Tampere University

MARKET POTENTIAL ASSESSMENT OF CAPTURED SOLID CARBON IN INFRA-STRUCTURES

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September 2024

ISBN 978-952-03-3716-2 (pdf)

ABSTRACT

Market potential assessment of captured solid carbon in infrastructures
Tampere University
September 2024

The market potential of solid carbon obtained with molten salt electrolysis in earth construction applications has been assessed in this report. The assessment was primarily done by investigating the use of foam glass aggregate and expanded clay in earth construction applications in Europe and North America. Other possible small-scale applications were also examined. Online publications and organized exchange of information with professional contacts were used as the main sources of information.

Captured solid carbon products are assumed to be usable in road and field structures in Nordic soil and climate conditions due to their lightness and estimated insulating properties. Based on the annual usage volumes of lightweight aggregates and insulating materials the annual consumption of the carbon products in infrastructures in Finland could be something like 100000 m^3. In Norway and Sweden, the corresponding annual consumption could fall into the range of 50000-200000 m^3. If the carbon products are available in large quantities and at a reasonable price, it might enable utilizing them as a substitutive material for virgin rock aggregates in structurally normal infrastructures. In that case the annual usage volume of the carbon products in Finland could be up to 3.0-3.5 Mm^3 which is equivalent to about 10 % of the annual consumption of virgin rock aggregates in Finland.

Utilizing the carbon products in small-scale applications might be a feasible option if they are not suitable to be used in infrastructures. Small-scale applications include using the carbon products as soil stabilizing agent or as an additive in cement and bitumen production. Utilization potential of carbon nano tubes and fibres in the aforementioned applications has been studied during recent years. The greatest challenge is associated with distributing the nanoparticles evenly with the other substance to avoid agglomeration.

Finding information on the production capacity and output of foam glass aggregate and expanded clay was quite challenging. It may be possible that data regarding lightweight aggregate consumption in building and road construction projects is not collected precisely, or that the production capacity of lightweight aggregates is not known publicly. Therefore, assessing the market potential by investigating the use of other lightweight construction materials was not straightforward. It is also worth noting that the report discusses a completely new material in earth construction that has not yet been utilized in large-scale projects. Therefore, the values of usage volumes presented in this report are only very rough estimates.

Keywords: CCU, captured solid carbon products, expanded clay, foam glass aggregate

The originality of this thesis has been checked using the Turnitin OriginalityCheck service.

TIIVISTELMÄ

Talteen otetun kiinteän hiilen tuotteiden markkinapotentiaali infrarakenteissa
Tampereen yliopisto
Syyskuu 2024

Tässä raportissa on tarkasteltu sulasuolaelektrolyysillä tuotettujen kiinteän hiilen tuotteiden markkinapotentiaalia infrarakenteissa. Hiilituotteiden menekkiä arvioitiin ensisijaisesti tutkimalla vaahtolasin ja kevytsoran käyttömääriä infrarakenteissa Euroopassa ja Pohjois-Amerikassa. Raportissa tutkittiin myös muita mahdollisia pienemmän mittakaavan käyttökohteita hiilituotteille. Lähdeaineistona käytettiin nettilähteitä sekä organisoitua tiedonvaihtoa ammattilaiskontaktien kesken.

Talteen otettujen kiinteän hiilen tuotteiden arvellaan soveltuvan käytettäväksi muun muassa tie- ja kenttärakenteissa pohjoismaisissa maaperä- ja ilmasto-olosuhteissa niiden keveyden ja arvioitujen lämmönjohtavuusominaisuuksien ansiosta. Kevennys- ja lämmöneristysmateriaalien käyttömäärien perusteella arvioituna hiilituotteiden vuotuinen menekki infrarakenteissa Suomessa voisi olla 100000 m^3 suuruusluokkaa. Ruotsissa ja Norjassa vastaavan vuotuisen potentiaalisen menekin arvioidaan olevan yhteensä 50000–200000 m^3. Jos hiilituotteita on saatavilla suuria määriä niin edullisesti, että niillä voidaan korvata neitseellisiä kiviaineksia niiden tavanomaisissa käyttökohteissa, voisi hiilituotteiden vuotuinen käyttömäärä Suomessa olla jopa 3,0–3,5 Mm^3, joka vastaa noin 10 % Suomessa vuosittain käytetystä neitseellisen kiviaineksen määrästä.

