Final Report Summary - SCOOP (Solar Collectors made of Polymers)

Executive Summary:
Glazed flat plate collectors and vacuum tube collectors are currently manufactured in time-consuming and cost-intensive manufacturing processes requiring different material classes (e.g. metals for absorber, trough and frame; inorganic materials for selective absorber coatings, thermal insulation and glazing; and organic materials such as wood or plastics for the frame, the thermal insulation or for the sealing). The final goal of this project was the exploration of the utilization of new materials and of a progress in technical innovation in order to further develop the solar-thermal market. In contrast to many developments so far, the research and development approach was not primarily guided by substitution considerations but searched principally new, multi-functional technical solutions.
The overall goal was to provide materials, technical design concepts and system concepts which compensate the actual weaknesses of polymers for their application in solar-thermal systems and use their strengths in cost-competitiveness in the future solar thermal market. Moreover, the global position of the European solar-thermal industry should have been improved by creating new business opportunities by using the potential of polymer materials in various concepts, with particular focus on the emerging markets in developing countries.

The feasibility of polymeric solar collectors in terms of performance, costs, architectural acceptance and environmental properties was evaluated in comparison with other technologies for thermal energy savings for Europe and emerging markets. A life cycle analysis (LCA) was performed to ensure the positive ecological impact of the collectors, too. Adapted collector designs were developed by the aid of Computational Fluid Dynamics (CFD) taking full advantage of the freedom offered by polymer processing techniques with respect to shaping, assembling and jointing. Strategies for sound complete solar systems were proposed by also taking into account the limitations implied by polymers.

The selection and optimization of multifunctional, polymeric materials for injection moulded components and extruded products for thermo-siphon and building integrated systems was the major activity of the material specialists and product designers in SCOOP. Materials and components were qualified continuously. Durability is always a crucial issue for sustainable products, and for polymeric materials an exposition to weathering is especially challenging. Service life prediction methodologies for solar materials developed within the IEA-Solar Heating and Cooling Programme were therefore adapted to the new materials and components with respect to their operating conditions in the systems designed in the project. Accelerated indoor tests were performed and validated by outdoor exposure tests. Another goal was the development of highly sensitive, non-destructive analytical methods which allow an early and reliable degradation analysis.

The basic requirements for building integration of polymeric solar-thermal systems were evaluated and collector prototypes for building integrated pumped and thermosiphon systems were assembled, using the innovative components developed in SCOOP. Possible obstacles for the application of the current performance standards on polymeric collectors or systems were identified. The comparison of the energy yields with conventional systems resulted in a competitive performance. Demonstration systems including roof and façade integrated systems were installed in different building types like passive houses and commercial buildings.

Project Context and Objectives:
The international solar thermal market has progressed strongly over the last years. Especially in China, the USA and Europe, both the manufacturing and commissioning of installations has grown rapidly. For the global market Bank Sarasin expects an average growth rate of approx. 20% p.a. until 2020 and also for the time beyond 2020 a stable market growth is expected. The major share of worldwide installed solar-thermal collectors currently consists of vacuum tube and glazed flat plate collectors. Both collector types are primarily used for hot water preparation with an operating temperature up to 90 °C. Cost-efficient plastics collectors are used mainly as uncovered absorber mats for swimming pool heating, with a working temperature of approximately 30 °C (Weiss et al., 2009).
Especially the sun-belt regions of the US and Asia, South Europe, Australia, Brazil, Mexico and South Africa are expected to contribute strongly to the global growth in the long term. Thermosiphon systems are dominant on many of these markets. The customers in these countries more and more ask for higher quality systems. This, in turn, offers good opportunities to increase the market share of European manufacturers with durable and easy-to-use and install systems in the future. Additional market volumes are expected for highly efficient building-integrated systems in Europe.

In 2008, polymeric collectors made up 12.4% of the worldwide solar heating capacity in operation (IEA-SHC Solar Heat Worldwide 2008), but almost exclusively as unglazed absorbers for swimming pool heating. The introduction of new polymeric materials and technologies is essential in order to meet the market requirements for heating applications in the medium and high temperature range. However, such new materials can only be used and marketed if the service-life is comparable to those of conventional products. The consortium of SCOOP brings together solar thermal and polymer experts from research institutions and industry to work on these challenges.

Novel polymeric materials and their application in solar-thermal systems are recognized as key for the attainment of mid- and long-term development targets of the solar-thermal industry (Weiss and Biermayr, 2009; Fink et al., 2009). The comprehensive review on the state of the art from the IEA-SHC Task 39 revealed that the market penetration of polymeric materials in solar-thermal systems has exceeded the threshold value in terms of relative market penetration only for swimming pool heating. However, water pre-heating or swimming pool heating with an average operating temperature of about 30 °C is a less important sector with regards to the overall final energy demand. Although in recent years also a tendency for an increased use of polymeric components in the very important sector of solar-thermal collector systems for low-temperature heat supply (up to 90 °C) is observed, only few complete polymeric collector systems are currently commercially available and installed. So, one important question is: What needs to be done to ensure that the high potential of plastics in the field of low-temperature solar-thermal energy supply can be transformed to marketable products? In analogy to other fields of highly successful plastics applications, a major factor certainly is related to the integration of key competences of the entire value chain (raw material – component – system) into a comprehensive collaborative research and development approach. In this context it is generally accepted that substantial research and development efforts still need to be undertaken to exploit the potential of polymeric materials to meet the requirements of both market segments: higher quality and flexibility. The presently existing market volumes now allow the usage of established cost efficient production technologies for polymers.

Injection moulding and extrusion are the most important plastics processing technologies in terms of production volume, offering a variety of advantages compared to other converting technologies. Advanced polymer processing technologies allow an integration of multiple functions in a single part or component. Especially injection moulding offers a nearly unlimited design freedom. In state of the art flat-plate or vacuum tube collector injection moulded or extruded parts with predominately mechanical functions (e.g. frame edges, absorber fixtures, end-caps) are already in use. But extrusion or injection moulding of plastics are applied for the main collector component, the absorber in a few of the commercially available glazed integrated storage collectors or flat-plate collectors, only. However, the development in other industrial sectors clearly indicates that extrusion, but also injection moulding technologies are nowadays also technologically feasible and economically advantageous for large components for automotives (e.g. 
bumpers or glazing) or buildings (e.g. windows or roofing).

The project addresses the necessary R&D work to select and develop suitable polymer grades and collector designs to enter these markets with cost efficient and durable solutions to significantly increase the share of renewable energies for domestic hot water and heating applications on a world-wide scale.

The final objectives are:

- Innovative polymer absorber designs with an optimised heat transfer competitive to metal absorbers
- New polymer material grades with promising cost performance ratio and proven long-term durability for absorbers used in thermo-siphon systems suitable for injection moulding and extrusion as production technology
- Innovative thermo-siphon solar-thermal systems suitable for polymer components
- Innovative solar-thermal systems suitable for polymer components using flat-plate collectors appropriate for the integration into the building envelope


Polymeric materials in solar collector applications

Polymeric absorber materials must be able to withstand elevated temperatures, exposure to sunlight (especially UV radiation), contact with the heat transfer fluid, and, depending upon design, working pressure. Further mechanical integrity (including dimensional stability) and optical durability must be maintained. In terms of collector efficiency, there are two primary challenges associated with polymeric solar absorbers. First, polymers are inherently less thermally conductive than metals. The range of thermal conductivity for polymers is in the order of 0.1-0.5 W/(m K), whereas it is 200-380 W/(m K) for conventional metals of choice (Al and Cu). Nevertheless with an appropriate design of the absorber this disadvantage can be compensated (thin wall thickness, integral surface wetting, optimal heat carrier flow, etc.) or by material modifications (additives that increase thermal conductivity), but this issue still poses a tough technological challenge.

