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Project Full Name: An Universal Flexible Low-cost Plumbing and Heating pipe system fully Environment-compatible by using innovative Nanoparticle technology

Final Report

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Final Report

PROJECT FINAL REPORT

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Name of the scientific representative of the project's co-ordinator, Title and Organisation:	Mr. Ole Larmerud NORSKE RORLEGGERBEDRIFTERS LANDSFORENING VVS
Tel:	+47 23 08 76 61
Fax:	+47 22 60 83 01
E-mail:	ole.larmerud@nrl.no
Project website address:	www.greenflextube.org

Final Report

Please note that the contents of the Final Report can be found in the attachment.

4.1 Final publishable summary report

Executive Summary

The NanoFlex technology replaces non-recyclable plastic pipes used by the building and construction community with an environmentally friendly pipe that meets EU Directives concerning landfill and waste management.
The building and construction sector in Europe is, with a market share of 23% and 8.3 million tonnes of plastics, the second largest user of plastics after the packaging sector. Plastic pipes have become the material of choice for the building industry, in particular in the growing market for building renovation. Today the market share of plastic pipes is higher than that of metal pipes and has reached 56%. It is forecast that this market share will continue increasing whilst the market share of metal pipes will steadily decrease. The sector is fundamentally concerned with long-lasting products, which may well be in place for 40 years before they require replacement. There is little experience of practical recycling of plastic building products on a large scale, about 3,500 tonnes of scrap plastic pipes are disposed of annually in landfill due to the use of non-recyclable plastics.
The building and construction community in Europe faces the challenge of reducing the environmental impact from waste materials and meeting two EC Directives concerning this topic.
The EU Landfill Directive (1999/31/EC) demands a reduction in land filling to reduce harmful methane emissions. Removing caloric waste from landfill across Europe could save up to 27% of the EU's 2020 CO# emissions reduction target.
The EU Waste Framework Directive (2006/12/EC) demands a five step waste hierarchy with firstly prevention, secondly reduction, then re-use, recovery and finally disposal of waste. A revision of this Directive (2008/98/EC) adopted in June 2008, states that treatment can deviate from the waste hierarchy if this is justified from a life-cycle perspective.
Under floor heating, radiator heating and sanitary plumbing systems are the key hot and cold water pipe applications. In Europe 46% of such pipes are manufactured from non-recyclable PEX or PEX/AL. These pipes are multilayer pipes where the inner and outer layers inhibit scaling and corrosion and the centre layer (EVOH or Al) provides a necessary oxygen barrier layer.
By offering an environmentally-compatible plastic pipe for under-floor heating, radiator heating and sanitary plumbing systems, it will minimise costs of waste management and result in a high quality product with fail safe operational and economic benefits.

Summary description of project context and objectives

The primary aim of the NanoFlex project was to develop a universal, flexible and low-cost plumbing and heating pipe system suitable for use in hot and cold water systems including under-floor heating and drinking water distribution. It was proposed to develop a thermoplastic pipe without PEX, without bonding of layers and without an integral aluminum layer layer to allow 100% of scrap pipe to be recycled.
In order to achieve this overall aim, the consortium needed to overcome a number of scientific and technical hurdles which had a defined list of key objectives listed below:
Scientific objectives:
1. Studies to select an optimal low-cost thermoplastic.
2. Create an oxygen barrier layer by using uniformity orientated nanoparticles.
3. Optimise pipe flexibility by using an unbonded 4-layer system.
4. Optimise strength properties and pressure resistance by wrapping with self-reinforced tapes.
5. Optimise heat resistance.
6. Optimise slide properties.

Technical Objectives:
1. To develop a process to extrude a self-reinforced plastic tape with a thickness <0.2mm.
2. To develop nanoparticle compounds with best achievable distributive mixing and dispersion of nanoparticles of montmorillonite clay (nanoclay) for use with the optimal low-cost thermoplastic.

3. To develop a process that can coat the self-reinforced plastic tape with 3%-5% nanoclay and a coating film <100µm and achieve a uniform alignment of the particles to achieve oxygen permeability <0.1 g/m³d (DIN4726).
4. To develop a process that wraps the inner pipe with nanoclay coated tape and maximises strength (test burst pressure 80 bar, tensile strength >25N/mm², ultimate elongation 450%-500%) and flexibility (elasticity modulus 500N/mm², limiting bending stress 20N/mm², coefficient of expansion 1.4x10-4 K-1) and temperature resistant (95°C at 10 bar).
5. To develop an outer layer with improved slip properties and reduce noise impact (sound velocity <700ms-1)
Integration Performance Objectives
1. To develop a minimum of two dimensions, 12 x 2 and 16 x 2 (outer diameter x wall thickness).
2. To develop a pipe suitable for pipe-in-pipe systems (mandatory in Scandinavia for drinking water pipes).
3. To produce a high quality flexible pipe that can be produced for <€0.5 per metre and cost-effectively sold for €1.10 per metre (retailer price).

The principle innovations are:
a) Development of nanoparticle compounds produced using optimal compounding conditions with best achievable distributive mixing and dispersion of nanoparticles of montmorillonite clay for use with a ;ow-cost thermoplastic.
b) Development of a tape extrusion process that allows production of a self-reinforced plastic tape by extrusion and stretching to its limits of extension.
c) Development of a nanoparticle film coating process that coats the tape with a molten polymer layer of the same polymer from which the tape is made with about 3%-5% nanoparticles of montmorrillonite clay addition level in the coating. The film coating must have a thickness <100µm.
d) Development of a pipe extrusion and wrapping process that allows extrusion of the inner pipe layer and its wrapping with two layers of previously developed self-reinforced nanoparticle coated tape.
e) Development of a crosshead extrusion process that allows coating with an outer layer and a surface treatment to improve slip properties and reduce noise impact (sound velocity <600ms-1).

Description of main S & T results/foregrounds

1. Enhancement of Scientific Knowledge on Plastics & Pipes & Nanocomposites.

A search of European and national standards on plastic pipes for use in under-floor heating, radiator heating and plumbing was conducted in order to identify product requirements based on current technologies, standards and practices. Literature studies were conducted on thermoplastics and their use as self-reinforced plastic and in-pipe production. Literature reviews were also carried undertaken on nanocomposites and corresponding protocols for surface compatibilisation, exfoliation and compounding conditions. Barrier properties and estimated oxygen permeability achievable with nanocomposites was also investigated. The requirements for the production of nanocomposites and pipes were researched and compared the findings with project objectives to produce a product specification. The following conclusions were reached:
a) The multi-layer pipe will need to meet European dimensions to standard EN161-1 and European piping system requirements EN ISO21003.
b) Mechanical approval of the pipe will have to comply with EN ISO 21003 (part 2). For fittings, part 3 can be used and for piping systems part 5.
c) The pipe will need to comply with ISO17455 for oxygen permeability approval.
d) The pipe will need to comply with EN ISO7686 for opacity requirements.
e) For hygienic requirements there is a voluntary approval process in operation in Scandinavia, similar processes exist in Germany, France and the United Kingdom.
Literature studies were conducted on thermoplastics and their use as self-reinforced plastic and in plastic pipes, this included an investigation into thermal characteristics, barrier properties, tensile strength, heat and burst pressure resistance and corresponding protocols for extruding thermoplastics.
PE-RT Type II (Dowlex 2388 RE resin) was identified as the best candidate material. This is because it is an approved material, cheap, flexible, easy to extrude, 100% recyclable, environmentally-compatible, widely accepted and capable of being used in pipes with thin walls.
We enhanced our knowledge of nanoparticle compounds with a literature study on the use of nanocomposites in thermoplastics and corresponding protocols for surface compatibilisation,

exfoliation and compounding conditions. We identified commercially-available nanoclays and investigated the barrier properties of these materials. We also estimated the oxygen permeability achievable with nanocomposites. D1.3 reported on nanocomposites and their use as an oxygen barrier.