Hiilituotteita voitaneen käyttää pienemmän mittakaavan käyttökohteissa, mikäli ne eivät sovellu käytettäviksi sellaisinaan infrarakenteissa. Esimerkkejä pienemmän mittakaavan käyttökohteista ovat muun muassa käyttö maan geoteknisiä ominaisuuksia parantavana aineena tai käyttö sementin tai bitumin lisäaineena. Viime vuosina on tutkittu hiilinanoputkien ja -kuitujen käyttömahdollisuuksia edellä mainituissa käyttötarkoituksissa. Pienen mittakaavan käyttökohteissa suurin haaste on nanohiilen tasainen sekoittaminen toiseen aineeseen.

Tiedon löytäminen kevytsoran ja vaahtolasin käyttö- ja tuotantomääristä oli hankalaa. Voi olla, ettei niiden käyttöä tilastoida tarkasti, tai ettei tietoa ole julkisesti saatavilla. Sen vuoksi hiilituotteiden markkinapotentiaalin arvioiminen muiden kevennemateriaalien käytön perusteella ei ollut yksiselitteistä. On myös huomioitava, että raportissa käsitellään infrarakentamisen kannalta täysin uutta materiaalia, jota ei ole vielä käytetty suuren mittakaavan hankkeissa. Sen vuoksi raportissa esitetyt arviot mahdollisista käyttömääristä ovat vain suuntaa antavia.

Avainsanat: CCU, kevytsora, talteen otetut kiinteän hiilen tuotteet, vaahtolasimurske

Tämän julkaisun alkuperäisyys on tarkastettu Turnitin OriginalityCheck –ohjelmalla.

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1. INTRODUCTION

This report aims to assess the market potential of solid carbon products obtained with molten salt electrolysis in earth construction applications. The market potential is assessed by investigating the use of two common lightweight construction materials, foam glass aggregate and expanded clay, in earth construction applications in Europe and North America. Small-scale utilization potential of the carbon products as a soil stabilizing agent and as an additive in asphalt binder production is also discussed.

The report is carried out at Tampere University's Research Centre Terra as a part of an interdisciplinary Bio-CCU research project.

2. UTILIZATION OF CAPTURED SOLID CARBON PRODUCTS IN INFRASTRUCTURES

Orkola (2024) has examined the utilization potential of solid carbon products obtained with molten salt electrolysis as an alternative earth construction material in infrastructures in his Master of Science thesis. The thesis focused on the following aspects: technical characteristics, possible earth construction applications, factors hindering the utilization potential, and the scale in which captured solid carbon products could be utilized. The results and conclusions of the work are presented, and their relevance in Nordic climate conditions is discussed in this Chapter.

The technical feasibility and the scale in which the captured solid carbon products could be utilized in infrastructures were evaluated on a theoretical basis by conducting preliminary frost protection design and settlement analysis of an imaginary road embankment, in which captured solid carbon products were utilized, according to the Finnish road design guidelines (Liikennevirasto 2018). Additionally, the performance of a 1 km long road embankment in which captured solid carbon products are utilized was compared to that of a normal embankment in three different use cases. The differences in occurring settlements and natural aggregate usage as well as the achievable benefits in frost protection design were examined.

2.1 Frost protection design

The performance against frost action of two imaginary road embankments was examined theoretically. The other embankment was built of natural aggregates (CRA) and the other was partly built of natural aggregates and captured solid carbon products (CSCP). The total thickness of both embankments was 1350 mm, and the embankments were assumed to be located on a well bearing but frost susceptible subsoil in Southern Finland where the theoretical frost penetration depth is 1600 mm on sandy soil during the freezing season. The obtained maximum frost heaving values were compared to the maximum allowable frost heaving values of different road types. It was assumed that captured solid carbon products are non-frost susceptible and due to their porous structure, their thermal insulation properties are better than those of sand but not as good as those of actual frost insulation materials like expanded clay or crushed foam glass aggregate.