Glazed polymeric collectors

Europe has played a leading role in the development of products for different solar thermal applications, e.g. systems for domestic hot water (DHW) preparation or solar heating systems for combined DHW preparation and space heating in single- and multi-family houses, hotels and large-scale plants for district heating. Due to the climate and heat losses these systems require a collector cover (glazing) and reliable freezing protection.

In conventional, glazed flat-plate collectors with an overall mass of approximately 20 kg/m2, the amount of plastics today is in the range of 0.5 kg/m2 (Kicker, 2009). For such collectors, but also for vacuum tube collectors, recent developments focused on substituting metals by polymeric materials for the collector
frame, trough or thermal insulation.

Glazed-flat plate collectors:
State of the art: Metal-absorber, aluminium frame, solar glass, mineral wool, high stagnation temperatures, first pioneering products from Aventa AS.
Progress beyond: Polymer absorber, polymer frame, foam insulation, moderate stagnation temperatures, new temperature- and UV-stable polymer grades, suitable for façade and building integration

Thermo-siphon systems and integrated storage collectors (ISC)

Thermo-siphon systems and integrated storage collectors (ISC) are typically installed in climates without freezing during the winter season. These systems have compact designs, are normally on-roof mounted and a relatively easy supplement or replacement of a domestic hot water boiler. Due to the low efficiency of ISC these cannot be used for direct space heating in continental clime.

For both, thermo-siphon systems and integrated storage collectors, the introduction of polymeric materials contributes to considerable reduction of weight and opens for innovative, functional designs and shapes. The latter is of major importance if building integration and interconnection of larger systems should be obtained.

Progress beyond the state-of-the-art for thermo-siphon systems and ISC:
State of the art: Flat-plate collector with steel tank in Europe, mainly Mediterranean market (no freeze protection); Evacuated tubular collectors with steel tank, mainly used in China, but recently exported to Africa and South America; the missing freeze protection causes reliability problems. Integrated storage collectors with a high plastic fraction in Australia and USA;
Progress beyond: Polymer collector with integrated buffer-storage for façade and roof-integration with pressure-less operation with freeze-protected heat-transfer fluid and an internal heat-exchanger. Polymer thermo-siphon with steel or polymer tank as stand-alone DHW-systems;

The project SCOOP focuses on:
• Selection and development of engineering plastic material, which can withstand the operation and stagnation conditions in collectors without pressure
• high-efficient polymeric solar collectors and on thermo-siphon- and integrated storage collectors with adapted efficiency for sun-rich regions,
• new design opportunities and successful building integration of polymeric solar collectors.

The project clearly aims at the demonstration of the competitiveness of polymeric materials with the existing state of the art to achieve considerable cost-reduction by mass production while keeping the performance and durability on a high level, y pushing forward the market penetration of solar thermal energy.

Project Results:
WP 1: MARKET, COSTS AND SCALE EFFECTS

Markets and specific requirements:

Market data were evaluated for 55 countries worldwide which represent over 90% of the installed solar thermal capacity. In order to get a general view, those countries were grouped into six economic regions (Europe, MENA Region, Sub-Saharan Africa, China, Asia excluding China and Central/South America). Worldwide about 85% of the collector surface is installed in China, 10% in Europe and 5% in the rest of the world. The evacuated tube collector represents the main part of the solar thermal world market (cheap Chinese thermosiphon systems).

Although the world market for solar thermal systems is continuously growing, the European market is continuously declining since 2009. This tendency did not change until 2014.

As the most promising regions for pumped polymeric systems central and northern Europe were identified. Nevertheless the fastest growing markets are outside Europe, where thermosiphon systems are predominant. Therefore Mexico, South America and South Africa are the most promising regions (beside South Europe) for the polymeric storage collector and the polymeric thermosiphon system.

Depending on the climatic conditions the reliability, quality and pressure of drinking water supply, system quality and lifetime requirements different configurations of thermosiphon systems are on the market. Most important criteria for their classification are:

- Pressurized and non-pressurized systems
- Open loop and closed loop systems

In geographical regions, where due to the mild or hot climate thermosiphon systems are common, integrated storage collectors are can be installed as well. Energy generation and energy storage are combined to one single unit. Due to the compact design they have several advantages such as easy and cheap installation or nice optical appearance.

Solar systems with pumped collectors are most common in central- and northern Europe. They are mostly used for hot water preparation and space heating. Most common are systems with pressurized solar circuits but drain-back systems are installed as well. Recently a strong request for large solar systems of several thousand square meters of collector surface for industrial applications and district heating can be observed.

The Solar Keymark Label is the most important standard for the quality control within Europe. Outside of Europe often local standards have to be followed.

Collector costs and scale effects:

Cost calculations were done for the polymeric storage collector, thermosiphone system and pumped collector and their comparable standard products. Calculations were based on 5.000 units per year and include material and manufacturing costs, but do not include any profit.

Following table shows the cost calculation results for the given calculation assumptions for polymeric and standard products.

Nevertheless it has to be pointed out, that compared products coincide in surface and/or volume, but not in thermal performance.

The replacement of the pressurized metal tank by a tank completely made of polymers slightly increases the production cost of the presently produced integral collector storage system. Even with high production volumes the costs of the tank cannot be significantly reduced. It is recommended to investigate other production technologies and/or the development of a pressure less tank (sufficient for many overseas
Manufacturing costs of the Aventa thermosiphon system made of polymer materials are significantly lower than those of a conventional system based on metal components and can be further reduced at higher production volumes. Nevertheless cost indications have to be considered with great care as the system concepts are very different.

According to the calculations, manufacturing costs of flat plate collectors made of polymers can be significantly reduced at higher production volumes. As the collector characteristic of both products is different, the different energy output for applications at different temperature levels have to be taken into account for further comparisons.

As transport costs are, especially for overseas transport, very high and directly influence the product price, optimizing of packing and logistics is of utmost importance for all investigated products.

Unit costs for certification can be hardly influenced, but become relatively low when sales achieve higher levels. As regulations for subsidies in most countries change quickly, the actual situation has to be checked before starting marketing activities.

Life cycle analysis:
Life Cycle Analysis (LCA) is a very powerful instrument to calculate and compare the ecological impact of any kind of industrial products.
In the frame of the SCOOP Project a LCA was carried out for the polymeric storage collector, the thermosiphon system, the pumped collector and the corresponding reference systems made of conventional materials.
In order to achieve comparable results, collector areas or system sizes were adjusted accordingly to generate the same solar energy contribution.
The recycling rate of the used materials shows great influence on the ecological impact. In this project the best and worst case (100% and 0% secondary materials) were calculated. In reality the industrial recycling rate is around 50%.

