directly into the wheel/rail interface from an on-board system. It is applied automatically when a driver selects "emergency braking" and at the driver's discretion when adhesion loss occurs in traction. There are a number of problems associated with sand application including its affect on damage to wheels and rails; its impact on traction detection through isolating the wheels from the rails and the residue left around the track infrastructure.

A Cool solution

The University of Sheffield in collaboration with Ice Tech Technologies UK have developed a novel technique for rail-head cleaning that has been demonstrated to work with a variety of low adhesion causes including leaf derived 'black layer', rust (iron oxides) along with grease, diesel fuel and moisture. Validation of the cryogenic spray technology for cleaning rail infrastructure, has been conducted through a series of fully funded research projects, totalling in excess of £1 million, from small scale lab based testing to live network testing in 5 locations, funded by RSSB, Arriva Rail North and Network Rail R&D

The process has been designed to replace high-pressure cleaning using water jets and other traditional methods that use materials such as sand, glass and plastic as abrasive agents as well as the wide range of cleaning methods that involve the use of hazardous chemicals and solvents. As the process is completely dry and non-conductive, dry-ice can be used where other methods are unsuitable, for example there would be no danger for point-operating motors, or to condition monitoring equipment. Similarly, there is no danger of the loss of electrical contact between the wheel and the rail that is a concern when sand is used. The cleaning process is low cost, flexible and therefore can be used in place of classical rail-head treatment trains and devices.

Carbon Dioxide gas, the gaseous form of dry-ice is viewed as a waste product by many industries and is vented to atmosphere. The Carbon Dioxide used in the rail-head cleaning process is **recovered** from these 3rd party industrial processes, such as fertilizer and bioethanol production, and compressed under a reduced temperature to create liquid CO_2, where it may then be safely stored (e.g. a CO_2 fire extinguisher). Through the use of a pelletiser, the liquid CO_2 is expanded and mechanically compressed to produce dry-ice pellets.

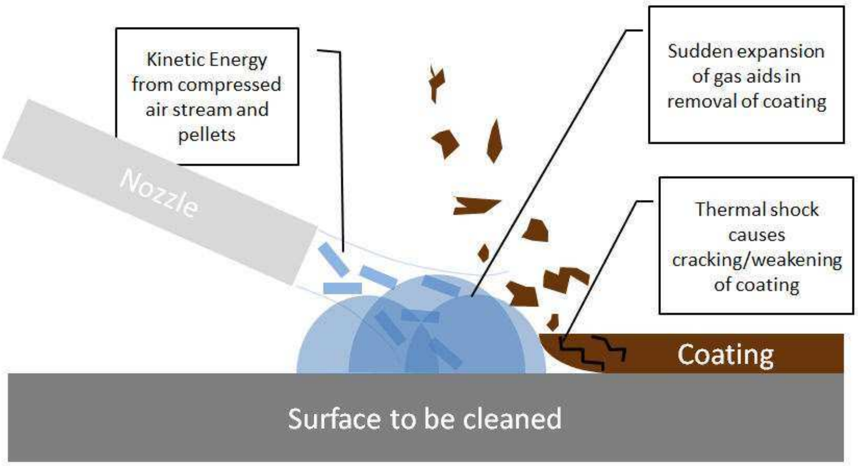

Figure 1. The three mechanisms of dry-ice cleaning

The technique cleans by blasting the contaminated substrate with dry-ice pellets in a flow of compressed air moving at Supersonic speed. The unique feature of dry-ice is that it sublimes on contact with the surface to be cleaned. The cleaning takes place via three different mechanisms (Figure 1):

1. Surface Cooling: this embrittles any surface contaminants which then shrink/crack, and the adhesive bond between them and the rail is weakened or broken
2. Kinetic Energy Input: the energy of the pellets and the air contributes to contaminant removal. This removal through impact will be enhanced if the cooling effect has additionally weakened the adhesive bonds between the contaminant material and the rail surface.
3. Sublimation: as the dry-ice pellets impact on the surface to be cleaned they change from their solid state to a gaseous state, with an associated volume increase of about 800 times.

Initial Tests – Autumn 2018

As reliably creating low adhesion under realistic railway conditions in a laboratory environment is a challenging task, it was necessary for the technology to be trialled representative railway conditions.

Track trolley

Initial field trials funded by Arriva Rail North were conducted over 12 sessions during Autumn 2018 on a low traffic freight line prone to heavy leaf contamination. Typically no treatment is conducted on the freight line, although it is notorious for low adhesion, to the extent that it is used for TOC Low adhesion driver training. The equipment was scaled to enable mounting on a Type B Rail track trolley, as shown in Figure 2. Although treatment speed was limited to walking pace, it was an opportunity to regularly clean a black leaf layer.

