NACHHALTIGwirtschaften

Solar Heating and Cooling (SHC) Task 39: Polymerwerkstoffe für solarthermische Anwendungen

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Solar Heating and Cooling (SHC) Task 39: Polymerwerkstoffe für solarthermische Anwendungen

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Ein Projektbericht im Rahmen der Programmlinie

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Im Auftrag des Bundesministeriums für Verkehr, Innovation und Technologie

Vorbemerkung

Der vorliegende Bericht dokumentiert die Ergebnisse eines Projekts aus dem Programm FORSCHUNGSKOOPERATION INTERNATIONALE ENERGIEAGENTUR. Es wurde vom Bundesministerium für Verkehr, Innovation und Technologie initiiert, um Österreichische Forschungsbeiträge zu den Projekten der Internationalen Energieagentur (IEA) zu finanzieren.

Seit dem Beitritt Österreichs zur IEA im Jahre 1975 beteiligt sich Österreich aktiv mit Forschungsbeiträgen zu verschiedenen Themen in den Bereichen erneuerbare Energieträger, Endverbrauchstechnologien und fossile Energieträger. Für die Österreichische Energieforschung ergeben sich durch die Beteiligung an den Forschungsaktivitäten der IEA viele Vorteile: Viele Entwicklungen können durch internationale Kooperationen effizienter bearbeitet werden, neue Arbeitsbereiche können mit internationaler Unterstützung aufgebaut sowie internationale Entwicklungen rascher und besser wahrgenommen werden.

Dank des überdurchschnittlichen Engagements der beteiligten Forschungseinrichtungen ist Österreich erfolgreich in der IEA verankert. Durch viele IEA Projekte entstanden bereits wertvolle Inputs für europäische und nationale Energieinnovationen und auch in der Marktumsetzung konnten bereits richtungsweisende Ergebnisse erzielt werden.

Ein wichtiges Anliegen des Programms ist es, die Projektergebnisse einer interessierten Fachöffentlichkeit zugänglich zu machen, was durch die Publikationsreihe und die entsprechende Homepage **www.nachhaltigwirtschaften.at** gewährleistet wird.

Dipl. Ing. Michael Paula
Leiter der Abt. Energie- und Umwelttechnologien
Bundesministerium für Verkehr, Innovation und Technologie

Inhaltsverzeichnis

Kurzfassung

In Kooperation von 13 Ländern wurden in IEA SHC Task 39 das Einsatzpotenzial von fortschrittlichen Polymerwerkstoffen für Komponenten von solarthermischen Systemen ausgelotet und Kostenreduktionspotenziale und Marktentwicklungsmöglichkeiten für solarthermische Systeme bei systematischer Nutzung von Kunststofftechnologien bewertet. Zudem wurde das Leistungsvermögen und die Zuverlässigkeit von kunststoffbasierenden Solarthermietechnologien durch neue, verbesserte Werkstoffe und angepasste Komponenten gesteigert. Durch die zielgerichtete Vernetzung von Solarthermie- und Kunststoffindustrie, die Implementierung von nationalen Forschungskonsortien (z.B. *SolPol*) und die starke Einbindung bei internationalen Forschungsinitiativen (z.B. EU-Projekt SCOOP) baute Österreich seine Vorreiterrolle auf dem Gebiet innovativer Solarthermiesysteme aus. Die Leitung von Subtask C „Materialien" hatte Österreich inne.

Was die österreichische Beteiligung anlangt, so wurden in allen Subtasks signifikante Beiträge geleistet. Es wurden neuartige Designs für solarthermische Komponenten (mit Fokus auf den Kollektor) mit erhöhtem Kunststoffanteil erarbeitet und bewertet. Zudem wurden maßgeschneiderte Polymerwerkstoffe und Verarbeitungstechnologien für solarthermische Absorber und Wärmespeicher entwickelt und ein Methodenmix zur adäquaten Qualitätssicherung von Kunststoffprodukten für solarthermische Systeme auf unterschiedlichen Stufen der Wertschöpfungskette konzipiert und implementiert. Den Markt betreffend wurden weltweite Entwicklungsszenarien für solare Heiz- und Kühltechnologien unter Berücksichtigung kunststoffspezifischer Einfluss- und Erfolgsfaktoren erstellt.

Als wesentliche Herausforderung für die weitere Entwicklung der Solarthermie wurde in Task 39 eine signifikante Kostenreduktion des Gesamtsystems (mindestens 50%) abgeleitet. Dies ist insbesondere auf dem Gebiet der gepumpten Systeme für die Warmwasserbereitung und Heizungsunterstützung in kontinentalen Klimazonen erforderlich. Kunststoffprodukte bieten ideale Voraussetzungen zur Steigerung der Kosten/Nutzen-Verhältnisse. Task 39 verdeutlichte jedoch, dass zur Erreichung signifikanter Kostenreduktionen nicht Einzelkomponenten sondern vielmehr das Gesamtsystem grundlegend zu überarbeiten ist.

Abstract

In cooperation of 13 countries, represented by 16 Scientific Partners and 14 Company Partners IEA SHC Task 39 was aiming in phase 2 (Duration: October 2010 – September 2014) at the assessment of the applicability and the cost-reduction and market potential by using polymeric materials and polymer based novel designs for components of solar-thermal systems. To promote increased confidence in the use of polymer based products appropriate methods for assessment of durability and reliability should be developed, implemented and applied. By systematic combination of the expertise of the polymer and solar energy industry, the implementation of national research collaborations (e.g., *SolPol*) and the strong Austrian involvement in international research activities (e.g., EU-project SCOOP) the worldwide leading position of the Austrian solar-thermal industry was strengthened by novel polymer based product developments and innovations. In continuation of phase 1, Austria also took main responsibility in phase 2 for Subtask C dealing with “Materials”.

As to the Austrian participation in IEA SHC Task 39, significant contributions were made to all Subtasks. In Subtask A “Information” it was deduced that based on 100% renewable energy scenarios solar-thermal systems offer a high potential for the plastics industry with an estimated annual plastics demand for the collector of about 8 mio tons/year. In Subtask B “Collectors” novel designs for solarthermal components (with a focus on collectors) were developed. A highlight was the conception and validation of a fully overheating protected collector based on instantaneous thermosiphonal backcooling. For the absorber and the lining of hot water stores novel materials based on polyolefins were developed along with appropriate processing technologies. In Subtask C also tool boxes for the quality assurance and durability testing of polymeric materials for components in solar-thermal systems were established.

As main challenge for the solar-thermal industry the absolute need of significant cost reductions (min. 50%) on system level were deduced. This is of special relevance for pumped systems used for hot water preparation and space heating. Due to their specific features plastics offer high potentials for cost reductions. However, solarthermal systems have to be fundamentally revised and optimized to achieve significant cost reductions.

1. Einleitung

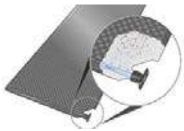
In Phase 1 von IEA SHC Task39 (Laufzeit: 2006 bis 2010) wurde der aktuelle Stand der Technik zu Polymerwerkstoffen in solarthermischen Systemen umfassend herausgearbeitet, wobei besonderes Augenmerk auf die kompakte und einfach verständliche Darlegung der Grundlagen der Disziplinen Solarthermie und Kunststofftechnik gelegt wurde (Wallner und Lang, 2006; Burch, 2006; Meir et al., 2008). Die Ergebnisse von Phase 1 sind im Handbuch mit dem Titel „Polymeric Materials for Solar Thermal Applications“ (Köhl et al., 2012) umfassend beschrieben und diskutiert.

Bei Kollektoren werden Kunststoffe vornehmlich für unabgedeckte Absorber in drucklosen Systemen für die Vorwärmung von Wasser eingesetzt (s. Abb. 1). Dabei kommen vornehmlich Rohr/Rohr-Absorber aus extrudierten Polyolefin-Rohren (z.B. Ethylen/Propylen/Dien-Copolymer (EPDM)) und mit unterschiedlichsten Technologien aufgebrachte spritzgegossene Sammelrohre aus Polystyroltypen (PS, ABS) zum Einsatz. Aus kunststofftechnischer Sicht stellen bei den Rohr/Rohr-Absorbern der Mix von thermoplastischen und elastomeren Werkstoffen und die aufwändigen, oft manuellen Verbindungstechniken von Absorberrohr und Sammler Verbesserungspotentiale dar. Wesentliche Entwicklungsfortschritte bei Schwimmbadkollektoren wurden in weitgehend automatisierten Fertigungsschritten (Blas- oder Rotationsformen; Überspritzen von Röhrchenstrukturen) erzielt. Aufgrund des begrenzten und moderat wachsenden Marktes für Schwimmbadvorwärmsysteme sind moderate Stückzahlen umsetzbar. Ein namhafter Marktführer (z.B. Magen EcoEnergy) stellte 2010 etwa 500.000 m^2 Schwimmbadkollektoren pro Jahr her.

Abb. 1: Kommerziell verfügbare unabgedeckte Absorber aus Kunststoff (Meir et al., 2008)

In Phase 1 von Task 39 wurde unter österreichischer Leitung eine umfassende Bewertung von Schwimmbadabsorbern unter material- und prozesstechnischen Gesichtspunkten vorgenommen und in einer Matrix zusammengestellt (s. Tabelle 1 (aus Kapitel 12 des Task 39-Handbuches). Dabei zeigte sich, dass insbesondere extrudierte Strukturen mit aufgeschweißtem Sammler, blas- oder roatationsgeformte Absorber mit eingelegten Anschlussstücken und verschweißte Folienabsorber ein hohes Automatisationspotenzial besitzen und für die Massen- und Serienfertigung geeignet wären. Zudem sind bei derartigen Absorberdesigns thermoplastische Werkstoffe einsetzbar, die keiner aufwändigen Nachvernetzung bedürfen.

Tabelle 1: Material- und prozesstechnische Bewertungsmatrix für Schwimmbadabsorber (nach Schobermayr und Wallner, 2007)

	1) Pipe-pipe absorber (EPDM)	**2) Pipe-pipe absorber (thermoplastics)**	**3) Panel-header**	**4) Film-pipe**	**5) Panel**
Illustration, example	 Source: G.Wallner	 Source: Solar-Flex	 Source: FAFCO	 Source: [18], Sarnafil	 Source: Texsun
Materials	Thermoplastics, elastomers	Thermoplastics	Thermoplastics	Thermoplastics	Thermoplastics
Design	Absorber: extruded (EX) elastomer Manifold: injection moulded (IM) thermoplastic	Absorber: EX thermoplastic pipe Manifold: IM thermoplastic pipe	Absorber: EX thermoplastic panel Manifold: IM thermoplastic header	Absorber: EX thermoplastic film Manifold: IM moulded fittings	Absorber: blow-moulded thermoplastic panel Manifold: blow-moulded with IM parts
Components	2 components: pipes, header; size and format: module length variable, width limited;	2 components: pipe is semi-finished; size and format: variation in length;	2 components: size and format: length variable, limited in width;	Film, fittings are semi-finished; size and format: length variable, width limited;	Film, fittings are semi-finished; size and format: limited in length+width
Production process	3 steps: EX: pipes IM: header mechanical joining	3 steps: EX: pipes IM: header mechanical joining	3 steps: EX: panel IM: header joining: welding	2 steps: EX + rolling: film joining: welding	2 steps: EX: film, BM: panel joining: -
Coating	after EX difficult	after EX difficult	after EX: easily	after EX: easily	after EX
Additional functions	Snap connectors in IM-header	Snap connectors in manifold and pipe	Snap connectors in manifold and pipe	Snap connectors in fittings	Snap connectors in panel
Investments	medium: EX, IM low: joining	medium: EX, IM low: joining	medium: EX, IM, welding	medium (EX)	low (mould)
Quantities	medium	medium	medium	high	medium
Automatisation	low: joining high: components	low: joining high: components	medium: joining high: components	high	high
Labour	intensive	intensive	less intensive	less intensive	low
Application	pool heating, unglazed	pool heating, unglazed	pool heating, unglazed; DHW and space heating, glazed	Pool heating and DHW pre-heating, unglazed;	pool heating, unglazed; DHW heating, glazed

EX: Extrusion, IM: Injection moulding, BM: Blow moulding;

Verglaste Kunststoffkollektoren betreffend erlangten Kunststoffe Bedeutung bei integrierten Speicherkollektoren oder Thermosiphonsystemen (s. Abb. 2). Insbesondere in Amerika und Australien wurden zwischen 1990 und 2010 Voll-

Kunststoff-Speicherkollektoren und Thermosiphonsysteme für die Warmwasserbereitung entwickelt und umgesetzt. Die Temperaturbegrenzung wurde durch die Ankopplung an den meist nicht gedämmten Speicher mit einhergehenden hohen Wärmeverlusten und begrenztem Wirkungsgrad bewerkstelligt. Für integrierte Speicherkollektoren auf Kunststoffbasis werden ausschließlich nicht-selektive schwarze Absorber aus rotations- oder blasgeformten Bauteilen aus thermoplastischen Polyolefinen (Polyethylen (PE) oder Polypropylen (PP)) und für die transparente Abdeckung Tiefziehteile aus Polymethylmethacrylat (PMMA) oder Polycarbonat (PC) verwendet. Da die kommerziell verfügbaren integrierten Speicherkollektoren für frostfreie Klimazonen konzipiert sind, kommt als Wärmeträger Wasser zum Einsatz. Aufgrund des begrenzten Wirkungsgrades eignen sich kommerziell verfügbare Speicherkollektoren derzeit nicht für die teil- oder vollsolare Raumheizung in gemäßigten Klimazonen.

Abb. 2: Integrierte Speicherkollektoren aus Kunststoff - kommerziell verfügbare Produkte und Entwicklungsprodukte (Meir et al., 2008)

Konventionelle Flachkollektoren in Glas/Metall-Hybridbauweise weisen bei einer Gesamtmasse von etwa 20 kg/m^2 einen Kunststoffanteil von lediglich etwa 0,5 kg/m^2 (2,5%) auf (Kicker, 2009). Bei derartigen Kollektoren, aber auch Vakuumröhrenkollektoren, wurden Kunststoffe insbesondere für Kollektorrahmen und –wannen untersucht und teilweise auch umgesetzt (s. Abb. 3).

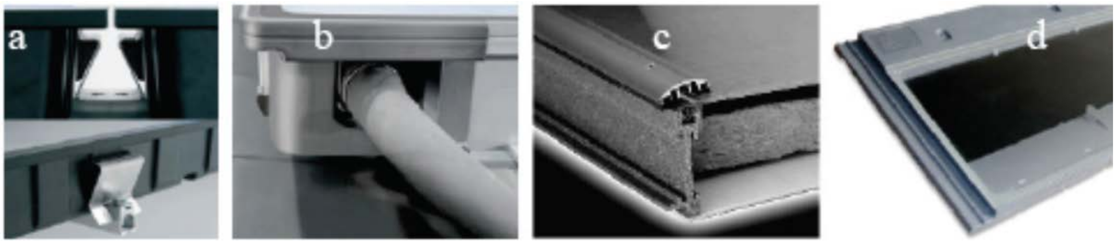


Abb. 3: Kunststoffkomponenten für die Einhausung konventioneller Flachkollektoren (Meir et al., 2008)

Flachkollektoren mit hohem Kunststoffanteil bzw. Voll-Kunststofflösungen wurden wegen der Überhitzungsproblematik bisher kaum umgesetzt. Für die Gewährleistung des Überhitzungsschutzes wurden vornehmlich thermotrope Materialien mit temperaturabhängiger Transmission oder Konvektionsmaßnahmen im Kollektor entwickelt und untersucht (Resch und Wallner, 2009; Resch et al., 2009; Roberts et al., 2000). In Phase 1 von Task 39 wurde von Österreich klar herausgearbeitet, dass durch den Einsatz thermotroper Materialien je nach Schalthub eine signifikante Begrenzung der Stagnationstemperatur möglich ist, wobei selektive Absorber und Einfachverglasungen nur unter bestimmten Bedingungen möglich sind. Für einen Kollektor mit Doppelstegplattenverglasung und schwarzem Absorber ist zur Begrenzung der Arbeitstemperatur auf 85°C eine Transmission im geschalteten Zustand von 25% erforderlich. Bei Verringerung der Transmission auf 60% im geschalteten Zustand ergibt sich eine Stillstandstemperatur von etwa 125°C (s. Abb. 4). Stillstandstemperaturen in den genannten Temperaturbereichen erlauben den Einsatz kostengünstiger Massenkunststoffe. Experimentelle Materialentwicklungen zu thermotropen Schichten mit fixierten Domänen im Rahmen der Dissertation Resch verdeutlichten, dass die oben angeführten Schulthübe allerdings nur mit relativ dicken (mehrere Millimeter) thermotropen Schichten erreichbar sind, was simultan zu einem starken Abfall des Transmissionsgrades im ungeschalteten Zustand führt (Resch et al., 2009).

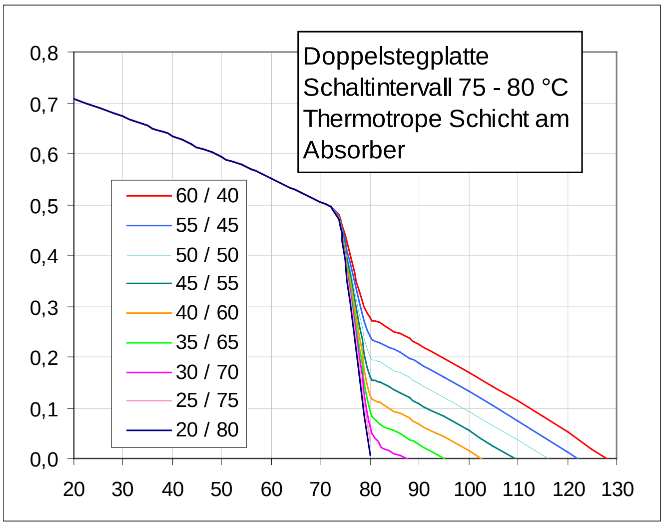


Abb. 4: Kollektorwirkungsgrad über der Temperatur des Wärmeträgermediums. Temperaturbegrenzungsverhalten bei ungenügendem Schalthub, Doppelstegplatte, thermotrope Schicht am Absorber, schwarzer Absorber, G = 1000 W/m², Tu = 20 °C (Wallner et al., 2008)

Bei den Kunststoff-Flachkollektoren sind insbesondere die Entwicklungen zu Stegplattenkollektoren an der Universität Oslo und den Spin-Off-Firmen Solarnor und Aventa hervorzuheben. Seit etwa 10 Jahren werden Kollektoren bestehend aus einer PC-Stegplatte für die transparente Abdeckung und einem schwarzen Absorber bestehend aus einer extrudierten Stegplatte und spritzgegossenen und aufgeklebten Sammlern lokal sehr begrenzt (Norwegen) vertrieben. In Phase 1 von Task 39 wurde der wesentliche Vorteil der vollflächig durchströmten Absorbergeometrie für

Materialien mit geringer Wärmeleitfähigkeit (wie bspw. Kunststoffe) im Vergleich zur Rohr/Finne-Geometrie üblicher Metallabsorber herausgearbeitet (s. Abb. 5). Mit einem von AEE INTEC implementierten Rechenmodell würde für transparent abgedeckte Kollektoren gezeigt, dass keine Erhöhung der für Kunststoffe üblichen Wärmeleitfähigkeit von 0,02 W/(mK) erforderlich ist, solange die Wanddicke großflächig durchströmter Absorbergeometrien 1 mm nicht übersteigt.

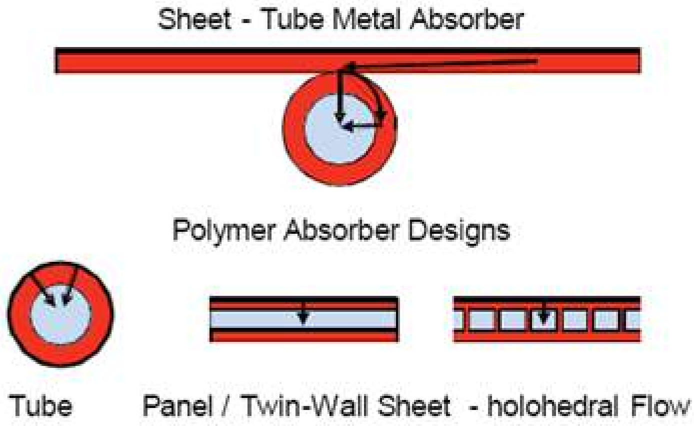


Abb. 5: Wärmefluss bei unterschiedlichen Absorberdesigns (Hausner, 2007)

Durch umfassende Untersuchung des von Solarnor verwendeten Absorbermaterials aus einem Blend aus Polyphenylenoxid und Polystyrol auf unterschiedlichen werkstofflichenen Ebenen, wurde die inadäquate Werkstoffauswahl und die damit einhergehende begrenzte Lebensdauer des nicht überhitzungsgeschützten Kollektors für drucklose Drainbacksysteme nachgewiesen. Maßgebliche Arbeiten erfolgten in Kooperation zwischen Norwegen und Österreich im Rahmen der Dissertation Kahlen (Kahlen et al., 2010a; Kahlen et al., 2010b). Dabei wurden auch neuartige Methoden für die Alterungscharakterisierung von Absorberstegplatten implementiert (s. Abb. 6; Olivares et al., 2008; Kahlen et al., 2010b).

In der Folge wurden in Phase 1 von IEA SHC Task 39 neuartige auf Polyphenylensulfid (PPS) basierende Kunststoffcompounds mit signifikant besserer Langzeitbeständigkeit entwickelt und von Aventa (Oslo, N) industriell umgesetzt. Durch die verbesserte Temperaturbeständigkeit des neuen Werkstoffes erscheint auch die Applikation von selektiven Absorberlacken möglich. Signifikante weitere Verbesserungspotenziale wurden insbesondere beim kunststoffgerechten Design von Stegplattenkollektoren, bei der Verbindungstechnik für Absorber und Sammler, bei der Rahmenkonstruktion und bei der Integration in die Gebäudehülle aufgezeigt (Köhl et al., 2012).

Abb. 6: Indentationsapparatur für die Prüfung von Bauteilsegmenten aus Kunststoffabsorbern (Kahlen et al., 2010b)

Auch im Bereich der Wärmespeicher erlangten Polymerwerkstoffe zunehmende Bedeutung. Neben funktionalen Speicherkomponenten (z.B. Beladungslanze, Wärmedämmung) wurden bereits Voll-Kunststoffspeicher entwickelt und umgesetzt. Während für drucklose Speicher blasgeformte Kunststoffbehälter zum Einsatz kommen, wurden für druckbeaufschlagte Speicher aus glasfaserverstärkten Kunststoffen (GFK) hergestellte Tanks realisiert. Zudem wurden in Phase 1 von Task 39 Wasser-Wärmespeicher mit unterschiedlicher und adaptierbarer Kapazität und Abdichtungsfolien für Saisonalspeicher mit einer maximalen Betriebstemperatur von 80°C entwickelt und umgesetzt (Wilhelms et al. 2009; Ochs, 2006).

Die systematische und umfassende Erhebung des Standes der Technik im Rahmen von Phase 1 der IEA SHC Task 39 verdeutlichte, dass die Marktdurchdringung von Kunststoffen in solarthermischen Systemen lediglich bei unabgedeckten Absorbern für die Schwimmbadvorwärmung den Schwellwert überschritten und die Wachstumsphase erreicht hat (s. schematische Darstellung in Abb. 7). Allerdings ist der Bereich der Schwimmbad- oder Kaltwasservorwärmung mit Arbeitstemperaturen um 30°C bei Betrachtung des Endenergiebedarfes von untergeordneter Bedeutung. Einen deutlich höheren Stellenwert nimmt die Wärmebereitstellung im Temperaturbereich zwischen 30 und 90°C ein. Hierzu sind abhängig von der Klimazone transparent abgedeckte Kollektoren besser geeignet. Für den Bereich der Warmwasser- und

Raumwärmebereitstellung liegt die Marktdurchdringung von Kunststoffen in solarthermischen Systemen in der Entwicklungsphase und bei Speichern in der Einführungsphase (s. schematische Darstellung in Abb. 7).

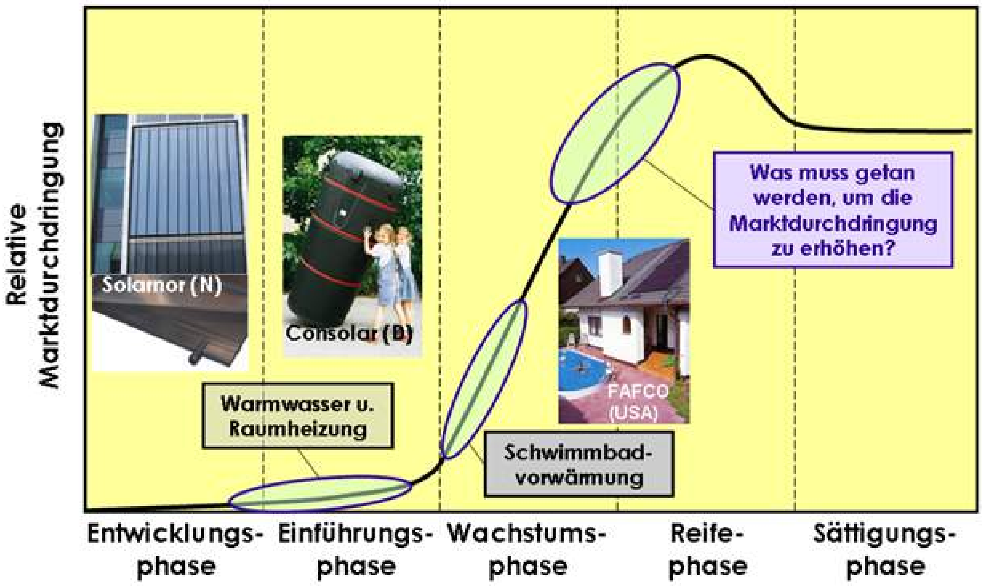


Abb. 7: Stand der Marktentwicklung für Kunststoffe in solarthermischen Systemen für die Einsatzbereiche der Schwimmbadvorwärmung sowie der Warmwasser- und Raumwärmebereitstellung (Lang und Wallner, 2006)

Bisherige Kunststoffanwendungen im Bereich der Solarthermie sind vorwiegend Substitutionslösungen existierender Bauteile, die lediglich in Kunststoffdesign ausgeführt sind, ohne das Potenzial der Fertigungs- und Funktionsintegration auszuschöpfen. Bezugnehmend auf Abb. 4 stellte sich für Phase 2 von IEA SHC Task 39 daher die Frage, was grundsätzlich getan werden müsste um Polymerwerkstoffen im Bereich der Niedertemperatur-Solarthermie zum Durchbruch zu verhelfen. In Analogie zu anderen Erfolgssektoren der Kunststoffanwendung stellt die Miteinbeziehung von wesentlichen Akteuren der Wertschöpfungskette (Rohstoff - Halbzeug - Komponenten - System) in eine gemeinsame Forschungs- und Entwicklungstätigkeit einen wohl wesentlichen Innovationsgarant dar. Dabei sollte nicht primär von der Vorstellung der Substitution der Werkstoffe bei existierenden Bauteilen und Komponenten ausgegangen werden, sondern grundsätzlich neue multifunktionale Lösungsansätze erarbeiten werden.

2. Hintergrundinformation zum Projektinhalt von Task 39

In Phase 2 von IEA SHC Task 39 nahmen insgesamt 13 Länder teil. In Tabelle 2 sind die Länder und die beteiligten Institutionen (16 wissenschaftliche Partner; 14 Unternehmenspartner) aufgelistet. Die Projektleitung (Operating Agent) hatte Deutschland inne, vertreten durch Dr. Michael Köhl (Fraunhofer-Institut für Solare Energiesysteme; Freiburg, D) im Auftrag des Projektträgers Jülich.

Tabelle 2: Teilnehmer in Phase 2 von IEA SHC Task 39

Land	Wissenschaftliche Partner	Unternehmenspartner
Österreich	JKU Linz, AEE INTEC, AIT, PCCL/MUL, UIBK	APC, AGRU, Borealis, Sunlumo
Belgien	-	Chevron Philips
Brasilien	-	DuPont
Deutschland	FhG-ISE, FH Ingolstadt, ITW Stuttgart	BASF, Dr. Axel Müller, BlueTec
Frankreich	CEA INES	
Israel	-	Magen EcoEnergy
Kanada		Enerconcept
Norwegen	Univ. Oslo	Aventa
Portugal	Univ. Aveiro	Pirev Surface Engineering
Schweden	Linnaeus Univ.	
Schweiz	SPF	
Slowenien	NIC	Color
USA	Univ. Minnesota, NREL	

Um Polymerwerkstoffen im Bereich der Niedertemperatur-Solarthermie zum Durchbruch zu verhelfen, wurden im Arbeitsprogramm von IEA SHC Task 39 für die Phase 2 folgende Hauptzielsetzungen definiert:

- Auslotung des Einsatzpotenzials von fortschrittlichen Polymerwerkstoffen im Bereich der Solarthermie.
- Bewertung des Kostenreduktionspotentials und der Marktentwicklungsmöglichkeiten für die Solarthermie bei systematischer Nutzung von Kunststofftechnologien.
- Unterstützung bei der Steigerung des Leistungsvermögens und der Zuverlässigkeit von kunststoffbasierenden Solarthermietechnologien.

Auf Basis der Hauptziele wurden folgende Ergebnisse angestrebt:

- Neuartige Designs für solarthermische Komponenten und Systeme mit erhöhtem Kunststoffanteil und deren Bewertung im Hinblick auf Anwendungsmöglichkeiten.
- Maßgeschneiderte Polymerwerkstoffe und Verarbeitungstechnologien für vielversprechende solarthermische Komponenten und Systeme.
- Gesamtheitliche Bewertung von kunststoffbasierenden Kollektorsystemen unter architektonischen, technischen, ökonomischen und ökologischen Gesichtspunkten.
- Weltweite Entwicklungsszenarien für solare Heiz- und Kühltechnologien unter Berücksichtigung kunststoffspezifischer Einfluss- und Erfolgsfaktoren.
- Methodenmix zur adäquaten Qualitätssicherung von Kunststoffprodukten für solarthermische Systeme auf unterschiedlichen Stufen der Wertschöpfungskette.
- Vorschläge zur Adaptierung von relevanten Normen (insbesondere EN 12975) und länderspezifischen Regelungen bei verstärktem Kunststoffeinsatz.

Das Arbeitsprogramm von IEA SHC Task39 (Phase 2) wurde in drei Subtasks mit dem Fokus auf „Information“ (Subtask A), „Kollektoren und Komponenten“ (Subtask B) und „Materialien“ (Subtask C) unterteilt. Für die fachliche und organisatorische Leitung der Subtasks (Arbeitsschwerpunkte) waren die folgenden Länder bzw. Subtask-Leiter verantwortlich:

- **Subtask A:** Norwegen (Dr. Michaela Meir, Universität Oslo)
- **Subtask B:** Frankreich (Dr. Stephan Fischer, ITW Stuttgart (ab 2011); Dr. Philippe Papillion, CEA INES (bis 2011))
- **Subtask C:** Österreich (Prof. Dr. Gernot Wallner, JKU Linz)

In Subtask A „Information“ wurden 5 Einzelprojekte mit folgenden Inhalten definiert:

- A1: Märkte und Stand der Technik zum Einsatz von Kunststoffen in solarthermischen Systemen
- A2: Gesamtheitliche Bewertung von ausgewählten kunststoffbasierenden Kollektorsystemen
- A3: Normen, Regelungen und Richtlinien für kunststoffbasierende solarthermische Komponenten und Systeme
- A4: Best-Practice zur architektonischen Integration von solarthermischen Anlagen

- A5: Dissemination von Ergebnissen

Zudem wurden in Subtask A drei Taskforces mit folgenden Schwerpunkten und Hauptverantwortlichkeiten definiert:

- Gesamtheitliche Bewertung: Schweden (Prof. Bo Carlsson, Linnaeus University)
- Normen, Regelungen und Richtlinien: Deutschland (Dr. Stefan Fischer, Universität Stuttgart)
- Architektonische Integration: Norwegen (Ingvild Skjelland, Aventa)

In Subtask B „Kollektoren und Komponenten“ wurden 3 Einzelprojekte mit folgenden Inhalten definiert:

- B1: Konzeption, Design und Bewertung von Kunststoffkollektoren
- B2: Entwicklung von solarthermischen Systemen aus Kunststoff
- B3: Analyse und Bewertung von sonstigen Systemkomponenten

In Subtask C „Materialien“ wurden unter österreichischer Leitung die im Folgenden angeführten 3 Einzelprojekte bearbeitet:

- C1: Entwicklung und Charakterisierung von multi-funktionalen Polymerwerkstoffen für Kollektoren und Systeme
- C2: Herstellung, Charakterisierung und Bewertung von Systemkomponenten aus Kunststoff
- C3: Prüf- und Charakterisierungsmethoden für Polymerwerkstoffe in solarthermischen Systemen

Von den beteiligten 13 Ländern haben 4 bzw. 5 in Task 39 Leitungsfunktionen übernommen. Die übrigen Partner unterstützten die Subtask-Leiter bei der inhaltlichen Ausarbeitung der Einzelprojekte.

In Phase 2 von IEA SHC Task 39 übernahmen JKU Linz und AEE – Institut für Nachhaltige Technologien als Projektpartner die Hauptverantwortung für die österreichische Beteiligung. Zudem wirkten die wissenschaftlichen Einrichtungen AIT, PCCL und UIBK aktiv mit.

Die übergeordnete Gesamtzielsetzung der österreichischen Beteiligung in Phase 2 von IEA SHC Task 39 war einen wichtigen Beitrag zur innovativen Weiterentwicklung von solarthermischen Systemen durch den stärkeren Einsatz von Kunststofftechnologien zu erbringen. In der Übertragung der Task 39-Projektergebnisse auf nationale Forschungsprojekte sollte zudem die existierende weltweite Spitzenposition Österreichs auf dem Gebiet der Solarthermie durch polymerbasierende innovative

Neuentwicklungen sichergestellt bzw. weiter ausgebaut werden.

Für die nationale Beteiligung wurden in Phase 2 von Task 39 folgende Einzelzielsetzungen verfolgt, die sich im Wesentlichen an den übergeordneten Projektzielen des Solar Heating & Cooling Programmes orientieren und sich auf die spezifische Thematik der Anwendung von Kunststoffen in solarthermischen Systemen fokussieren:

- Bereitstellung von technischen Grundlagen und Analysen zu kunststoffbasierenden solarthermischen Systemen
- Unterstützung bei der Verbesserung des Leistungsvermögens von kunststoffbasierenden solarthermischen Systemen.
- Verstärkung der Kooperation zwischen Industrie und öffentlicher Hand zur Steigerung des Markanteils von solarthermischen Systemen.
- Unterstützung bei der Weiterbildung von Entscheidungsträgern und der Öffentlichkeit zum Status und Nutzen von solaren Heiz- und Kühltechnologien.

Wie im Arbeitsprogramm von Task 39 beschrieben, kommt Kunststoffen besonderes Potenzial im Bereich der Warmwasserbereitung und der Raumwärmebereitstellung zu. Demzufolge lag auch in Phase 2 von Task 39 der Fokus bei diesen Einsatzbereichen. Hocheffizienz-Kollektoren mit erhöhtem Arbeitstemperaturbereich (größer 80°C) oder neuartige thermische Speichertechnologien mit signifikant erhöhter Energiedichte waren nicht primärer Gegenstand von Task 39. Zu letzteren Themen erfolgte jedoch ein regelmäßiger Austausch mit dem Implementing Agreement Solar PACES und dem IEA SHC Task 42 „Compact Thermal Energy Storage“ auf nationaler Ebene im Rahmen der IEA Vernetzungsworkshops. In Übereinstimmung mit den Einzelzielsetzungen wurden folgende Projektergebnisse für die österreichische Beteiligung angestrebt:

- Technisch-wissenschaftliche Publikationen zu neuentwickelten oder adaptierten Polymerwerkstoffen, zu kunststoffgerecht ausgelegten solarthermischen Komponenten und Systemen, zu den potenziellen Märkten und zu durch Polymertechnologien getriebenen Marktszenarien.
- Bewertung von Konzepten für neuartige solarthermische Systeme (mit angepassten Betriebs- und Stagnationsbedingungen) und für Komponenten in Teil-, Hybrid- und Vollkunststoffbauweisen für solarthermische Kollektoren und Wärmespeicher und von maßgeschneiderten multifunktionalen Polymerwerkstoffen mit geeigneten Eigenschaftsprofilen. Zur effizienten Entwicklung

kunststoffbasierender solarthermischer Systeme sollten in internationaler Abstimmung entsprechende Werkzeuge zum Screening und zur Charakterisierung von Werkstoffen, zum Design und zur Auslegung von Komponenten und zur Beschreibung des Leistungsvermögens von kunststoffbasierenden Systemen etabliert werden.

- Die bereits laufenden nationalen Forschungsarbeiten sollten in Phase 2 von Task 39 weiter verstärkt und ausgebaut werden (z.B. COMET-Forschungsprojekt mit industriellen Partnern entlang der Wertschöpfungskette). Zusätzlich sollen durch die Beteiligung in Phase 2 von IEA SHC Task 39 internationale Kooperationen etabliert werden, die entweder über partner- oder länderspezifische bilaterale Abkommen oder über Forschungs- und Förderprogramme der europäischen Kommission abgewickelt werden. Durch die initiierten und begleiteten Forschungsprojekte sollten die Voraussetzungen für eine deutliche Erhöhung des Kunststoffanteils in solarthermischen Systemen (~ 25% bis 2020) geschaffen werden, wobei stets die spezifischen Erfolgselemente von Kunststoffen (verbesserte Funktionalität, attraktives Design, verbessertes Preis/Leistungs-Verhältnis, garantierte Qualität und Leistungsvermögen) im Vordergrund stehen sollten.
- Regelmäßig upgedatete Website, Newsletters, Presseaussendungen und 2 nationale Verbreitungstagungen zum Status und zum Nutzen von Polymerwerkstoffen für solare Heiz- und Kühltechnologien; akademische Arbeit (Bachelor- oder Masterarbeit) zu den Einsatzpotenzialen von Kunststoffen und durch Polymertechnologien bestimmte Marktszenarien für solarthermische Systeme; Schaffung eines vertieften Verständnisses für Solarthermietechnologien bei Studenten der Kunststofftechnik und bei nicht unmittelbar involvierten Firmenpartnern aus der Kunststoff- und Solarbranche.

Zur Erreichung der angestrebten Projektergebnisse wurden für die österreichische Beteiligung in Phase 2 von IEA SHC Task 39 folgende methodischen Schritte definiert und dementsprechend auch Arbeitspakete abgeleitet:

1. Fortführung der Leitung von Subtask C „Materials“ zur Verdeutlichung und Stärkung der Vorreiter- und Führungsrolle Österreichs.
2. Teilnahme an transnationalen Task 39-Workshops; aufgrund des interdisziplinären Charakters dieser Forschungsthematik sollten sowohl Partner aus der Solarthermie als auch aus der Kunststofftechnik aktiv

mitwirken.