In the investigated circumstances the CSCP embankment prevented the frost front from proceeding into the subsoil and therefore no frost heaving was taking place. However, the frost front proceeded through the CRA embankment causing mild frost heaving.

With these assumptions and observations, the utilization of captured solid carbon products seems viable and beneficial at least in the lower structural layers of roads or similar structures when it comes to frost protection design.

2.2 Settlement analysis

In settlement analysis the settlements occurring under road embankments built of different materials, including natural aggregates (CRA), natural aggregates and captured solid carbon products (CSCP), and natural aggregates and crushed foam glass aggregate (CFGA), were investigated in varied subsoil conditions. The subsoil consisted of a dry crust layer, clay layer, and moraine layer in respective order from top to bottom. The thickness of the dry crust layer, the characteristics of the clay layer, and the embankment height were varied. The settlements were calculated with Janbu's tangent modulus method which only considers the consolidation settlement. The obtained results were then compared to the maximum advisable settlements of different road types.

The unit weight of captured solid carbon products was assessed approximately in laboratory. According to the laboratory tests, the unit weight of the carbon products was in the same order of magnitude as that of foam glass aggregate. An approximated value of 9 kN/m^3 was used in the calculations as the unit weight of the carbon products as the carbon products are expected to be in a well compressed state. The approximated unit weight is roughly half the unit weight of sand and double to that of expanded clay or crushed foam glass aggregate.

According to the settlement calculations the greatest settlements were caused by the CRA embankments and the least by the CFGA embankments. The CSCP embankments performed relatively well in comparison to the CRA embankments. Based on the obtained results partial replacement of crushed rock aggregates with captured solid carbon products seems to be possible in road embankments. Utilization of captured solid carbon products as lightweight construction materials reduces the overall stresses, settlements, as well as stability issues on structures built on soft subsoil. The reduction in overall stresses also reduces the need for expensive and emission intensive subgrade reinforcement procedures in certain situations.

2.3 Technical feasibility

The first use case investigated the achievable material savings when a 1000 mm thick layer of crushed rock aggregates is replaced with captured solid carbon products in a 1.7 m thick road embankment. Replacing the crushed rock aggregates in the layer with captured solid carbon products enabled reducing the amount of crushed rock aggregates by 10500 m^3 which roughly corresponds to 49 % of the total embankment volume.

The second use case investigated the benefits that are achievable in frost protection design with utilization of captured solid carbon products. Originally 1.7 m thick CRA and CSCP embankments were redesigned to limit the theoretical frost heaving value to 10 mm. The thickness of the CSCP embankment was reduced by 540 mm to a total of 1160 mm while the thickness of the CRA embankment could only be reduced by 40 mm to 1660 mm. In this case the use of captured solid carbon products allowed reducing the total embankment thickness remarkably and at the same time it saved roughly 12000 m^3 or 59 % of rock aggregates.

The point of the third use case was to evaluate the settlements occurring under the re-designed CRA and CSCP embankments when they are built on weak Finnish clay. The total settlements of the CSCP embankment remained below 400 mm which corresponds the maximum allowable settlement for highways in Finland. The total settlements of the CRA embankment were roughly 600 mm and the 400 mm limit value was exceeded when the clay layer thickness exceeded 5 m.

Utilization of alternative construction materials in earth construction applications reduces the use of valuable natural resources such as sand, gravel, or crushed rock aggregates. In urban areas these materials might already be in short supply. So, even though the use of captured solid carbon products would not be beneficial in terms of frost protection or settlement resistance design the use of natural resources is reduced anyway.

In the second and the third use case the utilization of captured solid carbon products enabled reducing the total embankment thickness. Lighter and thinner embankments inflict less stress on the subsoil which reduces the occurring settlements and the need for expensive and emission intensive subgrade reinforcement measures as well as the probability of stability issues. These features are of uttermost importance on weak subsoils.