Figure 2. The track trolley mounted equipment in use on a low traffic freight line in South Yorkshire

The trials were shown to be a great success, with the blackened leaf layer being visibly removed (Figure 3), particularly in the running band on each treatment date (twice weekly November- January). The blasting nozzles have been specially designed to optimize the cleaning effect within the running band, however further work is required to increase the cleaning width, such that, the entire railhead can be cleaned with a single nozzle.

Figure 3. A photograph showing where cryogenic cleaning of the "blackened leaf layer" has stopped

RRV mounted - Supertram

To demonstrate how the application could be successfully used in the field, the cryogenic cleaning equipment was mounted onto a Road Rail Vehicle (RRV) with collaboration from the Light Rail operator Stagecoach Supertram (Sheffield). The cleaning equipment was mounted on the flatbed of the "Multicar" RRV, while the basting nozzles were mounted on the rear rail wheel axle. Mounting in this manner ensured that when in road transport mode, the nozzles were lifted clear and protected but were ready for use as soon as the vehicle mounted the rails. The equipment was trailed on a heavily oxidised track in the Supertram depot (Figure 4). The running band was effectively cleaned in a single pass, at an operations speed of 10 mph.

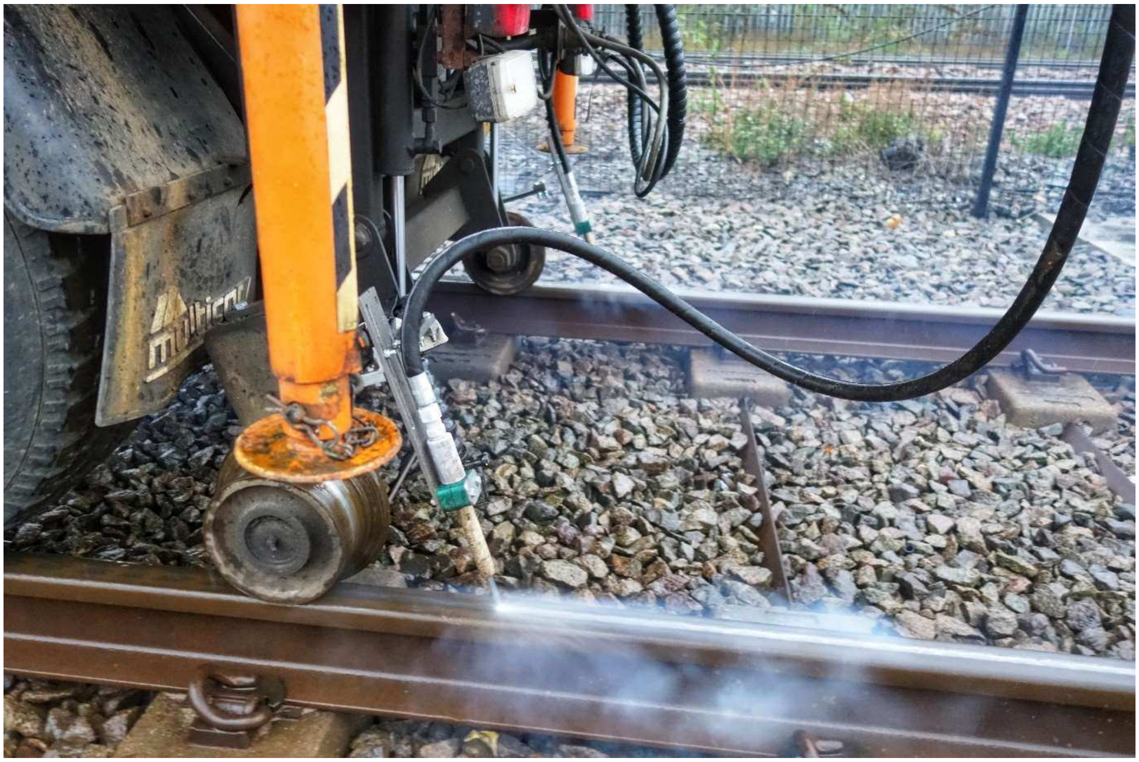

Figure 4. The Cryogenic Cleaning system mounted on the RRV Multicar at Sheffield Supertram Depot, cleaning heavily oxidised track

Figure 5 shows a still taken from one of the nozzle cameras, showing the running band being cleaned, but also the removal of water from the railhead, present from heavy rain on the day of the trials.