3. Forschungsaktivität zur Erarbeitung von Marktszenarien für die Solarthermie und daraus abgeleiteten Potentialen für Kunststoffe basierend auf neuesten, voll-regenerativen Energieszenarien (national, regional und global) in Wechselwirkung mit anderen IEA Tasks und Subtasks sowie der Ableitung der sich daraus ergebenden Potentialen für Kunststofftechnologien.
4. Nationale Vernetzung und Verbreitung der Ergebnisse durch die beteiligten Partner.

3. Ergebnisse des Projektes

Am Beginn von Phase 2 von Task 39 legten die österreichischen Beteiligten besonderes Augenmerk auf die Beantragung und Implementierung von kooperativen Forschungsprojekten mit industrieller Beteiligung. Es wurde eine Reihe von nationalen und internationalen Forschungsanträgen ausgearbeitet. Durch Task 39 wurden folgende kooperativen Forschungsprojekte (sieben nationale Projekte und ein internationales Projekt) mit österreichischer Beteiligung initiiert und etabliert:

- Solar Thermal Systems based on Polymeric Materials - Scientific and Methodological Aspects and Economical and Ecological Impact Assessment (*SolPol-1*; Laufzeit: 2009-2013; Projektleitung: JKU Linz; Fördergeber: KLIEN; Administration: FFG).
- Solar Thermal Systems based on Polymeric Materials - Development of Collectors and Plastics-Compounds (*SolPol-2*; Laufzeit: 2010-2014; Projektleitung: JKU Linz; Administration/Fördergeber: FFG/KLIEN).
- Solar Thermal Systems based on Polymeric Materials – Novel Pumped and Non-Pumped Collector Systems (*SolPol-4/5*; Laufzeit: 2014-2018; Projektleitung: JKU Linz; Administration/Fördergeber: FFG/KLIEN).
- Bioplastics for solar applications (Bio4Sol; Laufzeit: 2013-2015; Projektleitung: PCCL/MU Leoben; Administration/Fördergeber: FFG/KLIEN).
- Innovative thermal self-regulating solar facades by means of functional polymers (Poly2Facade; Laufzeit: 2012-2015; Projektleitung: MU Leoben; Administration/Fördergeber: FFG/BMVIT).
- Smart Windows-Smart Collectors (Laufzeit: 2010-2013; Projektleitung: PCCL; Administration/Fördergeber: Land Steiermark).
- Screening und Langzeiteigenschaftsprognose von Isolierwerkstoffen für solarthermische Kollektoren und Wärmespeicher (Laufzeit: 2011-2014; Projektleitung: AIT; Administration/Fördergeber: FFG/KLIEN).
- Solar Collectors made of Polymers (SCOOP; Laufzeit: 2011-2015; Projektleitung: FhG-ISE; Administration/Fördergeber: EU FP7).

Durch die assoziierten kooperativen Forschungsvorhaben war es möglich, in allen Subtasks von Task 39 wesentliche Beiträge einzubringen. Im Gegensatz zu Phase 1, in der die Gesamtergebnisse in einem Handbuch zusammengefasst und veröffentlicht wurden (Köhl et al., 2012), wurden in Phase 2 kompakte Informationsblätter (Info-Sheets) erarbeitet und über die Website von Task 39 veröffentlicht. In den folgenden Tabellen 3 bis 5 sind die Titel der Info-Sheets zu den Subtasks A bis C mit Angaben zu den Autoren und beteiligten Institutionen übersichtlich zusammengestellt. Die Info-Sheets befinden sich im Anhang 1.

Subtask A

In Subtask A wurden die Ergebnisse in 7 Info Sheets dargestellt, wobei 2 Beiträge von Österreich erarbeitet wurden. Zwei Info Sheets beschäftigten sich mit der Bedeutung von Kunststoffen für den Solarthermiemarkt, drei Arbeiten mit der Ökobilanzierung von Kunststoff-basierenden Solarthermiesystemen, ein Beitrag mit erforderlichen Anpassungen im Bereich der Normung und Zertifikation und ein Info Sheet mit der architektonischen Einbindung von Kunststoffkollektoren in die Gebäudehülle. Eine detaillierte Beschreibung der Ergebnisse ist in Anhang 1 dargelegt.

Tabelle 3: Info-Sheets zu Subtask A „Information“

Titel	**Autor(en)**	**Institution(en)**
100% Renewable Energy Scenarios – Relevance of Plastics for Solar Thermal Technologies	Holzhaider K., Wallner G.M., Kicker H., Lang, R.W., Hausner, R.	JKU-IPMT, AEE INTEC
Market and cost effects for polymeric solar thermal collectors	Piekarczyk A., Weiss, K.-A.	Fraunhofer ISE
Evaluation of thermosiphon systems by adopting a total cost accounting approach	Carlsson B., Meir M., Rekstad J., Piekarczyk A., Weiss R., Preiß, D.	Linnaeus University, Aventa, Fraunhofer ISE, AEE INTEC
Life cycle analysis for polymeric solar thermal collectors	Weiss R.	Fraunhofer ISE
Polymeric solar collectors and recycling	Feuchter M., Resch, K.	PCCL, MU Leoben
Standards, Certification and Regulations	Fischer S.	ITW Stuttgart
Architecturally appealing solar thermal systems	Skjelland I.	Aventa

Der Schwerpunkt der österreichischen Beteiligung in Subtask A lag bei der Erarbeitung von Marktszenarien für die Solarthermie und bei der Ableitung von Potentialen für Kunststoffe basierend auf voll-regenerativen Energieszenarien. Dazu wurde im nationalen IEA SHC Task 39 Projekt ein eigenes Arbeitspaket definiert, das in Zusammenarbeit zwischen AEE INTEC und JKU-IPMT im Rahmen einer Masterarbeit (von Klaus Holzhaider) abgearbeitet wurde. Die Masterarbeit befindet sich als pdf-Dokument im Anhang des Berichtes. Übergeordnetes Ziel war die Abschätzung des zukünftigen Materialbedarfs für solarthermische und photovoltaische Systeme und die Ableitung möglicher Potentiale für Kunststoff, basierend auf 100% erneuerbare Energie Szenarien. Zunächst wurden Szenarien, die 100% erneuerbare Energie bis 2050 zum Ziel haben, analysiert und mit Marktszenarien verglichen. Annahmen für den Materialeinsatz verschiedener Technologien wurden getroffen und der zukünftige Materialbedarf für solarthermische und photovoltaische Systeme berechnet. Während die Annahmen im Fall der Solarthermie alleine auf der Literatur beruhen, wurde im Fall der Photovoltaik zusätzlich eine Materialanalyse typischer PV-Module durchgeführt. Der kumulierte Plastikbedarf bis 2050 wurde zwischen 90 und 330 Mio. t berechnet (s. Abb. 8). In jährlichen Produktionsmengen würde dies zwischen 3 und 11 Mio. t/Jahr bedeuten. Die jährliche Produktionsmenge von Kunststoffen liegt bei etwa 300 Mio. t/Jahr. Dies verdeutlicht die große Herausforderung, wie auch das große Potenzial für die Kunststoffindustrie und legt die Verwendung von kostengünstigen und leicht verfügbaren Massenkunststoffen wie Polyolefinen (z.B. Polypropylen) nahe. Im Fall der Photovoltaik lag der abgeschätzte Materialbedarf um etwa einen Faktor zehn darunter, war aber dennoch beträchtlich.

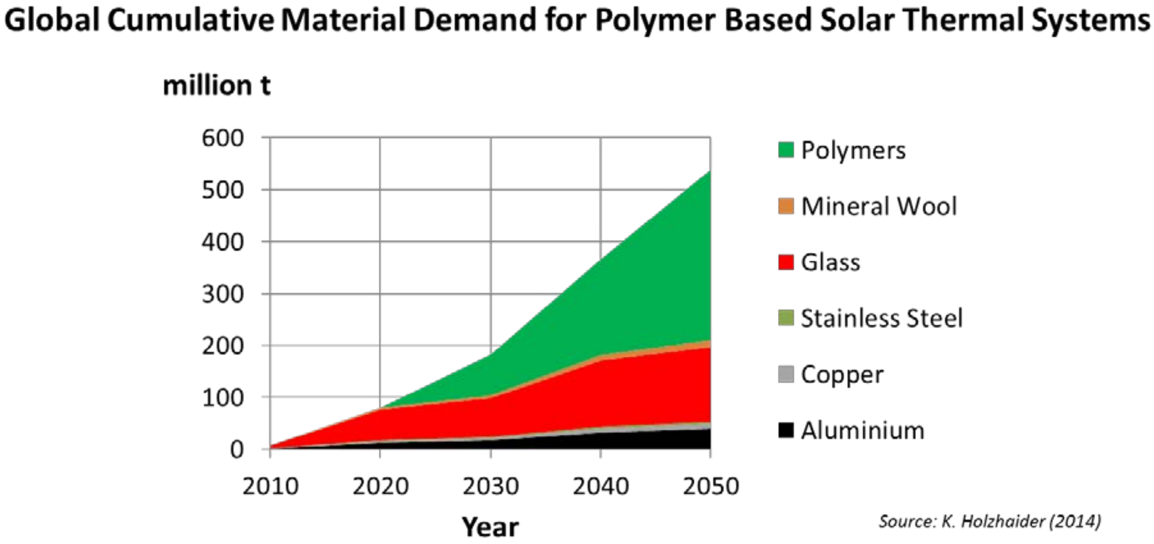


Abb. 8: Kumulierter Werkstoffbedarf (Kunststoffe, Mineralwolle, Glas, Stahl, Kupfer, Aluminium) für solarthermische Systeme im Fall eines 100% erneuerbaren Energieszenarios (nach Greenpeace Energy[R]evolution, 2012).

Bezüglich der Kosteneffekte von Kunststoffen zeigte sich, dass signifikante Kostenreduktionen vorrangig bei großen Stückzahlen gegeben sind. Beispielsweise wurde herausgearbeitet, dass auf Kollektorebene im Vergleich zu herkömmlichen Flachkollektoren Herstellkosteneinsparungen von bis zu 1/3 möglich sind. Die im Rahmen des Projektes *SolPol-1* durchgeführte umfassende Kostenanalyse ergab jedoch, dass ein wesentliches Problem der Solarthermie bei den Endkundenpreisen für das installierte Gesamtsystem liegt. Diesbezüglich wurden durchschnittliche Endkundenpreise von etwa 1000 €/m^2 abgeleitet. Zur Senkung der Endkundenpreise bedarf es daher einer gesamtheitlichen Betrachtung und der grundlegenden Adaptierung von solarthermischen Systemen für die Warmwasserbereitung und Heizungsunterstützung. In Österreich wurde die Problematik frühzeitig erkannt und entsprechende Konzepte und Anträge für weiterführende Forschungsprojekte ausgearbeitet. Die Etablierung eines kooperativen Forschungsprojektes (*SolPol-4/5*) gelang allerdings erst am Ende von Task 39. Ein Ansatz zur signifikanten Kostenreduktion wurde von Norwegen (Aventa und Universität Oslo) aufgezeigt und ausgearbeitet. Durch signifikante Reduktion der Anzahl der Stufen in der Wertschöpfungskette und durch systematische Zusammenarbeit von Kollektorhersteller, Systemanbieter und Bauträger gelang eine deutliche Reduktion branchenüblicher Aufschläge. Aventa etablierte ein Konsortium mit den Partnern UPONOR (Komponentenhersteller), OSO (Speicherhersteller für Drainback-Systeme) und OBOS (Bauträger). Der Vertrieb erfolgt direkt von den Herstellern (Aventa, UPONOR und OSO) an den Bauträger (OBOS) und damit an den Endkunden.

Subtask B

In Subtask B wurden die Ergebnisse in 18 Info Sheets (s. Tabelle 4 und Anhang 1) dargestellt, wobei sieben Beiträge von Österreich erarbeitet wurden. Wesentliches Augenmerk der Arbeiten in Subtask B lag bei der theoretischen und experimentellen Bestimmung von Leistungsanforderungen für Kunststoffkollektoren, bei der Auslotung und Bewertung unterschiedlicher Maßnahmen zum Überhitzungsschutz, bei der Konzeption und der Auslegung von Kunststoffkollektoren, Systemen und Speichern. Die Gesamtsysteme betreffend wurden keine umfassenden Arbeiten durchgeführt, sondern einzelne Fragestellungen (z.B. Systeme für die Warmwasserbereitung bzw. Heizungsunterstützung) bearbeitet.

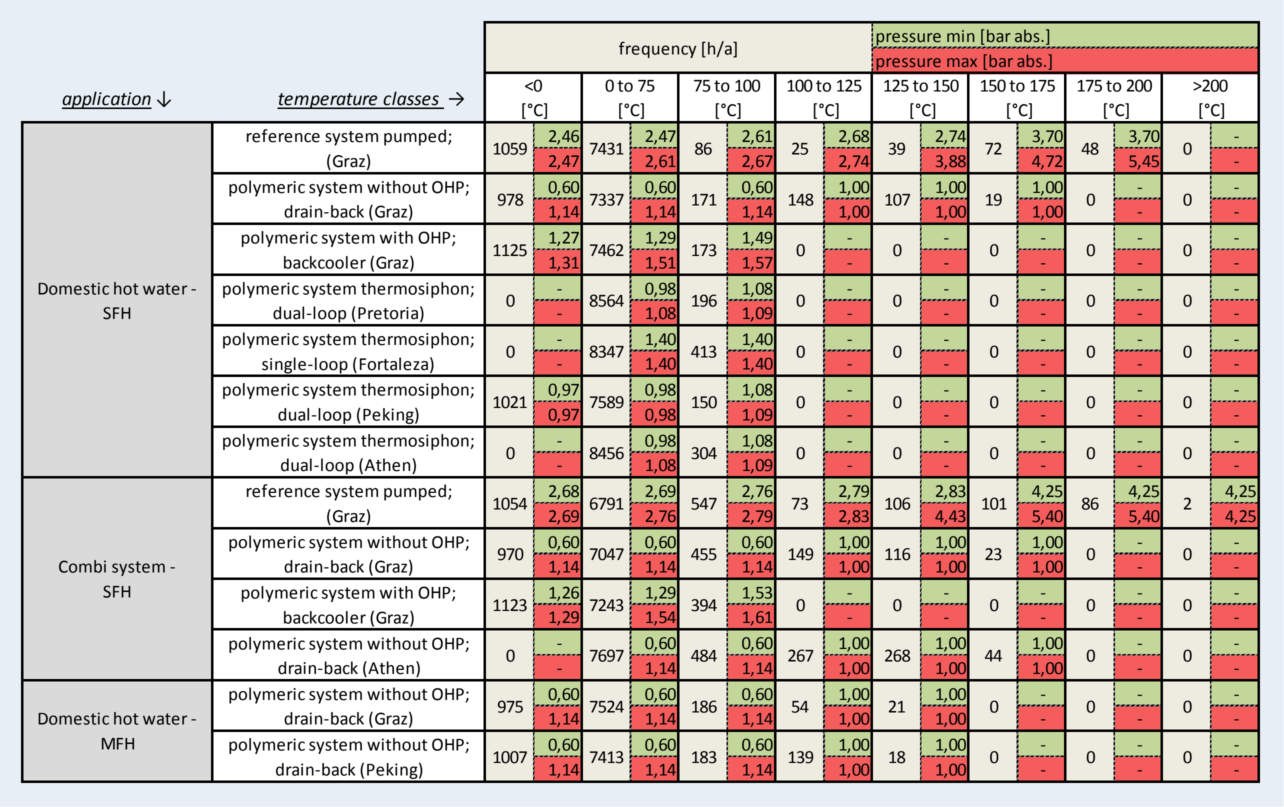
Tabelle 4: Info-Sheets zu Subtask B „Kollektoren und Komponenten“

Titel	**Autor(en)**	**Institution(en)**
Performace requirements (general)	Ramschak T., Preiß D.	AEE INTEC
Performance requirements (thermal stress)	Ramschak T., Preiß D.	AEE INTEC
Performance requirements (pressure stress)	Ramschak T., Preiß D.	AEE INTEC
Thermal loads at components of SOA flat-plate collectors	Reiter C., Brandmayr S., Trinkl C., Zörner W	FH Ingolstadt
Overheat Protection	Reiter C., Brandmayr S., Trinkl C., Zörner W	FH Ingolstadt
Collector Overheating Protection with Backcooler	Thür A., Hintringer C., Hauer N., Streicher, W., Hausner R., Kaiser, A., Riepl R., Wallner G.M.	UIBK, AEE INTEC, Greiner GTI, JKU-IPMT,
Overheat protection by thermotropic layers	Resch K., Weber A., Gruber D.P.	MU Leoben, PCCL
Thermotropic Materials for Overheat Protection – Collector Performance	Gladen A., Mantell S., Davidson J.,	University of Minnesota
Thermal limitation of glazed collector for DHW – Venting	Plaschkes M.	Magen EcoEnergy
Fully Polymeric Thermosiphon System	Piekarczyk A., Weiß K.-A.	Fraunhofer ISE
All polymeric thermosiphon system	Rekstad J., Meir A.	Aventa
All-polymeric collector Sunlumo	Buchinger R., Wesle M.	Sunlumo
AventaSolar collector system	Rekstad J.	Aventa
UNISOL – universal solar system for pre-heating water	Godinho L., Graca P., Baptista L., Batista D., Mota A., Escadas R., Azevedo J., Goncalves T., Amorim R.,	JPrior, Aveiro University, LNEG

	Facao J., Rodrigues J.C., Carvalho M.J.	
Conceptual solar domestic hot water systems	Reiter C., Brandmayr S., Trinkl C., Zörner W.	FH Ingolstadt
Polymeric solar heating systems	Meir M.	Univ. Oslo
Polymeric storage tanks	Plaschkes M.	Magen EcoEnergy
UNISOL – solar combistore evaluation and optimization	Amorim R., Facao J., Rodrigues J.C., Carvalho M.J., Godinho L., Graca P.	LNEG, JPrior

Die Leistungsanforderungen betreffend wurden unter Leitung von AEE INTEC die im assoziierten grundlegenden Konsortialforschungsprojekt *SolPol-1* generierten Ergebnisse eingebracht, mit den Partner relevante Kollektortypen diskutiert und die Simulationen durch Gegenüberstellung mit experimentellen Daten vom Partner FH Ingolstadt validiert. In den drei Info Sheets „Performance requirements“ werden erstmals die Leistungsanforderungen (Temperatur- und Druckverteilungen) an unterschiedliche Komponenten von einer Vielzahl von Kollektoren, Systeme und Standorte publiziert. Exemplarisch sind in Abb. 9 die Temperatur- und Druckbelastungsprofile für Absorber von Referenz- und unterschiedlichen Kunststoffkollektoren für die Warmwasserbereitung und für die Heizungsunterstützung in Ein- und Mehrfamilienhäusern an den Standorten Graz, Pretoria, Fortaleza, Peking und Athen angeführt. Diese Leistungsanforderungen wurden im *SolPol-2*-Projekt aber auch von internationalen Partnern (z.B. Aventa, Magen, Roth Werke) für die (Weiter)-Entwicklung von Kunststoffkollektoren genutzt.

Für den Überhitzungsschutz von Flachkollektoren wurden die folgenden schaltbaren Optionen untersucht und diskutiert: thermosiphonische Rückkühlung, konvektive Hinterlüftung, thermotrope Schichten. Zudem wurde von Sunlumo ein Konzept erstellt, das auf der Anpassung des Kollektordesigns (nicht-selektiver Absorber, geringere Dämmung) beruht. Die Ergebnisse zeigten klar, dass die Optionen „thermosiphonische Rückkühlung“, „konvektive Hinterlüftung“, „Anpassung des Kollektordesigns“ ein hohes Umsetzungspotenzial bieten. Im Gegenteil dazu wurde für thermotrope Schichten eine Reihe von gravierenden Nachteilen (Schalthübe, Verfügbarkeit, Lebensdauer und Kosten der Materialien) aufgezeigt, die deren Potenzial für Kollektoren einschränken.



		frequency [h/a]								pressure min [bar abs.] pressure max [bar abs.]							
application ↓	*temperature classes* →	<0 [°C]		0 to 75 [°C]		75 to 100 [°C]		100 to 125 [°C]		125 to 150 [°C]		150 to 175 [°C]		175 to 200 [°C]		>200 [°C]	
Domestic hot water - SFH	reference system pumped; (Graz)	1059	2,46 2,47	7431	2,47 2,61	86	2,61 2,67	25	2,68 2,74	39	2,74 3,88	72	3,70 4,72	48	3,70 5,45	0	- -
	polymeric system without OHP; drain-back (Graz)	978	0,60 1,14	7337	0,60 1,14	171	0,60 1,14	148	1,00 1,00	107	1,00 1,00	19	1,00 1,00	0	- -	0	- -
	polymeric system with OHP; backcooler (Graz)	1125	1,27 1,31	7462	1,29 1,51	173	1,49 1,57	0	- -	0	- -	0	- -	0	- -	0	- -
	polymeric system thermosiphon; dual-loop (Pretoria)	0	- -	8564	0,98 1,08	196	1,08 1,09	0	- -	0	- -	0	- -	0	- -	0	- -
	polymeric system thermosiphon; single-loop (Fortaleza)	0	- -	8347	1,40 1,40	413	1,40 1,40	0	- -	0	- -	0	- -	0	- -	0	- -
	polymeric system thermosiphon; dual-loop (Peking)	1021	0,97 0,97	7589	0,98 0,98	150	1,08 1,09	0	- -	0	- -	0	- -	0	- -	0	- -
	polymeric system thermosiphon; dual-loop (Athen)	0	- -	8456	0,98 1,08	304	1,08 1,09	0	- -	0	- -	0	- -	0	- -	0	- -
Combi system - SFH	reference system pumped; (Graz)	1054	2,68 2,69	6791	2,69 2,76	547	2,76 2,79	73	2,79 2,83	106	2,83 4,43	101	4,25 5,40	86	4,25 5,40	2	4,25 4,25
	polymeric system without OHP; drain-back (Graz)	970	0,60 1,14	7047	0,60 1,14	455	0,60 1,14	149	1,00 1,00	116	1,00 1,00	23	1,00 1,00	0	- -	0	- -
	polymeric system with OHP; backcooler (Graz)	1123	1,26 1,29	7243	1,29 1,54	394	1,53 1,61	0	- -	0	- -	0	- -	0	- -	0	- -
	polymeric system without OHP; drain-back (Athen)	0	- -	7697	0,60 1,14	484	0,60 1,14	267	1,00 1,00	268	1,00 1,00	44	1,00 1,00	0	- -	0	- -
Domestic hot water - MFH	polymeric system without OHP; drain-back (Graz)	975	0,60 1,14	7524	0,60 1,14	186	0,60 1,14	54	1,00 1,00	21	1,00 1,00	0	- -	0	- -	0	- -
	polymeric system without OHP; drain-back (Peking)	1007	0,60 1,14	7413	0,60 1,14	183	0,60 1,14	139	1,00 1,00	18	1,00 1,00	0	- -	0	- -	0	- -

Abb. 9: Temperatur- und Druckbelastungsprofile für Absorber von Referenz- und unterschiedlichen Kunststoffkollektoren für die Warmwasserbereitung und für die Heizungsunterstützung in Ein- und Mehrfamilienhäusern an den Standorten Graz, Pretoria, Fortaleza, Peking und Athen.

Beiträge aus Deutschland, Israel, Norwegen und Österreich beschäftigten sich mit der Konzeption und Entwicklung von unterschiedlichen Kunststoffkollektortypen. Für die Warmwasserbereitung in warmen Klimazonen wurden zwei Arten von Thermosiphonkollektoren konzipiert und entwickelt. Das Aventa-Konzept, das auf extrudierten Stegplatten aus Polypropylen basiert wurde in den Labormaßstab übergeführt und ausgetestet. Dabei wurde auch ein zylinderförmiger, druckbeaufschlagbarer, innenliegender Wärmetauscher erarbeitet, wobei auch Tools zur Simulation und Optimierung der Wärmetauschergeometrie implementiert und angewendet wurden. Neben den Thermosiphonkollektoren wurde von den österreichischen Partnern GreenOneTech, APC, Polytec, AEE INTEC und JKU-IPMT ein neuartiges Konzept eines spritzgegossenen und verschweißten Speicherkollektors ausgearbeitet, das ebenfalls in den Labormaßstab übergeführt wurde und dessen Machbarkeit und prinzipielle Umsetzbarkeit im Rahmen des EU-Projektes SCOOP nachgewiesen wurde. Vom österreichischen Partner Sunlumo wurde über die Entwicklung des Eine-Welt-Solarkollektors (Kunststoff-Flachkollektor) kontinuierlich berichtet, wobei durch intensiven Austausch in den IEA SHC Task 39 Experts Meetings Inputs zur Optimierung des Kollektors erzielt wurden. Ebenso wurden von

Aventa Meilensteine bei der Entwicklung des auf extrudierten Stegplatten aus Polyphenylensulfid basierenden Kunststoffkollektors vorgestellt und in der Expertenrunde diskutiert. Neben solartechnischen Aspekten wurden insbesondere auch kunststofftechnische Aspekte (z.B. Bartbildung bei der Extrusion) behandelt und teilweise gelöst.

Kollektorsysteme wurden von Experten aus Portugal (Wasservorwärmung), Deutschland (Warmwasserbereitung) und Norwegen (Solarheizung) behandelt. Zu diesem Thema erfolgten von den Österreichischen Partnern erst am Ende von Task 39 nach dem Start des Konsortialprojektes *SolPol-4/5* signifikante Inputs. Diese Thematik, insbesondere die Kostenreduktion von Solarthermiesystemen, wäre von besonderem Interesse für weiterführende Arbeiten.

Auf dem Gebiet der Wärmespeicher wurden von Israel und Portugal neuartige Konzepte in Kunststoffbauweise erarbeitet und in Task 39 diskutiert. Zudem wurde vom assoziierten Partner Roth Werke ein druckfester Warmwasserspeicher entwickelt, in die Serienreife übergeführt und im Rahmen der Task 39 Exhibition in Freiburg (D) vorgestellt.

Subtask C

Subtask C „Materialien“ wurde von Österreich geleitet. Von den insgesamt 10 Info Sheets (s. Tabelle 5 und Anhang 1) wurden sechs Beiträge von Österreich erarbeitet. Der Schwerpunkt der Arbeiten lag gemäß den Zielsetzungen bei der Entwicklung neuartiger Materialien und Compounds (inkl. Stabilisierung) für den Absorber (inkl. organische Beschichtungen), die transparente Abdeckung (insbesondere thermotrope Schichten) und die Auskleidung von Wärmespeichern. Zudem wurde in Phase 2 von Task 39 eine Toolbox für die Basischarakterisierung und Qualitätssicherung von Kunststoffen in der Solarthermie und Methoden für die Alterungscharakterisierung erarbeitet und diskutiert.

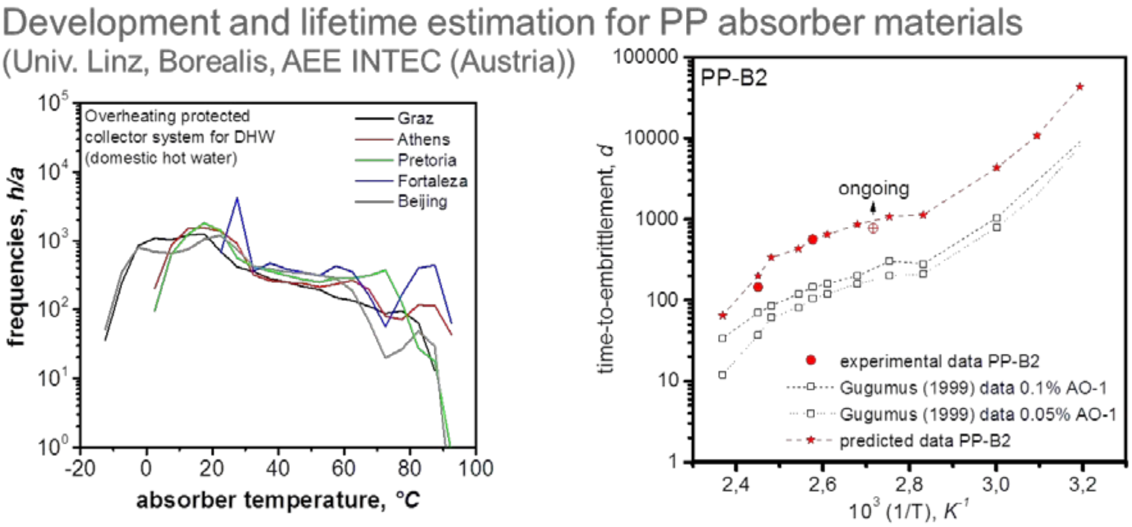
Die Absorberwerkstoffe betreffend lag der Schwerpunkt der Arbeiten bei Polypropylen-Compounds (PP) für überhitzungsgeschützte Flachkollektoren, glasfaserverstärkten Polyamiden (PA) für Speicherkollektoren und Polyphenylensulfid-Materialien (PPS) für Flachkollektoren ohne Überhitzungsschutz. Neuartige Absorberwerkstoffe wurden in den assoziierten Forschungsprojekten *SolPol-1/2* und SCOOP entwickelt und bei den Experts Meetings vorgestellt und erforderliche Verbesserungsmaßnahmen diskutiert. Neben den wissenschaftlichen Partnern JKU-IPMT und Universität Oslo ist die aktive Beteiligung der Firmen APC, BASF, Borealis und Chevron Philips hervorzuheben. Für eine mittlerweile in den Markt übergeführte PP-Type von Borealis wurden durch das Netzwerk in Task 39 neue Anwendungsfelder und Märkte in Israel, Norwegen oder China erschlossen. Für das im *SolPol-2*-Projekt erarbeitete PP-Material wurde im Vergleich zu dem am Markt etablierten PP-Absorberwerkstoff eine um den Faktor 2 erhöhte Lebensdauer nachgewiesen (s. Abb. 10).

Tabelle 5: Info-Sheets zu Subtask C „Materialien“

Titel	Autor(en)	Institution(en)
Polypropylene absorber materials	Wallner G.M., Povacz M.	JKU-IPMT
Polyamide based integrated storage collector	Wallner G.M., Lüftinger T., Schnetzinger K., Lutschounig K., Preiß D.	JKU-IPMT, Polytec, APC, GreenOneTec, AEE INTEC
TISS coating as added value for polymeric solar absorber	Jerman I.	NIC
Thermotropic Materials for Overheat Protection	Gladen A., Mantell S., Davidson J.,	University of Minnesota
Bioplastics for solar collector components	Resch K., Klein A., Oreski G.	MU Leoben, PCCL
Polymeric Liner Materials	Grabmayer K.	JKU-IPMT
The Art of Stabilization	Beißmann S.	JKU-IAC
Tool box for basic characterization of plastics	Wallner G.M.	JKU-IPMT
Twin wall sheet testing	Piekarczyk A., Durson, A.	Fraunhofer ISE, Univ. Oslo
Accelerated UV-Aging	Piekarczyk A., Weiss, K.-A.	Fraunhofer ISE

Für die Beschichtung von Absorbern wurden in Task 39 sowohl spektral-selektive Lacke (von NIC und Color (Slowenien)) als auch thermotrope Schichten (von PCCL, MU Leoben und NREL) weiterentwickelt. Für die spektral-selektiven Lacke wurden die Applizierbarkeit auf unterschiedliche Substrate (insbesondere extrudierte PPS-Absorber) und deren Langzeitbeständigkeit untersucht. Bei den thermotropen Schichten lag der Fokus bei der Simulation erforderlicher Schichtdicken und

Schalteigenschaften und bei der Optimierung von Matrixsystemen mit fixierten, schaltbaren Streudomänen. Bei den spektral-selektiven Lacken wurden in Zusammenarbeit zwischen Slowenien und Norwegen Demonstratoren im Labormaßstab umgesetzt und die Langzeitbeständigkeit nachgewiesen. Für die thermotropen Schichten wurden neben vielversprechenden Eigenschaften auch kritische Defizite aufgezeigt, die vor allem in den erforderlichen Schichtdicken und dem Materialaufwand (3 mm), den moderaten Eigenschaften (Transmissionsgrad im ungeschalteten Zustand von max. 85%, breite Schalttemperaturbereiche, begrenzte Schalthübe, Hysterese) und der Langzeitperformance lagen.



Lifetime, years	Graz, AT	Athens, GR	Pretoria, RSA	Fortaleza, BR	Beijing, CHN
PP-B1	21	15	14	8	23
PP-B2 (SolPol)	32	25	24	15	34

Abb. 10: Standortabhängige Verteilung der Absorbertemperaturen für überhitzungsgeschützte Kollektoren, Alterungsverhalten des *SolPol*-PP-Materials (PP-B2) und modellierte Lebensdauern im Vergleich zum Benchmark-Material (PP-B1).

Ein Schwerpunkt der österreichischen Aktivitäten lag auch bei der Weiterentwicklung von Kunststoff-Linermaterialien für Heißwasserwärmespeicher. In Task 39 wurden die in *SolPol-2* weiterentwickelten Linermaterialien vorgestellt und diskutiert. Zudem wurden Kontakte zu Partnern von IEA SHC Task 45 „Large Scale Solar Heating and Cooling Systems“ (insbesondere Dänemark) aufgebaut und neuartige Linermaterialien für Saisonalspeicher in Dänemark und Deutschland einer Vorqualifizierungsprüfung unterzogen. Die neuartigen Linermaterialien wurden vom Unternehmenspartner AGRU Anfang 2014 in den Markt eingeführt (s. Abb. 11).

News > Latest News > High Temperature Resistant Geomembrane

High Temperature Resistant Geomembrane

07.01.2014 LINING SYSTEMS - General - Research

AGRU for many years has supplied PE pipes for hot water applications. With this vast knowledge and experience AGRU developed the first high temperature resistant (HTR) PE geomembrane in the marketplace. It looks, feels and welds like every other HD-PE geomembrane. Additionally it offers an outstanding

Abb. 11: Vorstellung von neuartigen Linermaterialien für Saisonalspeicher mit erhöhter Dauergebrauchstemperatur (Quelle: Website der Firma AGRU).

Neben der Entwicklung von Materialien und Compounds für die Solarthermie wurde in Task 39 eine Reihe von neuartigen Prüf- und Charakterisierungsmethoden entwickelt und evaluiert. Aufgrund der Vielzahl an unterschiedlichen, maßgeschneiderten Kunststoffen und deren spezifischen Eigenschaftsprofilen und Charakteristika (z.B. ausgeprägte Zeit- und Temperaturabhängigkeit) wurde eine Tool-Box entwickelt, die aussagekräftige Rückschlüsse auf die werkstoffliche Zusammensetzung und die verwendeten Stabilisatoren zulässt. In Abb. 12 ist die implementierte Tool-Box für die Identifizierung und Basischarakterisierung von Kunststoffen für die Solarthermie angeführt. Der Methodenmix umfasst spektroskopische (IR, UV/VIS/NIR), thermoanalytische (DSC) bzw. thermomechanische (DMA) Methoden, mit denen eine grundsätzliche Überprüfung der spezifizierten Kunststoffe bspw. im Zuge der Eingangskontrolle möglich ist. Für die Analyse der Stabilisierung von Kunststoffen sind aufwändige chromatografische und spektrometrische Methoden erforderlich. Im Info Sheet „The Arts of Stabilization“ sind die Grundlagen der Stabilisierung und geeignete Analysemethoden kompakt und einfach verständlich dargelegt und zusammengefasst.

In Zusammenarbeit von Deutschland, Norwegen, USA und Österreich wurden Methoden und Kennwerte zur aussagekräftigen Überprüfung der Langzeitbeständigkeit auf Werkstoff- und Halbzeugebene etabliert. Für die beschleunigte Alterungsprüfung wurden die Konzepte der Miniaturisierung von Prüfkörpern, der Konzentrierung der Umgebungsmedien und der Sensitivität von kontaktlosen Analysemethoden (Fluoreszenzspektroskopie) ausgelotet und Möglichkeiten und Grenzen aufgezeigt. Für Absorberhohlkammerplatten wurde eine einfach durchführbare Indentationsprüfmethode für den Nachweis von Materialschädigungen implementiert. Letztlich wurden die neuartigen Absorberwerkstoffe (PP-, PA- und PPS-Grades) von

Deutschland bezüglich der Witterungsbeständigkeit umfassend charakterisiert.

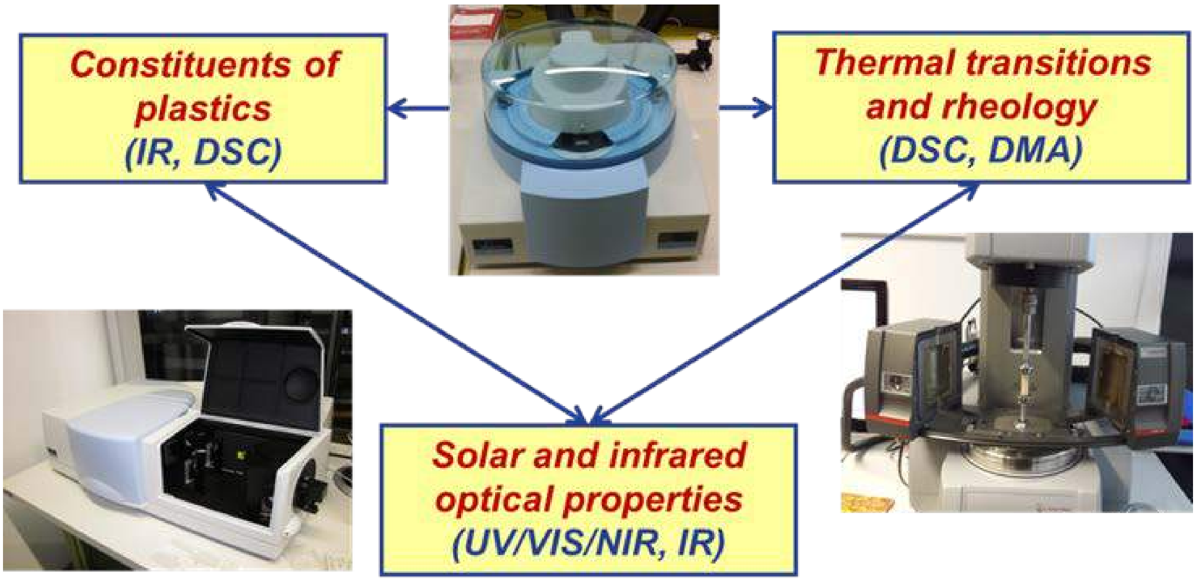


Abb. 12: Toolbox für die Basischarakterisierung von Kunststoffen für die Solarthermie.

Veröffentlichungen

Die Liste der Veröffentlichungen aus Phase 2 von IEA SHC Task 39 ist auf der Website http://task39.iea-shc.org/publications angeführt. Zudem sind die Veröffentlichungen als Referenzen bei den Info Sheets (s. Anhang 1) dargelegt und Themen-spezifisch geordnet. Eine kompakte Zusammenstellung der Hauptergebnisse von Task 39 und den Subtasks erfolgte im Zuge der SHC 2014 Conference in Peking (CHN) vor dem SHC Executive Committee. Die Foliensätze befinden sich im Anhang 2.