Conclusions:
Since project start no great changes of the solar thermal market situation were observed. The world market is still growing constantly. Nevertheless the decline of the European market, which started in 2009, still continues.
The market for thermosiphon systems is worldwide the largest solar thermal market. Nevertheless the largest market share by far have very low-cost Chinese thermosiphon systems (open loop and non-pressurized).
The advantage of the polymeric thermosiphon system is the small integrated steel tank, which contains drinking water and allows pressurized DHW circuit. The sales price of the within this project developed thermosiphon system will be above the low cost systems but clearly below the high end systems.
The market for integrated storage collectors is a niche market within the large world market for thermosiphon systems. Which market share can be reached will finally depend on the sales price to the end customers.
For markets with lower requirements the development of low cost products (with less pressure resistance and less thermal performance) seems to be useful (not part of this project). This are in general markets with high irradiation, high night temperatures and less requirements for comfort.
As polymeric collectors are not as pressure resistant as standard metal collectors, the hydraulic solar
heating system design needs to be adjusted accordingly. This means in general the application of the drain back technology.

For new companies, starting with the production of solar collectors, polymeric collectors (or complete polymeric systems) might be a good option, as investments for production facilities have to be done anyway. Existing companies, producing standard metal collectors might be reluctant with investments in polymeric production technologies.

WP 2: DESIGN OF SOLAR THERMAL COLLECTORS AND SYSTEMS BASED ON ALL-POLYMERIC OR POLYMERIC HYBRID MATERIALS

The overall objective of the work package 2 (WP 2) is to evaluate systematically concepts for both individual components (absorber, collector, storage tank, heat exchanger) and systems (thermosiphon system (TSS), integrated collector storage system (ICS) and pumped system (PS)) based on polymeric or hybrid materials. The successful use of polymeric materials requires totally new collector and systems concepts. The result of this work package forms a portfolio aligned to the manufacturing technology injection moulding, extrusion and partly welding techniques. One main target is an essential reduction of system costs at simultaneously high component and system efficiency with high market acceptance.

WP2 consists of three main tasks:
- Task 2.1 “Development of system concepts”
- Task 2.2 “Development of adapted absorber and collector concepts”
- Task 2.3 “Optimization process”

The development of polymeric systems needs to have a very clear focus on target markets and the economic, environment and operating conditions present there, in order for the developed products to be economically successful. The main boundary conditions (target markets, main system types and sizes in specific regions, water and electricity supply) were investigated in detail in WP 1 and served as Input for definition and development of novel polymeric specific system solutions.

In the course of task 2.1 various brainstorming workshops and expert talks were held in order to develop new concepts and to generate new ideas for more cost-effective system solutions for the three development lines (ICS, TSS, PS) with a high proportion of plastic. In order to reach the objective of realizing low-cost systems with engineering plastics high temperatures need to be avoided. In this context, several overheating and freezing protection measures have been gathered, analysed and evaluated. From over 25 system-ideas, 12 concepts were categorized and assessed. Their advantages and disadvantages were analysed by using a SWOT analysis, and the best rated concepts (two for each development line) with consideration of solar thermal and relevant material specific aspects, were chosen for further investigation. These concepts formed the system portfolio of most promising concepts in work package 3 and 4. In a second step a re-evaluation of the six best rated concepts, including first comprehensive theoretical analysis (model building, simulation, improvement) and first specific tests on components and systems, led to the conception and creation of functional models for ICS, TSS and pumped systems.

The theoretical results and the theoretical prediction were proven by real functional models under outdoor testing conditions (AEE INTEC, UNI Oslo, AVENTA).

For the ICS down-scaled models with two half shells which were manufactured by Polytec through an injection moulding process and fitted together in a second processing step, the thermal behaviour (warming-up and cooling-down) was evaluated. The test result showed what CFD-Simulations have predicted (comparable warming-up behaviour in comparison to a metal pipe) before, whereupon a full
scale model with polymeric pipes was manufactured by GREENoneTEC and compared on the basis of the performance to a conventional ICS with metal pipes. Based on this results a dynamic model of an ICS with polymeric pipes in Polysun 6.2 was validated and adapted to the measurement results to determine the system efficiency and the temperature loads profiles.

Based on a first approach of Aventa, a TSS with an extruded polymeric absorber with up- and down streaming channels in one plane and a polymeric storage tank directly connected to the top of the absorber was precisely measured and compared to an conventional TSS with a selective coated metal absorber and double-shell storage tank. The polymeric TSS showed satisfactory system efficiencies already in the prototype stage. For the theoretical analysis and optimisation of individual components as well as the determination of the annual solar fraction and temperature load profiles for different climatic conditions, punctual flow simulation with CFD and a dynamical model were developed and came into operation.

With respect to the pumped systems, the focus was on particular thermo-physical, optical and hydraulic aspects as well as mechanical requirements. In close cooperation with Aventa and UNI Oslo geometric aspects (geometries of absorber and wall thickness, conception of collector and connection of mainfolds) and material-specific (absorber-coating etc.) influence factors on the flow distribution and the efficiency factor $F^*$ of the component collector as well as the whole system (solar fraction, requirements and loads) were determined and optimised by punctual laboratory tests, and theoretical analyses. To overcome present barriers of solar thermal installation (high installation costs), Aventa and several major Nordic actors developed a novel window-integrated solar collector technology which installers are used to handle at the building site.

WP 3: MULTIFUNCTIONAL POLYMERIC OR HYBRID MATERIALS AND INJECTION-MOULDED COMPONENTS FOR COLLECTORS

The overall objective of WP3 is to evaluate systematically the opportunities and limitations of injection moulding technologies for the production of solar thermal collectors. Due to less critical service conditions and performance requirements, but also economic and market related reasons (e.g. material costs and availability or specific operating conditions), the main focus was given to the development of polymeric material grades and model components for integrated solar thermal systems based on integrated storage collectors. For work package 3 the following tasks were defined:

- Task 3.1: Multi-functional polymer grades for injection moulding
- Task 3.2: Injection-moulded components for collectors
- Task 3.3: Assembling of injection moulded components

The Tasks 3.1 to 3.3 were part of both consecutive series for the technological development of injection moulded components for collectors. The main aim of Series 1 was to check the feasibility of injection moulding technologies for integrated storage collectors and to develop model compounds and components. In Series 2 the material grades and model components were optimized including also the characterization of the long-term durability on specimen-level and the performance in lab environment. The research work was carried out in close collaboration between the Scientific Partners JKU Linz and AEE INTEC and the Company Partners APC, GOT and Polytec. Furthermore, WP3 was interlinked with the work packages WP2, WP5 and WP6.

Based from results in WP 2 various concepts for integrated storage collectors with injection moulded components were evaluated. The basic concept and cross-section of an integrated storage collector were
selected for further investigation. The main components of the collector are the injection moulded absorber/storage, the transparent and opaque insulation, the housing and the glazing.

For the absorber/storage tank the loading conditions were defined using a basic engineering assessment approach. The most critical loading conditions for the open-loop integrated storage collector were operating pressure levels of 6 bar at ambient temperature and 4 bar at 90 °C. Using Finite Element simulation tools mechanical loads were estimated and required material properties were deduced. Engineering polymer grades with glass-fibre reinforcement were selected, compounded and characterized. Considering also economic requirements special focus was given to aliphatic and aromatic polyamide grades and blends. Furthermore, modular tools were designed, implemented and used for the production of half-shell parts and assembled components. For assembling of half-shell parts mechanical fixturing, gluing and welding technologies were evaluated. The investigations in development series 1 revealed a high potential for injection moulded half-shell parts and absorber/storage tanks for integrated storage collectors.

In the optimization series 2 research work was dealing with the adaptation of the experimental mould for injection moulded half-shell components, the compounding and characterization of optimized polyamide grades and the realization and performance testing of half-shell parts and assembled model components for integrated storage collectors. To improve the weldability the edge of the half-shell parts was redesigned to a step-like profile. This allowed for intimate contact of the molten seam during welding of the parts. Adapted inserts for the experimental tool were manufactured and used to produce model parts with step-like edges.