Figure 5. A still from the nozzle camera showing water being removed from the railhead.

NR Trials Autumn 2019

Sites

Trials of the RRV mounted cryogenic cleaning equipment took place during Autumn 2019 across the UK network in 5 locations on both passenger and freight lines (Figure 6). These trials were conducted at an increased travel speed 10mph (maximum permissible for an RRV with a trailer).

Figure 6. Locations of the 5 trial sites on the UK network during Autumn 2019

RRV Set-up

For the use as a railhead cleaning device a prototype skid was developed, carrying the air compressor, generator and specialist dry-ice blasting units developed by The University of Sheffield. The skid was constructed for ease of use, both during transport and on site. All components were securely fastened to the skid, which was fitted with hydraulic outriggers meaning the skid could easily be mounted onto existing Road Rail trailers (Figure 7) propelled by typical RRVs. An electrical control box could quickly be connected and removed, enabling remote operation and monitoring of equipment from the RRV cab. Wireless cameras provided live feed of each nozzle cleaning the railhead

Figure 7. The RRV trailer mounted Cryogenic Cleaning Skid in operation

Outcomes

In order to assess the effectiveness of the technology, photographs of the railhead before and after treatment, along with railhead swabs from both contaminated and clean rail were taken throughout the trials. Where possible this was conducted every mile. The RRV was stopped with sufficient distance from the sampling site to allow for acceleration up to the treatment speed of 10mph when crossing, the sampling site. After the site had been passed, treatment was stopped until photographs and railhead swabs had been taken.

Railhead swabs were chemically analysed though X-ray Photoelectron Spectroscopy (XPS). This was initially conducted for a “blank swab”, which never came into contact with the railhead to obtain a blank reference signal for the species present on the filter paper. This XPS analysis allows the chemical composition of the “blank swab” to be established, so that when swabbing for railhead contamination, there can be a distinction between which species are present on the swab before it touches the railhead, and those that have been transferred to it from the railhead. The percentage atomic content of each species present on the “blank swab” is displayed for comparison against the results of the railhead swabbed before treatment and after treatment.

The results from two locations have been selected for reproduction here, however the trend was confirmed by the other trial sites and therefore have been omitted for repetition.

Oban/Connel

It was noted by both University of Sheffield staff and Network Rail Mobile operations managers (MOMs), that during the selected time for treatment, there was little leaf contamination evident on the railhead. It is understood that the weather conditions including heavy rainfall limited the formulation of the leaf layer. Some contamination (level 1) was identified, Figure 8 shows that this leaf contamination was effectively removed from the railhead, before (a) and after (b).

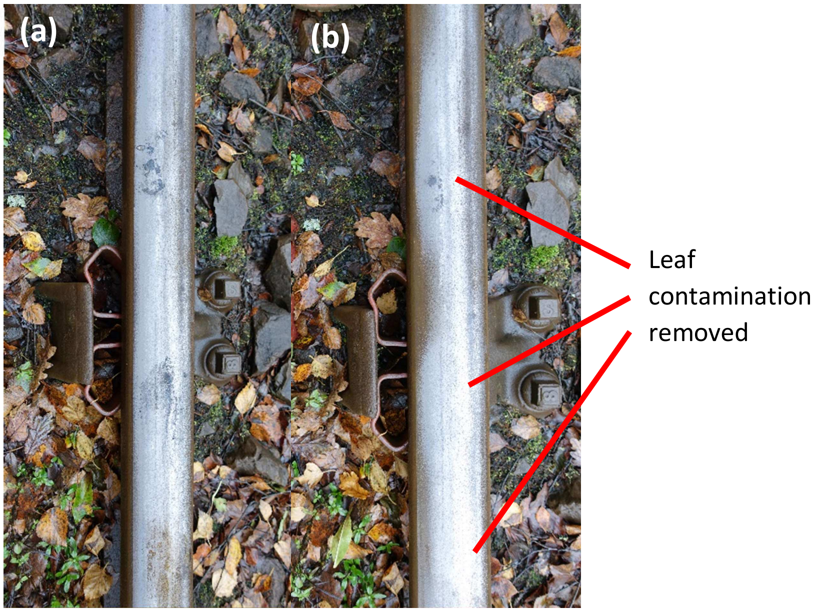

Figure 8. Level 1 leaf contamination present on the railhead before treatment (a), leaf contamination removed (b)

The conditions during and prior to testing meant that the railhead did not have a large amount of leaf layer contamination on, and this can be evidenced by the XPS analysis of the swabs taken. The percent atomic content of each species present on the railhead is displayed in figure 10 for the central running band. The blank reference swab data has been included in each of these figures for easy comparison.