To sum up the observations, utilization of captured solid carbon products in road embankments may be beneficial in terms of frost protection design and reducing settlements. It may also save remarkable amounts of natural and crushed rock aggregates as well as reduce the need for expensive subgrade reinforcement procedures. However,

there are some uncertainties regarding the material's technical characteristics, like grain size distribution and load bearing capacity, as they could not be examined thoroughly within the scope of the work.

3. MARKET POTENTIAL OF CAPTURED SOLID CARBON PRODUCTS IN INFRASTRUCTURES

3.1 Research approach in market potential assessment

The market potential of captured solid carbon products in infrastructures is discussed in this Chapter. The market potential was assessed primarily by investigating the use of two common lightweight construction materials, namely foam glass aggregate and expanded clay, in earth construction applications. The investigated regions include the Nordic countries, Europe, and North America. Scientific publications and various online material were used as the source material. In addition, the results of online survey were supplemented by organized exchange of information with the following professional contacts:

Sweden

- Professor Sigurdur Erlingsson, Swedish Road Research Institute
- Geotechnical specialist Johan Ullberg, Swedish Road Administration

Norway

- Professor Inge Hoff, The Norwegian University of Science and Technology

USA

- Professor Erol Tutumluer, University of Illinois Urbana-Champaign

Canada

- Professor Jean-Pascal Bilodeau, Laval University
- Dr. Pauline Segui, Laval University

3.2 Foam glass aggregate consumption and production

Foam glass production was commenced in Finland in 2011 with the annual production capacity being 150000 m^3. Since 2016 the annual production capacity has been approximately 300000 m^3. Roughly 80 % of the production output has been utilized in earth construction applications. A small proportion of the output has been exported to Sweden, Norway and the UK. (Vanhanen 2015, Tekniikka & Talous 2024)

In Norway the annual consumption of foam glass in road construction was 11000 m^3 between 1998 and 2005 (Aabøe et al. 2005). According to another source the combined foam glass consumption in road construction projects in Norway and Sweden has been 83000 m^3 between 1998 and 2005 (Eriksson & Hägglund 2008). Nowadays the annual foam glass production capacity in Sweden is roughly 180000 m^3 (Hasopor 2019).

In the UK, the first foam glass production plant was put into operation in 2023 with an annual production capacity of 240000 m^3. Most of the output is assumed to be used as feedstock for lightweight concrete. (Glass worldwide 2023)

The biggest foam glass production plant in North America was put into operation in 2017 in Philadelphia, US. Originally the annual production capacity of the plant was 65000 m^3 but the production was doubled already on the next year. In 2020 the production capacity was increased by 60000 m^3 so nowadays the production capacity of that particular plant is approximately 190000 m^3. Meanwhile the first foam glass plant in Canada was put into operation in 2023. (SGGC 2017, SGGC 2018, SGGC 2020, SGGC 2023)

3.3 Expanded clay consumption and production

Expanded clay is manufactured in many European countries and North America. Saint-Gobain is the market leader in Europe with their own Leca brand. The company has production plants at least in Denmark, Finland, Norway, Sweden, Germany, Portugal, Estonia, and Poland. Expanded clay is used as feedstock for Leca lightweight aggregate concrete blocks, insulating material, lightweight construction material in earth construction, plant substrate, and in water purification and storm water management systems. (LECA 2024)

In Finland, the expanded clay production has been centralized to Kuusankoski. The annual production capacity is not known publicly but according to one source it has been roughly 500000 m^3 since 1991. (Kivitaloinfo 2021) In the 1990's about half of the output was utilized as feedstock for lightweight aggregate concrete blocks and the other half was utilized as insulating material in building construction projects (Kilpailu- ja kuluttajavirasto 1999). For comparison, the annual expanded clay production in Estonia is known to be at least 350000 m^3 (LECA 2021).