Regarding material development a novel hydrolysis and weathering resistant, glass fibre reinforced polyamide 66 (PA66) grade was compounded and comprehensively characterized on specimen level. To assess the long-term behaviour pressure cooker tests were carried out in hot water at elevated temperatures of 95, 115 and 135 °C using autoclaves (in interaction with WP5). The global aging tests without superimposed mechanical loading run for more than 10000 hours. Internal cracking and failure of the novel material was obtained after 4000 hours at 115 °C and 1000 hours at 135 °C in hot water. By extrapolation of the endurance times at elevated temperatures to service-relevant temperatures (< 100 °C), simulation of installation site dependent temperature loading profiles and accumulation of damages using the Miner’s rule, lifetime values between 31 and 48 years were deduced. The lowest value of 31 years was obtained for hot-wet climate zones (e.g. Fortalza, Brasil). For Athens (Greece) a lifetime of 39 years was estimated.

Using the novel polyamide grade and the adapted tools pressure resistant model components were produced by injection moulding and frictional welding. By monotonic internal pressure testing critical pressure levels of >20 bar at ambient temperature and > 6 bar at 90 °C. The performance requirements were exceeded by a factor of at least 1.5.

The materials and model components were also tested in WP5 and WP8. On collector level a remarkable performance was ascertained. Hence, the technical feasibility of integrated storage collectors based on injection moulded absorber components was unambiguously ascertained.

WP 4: MULTIFUNCTIONAL POLYMERIC COMPOUNDS AND COMPONENTS FOR EXTRUSION OF ABSORBERS

Extrusion of polymers to structured sheets is a key-production technology opening simultaneously for mass production, related cost reduction through high volumes and for flexible absorber dimensions, which are needed when the aim is to integrate solar collectors into buildings roofs and facades. Further efficient
collectors require high temperature performance (HTP) polymer blends, which can sustain operational
temperatures during stagnation and at tough climates. These objectives were investigated in four Tasks:
- Task 4.1: Increase thermal stability and extrudability of polymer blends for sheet extrusion
- Task 4.2: Interconnection of intrinsic absorber components
- Task 4.3: Absorbers suitable for thermosiphon concepts
- Task 4.4: Absorbers for building integration

Increase thermal stability and extrudability of polymer blends for sheet extrusion:
The optimization of HTC polymeric blends/ compounds, in particular polyphenylene sulphide (PPS) has been aimed with regard to thermal stability and extrudability. The extrusion of PPS to structured sheets has been demonstrated for the first time worldwide by the present team of experts. An extrusion die, which can produce three absorber widths in parallel, is owned by Aventa and was modified and improved.
PPS is mainly used in injection moulding applications. For the extrusion to structured sheets PPS blends with higher viscosity and melt strength were developed in collaboration with the material provider. Post-polymerization treatments on processability of modified PPS has been evaluated in laboratory scale. A better understanding and control of the degree of crystallization during sheet extrusion are important in order to make a mechanically and dimensionally stable, structured sheets. An online annealing oven could successfully be implemented in the full-scale online extrusion line.
Advances in PPS blend modifications and full-scale extrusion were key-issues which contributed to reduce the unwanted waste production. The innovative processing efforts included also the improvement of the working environment for the extrusion staff, the development of a ventilation system and air analyses in order to secure a production in safe conditions for the operators. The extrusion of PPS has reached a very close to full industrial process. Few issues are identified which have the potential of further improvement; the recycling of waste material and re-incorporation in virgin material and further improvement of temperature stability during annealing.

Interconnection of intrinsic absorber components:
While the absorbers were made by structured sheet extrusion, the endcaps are naturally made by injection moulding, which requires a modified material blend with significantly lower viscosity and with glass fibre content. This mismatch in viscosity represented a challenge for welding, in particular for the building integrated collector of HTP polymers.
Concerning the jointing of absorber components of HTP polymers, hot plate welding and in-frared (IR) welding were investigated with jointing devices on laboratory and prototype type level. After the mechanical strength of the joints was confirmed, a full scale IR-welding line for HTP absorbers was designed, realised and installed in collaboration with international industrial partners.
The polypropylene blend, which was used for the thermosiphon system (TSS) components, revealed to have less critical material parameters for the chosen jointing methods. It was found that hot air- and hot plate welding to be the best and most flexible jointing technique at this stage of concept development, which allowed optimizing the functional and dimensional design of the TSS prototypes. It can be concluded that the investigations concerning the interconnection of absorber components produced by sheet extrusion and injection moulding were successfully completed.

Absorbers suitable for thermosiphon concepts:
Absorbers of extruded structured sheets for the TSS concept, which was designed in SCOOP were
developed. With the findings of the brainstorming sessions, optimisation process and progress of prototype component production, the absorber components were developed and modified for the application in a thermosiphon system. This included the integrated absorber-storage design, endcaps, glazing, thermal insulation and framing.

The thermosiphon concept exhibits promising properties regarding efficiency and energy performance. It is evident that the present thermosiphon concept has due to material choice very low weight compared to other concepts in the market. It indicates that the manufacturing costs, as well as transportation and installation costs will be low.

The possibility to make a compact design, with a less visually dominating heat store than in most other thermosiphon concepts, has been demonstrated. This offers also good possibilities for integration in buildings roofs and facades.

Absorbers for building integration:
The specific requirements for absorbers, which are suitable for building integration, were investigated from a mechanical, functional and aesthetic point of view. It concerned first of all the absorbers of the HTP polymer PPS, but also the TSS absorber of PP which has the option of building integration. The work included the feedback and input of the results from WP6 on the building integration at collector- and system level.

The feasibility of coloured, selective absorbers was demonstrated on sample level in order to provide the flexibility for building planners, architects and decision makers to choose different colours than black in particular for facade integrated collectors. The most central issue for the building designers was related to the interface between the installed collector field and the surrounding, conventional building surface covers and the modified construction and materials underneath.

Summary:
Extruded, polymeric structured sheets were successfully demonstrated as absorbers for building integrated collector- and thermosiphon concepts. The processing method is the key issue for the producing various collector lengths for easy building integration and opening for mass production and cost reduction of solar thermal technology relative to conventional technology. The processing of high temperature performance plastics to structured sheets has been a world premier pioneering effort. Also a thermosiphon concept based on extruded structured sheets has been developed. The different collector concepts require different polymeric materials with different material performance, processing parameters and costs. Different jointing methods for the two polymer collector concepts were tested, verified and optimized.

WP 5: QUALIFICATION OF NEW MATERIALS, ABSORBERS AND OTHER COMPONENTS
In WP 5 “Qualification of new materials, absorbers and other components” five partner institutions were involved in developing and conducting screening tests to identify suitable materials mainly for the use as solar absorbers. In the progress accelerated aging tests, simulating long term exposure to a harsh environment as expected under operation conditions in the system designs from WP 2, have been performed. State-of-the-art analytical tools were used to identify changes in the materials and to forecast the maximum service life time on this basis. For this purpose research institutes from different fields joint resources to perform different aging test and to exchange specimens to subject these to their own scientific methods and analytical routines. A broad exchange of scientific data enabled interdisciplinary
insight into degradation processes of polymers under different environmental and mechanical loads. To consider the superimposed mechanical, thermal and environmental loads properly, a fracture mechanics based in-situ testing approach was developed and established at JKU-IPMT. Therefore, a multi-wall glass container was concepted and implemented at an electrodynamic testing machine. Inside the specimen is immersed in service-relevant gases or fluids (e.g. air, drinking water). In the outer shell a heat carrier fluid is used to adjust and control the temperature (from 0 up to 95 °C). To detect deformations or the crack length of the specimen the setup was equipped with a camera system. This setup was used to perform fracture mechanics tests on unwelded and welded absorber material specimen from WP 3. The crack growth behaviour was characterized in air or water environment at temperatures of 23 and 80°C.