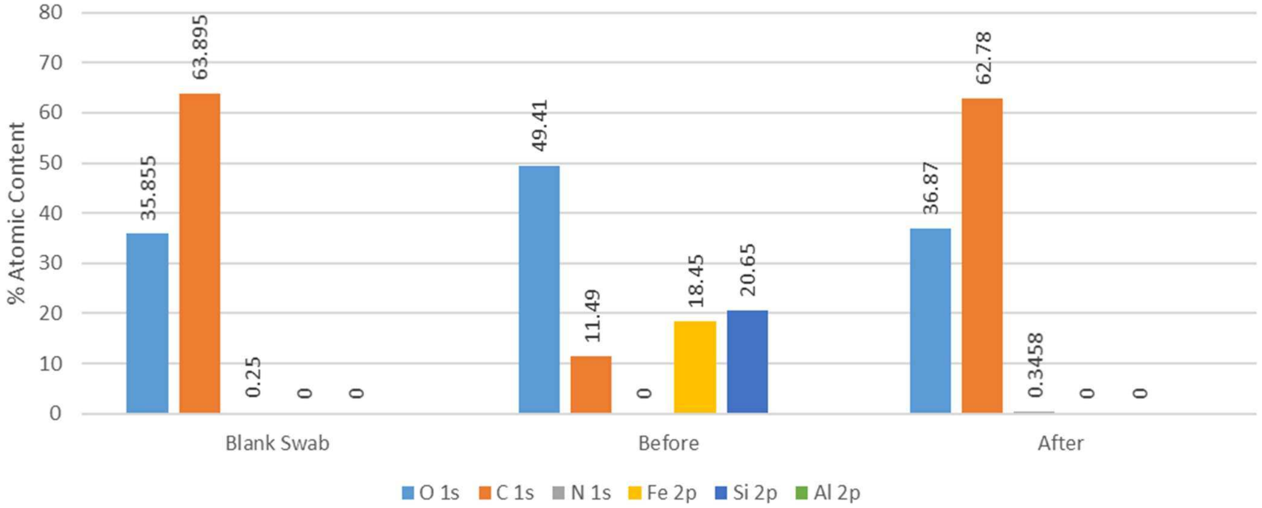

Figure 10. XPS analysis of railhead swabs, left – Blank swab, Centre – Rail before treatment, Right – After treatment

It can be seen from this data that there is a similar trend in the species detected before and after treatment. Prior to treatment analysis reveals that across the width of the railhead, there is **presence of low adhesion causing chemical species** in the form of loosely bonded iron oxides evidenced by the presence of Iron (Fe) and some of the Oxygen (O) species, but no identifiable evidence of leaf contamination. In addition Silica (Si) and Aluminium (Al) are easily identified, with the Silca likely to be from sanders or traction gel applicators (identified as SiO_2) and Aluminium from the protective foil used to wrap the sample. Carbon (C) and Oxygen (O) species as mentioned earlier are present on the blank swab.

Comparing the before and after measurements across the railhead, it can be clearly seen that the low adhesion causing iron oxide species have been **successfully treated** as the iron species have been **completely removed** from the running band to almost undetectable levels on the upper most surfaces of the railhead (10-15 nanometres). At the edges the quantity was significantly reduced, but not completely eliminated, which is a result of nozzle position having been optimised for the running band. The same is true for the silica (Si) as the presence is still observed either side of the running band – indicating that traction gel is still present either side of the running band.

The cryogenic cleaning beam width is yet to be optimised to cover the whole railhead, however, it has been set such that it is aimed at the running band. The current primary cleaning width is approximately 15mm, with some secondary, less intense cleaning spreading wider than this. Both of these zones can be seen to be cleaning in figure 8, here the leaf contamination has been effectively removed from the running band, but also wider afield, with only minor residue remaining.