4. Vernetzung und Ergebnistransfer

Zur österreichischen Zielgruppe von IEA SHC Task 39 gehörten insbesondere:

- Facheinschlägige Unternehmen aus den Bereichen
  - Solarthermie (Komponenten- und Kollektorhersteller; Systemanbieter)
  - Kunststofftechnik (Kunststofferzeugende und –verarbeitende Industrie)
- Forschungs- und Bildungseinrichtungen
- Unabhängige oder öffentliche Institutionen (Branchenverbände wie Austria Solar oder Kunststoff-Cluster)

Zur Einbindung der Stakeholder in das Projekt wurden die halbjährlich erschienen Newsletter von IEA SHC Task 39 über die Adressdatenbanken von AEE INTEC und dem Kunststoff Cluster Oberösterreich an über 10.000 Adressaten verteilt. Zudem wurde die Task 39-Website über die Webseiten der Projektpartner AEE INTEC und JKU-IPMT verlinkt. Pro Jahr erschienen 2 bis 3 Veröffentlichungen von Task 39 in der Zeitschrift „erneuerbare energie“. Hervorzuheben ist die Sonderausgabe 01/2013, in der 6 Artikel zu Kunststoff-Kollektoren publiziert wurden. In Phase 2 von Task 39 wurden zwei nationale Verbreitungstagungen an der JKU Linz abgehalten:

- 6. Juli 2011: Kunststoffe als Wachstumsmotor für die Solarthermie - Neue Technologieoptionen auf Basis von Polymerwerkstoffen (15 Vorträge)
- 11. Oktober 2013: Kunststoffe – die Wachstumsoption für die Solarthermie (12 Vorträge)

Bei der nationalen Verbreitungstagung im Juli 2011 nahmen 101 Personen aus 4 Ländern (Österreich, Deutschland, Norwegen, Schweiz), jeweils etwa 50% aus der Wirtschaft und von Forschungsinstitutionen, teil. In 15 Vorträgen wurden die Hauptergebnisse von Phase 1 von Task 39 vorgestellt. Der Schwerpunkt lag bei neuartigen Kunststoffen für Kollektoren. In je 2 Vorträgen wurde auf Speicheranwendungen und systemische Fragestellungen eingegangen.

Die nationale Verbreitungstagung im Oktober 2013 besuchten trotz des für die Solarthermie schwierigen wirtschaftlichen Umfeldes (Marktrückgang in den Hauptabsatzmärkten) 74 Teilnehmer aus 3 Ländern (Österreich, Deutschland, Norwegen). In einem Begrüßungsreferat und 12 Fachvorträgen wurden die Schlüsselergebnisse von Task 39 vorgestellt. In mehreren Präsentationen wurden Highlights der nationalen Forschung und Entwicklung (z.B. aus den assoziierten Forschungsprojekten *SolPol-1/2*) verbreitet. 9 der 12 Fachvorträge wurden von Beteiligten des IEA SHC Task 39-Projektes gehalten (3 Vorträge durch JKU Linz und je 1 Präsentation durch AEE INTEC, PCCL/MUL, UIBK und den Unternehmenspartnern APC, GTI und Sunlumo). Die intensive Diskussion der Ergebnisse verdeutlichte das hohe Interesse an der Thematik. Bei dieser Tagung wurde als wesentliche Herausforderung für die Weiterentwicklung der Solarthermie eine signifikante Kostenreduktion des Gesamtsystems (von etwa 50%) abgeleitet. Es wurde gefolgert, dass dies nur durch einfach installierbare plug&function Systeme mit hohem Vorfertigungsgrad zu erreichen ist, wobei die Kunststoffbauweise beste Voraussetzungen dafür bietet.

Durch die Beteiligung von Österreich auch in Phase 2 von Task 39 wurde die österreichische Vorreiterrolle auf dem Gebiet der Kunststoffe für die Solarthermie signifikant gestärkt und ausgebaut. Einerseits gelang es in Österreich Leuchtturmprojekte (insbesondere *SolPol-1/2* und *SolPol-4/5*) zu etablieren, in denen in Konsortien mit bis zu 10 Unternehmenspartnern und 8 wissenschaftlichen Partnern bahnbrechende Ergebnisse erzielt wurde. Beispielsweise wurde als Spin-off die Nullserie für den Eine-Welt-Kollektor (von Sunlumo) für den weltweiten Massenmarkt realisiert. Andererseits wurde eine schwarz-pigmentierte Polypropylentype für solarthermische Absorber entwickelt und kommerzialisiert, die im Vergleich zum Benchmark-Material je nach Anwendung und Einsatzgebiet eine Verdoppelung der zu erwartenden Lebensdauer ermöglicht. Die neuartige Type (von Borealis) wird von Magen EcoEnergy (Israel) und Aventa (Norwegen) bereits für Kunststoffabsorber verwendet. Zudem wurde im Zuge der abschließenden Task 39-Verbreitungstagung bei der SHC 2014 in Peking Kontakte zu einem chinesischen Hersteller von Rohrbündelabsorbern aufgebaut, der die neuartige Type bereits austestet. Auch für Saisonalspeicher wurden in Task 39 neue Polyolefintypen mit erhöhter Dauergebrauchstemperatur entwickelt und von AGRU in den Markt eingeführt. Die neuartigen Liner wurden bereits für Großspeicherprojekte in Deutschland und Neuseeland verwendet bzw. für Speicher in Dänemark von Anlagenbauern ausgetestet. Zudem wurde durch die Task 39-Beteiligung eine Vielzahl neuer Ideen und Ansätze für konkrete Produktentwicklungen nukleiert, die in laufenden Forschungsprojekten (z.B. *SolPol-4/5*) bearbeitet werden.

Neben dem kommerziellen Nutzen der österreichischen Task 39-Beteiligung, ergaben sich auch für die wissenschaftlichen Partner signifikante Vorteile. Hervorzuheben sind Forschungskooperationen im Rahmen des EU-Projektes SCOOP sowie ein akademischer Austausch zwischen JKU-IPMT und der

Bundesanstalt für Materialprüfung (in Berlin) und der Humboldt Universität Berlin. Zudem wurden in Phase 2 von Task 39 neben Bachelor- und Masterarbeiten vier Dissertationen (Andreas Weber (PCCL), Susanne Beißmann (JKU-IAC), Markus Povacz (JKU-IPMT) und Klemens Grabmayer (JKU-IPMT)) bearbeitet und abgeschlossen. Eine weitere Dissertation an der Universität Innsbruck (Claudia Hintringer) wurde in Phase 2 von Task 39 begonnen; der Abschluss ist für 2015 geplant. Aus den Dissertationen gingen 20 Papers in referierten Journalen hervor, die ein klarer Beleg für die österreichische Vorreiterrolle auf dem Gebiet der Kunststoffe für die Solarthermie sind.

5. Schlussfolgerungen, Ausblick und Empfehlungen

Durch die Beteiligung in Phase 2 von IEA SHC Task 39 und die Übertragung der Task 39-Projektergebnisse auf nationale Forschungsprojekte wurde die österreichische Vorreiterrolle auf dem Gebiet der kunststoff-basierenden, solarthermischen Systeme signifikant gestärkt und die existierende weltweite Spitzenposition Österreichs auf dem Gebiet der Solarthermie durch polymerbasierende innovative Neuentwicklungen sichergestellt bzw. ausgebaut. Von den österreichischen Partnern wurden wesentliche Beiträge zur innovativen Weiterentwicklung von solarthermischen Systemen durch den stärkeren Einsatz von Kunststofftechnologien erbracht. Diese umfassen sowohl technische Grundlagen (z.B. Rechenmodelle, Anforderungskataloge und Eigenschaftsprofile für Werkstoffe, adaptierte Prüf- und Charakterisierungsmethoden für Werkstoffe, Halbzeuge und Bauteile) als auch konkrete Werkstoff- und Produktentwicklungen und deren Markteinführung. Zudem wurde abgeleitet aus 100% erneuerbaren Energieszenarien erstmals das hohe Marktpotenzial der Solarthermie für die Kunststoffherstellende und –verarbeitende Industrie herausgearbeitet und so ein vertieftes Verständnis und Bewusstsein für Solarthermietechnologien in der Kunststoffindustrie geschaffen. Auch von der Solarthermieindustrie wurde erkannt, dass Werkstoff-dominierte Weiterentwicklungen mit dem Ziel massentauglicher Produkte und Systeme unerlässlich sind, um der Solarthermie in einer Phase des regionalen Marktrückganges zum Durchbruch zu verhelfen.

Als wesentliche Herausforderung für die weitere Entwicklung der Solarthermie wurde in Task 39 eine signifikante Kostenreduktion des Gesamtsystems (mindestens 50%) abgeleitet. Dies ist insbesondere auf dem Gebiet der gepumpten Systeme für die Warmwasserbereitung und Heizungsunterstützung in kontinentalen Klimazonen erforderlich. Bei einfacheren nicht-gepumpten Systemen für die Warmwasserbereitung in heißen Klimazonen wurde die Notwendigkeit der Steigerung des Nutzerkomforts bei gleichzeitig hoher Qualität und Zuverlässigkeit und moderaten Systemkosten identifiziert. Kunststoffprodukte bieten aufgrund des hohen Vorfertigungsgrades und der Funktionsintegration, der einfacheren Montier- und Installierbarkeit (plug&function), der hohen Zuverlässigkeit und Lebensdauer und der hohen Designfreiheit ideale Voraussetzungen zur Steigerung der Kosten/Nutzen-Verhältnisse und zur Kosten/Preis-Reduktion.

Die in Task 39 generierten Ergebnisse sind sowohl für die Solarthermie- als auch für die Kunststoffindustrie von hoher Relevanz. Es wurden ideale Voraussetzungen und Grundlagen für weitere Produktentwicklungen und –optimierungen geschaffen. Auch bei den Forschungseinrichtungen wurde durch Task 39 eine weltweit einzigartige, nationale Kooperation zwischen den Disziplinen Solarthermie und Kunststofftechnik erreicht.

Die Ergebnisse von Task 39 mit dem Fokus auf Kunststoffkollektoren stellen die Basis für weiterführende Arbeiten mit dem übergeordneten Ziel der Kostenreduktion von Solarthermiesystemen dar. Dazu wurde bereits ein kooperatives, nationales Leitprojekt (*SolPol-4/5*) initiiert und gestartet. Zudem wurden bei aktuellen Calls (z.B. Energieforschungsprogramm) zwei Anträge für Einzelprojekte in den Bereichen industrielle Forschung und experimentelle Entwicklung gestellt. Thematisch liegen die Schwerpunkte bei der Entwicklung und Optimierung von kostengünstigen Systemen für die Warmwasserbereitung und Heizungsunterstützung und bei der Entwicklung von industriell vorgefertigten, einfach assemblierbaren Komponenten. Als ein wesentliches Hemmnis bei der Umsetzung von Kunststoffkomponenten wurden die derzeit ungeeigneten Zertifizierungsverfahren und die auf Metall/Glas-Technologie ausgerichteten Standards identifiziert. In diesem Bereich sind grundlegende Arbeiten erforderlich um eine schnelle, aussagekräftige und zielgerichtete Zertifizierung und Zulassung neuer Komponenten und Systeme zu ermöglichen.

Internationale Kooperationen betreffend ist eine Verstärkung und Intensivierung insbesondere in den Wachstumsmärkten außerhalb Europas erforderlich. Diesbezüglich wurden in Task 39 bereits Kooperationen mit Israel und China etabliert. Anzustreben sind Kooperationen mit beispielsweise Südafrika, Mittel- und Südamerika, Indien, arabischer Raum aber auch der Türkei. In diesen Märkten wird die Solarthermie derzeit vornehmlich für die Warmwasserbereitung genutzt. Deshalb wird ein Schwerpunkt bei kosteneffizienten, nicht-gepumpten Systemen mit verbessertem Komfort und hoher Qualität und Zuverlässigkeit liegen.

In Europa erlangen solare Nah- und Fernwärmenetze immer stärkere Bedeutung. Dabei hat sich Kunststoff als Linermaterial für kosteneffiziente Großspeicher etabliert. Um großflächige, einfach installierbare und funktionale Kollektorfelder zu realisieren, sind Leichtbautechnologien und ein adäquater Überhitzungsschutz bei Stagnation unerlässlich. In Task 39 wurden zu beiden Themenstellungen bereits entsprechende Lösungen erarbeitet, weshalb zu erwarten ist, dass das generierte

Know How mittelfristig auch in diesem Anwendungsbereich einfließen wird. Eine Vernetzung mit IEA SHC Tasks mit Fokus auf Nah- und Fernwärmenetze wird empfohlen.

Zur Kostenreduktion von Solarthermiesystemen wurde im September 2014 ein IEA SHC Task initiiert, der sich derzeit in der Konzeptions- und Definitionsphase befindet. Österreich strebt in diesem Task eine zentrale Rolle an, wobei die Aktivitäten und Schwerpunkte insbesondere auf den Vorarbeiten in Task 39 und dem Mitte 2014 gestarteten, kooperativen Forschungsprojekt *SolPol-4/5* (Titel: Solar-Thermal Systems Based on Polymeric Materials - Novel Pumped and Non-Pumped Collector Systems) aufbauen werden.

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Die vollständige Liste der Task 39-Veröffentlichungen (inkl. Vorträge) ist unter folgendem Link angeführt:

http://task39.iea-shc.org/publications

Anhang

1. **Info-Sheets zu den Subtasks** (s. Auflistung in den Tabellen 2 bis 4)

2. **Folien der Task 39-Abschlusspräsentationen** (im Rahmen der SHC 2014 Konferenz in Peking)

   - ➢_**Task 39-Präsentation** (Köhl, M., Operating Agent)
   - ➢_**Subtask A-Präsentation** (Meir, M.)
   - ➢_**Subtask B-Präsentation** (Fischer, S.)
   - ➢_**Subtask C-Präsentation** (Wallner, G.M.)

3. **Masterarbeit Holzhaider**

100% Renewable Energy Scenarios – Relevance of Plastics for Solar Thermal Technologies

Description:	*This Info Sheet describes the role of solar thermal systems in 100% renewable energy scenarios, the resulting plastics material demand and possible consequences for the plastics industry.*
Date:	22.7.2014
Authors:	*Klaus Holzhaider, Gernot M. Wallner, Harald Kicker, Reinhold W. Lang* *Institute of Polymeric Materials and Testing, JKU Linz, Austria* *Robert Hausner, AEE-Institute for Sustainable Technologies, Gleisdorf, Austria*
Download possible at:	http://task39.iea-shc.org/publications

Introduction

In order to estimate the future demand for polymeric materials used for solar thermal systems, the Institute of Polymeric Materials and Testing at JKU Linz (AT) and the AEE-Institute for Sustainable Technologies (Gleisdorf, AT) have analysed global and European scenarios that aim for a 100% renewable energy supply by 2050. Those scenarios were compared to European market scenarios established by ESTIF (European Solar Thermal Industry Federation). Based on these scenarios the resulting polymeric material demand until 2050 was calculated. Finally, the results were compared to the potential development of the total global oil reserves and plastics production.

100% Renewable Energy Scenarios

In recent years a variety of energy scenarios were developed. However, few of them describe the pathway to a 100% renewable energy future within the next decades, including all major renewable technologies and solar thermal systems in particular. On a global scale, the scenarios *Energy [R]Evolution – A Sustainable World Energy Outlook* (E[R]) by Greenpeace, GWEC and EREC and *The Energy Report – 100% Renewable Energy by 2050* (TER) by WWF International, ECOFYS and OMA were chosen for the calculations. European scenarios often vary in the scope (especially concerning geographic confines) which makes a comparison more difficult. Again two scenarios were chosen: *RE-thinking 2050 – A 100% Renewable Energy Vision for the European Union* by EREC includes solar thermal scenarios for the former EU 27 member states while the European part of *Energy [R]Evolution* refers to OECD Europe (+37% installed capacity compared to EU 27, mainly due to Turkey).

Potential for Polymeric Materials

Based on conventional solar thermal systems and the assumption that the mass of the polymeric collector equals 0.7 times the mass of the conventional collector, the plastic demand per m^2 collector area was defined for both pumped and thermosyphon systems. Additionally, assumptions for the yield (global: 2.61 PJ/(GW·a); Europe: 2.19 PJ/(GW·a)), the development of the share of pumped/thermosyphon systems (global: 50%/50%, Europe: 60%/40% by 2050) and the life expectancy (20 years) were defined. Considering the current phase of polymeric collector development, mass production and installations on a worldwide scale are assumed to kick off by 2020.

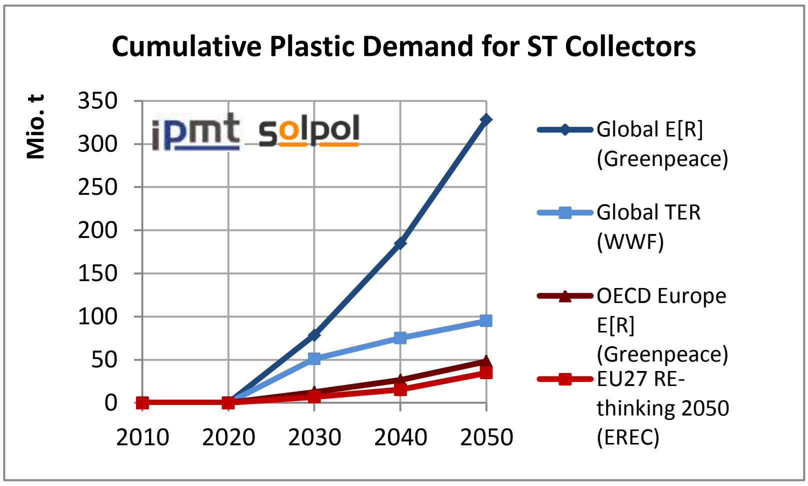

Figure 1 Cumulative plastic demand for solar thermal collectors between 2010 and 2050 on a global and European scale

In the calculations, baseline capacity is covered by conventional collectors while the residual part of the 100% scenarios is covered with collectors based on plastics. **Fehler! Verweisquelle konnte nicht gefunden werden.** shows the result on a global and European scale. Especially on a global scale, the differences between the two scenarios are significant. This shows the great uncertainty of such energy scenarios covering several decades. Up to 2050 a cumulative plastics demand ranging from about 100 and 330 Mio. t was deduced.

Consequences for the Plastics Industry

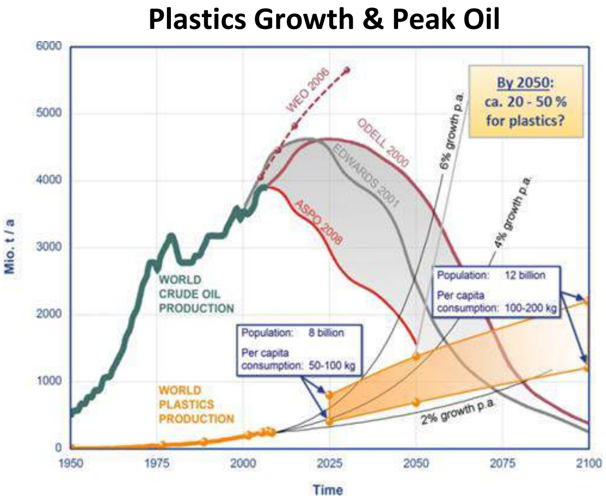

Figure 2 Peak oil curve and global plastic production scenarios R. W. Lang and H. Kicker (2010)

The realization of such 100% scenarios has a big impact on the material demand of all renewable technologies, including solar thermal. The annual worldwide plastics production in 2012 was 288 Mio. t. At the moment a fraction of about 20.3% of the European plastics production is used in the "Building and Construction" sector, which results in an annual global demand of about 60 Mio. t. In this market sector cost-efficient commodity plastics (e.g., polyolefins) are dominating. Assuming the Global E[R] (Greenpeace) scenario an additional annual quantity of about 10 Mio. t has to be provided for the solar thermal industry. This figure clearly indicates the high attractiveness of solar thermal technologies for the plastics industry. A significant benefit of solar thermal energy supply is the saving of fossil resources which will be used in future primarily as a feedstock for materials (see Figure 1Figure 2).

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Market and cost effects

Description:	*Market and cost effects for polymeric solar thermal collectors*
Date:	23.01.2015
Authors:	Andreas Piekarczyk, Karl-Anders Weiss, Fraunhofer ISE
Download possible at:	http://task39.iea-shc.org/

Introduction

Talking about polymeric collectors, the reduction of production costs is one main argument for the use of polymeric materials instead of metals. This cost advantage can be split into two categories: lower material costs of the polymeric materials on the one hand and lower manufacturing costs on the other hand. Comparing just the prices for raw materials per kilogram is not sufficient and only little can be said about the saving potential of polymeric materials. In the here presented manner, using some assumption, a detailed analysis of the cost effects of polymeric materials for the use in solar thermal applications can be performed. In a case study for extruded collectors this analysis is broken down into several steps and the importance of every step explained in further detail:

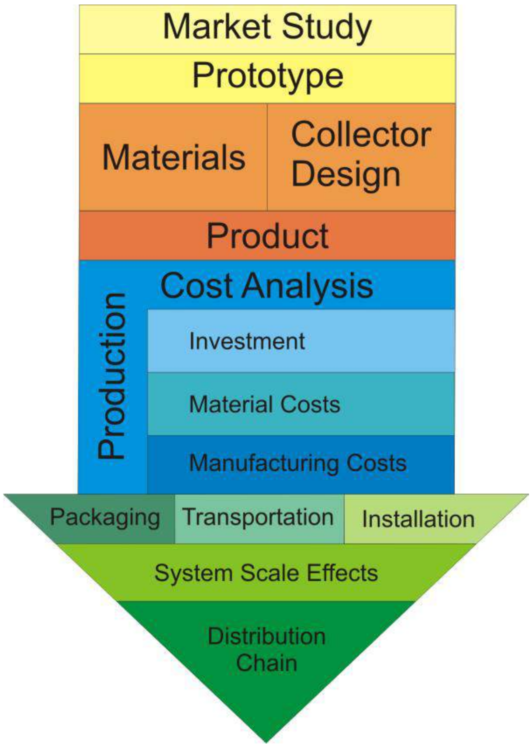

Fig. 1 Schematic of the different steps of the cost calculation. At the end of each block the product has to pass the cost analysis. From top to bottom more detailed information about the value chain of the product is needed.

Market

The outcome of a market study is essential for all following steps, influencing not only the collector design, material choice and other product related factors, but also dictates the output and scaling of the production and the targeted price range. Based on the market for conventional collectors and its development, assumptions for the potential market for polymeric collectors can be made.

Materials and Collector Design

Choosing suitable materials demands a detailed consideration of the chemical stability, mechanical performance and other limiting factors. More detailed information on this topic can be found in the corresponding info sheet. For the calculation of the material costs, the necessary material volume needs to be calculated depending on the collector's design. Compared to metal based collectors, the significantly lower Young modulus needs to be considered and the wall thickness adjusted accordingly, taking into account the decreasing thermal conductivity with increasing wall thickness. Overheating of the material needs to be prevented and the design optimized for the appropriate production technology. Costs are increased or the collector efficiency is reduced by additional measures for preventing overheating, and additives for the production are factors that need to be considered in the further calculation.

Production

An annual production rate has to be estimated and the production line are to be scaled accordingly. The manufacturing of the collector has been split into individual steps for which the material costs, individual production costs, the overhead and machine costs can be estimated. Energy costs, investment costs, wages, storage and others are to be mentioned here and depend strongly on the production process and the collector design. Therefore no general consideration can be made. The collector design may have a strong impact on the investment costs (injection mold, extrusion die, welding…) and should be optimized towards process ability. At this step many assumptions need to be made, as detailed data for individual production steps is usually not available. For further analysis a parameter sensitivity study can be included to check, for example, the influence of the energy prices, which are considered one major cost factor.

Scale effects and distribution chain

For some collector designs and systems, scale effects can be investigated, which may reduce the product’s market price additionally. Furthermore, the presumed lower weight of a polymeric collector can reduce installation and transportation costs. Based on the distribution chain of conventional collectors, it can be assumed, that most of the savings in production costs, which normally account for one third of the market price, are consumed by the trade margin, installation costs and others. For a thorough analysis of the costs of polymeric and metal based collectors, detailed information about the distribution chain is necessary.

Summary

The production cost analysis can be addressed as known for other products in general, but some differences to metal based collectors should be kept in mind. Material properties vary and require design adjustments.. Polymers have significant lower density leading to a lower collector weight and related transport costs.

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“*Markets and Contribution to the Energy Supply 2011*”; F. Mauthner, W. Weiss, EDITION 2013

TASK39

SHC
SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

Evaluation of thermosiphon systems by adopting a total cost accounting approach

Description:	• The pros and cons of replacing traditional materials with polymeric materials in solar thermosiphon systems are analyzed by adopting a total cost accounting approach. • In terms of climatic and environmental performance, polymeric materials reveal better key figures than traditional ones like metals. In terms of total costs this may also be true but more work is needed to answer this question properly.
Date:	2014-06-27
Authors:	Bo Carlsson, Linnaeus University; Michaela Meir, John Rekstad, Aventa AS; Andreas Piekarczyk and Regine Weiß, Fhg ISE; Dieter Preiß, AEE-INTEC
Download possible at:	http://task39.iea-shc.org/publications

Introduction

To assess the suitability of polymer based solar thermosiphon systems three polymeric systems under development have been selected and compared with thermosiphon systems in which traditional materials like metals were used. For the comparison, a total cost accounting approach is adopted, which involves the analysis of differences in thermal performance, end-user investment costs, operation and maintenance (O&M) costs, reliability and long-term performance, climatic and environmental performance in relation to the costs of the polymeric systems versus those of the traditional ones.

All thermosiphon systems are analyzed on the assumption that they are installed in Palermo, Italy. All systems have a hot water tank of 120 liters which corresponds to the daily hot water load for a typical one-family house in that region. The solar absorber area for all systems is approximately 2 m^2. But, by making use of computer simulation, the solar absorber area for each system is adjusted so that all systems yield the same solar fraction with respect to hot water production.

Life cycle analysis

Assessment of climatic and environmental performance in relation to costs is made by life cycle analysis. To convert an environmental or a climatic impact indicator into costs, the same methodology as in a previous Task 39 case study [1] is employed.

For the life cycle analysis, process trees with inventory data from the Ecoinvent data base [2], representative for Europe, are used; see e.g. [3]. End-of-life scenarios including both recycling and no recycling are considered.

The life cycle analysis results clearly indicate that a replacement of traditional materials, e.g. metals, with polymeric materials increases the climatic and environmental performance significantly, when they are expressed in terms of the IPCC 100 as indicator and the Ecoindicator 99, H/A indicator. [4]. In terms of climatic and environmental costs per amount of solar heat collected, this difference, however, is not that significant. When present day carbon dioxide emission tax rates are used to convert climatic performance into climatic costs and a comparison is made with existing energy prices, the climatic cost per solar heat collected is small. [1].

End-user investment costs, O&M costs, long-term performance and expected service life of systems

In estimating future end-user investment costs and O&M costs for the systems studied, models and results from the ongoing EU project SCOOP [5] were consulted. If the yearly O&M costs may be set at 1% and the expected lifetime of the solar thermosiphon systems at 15 years, we expect the sum of end-user investment costs and operation and maintenance costs for the polymeric based thermosiphon systems to be less than 290 €/m^2 solar collector area or 400 €/kWth. From the analysis made on the polymeric based solar thermosiphon systems so far this seems to be competitive with traditional systems and a realistic goal to achieve.

References

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Life Cycle Analysis

Description:	*Life cycle analysis for polymeric solar thermal collectors*
Date:	25.8.2014
Authors:	Regine Weiss, Fraunhofer ISE
Download possible at:	http://task39.iea-shc.org/

Introduction

When developing new solar collectors with novel materials, the reduction of their environmental impact should be considered. In this context, several studies were published analyzing the environmental impact through polymeric materials and comparing them with conventional metal based collectors and systems by using life cycle analysis methodologies [1], [2].

Methodology

Life cycle analysis (LCA) is a method to evaluate the environmental impact of a product throughout its life cycle. The life cycle starts at the raw material extraction and runs throughout the production to the disposal of the product (“cradle to grave”). Different approaches, from the raw material extraction to the end of production (“cradle to gate”) or just the production (“gate to gate”), are also possible. The analysis allows the description of potential environmental impacts caused by the consumption of raw materials, use of energy and the emission of pollutants. The principles and framework of life cycle analysis are defined in ISO 14040[3] and ISO 14044[4]. The methodology itself is flexible and can be adjusted according to the specific objectives. There are different models with different indicators (Ecoindicator 99, ReCiPe 2008, IPCC 2013, etc.) [5] which focus on different environmental aspects such as climatic change and cancerous risk.

Implementation

First the product system (Fig. 1) should be defined with all life stages and steps throughout the stages of interest. In the next phase the inventory data for the description of the product system should be collected. The inventory data includes, for example, aspects such as the amount of materials used, energy demands, as well as the amount of emissions and waste. For the collection databases like ECOINVENT® [6] or the European Reference Life-Cycle Database (ERPLCA) [7] are available. It should be noted that most available datasets are averaged for regions or materials. Therefore, they are not always in accordance with the objective of the individual research and should be adjusted accordingly. Depending on the required precision, inventory data has to be collected additionally or assumptions have to be made. For example more additional data is necessary or the data must be simulated using assumptions, if a material with a specific additive is analyzed. These assumptions have to be consistent till the end of the life cycle and must also be considered in the disposal of the product due to the caused emissions. In an additional sensitivity study those assumptions can be evaluated.

Different software packages can be used like e.g. SimaPro® [8] or GaBi® [9] Software for the evaluation and calculation. The software enables the construction of the life cycle, the integration of a database and calculation of the environmental impact and overall damage according to the selected indicator.

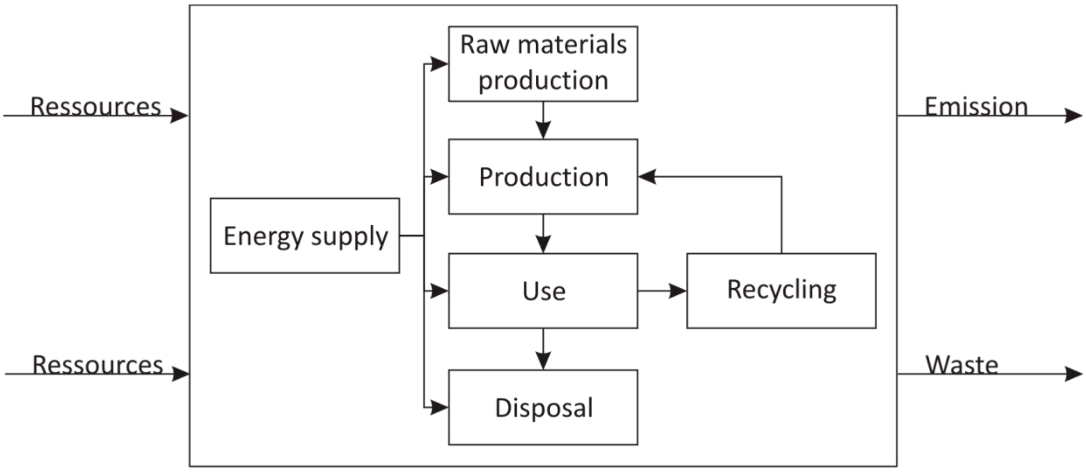

Fig 1. Scheme of a product system, which describes the life cycle of the product including all life stages and steps.

Attributes and prospects

The studies conducted in the frame of IEA SHC Task 39 show a lower environmental impact by polymeric collectors compared to traditional collectors like flat plate collectors and evacuated tube collectors [1], [2]. The results indicate a high environmental impact in the production phase especially for the production of raw materials. The environmental impact of plastics is significantly lower than the impact of metals. The influence of the transport is very low compared to the overall environmental impact.

In the implementation of life cycle analysis it must be kept in mind that the results may vary depending on the particular objectives, indicators and assumptions.

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[1] **B. Carlsson, H. Persson, M. Meir, J. Rekstad**, *A total cost perspective on use of polymeric materials in solar collectors – Importance of environmental performance on suitability*, Applied Energy, Volume 125, 2014, p. 10–20. (http://dx.doi.org/10.1016/j.apenergy.2014.03.027)
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[9] http://www.gabi-software.com/

Polymeric solar collectors and recycling

Description:	*Recycling options for polymeric materials* *Recycling of polymeric collectors*
Date:	30.06.2014
Authors:	Michael Feuchter, Polymer Competence Center Leoben Katharina Resch, Montanuniversitaet Leoben
Download possible at:	http://task39.iea-shc.org/publications

Introduction

Today *recycling* is one of the vogue words and heavily used when it comes down to green technology. With the increasing amount of waste, recycling has become one of the key topics in the last years. The waste itself is already an important resource of raw material. The amount of polymeric waste has increased significantly over the last decades. As a consequence different recycling options for polymeric materials arose. Within the following currently used recycling technologies for polymeric materials are outlined. Subsequently challenges and opportunities concerning recycling of polymeric solar collectors are discussed.

Recycling technologies for polymeric materials

Three principal recycling options for all polymeric materials are available: mechanical recycling, chemical (feedstock) recycling, and thermal recycling (energy recovery).

Mechanical recycling is defined by recovering material from waste while maintaining the polymers' molecular structure. This is done via mechanical processes (e.g. grinding, washing, separating, drying, re-granulating and compounding). To reach a win-win situation from an environmental and economic perspective, large amounts of clean not aged and homogeneous polymeric waste is necessary. [1]

Chemical or feedstock recycling tends on recovering the components out of the source material. The used polymer is intentionally degraded to small molecules (feedstock of the material). These molecules can be further used as raw material for the chemical (and plastic) industry. Various processes which can be utilized include chemical depolymerisation, gasification, thermal decomposition (pyrolysis and thermal cracking) and catalytic thermal decomposition as well as reducing agents in blast furnaces. [2]

Thermal recycling can be regarded as the last way out for polymeric waste recycling. This approach is usually used for strong diluted, contaminated, and mixed polymeric waste without any treatment processes. The energy of the polymeric feedstock is recovered and can be used for producing electrical and thermal energy. Due to the material's different chemical composition in a non-homogeneous mixture of waste the incineration process should be equipped with a complex off gas treatment. In this process the polymeric structure material is completely decomposed. [3]

Recycling solar collectors

Studies pointed out that – in contrast to every day used polymeric products like water bottles – polymeric materials and components with operating life-time over 20 years [4] are not captured by the existing waste collecting systems [5]. Thus recycling of polymeric solar collectors might be challenging – also regarding the operating sites spread all over the world (maybe refund systems will work in the future). However, during operation also ageing processes take place and polymers degrade. This leads to different material properties at the end of the product's lifespan. Thus, feedstock recycling (chemical or energetic) might be the preferable option for the recycling of polymeric solar collectors. However, also numerous questions arise, which should be addressed within future Tasks or research projects:

- How is it possible to capture the used solar collectors?
- Is it possible to guarantee a large fraction of homogeneous polymeric waste?
- Which qualities exhibit the discardeded solar collectors?
- To which extent is the polymeric material degraded during operation?

References

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[4] Plastics Architects of modern and sustainable buildings, brochure found at: http://www.plasticseurope.org/documents/document/20121211140948-final_b&c_brochure_111212_web_version.pdf.
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Standards, Certification and Regulations

Description:	*Overview about current standards, certification schemes and regulations regarding solar thermal components and systems*
Date:	11.07.2014
Authors:	Stephan Fischer, Institute for Thermodynamics and Thermal Engineering (ITW), University of Stuttgart, Germany
Download possible at:	http://task39.iea-shc.org/publications

Introduction

To ensure the quality of the products in the rapidly growing solar thermal market, national and international standards for solar collectors, hot water stores and for complete thermal solar systems have been established. In these standards basic requirements for products as well as testing methods for the verification of these requirements are specified. Furthermore, test methods for the determination of the thermal performance are standardised. The target groups of the standards are manufactures and planners as well as testing institutes for thermal solar systems and components.

Based on the standards national and international certification schemes have been developed and put in place to assess the performance and quality of the solar thermal products and to facilitate ranking of the different products by the consumer.

This report gives an overview about the existing standards for testing of solar thermal components and systems as well as the most important certification schemes and gives an outlook about the requirements coming up for solar thermal collectors with respect to the European Construction Product Regulation

Standards

There are European Standards for three different solar thermal technologies: solar thermal collectors (EN 12975 series), factory made systems (EN 12976 series) and custom built systems (EN 12977 series), see Table 1. Part 1 of the standard always lists the general requirements for the product whereas the other parts are related to test methods.

A huge step in international harmonisation of collector test standards was taken 2013 when the EN 12975-2 and the ISO 9806-1, -2 and 3 have been merged to the now valid EN ISO 9806.

Table 1. Standards for solar thermal collector and systems.

Number	**Title**
EN 12975-1	*Thermal solar systems and components-collectors-Part 1: General Requirements*
EN ISO 9806	*Thermal solar systems and components-collectors-Part 2: Test Methods*
EN 12976-1	*Factory made systems – Part 1: General requirements*

EN 12976-2	*Factory made systems – Part 2: Test methods*
EN 12977-1	*Custom built systems – Part 1: General requirements for solar water heaters and combi-systems*
EN 12977-2	*Custom built systems – Part 2: Test methods for solar water heaters and combi-systems*
EN 12977-3	*Custom built systems – Part 3: Performance characterization of stores for solar heating systems*
EN 12977-4	*Custom built systems – Part 4: Performance test methods for solar combi-stores*
EN 12977-5	*Custom built systems – Part 5: Performance test methods for control equipment*

Certification schemes

Solar thermal collectors and systems can be certified according to different certification schemes. A certification demonstrates the compliance of the product with the requirements of the certification scheme. Furthermore valid certification can reduce testing costs since only one test and certification is valid in different countries.

The most relevant certification schemes at present are Solar Keymark (European scheme but also accepted in various countries worldwide, http://www.estif.org/solarkeymarknew/), SRCC (North American scheme, http://www.solar-rating.org/), Golden Sun (Chinese scheme, http://www.cgc.org.cn/eng/).

At present the harmonisation of the existing certification schemes is aimed to introduce a Global Solar Certification (http://task43.iea-shc.org/) to achieve one test and one certification excepted worldwide. This is expected to be in place within 2015.

Regulations and directives

In the context of the European Union (EU) certain products have to fulfil certain requirements. These requirements are described in European regulations and directives respectively. Relevant regulations and directives for solar thermal collectors and systems are:

Construction products regulation, solar thermal collectors only
(http://ec.europa.eu/enterprise/sectors/construction/legislation/index_en.htm)

Ecodesign directive (http://ec.europa.eu/enterprise/policies/sustainable-business/ecodesign/)

Energy labelling directive (http://ec.europa.eu/energy/efficiency/labelling/labelling_en.htm)

The EU formulates so called mandates to convert these regulations and directives into national law, which require the harmonisation of European Standards with the European directives and regulations.

At present the relevant standards listed in Table 1 are under revision to be harmonised with the above mentioned directives and regulations.