It was highlighted that the crack kinetics is significantly dependent on environment, temperature and processing conditions. In general, a worse crack growth behaviour was obtained for specimen exposed in hot water at elevated temperature (80 °C) and welded specimen. The more critical environment of hot water is in agreement with conventional (no superposition of loading conditions) aging data results obtained in WP 3. Furthermore, critical stress intensity factors were calculated assuming a pressurized pipe made from PA66-GF30 with a wall thickness of 3 mm. By comparison of the critical K-value with the experimental data it was shown that the critical K-value is below the threshold K-value even for the welded specimen tested in hot water. Hence, it was concluded that the superimposed mechanical, thermal and environmental loading of PA66-GF30 is not critical for the investigated pressurized storage tank.

Regarding lifetime estimation further research work has to be done including experiments at different temperatures and developing advanced models considering accumulated damages. Another focus was on the development of straightforward mechanical tests on components, allowing not only performing accelerated aging tests on processed materials, but also to have reliable methods for quality control and test on hand. Such tests for extruded twin wall sheets made of Polypropylene (PP) and Polyphenylen sulfide (PPS) have been developed by UiO and Fraunhofer ISE in cooperation. In two different approaches the tools to test such sheets for crack resistance on one hand and to gain information of changes of the mechanical properties on a more quantitative base were developed. For these so-called indentation tests, a tool, the indenter, is pressed into der sheet material and the force response over distance is recorded. Additionally a qualitative evaluation of the indentation area regarding plastic deformation or brittle crack formation can be made. The broad basis of these indentation test results for sheets after different accelerated aging tests is valuable for the production of the flat plate collectors from WP 4. Such detectable changes in the mechanical properties however require long exposure times to harsh environments, like high temperatures, and the acceleration factors are limited by the materials individual physical properties, like the melting point. In order to identify material changes in a very early stage a significant part of the work done in WP 5 was on the development of advanced optical methods. Here the development and the adjustment of luminescence measurements by UBER was one major step forward. Measuring the specimens’ emission for different excitation wavelengths a full 3D mapping of the excitation-emission properties is performed. Different polymer classes have their very specific excitation-emission spectra. Comparing specimens from different aging tests the spectral changes allow differentiating between different degradation mechanisms on the basis of their kinetics.

In contrast to the investigation of nearly undetectable material changes the testing on a much larger scale, the tests of functional models and prototypes, was one objective of work package WP 5. The mechanical and thermomechanical loads on different components of the collectors developed in WP 3 and WP 4 were analysed using FEM simulation. These results were fed back to the work packages influencing design and
Concrete results from these work packages in terms of prototypes and functional models were equipped with temperature sensors and sent to three distinct climatic regions for outdoor exposure testing in dry and water filled state. In all these locations for all three concepts realized as test specimens the temperature was measured in 5 points per collector. These measurement points characterize specific components and locations within the collector and provide together with the climatic data recorded a very unique data set. Not only design aspects of the investigated collectors could be studied in this way, but also reference materials for the accelerated aging tests were generated. Material specimens from these outdoor exposed collectors a valuable reference to test the acceleration factor and precision of the accelerated aging tests performed indoors on the lab scale, where environmental conditions were controlled steadily on one hand, but degradation factor were applied individually or only in little combination. The evaluation of the collector data with regards to the climatic data recorded for each location, however, required the development of new approaches for data analysis.

In addition material specimens of new materials, like coatings, were exposed by SPF in two different locations, to study further environmental impacts on the materials. Also the investigation regarding the effects of saline heat carrier fluids on the absorber materials was investigated by long-term exposure to different saline solutions, followed by spectroscopic and mechanical testing lead to no detectable material failure.

In order to check for interaction between different materials within the collector Fraunhofer ISE developed a new approach to test materials for outgassing of volatile compounds.

During the project’s progress a broad set on analytical tools have been developed and applied to the materials developed in WP 3 and WP 4, marking a large step ahead in the development of polymeric collectors.

WP 6: USABILITY AND BUILDING INTEGRATION OF SYSTEMS AND POLYMER MATERIALS

The objective was to investigate the feasibility of solar collectors in polymer materials as building integrated or building embodied parts in new and retrofit projects. Further the feasibility of polymer materials in thermosiphon systems and collectors with integrated storage was studied. The challenges related to interconnection of modules and organisation of heat carrier flow schemes was investigated. These objectives were investigated in three Tasks:

- Task 6.1: Basic requirements on building integrated polymer collectors and systems
- Task 6.2: Building integrated polymer collectors and systems with the focus on pumped systems
- Task 6.3: Building integrated polymer collectors and systems with the focus on thermosiphon systems/integrated storage collectors.

Basic requirements on building integrated polymer collectors and systems:

The study on basic requirements was a theoretical and conceptual work. The availability of solar irradiation on roofs and facades for different climatic locations and season was illustrated and compared with the heating demand in different building types, as residences, public buildings, institutional buildings, new-built and rehabilitation projects. The degree of building integration of solar collectors was discussed, simplifications are proposed and the environmental loads as temperatures, solar irradiation, wind, hails and snow are defined. The impact of all parameters on the building physics, in particular if solar collectors are introduced, is considered. For that relevant regulations and norms are listed, which apply for building sur-face modules on European level.
Examples for different solar collector technologies and solar heating systems types are presented and how solar collectors could ideally be integrated into the building skin. The integration aspect concerned also the infrastructure and the location of the technical room with heat store, auxiliary heating and heat distribution systems in the building.

The practical experiences with examples of two large-scale solar thermal collector integration were presented. Although the collector technology were conventional metal-based collectors, the learnings were exhibited, which can be easily transferred to new-developed polymeric collector technology. It was found that the requirements of pre-fabricated modules are more or less the same as for standard facades. Material-related issues, eventually drain-back function and related piping require separate assessment. The weight of the prefabricated, all-over facade modules will be considerably reduced with polymeric collectors.

Favourable for polymeric collectors as facade integrated modules are the reduced overheating risk during summer time; further the increased space on buildings' facades caused by the passive house requirements demanding more thermal insulation and less window area in buildings.

Building integrated polymer collectors and systems with focus on pumped systems:
Integration principles for polymeric solar collectors in pumped systems were elaborated. Only glazed solar collector systems were studied, which are relevant for the main European market, either for domestic hot water (DHW) preparation or so-called solar combisystems for combined solar space heating and domestic hot water preparation.

The study distinguished permanently filled solar collector loops with freezing- and overheating safe heat carrier liquid (typically glycol-water mixture) and drain-back systems (water filled during operation). The first is the present state of the art technology used for conventional metal-based collectors while the latter is favourable for pumped, polymeric collector systems. Basic characteristics of pumped polymeric collector systems relative to known state of the art are exhibited together with the impact on hydraulic system design: Simpler hydraulic design, less components, higher heat carrier flow, difference in collector material properties as absorbance, transmittance, thermal conductivity and -expansion coefficients.