Literature studies showed that the clay most often used as a barrier layer is Montmorillonite (MMT) which is hydrophilic and therefore not miscible with hydrophobic polymers like polyolefins. MMT consists of stacked negatively charged aluminium silicate layers, the thickness of the individual aluminium silicate layers being about 1 nm and their diameter 100 – 2000 nm. Inorganic cations are found in between the clay layers to satisfy the condition of electro neutrality. The clay layers can be separated from each other (exfoliated) in water, then the inorganic cations exchanged with organic cations. After washing and drying, a hydrophobic 'organoclay' is obtained, which can be mixed with hydrophobic solvents or polymers. For polyolefins the preferred cation is quaternary ammonium with two long alkyl chains and two methyl groups (usually dimethyl dihydrogenated tallow: M2(HT)2). If the clay can be separated into individual layers and exfoliated, then aligned perpendicular to the direction of diffusion, a barrier effect is obtained, as oxygen has to diffuse through an impossibly long, tortuous path. To achieve exfoliation of organoclay with M2(HT)2 in polyolefin, a modified polyolefin (compatibiliser) must also be used. This contains polar groups that can interact with the surface of the clay and aid exfoliation. In the most favourable case, it has been possible to reduce the oxygen permeability of polyolefins by 2 – 3 orders of magnitude. Biaxial stretching of clay polymers films improves their barrier properties. This can be applied to the production of barrier tapes that can be wrapped around pipes to give a barrier layer. In D1.3, we suggested that the following approaches should be tested:
- Composites of edge-modified clay and polyethylene.
- Composites containing high clay content (20 – 25 wt%) in modified polyethylene.

Both composites can either be extruded as a layer on an inner pipe or wrapped around an inner pipe to give a barrier layer. Highlight clearly significant results: D1.2, D1.2 and D1.3 show that M1.1 (Creation of a body of new enhanced understanding and scientific knowledge that enables the development of a process to manufacture environmentally-compatible universal plastic pipes) has been met. The selection of PE-RT and modified clays is as expected.

2. Development of Nanoparticle Compunds.

The techniques and protocols identified in WP1 were used to establish a process for the dispersion of suitable nanoclay in a selected polymer. A process to exfoliate the nanoclay in the selected polymer process was developed and a compounding process to achieve the best mixing and dispersion conditions for the nanoclay.

A process for the compatiblisation of nanoclay for dispersion in the in PE-RT II and maleated polyethylene was developed and different compatibilisation techniques and compatibilisation agents were tested to achieve optimal compatibilisation with PE-RT II and maleated polyethylene. A process to exfoliate the previously compatibilised nanoclay in PE-RT and maleated polyethylene was developed. Best exfoliation was achieved by compounding nanoclay with maleated polyethylene at 170°C for 10 minutes at 100 rpm and 72% fill volume in a Haake 600p Rheomix. The quality of exfoliation with electron microscopic examinations, are listed in detail in D2.2.

A compounding process to mix and disperse the compatibilised nanoclay was established, this maximises the percentage of exfoliated compatibilised nanoclay. Testing of the quality and degree of exfoliation was undertaken using electron microscopic examinations, recording them in D2.2. D2.2 reports on the development of prototype nanocomposites. It describes the methods and materials used, such as for edge modification of clay with 1-hydroxy-dodecane-1,1-diposphonate and polyethylene-block-(polyethylene glycol). It also describes the results of compounding commercial clay with unmodified polyethylene, then compounding of commercial clay with commercial compatibilisers consisting of maleated polyethylenes. The results of compounding of the edge modified clay with polyethylene and with compatibilisers are outlines. The report concluded with the suggestion of a prototype nanocomposite. The extent of clay dispersion and exfoliation was examined, using scanning electron microscopy (SEM) and X-ray diffraction (XRD) measurements.

The results show that best clay exfoliation was obtained with composites containing 10% clay (calculated as % inorganic clay) compounded at 170°C for 10 minutes. No difference was found in the degree of exfoliation for the two different maleated polyethylenes (Amplify TY1053H and Amplify GR204). Montmorillonite clay was edge-modified in an aqueous clay dispersion. The clay was then washed and freeze dried to obtain edge modified clay that was compounded into maleated polyethylenes. SEM investigations and XRD analysis showed that this clay sample exfoliated better than the commercial clay. From this study, a prototype
nanocomposite for the project was identified: a freeze dried edge modified clay, prepared as described above, compounded with maleated polyethylene at 170°C.

Samples of a preliminary nanocomposite intended for use in WP3 and WP5 were produced. Deliverable report D2.1 Nanoparticle compounds describes the process technology and parameters for producing nanoparticle compounds to be used as oxygen barrier layer in polymer pipes for hot and cold water used in buildings. In addition to the work described in deliverable report D2.2 Production of nanocomposites, further tests were undertaken with compounding of organoclays with maleated polyolefins. Organoclay dispersion and exfoliation was examined with scanning electron microscopy (SEM) and X-ray diffraction (XRD) measurements. Organoclays, both commercial (Nanomer I.44PS; Cloisite 20A) and developed in the project, were compounded with maleic anhydride modified polyethylene (PE-g-MA) – Amplify GR204 and Amplify TY1053H - in an internal mixer and in twin screw extruder. The results show that compounding in a twin screw extruder resulted in better exfoliation than compounding in the internal mixer. The mixing time in the twin screw extruder is also much shorter, which is beneficial since dwell time at high temperature (about 200°C) can be reduced, which decreases the possibility of thermal degradation. Clay loadings in polyethylene ranged from from 2.5% to 15% (expressed as inorganic component of the clay). As expected it was found that the viscosity of the mixture increased considerably with increase in clay loading. This resulted in an increase in the torque of the roller rotor motor required to keep the speed of the roller rotor constant as well as increase in the temperature of the mixture with increase in clay loading. When clay loading was increased from 2.5% to 15% it was found that that the intensity of the peak in XRD spectra due to unexfoliated clay increases. Acceptable clay exfoliation was achieved at clay loading of 10% both in Amplify GR204 and Amplify TY1053H. XRD spectra and SEM micrographs of samples prepared in the twin roll internal mixer show that organoclays produced within the consortium exfoliated better than the commercial polymer Nanomer I.44PS. It is noteworthy that the basal plane spacing of the organoclay produced in this project is up to 1 nm larger than in commercially available organoclay, although the organic content is only about 10 – 12% higher. No difference was found in the degree of exfoliation for the two different maleated polyethylenes, Amplify GR204 and Amplify TY1053H. For samples produced in the twin screw extruder the difference between exfoliation of Nanomer I.44PS and ICI clay was not as pronounced. The main difference was seen in SEM micrographs at low magnification which showed more of the large agglomerates in samples containing Nanomer I.44PS than ICI organoclay, indicating better dispersion of ICI organocalys. Compounding nanoclays into the polyolefin chosen for pipe and tape extrusion, PE-RT – Dowlex 2388 was attempted. It was found that the organoclays did not exfoliate well in Dowlex 2388, which can be explained by the fact that the unmodified polyolefin does not contain any polar groups that can interact with the surface of the clay. Blending Dowlex 2388 with PE-g-Ma improved clay compatibility. Further improvements in nanoclay exfoliation were attempted by modifying maleated polyethylene with 2-[2-(dimethylamino)ethoxy]ethanol (DMAEE, 98%) to increase its ionic functionality. Dehydrated PE-g-MA blended with DMAEE was compounded with nanoclays (Nanomer I.44PS, Cloisite 20A and ICI organoclay). Overall, the compounding trials with the modified polymer give considerably better results for exfoliation of the high clay loading levels that were tested (15% and 20% inorganic clay loading). Cloisite 20A was found to exfoliate very well and is the best clay option for producing nanocomposites with high clay loading and modified polymer.
Compounding trials in a twin screw extruder resulted in 22 nanocomposite samples. Seven nanoparticle compounds were selected for WP3 and WP5 – five comprising Amplify GR204 and Amplify TY1053 with a selection of two different organomodified nanoclay, Nanomer I.44PS and ICI-organoclay; two prepared with an ionomer modified Amplify GR204 with Nanomer I.44PS and Cloisite 20A. Difficulties experienced in preparing homogeneous blends of nanoclay polymer composites may be overcome at industrial scale by milling the organoclay so that low bulk density and particle size is obtained and then metering the organoclay and polymer separately and directly into the extruder. The compatibilisation, exfoliation and compounding processes was reviewed with

regards to the risks involved in progressing with the proposed materials. Within the risk assessment and contingency management activity for WP2, it was acknowledged that, although improvements in dispersion quality of the nanoclays in the modified polyolefins have been achieved, the improvements in oxygen barrier property of these poor barrier polymers by nanoclay exfoliation would prove critical in whether further progress is made with this nanocomposite technology.