TASK39

SHC
SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

Architecturally appealing solar thermal systems

- A marketing tool in order to attract new market segments

Description:	Online database consisting of showcases where solar thermal energy systems have been successfully integrated into the architecture
Date:	2014-07-15
Authors:	Ingvild Skjelland, Aventa AS
Download possible at:	http://projects.iea-shc.org/task39/projects/default.aspx

Intro

Architectural integration is a major issue in the development and spreading of solar thermal technology. Unfortunately, the architectural quality of integrated solar thermal systems in many existing buildings is poor, which often discourages potential new users. Because solar thermal systems are relatively large in relation to the building envelope, the architectural quality of their integration has a major impact on the visual quality of the building. This should, together with the fact that public acceptance of solar energy to a high extent depends on the quality of the architectural integration, stimulate and motivate a much stronger focus on making solar thermal systems visually appealing– something people really would want to put on their houses and something architects would want to implement in their design of new buildings.

Project presentations

As contribution from IEA-SHC Task 39 to the challenge of making solar thermal systems more desirable, a database consisting of showcases where solar thermal energy systems have been successfully integrated into the architecture has been established - as a source of inspiration for architects and others [1]. The database presents a broad range of buildings divided into four different categories: Single-family houses, multi-family houses, institutional and commercial buildings.

An experts group (architects and solar thermal engineers) evaluated incoming project proposals and selected the best examples. A short, easy to fill in questionnaire was used for collecting relevant information like general project data, type of solar heating system, collector area, auxiliary heating, type of heat store etc., estimated pay back time and collector description.

Project presentations as pdf-files – 3-4 pages

Architecturally appealing solar thermal systems

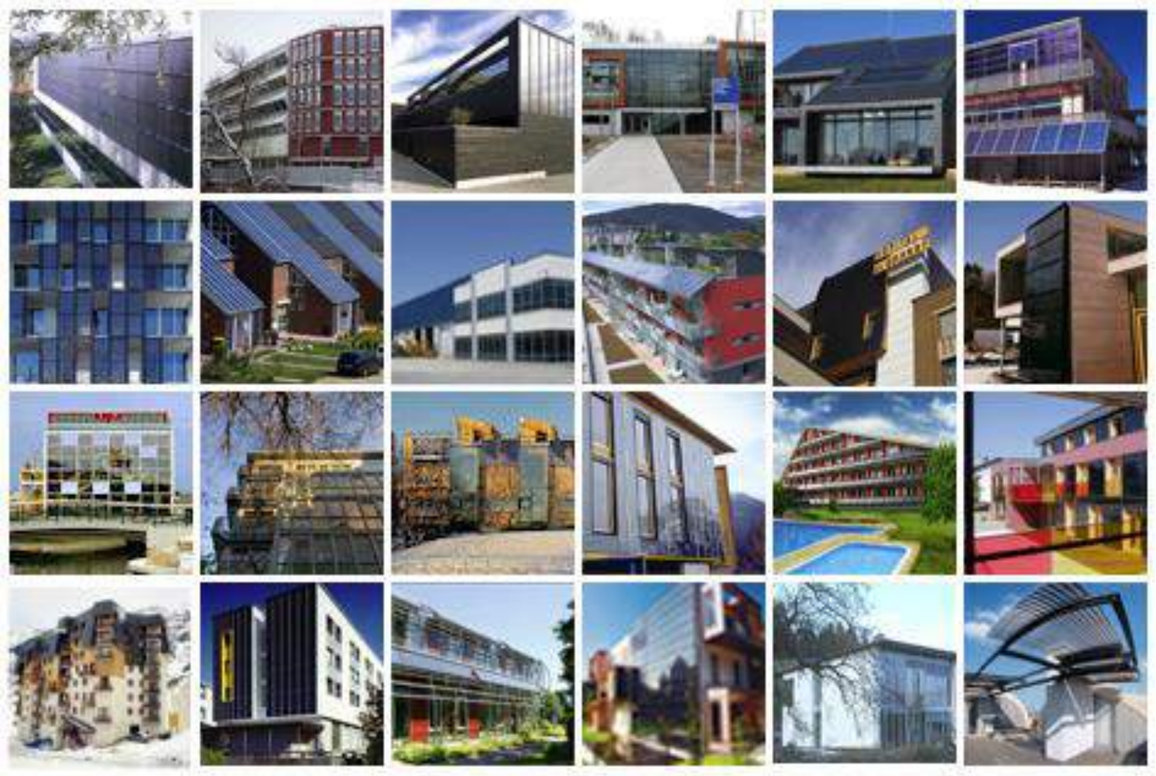
- A marketing tool in order to attract new market segments

Architectural integration from a marketing perspective

The appearance of a product certainly counts in making a first impression on a customer and often plays a decisive role in the final decision to buy or not. Effective use of design and high visual quality adds value to the product and builds trust and confidence. Attractive design also helps in differentiating between competing products.

When it comes to solar thermal systems, the collector design is only one part of the final product. Placement of the collector field and good architectural integration is more important for the final result that will be judged by the public. The database consists of 41 project presentations of buildings where solar heating systems have been successfully integrated in the architecture – giving added value to each building.

Suggestions for further reading [2, 3].



References

[1] Database with architecturally appealing solar thermal systems: **http://www.iea-shc.org/task39/projects/**

[2] I. Skjelland. Architecturally appealing solar thermal systems – a great marketing tool in order to attract new customers and market segments. In Proceedings: EUROSUN 2010 Conference, Gleisdorf, Austria, Sept. 28-Oct. 01, 2010.

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Performace requirements (general)

Description:	*Performance requirements at reference sites and applications*
Date:	2014
Authors:	T. Ramschak, D. Preiß / AEE INTEC, Gleisdorf, Austria
Download possible at:	http://task39.iea-shc.org/publications

Intro

A crucial aspect of using polymeric materials in solar thermal systems is the exact knowledge about the occurring loads especially for temperature and pressure changes. The limited thermal property in various polymers in comparison to the present primarily used materials (copper, aluminum or glass) in reference systems makes it inevitable to determine load profiles. In the framework of the national project SolPol investigations were made to create temperature and pressure load matrices for the main components of solar thermal systems. To achieve a broad knowledge-base, different applications (domestic hot water in single and multifamily houses, combi-systems) and systems concepts for the main climate zones of the world have been investigated. Furthermore, modified polymeric solar thermal systems with overheat protection (backcooling, ventilation, thermotropic layer) and without overheat protection (drain-back, thermosiphon) have been examined. Extended simulations form the basis to deliver load profiles for solar thermal systems based on polymeric materials. Building on the results (system efficiency) derived from reference systems, the accompanying INFO Sheets B2: "Thermal stress" and B3: "Pressure stress" give an overview about the performance requirements for the materials which will be investigated.

Reference sites and applications

Five reference sites with existing potential and intensified solar thermal market activities have been identified to generate a wide range of system loads as a result of different climate conditions: continental, mediterranean, hot and dry, tropical and moderate. The dimensioning of the reference systems was determined by the collector area which is in line with the market and the climate conditions (see Table 1).

Table 1: Summary of the climatic conditions at the selected locations; applications as well as the dimensions of the reference solar thermal systems (gross collector area) correspond to the chosen site; DHW…domestic hot water, SFH…single-family house, MFH…multi-family house; datasource: Meteonorm(test) 6.1

	climatic conditions			**gross collector area [m²]**			
site / climatic zone	accumulated global radiation (horizontal) [kWh/m²a]	ambient temperature min [°C]	ambient temperature max [°C]	DHW-SFH, pumped	DHW-SFH, thermo siphon	Combi-System-SFH, pumped	DHW-MFH, pumped
Central Europe (Graz) / continental	1160	-12	33	6,6	-	18	44
South Europe (Athen) / mediterranean	1610	2	38	-	3,8	17	42
Africa (Pretoria) / hot, dry	2050	1	34	-	2,5	-	38
Brazil (Fortaleza) / tropical	2030	22	33	-	2,4	-	22
China (Peking) / moderate	1480	-14	38	-	4	18	50

Thermal loads in one reference system

Determination of load profiles prerequisites an overall consideration of the whole solar thermal system. Figure 1 shows the temperature load profiles from different system components derived from a typical reference system in Graz (Austria) as a representative location in Central Europe. The solar thermal system provides domestic hot water and supports space heating. The temperature in the hot water storage tank is limited to a maximum value of about 90 °C by the controller. Especially during summer month, temperatures above 200 °C can be reached at the surface of a selective coated absorber in the state of system stagnation. This implies that several technological challenges have to be met prior to the use of polymeric materials in solar thermal systems. This includes active overheat protection (backcooling, ventilation, thermotropic switching) and passive overheat protection (thermosiphon systems) for commodity plastics as well as “drain-back” solutions for engineering and high performance polymers.

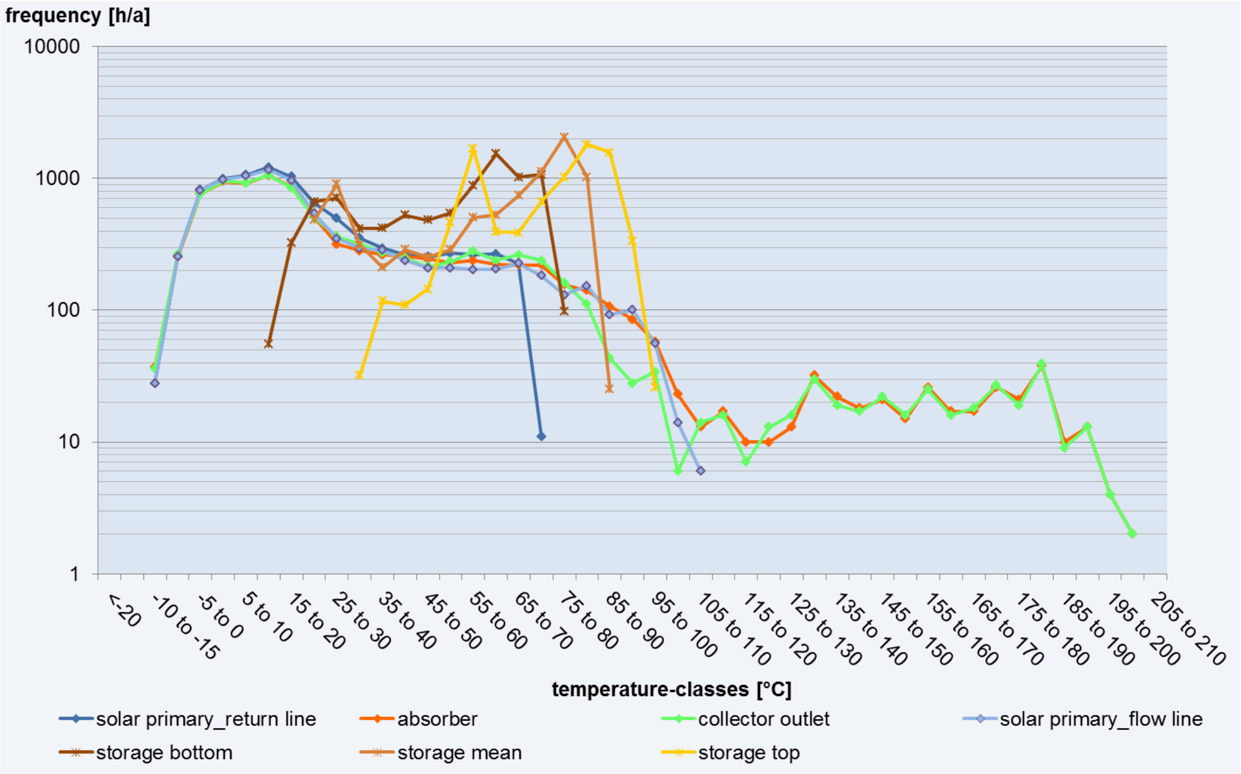

Figure 1: Frequency (log scale) of the occurring thermal loads on different system components; reference combi-systems single family houses in Central Europe (Graz) with selective metal absorber.

References

Kaiser A., Hausner R., Ramschak T., Streicher W. (2013) Leistungsanforderungen an Polymermaterialien in solarthermischen Systemen, EE-Zeitschrift für eine nachhaltige Energiezukunft 2013-1:12-16, Gleisdorf, Austria

Performance requirements (thermal stress)

Description:	*Thermal stress in polymeric solar thermal collectors*
Date:	2014
Authors:	T. Ramschak, D. Preiß / AEE INTEC, Gleisdorf, Austria
Download possible at:	http://task39.iea-shc.org/publications

Intro

Solar thermal systems that reach the stagnation state will overheat, resulting in high temperature and pressure loads for the collector and the surrounding components. Depending on how well these loads can be limited without reducing the efficiency in normal operation, determines whether high performance polymers or low-cost engineering or commodity plastics can be used.

Thermal stress in solar thermal collectors with and without overheating protection

In the case of collectors based on polymeric materials with overheating protection (OHP), the thermal loads will be reduced by a controlled increase of the heat- or optical losses by either backcooling, ventilation, thermotropic switching or in the case of thermosiphon systems by hydraulic circuits that are open to the atmosphere. All these methods should keep the collector temperature below the critical temperature of about 95 °C (max. 100 °C) during stagnation. In the other case a drain-back system provides for the automatic emptying of the collector and piping when the system is turned off. The circulation pump shuts itself down and the water drains by gravity to the drain-back tank which can be open to the atmosphere. By means of such drain-back systems collector overheating can´t be avoided but the correlated pressure loads are reduced or waived entirely. The pressure progression can be looked up in the accompanying INFO Sheet “Pressure stress”.

Figure 1 depicts the simulated mean absorber temperature frequency of the reference systems and solar thermal systems based on polymeric materials with OHP (backcooling) and without OHP (drain-back) for a single-family house in Central Europe by varying applications. In the reference system the maximum achieved temperatures during stagnation reaches 195 °C. The temperature in the drain-back systems reached a maximum level of 165 °C due to the nonselective coated polymeric absorber. The systems with an active OHP are limited to 90 °C. Figure 2 represents a cross-section of the mean absorber temperature frequency per year through the simulated polymeric systems with and without OHP for different applications and systems concepts in various locations. The lower limits of the temperature profiles are mainly determined by climate conditions, whereas the upper limits additionally depend on the collector properties and concepts as well as on the heat demand. The maximum temperature in thermosiphon systems is limited to system design and due to the fact of an inherent mains water supply and of course the user behavior (hot water tap profiles).

The performance requirements (thermal-pressure stress) for the reference and polymeric systems are summarized and displayed in a convenient matrix format in the INFO Sheet “Pressure stress”.

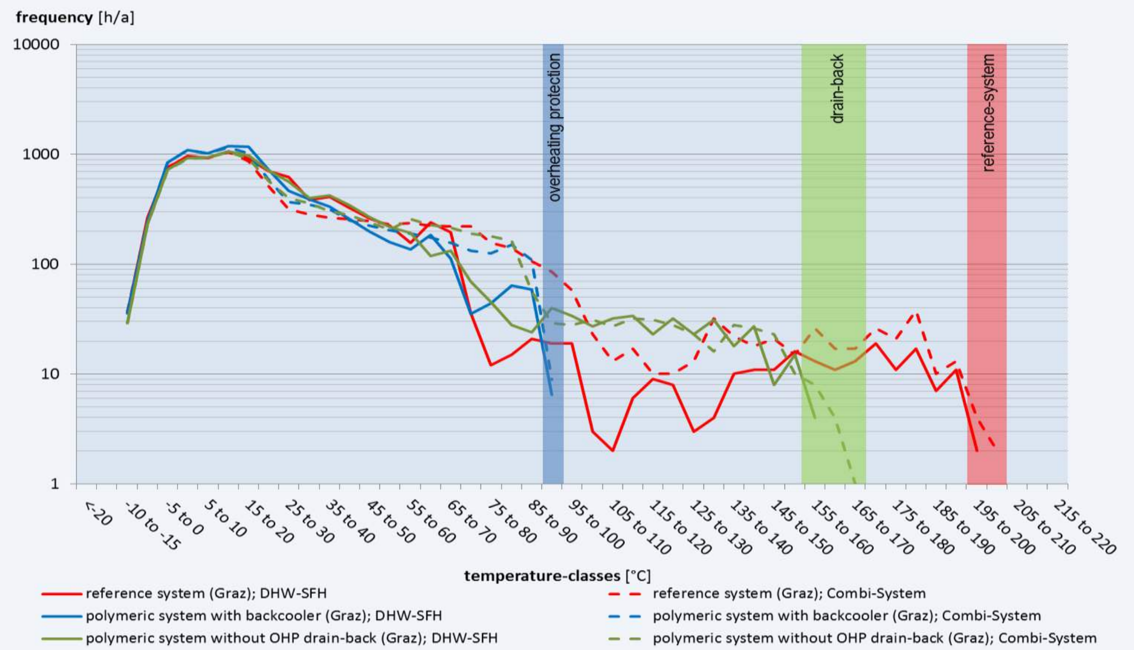

Figure 1: Frequency (log scale) of the mean absorber temperatures of polymeric collectors with OHP (backcooler; blue), without OHP(drain-back; green), and the reference collector (red) in varying applications (domestic hot water; combi systems) for single family houses in Central Europe (Graz, Austria)

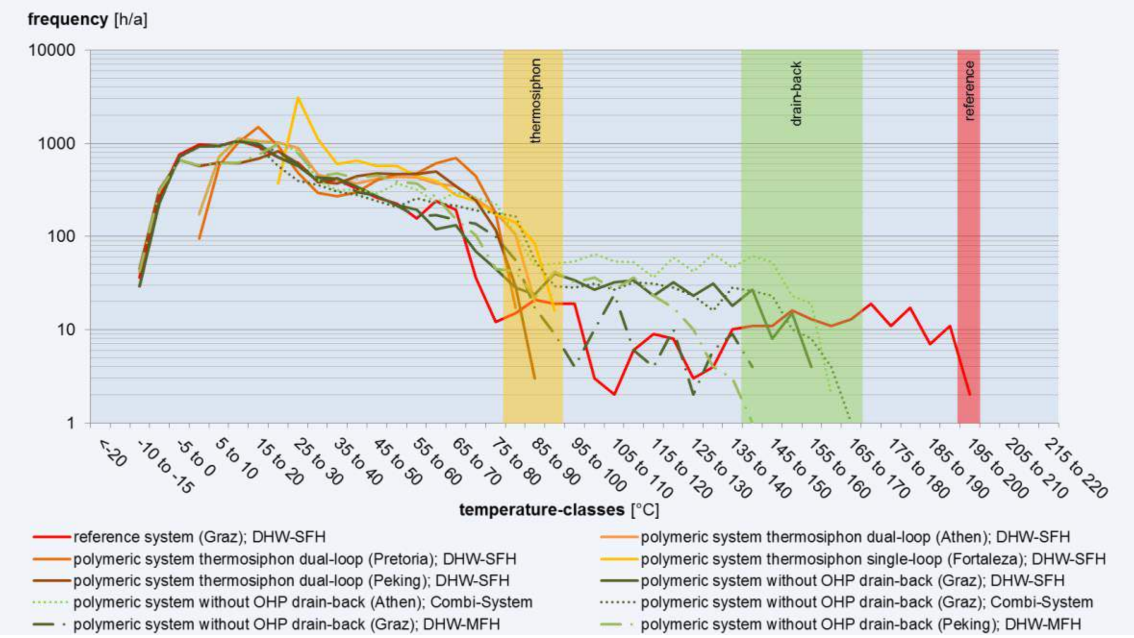

Figure 2: Frequency (log scale) of the mean absorber temperatures of polymeric collectors with OHP (thermosiphon; yellow), without OHP (drain-back; green), and the reference collector (red) in varying climate zones and applications (domestic hot water; combi-systems) for single- and multifamily houses.

References

Kaiser A., Hausner R., Ramschak T., Streicher W. (2013) Leistungsanforderungen an Polymermaterialien in solarthermischen Systemen, EE-Zeitschrift für eine nachhaltige Energiezukunft 2013-1:12-16, Gleisdorf, Austria

Performance requirements (pressure stress)

Description:	*Pressure stress in polymeric solar thermal collectors* *Temperature-pressure matrix*
Date:	2014
Authors:	T. Ramschak, D. Preiß / AEE INTEC, Gleisdorf, Austria
Download possible at:	http://task39.iea-shc.org/publications

Intro

Conventional system behaviour during stagnation is well understood and measures to handle this state are known. Nevertheless for economically priced polymer collectors stagnation will be a considerable challenge caused by the high temperature and pressure stress during standstill times of the solar system. In closed systems the pressure development is directly related to the temperature development. Therefore measures to overcome this disadvantage have already been mentioned in the accompanying INFO Sheet B2: “Temperature stress”. Open drain-back systems offer the ability to reduce the pressure stress.

Pressure stress in solar thermal collectors with and without overheating protection

Figure 1 depicts the frequency of the calculated pressure stress for the reference- and polymeric systems with overheating protection (OHP) with backcooler and without OHP as drain-back solution for the application domestic hot water in single-family houses at five reference sites (see INFO sheet “Performance requirements (general)”).

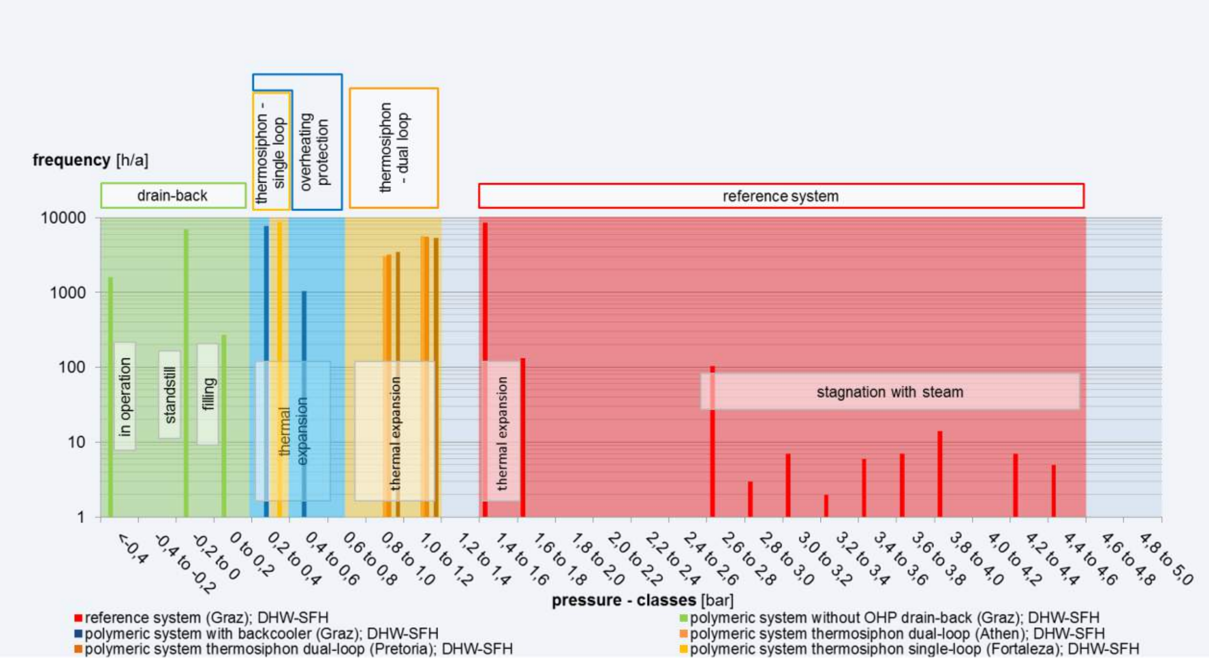

Figure 1: Frequency of pressure stress of polymeric- and reference absorbers for the application “domestic hot water” in single family houses at various sites (excess pressure).

Performance requirements (pressure stress)

In the closed reference systems (red area) the pressure development depends on different facts: temperature, stagnation behavior of the solar loop and the dimension of the expansion vessel. In systems with active overheating protection (blue area) and dual-loop thermosiphon systems (brown area) evaporation doesn´t take place, so the maximum pressure depends on the thermal expansion of the heat transfer medium. The maximum occurring pressure in atmospheric single-loop thermosiphon systems (yellow area) is corresponding to the geodetic height difference between the storage and the collector. Due to the automatic emptying of the collector and piping in drain-back systems (green area), evaporation can be almost completely avoided. The maximum occurring pressure takes place during the filling process (geodetic height of the collector approx. 2 m). However, during operation there will be a negative pressure caused by the suction effect (geodetic height difference between collector and drain-back tank) of the flow pipe.

The following matrix (Table 1) summarizes the temperature- and pressure stress levels of the regarded solar thermal systems in the INFO Sheets "Reference systems", "Thermal stress" and "Pressure stress". The frequencies of the temperature have been summarized to larger temperature classes. The corresponding values of the pressure are in the same column.

Table 1: Pressure and temperature matrix (more precise data are available on request)

		frequency [h/a]								pressure min [bar abs.] pressure max [bar abs.]							
application ↓	*temperature classes* →	<0 [°C]		0 to 75 [°C]		75 to 100 [°C]		100 to 125 [°C]		125 to 150 [°C]		150 to 175 [°C]		175 to 200 [°C]		>200 [°C]	
Domestic hot water - SFH	reference system pumped; (Graz)	1059	2,46 2,47	7431	2,47 2,61	86	2,61 2,67	25	2,68 2,74	39	2,74 3,88	72	3,70 4,72	48	3,70 5,45	0	- -
	polymeric system without OHP; drain-back (Graz)	978	0,60 1,14	7337	0,60 1,14	171	0,60 1,14	148	1,00 1,00	107	1,00 1,00	19	1,00 1,00	0	- -	0	- -
	polymeric system with OHP; backcooler (Graz)	1125	1,27 1,31	7462	1,29 1,51	173	1,49 1,57	0	- -	0	- -	0	- -	0	- -	0	- -
	polymeric system thermosiphon; dual-loop (Pretoria)	0	- -	8564	0,98 1,08	196	1,08 1,09	0	- -	0	- -	0	- -	0	- -	0	- -
	polymeric system thermosiphon; single-loop (Fortaleza)	0	- -	8347	1,40 1,40	413	1,40 1,40	0	- -	0	- -	0	- -	0	- -	0	- -
	polymeric system thermosiphon; dual-loop (Peking)	1021	0,97 0,97	7589	0,98 0,98	150	1,08 1,09	0	- -	0	- -	0	- -	0	- -	0	- -
	polymeric system thermosiphon; dual-loop (Athen)	0	- -	8456	0,98 1,08	304	1,08 1,09	0	- -	0	- -	0	- -	0	- -	0	- -
Combi system - SFH	reference system pumped; (Graz)	1054	2,68 2,69	6791	2,69 2,76	547	2,76 2,79	73	2,79 2,83	106	2,83 4,43	101	4,25 5,40	86	4,25 5,40	2	4,25 4,25
	polymeric system without OHP; drain-back (Graz)	970	0,60 1,14	7047	0,60 1,14	455	0,60 1,14	149	1,00 1,00	116	1,00 1,00	23	1,00 1,00	0	- -	0	- -
	polymeric system with OHP; backcooler (Graz)	1123	1,26 1,29	7243	1,29 1,54	394	1,53 1,61	0	- -	0	- -	0	- -	0	- -	0	- -
	polymeric system without OHP; drain-back (Athen)	0	- -	7697	0,60 1,14	484	0,60 1,14	267	1,00 1,00	268	1,00 1,00	44	1,00 1,00	0	- -	0	- -
Domestic hot water - MFH	polymeric system without OHP; drain-back (Graz)	975	0,60 1,14	7524	0,60 1,14	186	0,60 1,14	54	1,00 1,00	21	1,00 1,00	0	- -	0	- -	0	- -
	polymeric system without OHP; drain-back (Peking)	1007	0,60 1,14	7413	0,60 1,14	183	0,60 1,14	139	1,00 1,00	18	1,00 1,00	0	- -	0	- -	0	- -

References

Kaiser A., Hausner R., Ramschak T., Streicher W. (2013) Leistungsanforderungen an Polymermaterialien in solarthermischen Systemen, EE-Zeitschrift für eine nachhaltige Energiezukunft 2013-1:12-16, Gleisdorf, Austria

Thermal loads at components of state-of-the-art flat-plate collectors

Date:	*30.9.2014*
Description:	*Overview on thermal loads on components of standard flat-plate collectors in an one year lasting field-test as a basis for overheating protection and material selection for polymeric collector development*
Author:	Dipl.-Ing. (FH) Christoph Reiter; christoph.reiter@thi.de
Co-author(s):	Dr. Sebastian Brandmayr, Dr. Christoph Trinkl, Prof. Dr.-Ing. Wilfried Zörner Technische Hochschule Ingolstadt Institute of new Energy Systems (InES)
Available languages:	*English*
Download possible at:	http://task39.iea-shc.org/

Contents

Introduction

Apart from the maximum absorber temperature according to DIN EN ISO 9806 (2014), the thermal loads inside solar-thermal collectors are widely unknown. However, the use of cost-effective polymers requires a detailed knowledge about the thermal conditions the collector components are facing. Therefore, a conventional solar-thermal system integrated in a four person one-family house was analysed in a field-testing (cf. Reiter et al. 2010). The house was equipped with a solar hot water and space heating system with 20 m^2 of standard flat-plate collectors. The measurement data were analysed in detail regarding the following aspects:

- Maximum temperatures at the collector components
- Dynamic behaviour of thermal loads
- Accumulated temperature exposition times

The latter are an essential basis for polymeric material selection and development, a prediction of material property changes over the expected life time and an adoption of solar-thermal systems and collector design to polymer requirements.

Measurement Equipment

Measurement equipment was applied to both the system and one collector in order to specify the thermal and pressure loads on the collector at casing, absorber, glazing and insulation in detail. Furthermore, a dry collector without connection to the solar-thermal system was installed to refer to maximum loads during continuous stagnation. Table 1 shows the parameters of the investigated collectors.

Parameter	Symbol	Value	Unit

Optical efficiency	η_0	0.798	-
Linear heat loss coefficient	a_1	3.34	W/(m²K)
Quadratic heat loss coefficient	a_2	0.0075	W/(m²K²)
Heat capacity of the collector	C	9.5	kJ/K

Table 1. Parameters of the investigated state-of-the-art collector

Figure 1 shows a part of the tested collector array and exemplary temperature sensors applied at the frame of the collector. In Reiter et al. 2011 the measurement equipment and the sensor positions are described in detail.

Figure 1. Field-testing of collectors (left) and exemplary temperature measurement equipment at a collector casing (right; Reiter et al. 2012)

Annual Field-Testing Results

In the following, measurement results of one year (Jan. 2009 to Dec. 2009) are analysed in histograms with a class width of 10 K (Figure 2). In order to provide a more detailed overview on periods at high temperatures, the vertical axis is limited to 500 h, so that the comparably long durations at low temperatures, e.g. during night, are not shown. Furthermore, it has to be considered, that technical problems with the data acquisition led to 10 missing measurement days in March and 19 missing days in June.

The absorber in the system reached temperatures up to 140 °C while operation and during stagnation temperatures up to 192 °C. These high temperatures were measured at the upper part of the collector near the outlet. Despite the relatively large collector area, the solar-thermal system rarely was in stagnation, as the radiators in the basement of the house were used to avoid stagnation by cooling the buffer storage.

To measure the hottest spot of the dry absorber the sensor was positioned in the centre point of the component, where a maximum temperature of 208 °C was recorded. During the measurement period shown, the absorber stayed more than 1,100 h above a temperature level of 95 °C as shown in Figure 3.

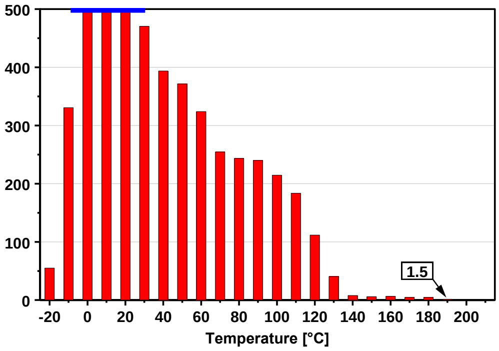

Figure 2. Temperature histogram of the absorber fin (collector in the system; Reiter et al. 2012)

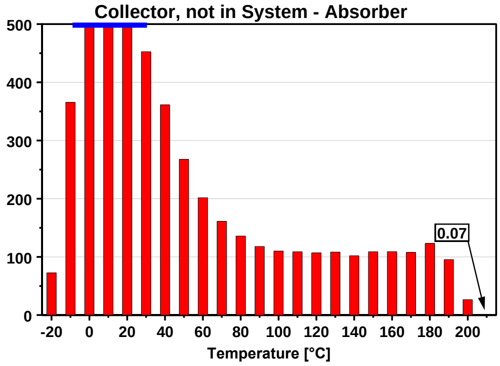

Figure 3. Temperature histogram of the absorber fin (dry collector; Reiter et al. 2012)

The temperature of the transparent cover was measured with a shaded, bonded sensor at the inner surface in central position for both collectors. At the glazing of the collector in the system, temperatures above 55 °C mainly occurred during the system stagnation (Figure 4). The maximum temperature was 82 °C. However, the temperature load is on an uncritical level for a wide variety of potential transparent cover sheet materials.

As was anticipated, the cover of the dry collector showed a significantly higher temperature level than the collector in operation (Figure 5). The surface temperature of this component was above 55 °C for 585 h in the considered measurement period. The maximum temperature lay at 86 °C, also an uncritical level for most polymeric cover sheet materials.

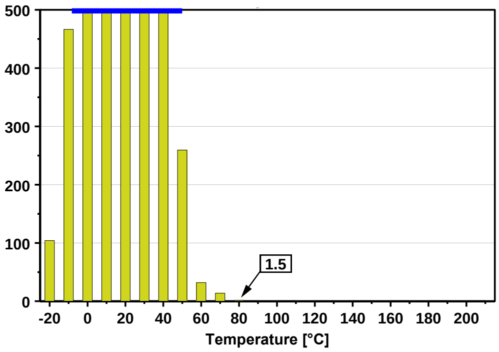

Figure 4. Temperature histogram of the glazing (collector in the system; Reiter et al. 2012)

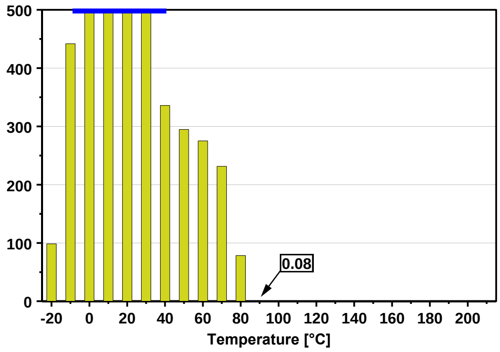

Figure 5. Temperature histogram of the glazing (dry collector; Reiter et al. 2012)

For the investigation of the frame temperatures, several sensors were positioned on the inner surface of the aluminium frame by rivets, outside the collector insulation. The sensor used for the analysis of the collector in the system was located at the upper side of the collector near the outlet (cf. Figure 1; right picture). The temperature sensor in the dry collector was positioned central at the upper part of the frame.

The maximum temperatures of both collectors measured by these sensors were below 80 °C. The frames mostly reached temperatures below 65 °C. Figure 6 and Figure 7 show the limited thermal loads on the housings. Hence, the temperature of the casing already fulfills the thermal requirements of commodity plastics.

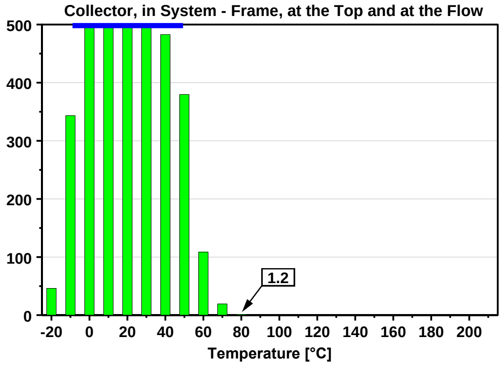

Figure 6. Temperature histogram of the frame (collector in the system; Reiter et al. 2012)

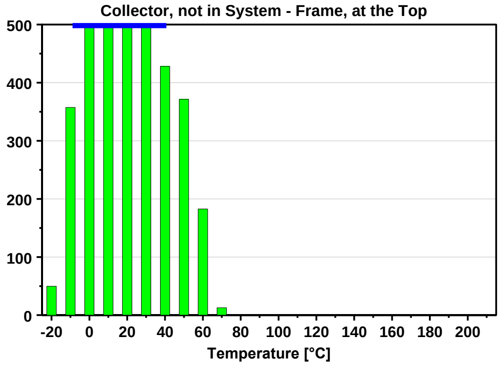

Figure 7. Temperature histogram of the frame (dry collector; Reiter et al. 2012)

Detailed Field-Testing Results

Apart from the maximum collector temperature, the dynamic behaviour of the components is of major interest. On the one hand, rapid temperature changes must be considered in the collector design, due to different linear thermal expansion of components and materials. On the other hand, the response time for temperature reducing measures in the solar-thermal system can therewith be estimated.

Figure 8 demonstrates the outstanding dynamic behaviour of the dry absorber in comparison to the moderate response of the casing. The temperature of the absorber increased by 125 K (09:30–10:45 a.m.) and decreased by 121 K (10:45–12:00 a.m.) in only 2.5 hours. During cooling down, short sunshine periods between 11:00–11.30 a.m. caused further significant rises of the absorber temperature. The temperature of the casing increased from 12 °C up to only 35 °C, while the ambient air temperature was between 9 °C and 14 °C.

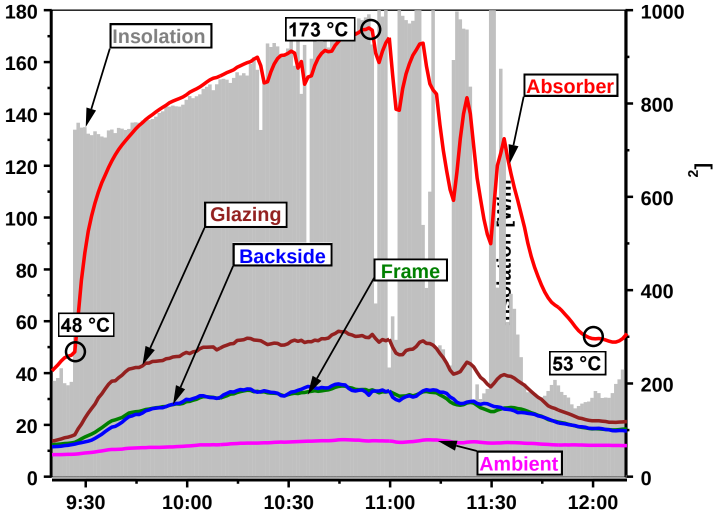

Figure 8. Temperature profile of the dry collector in September (Reiter et al. 2012)

There is also high absorber dynamics at ambient temperatures near to freezing point in winter. The temperatures of the components of the dry collector were below 5 °C (10:45 a.m.). After clearing up of the sky, the absorber temperature increased by 140 K in 45 minutes whereas the glazing temperature increased only by 45 K (Figure 9). Especially at low ambient temperatures, there is a large difference between thermal behaviour of the absorber and the housing which have to be considered in the collector design.