The variation of system parameters reveals that the overall system performance is less de-pendent on whether the collector is a conventional metal-based collector or a polymeric collector than on a "good" system design with suitable dimensions and temperature level.

Special attention was given to the stagnation behaviour, which can be expected in polymeric collectors systems. A simulation study was performed with different consumption load profiles for extreme conditions under south European climate comparing the temperature frequency distribution and fraction of pressure load in a building-integrated polymeric collector system for a single and multi-family house.

In laboratory studies the filling-, emptying and operational behaviour of pumped, open loop and non-pressurised polymeric collectors is studied with IR-camera imaging and verified by calculations, which shows that the hydraulic heat carrier flow is well understood.

Building integrated polymer collectors and systems with the focus on thermosiphon systems/integrated storage collectors:
Two different collector types for building integration were investigated, which also are demonstrated in real installations. For facade-integrated collectors a relation for the heat transfer in conventional wall construction and in constructions with integrated collectors was derived. Wall constructions with integrated collector facades with and without back venting were studied. For constructions without back venting it is
concluded that during daytime the heat loss through the construction with the solar collector is smaller than through the ordinary wall construction, while during night-time the situation is opposite. For constructions with back venting the heat transfer through the wall construction with and without solar collectors was shown. The heat loss of the collector facade during daytime is a function of the solar irradiance. Calculated solar radiation levels for the location Oslo are shown for collector facades with back venting and compared to real measurements during 2013 in Oslo.

Polymer based thermosiphon systems (TSS) were investigated by simulations and experimental studies under ambient conditions. It was found that the circulation of the heat carrier in the absorber module driven by the thermosiphon principle with up- and downstream channels in one plane work satisfactory. The simulated results can be confirmed by temperature monitoring. For indirect TSS the heat exchanger should preferably be of metal (steel) instead of polymers, because of costs, limited space, and heat transfer capacity. Preferable to a spiral heat exchanger is a tank heat exchanger due to dimensional design, DHW draw-off and varying weather conditions. For the design of a tank heat exchanger, a tank with connecting in- and outlet pipes mounted on the cylindrical sides reveals best performance for the tapping profile.

WP 7: DEMONSTRATION OF SOLAR SYSTEMS WITH POLYMERIC COLLECTORS

The feasibility of polymeric solar collectors in solar thermal systems was demonstrated. The demonstrations are presented at different stages of maturity. Selected prototypes were put into complete systems, and the operation and performance is shown. Other concepts were demonstrated in terms of design examples, showing how the concepts can be integrated or embodied in various kinds of buildings and used in various applications. The work included also the feedback from central actors within building and construction (B&C) on the issue of integration solar thermal technology in the building. These objectives were investigated in five Tasks:

- Task 7.1: Feasible integration principles deduced from survey among architects and building industries
- Task 7.2: Demonstration of thermosiphon systems and systems with integrated heat store
- Task 7.3: Demonstration of façade integrated solar collector in polymer materials
- Task 7.4: Demonstration project with roof-integrated solar collectors in passive houses
- Task 7.5: Demonstration of polymer absorbers embodied in prefabricated glass façade modules

Feasible integration principles deduced from survey among architects and building industries:
One objective was to overcome the constrains apparent for design of well-functioning solar thermal systems in polymer materials, and the restrictions from building regulations, building physics and economy that the building industry has to obey.
A questionnaire for a survey addressing different branches of the building industry on architectural integration of solar thermal collectors has been worked out. Although the feedback rate was moderate, the summary of the survey helped to exhibit attitudes and barriers for central actors within B&C towards integration of solar collectors into the roof or facade. Several issues, which were pointed out in the survey, were discussed in connection with real demonstration projects, one facade-, one roof integration and one project, where polymeric absorbers were integrated behind standardised glass windows. It is shown how certain challenges were solved or attempted to be solved by using the polymeric collector concept developed in the project SCOOP. The interface between the collector roof/-façade, the piping and interconnection of collectors were discussed with regard to easy installation and integration.
Demonstration of thermosiphon systems and systems with integrated heat store:
Polymeric thermosiphon systems (TSS) and systems with integrated storage collector (ICS) were
demonstrated in terms of design examples, reports, posters and 3D presentations. Physical models and
prototypes were produced, demonstrated and improved in an on-going process. Stand-alone systems
were assembled, tested and are operative in several European countries as Austria, Germany,
Switzerland and Norway. The building integration aspect of thermosiphon systems has been
demonstrated in full-size models. A German and international patent application of the thermosiphon
concept has been filed.

Demonstration of façade integrated solar collector in polymer materials:
Polymeric collectors integrated in facades are particularly interesting in solar combisystems at northern
latitudes due to the low solar angle during the heating season. One demonstration deals with façade
integrated solar collectors in a solar combisystem.
One new-built project is the first field with single-family passive houses in Norway and consists of 17
detached houses situated in a south suburb of Oslo, named Rudshagen. Rudshagen building cooperative
is owned by OBOS (Oslo Housing and Savings Society), the largest Nordic cooperative building
association, which has built more than 100,000 homes, representing a quarter of Oslo's housing stock.
Energy monitoring was carried out for more than one year. The "lessons learned" from the solar heated
house at Rudshagen are transferred to a follow-up project with 34 passive houses built in Oslo, all with
polymeric collectors.
Further two retrofit projects with polymeric solar collectors are exhibited, a single-family house in a rural
area and a multi-family house in Oslo, both with facade collectors in a solar combisystem.

Demonstration project with roof-integrated solar collectors in passive houses:
The row house project "Stenbråtli housing cooperative" in Oslo, Norway, is chosen as demonstration of
roof-integrated solar collectors in passive houses. Stenbråtli consists of 34 detached- and row houses
with passive-/ low energy standard. The polymeric solar collectors contribute to space heating and DHW
preparation and are architecturally integrated on tilted- and flat roofs. Stenbråtli housing cooperative is
owned by OBOS (Oslo Housing and Savings Society). Several central actors were involved in the design
planning and construction of Stenbråtli. At Stenbråtli the solar collectors were installed as a part of the
workflow at the building site by the installers, which also did the roof- and facade of the buildings.

Demonstration of polymer absorbers embodied in prefabricated glass façade modules:
The NorDan Solar concept is used as demonstration of polymer absorbers in prefabricated glass façade
modules. As demonstration projects three onsite installations are chosen. Two of them were the winners of
a piloted glass facade collector system after a competition, which took place in connection with the major
B&C fair in October 2013 in Norway. The NorDan Solar collector window is considered to overcome
certain barriers of conventional solar collectors: Available in almost any window dimension for easy
architectural integration into the facade; polymeric pipe-in-pipe system with "quick and easy connectors",
connecting window collectors and heat store; pressure less solar collector circuit which can be installed by
any skilled installer (plumbers or HVAC are not required), domestic hot water store with integrated drain-
back tank, heat exchanger and pre-mounted pump station;
NorDan as the largest window producer has an established distribution and installer network, including
also contact to central actors within B&C (housing associations, entrepreneurs; producers of prefabricate
houses, type houses, etc.). The NorDan Solar window collector concept is just before market launch in 2015. After the introduction into the Norwegian home market, the introduction is planned to be extended to Sweden, Poland and UK.