Kivi (2021) conducted a brief online survey in his Master of Science thesis for Finnish construction professionals regarding the use of various ground reinforcement methods and lightweight materials. The professionals who responded to the survey estimated that they use a total of approximately 45000 m^3 of foam glass aggregate and expanded clay in infrastructure construction projects annually. According to one interviewee, lightweight

materials are more often used in building construction projects than in road and street construction projects. The choice of lightweight aggregate is primarily influenced by the distance between the aggregate production facility and the construction project.

Expanded clay production was initiated in the US already in the early 20th century. Nowadays there are numerous production plants and most of the production output is used in building construction projects. Expanded clay seems to be a relatively new road building material in the US as it has been utilized in only a few road construction projects. (Saboundjian & Armstrong 2003, ESCSI 2007, Saride et al. 2008, Tutumluer & Qamhia 2024)

3.4 Trends in the use of lightweight embankment fill materials

As it comes to current trends in the use of foam glass, expanded clay aggregates and different types of alternative materials as lightweight embankment fill materials according to Hoff (2024), Ullberg (2024), Tutumluer (2024) and Bilodeau (2024) both in the Nordic countries and North America the trend seems to be that foam glass is replacing expanded clay aggregate. The main reasons for this development are considered to be the simpler handling of foam glass aggregate with normal construction equipment and sustainability aspects as foam glass aggregate is produced using recycled raw material. The usage volume of expanded polystyrene (EPS) blocks is rather marginal in all of the investigated countries except in Canada were EPS and extruded polystyrene (XPS) are standardized materials for infrastructure construction (Bilodeau 2024).

In general, it can be concluded that interest in more widespread use of various types of alternative materials in infrastructure construction applications is emerging, but there is still quite of a lot of lack in the knowledge concerning the long-term performance and lifecycle assessment based environmental impacts of them (Tutumluer & Qamhia 2024). Quite obviously this concerns also the use of captured solid carbon material in infrastructure construction.

3.5 Small-scale utilization potential

Before the carbon products can be utilized in large-scale, it is reasonable to think of their utilization potential in small-scale applications first. The utilization potential of small amounts of nanocarbons in improving the geotechnical characteristics of fine-grained soils has been studied during recent years and the results have been auspicious.

Morais et al. (2024) investigated the effects of adding small amounts of carbon nanotubes on the geotechnical characteristics of a lateritic soil. Lateritic soil forms in tropical

and subtropical regions in humid climate as a result of rocks weathering under strongly oxidizing and leaching conditions. Lateritic soils are often porous and claylike, and rich in iron oxide. (Britannica 2024) Adding small amounts of carbon nanotubes into the soil improved its compressibility characteristics by decreasing its liquid and plastic limits. Adding 0.2 % of carbon nanotubes decreased the liquid limit by 10 % and plastic limit by 13 %. No significant effect on the soil's specific gravity, maximum dry density or optimal water content was noted.

Al-Obaid et al. (2022) investigated the effects of adding small amounts of carbon nanofibers and nanotubes on the geotechnical characteristics of a mixed soil with mostly sandy texture. The plastic and liquid limits as well as the plasticity index, dry density, water content, permeability, pH, and specific gravity were examined. A slight decrease was noted in specific gravity and permeability. Plastic limit and liquid limit both increased while the plasticity index decreased. Also, pH and dry density increased slightly with increasing nanocarbon content.

Taha et al. (2018) examined the effects of adding small amounts of carbon nanotubes on the swelling and shrinkage behavior of clay. The clay samples were mixed with varied amounts of bentonite and carbon nanotubes and nanofibers. The swelling and shrinkage behavior was evaluated based on the crack intensity factor. The addition of nanocarbons was noted to decrease the expansive and shrinkage strain of the clay due to the high aspect ratios of the nanomaterials. The specific gravity and maximum dry density also increased slightly.

Another study by Taha & Alsharef (2018) focused on the geotechnical effects of adding small amounts of nanocarbons into a soil. The investigated soil was classified as clayey sand according to the Unified Soil Classification System (USCS). The addition of nanocarbons caused a slight increase in the soil's dry density and pH. No significant effects were observed on the plasticity index or optimum water content but a slight decrease in the specific gravity was noted. Water permeability on the other hand decreased remarkably with increasing nanocarbon content.