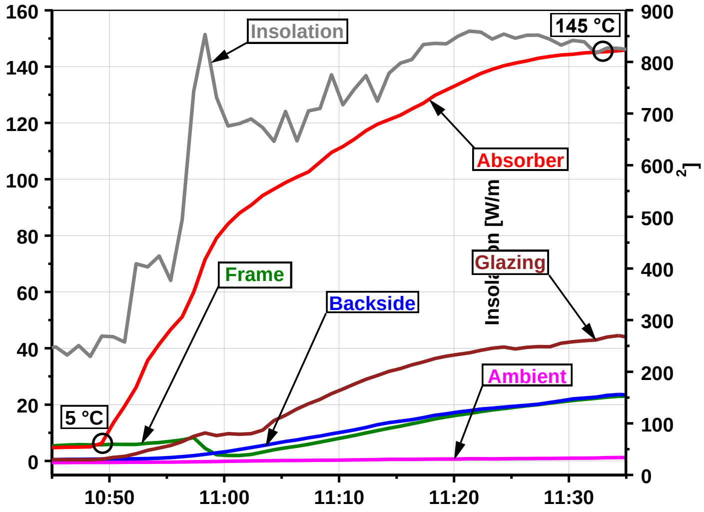

Figure 9. Temperature profile of the dry collector in winter (December)

Summary

In summary, the field-testing measurements show that the specification for the material selection has to be based on the thermal loads of each single collector component. The common maximum absorber temperature from certification measurements is not an adequate approach for the determination of the thermal loads on the collector. The measured data from field-testing clearly show that temperatures at the glazing and at the casing do not represent major obstacles for cost-effective polymers, even in highly efficient state-of-the-art collectors. The absorber and the insulation have to withstand remarkable thermal loads and are subject to considerable temperature fluctuations. Therefore, temperature limiting approaches and suitable component designs for polymeric collector development are needed.

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Overheating protection

Description:	*Summary of approaches to reduce critical thermal loads on collector components to enable the usage of cost-effective polymeric materials*
Date:	20.05.2014
Authors:	Dipl.-Ing. (FH) Christoph Reiter, Dr. Sebastian Brandmayr, Dr. Christoph Trinkl, Prof. Dr.-Ing. Wilfried Zörner Technische Hochschule Ingolstadt Institute of new Energy Systems (InES)
Download possible at:	http://task39.iea-shc.org/publications

Introduction

In order to enable the usage of cost-effective polymeric materials in flat-plate collectors, approaches to control and reduce the absorber temperature are necessary.

Principles for Overheating Protection Measures

Overheating protection measures are characterized by changing the collector performance when critical thermal loads occur. There are two basic approaches that need to be differentiated: the reduction of the optical efficiency and the increase of excess thermal energy removal.

A reduction of the optical efficiency can be either achieved by transmitting less solar radiation through the front side or alternatively by a lower heat conversion at the absorber surface. Therefore, these measures change the effective transmission-absorption product. Figure 1 shows the potential mechanisms that can reduce the optical efficiency of a collector.

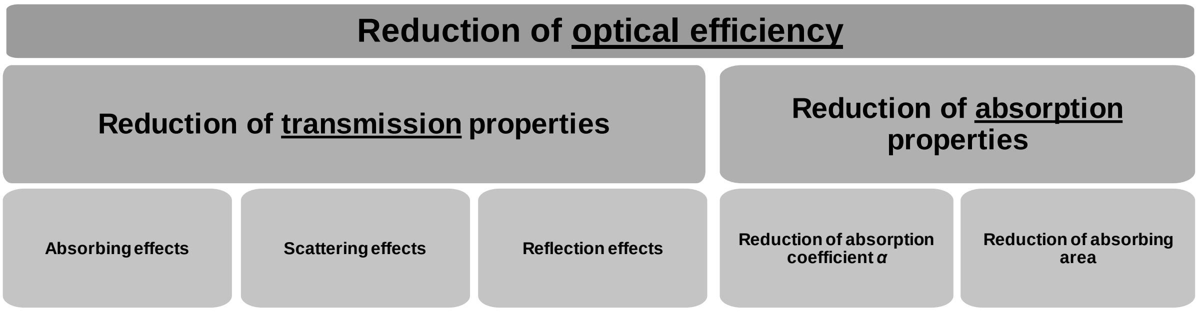

Figure 1. Overview of mechanisms reducing the optical efficiency (according to Reiter et al. 2012)

In addition to these measures, the removal of excess thermal energy is a further option, which could be realized either by increased thermal losses of the solar collector or by active cooling. Figure 2 shows the various modes of removal of thermal energy which can be applied in the collector or in the solar-thermal system.

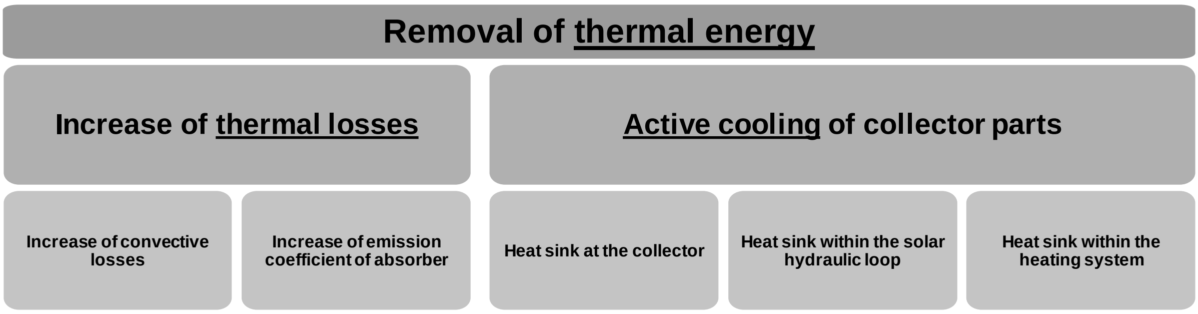

Figure 2. Overview of mechanisms and solutions for the removal of excess thermal energy (according to Reiter et al. 2012)

Adjustment of the Collector Efficiency

Beside active or passive measures to control the performance of the collector and the component temperatures, lowering the collector efficiency provides relevant potential for overheating protection. The efficiency reduction by increased losses can be divided into two effects. On the one hand, there are constant losses caused by the transmission properties of the glazing and the absorption properties of the absorber. On the other hand, there are temperature dependent thermal losses caused by convection, conduction and radiation.

In order to adjust the efficiency, the collector performance is to be reduced with regard to the overall system yield. During system operation, the efficiency of such a collector must therefore be close to a conventional collector and should strongly decrease at higher collector temperatures.

As a second aspect for the efficiency adjustment, the collector manufacturing costs also need be taken into consideration. Due to the lowered solar yield of the polymeric system, the collector cost reduction has to compensate the efficiency reduction when competing with metal based collectors.

By means of those requirements, efficiency reduction has to be realized by omitting manufacturing steps or by saving material. The most effective approach is using a black pigmented absorber material instead of a selective absorber coating. The second possibility to simplify the manufacturing process is to leave the insulation out. Besides that, innovative casing designs made of polymeric foam — combining standard casing and insulation functions — are very promising.

References

REITER, C. and TRINKL, C. and ZÖRNER, W. (2012) Thermal Loads on Solar Collectors and Options for their Reduction. In: KOEHL, M. et al. (eds.) *Polymeric Materials for Solar Thermal Applications*. 1st ed. Weinheim (GER): Wiley-VCH Verlag GmbH & Co. KGaA.

Collector Overheating Protection with Backcooler

Description:	*Collector Overheating Protection with Backcooler*
Date:	July 30th, 2014
Authors:	Alexander Thür, Claudia Hintringer, Norbert Hauer, Wolfgang Streicher (University of Innsbruck), Robert Hausner, Alexander Kaiser (AEE INTEC), Roland Riepl (Greiner Technologies), Gernot Wallner (IPMT-JKU)
Download possible at:	http://task39.iea-shc.org/publications

Introduction

Within the Austrian project SolPol-2 (www.solpol.at) the concept of a flat plate collector which completely can be produced with cheap plastic (max. temperature 90°C) with integrated overheating protection was investigated and functional models were developed, constructed and tested. The principle concept is shown in the figure 1:

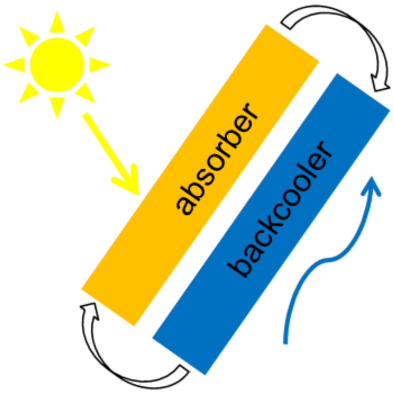

Figure 1: Principle of overheat protection via thermosyphonal backcooling.

In case of risk of overheating a special valve is opening the connection from absorber to the backcooler and due to the solar irradiation on the absorber and the cooling effect at the backside at the backcooler a thermosyphon driven cooling flow occurs.

Test Results

In several steps functional model collectors were developed, constructed and tested. For the absorber black-pigmented polypropylene grades were used. In figure 2 left selected model collectors (small and large) are depicted. Performance tests and stagnation tests were performed at different test facilities. In figure 2 right the efficiency curve of a model collector is presented.

In figure 3 a stagnation test shows the potential of the cooling effect. Without backcooling (until 12:30) the absorber temperature increases up to 115°C and still did not reach the maximum. After activating the backcooling system the absorber temperature dropped to about 85°C at about 950 W/m^2 solar irradiation and about 20°C ambient temperature.

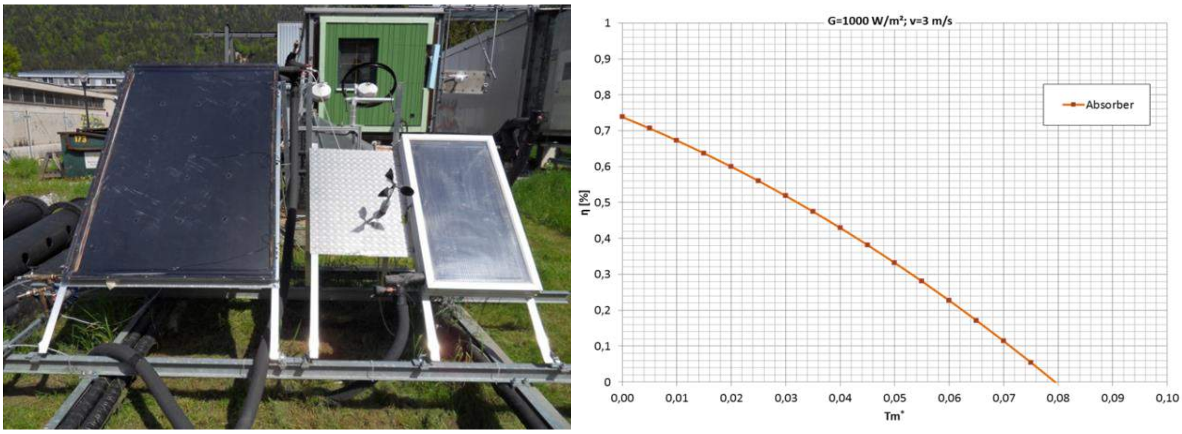

Figure 2: left: Functional model collectors at the outdoor test facility; right: measured efficiency curve of the large collector.

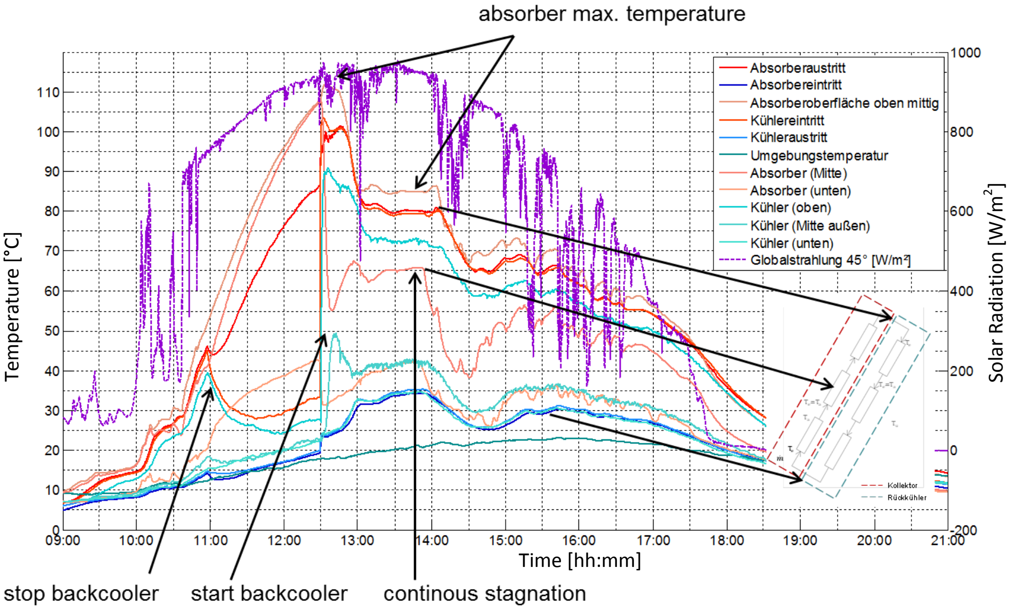

Figure 3: Stagnation test showing the potential of temperature limitation at the absorber.

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Thür, A., Hintringer, C., Richtfeld, A., Streicher, W., Kaiser, A., Hausner, R., Fink, C., Koller, W., Riepl, R., (2013), Status Quo der Entwicklung eines überhitzungsgeschützten Kunststoffkollektors, erneuerbare energie ee1-13, Gleisdorf.

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Overheating protection by thermotropic layers

Description:	*Material simulation and modeling* *Material and process development*
Date:	30.06.2014
Authors:	Katharina Resch, Montanuniversitaet Leoben Andreas Weber, Polymer Competence Center Leoben Dieter P. Gruber, Polymer Competence Center Leoben
Download possible at:	http://task39.iea-shc.org/publications

Introduction and scope

In recent years thermotropic overheating protection glazings are in focus of interest both, in solar thermal collector technology and architectural design of buildings. A thermotropic glazing changes its light transmittance from highly transparent to light diffusing upon reaching a certain threshold temperature autonomously and reversibly [1, 2]. Among different thermotropic systems, especially thermotropic systems with fixed domains (TSFD) are considered to have the highest potential for practical application [3, 4]. In TSFD scattering domains are embedded in a polymer matrix, which exhibit a sudden change of the refractive index upon reaching the threshold temperature. At low temperatures the layer is translucent, as the refractive indices of matrix and domain are almost equal. If the difference of the refractive index of both components increases due to warming up to a determined temperature (switching threshold) the thermotropic film turns opaque [1, 3, 5]. However, the overheating protection performance of TSFD produced so far is limited and only moderate light shielding efficiency was achieved [4, 6, 7]. Thus, within the scientific research project “Smart Windows – Smart Collectors: Development, Modeling and Application Demonstration of Overheating Protection Glazings for Facades and Solar Thermal Collectors” (funded by the State Government of Styria, Department Zukunftsfonds (project number 5019)) a systematic investigation of the effects of the refractive index difference, scattering domain parameters and the layer thickness on the overheating protection performance of TSFD was carried out on the one hand. Aim was to evaluate the theoretical light shielding potential of TSFD. Based on assessed ideal material parameters TSFD were developed, characterized and optimized systematically based on sound polymer physics on the other hand.

Theoretical modeling of light-shielding efficiency of TSFD

Light shielding characteristics and potential of TSFD were studied by applying simulation of light scattering in particle filled layers. In random walk simulations numerous parameters were varied systematically and the effect on the light transmittance of TSFD was studied. Parameters included index of refraction of both the matrix material and the scattering domain, concentration of the scattering domains, and thickness of the scattering layer. The simulations demonstrated that there is great potential for the production of TSFD with excellent overheating protection performance. TSFD exhibit adequate light-shielding efficiency (90% transmittance in clear state, 40% transmittance in scattering state) if they are prepared by applying appropriate material formulation and a tailored layer thickness, provided spherical scattering domains with diameters between 200nm and 400nm. Details are found in:

Gruber, D.P., Winkler, G., Resch, K. (2014). Comprehensive evaluation of the theoretical light shielding potential of TSFDs for material development and optimization, submitted to Solar Energy Materials and Solar Cells.

Development and optimization of TSFD

TSFD were developed by applying a systematic material formulation and characterization strategy. Various matrix materials (thermoplastics, thermosets) and additives as scattering domains (paraffin waxes, fatty acids and their derivatives, polymers) were used. In total 41 different TSFD were investigated. Relationships between thermo-refractive properties of TSFD constituents, internal material structure (morphology), and light-shielding efficiency of TSFD were studied. Although thermo-refractive properties of TSFD constituents were sufficient in order to achieve efficient overheating protection performance, light shielding characteristics of produced TSFD were moderate. This was mainly ascribed to inappropriate shape and/or size of scattering domains and – to a less extent – to defects. Polymer-physical effects triggering scattering domain size/shape and defect formation were identified. Based on these results TSFD were optimized systematically. Focus was on TSFD based on UV-curing acrylate resins. Defects were prevented by optimization of processing conditions (radiation dose and intensity) and material formulation (reactive diluent, photo initiator). Adjustment of scattering domain size and shape was done via a specifically developed photo-initiated miniemulsion polymerization mediated encapsulation process for the additive. TSFD formulated with the encapsulated additive exhibited significantly improved overheating protection performance. Solar hemispheric transmittance was around 73 and 49% below and above the switching threshold, respectively. Details are found in:

Weber, A., Resch, K. (2014). Thermotropic glazings for overheating protection. I. Material preselection, formulation, and light-shielding efficiency, Journal of Applied Polymer Science 131 (4), doi: 10.1002/app.39950.

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Thermotropic Materials for Overheat Protection

Description:	Thermotropic Materials for Solar Thermal Collectors: Collector Performance
Date:	04.11.14
Authors:	Adam Gladen, Susan Mantell, Jane Davidson, University of Minnesota, USA
Download possible at:	http://task39.iea-shc.org/publications

Overview

Absorbers fabricated from low cost, commodity polymers require a cost effective and reliable approach to prevent the polymer from exceeding its maximum service temperature during stagnation. Overheat protection can be achieved by adding a thin thermotropic material to the surface of the absorber. Thermotropic materials provide passive overheat protection by switching from high transmittance (the clear state) to high reflectance (the translucent state) depending on the temperature. In this project, a collector model was developed to study the effects of the optical properties of the thermotropic material on the optical efficiency and stagnation temperature of a collector. From this model, recommendations are given for the normal-hemispherical, solar-weighted reflectance of a thermotropic material in its translucent state required to provide overheat protection for solar absorbers fabricated from various polymeric materials.

Collector Model

In this project, a one dimensional model of a glazed, flat plate collector with a polymer absorber coated with a thin layer of thermotropic material was developed (Figure 1). The corresponding material properties and collector parameters are listed in Table 1. A one-dimensional energy balance on the collector yields the traditional expression for the useful energy output q_u of a collector:

$$q_u = G(\tau\alpha)_n - U_L(T_A - T_{amb}) \qquad (1)$$

where G is the insolation, the transmission-absorptance product $\tau\alpha_n$ is the optical efficiency, U_L is the overall loss coefficient., T_A is the absorber temperature and T_{amb} is the ambient temperature. When there is no flow through the collector or when the thermal losses are equal to the solar gain, q_u is zero and the stagnation temperature T_{stag} of the absorber is determined from an iterative solution of

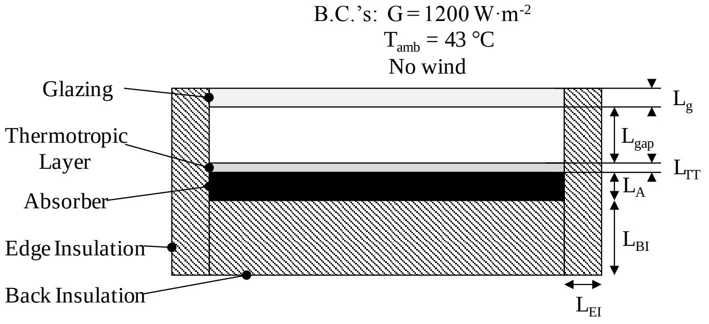


Figure 1. Schematic of the collector.

$$T_{stag} = \frac{G(\tau\alpha)_n}{U_L} + T_{amb}. \qquad (2)$$

The optical efficiency for a collector with a thermotropic material on the top surface of the absorber is [1]:

$$(\tau\alpha)_n = \frac{(1-\rho')\tau_g}{1-\rho_g\rho'} \qquad (3)$$

where τ_g and ρ_g are the glazing transmittance and reflectance, respectively. The overall reflectance of the thermotropic-absorber laminate *ρ'* is a function of the *temperature* dependent transmittance τ_{TT} and reflectance ρ_{TT} of the thermotropic material:

$$\rho' = \rho_{TT} + \frac{\tau_{TT}^2(1-\alpha_A)}{1-\rho_{TT}(1-\alpha_A)} \qquad (4)$$

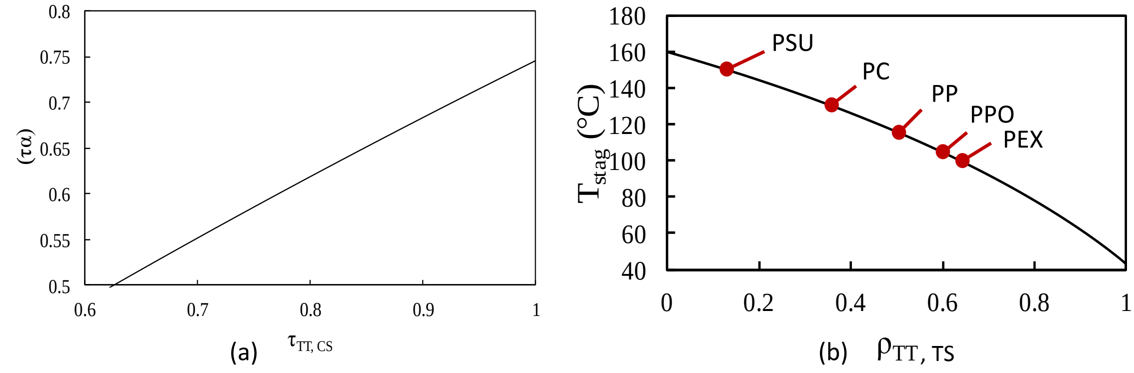
where α_A is the absorptance of the polymer absorber.

Table 1 Optical and geometric parameters

Component	τ_{solar}	τ_{IR}	ε_{IR}	L (mm)	k ($W \cdot m^{-2} \cdot K^{-1}$)
Glazing	82	0	90	4	0.2
Thermotropic Layer	Variable	0	90	1	0.2
Absorber	0	0	90	10	0.2
Back Insulation	N/A	N/A	N/A	50	0.038
Edge Insulation	N/A	N/A	N/A	30	0.038
Miscellaneous Parameters:					
Tilt Angle	30°				
L_{gap}	10 mm				
Aperture Area	2 m^2				

Results

Thermotropic materials must be selected such that (1) the reduction in the optical efficiency of the collector caused by the added thermotropic layer does not significantly diminish the collector performance, and (2) T_{stag} does not exceed the absorber material service temperature. As shown in Figure 2(a), the added thermotropic layer reduces the optical efficiency of the collector. For example, when a thermotropic layer is added with a clear state transmittance of 0.80 (i.e. $\tau_{TT,CS}=0.8$) the optical efficiency is reduced from 0.75 to 0.62. Figure 2(b) shows the translucent state reflectance ($\rho_{TT,TS}$) required to limit the stagnation temperature. The graph includes the manufacturer recommended service temperatures for several polymer materials. For example, if the absorber is fabricated from polypropylene, T_{stag} should be limited to 115°C and the corresponding limit for $\rho_{TT,TS}$ is approximately 50%.



(a) (b)

Figure 2. (a) Optical efficiency as a function of τ_{TT} in the clear state and (b) T_{stag} as a function of ρ_{TT} in the translucent state.

References

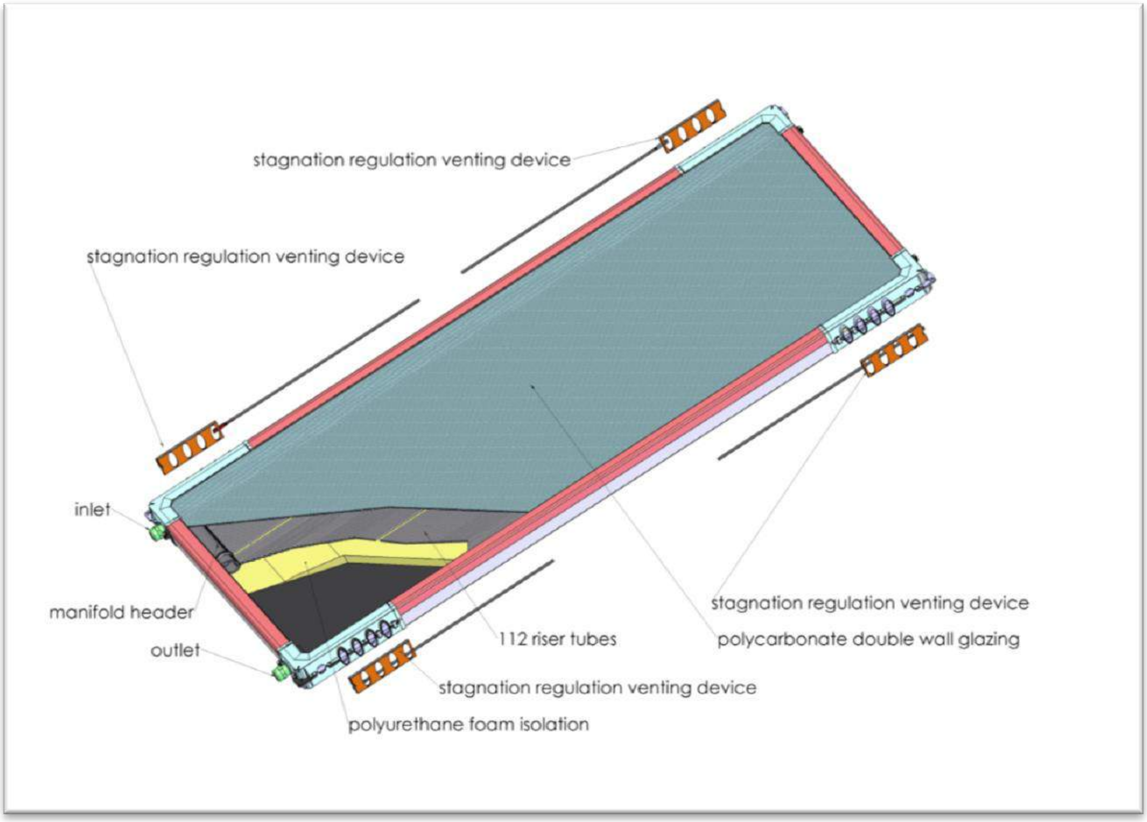
[1] A.C. Gladen, J.H. Davidson, S.C. Mantell, The Effect of a Thermotropic Material on the Optical Efficiency and Stagnation Temperature of a Polymer Flat Plate Solar Collector, J.Solar Energy Eng. In Press.

Thermal limitation of glazed collector for DHW

Description:	*Dry stagnation Overheating protection based on automatic venting of collector casing.*
Date:	06/07/14
Authors:	Michael Plaschkes, Magen –ecoenergy Kibutz Magen /Israel

A plastic collector using a Polyolefin absorber, a Nylon glass reinforced casing and a double wall Polycarbonate glazing were designed. In order to limit the dry stagnation temperature to an acceptable level (120 °C) it was necessary to invent a venting system which would function without external intervention.

The polyolefin absorber will expand due to its inherent thermal expansion coefficient. This change in total length of approximately 30 mm is exploited to open particularly designed venting orifices situated on the lateral sides of the collector frame. This automatically controlled device produces a thermo-gravitational air flow throughout the collector casing and reduces the stagnation temperature to an acceptable level for the specially formulated heat resistant polyolefin used for the absorber.
NB: this system is patented by Magen-Eco –energy.



Measurements and results:

1) The effectiveness of the system is influenced by the installation angle of the collector. The upper vents should be situated higher above the lower vents in order to generate a thermo-gravitational air flow. Thus an installation angle of 45° will produce better results compared to a 30° angle.
2) Temperature tests measured during the months June, July, August 2012 in the Negev climate at Kibbutz Magen (Israel) showed that this collector system installed at an tilt angle of 39° limited the absorber dry stagnation temperature at its upper position (2/3 height) to a maximum of 128 °C when compared to an unprotected collector. The temperature reduction is approximately 15 °C.

Absorber temperature without limitation

Absorber temperature

TYPICAL MEASUREMENTS: SUMMER JULY 2012: Max radiation 1015 W/m^2 / ambient air 35 °C

Fully Polymeric Thermosiphon System

Description:	*Three different concepts of thermosiphon systems using polymeric materials are introduced and compared in terms of costs*
Date:	01.09.2014
Authors:	Andreas Piekarczy, Karl-Anders Weiß
Download possible at:	http://task39.iea-shc.org/

Introduction

While the development of fully polymeric collectors is proceeding very well, one of the major questions to address is the integration of polymeric collectors into existing systems. Considering the large number of thermosiphon systems sold worldwide, in many regions the focus should be on the development of cost-efficient thermosiphon systems. Comparing the actual market situation, the requirements on a thermosiphon system from the consumers point of view can be summarized: low investment costs, small systems for easy modular expansion and direct usability.

Application and system design

Mounted on a flat or tilted roof top, the thermosiphon system consists of a storage tank and a collector and is generally used for the preparation of domestic hot water. Unlike in pumped systems, the water circulates due to density differences between heated and cold water, called natural convection. Therefore, the storage tank has to be mounted higher than the collector and the flow resistance within the system has to be kept low. The solar thermal circuit can be operated as open or closed system, using a heat exchanger, pressurized or pressureless, with the resulting different system specifications. This specification may vary, depending on regional requirements. Developing regions tend to have strong variation in water pressure, which need to be considered in the system design, for example resulting in an open system with pressure reduction at the fresh water inlet. Furthermore, depending on the system, a heat exchanger or backup heating may be necessary. In the following three different systems, for three applications and in different price ranges, will be characterized in more detail to illustrate the system implementation using polymeric materials.

Collector

At the moment there are only few polymeric collectors on the market counting as standard product and even fewer fully polymeric collectors. The model eco-SPARK®, produced by Magen EcoEnergy (Israel), is a glazed collector of extruded polypropylene (PP) tubes and polycarbonate (PC) twin wall sheets. It is produced in variable length defining the collectors' surface. The chosen model has a surface of 2.77 m² and is selected for all three system concepts.

Additional Parts

The large variety of additional parts for the systems is either available in polymeric materials (connections, fittings, valves, etc.) or cannot be replaced (Backup heating, valves, electronics, etc.).

Storage tank

The requirements for the storage tank depend strongly on whether the system is pressurized or pressureless. Also the proportions between the collector surface and tank volume define the maximum temperature in the tank and therefore the operation temperature for the used materials. Further, the total dimensions of the tank define the total mechanical load on the construction material. Inexpensive polymers are not suitable for the occurring loads at elevated temperatures and make an uneconomic wall thicknesses or reinforcement necessary. For this reason, the choice of the storage tank is one of the significant differences between the three systems. Small tanks are cheaper than one large tank and therefore system 1, which is based on two tanks instead of one large one, is more promising. For an operation of a pressurized solar circuit, only steel tanks or more expensive tanks of composite materials are suitable options.

Frame and Mounting

In order to complete the fully polymeric solar thermal system, aluminum or steel mounting systems should be replaced by more eco-friendly materials. Possibilities would be recycled plastic or wood-plastic-composites (WPC).

Piping

Replacing metal pipes with polymeric materials is possible, using standard materials like PP or cross-linked polyethylene (PEX), however restrictions regarding the maximums service life time at temperatures above 100 °C need to be considered.

Overview

Table 1: Specifications, target costs and estimated costs of the components for the 3 proposed systems. Prices are based on market experience and may vary for individual components.

Name:	**System 1**		**System 2**		**System 3**	
Description:	**Non pressurised, no back up heating**		**With heat exchanger, back up heating**		**Pressurised system (6 bar), back up heating**	
	Specification	Price [€]	Specification	Price [€]	Specification	Price [€]
Collector	Magen Spark	80	Magen Spark	80	Magen Spark	80
Storage	2 x 80 l, PP	100	100 l, PP*	???	150 l; steel	250
Frame	Rec. PP/WPC	30	Rec. PP/WPC	30	Rec. PP/WPC	30
Piping	PP/PEX	10	PP/PEX	10	PP/PEX	10
Connection/ Others	Valves, Connections	30	Heating, Heat exchan.	>60	Electr., Connections	>75
Target Price	**Total system**	**250**	**Total system**	**400**	**Total system**	**500**

* not necessarily potable water approved

All polymeric thermosiphon system

Description:	Low cost simple design thermosiphon concepts based on polymer structured sheets have been patented and developed. One concept is presented.
Date:	July 2014
Authors:	John Rekstad, Michaela Meir, Aventa AS, Norway
Download possible at:	http://task39.iea-shc.org/publications

Introduction

The challenge to develop a thermosiphon system (TSS) based on polymeric materials was background of the EU FP7 research project SCOOP. A patent related to two TSS designs based on extruded, structured polymeric sheets was submitted for evaluation (Köhl et al, 2013). The present INFO Sheet deals with the Aventa TSS-concept only. The second was presented in (Piekarczyk et al., 2014). Major advantages using polymeric materials are: low material costs, advanced processing techniques allowing mass production and low manufacturing costs, low weight, easier handling, transport and installation.

Twin-wall sheet absorber

The TSS is based on the use of extruded twin wall sheets from the commodity plastic Polypropylene (PP) as absorber material. The channel structure in extruded twin wall sheets gives an opportunity to design a flow circuit with a minimum of flow resistance where a quite moderate “driving pressure” due to temperature gradients in a hydraulic system, can provide a significant volume flow. Consequently, fair system efficiency can in principle be achieved in spite of the pure heat conductivity of the polymeric material.

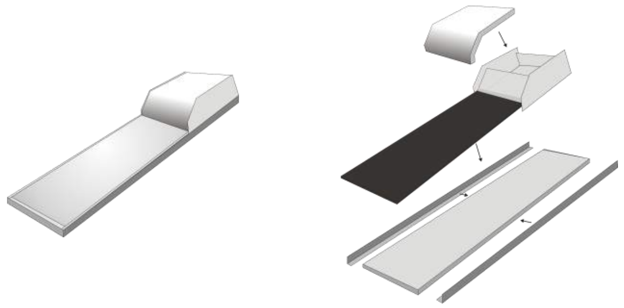


Fig. 1 – Illustration of the AventaSolar TSS. The flat design with integrated storage (left) consist of polycarbonate glazing, a twin-wall sheet absorber, rear and storage tank insulation and framing for façade or roof mounting (right).

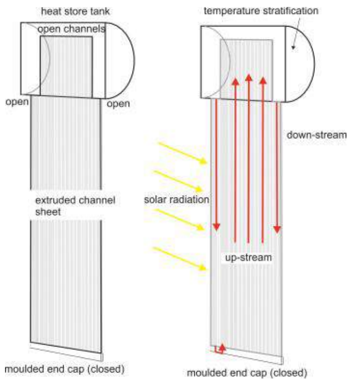


Fig. 2 – Functional design of the AventaSolar TSS

Hydraulic design of the thermosiphon system

Figure 1 shows the principal design of the thermosiphon system. The basic components are an extruded twin-wall sheet, a storage tank of about 60 litres welded to the top end of the sheet and an endcap to the bottom end of the sheet. The collector area is approximately 1 m². The circulation of the heat carrier fluid develops within the same twin wall sheet. Cold water flows down in the outer channels terminated at the bottom of the storage tank and rises –heated by solar irradiation - in the central channels ending close to the top of the storage tank (Fig. 2). This is a key design for developing a well defined hydraulic circulation, where stratification inside the storage tank initiates the water circulation. An important aspect is how this design functions during night-time: The absorber sheet cools down and both channel groups are exposed to the same cooling effect due to radiation and convection. This prohibits inverse circulation and tapping of heat from the storage tank. Since a thermosiphon system is permanently filled with water, overheating and boiling can be a challenge. Low pressure is preferable for a thermosiphon system of polymeric materials, which means that the boiling temperature in the system is close to 100 °C. To limit the system temperature below this threshold is a necessity, but this requirement opens at the same time for using commoditive polymeric materials, which are less expensive than high temperature performance polymers. Hence, the overheating protection is a crucial part of the design.

Preparation of domestic hot water

The domestic water can in principle be heated in two ways: One way is to use the water in the thermosiphon storage tank directly as domestic water (direct system); the other way is to insert a tank heat exchanger into the system water of the TSS heat store (indirect system). The heat exchanger sustains the pressure of the domestic water grid, while the pressure inside the heat store is equal the atmospheric pressure. One aspect for the choice is the stationary heat transfer during continuous tapping of domestic hot water, another aspect is the stored volume of heated water contained in the heat exchanger.

Installation and integration - Advantages

Several basic installation modes are targeted with the present design: For roof- or façade integration with the storage tank on the back side of the system, a roof top or free standing installation with the storage tank on the top side or behind of the absorber surface as illustrated in Fig. 3.

Fig. 3 – Different installation and integration options for the AventaSolar TSS concept.

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Piekarczyk A. et al., 2014. Development of Fully Polymeric thermosiphon systems based on extruded commodity plastic sheets. Gleisdorf Solar 2014, Gleisdorf, Austria.

All polymeric collector Sunlumo

Description:	**Developing plastic-based solar collectors for the volume market**
Date:	14.10.2014
Authors:	Robert Buchinger and Max Wesle, Sunlumo
Available for download from:	http://task39.iea-shc.org/publications

Solar collector panels for the volume market

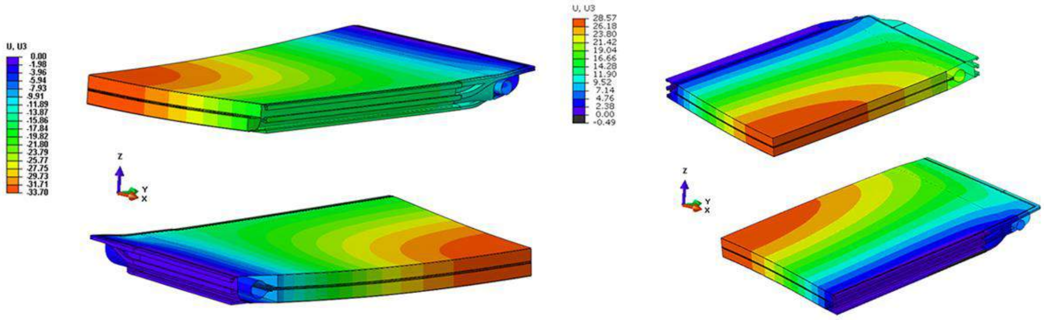
Recent estimates have shown a steadily rising need for solar collector panels worldwide, from 10 to 15 per cent annually. By 2020 the annual demand for collector surface is thought to be around 200 to 400 million square meters. This demand will be met with great difficulty only, if at all, when relying on conventional aluminium or copper panels. Materials for traditional collector panels are scarce and, therefore, too expensive to produce or sell collectors as an affordable mass product. Sunlumo's R&D is geared to bridge this gap between two poles – of a sufficient raw material supply on the one hand and of low prices for the volume market on the other. Their R&D is thus focused on innovative technologies, new materials such as polymers, and manufacturing options for the mass market.