Samples of Dowlex 2388 compounded with 6 wt%, 12 wt%, and 24 wt% EVOH (and Amplify TY1053 tie resin to compatibilise the high polarity EVOH with low polarity polyolefin resin) were prepared and subjected to characterisation studies. Tensile testing of test pieces prepared using these composites, and using PE-RT without EVOH addition indicated a slight reduction in yield strength at 6 wt% EVOH, followed by a linear increase in strength with increasing EVOH addition. This was accompanied by an increase in strain at yield and a corresponding increase in Young's modulus with increasing EVOH addition, revealing an increase in stiffness of the composite compared to virgin PE-RT. Tensile strength at break was observed to increase slightly between 0 and 6 wt% EVOH, followed by a dramatic reduction in strength at higher EVOH loading. Strain at break initially doubled, followed by rapid decrease at higher EVOH below the virgin PE-RT value. In summary, addition of 6 wt% EVOH to PE-RT resin provided improved strength within the elastic region of the composite but this was at the expense of flexibility; with the onset of plastic deformation, performance properties improved at 6 wt% EVOH but further EVOH addition resulted in weakening and stiffening of the composite. Addition of EVOH would need to be limited to low levels to avoid unwanted loss of pipe flexibility. The polar nature of EVOH renders this resin water soluble and, as such, its presence in the pipe construction materials is likely to reduce moisture resistance of the PE-RT, thus providing less protection to the moisture-sensitive EVOH barrier layer. It was concluded that the inevitable increase in moisture sensitivity of the PE-RT pipe walls, in the absence of improvement in performance properties was not desirable and further NanoFlex pipe development would not include this concept.

3. Development of a Nanoparticle Coating Process.

The techniques and protocols identified in WP1 were developed into a a process for the production of a self-reinforced tape by extrusion of the selected polymer and stretching to its limit. The objective was to coat the tape with nanocomposites, test different tape thicknesses and different nanocomposites for oxygen permeability properties so optimising the alignment of the nanocomposites on the tape and the oxygen barrier properties of the nanoparticle-coated tapes. A tape extrusion process was designed and developed. Two film thicknesses in the range of 0.2 mm to 0.02 mm were tested and samples for testing the wrapping process of the inner pipe in WP4 produced.

The specifications for extruding tapes were studied and a suitable tape extrusion design identified. The tape was extruded using a custom designed and manufactured die and a commercial extrusion system, using both an air- and water cooling system with a hot draw frame and winding unit. All trials proved to be very successful and needed only minor modifications to the tooling for successful production. The PE-RT reacted as expected and the extrusion of the tape was fairly trouble free. The best extrusion results were achieved with the 5 mm wide tape. However, the 15 mm tape proved too rigid to use as a tape when cooled, and would need to go through a heating process before wrapping. Tape samples were produced for preliminary testing of the wrapping process. The best size for wrapping was found to be the 5 mm wide tape on the base, wrapped with a tight angle to maximise slip and flexibility. This would be overlaid with the 10 mm wide tape at an angle of approximately 20 degrees with an overlap of 2-3 mm to provide reinforcement.

Further work was conducted into the proposed self-reinforcement of the polymer tape by stretching to its limit. This has been summarised in an addendum to D3.1 to provide a Version 2 of the deliverable report. The properties that stretching and orientation conferred to the PE-RT tape was evaluated by a combination of uniaxial orientation up to a ratio of 1.8 by extrusion of film and by biaxial stretching of extruded film under controlled conditions up to a ratio of 3.5. Tensile testing of the uniaxially stretched samples revealed no apparent trend for film strength or stiffness properties with stretching ratio. The tensile elongation results plotted appeared to indicate an increase in elongation at peak with increased film stretch ratio. The biaxial stretching of PE-RT film revealed a practical limit to stretching of the film to a ratio of between 2 and 3 using this technique. Above this limit, the film became very fragile, with small tears appearing. It is suggested that stretching and orientation of the PE-RT film may result in the dissociation of the interconnected crystal network, thus eliminating the interactions required to provide the resin with its enhanced structural properties. Focus was given to the development of a film coating process for the optimisation of the oxygen barrier properties of the reinforcing tape. A reduction in oxygen transmission rate (OTR) through the composite to provide a satisfactory gas barrier according to EN ISO 21003-2:2008 requires OTR to be # 0.32 mg/(m2•day) or # 0.24 cm3/(m2•day) calculated at 20°C.

Extrusion offers the most attractive option for clay platelet alignment parallel to the shear plane during processing: the most efficient process for producing multilayer tape is coextrusion of the layers. Clay films produced from aqueous dispersions were considered. The incompatibility of the aqueous phase with the polyethylene substrate, resulting in poor film-forming properties, was addressed by use of a plasma-treated substrate. Adhesion was, however, still inadequate. Incorporation of an adhesive layer was found to improve clay-polyethylene bonding. This clay layer was found to be sensitive to stretching, with cracking of the clay layer observed at very low film stretching level. This approach will not provide barrier layer durability required of the application. In addition, incorporation of a hydrophilic clay layer will make the pipe susceptible to swelling during thermal cycling, possibly resulting in pipe failure. Nanocomposite films were produced using fully compatibilised montmorillonite dispersed in polyethylene. Characterisation by XRD indicated good exfoliation had been achieved, but oxygen permeability was found to be insufficient for the barrier layer of NanoFlex pipes. Even if clay content could be increased above the 10 wt% inorganic content achieved here, and enhanced alignment of the platelets could be achieved through processing modifications, it must be concluded that adequate barrier performance will not be achieved by this process for dispersion of nanoclay in polyethylene. Ultrasound sonication of polymer nanocomposite during extrusion was investigated to evaluate dispersion enhancement but failed to make any significant difference to the degree of exfoliation of the clay platelets. This was regardless of the amplitude of sonication. Modification of maleated polyethylene with a tertiary amino alcohol has been shown to improve exfoliation of onium ion-exchanged montmorillonite clay during preparation of polyethylene nanocomposites. This process could be employed to allow higher clay loading, but from the results presented here, it appears unlikely that this will benefit oxygen barrier properties sufficiently to achieve target OTR. Following disappointing barrier performance of the polyolefin nanocomposite materials examined in Version 1, further work was initiated for barrier film production. There is evidence in the literature that compounding a wet nanoclay (i.e. undried organoclay filter cake prepared in aqueous phase) into a polyolefin during extrusion acts to prevent collapse of exfoliated platelets. This modified approach was investigated to improve nanoclay dispersion in maleic anhydride grafted polyethylene (PE-g-MA) and in PE-RT. XRD analysis of organically modified nanoclays indicated that the basal spacing of platelets was not significantly affected by drying the clay, contrary to the suggestion that drying can result in platelet collapse and subsequent poor dispersion properties when compounded into polymers. This result was supported by comparison of the XRD measurements of polymer nanocomposites prepared using undried filter cake and freeze-dried organoclay. The results of this work indicate that this process, although providing good dispersion properties of the nanoclay, provides no significant improvement over previously investigated nanoclay production methods. The lack of improvement in platelet exfoliation using the wet nanoclay filter cake route suggests that target gas barrier property, which is a function of the tortuous diffusion path presented by well dispersed discrete clay platelets, will not be achieved by this technique. The use of a high oxygen barrier polyamide (nylon) augmented with exfoliated organically modified nanoclay was identified as an alternative system that will allow OTR to be reduced sufficiently to meet the target specification whilst maintaining pipe recyclability. This was pursued and reported. Nylon polymers possess lower oxygen transmission properties than EVOH but are known to be less sensitive to humidity and temperature. This is likely to be a critical factor for application as a gas barrier in water pipes. A commercial product, Imperm 103 from Nanocor - comprised of low oxygen transmission rate (OTR) nylon MXD6 with nanoclay dispersed within the matrix by in situ polymerisation – was investigated. Measurement of barrier property by ICI of film samples prepared at UK-MaTRI has found that this nanocomposite will be able to provide the OTR required of the NanoFlex product. A concern for MXD6 is its low tensile elongation property (2.3%, according to Nanocor literature). Improvement in flexibility by blending with nylon-6 (tensile elongation ~ 200%) was investigated, although it was expected that this would reduce the barrier efficacy of the composite. It was found that adding up to 20 wt% nylon-6 had negligible benefit upon flexibility. However, the Imperm samples tested at MaTRI (without nylon-6) were found to have elastic elongation of 4% which, although higher than the manufacturer's estimate, is still low compared to other (high OTR) engineering polymers. However, elongation at break was to be >100%. So, although some plastic deformation can be anticipated when pipes are bent, the barrier layer will remain intact.