Deepcar

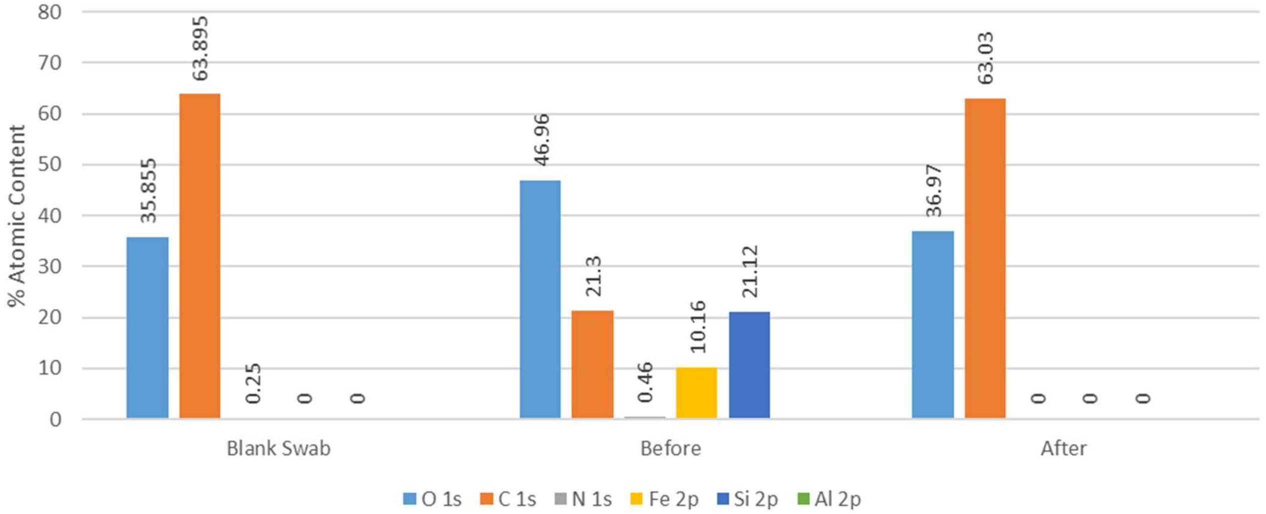

Figure 11. XPS analysis of railhead swabs, left – Blank swab, Centre – Rail before treatment, Right – After treatment

Figure 12: Contaminated untreated railhead (a), treated cleaned railhead (b)

Conclusions

It can be concluded that the cryogenic cleaning equipment successfully removed low adhesion causing species from the railhead such as Iron oxide(s). This was confirmed across a variety of trial sites throughout the UK. Visual inspection and chemical analysis confirmed that these species were removed from the railhead. Trace amounts remained in some cases at the edges of the railhead, where the blast stream has not been optimised for maximum cleaning width. Across all trial sites during the Autumn 2019 season there was found to be very little leaf contamination present on the railhead at the time of the trials. This was seen to be a national trend, due the heavy rainfall limiting the movement of leaves. An additional or extended trial will assist in building confidence that the technology was also capable of removing a typical leaf layer.

Future Steps

The cryogenic cleaning equipment performed well overall, some teething issues were identified such as the importance of weatherproofing. The RRV trailer mounted skid system was found to provide extra flexibility through the self-loading nature, meaning that the transport logistics across the country were simplified.

A method of providing a quick raise and lower of the nozzle bar would have been an advantage during the on/off tracking process. In addition, although the width of the cryogenic blast stream was aligned with the running band, and therefore narrower than the full width of the railhead. It was shown that from the chemical analysis, the edges of the railhead were benefiting from the cleaning process except in rare cases where the railhead condition was poor. It is therefore recommended that the cleaning width of the cryogenic technology should be increased, and made such that curves and cant have less effect of the alignment.

The supply and quantities of dry ice was found to work well, deliveries to site were arranged through IceTech Technologies UK, while University of Sheffield staff transported sufficient to start the testing in each location. It is recommended that for further trials/roll out that a pelletiser system which can produce fresh dry ice from liquid CO_2 be used for the more remote location. This would enable a single liquid CO_2 delivery to be made with the equipment delivery and quantities could be adjusted depending on the weather conditions. It was noted during the use of the trial equipment that a more refined system would be required for the loading of dry ice into the blasting unit hoppers to minimise risk of exposure, and manual handling.

In addition to the recommendations made above for further work on the RRV mounted system(s), it is important to note that future work should include trialling at higher speeds. The operational speed has been restricted by the Network Rail rules and regulations for RRV's. Trialling of the equipment on board an RHTT (Rail Head Treatment Train) or MPV (Multi-Purpose Vehicle) would not only allow higher speed treatment to be trialled, but also on board production of dry ice from liquid CO_2, enabling greater distances to be treated without re-filling.

At the time of writing, plans for further trials and an updated prototype to address the issues raised are being formulated for final testing during Autumn 2020. Furthermore, opportunities for trials at higher speed and on-site production of the CO_2 are being identified. Discussions are presently taking place with regards to establishing suitable manufacturing facilities.

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