One World Solar Collector (Sunlumo)

Quality factors in developing solar collectors

Adapting manufacturing processes for serial production in great numbers is one of the major challenges in developing plastic-based solar collectors. It requires top-quality components that meet even the highest standards. This means defining the loads acting on each of the collector components and adapting the design of components accordingly. The resulting knowledge is then used for a detailed component design. The design of joints and the materials used in their fabrication have to be tested and optimized. Process simulations, such as injection moulding simulations, are carried out in order to check the suitability for serial production of components and the relevant manufacturing processes; in addition, parameter ranges for the manufacturing processes and the design of tools must be defined. In the run-up, expensive procedures will serve to determine the parameters for the plastic to be used in the simulations.

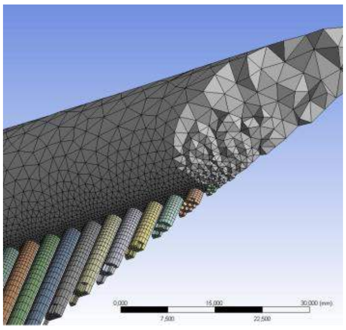
The tests both include FEM analyses of all components and simulations with different load profiles (e.g. snow or wind loads, see fig.) as well as a modelling of the collector structure, including the load transfer to the substructure (e.g. clamping rails or roof fastening). Life cycle analyses help to ensure the operability of collectors over the required time span. In addition, worst case scenarios perhaps caused by erroneous assembly, are computed in order to detect potential failure points in the design. These modelling and virtual prototyping processes help us to verify the ability of components to meet the corresponding physical requirements. This allows us to detect potential failure points from the early development and design phase onwards and to make the necessary improvements. (Prototypes are implemented faster and in a more perfect way. This helps to shorten development times and reduce R&D costs).



FEM analysis and results:
exposure of solar collectors to snow and wind loads

Special system technology for plastic-based solar collector units

If plastic-based solar collectors are to function as plug & play systems, the system hydraulics of the collector units will have to face new requirements: in order to ensure safe and easy functioning, the control mode, volume flows, and absorber hydraulics need to be synchronized. So CFD simulations are carried out in order to simulate the operating mode with different functional parameters in place. This allows us to compute even more complex flow patterns. Simulated filling modes of solar units and the flow distribution within collector panels provide useful information for the dimensioning of components (e.g. absorber or collector joints).



CFD – mesh modelling for absorber and collector

AventaSolar collector system

Description:	Instead of replacing major components of conventional materials with polymeric components, the present concept modifies conventional solar heating system design for optimal use of polymeric materials
Date:	September 2014
Authors:	John Rekstad, Aventa AS, Norway
Download possible at:	http://task39.iea-shc.org/

Introduction

The motivation for the development of the AventaSolar concept was to offer architecturally appealing and cost competitive solutions for solar thermal energy production to the end user.

AventaSolar collector

An innovative part of the AventaSolar collector is the absorber, consisting of extruded, polyphenylene sulfide (PPS) sheets (Fig. 1). Aventa together with the raw material supplier and processing partners have been worldwide pioneers to demonstrate the extrusion of high temperature performance polymers to structured sheets (Köhl et al., 2012).

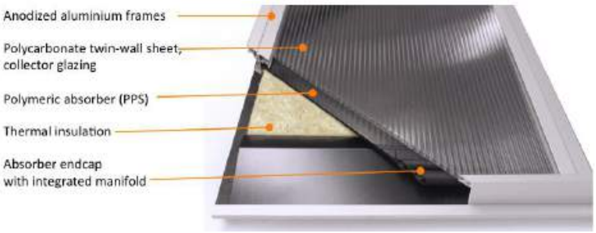


Fig. 1. Components of the AventaSolar collector module

Main characteristics

Modular, adaptable, light-weight – The collector has modular design with units of 60 cm width and various collector lengths between 200 to 500 cm. Hence the collector's size is rather flexible and adaptable to almost any roof or facade shape. The weight of the collector per square meter is considerably lower (approx. 8 kg/m^2) than conventional flat plate collectors of metals and glass (… kg/m^2). The low weight opens for the design and easy handling of large modules (up to 5 m length) reducing the amount of inter-connections.

Building modules – The availability of various module lengths together with the functional design of replacing conventional roof- or facade covers makes the AventaSolar collectors multi-functional modules, covering buildings' roofs or facades and producing thermal energy. The collector design is such that the thermal insulation of the building also acts as collector insulation where possible. Both aspects contribute to cost savings in terms of materials and installation. The intention with developing this design is to create architecturally appealing solutions, which inspire decision makers and planers to take solar thermal technology in use.

Simple system design - The present collector is part of drain-back system with non-pressurized solar heating loop, being open to atmospheric pressure, not having intermediate heat exchangers between the collector loop and the heat buffer store volume. The present solar heating concept has a simple system design, avoiding various state of the art components included in conventional solar heating systems (Fig. 2, right): Antifreeze liquid, expansion vessel, overpressure safety valve, heat exchangers between heat buffer store volume and solar/floor loop. All important components as shunts valves, solar pump, floor circulation pump and system controller are pre-installed at the front panel of the Aventa heat buffer store in the factory and are all -for easy logistic in the boiler room- placed on one side of the heat storage.

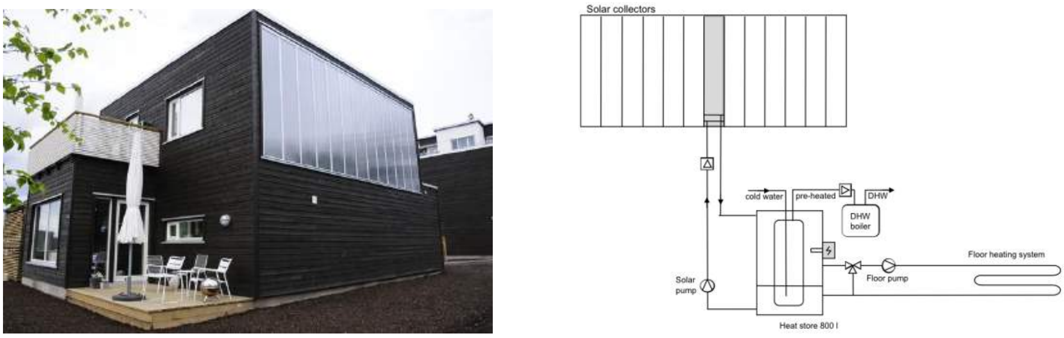


Fig. 2. Façade integrated AventaSolar collectors in a project of Norway's largest housing association (left) and hydraulic design (right).

Building integration, installation, cost savings – The above mentioned aspects make the AventaSolar collector suitable to be mounted by roof or facade installers during the building/retrofit process. The installation time of the collector is in the same order of magnitude as for conventional roof- or facade covers. For the collector installation, the weight of all parts is below the limit for being handled by one person. Due to the fact that the solar collector loop is not pressurized, the on-roof or on-facade installation does not require authorized HVAC installers, but can be carried out by skilled roof- or façade experts. In the collaboration with building industry, the involved actors in the distribution chain are reduced, logistics at the building site is improved and resulting in overall cost savings for the end customer.
The production method of the absorber and the collector cover offer a large potential for cost reduction, especially when large production volumes can be obtained (extrusion and moulding).

Environmental friendly because of more favourable LCA figures compared to conventional collector systems (Carlsson et al., 2013; Task 39 Info Sheet A4), reduction of system components and using pure water instead of antifreeze liquid.

Favourable applications for the AventaSolar concept are systems for combined DHW preparation and space heating (solar combisystem) or solar DHW systems with large DHW consumption (hospitals, nursing homes, sport centres, hotels, etc.).

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UNISOL – universal solar system for pre-heating water

Description:	*UNISOL project – general presentation*
Date:	2014
Authors:	Luis Godinho, Pedro Graça, Liliana Baptista, Diogo Batista JPrior - Fábrica de plásticos, Lda, 3840-324 Ponte de Vagos, Portugal Alexandre Mota, Rui Escadas, Jorge Azevedo, Tiago Gonçalves Electronic Engineering Department – Aveiro University, 3810-193, Portugal Ricardo Amorim, Jorge Facão, João C. Rodrigues, Maria João Carvalho LNEG – Laboratório Nacional de Energia e Geologia, Estrada do Paço do Lumiar, 22, 1649-038 Lisboa, Portugal
Download possible at:	

Resume

In any solar thermal system, from the absorption, accumulation and distribution sub-systems, accumulation is the one that defines the principles and controls the other two and thus, the overall efficiency of the system. From this assumption, the Unisol project aims to develop an integrated set of R&D activities to design a universal, innovative, independent and intelligent system that manages the accumulation of heat that is capable of using almost any solar collector. This system is intended for pre-heating domestic hot water (DHW) as well as for low-temperature space heating, and also to simplify integrated systems (IS) for the support of individual subsystems in multifamily housing buildings. The project introduces several new peculiarities, such as its unique principles of universality and integration inside and outside of buildings and a reversible heat-exchanger circuit. The main promoter is JPrior - Fábrica de Plásticos Lda, a private Portuguese company, Aveiro University and the National Laboratory of Energy and Geology (LNEG).

Introduction

Almost all forced solar thermal systems available in the Portuguese market have an accumulator tank that is maintained at relatively high temperatures. The solar energy collected by the absorbers is usually transferred to the accumulator through a pressurized solar circuit which includes a copper coil (heat-exchanger) placed inside the tank. It is understood that systems based on these principles have been developed for countries where the danger of freezing is a current concern. However, it is not the freezing but the danger of stagnation with the pressurized absorber filled, the most likely situation to occur in our country. The pressurized solar circuit is more complex, more expensive and less reliable than a non-pressurized circuits. On the other hand, it is clear that keeping heat storage tanks at relatively high temperatures with the aid of other heat sources increases the rate at which materials degrade, increases thermal losses of the system and lowers absorbers efficiency.

The explanation for our market being dominated by forced pressurized systems can perhaps be found in our small dimension and lack of tradition in this area of technology. In this "quasi-tropical climate" only recently the thermal insulation of houses began to draw real attention and, until the invasion of Iraq in 2003, the energy problem was something that oil could conveniently keep away our worries.

Unlike traditional solar circuits, systems running according to the "drainback" principle are not pressurized and are naturally protected against freezing and over-heating. The solar circuit empties when there is not enough energy in the collector (prevents freezing) and also empties when there is energy in excess (avoids stagnation and slow degradation).

UNISOL is a solar thermal system of forced circulation, working on a "drainback" principle, which is designed primarily for small / medium-sized dwellings (maximum of 3/4 - 6 people), isolated or integrated into buildings, just for DHW or DHW and low-temperature space heating.

Contrary to most developments in this area, which are often targeted at specific components (usually solar thermal collectors), this project is aimed exclusively at the core of the thermal system, using principles and solutions that will optimize, simplify and reduce costs, worrying only with its flexibility and universality in both the application and integration and in the use of third-party components, such as collectors. UNISOL not only allows a better integration of the collectors, solving also the problem of energy distribution in apartment buildings, but also facilitates the integration of the control and the heat storage inside the dwelling. This solar circuit at low pressure and low temperature (up to 80 °C) can be connected to almost all solar collectors, more particularly to a new generation of polymeric collectors, and also to the majority of floor heating systems, forced circulation convectors, etc.

General objectives of the project are the production, optimization and placement on the market an autonomous and intelligent system of distribution and accumulation of thermal energy, operating at low pressures and low temperatures, which can use virtually any type of solar panel thermal (or distribution of collective heat), and be connected to any system for space heating at low temperature.

Experimental setup

This project was divided in 3 phases: i) DHW; ii) DHW and floor heating; iii) integrated system (IS). In the first phase a domestic hot water (DWH) system, with 600 L water storage capacity, containing an immersed cylindrical heat-exchanger with 120 L, was tested for several consumption profiles. The second phase consisted in testing the efficiency of the system, using the same heat store, answering to some floor-heating demands. A special test was performed using a standard gas water heater, consisting in analyzing the efficiency of using this auxiliary heating in maintaining a minimum temperature level in the 600 L accumulator, regardless the type of heating consumption profile. The third phase consisted in connecting several systems of type i) and/or type ii) to an oversized central accumulator, which can be feed mainly by solar collectors and/or other means, ensuring that all the individual 600 L heat stores can have a minimum level of energy available. Figure 1 shows the diagram of UNISOL test assembly, built to evaluate the performance of all three UNISOL phases.

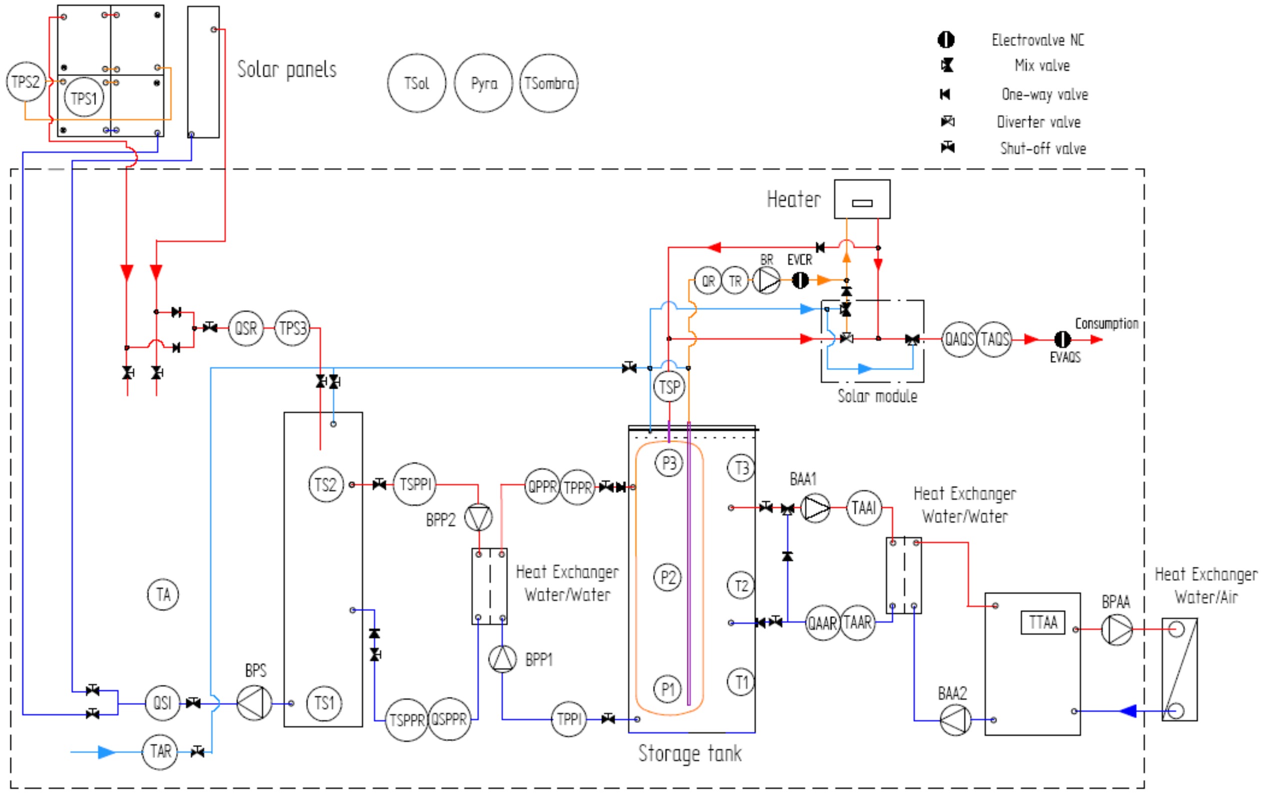

Fig. 1. Schematic representation of the experimental setup assembled in JPrior facilities.

A specific electronic circuit to actuate the pumps, valves and signal acquisition of all temperature and flow sensors was developed. This electronic circuit is the basis for the construction of a controller prototype. The software for the acquisition, control and communication system has been developed in collaboration with the Aventa AS. Presently some control algorithms are being tested.

It is expected the presentation of a final UNISOL prototype, base to evaluate serial fabrication, in the end of 2014.

References

[1] European Patent 1172328.2 – WO 2011/133058 – AUXILIARY CIRCUIT FOR HEATING HEAT STORAGE TANKS

Acknowledgements

The work presented was developed in QREN SI I&DT n. 21507, financed by FEDER funds in the frame of "Programa Operacional Factores de Competitividade".

Conceptual solar domestic hot water systems

Description:	*Conceptual workshop on solar domestic hot water systems with focus on the use of polymeric materials*
Date:	20.05.2014
Authors:	Dipl.-Ing. (FH) Christoph Reiter, Dr. Sebastian Brandmayr, Dr. Christoph Trinkl, Prof. Dr.-Ing. Wilfried Zörner Technische Hochschule Ingolstadt Institute of new Energy Systems (InES)
Download possible at:	http://task39.iea-shc.org/publications

Introduction

In order to reach a further cost reduction for solar domestic hot water preparation, a workshop to identify concepts for adjusted solar-thermal systems with polymeric collectors was carried out. The objective was an extended use of polymeric materials in the solar-thermal system. This comprises the solar circuit as well as the buffer storage.

Background

In Reiter et al. 2011, a reachable cost reduction by polymeric collectors of about 50% was identified. However, the collector costs are only about 30–40% of the total costumer costs of the solar-thermal system. As a result, the total cost reduction caused by new collector designs is about 20%. In contrary to that, the solar yield is smaller using these polymeric collector approaches with limited efficiency, for example, due to a non-selective coating. This condition compensates the economic benefit of polymeric collectors within standard solar-thermal systems.

However, the components of pressurized state-of-the-art solar-thermal systems are configured for collectors facing temperatures up to 200 °C and high pressure. The system set-up with many individual components, costly materials and the large installation effort result in high costs. According to the lower resistance of polymeric collectors regarding system pressure and especially temperatures, it will be possible to lower the technical requirements for the solar-thermal system. This enables further cost reduction in the system by fewer and cheaper components as well as an easier installation.

Solar Circuit

For the solar circuit two set-ups were identified. The first concept is close to the state-of-the-art set-up — a pumped, pressurized solar-thermal system with water/glycol as antifreeze. The copper piping in the solar circuit is replaced by polymeric pipes which are already used in heat distribution systems like floor heating. The cross-linked polyethylene (PE-X) pipes are bendable and can be easily connected by press fittings. Such piping system from the German manufacturer Roth Werke GmbH (n.d.), for example, can be used permanently in pressurized circuits up to 95 °C. Another piping system from the German manufacturer aquatherm GmbH (n.d.) on the basis of polypropylene (PP) is connected by heating element socket welding and allows a fluid temperature of 90 °C in the pressurized circuit. Both pipes are suitable for normal solar-thermal system operation, but the thermal loads during stagnation may cause problems.

The second concept is a drain-back system. The open, non-pressurized circuit on the basis of the polymeric pipes offers several advantages. The self-emptying system is frost-resistant and enables water as cost-effective and easy to handle heat carrier. Furthermore, components like the expansion vessel, air bleed valves and the pressure relief valve can be omitted. The missing pressure load also enables the use of volumetric absorbers and low material thicknesses.

Buffer Storage

There are several polymeric buffer storages on the market. For example, the storage *Thermotank Quadroline* from Roth Werke GmbH (n.d.) is made of PE with an expanded polystyrene (EPS) insulation. The versions with 325 l and 500 l are used for domestic hot water preparation in connection with solar-thermal systems. The storage is permanently resistant against temperatures up to 90 °C and pressures up to 3 bar. The internal heat exchangers enable the use of both solar circuit concepts — pressurized and self-emptying. Figure 1 shows the polymeric storage with internal heat exchangers for domestic hot water and solar-thermal heat supply. For the use in a drain-back system, an external tank for the heat carrier of the solar circuit is necessary.

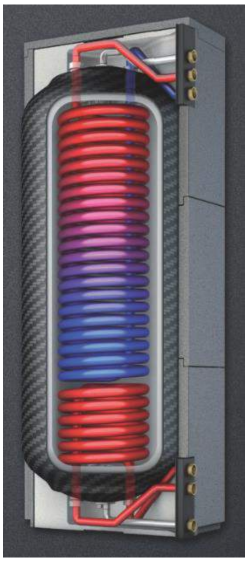

Figure 1. Sectional view of Thermotank Quadroline (Roth Werke GmbH n.d.)

Another approach is the non-pressurized buffer storage made of PP by the Spanish manufacturer BUNKSOLAR S.L. (n.d.). This storage is especially designed for drain-back systems. The solar circuit is connected directly to the storage volume. Thus, the buffer storage requires no additional drain-back tank. Suitable storage volumes of 250 l, 400 l and 500 l are available and are premised for temperatures up to 85 °C. Two heat exchangers are integrated for domestic hot water supply and the back-up heating.

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TASK39

SHC
SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

Polymeric solar heating systems

Building integration and scalability of components

Description:	An important outcome of the Subtask B workshop at the 15th Task 39 Meeting in March 2013 was to exhibit the scalability of polymeric collectors and heat stores.
Date:	September 2014
Authors:	Michaela Meir, University of Oslo, Norway *
Download possible at:	http://task39.iea-shc.org/

Introduction

Polymeric materials for solar thermal applications open for new processing techniques, which allow modular and scalable solutions for solar thermal collectors and system components. During the Subtask B Industry Workshop at the 15th Task 39 Expert Meeting in March 2013 in Mallorca, Task 39 experts investigated, which products presently could be found in the market. In a brainstorming session joint efforts were made how various scalable polymeric solar thermal components could be combined in a complete system and how it could be presented to a broad professional audience.

Scalable solar collectors: Roof and facade integration

Scalability of solar collectors is of particular importance if these should be integrated into the building, replacing conventional roof or facade covers. The polymeric collector concept by the company Aventa AS has been pointed out as an example of being scalable and is described in Task 39 INFO Sheet B18. The AventaSolar collectors have a fixed width (Norwegian standard building width of 60 cm) and flexible lengths (five standard sizes between two to five meters length). The scalability allows architects and building designers to fit the collector field to the actual available space on a building's roof or facade to avoiding costly transitions between collector field and the conventional roof/facade covers. Additional aspects suggest that this type of polymeric collector is particularly suitable for building integration: Light-weight modules, installation process fitting to typical handling of conventional roof/facade modules. Following technical characteristics are rather different from conventional solar thermal systems and important to be considered when choosing other system components fitting to these scalable collectors:

Drain-back collector system, non-pressurized
open to atmospheric pressure
Heat carrier: water, no additives
Heat carrier volume: 3.5 l/(m^2 collector area)
Volume flow: 2 -2.5 l/(module min)

Fig. 1 Left: Scalable, facade integrated polymeric collectors (source: Aventa) Right: Scalability illustrated at the SHC2013 (right, source: Fraunhofer ISE).

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* On behalf of the experts at the Subtask B Industry Workshop in Mallorca, March 2013: AIT (AT), Aventa AS (N), Chevron Phillips Chemicals (BE), Johannes Kepler University Linz (AT), PCCL (AT), Prirev (PT), TSC-Concentra (ES), University of Innsbruck (AT), Vaillant GmbH & Co. KG (DE).

Polymeric solar heating systems

Building integration and scalability of components

Scalable heat stores: System size, logistics and available space

Scalability of solar heat stores is an important issue especially for retrofit projects with limited space and access to the technical room (basement). Several small and medium sized solar heat stores of polymeric materials are available in the market (Köhl et al., 2012). Concerning scalability two heat store concepts were more closely investigated at the Subtask B Industry workshop. The FLEXSAVE VARIO by the company FASVE is a non-pressurised buffer store concept available from 1.5 to 150 m^3 suitable for single-family houses up to large industrial applications (Fig. 2, left). The storage size and technical heating equipment can individually be chosen for each project from pre-configured standard units. For easy access to the boiler room (in small projects) or handling and transport (for larger projects) the heat store is light weight compared to conventional non polymeric stores and delivered modular. The inner tank consists of PP sheets and is easily welded on-site by the installation team. The Thermotank QUADROLINE heat storage concept by the company ROTH WERKE GmbH is also modular, but available as prefabricated 325 l units and first of all for small and medium sized domestic projects. The pressure resistant storage tank consist of fibre/plastic composite technology and the thermal insulation of modular EPS blocks. The QUADROLINE modules can be integrated into domestic heating and drinking water systems in various configurations, individually or in a battery installation (Fig 2, right).

Both heat stores are award winning concepts. The FLEXSAVE VARIO received among others the Intersolar Award 2010 for ”Solar thermal technology” and the pro-K industrial association named the Thermotank Quadroline "Product of the year 2013".

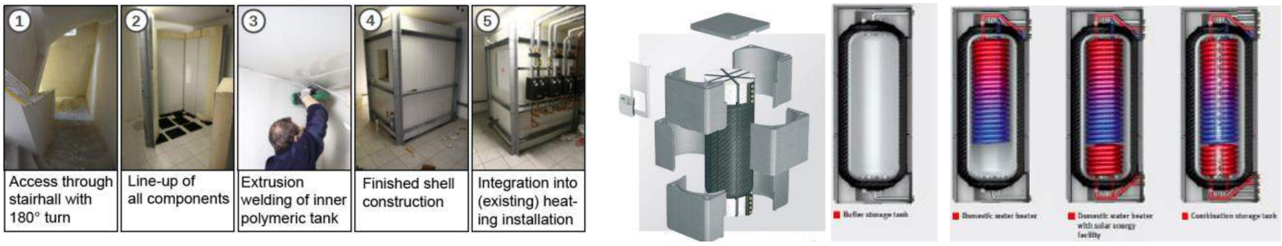


Fig. 2 Scalable heat store concepts of polymeric materials: FLEXSAVE VARIO by FSAVE GmbH and Thermotank QUADROLINE by ROTH WERKE GmbH.

Exhibition at SHC 2013 in Freiburg

As a follow-up and dissemination event of the Subtask B Industry Workshop products revealing among others scalability of polymeric solar applications were presented to a broad professional audience at the Task39 Exhibition at the SHC 2013. The Exhibition was a meeting point in front of Freiburg Concert House where the SHC 2013 took place. Further reading.

References

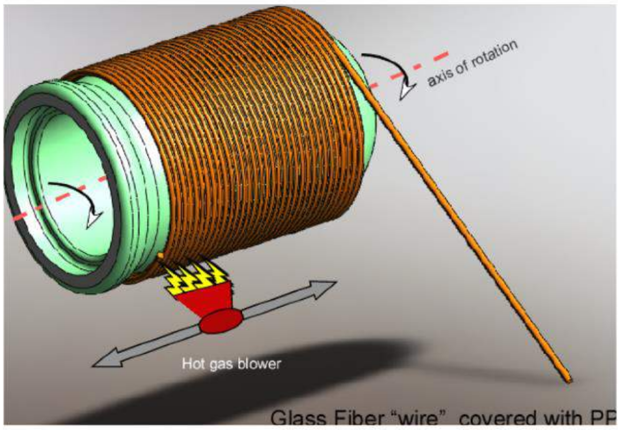
Köhl et al., 2012. Polymeric Materials for Solar Thermal Applications. John Wiley & Sons, Inc., ISBN: 978-3-527-33246-5
418 pages, October 2012.

Polymeric storage tanks

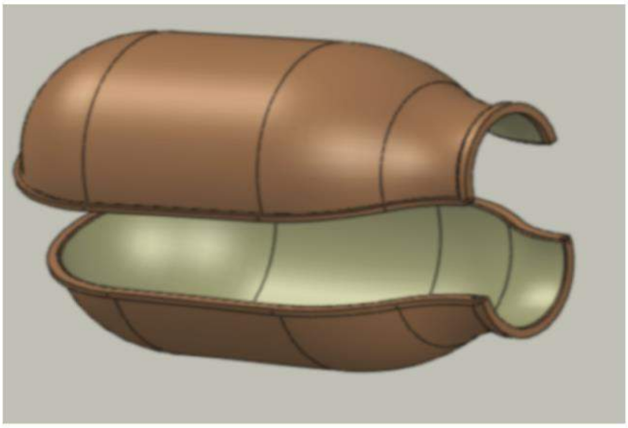
Description:	*Ideas for design and manufacturing of plastic storage tanks*
Date:	07.05.14
Authors:	Michael Plaschkes Magen ecoenergy . Kibbutz Magen - ISRAEL
Download possible at:	http://task39.iea-shc.org/publications

In the last years plastic solar collectors have been developed and manufactured by various companies. Plastic pipes are used in these solar systems (PP, PEX, CPVC) but storage tanks are still mainly metallic. This info sheet presents some ideas for manufacturing low cost thermoplastic pressure storage -tanks for DHW solar systems.

1) Thermoplastic endless glass fiber wound reinforced polyolefin tank.
A blow-moulded, thin wall vessel (100 -120 litre volume) will be covered by a cross-wound sheath of endless glass-fibers, encapsulated in a polypropylene coating similar to a wire. These cross-wound layers of PP and fibers are molten by means of hot air and fused to the vessel (Leister system) and form a hybrid pressure resistant tank. This method is similar to the process using thermoset polyester glass reinforced resins (GRP) but presents the advantage of a clean, chemical free procedure and yields a recyclable product.



2) Injection moulding of two half shells made from glass reinforced engineering materials specially designed for liquid applications.
No internal lining will be necessary.
The shells can be welded by means of hot-plate, vibration welding or infrared radiation.
Welding coefficients are quite strong
This will enable to make a lightweight but pressure resistant tank. The water temperatures are moderate and do not negatively impact the pressure resistance of these engineering materials. The materials used have to be certified according to NSF 61.



For both methods the pressure vessel is insulated by means of PU foam or mineral wool, covered by an external injection moulded or thermoformed protection, and enhanced with an electric heater and thermocouple, inlets outlets, and connection flanges etc.

UNISOL – solar combistore evaluation and optimization

Description:	*Characterization of UNISOL combistore according to tests using EN 12977-3:2012 and EN 12977-4:2012.*
Date:	2014
Authors:	Ricardo Amorim, Jorge Facão, João C. Rodrigues, Maria João Carvalho LNEG – Laboratório Nacional de Energia e Geologia, Estrada do Paço do Lumiar, 22, 1649-038 Lisboa, Portugal Luis Godinho, Pedro Graça Jprior - Fábrica de plásticos, Lda, 3840-324 Ponte de Vagos, Portugal
Download possible at:	http://www.sciencedirect.com/science/article/pii/S1876610214002938

Introduction

UNISOL is a national project aiming at the development of an innovative, autonomous and intelligent universal system for management and accumulation of solar heat that can practically use any solar collector in the market. The system will simultaneously pre-heat domestic water (DHW) and space heating (SH). The main component is a combistore which includes a two-way heat exchanger [1].

In Fig.1 a schematic presentation of the combistore is shown. This figure also shows the flow direction for each port and the used ports. In order to study the configuration of the inner storage tank, used for DHW pre-heating or as back-up of the space heating, tests according to EN 12977-3:2012 [2] were performed. Tests according to EN 12977-4:2012 [2] were also performed for characterization of the complete combistore.

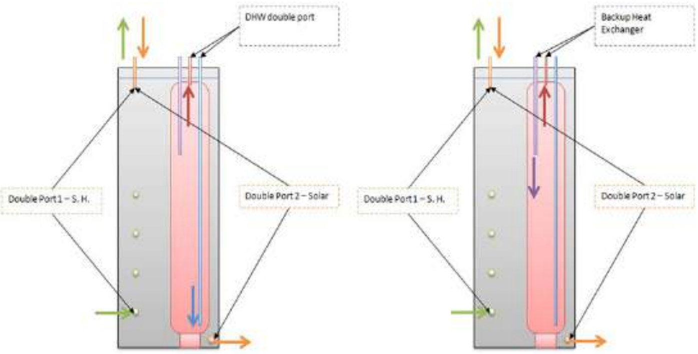


Fig. 2. Schematic representation of the combistore of the type tank in tank where the tank inside works as preheat for DHW preparation (Left) or back-up for SH (right).

Numerical simulations were performed in the software TRNSYS [3] in order to test the selected numeric model Type 340 [6] and optimization algorithm available in GENOPT [4] according to EN 12977-3:2012 [2], respectively, Annex A and C. Parameters were identified based on the tests performed according to EN 12977-3:2012 [2] and EN 12977-4 [2]. A new deck was created in TRNSYS [3] to calculate the long-term performance energies. This deck has 4 circuits, the solar collector loop, auxiliary loop, space heating loop and DHW consumption. The best results of the identification parameters process are used in Type 340 [4] to perform the long-term performance.

Results and discussions

In reference [6] the identified parameters for both prototypes are listed. Results for long term performance is also presented in the same reference.

Conclusions

Two combistore prototypes were tested according to EN12977-3:2012 [2] and EN12977-4:2012 [2]. Although prototype 2 reduces the solar energy delivered to the system and also imposes higher losses, it makes more energy available to the space heating. The controller set-point also influences in the performance of the combisystem. Lower set-points reduce the energy lost and the interference with the solar loop.

Prototype 2, when tested according to EN 12977-3:2012 [2] fulfilled better the energy demanded for space heating. It was then tested as combistore according to EN 12977-4:2012 [2]. Since the prototype has imperfections in the way the insulation is applied to the store walls, it shows high heat losses coefficients (Top, Bottom and side losses). Simulations using TRNSYS [3] were performed, for a system using this combistore and a solar field of 10 m^2 and delivering energy to space heating and preheating DHW. The performance indicator used is f_{sav} (fractional energy savings) and the results for Davos and Würzburg show values of fsav, respectively, of 18.6% and 6.3%. Simulations using lower heat losses coefficients, considering a heat conduction value for the insulation of 0.04 W/mºC, showed large improvement in the f_{sav} values, respectively 39.3% and 25.3%. These results show that the performance of the combisystem increases substantially with a better insulation.

References

[1] Patent INPI n. 105061 - Circuito Auxiliar para Aquecimento de Acumuladores Térmicos.
[2] EN 12977-3 and 4 :2012 (Ed. 2) - Thermal solar systems and components. Custom built systems. Part 3: Performance test methods for solar water heater stores. and Part 4: Performance test methods for solar combistores.
[3] TRNSYS, A Transient System Simulation Program, version 17.00.0019, Solar Energy laboratory, Univ. Of Wisconsin-Madison.
[4] Harald Drück, MULTIPORT Store – Model for TRNSYS Stratified fluid storage tank with four internal heat exchangers,ten connections for direct charge and discharge and an internal electrical heater, Type 340, Version 1.99F, March 2006
[5] GENOPT®, Generic Optimization Program, version 3.1.0, Lawrence Berkeley National Laboratory
[6] Ricardo Amorim, Jorge Facão, João C. Rodrigues, Maria João Carvalho, UNISOL – solar combistore evaluation and optimization, Energy Procedia 48 (2014) 264 – 27 .

Acknowledgements

The work presented was developed in the frame of project n. 21507, financed by FEDER funds in the frame of "Programa Operacional Factores de Competitividade".

Polypropylene absorber materials

Description	• Black-pigmented PP grades for absorbers • Temperature load profiles for fully overheating protected flat plat collectors • Aging behavior of PP grades and lifetime modelling
Date:	07.08.14
Author:	Gernot M. Wallner, Markus Povacz JKU Linz, Institute of Polymeric Materials and Testing, Austria
Download possible at:	http://task39.iea-shc.org/publications

Polypropylene grades (PP) offer a high potential for use in solar thermal absorbers, in particular for flat plate collectors with adequate overheating control. For unglazed swimming pool collectors black-pigmented PP grades are state of the art. PP absorber grades for glazed collectors have to be tailored according to the specific loadings conditions and performance requirements which are significantly dependent on collector and system type. In this info sheet a PP grade widely used for swimming pool absorbers and a novel PP grade investigated within the collaborative research project *SolPol-2* are evaluated as to their applicability for glazed collectors with full overheating protection.

Polypropylene materials (PP)

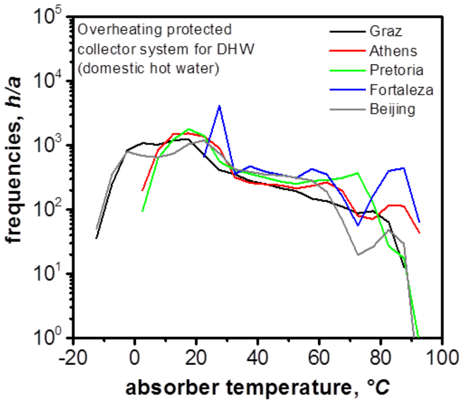
Polypropylene (PP) is a hydrocarbon (C, H) based thermoplastic produced in high quantities (~ 50 million metric tons worldwide) and used in a variety of applications. Compared to polyethylene (PE), semi-crystalline PP grades exhibit a higher melting temperature range (maximum at about 165°C), which allows for slightly higher service temperatures. PP grades are tailor-made for specific applications fulfilling rather different property requirements. Besides PP homopolymers (solely based on the propylene monomer) also random copolymers, block copolymers or elastomer modified grades have been developed and commercialized. The most important comonomer is ethylene. Besides the molecular structure also the additive system is varied to adopt the morphology and the property profiles of PP grades.

PP grade for swimming pool absorbers

The market dominating PP grade for swimming pool absorbers with proven long-term durability is based on a black-pigmented PP block copolymer with elastomer modification (also termed PP impact copolymer). Due to the direct light and UV exposure the carbon black content amounts to about 2 m%. The morphology of extruded PP impact copolymer sheets for swimming pool absorbers is characterized by a semi-crystalline structure with spherulite domain sizes up to 100µm. As common for polymeric materials the elastic modulus as a measure for the stiffness of the material is significantly dependent on temperature with a significant decrease from about 1100 MPa at ambient temperature to about 300 MPa at 100°C. The thermal index of the PP impact copolymer for swimming pool collectors, which is an indication for the upper service temperature limit, is about 75°C. Due to the impact modification this grade provides a good low temperature capability down to about -30°C.

Load profiles for overheating protected glazed flat-plate collectors

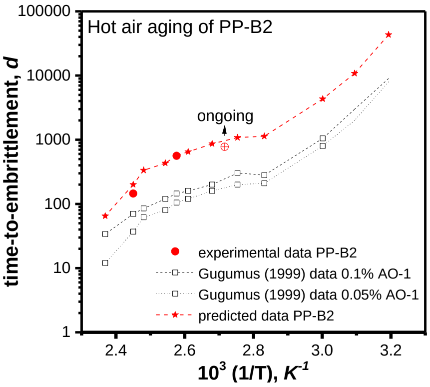
As described in the info sheet "Collector Overheating Protection with Backcooler" a novel fully overheating protected collector concept was developed and validated in *SolPol-2*. Testing of functional model collectors with extruded swimming pool absorbers based on the above mentioned PP impact copolymer revealed, that it is possible to limit the maximum operating and



stagnation temperature of a pumped and pressurized flat plate collector with temperature triggered thermosyphonal backcooling to temperatures below 100°C. For this collector type annual temperature loading profiles were calculated for a pumped hot water system for multifamily houses installed in different climate zones. Depending on the location especially the temperature loads at elevated temperatures are rather different. Higher temperature loads were obtained for e.g., Fortaleza or Athens.