T3.4 of the NanoFlex project Annex 1 (DoW) requires the production of nanoparticle-coated tape. It is not possible to provide the required barrier using an unbonded tape as this will allow channels to exist between the layers; any barrier achieved in the production of the nanocomposite will be lost to the pipe using this procedure. It was proposed that the barrier property be supplied by a layer of the polyamide nanocomposite co-extruded over the inner pipe. Options for achieving the barrier requirements using this approach to the multilayer structure have been identified and reported. Further attention was focussed on this development route and work regarding production of nanoparticle-coated tape discontinued. All of the material development processes and products were subject to an assessment of the corresponding risks and identification of any contingencies required in the event that the objectives were not realised. It was as a result of this activity that the various alternative technologies and materials were identified with a view to providing a NanoFlex product that would meet the requirements of the industry, as identified in the scope of the project. The results of the film stretching investigation indicated that there may be little performance benefit to stretching PE-RT film for reinforcement of a wrapping tape. There was a possibility that stretching the tape may result in a deterioration in strength. This called into question the process of reinforcement of the wrapping tape, as proposed in the NanoFlex Description of Work. Intensive investigation of nanoclay dispersion in polyolefins has found that the very challenging goal of producing a high oxygen barrier material with a polyolefinic nanocomposite system would not be achieved within the scope of the NanoFlex project.

The investigation into the use of a high oxygen barrier polyamide (nylon) augmented with exfoliated organically modified nanoclay identified this as an alternative system that will allow OTR to be reduced sufficiently to meet the target specification whilst maintaining pipe recyclability.

4. Development of a multilayer pipe extrusion and wrapping process

Focus was given to the development of a multi-layer pipe extrusion and wrapping process. We developed pipe extrusion, wrapping, and crosshead extrusion The multilayer pipe will be constructed of four layers.

Various options for wrapping the inner pipe were examined. However, due to the nature of the wrapping (it must provide both reinforcement and oxygen barrier properties) a customised piece of equipment already in use by UL MatRI was considered a viable option. A number of adaptations and mechanical changes were carried out on the machine to enable wrapping of the inner pipe. This resulted in the use of a custom wrapping machine being used in our trials. This could wrap 4 layers on each side (clockwise and anti-clockwise). We found that the best speed for the wrapping on the 10mm OD pipe was 0.4mtrs per minute, with a haul off set at a wrapping angle of 35°. This provided a very smooth layer and constant coverage on both layers in both directions. It also allowed for a 1mm overlap to aid oxygen barrier and reinforcement properties. For the 10mm OD pipe, we used 1.8m of 25mm wide tape to cover 1m of pipe. To wrap the 15mm OD pipe, the machine's haul off speed was reduced to 0.2m per minute and the speed of the wrapping machine was doubled. The angle was altered 45° to compensate for change in speed. This also provided a very smooth and even coverage in both directions. The 15mm pipe used 2.2m of tape for 1m of pipe; this was due to the increase in speed and the bigger OD of the pipe Based on the trials carried out, the best speed for the wrapping on the 10mm OD pipe was 0.4mtrs per minute and a wrapping angle of 35°. This provided a very smooth layer and constant coverage on both layers in both directions. It also allowed for a 1mm overlap to aid barrier and reinforcement properties. For the 10mm OD pipe, it used 1.8m of 25mm wide tape to cover 1m of pipe. To wrap the 15mm OD pipe the haul off speed was reduced to 0.2m per minute and the speed of the wrapping machine was doubled. The angle was altered to 45° to compensate for change in speed. This also provided a very smooth and even coverage in both directions. The 15mm pipe used 2.2m of tape for 1m of pipe; this was due to the increase in speed and the bigger OD of the pipe.

Type II PE-RT was identified as the most appropriate material of construction for the inner pipe due to the high temperature hydrostatic strength provided by this material; Dowlex 2388 PE-RT from Dow Chemical Corp. was chosen to provide the outer slip layer of the NanoFlex pipe. The extruder used for the NanoFlex inner pipe extrusion manufacture was a Boston Matthews extruder with 30mm diameter single screw with a length to diameter ratio (L/D) of 25:1, running at 73 revs per minute and a throughput of approximately 9kgs per hour. The temperature of the polymer and the tooling were individually controlled by nine different settings to allow for close control of extrusion conditions. Temperature profile and subsequent flow viscosity of the extrudate was used to control pipe wall thickness. Using established design techniques two lots of tooling and an extrusion head were designed and ordered. A vacuum bath was used to allow the pipe to form and cool as it exited the extruder. The final sizing of the pipe was controlled by a sizing die mounted at the front of the vacuum bath. Initial trials were carried out with both PE-RT and with HDPE (HDPE for comparison only); the PE-RT extruded well and produced an even melt flow when extruded at temperatures between 187 ºC and 205ºC along the length of the extruder barrel. Three sizes of pipe were extruded: 10mm I.D x 0.8mm wall - this was the strongest of the pipes and would be the best option to wrap for the final product. However, this would lead to the O.D of the outer pipe being out of specification (12 mm) given the thickness of the wrapping and final layer; 10mm I.D x 0.6mm wall – this was a good pipe but kinked very easily and would tend to crush during the wrapping stages; 10mm I.D x 0.5mm wall – the thinnest of the pipes extruded and very easily crushed and kinked - not at all suitable for wrapping. However this size is the best suited to the overall construction based on wrapping thickness and final slip layer thickness. Following agreement within the NanoFlex consortium, it was concluded that there is no market for the 12 mm OD pipe and that subsequent work would focus on 16 mm OD and 20 mm OD pipes. Inner pipes with 15 mm OD and 18 mm OD were subsequently produced for wrapping and extrusion of the outer slip layer for the production of pre-prototype multilayer pipes for Further development of the wrapping process in and production of the wrapping tape resulted in an inner 18 mm OD PE-RT pipe wrapped with tape of width 37 mm and thickness 60 #m (4 layers in total wrapped in opposite directions). The thickness of the outer layer is dependent upon the thickness of the preceding inner pipe and wrapped layer. A pre-prototype multilayer pipe was produced consisting of a PE-RT inner pipe of ID = 16 mm / OD = 18 mm (T4.1) with the remaining 1 mm thickness consisting of 240 #m wrapped layer of uniaxially stretched PE-RT tape and a 760 #m outer slip layer. Problems were encountered with the non-bonded tape layers slipping within the crosshead tooling. We conducted testing of flexibility; bendability; slip properties; strength; and temperature resistance. The flexibility, bendability and slip properties are functional characteristics of the pipe when used in Norway and Sweden in pipe in tube systems. Nordtest method NT VVS 129 was used for guidance for choosing the appropriate test method and to define functional requirements. The strength and temperature resistance are functional characteristics mentioned in EN-ISO 21003-2, the standard for multilayer piping systems for hot and cold water installations inside buildings that must be met in most European Countries. The flexibility of the pipe was measured by means of a three point bending test at 23 ± 2°C on the pre-prototype multilayer pipe according to EN-ISO 178. When testing the flexibility of the pre-prototype pipes the pipes showed kinking at a relatively low applied force. The bendability of the pipe is particularly important for underfloor heating application in which the pipe may be mounted in a pre-formed system plate. When testing the bendability the pre-prototype pipes the pipes showed kinking before the required minimum bending radius was reached. The kinking of the pre-prototype pipe is greatly influenced by the fact that the wrapped taped layers are not bonded (by adhesive) to the inner pipe. Improved kinking resistance can be expected with all layers bonded. Slip properties were tested by placing the NanoFlex pipe within a 25 mm ID corrugated protective pipe which was bent through 180° around a template with a radius of eight times the outer diameter of the protective pipe (28 mm). The force to pull out the test pipe is a function of the slip properties of the pipe. When testing the slip properties of the pre-prototype pipes the pipes showed kinking during bending of the corrugated pipe. Strength was measured as the resistance to internal pressure, tested at 20°C and 95°C. The effect of the wrapped taped layers was visible in the pressure testing results. All test results are above the expected test results of mono layer pipes of the same material. The effects of heating and the longitudinal reversion were determined by an oven test. Three pipe samples were heated in an oven at 120°C for one hour and the longitudinal reversion of the pipe was measured after heating. Longitudinal reversion of 0.6% was recorded for the test pipes. The process of risk assessment and contingency management adopted for identified the areas required for modification highlighted in the test results.