WP 8: PERFORMANCE ASSESSMENT, SYSTEM QUALIFICATION ASPECTS

In WP8 the collector and system prototypes developed in the course of the SCOOP project were tested according to the currently valid European standards: EN12975-1 and ISO9806 for collectors and EN12976 for the factory made systems and integrated storage collectors. None of the SCOOP prototypes fitted in the scope of the standard EN12977 for Custom Built Systems. The main objective of WP8 was to analyse the applicability of the standard test procedures to polymeric solar thermal devices and to investigate the significance of the test results. Furthermore, specific technical problems and obstacles of testing polymeric devices according to these standards were investigated.

In WP 8.1 the thermal performances of the SCOOP collector- and system prototypes were measured. The performance test methods are black-box procedures, hence almost independent of the design and materials used for the device. The standard test methods are therefore fully applicable to polymeric devices and the results from different laboratories using different test methods are in general comparable. The observed deviations between the results are either explainable or within the uncertainty of the procedures. One of the SCOOP prototypes is also available with a metallic absorber. The comparison of the results with the results for the polymeric absorber confirmed that at least in this case the absorber material does not affect the performance substantially. Some basic questions about the impact of low flow-rates and low system pressures applied for testing arose during the measurements. These questions are not directly linked to the polymeric materials, but may surface more frequently for such devices.

In WP8.2 the prototypes were tested for quality and durability. The relevant standards are fully applicable and some of the standard test procedures, especially in the ISO9806:2013, are already slightly adapted to polymeric devices. However, these modifications must be considered as preliminary. To better consider the specific properties of polymeric materials some of the test procedures should probably be further modified. One of the evident threats for polymeric materials in solar thermal applications are the stagnation tests where the samples are exposed to the sun in dry conditions. Depending on the design of the device, temperatures in the range of 150°C can be reached, thus requiring special attention for the selection of the materials. Another issue is the pressures resistance of the devices. Most of the problems observed were due to these two impacts.

Supplementary tests were added such as freeze tests and freeze-humidity tests to verify the suitability for colder climates, or impact resistance tests to assess the resistance against hail events. The standard test procedures are sometimes not fully applicable to all prototype samples. This must be considered especially when designing polymeric devices. Negative results of a quality test may become evident only in a late stage of the development phase after having installed already in the expensive production tools.

In WP8.3 the specific obstacles and problems when applying the standards were analysed and recommendations for the future standardisation are identified. As outlined before the above mentioned European standards are in principle applicable without any restriction to polymeric solar thermal devices. For the performance measurements, the dependency on flowrate and testing pressure may be an issue affecting the results. Further investigations on this point would however be required before providing input to the standards. The durability and reliability tests are not yet particularly targeting at the assessment of polymeric materials. Additional material tests or requirements would therefore be recommended to provide
a reliable rating of an equivalent lifetime as for standard solar thermal products. Such tests could be adopted from standard polymeric test procedures such as for example from the ISO9080 for the long-term pressure resistance of plastic pipings. Also for other important aspects such as the UV resistance or weathering ageing, there are already reference standards available. Some first input for amendments has been provided already to the currently ongoing ISO9806 revision.

Potential Impact:

WP 1: MARKET, COSTS AND SCALE EFFECTS

Since project start no great changes of the solar thermal market situation were observed. The world market is still growing constantly. Nevertheless the decline of the European market, which started in 2009, still continues.

The market for thermosiphon systems is worldwide the largest solar thermal market. Nevertheless the largest market share by far have very low-cost Chinese thermosiphon systems (open loop and non-pressurized).

The advantage of the polymeric thermosiphon system is the small integrated steel tank, which contains drinking water and allows pressurized DHW circuit. The sales price of the within this project developed thermosiphon system will be above the low cost systems but clearly below the high end systems.

The market for integrated storage collectors is a niche market within the large world market for thermosiphon systems. Which market share can be reached will finally depend on the sales price to the end customers.

For markets with lower requirements the development of low cost products (with less pressure resistance and less thermal performance) seems to be useful (not part of this project). This are in general markets with high irradiation, high night temperatures and less requirements for comfort.

As polymeric collectors are not as pressure resistant as standard metal collectors, the hydraulic solar heating system design needs to be adjusted accordingly. This means in general the application of the drain back technology.

For new companies, starting with the production of solar collectors, polymeric collectors (or complete polymeric systems) might be a good option, as investments for production facilities have to be done anyway. Existing companies, producing standard metal collectors might be reluctant with investments in polymeric production technologies.

WP 2: DESIGN OF SOLAR THERMAL COLLECTORS AND SYSTEMS BASED ON ALL-POLYMERIC OR POLYMERIC HYBRID MATERIALS

Within the work package 2 novel collector- and system designs with advanced operating methods and innovative individual components have been developed and tested and are ready to enter the solar thermal market.

One highlight is the high potential for the production of cost-efficient integrated collectors storage systems based on two half-shells and assembling by frictional welding by mass production (>10,000 units per year). Furthermore, the measurements on the polymeric full scale model confirmed, that the thermal performance is comparable to the conventional ICS based on metal pipes. An additional feature of a polymeric solution is the corrosion resistance in comparison with other materials. With respect to the polymer-based Aventa thermosiphon system a very compact design, with a less dominating (aesthetic) heat store and very low weight which offers good possibilities for building integration was developed. Due to the choice of the material the production costs at industrial scale and the environmental impact of the life cycle are significantly lower than those of a conventional TSS. These are very important factors that
facilitate the market uptake and apply both to the TSS as well as for the pumped systems. Regarding the pumped systems, polymeric based solutions for systems and single components have great potentials to reduce installation barriers, time and costs. Furthermore, theoretical models were developed to evaluate relevant design and material specific aspects (thermal, hydraulic, mechanical) and important key findings for the use of polymeric materials were collected. Some of the results were presented to scientific events (OTTI-Symposium Thermal Solar Energy, Gleisdorf Solar), transferred to the IEA SHC Task 39 (Polymeric Materials for Solar Thermal Applications) and also published in the journal “Erneuerbare Energie”.

WP 3: MULTIFUNCTIONAL POLYMERIC OR HYBRID MATERIALS AND INJECTION-MOULDED COMPONENTS FOR COLLECTORS

In WP3 multifunctional polyamide grades and advanced injection moulded and welded absorber/storage tank model components were developed for integrated storage collectors. The novel collector concept can be realized by using cost-efficient mass production technologies. Highlights of WP3 are the novel polyamide grades with remarkable long-term durability under service relevant loading conditions. By thorough formulation, compounding and advanced aging testing it was revealed that glass-fibre reinforced, aliphatic polyamide grades allow for lifetimes of more than 30 years depending on the installation site of the collector system. Furthermore, large absorber/storage tanks fulfilling the main performance criteria were attained using a combination of injection moulding and frictional welding. Therefore, optimized half-shell parts with step-like edges were designed, manufactured, assembled and successfully tested as to their pressure resistance at elevated temperatures. The main results of WP3 have been presented at various international conferences and experts meetings (e.g. SHC 2014 in Beijing (CHN); IEA SHC Task 39 in Ashkelom (ISR), Linz (AT) and Oslo (NOR)). Furthermore, two scientific papers are currently prepared and submitted to distinguished peer-reviewed journals (Solar Energy and Polymer Testing), which are part of the dissertation thesis of Klaus J. Geretschläger (Institute of Polymeric Materials and Testing at JKU Linz, Austria). The main findings are already exploited by the company partners by using the novel materials and established technologies for products with comparable loading profiles in the automotive industry. Further technology development needs, demonstration activities and transfer towards commercialization are currently discussed and evaluated by the company partners GOT, Polytec and APC.