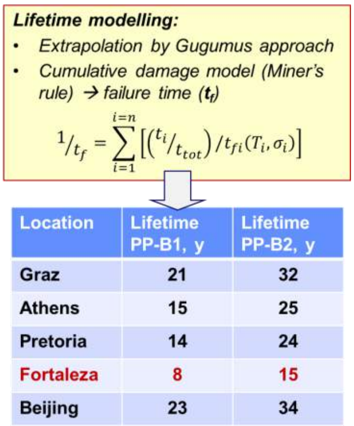
Novel PP grades for absorbers of glazed collectors with overheating protection

In comparison to swimming pool absorber materials, PP grades for glazed collectors have to provide an improved thermomechanical stability (higher thermal index), aging behaviour in air or water/glycol at elevated temperatures and internal pressure resistance, but less weathering resistance due to the protection with an UV screening transparent cover. Hence, the focus of the material development in *SolPol-2* was on the optimization of the semi-crystalline morphology, the carbon black content and the stabilization system. A comprehensive investigation of a variety of formulations exhibited that a lower carbon black content (0.1 m%) is beneficial to increase the thermooxidative stability in hot air. The exposure in hot heat carrier fluid was less critical, which is also related to the stabilizing effect of corrosion inhibitors in glycol. The mechanical properties at elevated temperatures were enhanced by adjusting the crystalline morphology adding a ß-nucleating agent. For the novel PP grades a PE80 classification was achieved providing a long-term strength of components for pressure applications. Using a unique aging characterization approach based on micro-sized specimen, a comprehensive set of aging data was established. For the extrapolation of time-to-embrittlement data at enhanced temperatures (115 and 135°C) to service relevant temperatures (< 100°C) theoretical and empirical models were used.



Lifetime modelling of PP absorbers in overheating protected collector systems for DHW

Assuming a model of cumulative damages endurance limits for the commercial swimming pool PP absorber grade (PP-B1) and a representative *SolPol-2* grade (PP-B2) were deduced for PP absorbers in overheating protected collector systems for domestic hot water preparation in different climate zones worldwide. Due to the enhanced aging behaviour of the novel grade it was possible to increase the expected lifetime by a factor of 2. Ongoing aging investigations are indicating a factor of up to 4 for further improved grades.



Lifetime modelling:

- *Extrapolation by Gugumus approach*
- *Cumulative damage model (Miner's rule) → failure time (**t**$_f$)*

$$^1/_{t_f} = \sum_{i=1}^{i=n}\left[\left(^{t_i}/_{t_{tot}}\right)/t_{fi}(T_i,\sigma_i)\right]$$

Location	Lifetime PP-B1, y	Lifetime PP-B2, y
Graz	21	32
Athens	15	25
Pretoria	14	24
Fortaleza	8	15
Beijing	23	34

Summary and conclusions

Black pigmented polypropylene grades are suitable also for absorbers of glazed solarthermal collectors. However, the collector design and the material grades have to be adjusted. While Magen EcoEnergy (Israel) has already commercialized an all-polymeric glazed collector with PP absorber, in *SolPol-2* further concepts for collector types with significantly improved instantaneous overheating protection and novel PP grades tailored especially for absorber applications have been developed. In further research work, special attention is given to superimposed mechanical and environmental loads.

Recommended literature

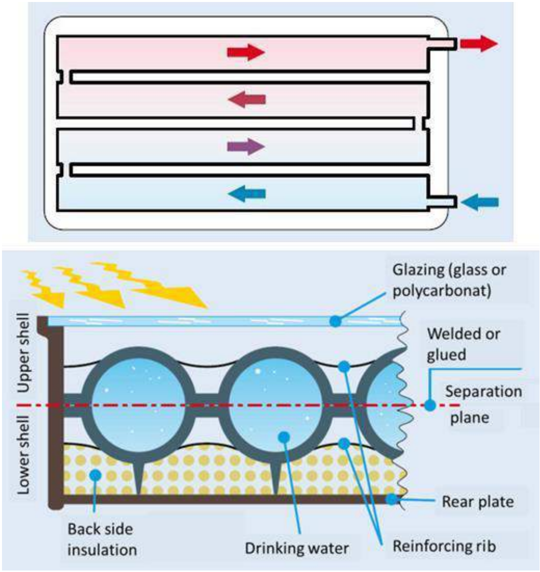
Povacz, M. (2014). Black-pigmented polypropylene absorber materials – Aging behavior and lifetime modelling, Dissertation at the Institute of Polymeric materials and Testing at the University of Linz (JKU-IPMT), Austria.

Polyamide based integrated storage collector

Description	*Glass-fiber reinforced polyamide; injection-moulding and welding of collector parts; performance of pressurized storage collector models*
Date:	16.07.14
Authors:	Gernot M. Wallner, JKU Linz, Institute of Polymeric Materials and Testing, Austria Thomas Lüftinger, Polytec Plastics Ebensee GmbH, Austria Karl Schnetzinger, Advanced Polymer Compounds, Gai, Austria Klaus Lutschounig, GREENoneTEC Solarindustrie GmbH, St. Veit, Austria Dieter Preiß, AEE – Institute for Sustainable Technologies, Gleisdorf, Austriah
Download possible at:	http://task39.iea-shc.org/publications

Integrated storage collectors (ISC) offer a high potential for domestic hot water preparation in tropical, dry and moderate climate zones. In commercially available pressurized single-loop ISC systems the absorber/storage-tank is made from costly metals such as stainless steel or copper pipes. A specific objective of the European Union collaborative research project SCOOP (Solar COllectors made Of Polymers) is to develop and evaluate plastics based ISC tanks manufactured by well-established, high-throughput injection moulding technologies. This info sheet describes the collector concept, most-promising engineering plastics grades, experimental tools and manufacturing processes and the performance of functional model components.

Design of ISC collectors with injection moulded absorber/storage tank and material selection



Integrated storage collectors consist of a pressurized absorber/storage tank with a meander structure, a front-side transparent insulation (incl. glazing), a back-side opaque insulation and a casing. Relevant loading conditions of the pressurized absorber/storage tank in open loop ISC comprise operating temperature limits of 0 and 95°C, a maximum internal pressure of 4 bar at 95°C and a water based heat carrier fluid. To deduce material requirements for the pressurized tank finite element modelling was carried out. At the critical position "fitting/pipe" maximum equivalent stresses of 9 MPa at 95°C were deduced for components with 3 mm wall thickness made from glass-fiber reinforced engineering plastics. Considering thermo-mechanical property requirements along with optical, environmental and processing properties and material costs polyamide grades with a glass-fiber content of at least 30 m% (PA-GF) were selected for manufacturing of functional model absorber/storage tanks. PA-GF exhibits a high capability for injection moulding and welding or bonding of half-shell parts in order to realize hollow components.

Aging behavior of glass-fiber reinforced polyamides

To assess the aging behavior of glass-fiber reinforced polyamides under service-relevant loading conditions various advanced testing procedures are established. On the one hand, pressure cooker testing is performed using injection moulded specimens, which are exposed in water at elevated temperatures (up to 135°C) without additional mechanical loads. On the other hand, a fracture mechanics method is implemented allowing for the characterization of the crack initiation and growth behavior under superimposed environmental and mechanical loads. For selected polyamide grades a good hydrolysis resistance was ascertained without significant embrittlement and a drop of the tensile strength below the critical limit of 20 MPa within an aging time of more than 2000 hours. Hence, the pressure cooker tests at are carried on to generate failure data which are needed for lifetime assessment of polyamide grades for ISC tanks. For the lifetime assessment the Miner`s rule will be applied assuming cumulating damages in the operating temperature range up to 95°C.

Manufacturing and performance of functional model absorber/storage tanks

For injection moulding and joining of functional half-shell parts experimental tools were implemented and used. For different polyamide types with varying glass fiber content a good processability was obtained. As most appropriate technique for joining of half-shell parts frictional welding was established. Internal pressure testing and pressure rise testing of absorber/storage tank subcomponents with a wall thickness of 3 mm revealed a remarkable pressure resistance. At ambient temperature and 90°C brittle failure of the frictional welding seam was obtained at 20 and 10 bar, respectively. In an ongoing optimization loop the wall thickness of the half-shell parts is further reduced to 2 mm.

Using the injection moulded and welded absorber/storage tank subcomponents model collectors were manufactured and examined on an outdoor test facility in Gleisdorf (Austria). To evaluate also meander-type absorber/storage tanks several subcomponents were interconnected with pressure tight tubes. Furthermore, model collectors with state-of-the-art stainless steel absorber/storage tanks and comparable tank volume were realized and investigated. The performance of the novel polyamide based integrated storage collectors was as good as the behavior of the model ISC with stainless steel pipes. Only slight differences were obtained for the heating up cycle during a sunny day and the overnight heat losses.

Summary and conclusions

Within the European Union research project SCOOP a high feasibility for integrated storage collectors based on injection moulded absorber/storage tanks was established. The main advantages are the simplicity (e.g., no hot exchangers or extra storage tanks) and high efficiency of this hot water preparation technology. Compared to stainless steel solutions plastics based ICS offer a high potential for cost-efficient, fully automated mass-production and an improved corrosion resistance and long-term performance.

Recommended literature

Meir, M., Ochs, F., Wilhelms, C., Wallner, G.M. (2012) In: Polymeric Materials for Solar Thermal Applications (Köhl, M. et al., eds), pp. 221-242, Wiley-VCH, Weinheim.

http://www.solcrafte.com/en/models

http://eu-scoop.org/Scoop-Newsletter-No-3.pdf

http://eu-scoop.org/Scoop-Newsletter-No-4.pdf

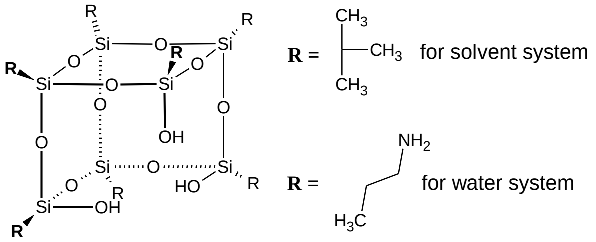
TISS coating as added value for polymeric solar absorber

Description	*TISS coating as added value for polymeric solar absorber*
Date:	15.08.14
Author:	Ivan Jerman, Laboratory for materials chemistry, NIC, Slovenia
Download possible at:	http://task39.iea-shc.org/publications

Polymer based solar collectors are one of the important parts of modern architecture. Market demands are oriented to the coloured absorbers to fulfil the demand of architects and integrate the collectors in new buildings. One of the options for production of coloured collectors is usage of the Thickness Insensitive Spectrally Selective (TISS) paints. TISS paints are tailor-made, multifunctional materials based on a variety of organic macromolecules and functional and processing additives. The material aspects of the coloured TISS paint coatings are focusing on pigments, metallic and metallised flake pigments and polymeric resin binders used for the production of solar paint coatings with the help of dispersant molecules in order to achieve uniform distribution of the finely ground pigment particles in the polymeric resin binder. An important prerequisite for the successful selection and use of pigments in solar-thermal systems is the usage of high absorptivity pigments with their high loading in combination with the low thermal emitting binder. The addition of various organic or inorganic pigments changes the black colour of the TISS coatings to other shades characterized by colour coordinates a, b and chroma C, which differ from those of black TISS coatings but retain the spectral selectivity determined with a_s≈0,88–0,92 and e_T≈0.28–0.43. For industrial application beside the mentioned optical values also low paint surface free energy, adhesion, hardness, weathering resistance thermal and UV stability are important demands. In this info sheet a proposed option for the preparation of paints for solar-thermal systems is described on the basis of Polyhedral Oligomeric SilSesquioxane (POSS) molecules. Relevant features and properties are exemplarily depicted for solvent and water based binders.

Pigment modification by silsesquioxane molecules

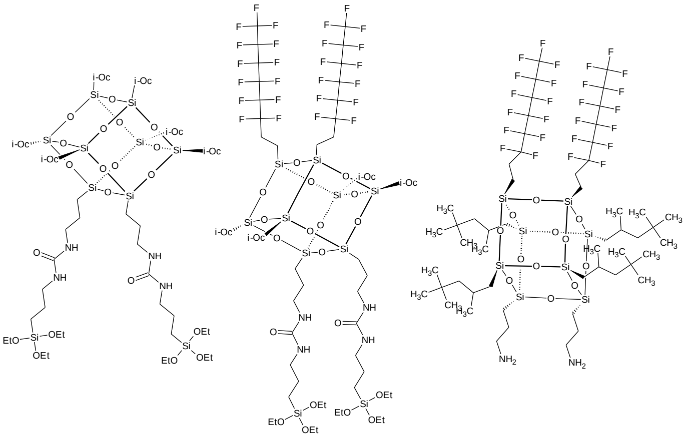
Appropriate pigment dispersion is the key point for obtaining TISS coatings. The pigment dispersion should allow in combination with metallic pigment and binder deposition of thin (≈500–1500 nm) layer over the top flakes in order to impart pigment/metal tandem stack low thermal emittance (e_T). At the same time this tandem must ensure high solar absorptance (a_s). This is achieved when the coating consists of well-dispersed non-agglomerated pigment particles, preferentially smaller than ≈150 nm. Binder selection is very important in this step.



Proposed molecules for pigment surface modification.

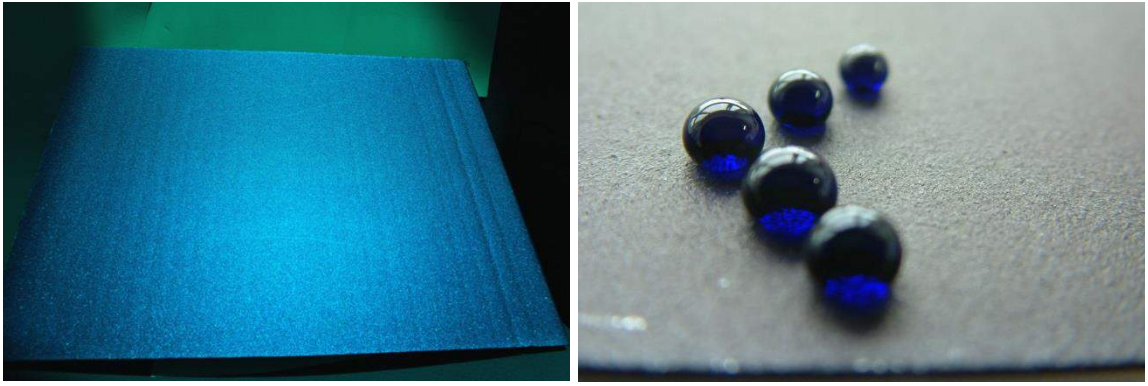
Tuning of the free surface energy by silsesquioxane molecules

Low surface energy is an important aspect. It is reflected in low dew collection, low dust and pollen collection and prevention of dirty water evaporation from the coating surface of glazed and unglazed solar absorbers. Low free surface energy is expressed with a high contact angle for water (>140–150°) and small (α<5–10°) sliding angle of water drops. We have achieved low surface energy by incorporating various POSSs molecules into the structure of TISS paints prepared in our laboratory.



POSS molecules proposed as an additive for decreasing free surface energy of TISS coatings.

Features and properties of TISS paint coatings



Coloured TISS coating on PPS absorber (left) and coloured water droplets on TISS paint surface (right).

Summary and conclusions

The presented silicon compounds allow on one side modification of the pigments and on the other side modification of coatings surface. Both modifications are necessarily for industrial coating demand for polymeric absorbers used for solar-thermal applications. POSS molecules are UV, thermal and weathering resistant. Furthermore, the formulations with proposed additives are candidates for industrial application.

Recommended literature

Jerman, I., Orel, B., Koželj, M. (2012) In: Polymeric Materials for Solar Thermal Applications (Köhl, M. et al., eds), pp. 271-290, Wiley-VCH, Weinheim.

Jerman, I., Mihelčič, M., Vrhovšek, D., Kovač, J., Orel, B. (2011) Solar Energy Materials and Solar Cells, 95, 2, 423-431.

Thermotropic Materials for Overheat Protection

Description:	Thermotropic Materials for Solar Thermal Collectors: Material Selection
Date:	01.11.14
Authors:	Adam Gladen, Susan Mantell, Jane Davidson, University of Minnesota, USA
Download possible at:	http://task39.iea-shc.org/publications

Overview

A Monte Carlo model was developed to determine the steady-state, solar-weighted optical properties of potential thermotropic composite materials for overheat protection of polymer solar absorbers. The key results are dimensionless plots of normal-hemispherical transmittance and reflectance as a function of particle size parameter, scattering albedo, and overall optical thickness. The optical behavior of thermotropic materials at different temperatures is represented by a change in the relative refractive index which, in turn, affects the optical thickness. For example, to provide overheat protection for a PP absorber, the overall optical thickness at the clear state should be less than 0.8 to ensure high transmittance for the preferred particle size parameter of 2.5. At higher temperatures where overheat protection is required, referred to as the translucent state, the overall optical thickness should be greater than 8 and the scattering albedo should be greater than 0.995 to achieve 50% reflectance.

Radiative Model for Thermotropic Materials

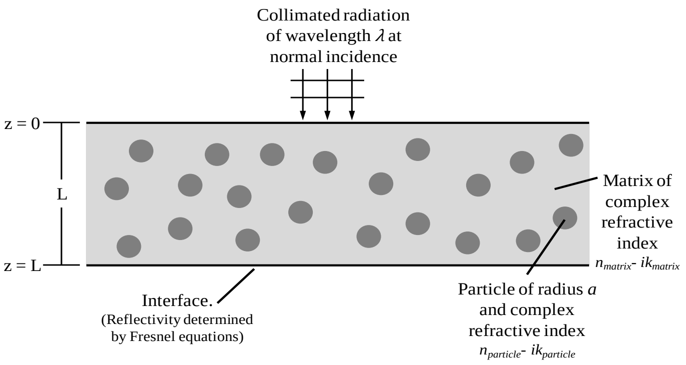
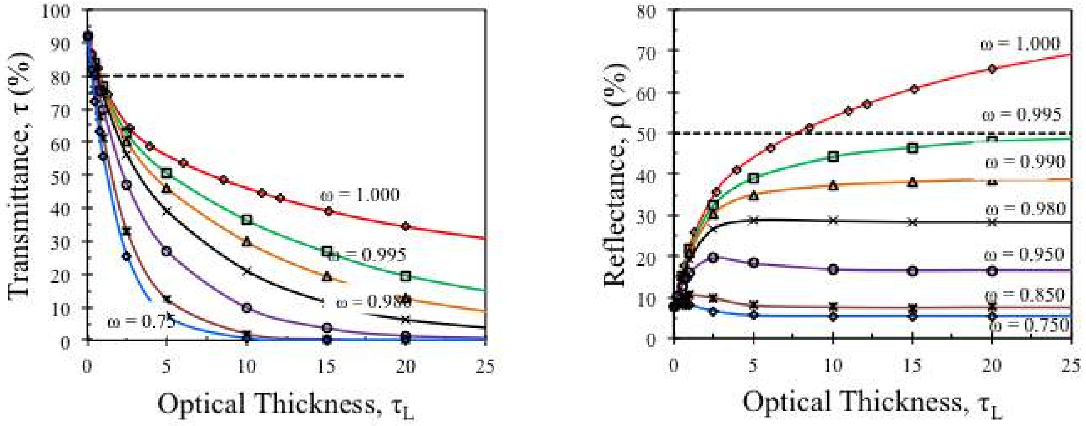


Figure 1. Model of thermotropic material

The thermotropic material (Figure 1) is modeled as a slab with uniform thickness L irradiated with collimated radiation of wavelength λ = 589 nm at normal incidence. The slab is comprised of a matrix material with index of refraction n_{matrix} and absorptance k_{matrix} and monodispersed, randomly distributed, spherical particles with radius a and index of refraction $n_{particle}$ and absorptance $k_{particle}$. Volumetric scattering and absorption within the slab are governed by the equation of radiative transfer. A pathlength Monte Carlo ray tracing algorithm is used to solve the RTE and calculate the normal-hemispherical transmittance, reflectance, and absorptance of the slab as a function of several non dimensional material parameters: the particle size parameter x (= $2\pi a/\lambda$), the relative refractive index m (=$n_{particle}/n_{matrix}$), the overall optical thickness of the slab τ_L, and the scattering albedo ω. For weekly scattering materials (such as polymers), $\omega \approx 1$ and the overall optical thickness can be approximated as $\tau_L \approx 0.75\, f_v Q_s L/a$. The scattering efficiency factor Q_s is a function of the relative refractive index between the matrix and the phase change material, and thus is the only parameter that is a function of temperature.

Material Selection Criteria for Overheat Protection of a PP Absorber

As an example of material selection for overheat protection, we consider the requirements to provide overheat protection of a polypropylene absorber. A solar-weighted transmittance greater than 80% is desirable to maintain high optical efficiency during solar collection [1]. The reflectance in the translucent state required to protect the absorber depends on ambient conditions, the collector design, and the polymer used for the absorber. For worst-case ambient conditions, a solar-weighted reflectance greater than 50% is required to adequately protect a polypropylene absorber (service temperature of 115ºC) [1]. Given the desired optical performance and the particle size parameter (x=2.5), the optical thickness for the clear state must be less than 0.8 and greater than 8 in the translucent state Figure 2 [2]. This change in optical thickness can be achieved by properly selecting the matrix and phase change material.



(a) (b)

Figure 2. Optical thickness to achieve the target performance levels in the (a) clear state and (b) translucent state for x =2.5.

Case Study for a Thermotropic Material with PMMA as a Matrix

Recall the optical thickness is a function of f_v, L, a and Q_s—where only Q_s changes with temperature. Thus, to achieve the desired change from τ_L < 0.8 (clear) to τ_L >8 (translucent) for the PP absorber, Q_s must be evaluated for various matrix/particle combinations at the clear and translucent states [2]. For the case study, poly(methyl methacrylate) was considered as a potential matrix material, because it has high clarity and low absorption. The scattering domain materials considered were drawn from the list provided Weber et al. [3]. The selection process requires calculating Q_s at the two states for various combinations of materials, and selecting f_v and L such that the target optical performance is achieved [2]. Following this process, hydroxystearic acid (HSA), a fatty acid derivative, in a matrix of PMMA ($m_{clear} = 1.0054$; $Q_s = 0.0021$ at $T = 29$°C ; $m_{trans} = 0.9734$; $Q_s = 0.0064$; $T \approx 80$°C) was identified. At f_v= 18%, and L= 3mm, the transmittance in the clear state is 80% (optical thickness of 0.49) and the reflectance in the translucent state is 51% (scattering albedo of 0.998, optical thickness of 11). Note this case study is intended to demonstrate an approach that can be applied for other thermotropic material combinations and optical performance requirements.

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Bioplastics for solar collector components

Description:	*Novel materials* *Green systems*
Date:	30.06.2014
Authors:	Katharina Resch, Montanuniversitaet Leoben Andrea Klein, Montanuniversitaet Leoben Gernot Oreski, Polymer Competence Center Leoben
Download possible at:	http://task39.iea-shc.org/publications

Introduction and scope

Numerous research and development activities carried out by renowned research facilities and the global players in the polymer and solar industry – presented and discussed also within the framework of IEA SHC Task 39 – demonstrate that polymers are the materials of choice for next generation solar thermal systems [1]. In addition to classical polymers made from petrochemical resources bioplastics (i.e. polymers based on renewable resources and/or biodegradable polymers) have been introduced as a sustainable and seminal alternative [2,3]. Bioplastics are already successfully used in the automotive and electronic industry [3]. Therefore, bioplastics are expected to have a high potential in the solar industry as well, yielding further greening of solar thermal systems. However, so far no systematic and comprehensive investigation of bioplastics for solar applications has been carried out. Hence, in scientific literature there are almost no data on relevant properties regarding solar applications (optical, mechanical, and thermal properties). Also the material characteristics after exposure to application relevant external stress factors such as ultraviolet (UV) radiation, humidity and temperature have not been investigated extensively so far. Therefore, within the project “Bio4Sun – Bioplastics for solar applications” (funded by the Klima- und Energiefonds (Austrian Climate and Energy Funds) and carried out within the framework of the e!mission program) the principle potential and applicability of bioplastics in solar thermal devices (absorbers, glazings, framing for various collector types) was evaluated and tested.

Material selection, processing and characterization

In total 38 materials were selected following extensive literature research and market survey. Elected biopolymers include cellulose derivatives (CA, CAB), thermoplastic elastomers (TPU, TPE, TPA), poly lactic acid (PLA) and blends thereof, poly hydroxy alcanoates (PHA, PHB), poly trimethylene terephthalate (PTT), bio polyethylene (PE), poly butylene succinate (PBS) and blends thereof, bio polyamide (PA) as well as starch blends. Bioplastics were extruded into films with a thickness between 200 and 500µm on a Dr. Collin Laboratory extruder. Following a basic characterization after extrusion into films, several of the biopolymers were nominated for further investigation regarding their ageing behavior. Depending on the specific application (collector glazing, absorber, swimming pool absorber, air collector etc.) accelerated ageing was done on film specimens in air, in air including UV radiation (Xenontester), and in water at various temperatures ranging from 35°C up to 80°C. Specimens were tested after 250, 500 and 1000h of exposure. Moreover, outdoor exposure is conducted for 2.5 years with specimens being tested after 3, 6, 12, 18, 24 and 30 months. Characterization of as-produced and aged samples focused on thermal, thermo-mechanical, mechanical and optical properties. Differential Scanning Calorimetry (DSC), Dynamic Mechanical Analysis (DMA), tensile testing, UV/Vis/NIR spectroscopy and IR spectroscopy were applied.

Performance characteristics and applicability

The generated polymer physical property profiles of as-produced samples indicated that bioplastics in general possess a high potential for application in solar thermal devices. However, long-term service temperatures are limited. Thus bioplastics available so far are mainly suitable for low-temperature components (glazings, swimming pool absorbers, air collector absorbers) or for components with integrated overheating protection (e.g. flat-plate collectors with thermotropic glazing or integrated venting mechanisms). Most promising candidate materials are CA, CAB, PA, Bio-PE, PTT, PLA and blends of it, PHA, and PBS. Several biopolymers came into consideration for more than one component type. Ageing tests emphasized the potential of bioplastics for application in solar thermal technology. However, also high potential and necessity for further optimizing performance properties by using specific or functional (bio-) additives to enhance long-term service temperatures and thermo-mechanical characteristics as well as long-term stability were revealed. Especially after exposure to UV radiation or storage in water at elevated temperatures deterioration in mechanical performance characteristics was determined. Details are found in:

Resch, K., Klein, A., Oreski, G. (2014). Bioplastics in solar thermal applications: opportunities and limits, manuscript in preparation.

Klein, A., Oreski, G., Resch, K. (2014). Ageing characteristics of bioplastics, manuscript in preparation.

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[3] www.european-bioplastics.org

Polymeric Liner Materials

Description	*Polymeric Liner Materials for Hot Water Heat Storages*
Date:	15.07.14
Author:	Klemens Grabmayer, JKU Linz, Institute of Polymeric Materials and Testing, Austria
Download possible at:	http://task39.iea-shc.org/publications

Hot water heat storages are important components of solar thermal systems. Various polyolefin-based material grades are material candidates to serve as liners in hot water heat storages. In order to fulfill the requirements, characterization of the aging behavior is indispensable for material selection.

Solar thermal systems and heat storage


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Centralized large-scale solar thermal plants for district heating substantially raise the cost effectiveness of solar thermal energy conversion. Using seasonal heat storage, solar fractions of 50 % or more can be achieved for the annual demand in domestic hot water and space heating. Pit and tank storages are the most relevant types of storages, since they do not require specific hydro-geological conditions like borehole or aquifer storages. They use water (pure or mixed with gravel or soil) as storage medium. Since the relative heat losses as well as the relative costs of installation are inversely proportional to the storage capacity, heat storages are most efficient for big storage volumes. The biggest operating storage is the hot water pit heat storage situated in Marstal, Denmark, with a storage capacity of 75000 m³ of water.

Polymeric liner materials

To ensure water tightness, hot water storages (tank or pit) are sealed by a water-proof liner. Liners for tank storages are made from stainless steel or polymeric materials, while for pit storages, polymeric liner materials are preferred to stainless steel due to their lower material and installation costs. For example, by using a polymeric liner, the specific installation costs for storages bigger than 50000 m³ can be kept at approx. € 20 to 30 per m³.

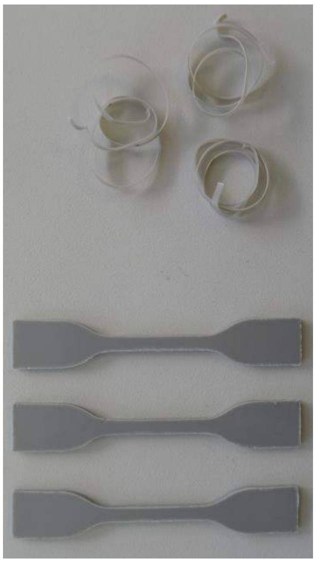
Common polymeric liner materials are semicrystalline polyolefin-based polyethylene or polypropylene grades developed for applications with water contact (piping, tunnel and landfill construction, etc.). The relevant material classes are PE-RT for polyethylene-based liners and PP-R and PP-RCT for polypropylene based liners. These polymeric materials exhibit a ductile material behavior in the service temperature range between about 40°C to 95°C, they are waterproof, resistant to hydrolysis and weldable. For applications which require a low water vapour transmissivity, polyolefin-based lining materials are available as multi-layered films containing a vapour barrier.

Polyethylene of raised temperature resistance (PE-RT) comprises a material class of medium and high density polyethylenes (PE-MD, PE-HD) that due to their special morphological composition are particularly suitable for applications with hot water contact. Based on the controlled incorporation of octene and hexene comonomers into the growing polyethylene chain during polymerisation, the probability of the formation of tie molecules which are single molecules incorporated into different crystal lamellae, is enhanced. Tie molecules are known to improve material toughness and the resistance to environmental stress cracking as well as the long-term creep properties, the latter of which are particularly relevant for hot water applications.

Polymeric Liner Materials

PP-R (polypropylene-random) and PP-RCT (polypropylene-random with enhanced crystalline structure and improved temperature resistance) are random copolymers of polypropylene and ethylene. For hot water applications, the total amount of ethylene typically does not exceed 5 m%. Similarly to PE-RT type materials, the incorporation of ethylene into the polypropylene molecule enhances tie molecule formation. By increasing the tie molecule fraction, the molecular network in the amorphous PP phase is tightened improving impact toughness and long term creep resistance of PP-R materials. PP-RCT materials are similar to PP-R materials. Due to the introduction of a defined semicrystalline morphology by a special nucleation technique, these materials exhibit even better toughness and creep properties than common PP-R types.

Development of polymeric liner materials



The objective of work package 05 within the cooperative research project *SolPol-2* (www.solpol.at) was the development of polyolefin-based liner materials for hot water heat storages. For this purpose, more than 10 different polyolefin-based matrix systems were prepared. The compounds were screened regarding the basic requirements for lining applications such as weldability and a sufficiently low modulus around 600 MPa at room temperature providing a certain degree of flexibility during installation. 6 compounds were selected to serve as matrix systems for further investigations. Prior to aging testing, selected compounds were further modified with additional amounts of various types of stabilizers (sterically hindered phenols, thiosynergists, hindered and aromatic amines) in order to improve the performance of the commercial base stabilization contained within the materials. In total, more than 20 different formulations of polyolefin-based model compounds were characterized as to their aging behavior on specimen level. Specimens were exposed in hot air or water at temperatures between 95°C and 135°C. Aging characterization was performed by Infrared Spectroscopy, Differential Scanning Calorimetry, High Performance Liquid Chromatography and tensile testing. The results revealed significant differences in the thermal stabilities of the formulations depending on the material type as well as the stabilizer system. Based on the results, the first PE-RT based geomembrane explicitly suitable for lining of hot water heat storages was brought to the market by AGRU Kunststofftechnik, Bad Hall, Austria, under the trademark *HTR PE Liner* (HTR: high temperature resistant).

Summary and conclusions

Polyolefin-based liners are suitable for hot water heat storages and outperform steel liners due to low material and installation costs. However, because of the abundance of polyolefin-based materials on the market and the differences in the thermo-oxidative stability of the various material grades in hot water, careful material selection is a prerequisite to ensure the reliability of the heat storage system. This can be realized by systematic aging characterization of polyolefin-based liner materials. Regarding the material grades, PE-RT, PP-R and PP-RCT grades are considered most suitable to serve as liners in hot water heat storages.

Recommended literature

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Grabmayer, K., Wallner, G.M., Beißmann, S., Braun, U., Steffen, R., Nitsche, D., Röder, B., Buchberger, W., Lang, R.W. (2014). Polymer Degradation and Stability, 109, 40-49.

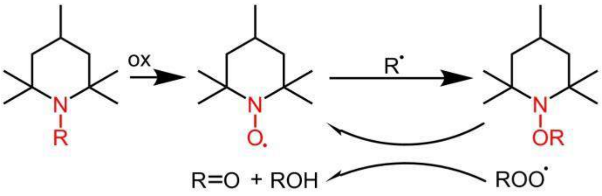
AGRU (2014). http://www.agru.at/en/products/lining-systems/product-catalogue/cat/pe-high-temperature-resistant-liners; accessed on July 22, 2014.

The Art of Stabilization

Description	*The Art of Stabilization – Analytical Evaluation of Stabilizer Systems*
Date:	03.08.14
Author:	Susanne Beißmann, JKU Linz, Institute of Analytical Chemistry, Austria
Download possible at:	http://task39.iea-shc.org/publications

Without proper stabilization, polymers are susceptible to degradation caused by reactions with oxygen or UV-light, which lead to undesirable changes in the properties of the polymer. A stabilization system is normally added to the polymeric material, which is responsible for maintaining mechanical properties like strength and toughness. Unfortunately, it is not yet fully clear which combination of stabilizers provides the best performance for a specific application. Furthermore, interactions between different stabilizer classes have to be carefully investigated as they may lead to exploitable synergistic or avoidable antagonistic effects.

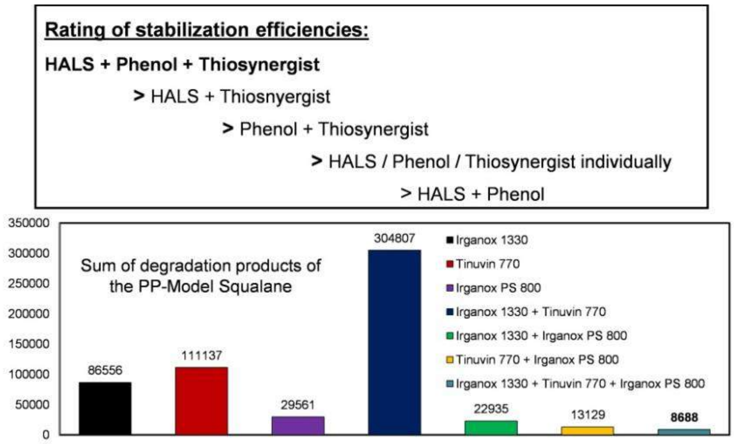
Stabilizer Systems



Suitable stabilizer systems have been developed to inhibit or slow down thermal oxidation of polymeric materials. The most important classes of additives suitable for long-term heat protection of polymers are phenolic antioxidants, thiosynergists and so called hindered amine light stabilizers (HALS), which show a high protecting efficiency against light and heat-induced degradation of polymers. The high efficiency of HALS is considered to originate from a complex set of reactions including scavenging of alkyl and peroxy radicals formed during oxidative attack on the polymer. According to the Denisov Cycle (Figure shown above) the parent amine is oxidized to the corresponding nitroxide radical, which subsequently reacts with polymeric alkyl radicals. HALS are often used in combination with primary and secondary antioxidants as they fail as processing stabilizers. This combination may show antagonism as well as synergism. Due to these unpredictable synergistic or antagonistic effects in complicated mixtures used in real polymer materials, the rating of stabilizer efficiencies is rather complicated. Obviously the investigation of interactions between stabilizers from different chemical classes is very important as they can be critical to their functionality.

Analytical Evaluation of Stabilizer Systems

Analytical evaluation of individual degradation pathways of additives is of major importance to get an idea about the suitability of individual stabilizers for certain applications.
Stabilization mechanisms of the most important additive groups for long-term heat protection of polymers were investigated. A highly sensitive HPLC-MS method was developed to detect and identify stabilizers and their degradation pathways. To elucidate the long-term heat protection efficiency of different stabilizer formulations and the possible chemical reactions between different stabilization classes, several antioxidant systems consisting of HALS in combination with a phenolic antioxidant or a thiosynergist were subjected to aging tests in squalane (mimicking a polyolefin), and decomposition rates as well as chemical changes in the molecular structure of the additives were monitored. Additionally ternary mixtures, including all three stabilizer groups were tested. Stabilization efficiencies were rated upon the observed protection of the PP-mimicking squalane.



Results visualized a strong antagonistic effect between phenolic antioxidants and HALS. The reaction mechanism between HALS and thiosynergists as proposed in the literature also would suggest a strong antagonism, as acidic degradation products of the thiosynergist deplete the protection efficiency of the HALS. In the present study no antagonistic effects were observed and combination of these two stabilizers was rather favourable to extend the service life of the polymer. Of all investigated formulations the ternary combination HALS/phenol/thiosynergist showed the highest protection efficiency for the polymeric material.

Summary and conclusions

In the present study the potential of HPLC coupled to highly sensitive MS detection could be clearly demonstrated for detection and identification of HALS and their degradation products. By comparing degradation products derived from squalane using different additive packages, stabilization efficiencies could be rated. The best performance was given with the ternary mixture HALS / thiosynergist / phenol, followed by the mixture HALS / thiosynergist. These results suggest a synergistic effect between these stabilizer groups, which was not reported in the literature until now. A strong antagonistic effect between phenolic antioxidants and HALS was observed. Both stabilizer groups were consumed faster if used in combination compared to the separately aged solutions, and once the concentration of the effective form of the stabilizers drops below a critical value there is a rapid chemical change of the polymer.

The developed analytical method and newly acquired knowledge of individual complex degradation pathways and interactions between chemical groups are of significant importance to avoid antagonistic effects in additive formulations.

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Beißmann S, et al. Analytical evaluation of the performance of stabilization systems for polyolefinic materials. Part I: Interactions between hindered amine light stabilizers and phenolic antioxidants. 2014; manuscript submitted to the Journal of Polymer Degradation and Stability.

Beißmann S, et al. Analytical evaluation of the performance of stabilization systems for polyolefinic materials. Part II: Interactions between hindered amine light stabilizers and thiosynergists. 2014; Manuscript submitted to the Journal of Polymer Degradation and Stability.