It was found that the self-reinforced tape used for the wrapped layers conferred enhanced strength to the pipe during pressure testing. However, the additional strength observed is doesn't provide the required design pressure of the pipe for the intended use as a hot and cold pipe where the classes 2 + 5/10 bar are met. Further reinforcement of the tape or increased pipe was thus required. It was evident that the pipe did not have adequate resistance to kinking for underfloor heating applications and it was hence recommended that bonding the layers will provide additional kinking resistance.

5. Optimisation and validation of the NanoFlex product and production.

This work involved the validation of the prototype NanoFlex pipe, including barrier property supplied by the nanocomposite layer; the enhanced strength and flexibility provided by the wrapped tape layer; and the slip property and noise reduction potential of the outer layer.
Two general approaches were adopted to achieve the desired performance properties, as well as multifunctionality, and recyclability of the NanoFlex product. These were A) extrusion and B) extrusion combined with tape wrapping. In both production options, a polyamide/nano-composite layer (Imperm 103 manufactured by Nanocor, USA) was incorporated into the pipe by co-extrusion which is designed to meet the oxygen barrier requirements.
A prototype 5-layer extruded pipe (Option A; 16.0 mm OD; 2.0 mm wall thickness) was manufactured. Bonding between the Imperm barrier layer and PE-RT inner and outer layers was achieved by co-extrusion of maleic anhydride grafted polyethylene (PE-g-MA) adhesive layers. Testing of the pipe by revealed that the pipe has good flexibility and kink resistance, similar to that of PE-RT (Type II) pipes currently available in the market. Strength testing of the 5-layer pipe concluded that, in order for a 20 mm OD pipe to meet strength requirements for Class 2, 10 bar design pressure 70º C hot water application, wall thickness of 2.8 mm will be required. This is unsurprising as this is the design requirement of standard monolayer PE-RT pipes for this application. Oxygen permeability testing of the 5-layer pipe found that permeation was less than the instrument lower detection limit of 0.01 mg O2/m2.day. This is less than the required value of 1.8 mg O2/m2.day.
Optional tape wrapping was used to increase the burst pressure of the pipe. Initially, stretched PE-RT film was used to wrap the pipe, but testing of the pre-prototype by revealed that the required strength for design pressure of the pipe for Class 2 10 bar could not be achieved (deliverable report D4.3 Testing of pre-prototype multilayer pipes). For this reason, a bi-axially oriented polypropylene (BOPP) tape with high tensile strength (typically 140 MPa) was used for enhanced strength of the pipe.
A pre-prototype PE-RT pipe was produced comprising a PE-RT inner pipe wrapped with 8 layers 25 µm thick, 25 mm wide BOPP tape; an outer layer of PE-RT was coextruded over the wrapped layer. Strength testing of the pipe revealed that the circumferential hoop stress was higher than the NanoFlex pipe samples produced previously, although the actual (absolute) test pressure was similar to previously tested NanoFlex pipes. It was concluded that the BOPP tape provided a significant effect on hoop stress of the pipe, indicating that the 10 bar design pressure could be achieved with a 20 mm x 2.0 mm pipe.
Following the promising strength performance of the BOPP wrapped pipe, a process of bonding the layers was investigated to provide the flexibility and reduced kinking required of the finished pipe. An acrylic-coated heat sealable BOPP grade from (Propafilm RC30) was selected as the wrapping tape, providing good adhesion between the wrapped layers within the temperature range acceptable for the product (> 115 ºC for hot water pipes; < 130 ºC to avoid distortion of the PE-RT pipe).
A wrapped prototype pipe was produced with all layers bonded (Option B; 20 mm OD; 2.0 mm wall thickness). The pipe was comprised of PE-RT inner pipe; adhesive; Imperm 103; adhesive; BOPP wrapped layers; adhesive; PE-RT puter slip layer. Heat activated adhesive materials based on PE-g-MA were selected to provide bonding between the incompatible Imperm 103 polyamide and the BOPP, and between the BOPP and the outer PE-RT layer.
A wrapping calculator has been developed for the NanoFlex project using geometrical relationships. This allows set up of the winding machine, providing ideal wrapping angle and haul-off rate with respect to tape and pipe dimensions.
Testing of the pipe revealed that the pipe satisfied the required performance requirements with

regards to oxygen permeability, bending and kink resistance, and resistance to heating (longitudinal reversion); strength testing of the pipe is ongoing, but initial results indicate good strength properties; likewise, thermal cycling tests are still ongoing.
This approach permits a lower overall pipe wall thickness to be specified, albeit at higher cost. Ensuring good inter-layer adhesion between the wrapped tape layers and obtaining a reliable bond between these layers and the final PE-RT coating has been a particular area of focus.
The production processes used for the manufacture of the two NanoFlex options for performance testing is summarised as follows:

• Option A – nominal 16 mm OD pipe.
i. Initial pipe was extruded from PE-RT Type 2, Dowlex 2388 internal diameter 11.4 mm; wall thickness 2.0 mm.
ii. The pipe then passed through a water bath to cool the polymer and improve rigidity before passing through a haul-off unit.
iii. The pipe was then surface heat treated to improve adhesion with subsequent layers.
iv. The pipe then passed into a 3 layer co-extrusion die which applied two layers of PE-g-MA adhesive either side of an Imperm 103 barrier layer (thickness 1.7 mm). A single extruder was used for the adhesive layers using a common feed into the die to produce both layers.
v. The final layer of PE-RT (thickness 0.4 mm) was then over extruded using a second die and extruder.
• Option B – nominal 20 mm OD pipe.
i. Inner PE-RT pipe with internal diameter 16 mm; wall thickness 1.4 mm
ii. Water bath
iii. Surface heat treatment
iv. Imperm 103 layer (thickness 1.0 mm) coextruded with PE-g-MA adhesive either side
v. Pipe transported to MaTRI's facility in the UK
vi. Reinforcing film (BOPP, 30 mm wide; 30 µm thick) wrapped as four completely overlapping layers at an angle appropriate to prevent overlap or underlap of each individual layer upon itself as the tape progresses along the length of the pipe.
vii. Step (vi) was repeated, with three completely overlapping layers of tape angled in an equal and opposite direction to (vi)
viii. A layer of adhesive film – (PE-g-MA, 30 mm wide x 60 microns thick) was wrapped upon all previous layers at the same angle as (vii). This adhesive layer may also be applied as an extruded layer.
ix. A final layer of PE-RT was extruded over the wrapped layers of the inner pipe with a thickness calculated to achieve nominal outer diameter of the pipe of 20 mm.
x. Final heat treatment step - the entire pipe was placed in an oven at 120ºC for 20 minutes to ensure activation of the adhesive layers to bond the BOPP film to the barrier layer and to the outer PE-RT layer. An in-line heat treatment process may be preferred for full-scale manufacturing.
In a fully integrated design, the wrapping head speed would need to be varied automatically to match any variations in speed through the extrusion processes. This could be achieved by monitoring the tape position between the spools and the pipe during the wrapping process and using a closed feedback controller system to adjust the rotational head speed. Alternatively, the wrapping machine could operate off-line by coiling the pipe from extrusion and wrapping it separately. This would be less efficient, although it would offer more production line design flexibility.
Materials cost analysis has been carried out for the NanoFlex pipe using production option A & B (extrusion and extrusion/wrapping). Materials costs for Option A was estimated to be €0.31-0.33 per linear metre for a 20 mm x 2.8 mm pipe (this thickness is required of the non-reinforced pipe to meet the Class 2, 10 bar water pressure requirements). Materials cost for Option B range from €0.31-0.34 per linear metre for a 20 mm x 2.0 mm pipe. These costs include the relatively high price charged for the barrier layer and for the BOPP film, both of which were purchased as small lots of less than 50 kg. It is likely that the price of these materials will be significantly reduced for large volume orders, reducing the NanoFlex materials cost further.
A principle objective of the NanoFlex project was to produce a high quality flexible pipe that can be produced for <€0.50 per metre and cost effectively sold for €1.10 per metre (retailer price). The cost analysis of the NanoFlex product fits well within this price specification.
Two prototype multilayer pipes have been produced and have been tested for performance properties. Both prototypes meet the application specifications with regards to flexibility, bendability, slip properties, temperature resistance, and oxygen permeability; the wrapped 20 mm x 2 mm pipe was