WP 4: MULTIFUNCTIONAL POLYMERIC COMPOUNDS AND COMPONENTS FOR EXTRUSION OF ABSORBERS

The SCOOP work package on Multifunctional polymeric compounds and components for extrusion of absorbers necessarily included a cooperative effort of small, innovative and large industrial partners, which secured good progress for the research and technological development. As in the present case polymer material suppliers and processing companies are often linked to packaging, building and construction, automotive and commoditive plastic products. With regard to extrusion of high-temperature performance plastics to structured sheets ground breaking RTD work was done and demonstrated world-wide for the first time by the processing company, material supplier and technology owner. The application of polymeric materials in new technology as solar thermal heating brings these industrial actors in connection to green products for renewable energy production. Simultaneously solar thermal applications have demanding requirement profiles as high temperatures, exposure to UV radiation and will lead to the development of new or improvement of existing polymer blends in order to meet the demands. The
expected cost reductions with the large-scale introduction of polymeric collectors will reach new customers and new market segments. In particular the attempt to provide an alternative to the world leading collector technology (low-cost Chinese vacuum pipes) can have major impact.

To the main dissemination activities count the exhibition of full-scale models at the Task 39 exhibition of polymeric materials in solar thermal applications arranged in connection with the SHC 2013 conference in Freiburg Germany (29.09.-01.10.2013). A mini-symposium was held in connection with the official opening of the IR welding line in Aventa’s production facility in February 2013. A presentation as invited speaker for the SKZ-Experts Symposium ‘Serienschweißlösungen für Kunststoffformteile’ with application workshop (Würzburg, Germany, June 4-5, 2013) was given by Aventa together with the IR-welding line supplier. A full-scale high-temperature performance solar collector model was exhibited at the world leading plastics fair K13 (218 000 trade visitors) in Düsseldorf as a welding application at the booth of Aventa’s welding machine supplier.

WP 5: QUALIFICATION OF NEW MATERIALS, ABSORBERS AND OTHER COMPONENTS

In WP 5 of SCOOP, dealing with the “Qualification of new materials, absorbers and other components”, five partner institutions were involved in developing and conducting screening tests to identify suitable materials mainly for the use as solar absorbers. The investigated materials have proven to be sufficiently resistant towards the expected loads and are therefore, together with the developed analytical tools, available other solar application. The tested materials and components can be seen as the basis for the development of new generations of polymeric collectors and the realization of new collector designs. Some of the functional models and prototypes tested in WP 5 are ready for scale-up. It can be stated, that the environmental influences hazardous to the polymeric materials, which were considered as limiting factors to the realization of polymeric collectors, can be dealt with by the right choice of materials and collector design. Without these obstacles for the further propagation of this technology, polymeric collectors can be deployed on the solar thermal market much easier.

These findings can be seen as a fundamental basis for development of new materials not only for polymeric solar thermal collectors but for other applications, like for example for the automotive industry, as well. To these belong especially the developed testing methods and optical measurements, allowing identifying degradation processes at an early stage.

Based on the recorded data from outdoor exposure tests a better understanding of the maximum temperatures occurring in different climates for different designs of polymeric collectors is available and can be transferred to other aspects of solar application.

The research work done in WP 5 has led to numerous scientific publication, conference contributions and final theses and others are currently in preparation. These contributions to the scientific community help to establish polymeric materials in solar thermal context and promote new and innovate research topics in well-established fields.

WP 6: USABILITY AND BUILDING INTEGRATION OF SYSTEMS AND POLYMER MATERIALS

The SCOOP work package on Usability and building integration of systems of polymer materials has shown that effective solar collectors made in polymeric materials are feasible as full valued replacements of conventional building skins like roof tiles or facade plasters. Design issues have been investigated with emphasis on common methods and practise in the building industry. Since the technical challenges related to building physics and aesthetics have been satisfactory solved, one can expect that solar collectors in polymer materials will gradually be accepted as an alternative to conventional building
materials. Furthermore, the hydraulic conditions in the polymer-based solar thermal systems solve logistical barriers since professionals with various specialities can provide installations. The final result of this exploration is that solar thermal energy can become significantly lower in costs, compared to conventional products. This key issue for growth in the utilization of solar thermal energy will presumably lead to an expansion of the market, growth in employments and with new players related to solar thermal energy among the building industries.

The technology developed for using polymeric materials in thermosiphon concepts, representing approx. 90% of the world market for solar thermal collectors, has demonstrated excellent competitive properties in comparison with conventional thermosiphon systems. High performance and estimated production costs significantly under conventional products, represents an ideal case for a new industrial expansion addressing a growing world market. European companies have experienced decreasing market shares, a development that can be reversed with the new technology developed in this project.

WP 7: DEMONSTRATION OF SOLAR SYSTEMS WITH POLYMERIC COLLECTORS
Concerning the market in central and northern Europe with a large diversity of solar thermal system designs, the building integration of polymeric solar collectors, a close collaboration with and acceptance by the building industry is considered to be a key for substantial increase of solar thermal installations. Presently the installation costs of solar thermal systems, which can be up to 50% of the total retailer price, represent a major part of the total end-user price. Cost reductions can be achieved by designing solar components in collaboration with the building industry considering optimal substitution of conventional facade and roof cladding and installation procedures, which are adapted to the skills and workflow at the building site.

The design of the polymeric collector concepts aims to remove some of the main barriers for acceptance by the building industry. Low weight, modular structure and collector loop without hydraulic pressure gives the solar collector features similar to a building skin product similar to other roof- or façade covers and the collectors can consequently be mounted by any skilled construction worker saving time and costs.

With regards to southern European markets, large markets in Asia and in the MENA region, the TSS and ICS concepts have great potential to compete with market leading products if outstanding issues are solved successfully.

The realised projects have very actively been used for demonstration of polymeric solar thermal collectors. Numerous articles appeared in international and Norwegian press, journals or websites. Some of the highlights from the excursions with professional or scientific contacts were: Visit by BBC, who records a film on well insulated passive houses with low heat demand in Norway (Oct. 2013); excursion with 31 experts from SCOOP-, IEA-SHC Task 39 network and selected Norwegian business partners (Oct. 2014); excursion with 15 delegates from Nordic Built project Active Roofs and Facades in connection with project meeting in Oslo (Feb. 2015); excursion with delegates from KCL - Korea Conformity Laboratories (South Korea; Nov. 2014); visit by the Norwegian State secretary of the Ministry of Local Government and Modernisation Per Willy Amundsen (Jan 2014) in addition to business contact by Aventa.

WP 8: PERFORMANCE ASSESSMENT, SYSTEM QUALIFICATION ASPECTS
The appropriate assessing of the durability and the operational lifetime is one of the keys for the successful use of polymeric material in solar thermal products. This is an important aspect as there are high hopes that the use of polymeric materials will help reducing the total cost of solar thermal systems by
decoupling the products from the rising commodity markets for metals. To support this approach there are currently activities ongoing to initiate a new IEA Task on “Price Reduction of Solar Thermal Systems”, which will also focus on the use of polymeric materials. But already now, the insights and experiences of the SCOOP project are providing input for the standardisation. Up to now polymeric materials have been used mainly in low-demanding applications such as swimming pool heating. The improved focus of the test standards on the properties of polymeric materials will therefore support in a very direct way the rating of durability, reliability and performance of more sophisticated products allowing replacing conventional solar thermal devices also for other applications.

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