According to the studies presented in this Chapter, mixing small amounts of nanocarbons with fine-grained soils may have a positive influence on the geotechnical characteristics of the soil. For example, the nanocarbons' tendency to reduce desiccation cracking of clays might be a useful feature in sealing structures of landfill sites. Also, the pH increasing feature might be of use in soil remediation purposes. On the other hand, changes in the permeability of the soil might not be desired.

Krishnan & Shukla (2019) conducted an extensive review on soil behavior stabilized with various nanomaterials including nanocarbons. The outcome of the review is that the variation in soil properties due to the addition of nanoparticles is not understood yet. Also, there are still challenges associated with large-scale utilization of nanoparticles in soil. According to Taha et al. (2018) the greatest challenge is associated with distributing the nanoparticles evenly in the soil body as they tend to agglomerate together. Therefore, more research is needed to better understand the variation mechanisms in soil properties due to the addition of nanoparticles, and to overcome the challenges in mixing the soil with the nanoparticles.

Other possible small-scale applications include utilizing the carbon products as reinforcing materials in cement production, or as a substitute material in asphalt filler production. Han et al. (2011) have covered extensively the possibilities and challenges related to using nanocarbons as an additive material in cement production.

Some research has been conducted during recent years on utilizing carbon nanotubes in asphalt filler production (Gong et al. 2018, Yang et al. 2020, Zhang et al. 2022) Gong et al. (2018) stated that the addition of carbon nanotubes in the binder mixture improves its rutting resistance and anti-aging characteristics. It also improves the binder's performance on high temperatures by decreasing the penetration and increasing the softening point of the binder. Yang et al. (2020) and Zhang et al. (2022) noted that the addition of carbon nanotubes in the binder mixture improves its performance on high temperatures but reduces its resistance against cracking in low temperatures. Zhang et al. (2022) also noted that adding 1.5 % of carbon nanotubes into the mixture had a positive influence on the binder's self-healing properties. When the nanotube content exceeded 1.5 %, agglomeration of the nanotubes was observed in the mixture.

Resistance against cracking and aging are important asphalt binder characteristics. However, increasing binder stiffness decreases its resistance against transversal cracking caused by freezing temperatures. Therefore, stiff binders are not very well-suited for regions with cold climatic conditions such as the Nordic countries. Utilizing the carbon products in asphalt binder might be possible in warmer regions where freezing temperatures are less likely to occur.

More research is needed before the small-scale utilization potential of captured solid carbon products can be evaluated reliably. Research is needed on the material's applicability as a soil stabilizing agent and as an additive in asphalt binder and cement production. The greatest challenge in these applications is mixing the carbon products uniformly with the other material without causing particle agglomeration.

3.6 Market potential assessment

There is a growing demand for lightweight road construction materials with good insulating properties in the Nordic countries. The demand is boosted by the need to reduce the use of natural aggregates, and the need to guide urban development and zoning towards previously unbuilt areas where the subsoil conditions are poor. The latter applies especially to growing urban areas.

It seems that outside the Nordic countries lightweight construction materials are more likely used in building construction projects and that their light weight is not necessarily seen as an advantage in road construction projects. In general, lightweight construction materials might be a rather new concept in road construction projects at least in North America. However, the need for efficient frost protection of roads is recognized at least in Canada where extruded and expanded polystyrene blocks and panels are widely being used for pavement insulation purposes. In fact, they are the only standardized insulating materials even though other insulating materials like foam glass aggregate are already available on the market. (Ghafari et al. 2019)

Let's discuss the utilization volumes in the Nordic countries. In Finland, the annual usage volume of foam glass aggregate in infrastructures is estimated to be 240000 m^3 since the annual production output is 300000 m^3 of which 80 % is utilized in earth construction. When expanded clay and other possible lightweight construction materials are taken into consideration, the estimated total annual usage volume of lightweight aggregates in earth construction applications is in the range of 250000-350000 m^3.