sufficiently reinforced to meet the strength requirements for Class 2 70#C applications; the co-extruded 20 mm OD pipe will require wall thickness of 2.8 mm to achieve Class 2 burst resistance, in line with current PE-RT monolayer pipe. Oxygen barrier property has been achieved using a novel nanocomposite process, incorporating a polyamide-nanoclay resin to provide similar resistance to oxygen permeability as EVOH but with superior moisture resistance. The prototypes are cost competitive, meeting the production and retail cost requirements of the project DoW and comparing favourably with current commercial products. Both prototypes are fully recyclable.

Potential impact and main dissemination activities and exploitation results

The NanoFlex project has provided the SME members with an IP protectable technology to manufacture a universal flexible low-cost plumbing and heating pipe system that is 100% recyclable, complying with current European legislation concerning landfill and waste management, namely the EU Landfill Directive (1999/31/EC) and the EU Waste Framework Directive (2006/12/EC) and its revision (2008/98/EC). The pipe can be used with standard fittings (as proven during testing) and is a cost effective solution for end-users.

The plastic pipe industry is urgently looking for recyclable plastic pipe technologies since; the regulatory environment is increasing the pressure on manufacturers to supply recyclable products. In particular, the Revised EU Waste Framework Directive sets a recycling target of 50% for household and 70% for construction and demolition waste to be achieved in Europe by 2020. Further, the EU Landfill Directive (Council Directive 1999/31/EC) demands a reduction in land filling to reduce harmful methane emissions. And finally the EU Waste Framework Directive (Directive 2006/12/EC) demands a five-step waste hierarchy with first prevention, second reduction, then reuse, recovery and at lastly the disposal of waste.

The regulatory environment places pressure on manufacturers through these legislative instruments to provide and use recyclable products. The construction industry in particular uses plastic pipes. Hence recycling of plastic pipes will make a significant contribution to recycling of construction waste in future, (plastic pipes have a working life time up to 80 years).

The plastic pipe industry including pipe manufactures and pipe distributors will benefit from the Nanoflex technology in 3 ways:

1. The direct economic gain from selling a new innovative fully recyclable pipe system for under floor heating, radiator heating and drinking water systems;
2. Indirect economical gain from avoiding future penalty charges for using non-recyclable plastics
3. Indirect economical gain from improving installation processes by using an easy to install pipe system that is simple to bend by hand but resistant to deformation and kinking. This will require less work time for installation (labour-saving), and a reduced risk of material losses (material saving), both of which will increase profit.

The construction industry in Europe uses 8.3 million tonnes of plastic annually with plastic pipes as the biggest single item (more than 3 million tonnes annually). Plastics have become the material of choice for pipes in the building industry, in particular in the growing market for building renovation. In 2012, the market share of plastic pipes was higher than that of metal pipes and reached 56%1 of the market by volume. It is forecast that the market share of plastic pipes will continue to dominate through to 2020.

Based on the cost competitiveness of the Nanoflex pipe, the NanoFlex consortium believes that it will be realistic to capture the following market shares by 2019 (direct sales or licensing) for pipes that use the NanoFlex technology: 7% (7.7 million meter) of the market for under floor heating pipes, 3% (9.3 million meters) of the market for radiator heating and 2% (4.8 million meters) of the market for sanitary or plumbing systems.

Address of project public website and relevant contact details

www.greenflextube.org

Coordinator: Mr. Ole Larmerud – ole.larmerud@nrl.no

Technical Manager: Mr. Tim Beaver – tim.beaver@peratechnology.com

Dissemination Manager: Mr Thijs de Wolff – thijs.dewolff@orgalime.org

4.2 Use and dissemination of foreground

Section A (public)

Publications

LIST OF SCIENTIFIC PUBLICATIONS, STARTING WITH THE MOST IMPORTANT ONES											
No.	Title / DOI	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Date of publication	Relevant pages	Permanent identifiers (if applicable)	Is open access provided to this publication ?	Type

LIST OF DISSEMINATION ACTIVITIES								
No.	Type of activities	Main Leader	Title	Date	Place	Type of audience	Size of audience	Countries addressed
1	Organisation of Workshops	THE CHARTERED INSTITUTE OF PLUMBING & HEATING ENGINEERI NG	Demonstration to member company.	18/03/2011	CIPHE, London	Industry	1	UK
2	Organisation of Conference	THE CHARTERED INSTITUTE OF PLUMBING & HEATING ENGINEERI NG	Area Meeting (South-West)	19/03/2011	CIPHE, London	Industry	10	UK
3	Organisation of Workshops	THE CHARTERED INSTITUTE OF PLUMBING & HEATING ENGINEERI NG	Demonstration to member company	11/04/2011	CIPHE, London	Industry	3	UK
4	Organisation of Conference	THE BRITISH PLASTICS FEDERATIO N LBG	Demonstration to industri al group (Plastic Pipes C ommittee)	12/01/2011	London, UK	Industry	10	UK
5	Organisation of Conference	THE BRITISH PLASTICS FEDERATIO N LBG	Dissemination to industri al group (AG4)	03/02/2011	London, UK	Industry	10	UK
6	Organisation of Conference	THE BRITISH PLASTICS FEDERATIO N LBG	Dissemination to industri al group (Recyclers)	17/03/2011	London, UK	Industry	10	UK
7	Organisation of Workshops	THE BRITISH PLASTICS FEDERATIO N LBG	Demonstartion to BPF Technical staff	25/03/2011	London, UK	Scientific comm unity (higher educat ion, Research) - Pol icy makers	10	UK
8	Organisation of Conference	THE BRITISH PLASTICS FEDERATIO N LBG	Dissemination to industri al group	11/04/2011	London, UK	Industry - Policy makers	10	UK
9	Organisation of Conference	THE BRITISH PLASTICS FEDERATIO N LBG	Demonstration to UK Goverment (BIS)	11/04/2011	London, UK	Civil society	20	UK
10	Organisation of Conference	THE BRITISH PLASTICS FEDERATIO N LBG	Demonstration to industri al group (plastic pipes)	26/04/2011	London, UK	Industry	10	London, UK
11	Organisation of Conference	THE BRITISH PLASTICS FEDERATIO N LBG	Demonstration to industri al group (plastic pipes)	25/07/2011	London, UK	Industry	10	UK
12	Organisation of Conference	THE BRITISH PLASTICS FEDERATIO N LBG	Demonstration to industri al group (plastic pipes)	15/08/2011	London, UK	Industry	10	UK
13	Organisation of Conference	THE BRITISH PLASTICS FEDERATIO N LBG	Demonstration to industri al group (plastic pipes)	07/09/2011	London, UK	Industry	10	UK

14	Exhibitions	THE CHARTERED INSTITUTE OF PLUMBING & HEATING ENGINEERI NG	Plasteurasia	26/10/2011	Istanbul, Turkey	Scientific comm unity (higher educat ion, Research) - Ind ustry	5000	Turkey
15	Press releases	GENIE CLIMATIQUE INTERNAT IONAL UNION INTERNATIONALE DE LA COUVERTURE ET DE LA PL OMBERIE AISBL	News article	22/09/2011	Brussels, Belguim	Industry - Policy makers	1000	Belguim, Germany, Norway, Spain, Ho lland, Sweden, France
16	Organisation of Conference	GENIE CLIMATIQUE INTERNAT IONAL UNION INTERNATIONALE DE LA COUVERTURE ET DE LA PL OMBERIE AISBL	Demonstration to member associations	22/09/2011	Brussels, Belguim	Industry - Policy makers	17	Belguim, UK, Ge rmany, France, Norway, Sweden
17	Organisation of Workshops	THE CHARTERED INSTITUTE OF PLUMBING & HEATING ENGINEERI NG	Presentation to technical staff	19/12/2011	London, UK	Scientific comm unity (higher educat ion, Research) - Ind ustry	10	UK
18	Organisation of Conference	THE CHARTERED INSTITUTE OF PLUMBING & HEATING ENGINEERI NG	Demonstration to member associations	23/06/2012	London, UK	Industry	10	UK
19	Exhibitions	THE BRITISH PLASTICS FEDERATIO N LBG	Ecobuild	09/01/2012	London, UK	Scientific comm unity (higher educat ion, Research) - Ind ustry - Civil society - Policy makers - Medias	1000	UK
20	Organisation of Conference	THE BRITISH PLASTICS FEDERATIO N LBG	Dissemination to TEP PFA (European Plastic Pipes Body)	01/10/2012	London, UK	Policy makers	12	UK
21	Organisation of Conference	THE BRITISH PLASTICS FEDERATIO N LBG	Dissemination to Plastics Europe (European trade b ody)	09/01/2012	London, UK	Industry - Policy makers	12	UK
22	Organisation of Conference	THE BRITISH PLASTICS FEDERATIO N LBG	Demonstration to industri al group (pipes group)	03/11/2012	London, UK	Industry	10	UK
23	Organisation of Conference	THE BRITISH PLASTICS FEDERATIO N LBG	Dissemination to industri al group (ICER)	01/11/2012	London, Uk	Industry	10	UK
24	Organisation of Conference	THE BRITISH PLASTICS FEDERATIO N LBG	Dissemination to industri al group (ICER)	01/11/2012	London, Uk	Industry	10	UK
25	Organisation of Conference	THE BRITISH PLASTICS FEDERATIO N LBG	Dissemination to industri al group (vinyls)	01/02/2012	London, UK	Industry	10	UK

26	Organisation of Conference	THE BRITISH PLASTICS FEDERATIO N LBG	Dissemination to industri al group (Recyclers)	15/03/2012	London, UK	Industry	10	UK
27	Exhibitions	THE BRITISH PLASTICS FEDERATIO N LBG	Ecobuild 2012	19/03/2012	London, UK	Scientific comm unity (higher educat ion, Research) - Ind ustry - Medias	5000	UK, Germany, Be lguim, Spain, H olland, Norway, Sweden
28	Organisation of Conference	THE BRITISH PLASTICS FEDERATIO N LBG	Dissemination to industri al group (SIMPL)	03/07/2012	London, UK	Industry	10	UK
29	Exhibitions	ASOCIACION ESPANOLA DE IN DUSTRIALES DE PLASTICOS - ANAIP	PLAST MILAN	09/05/2012	Milan, Spain	Industry - Civil soc iety - Policy makers - Medias	1000	Spain, Portugal
30	Organisation of Conference	ASOCIACION ESPANOLA DE IN DUSTRIALES DE PLASTICOS - ANAIP	Dissemination to industri al group (AENOR)	15/12/2011	Madrid, Spain	Scientific comm unity (higher educat ion, Research)	10	Spain
31	Exhibitions	NORSKE RORLEGGERBEDRIFTERS LANDSFORENING VVS	Norwegian Plumbing Fair	22/10/2013	Oslo, Norway	Industry	1000	Norway
32	Organisation of Conference	THE CHARTERED INSTITUTE OF PLUMBING & HEATING ENGINEERI NG	Demonstration to member organisations	22/06/2013	London, UK	Industry	50	UK
33	Organisation of Workshops	THE CHARTERED INSTITUTE OF PLUMBING & HEATING ENGINEERI NG	Demonstration to CIPHE Technical Committee	12/02/2013	London, UK	Industry	10	UK
34	Exhibitions	THE BRITISH PLASTICS FEDERATIO N LBG	Plasteuasia	27/11/2012	Turkey	Scientific comm unity (higher educat ion, Research) - Ind ustry - Medias	1000	Turkey
35	Exhibitions	THE BRITISH PLASTICS FEDERATIO N LBG	K2013	18/10/2013	Germany	Scientific comm unity (higher educat ion, Research) - Ind ustry - Medias	5000	Germany, UK
36	Exhibitions	ASOCIACION ESPANOLA DE IN DUSTRIALES DE PLASTICOS - ANAIP	Climatizacion Fair	30/01/2013	Spain	Scientific comm unity (higher educat ion, Research) - Ind ustry - Medias	1000	Spain
37	Organisation of Workshops	ASOCIACION ESPANOLA DE IN DUSTRIALES DE PLASTICOS - ANAIP	Demonstration to potentia l end-users	26/09/2013	Zaragoza, Spain	Industry	15	Spain
38	Organisation of Conference	GENIE CLIMATIQUE INTERNAT IONAL UNION INTERNATIONALE DE LA COUVERTURE ET DE LA PL	European Installers Summit	25/09/2013	Copenhagen, Den mark	Industry	50	UK, Germany, Sp ain, Belguim, D enmark, Sweden,

		OMBERIE AISBL						Norway, Ireland, Holland,

Section B (Confidential or public: confidential information marked clearly)

LIST OF APPLICATIONS FOR PATENTS, TRADEMARKS, REGISTERED DESIGNS,UTILITY MODELS, ETC.					
Type of IP Rights	Confidential	Foreseen embargo date dd/mm/yyyy	Application reference(s) (e.g. EP123456)	Subject or title of application	Applicant(s) (as on the application)

OVERVIEW TABLE WITH EXPLOITABLE FOREGROUND								
Type of Exploitable Foreground	Description of Exploitable Foreground	Confidential	Foreseen embargo date dd/mm/yyyy	Exploitable product(s) or measure(s)	Sector(s) of application	Timetable for commercial use or any other use	Patents or other IPR exploitation (licences)	Owner and Other Beneficiary(s) involved
Commercial expl oitation of R&D results	Product require ments and speci fications, thermopla stics and nanopartic le compounds	Yes	01/01/2014	Specification for us e of nano-particles in polymer pipes	Plastic pipe ma nufacture	Jan 2015	Trade secret for 5 y ears using the consortium agre ement	Owner: Notio AS
Commercial expl oitation of R&D results	Nanocomposites and corresponding technology.	Yes	01/01/2014	Know-how in com pounding and di spersion of nan o-composites in polymers	Plastic pipe ma nufacture	Jan 2015	Patent Application No: 13190880.8	Notio AS
Commercial expl oitation of R&D results	Prototype of na no-particle coated t ape and corresp onding process technology	Yes	01/01/2014	Use of nano-par ticle coated tape as an oxygen barrier l ayer in plastic pipe s.	Hot and cold water systems	Jan 2015	Trade secret for 5 y ears using the consortium agre ement	Notio AS
Commercial expl oitation of R&D results	Wrapping process technology	Yes	01/01/2014	Wrapping proces sing of plastic pipes	Plastic pipe ma nufacture	Jan 2015	13190880.1	Notio AS
Commercial expl oitation of R&D results	Multi-layer extrusio n process techn ology.	Yes	01/01/2014	Extrusion of na no-composite pl astic pipes.	Ht and cold water plumbing systems	Jan 2015	Trade secret for 5 y ears using the Consortium Agre ement	Notio AS