Total foam glass aggregate consumption in road construction projects in Norway and Sweden has been 83000 m^3 between 1998 and 2005. It is expected that the annual consumption has increased since then.

If the captured solid carbon products can compete with price, their technical characteristics are comparable to those of foam glass aggregate and expanded clay, and their hauling distance is shorter, then they have potential to become a viable alternative to those materials. In that case the annual usage volume could be something like 100000 m^3 in Finland. In Norway and Sweden, the annual usage volume could be something like 50000-200000 m^3.

Another possible scenario is that the carbon products are available in large quantities at a reasonable price, and their technical characteristics resemble those of natural aggregates. In other words, the carbon products are used to replace natural aggregates and not necessarily utilized as lightweight or insulating material.

Let’s discuss the annual rock aggregate consumption in Finland. According to Syke (2023) the annual rock aggregate consumption in Finland is about 120-140 Mtons (57-67 Mm^3) of which about 60 % are excavated from mines, quarries, and other excavation sites, and the remaining 40 % are extracted from construction sites. According to Huhtinen et al. (2018) the annual rock aggregate consumption in Finland is about 200 Mtons (95 Mm^3) of which the amount of virginal rock aggregates is roughly 70 Mtons (33 Mm^3). Another 70 Mtons (33 Mm^3) is extracted from construction sites and the remaining 60 Mtons (29 Mm^3) consist of attle. The presented aggregate consumption values are converted from tons to cubic meters by assuming that the bulk density of the rock aggregate is 2,1 t/m^3.

It can be assumed that the annual consumption of virginal rock aggregates in Finland is roughly between 30 and 35 Mm^3. It is unlikely that the virginal rock aggregates could be completely replaced with alternative materials because in some applications it is simply a superior material. Anyway, if even 10 % of the annual consumption of virginal rock aggregates can be replaced with the carbon products, then their annual usage volume would be about 3.0-3.5 Mm^3 in Finland.

4. CONCLUSIONS

Utilizing alternative lightweight construction materials with good insulating characteristics in traffic infrastructures reduces the need for expensive and emission intensive subgrade reinforcement procedures when constructing on soft post-glacial soil deposits. Another benefit of utilizing alternative construction materials is the reduction in the consumption of natural aggregates. Captured solid carbon products are presumed to be suitable for use in infrastructures due to their light weight and estimated thermal insulation properties.

The market potential of captured solid carbon products in earth construction was evaluated by investigating the production output and utilization volumes of two common alternative construction materials, namely foam glass aggregate and expanded clay. In Finland the annual consumption of captured solid carbon products in road construction projects is expected to be something like 100000 m^3 whereas in Norway and Sweden the annual consumption is expected to fall in the range of 50000-150000 m^3.

In Finland, the annual consumption of virginal rock aggregates is approximately between 30 and 35 Mm^3. If 10 % of this amount can be replaced with captured solid carbon products, then their annual consumption would be something like 3.0-3.5 Mm^3. This requires that the carbon products are available in large quantities and at a reasonable price, and that their technical characteristics resemble those of natural aggregates.

Utilizing the carbon products in small-scale applications might be a feasible option if they are not suitable to be utilized in large-scale applications. Possible small-scale utilization applications include using the carbon products as additive or strengthening agent in cement or asphalt binder production, or as a soil stabilizing agent. The greatest challenge regarding the small-scale applications is mixing the carbon products uniformly with the other material without causing particle agglomeration.

Finding information regarding the production capacity and output of foam glass aggregate and expanded clay was quite challenging. It may be possible that data regarding lightweight aggregate consumption in building and road construction projects is not collected precisely. It is also possible that the production capacity of lightweight aggregates is not known publicly. Some market analysis reports which were focused on foam glass aggregate and expanded clay consumption and production were however found on the internet. Two sample reports were received regarding the use of foam glass aggregate,

but the sample reports were mainly meant for advertising the full reports which were subject to a charge.

Captured solid carbon products are a completely new material in earth construction. The material has not been utilized in large-scale projects yet. Therefore, the values of usage volumes presented in this report are only rough estimates.

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