Commercial expl oitation of R&D results	NanoFlex pipe and corresponding pro cess technology.	Yes	01/01/2014	Universal, flexible, plumbing and h eating pipe system, fully environment friendly	Plumbing systems, hot and cold water systems	Jan 2015	Patent Application Ref: 13190880.1	Notio As

ADDITIONAL TEMPLATE B2: OVERVIEW TABLE WITH EXPLOITABLE FOREGROUND	
Description of Exploitable Foreground	Explain of the Exploitable Foreground
Product requirements and specificat ions, thermoplastics and nanopartic le compounds	Nano-particle compounds that give oxygen barrier properties in thermoplastics.
Nanocomposites and corresponding technology.	Use of foreground in plumbing and heating applications.
Prototype of nano-particle coated t ape and corresponding process technology	Use of foreground in plumbing and heating applications.
Wrapping process technology	Process for wrapping un-bonded tape onto thermoplastic pipe.
Multi-layer extrusion process techn ology.	Process of multi-layer extrusion for nano-composites.
NanoFlex pipe and corresponding process technology.	NanoFlex technology for use in under-floor heating and plumbing applications.

4.3 Report on societal implications

B. Ethics

1. Did your project undergo an Ethics Review (and/or Screening)?	No
If Yes: have you described the progress of compliance with the relevant Ethics Review/Screening Requirements in the frame of the periodic/final reports?	

2. Please indicate whether your project involved any of the following issues :

RESEARCH ON HUMANS	
Did the project involve children?	No
Did the project involve patients?	No
Did the project involve persons not able to consent?	No
Did the project involve adult healthy volunteers?	No
Did the project involve Human genetic material?	No
Did the project involve Human biological samples?	No
Did the project involve Human data collection?	No
RESEARCH ON HUMAN EMBRYO/FOETUS	
Did the project involve Human Embryos?	No
Did the project involve Human Foetal Tissue / Cells?	No
Did the project involve Human Embryonic Stem Cells (hESCs)?	No
Did the project on human Embryonic Stem Cells involve cells in culture?	No
Did the project on human Embryonic Stem Cells involve the derivation of cells from Embryos?	No
PRIVACY	
Did the project involve processing of genetic information or personal data (eg. health, sexual lifestyle, ethnicity, political opinion, religious or philosophical conviction)?	No
Did the project involve tracking the location or observation of people?	No
RESEARCH ON ANIMALS	

Did the project involve research on animals?	No
Were those animals transgenic small laboratory animals?	No
Were those animals transgenic farm animals?	No
Were those animals cloned farm animals?	No
Were those animals non-human primates?	No
RESEARCH INVOLVING DEVELOPING COUNTRIES	
Did the project involve the use of local resources (genetic, animal, plant etc)?	No
Was the project of benefit to local community (capacity building, access to healthcare, education etc)?	No
DUAL USE	
Research having direct military use	No
Research having potential for terrorist abuse	No

C. Workforce Statistics

3. Workforce statistics for the project: Please indicate in the table below the number of people who worked on the project (on a headcount basis).

Type of Position	Number of Women	Number of Men
Scientific Coordinator	0	1
Work package leaders	17	3
Experienced researchers (i.e. PhD holders)	11	3
PhD student	0	0
Other	13	4

4. How many additional researchers (in companies and universities) were recruited specifically for this project?	0
Of which, indicate the number of men:	0

D. Gender Aspects

5. Did you carry out specific Gender Equality Actions under the project ?	No

6. Which of the following actions did you carry out and how effective were they?	
Design and implement an equal opportunity policy	Not Applicable
Set targets to achieve a gender balance in the workforce	Not Applicable
Organise conferences and workshops on gender	Not Applicable
Actions to improve work-life balance	Not Applicable
Other:	

7. Was there a gender dimension associated with the research content - i.e. wherever people were the focus of the research as, for example, consumers, users, patients or in trials, was the issue of gender considered and addressed?	No
If yes, please specify:	

E. Synergies with Science Education

8. Did your project involve working with students and/or school pupils (e.g. open days, participation in science festivals and events, prizes/competitions or joint projects)?	No
If yes, please specify:	

9. Did the project generate any science education material (e.g. kits, websites, explanatory booklets, DVDs)?	No
If yes, please specify:	

F. Interdisciplinarity

10. Which disciplines (see list below) are involved in your project?	
Main discipline	1.2 Physical sciences (astronomy and space sciences, physics and other allied subjects)
Associated discipline:	1.3 Chemical sciences (chemistry, other allied subjects)
Associated discipline:	

G. Engaging with Civil society and policy makers

11a. Did your project engage with societal actors beyond the research community? (if 'No', go to Question 14)	No
11b. If yes, did you engage with citizens (citizens' panels / juries) or organised civil society (NGOs, patients' groups etc.)?	
11c. In doing so, did your project involve actors whose role is mainly to organise the dialogue with citizens and organised civil society (e.g. professional mediator; communication company, science museums)?	

12. Did you engage with government / public bodies or policy makers (including international organisations)	

13a. Will the project generate outputs (expertise or scientific advice) which could be used by policy makers?	

H. Use and dissemination

14. How many Articles were published/accepted for publication in peer-reviewed journals?	0
To how many of these is open access provided?	0
How many of these are published in open access journals?	0
How many of these are published in open repositories?	0
To how many of these is open access not provided?	0
Please check all applicable reasons for not providing open access:	
publisher's licensing agreement would not permit publishing in a repository	No
no suitable repository available	No
no suitable open access journal available	No
no funds available to publish in an open access journal	No
lack of time and resources	No
lack of information on open access	No
If other - please specify	
15. How many new patent applications ('priority filings') have been made? ("Technologically unique": multiple applications for the same invention in different jurisdictions should be counted as just one application of grant).	0

16. Indicate how many of the following Intellectual Property Rights were applied for (give number in each box).	
Trademark	0
Registered design	0
Other	0

17. How many spin-off companies were created / are planned as a direct result of the project?	0
Indicate the approximate number of additional jobs in these companies:	0

18. Please indicate whether your project has a potential impact on employment, in comparison with the situation before your project:	Increase in employment, In small and medium-sized enterprises

19. For your project partnership please estimate the employment effect resulting directly from your participation in Full Time Equivalent (FTE = one person working fulltime for a year) jobs:	0Difficult to estimate / not possible to quantify

I. Media and Communication to the general public

20. As part of the project, were any of the beneficiaries professionals in communication or media relations?	No

21. As part of the project, have any beneficiaries received professional media / communication training / advice to improve communication with the general public?	No

22. Which of the following have been used to communicate information about your project to the general public, or have resulted from your project?	
Press Release	Yes
Media briefing	No
TV coverage / report	No
Radio coverage / report	No
Brochures /posters / flyers	Yes
DVD /Film /Multimedia	No
Coverage in specialist press	Yes
Coverage in general (non-specialist) press	No
Coverage in national press	No
Coverage in international press	No
Website for the general public / internet	Yes

Event targeting general public (festival, conference, exhibition, science café)	Yes

23. In which languages are the information products for the general public produced?	
Language of the coordinator	No
Other language(s)	Yes
English	Yes

Attachments	
Grant Agreement number:	243725
Project acronym:	NanoFlex
Project title:	An Universal Flexible Low-cost Plumbing and Heating pipe system fully Environment-compatible by using innovative Nanoparticle technology
Funding Scheme:	FP7-BSG-SME-AG
Project starting date:	01/11/2010
Project end date:	31/10/2013
Name of the scientific representative of the project's coordinator and organisation:	Mr. Ole Larmerud NORSKE RORLEGGERBEDRIFTERS LANDSFORENING VVS
Name	
Date	

This declaration was visaed electronically by Ole LARMERUD (ECAS user name nlarmeoe) on