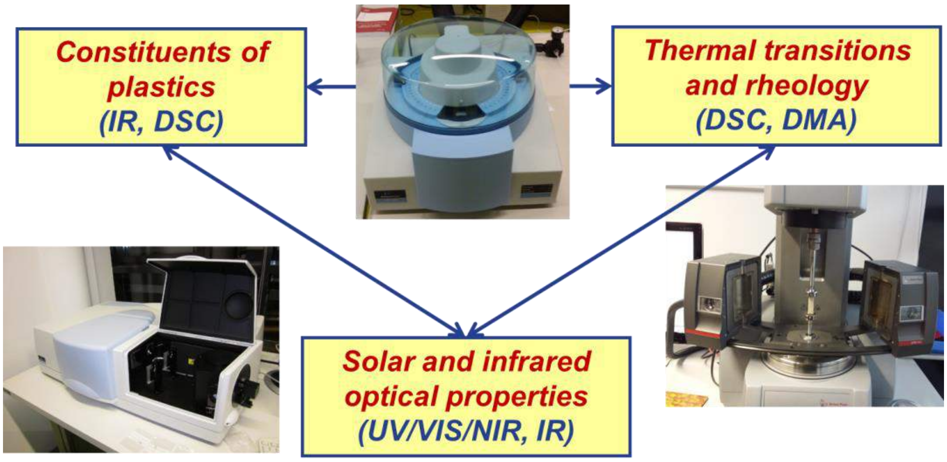
Tool box for basic characterization of plastics

Description	*Basic characterization of polymeric materials for solar-thermal applications*
Date:	15.07.14
Author:	Gernot M. Wallner, JKU Linz, Institute of Polymeric Materials and Testing, Austria
Download possible at:	http://task39.iea-shc.org/publications

Plastics are tailor-made, multifunctional materials based on a variety of organic macromolecules and functional and processing additives. An important prerequisite for the successful selection and use of plastics in solar-thermal systems is the comprehensive definition and description of application-relevant loading profiles and the deduction of property requirements. For specified plastics grades reproducible material quality has to be controlled and assured. In this info sheet a tool box for the basic characterization of plastics for solar-thermal systems is described. Relevant features and properties are exemplarily depicted for absorber materials based on polyphenyleneoxide (PPO) and polyphenylene-sulfide (PPS).

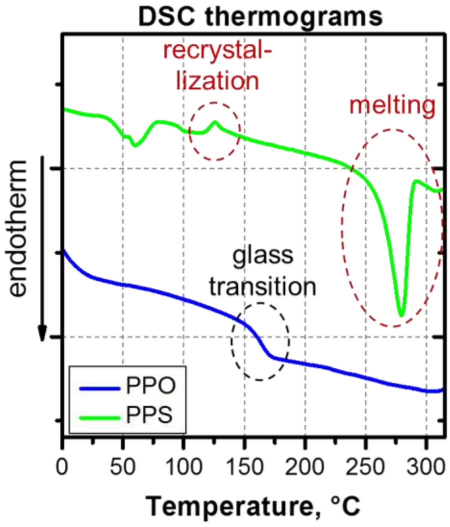
Basic characterization tool box

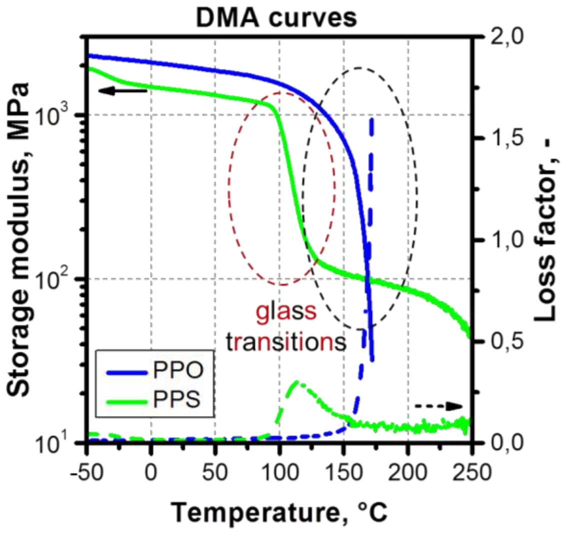
For the basic analysis of the constituents of polymeric materials infrared spectroscopy (IR) in attenuated total reflection mode (ATR) and differential scanning calorimetry (DSC) are commonly used. By IR spectroscopy the material structure based on e.g., CHON atoms (C..carbon, H..hydrogen, O..oxygen, N..nitrogen) is elucidated. DSC allows for the description of the morphological structure (amorphous or semi-crystalline) and relevant thermal transitions (e.g., glass transition, melting range). A characteristic feature of plastics is their inner mobility which is responsible for time- and temperature dependent mechanical properties commonly characterized by dynamic mechanical analysis (DMA). In the molten state DMA is carried out to describe rheological properties which are affected by the macromolecular structure (e.g., average molar mass, branching or crosslinking). A simple rheological method for quality control of plastics is melt flow index (MFI) testing. For the assessment of application-relevant optical properties in the solar and heat radiation range UV/VIS/NIR- and IR-spectroscopy with Ulbricht globe detectors are well established.



Features and properties of PPO and PPS absorber materials

Polyphenyleneoxide and polyphenylenesulfide are classified as engineering plastics characterized by elevated service temperatures above 100°C. The good heat resistance is resulting from the macromolecular main chain structure based on aromatic rings (phenylene groups (P)) which are linked by oxygen (in PPO) or sulphur (in PPS). For PPO and PPS tailor-made grades have been developed which are used for the production of twin wall sheets for solar-thermal absorbers. These grades are pigmented with small amounts of carbon black and modified with another polymer type to adjust the processing and performance property profiles. While PPO is commonly blended with polystyrene (PS), PPS is impact-modified with a polyolefin elastomer (PO). Because of their chemical structure PPO and PPS exhibit significant differences in their morphology and the thermal transitions. These differences can be clearly elaborated by DSC and DMA (s. representative Figures). PPO+PS blends are fully amorphous materials with a glass transition region between 150 and 175°C. For PPO the glass transition is discernible in the DSC thermogram (endothermic step) and the DMA storage modulus (stepwise transition) and loss factor (peak) curves. The glass transition region is associated with significant softening of the material expressed by the decay in the storage modulus. The maximum service temperature of amorphous plastics such as PPO is usually limited by the glass transition and should be about 20°C below the onset.


DSC thermograms


DMA curves

For PPS the DSC thermograms and DMA curves indicate the semi-crystalline morphology. In the DSC trace a significant endothermic peak is denoting the melting range which is around 280°C for PPS. Due to semi-crystallinity of PPS also a glass transition is observed between 90 and 120°C which can be reliably determined by DMA. A characteristic feature of extruded polymeric components based on slowly crystallizing semi-crystalline plastics such as PPS is an exothermic recrystallization peak between glass transition and melting range. For PPS recrystallization takes place around 130°C. To avoid physical changes in the use phase and to improve the mechanical properties PPS components are commonly tempered at elevated temperatures around 140°C.

Regarding the solar and infrared optical properties black-pigmented PPO and PPS grades are characterized by high absorbance in the solar and heat radiation range (90 to 95%). Due to the higher index of refraction of PPS the reflectance (up to 10%) is slightly higher for PPS.

Summary and conclusions

The presented tool box allows for the material characterization on specimen and component level and provides a basic understanding of specific features and properties of plastics for solar-thermal applications. As to the long-term behavior under service-relevant loading conditions the time- and temperature dependent mechanical properties (creep or relaxation phenomena) have to be considered and assessed. Furthermore, the formulation of the material with stabilizer packages is of utmost importance. For the analysis of additives specific separation and detection methods are required.

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Twin wall sheet testing

Description:	*Material testing - indentation test of twin wall sheets*
Date:	01.10.2014
Authors:	Andreas Piekarczyk, Alyin Durson
Download possible at:	http://task39.iea-shc.org/

Introduction

When using polymeric materials for solar thermal flat plate collectors, one distinct difference in physical properties compels us to reinvent the absorber design. Due to the low thermal conductivity of polymeric materials, the absorber, in order to prevent local overheating and to increase the collectors' efficiency, needs water contact throughout the whole surface. In general only few absorber designs fulfill this requirement, e.g. thin plastic film absorbers, tube absorbers or twin wall sheets. The latter two are in the focus of recent development due to mechanical stability and economic efficiency. In order to investigate changes in the mechanical properties of the used materials as closely to the product as possible suitable mechanical testing methods need to be applied. For pipes, methods to test different mechanical loads already exist, but for twin wall sheets none of these can be applied.

Twin wall sheets

Produced by melt extrusion, twin wall sheet can be produced with a constant cross-section but variable length. With a little effort, this allows for the production of absorbers with variable dimensions. With these scaling effects the production cost can be reduced effectively. During production the molted polymer is pushed through a dye with the negative profile of the intended cross-section. This original geometry of the twin wall sheets can be distort during the production by fluctuations in temperature, cooling behavior and other factors. The occuring deformations are illustrated in *Fig. 1* and may even occur in combination. These deformations make twin wall sheets, from an analytical point of view, a very inhomogenous speciemen. Therefore it is important to either test many speciemen or to developl new methods that are not influenced by these inhomogenities.

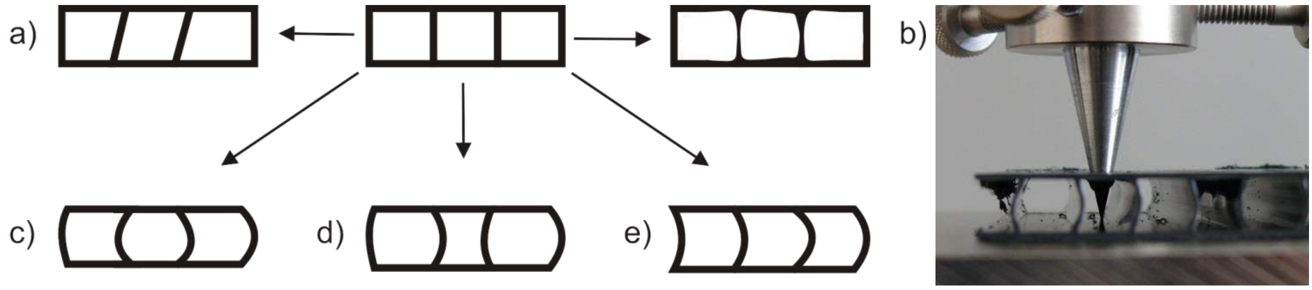

Fig. 1. Left: Geometry variation of an ideal twin wall sheet structure.
Right: Indentation test with sharp indenter.

Two different approaches

For the indentation test a specimen is placed on the table of the testing equipment (standard material testing machine) and an indenter of specific shape is pressed with constant speed into the specimen while the necessary force is recorded. The resulting force-depth-diagram provides information about basic material properties. These properties are expected to change during the ageing of the material and therefore this method is a good qualification for the degradation of the mechanical properties of a material. If changes are little and the inhomogeneity is high, many samples need to be analyzed. In order to reduce effort, a blunt indenter can be used and the testing of the sheets can be analyzed regarding pass or fail criteria.

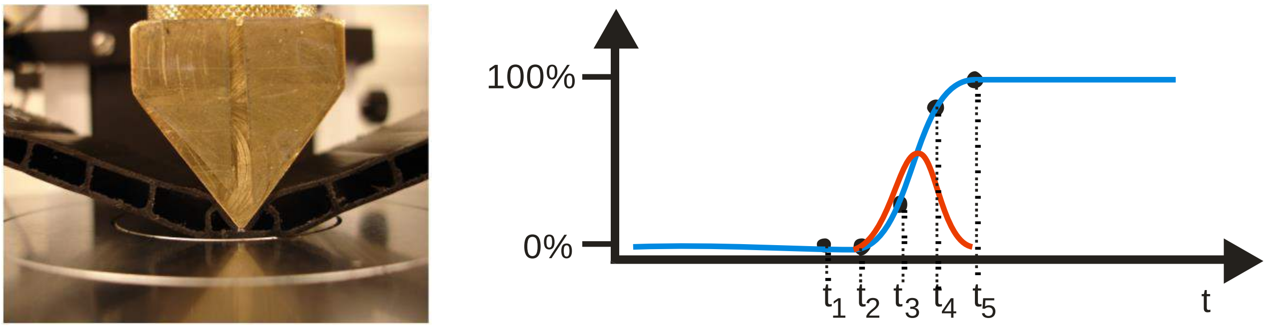

Fig. 2. Left: Indentation test with blunt, prismatic indenter.
Right: Schematic of data analysis: At five time (t1-t5) intervals of accelerated ageing samples certain amount of specimen were failing the pass criteria. Based on the distribution function (blue) a probability distribution (red) can be estimated. The interval t5 marks the failure of all specimen.

However, for accelerated ageing tests with unidirectional load exposure, like UV irradiation, this method is not suitable as several geometry related effects interact and make it difficult to identify changes in the force-depth-diagrams related to individual degradation effects. For this purpose the indentation test was modified by using a sharp indenter (*Fig. 1*) piercing through one of the external walls. This way the overall geometry is not affected by the indentation procedure and information about one structural element of the sheet is acquired. In the context of accelerated ageing through UV exposure, by analyzing both sides of the twin wall sheets, it can be differentiated between UV induced and temperature related changes in the mechanical properties of the extruded sheets. Combining these two methods will allow for the improvement of this product specific mechanical testing method which can be used as a standard tool for material testing and quality analyses.

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*“*Entwicklung neuer Prüfverfahren für die Alterungsbeständigkeit von Polymerwerkstoffen für solarthermische Kollektoren*”*, A. Piekarczyk, T. Meier, T. Trötschler, M. Köhl, K.-A. Weiß; 24. Symposium Thermische Solarenergie, Bad Staffelstein, 2014

Accelerated UV-Aging

Description:	*UV stability* *Ageing tests*
Date:	01.10.2014
Authors:	Andreas Piekarczyk, Karl-Anders Weiß
Download possible at:	http://task39.iea-shc.org/

Introduction

Polymeric materials for solar thermal applications have to be tested thoroughly before they can be used for the construction of novel collectors. Used as absorbers, glazing or framing, just to mention a few applications, polymers are exposed to a broad variation of different environmental influences which may affect physical and mechanical properties of the materials and limit their service life time. Three major environmental influences, so called degradation factors are: temperature, UV radiation and humidity. One of these factors, the UV radiation, is of great impact on all organic macromolecules, like polymeric materials.

UV influence and protection

Around 6% of the intensity of solar radiation reaching the earth´s surface are within the UV range (100-380/400 nm). This high energy radiation can be further distinguished in UVA (315-380/400 nm9, UVB (280-315 nm) and UVC (100-280 nm). As UVC radiation is quantitatively absorbed by earth´s atmosphere the relevant part of the UV spectrum is within the UVA and UVB region, while the amount of UVB varies between 15 and 35% depending on location and definition of the UVA range. The photon energy of radiation in the UVA and UVB range is high enough to induce damage in molecules through photochemical processes. Polymers, as macromolecules, are especially affected by this as a cleavage of the polymer chain can significantly change the materials physical properties, to mention just one effect of UV radiation.

UV radiation is absorbed by the matter it interacts with and therefore has a limited penetration depth into the materials. However damage is induced to the surface, like embrittlement or cracks, can spread through the material and significantly affect the mechanical stability of work pieces. In order to protect polymeric materials and prevent UV induced damage polymers are often, depending on the application, equipped with UV stabilizers. Among others carbon black, a carbon based pigment, is used for UV protection. The broad absorption, from the UV to the infrared range, of carbon black is used to prevent the actual polymer from damage. Other stabilizers, like hindered amine light stabilizers (HALS), are radical scavengers and inhibit radical chain reactions which would lead to degradation of the polymer.

Accelerated aging test methods

In order to simulate the effects of years of UV exposure under laboratory conditions different UV sources are available, but they have to be chosen carefully according to the material and addressed question. Some light sources emit not only high intensities of UV radiation, but also a large amount of visible light and infrared radiation. Especially by black polymers this additional energy input is largely absorbed and causes a non-negligible increase in temperature of the test specimen. Further, different light sources have different spectral distributions even in the UV range, as illustrated in *Fig. 1*, showing a comparison of different UV sources. For polymers, depending on the polymer type, pigments, UV stabilizers and other additives, certain wavelength of the UVA and UVB may have more impact on the materials than others. For material screenings and comparison of different aging intervals it is necessary to take care that the light sources have a high level of spatial homogeneity, even over large irradiation areas.

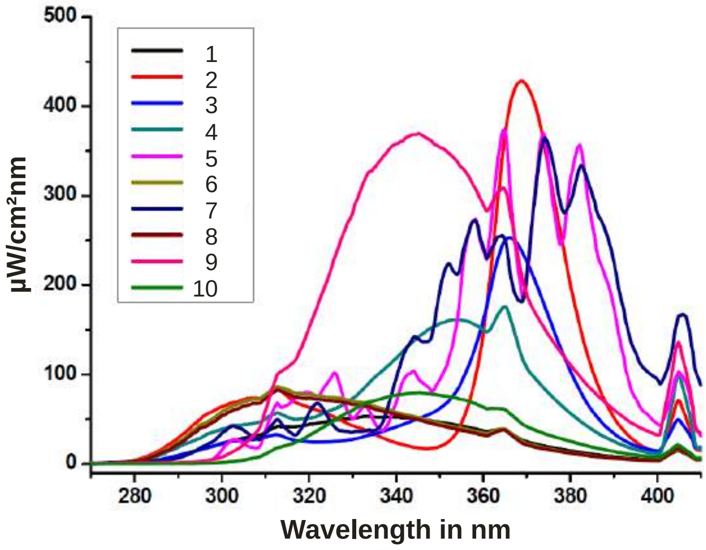

Fig. 1 left: Comparison of the spectral intensity distribution of different light sources for UV aging. It shows not only a broad variation in total intensity, but also in regions of the UV range.
Right: Researcher in protective gear sampling different polymer specimen in a UV chamber.

Summary

In order to study solely UV induced degradation effects, light sources with high UV loads and low share of spectral intensity in other regions are to be preferred. Further care has to be taken to eliminate intensity inhomogeneities in the irradiated surface. The choice of the suitable spectral range is essential for the observed effects and should reflect the real environmental conditions. Concerning dose effect correlations a detailed study is necessary as a linear correlation does not always apply as UV induced damage is inflicted on the materials surface and affects the materials properties in various ways.

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Polymeric Materials for Solar Thermal Applications

2006 - 2014

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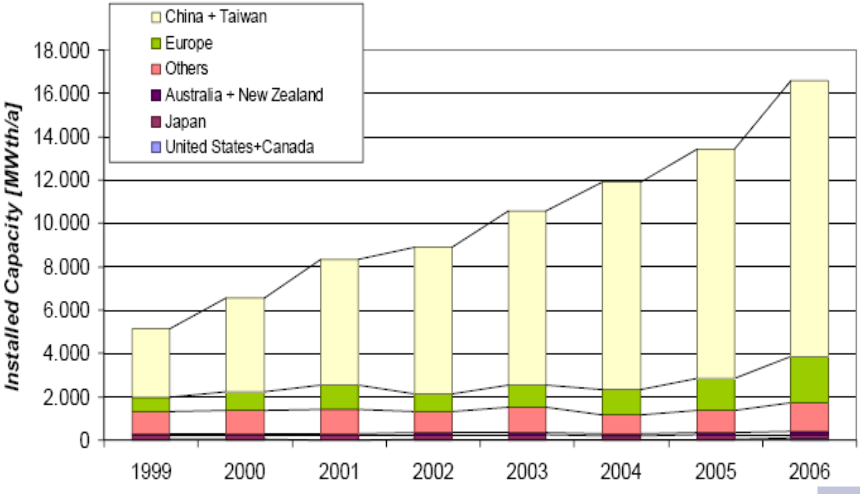
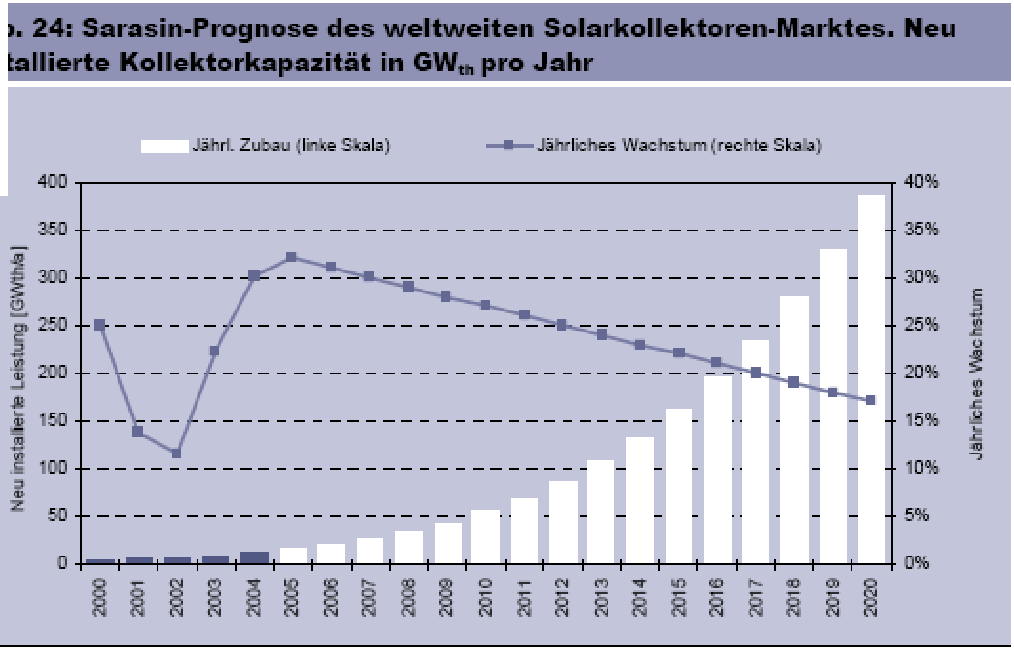
gernot.wallner@jku.at

Background: Solarthermal growth



20% Annual growth:
390 GW ~ 560 Mm² in 2020



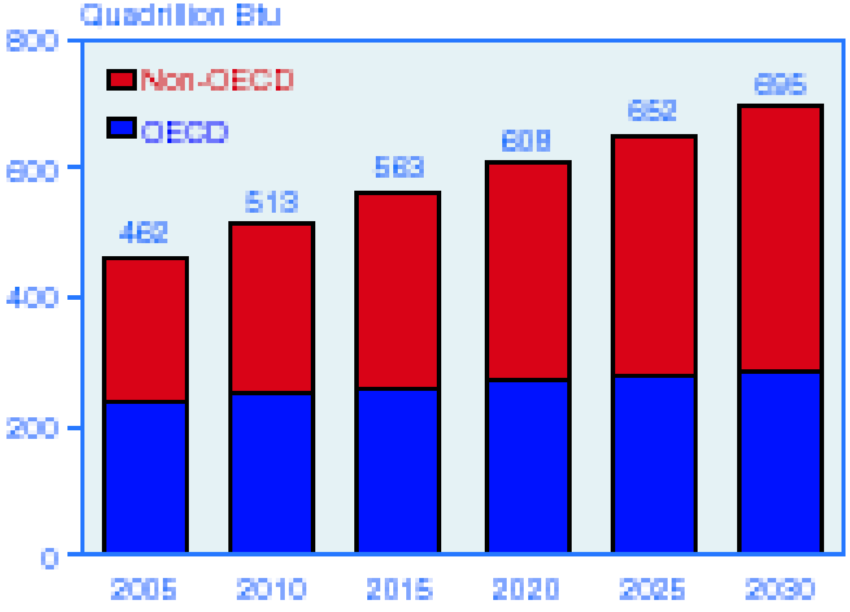
. 24: Sarasin-Prognose des weltweiten Solarkollektoren-Marktes. Neu tallierte Kollektorkapazität in GW_{th} pro Jahr

Quelle: Sarasin, 2005

How to provide the raw materials?

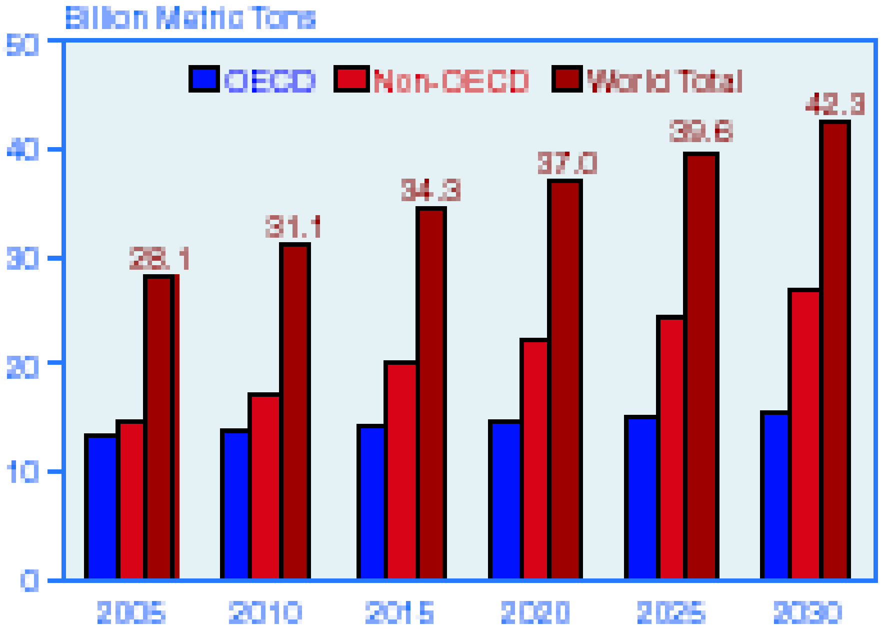
Energy consumption

Figure 1. World Marketed Energy Consumption, 2005-2030



Sources: 2005: Energy Information Administration (EIA), *International Energy Annual 2005* (June-October 2007), web site www.eia.doe.gov/iea. Projections: EIA, World Energy Projections Plus (2008).

Figure 8. World Carbon Dioxide Emissions, 2005-2030



Source: Energy Information Administration, World Energy Projections Plus (2008).

Cost scenarios


5 Year Copper

Mar 23, 2001 to Mar 23, 2006


5 Year Aluminum

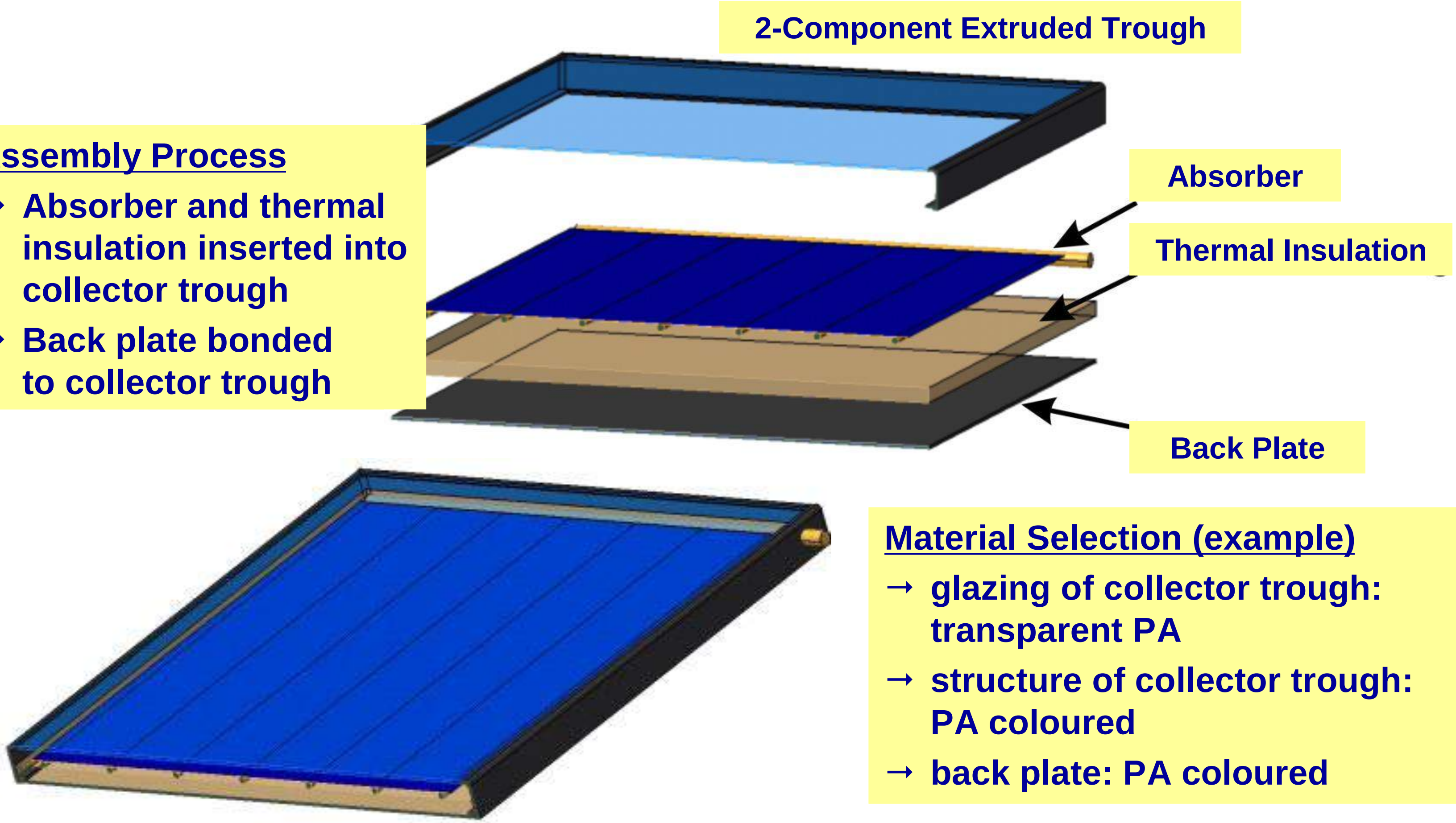
Mar 23, 2001 to Mar 23, 2006

cost (eur/m2)		**metal**	**plastics**	**savings**	**savings%**
Materials					
	absorber	38	22	16	42%
	transp cover	23	14	9	39%
	casing	6	4	2	33%
	sealing	3	3	0	0%
	insulation	2	2	0	0%
	other	4	4	0	0%
Material total		76	49	27	36%
labor		15	9	6	40%
Total production		91	58	33	36%
overhead		50	50	0	0%
Panel cost		**141**	**108**	33	23%
Installation		100	70	30	30%
Grand Total		**241**	**178**	63	26%

Objectives

- Assessment of the **applicability** and the **cost reduction potential of polymeric materials** for solar thermal systems
- Novel polymer based **designs**
- Evaluation of **less expensive materials**
- Assessment of **durability** and **reliability**
- Promote increased **confidence** in the use of these products
- Development and application of appropriate **testing and certification methods**
- Identification of **less expensive manufacturing** processes

Collector components



Assembly Process

→ Absorber and thermal insulation inserted into collector trough

→ Back plate bonded to collector trough

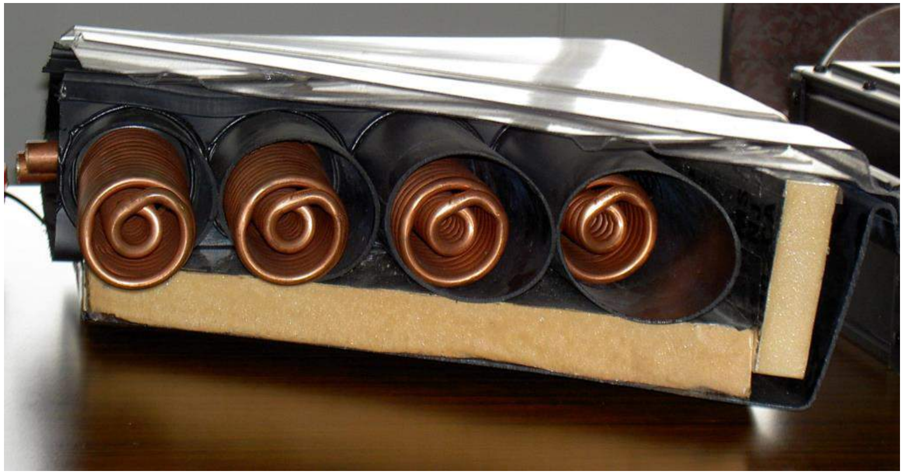
Material Selection (example)

→ glazing of collector trough: transparent PA

→ structure of collector trough: PA coloured

→ back plate: PA coloured

Integrated storage collectors



Mass production

Design-Concept

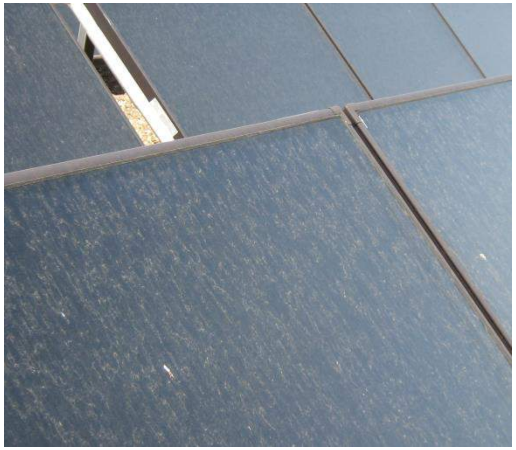
Creation of suitable materials

Processing Development

Coating application

Functional coatings

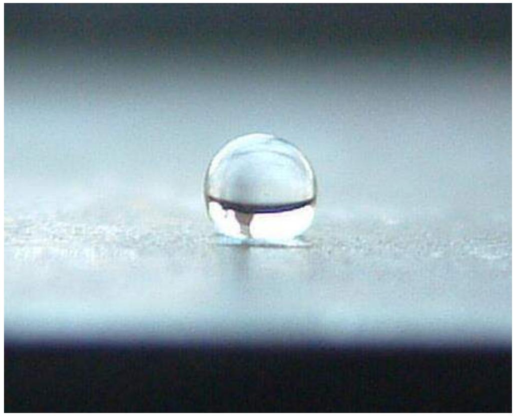
thermotropic polymeric materials allowing for temperature control of a collector



thickness insensitive spectrally selective paints (TISS)

and glazing with self-cleaning properties

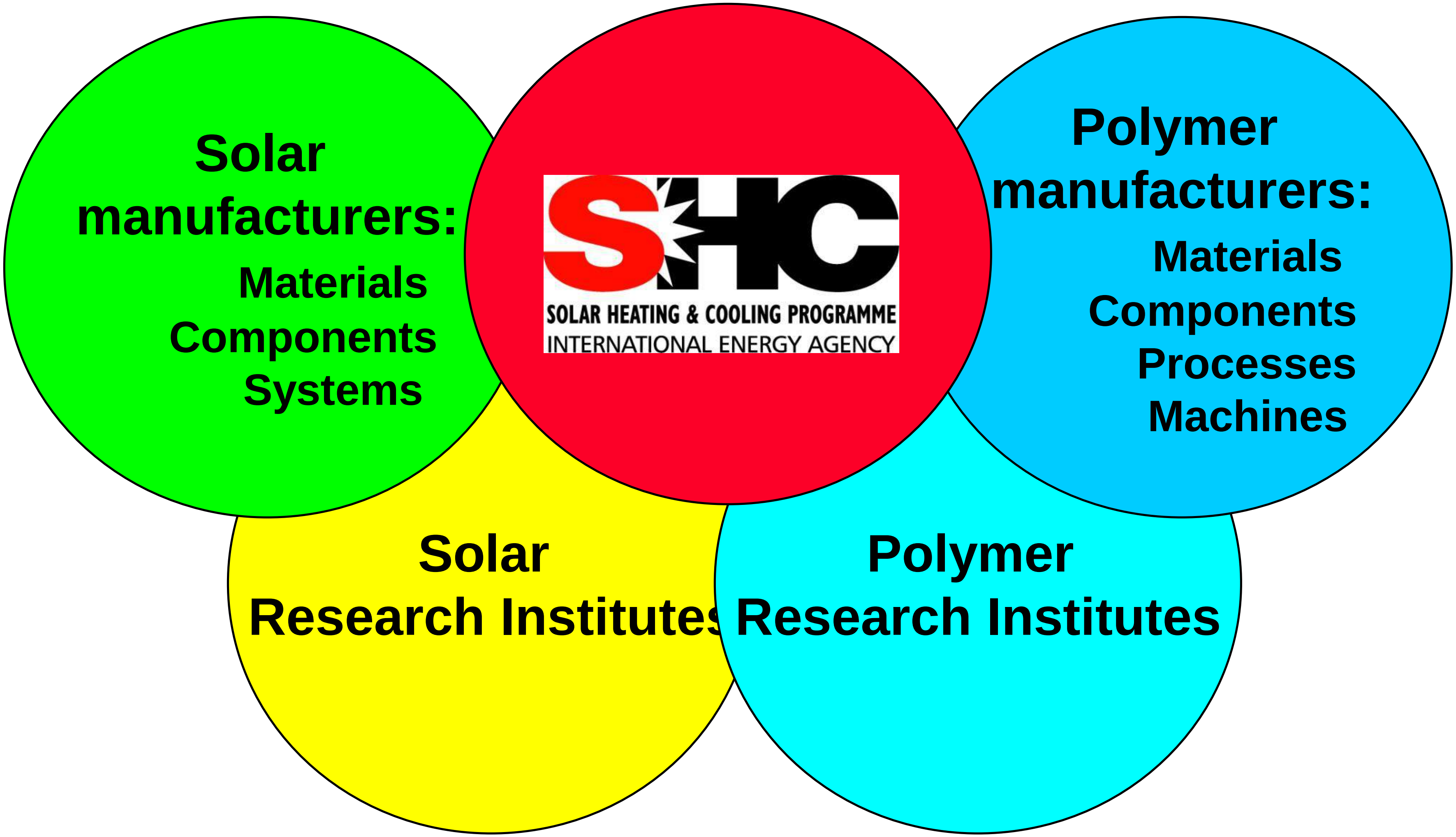
adhesion of functional polymeric materials to polymeric substrates



ageing behaviour of functional polymeric layers and glazing under service relevant loading and environmental conditions

Building integration

Stakeholder



Solar manufacturers:
- Materials
- Components
- Systems

Polymer manufacturers:
- Materials
- Components
- Processes
- Machines

Solar Research Institutes

Polymer Research Institutes

Subtask division

SUBTASK A

- **Information**
- Dr. Michaela Meir
- Norway

SUBTASK B

- **Collectors**
- Dr. Stephan Fischer
- Germany

SUBTASK C

- **Materials**
- Prof. Dr. mont. Gernot Wallner
- Austria

OPERATING AGENT: Dr. Michael Köhl, FhG ISE, Germany

Subtask A

Polymeric materials for solar thermal collectors - Market overview - life cycle study - dissemination

Michaela Meir, University of Oslo, Department of Physics, Norway

Funded by: enova

State of the art - Inspiration : Polymers in automotive industry

Source: BMW

Polymeric pool absorbers

Rodgau-Poolshop, Pfohl-
Schwimmbadtechnik (D)

Fafco (USA)

ROOS Freizeitanlagen GmbH (D)

ROTH-Werke GmbH (D)

Magen Eco Energy (ISR)

Collector design: Replacing conventional materials with polymers (1)

Flat plate collector
(casing)

Trough: Polycarbonate (PC)
Thermoforming
- Smart Design, Installation

Roth Werke GmbH (D)

Collector design: Replacing conventional materials with polymers (2)

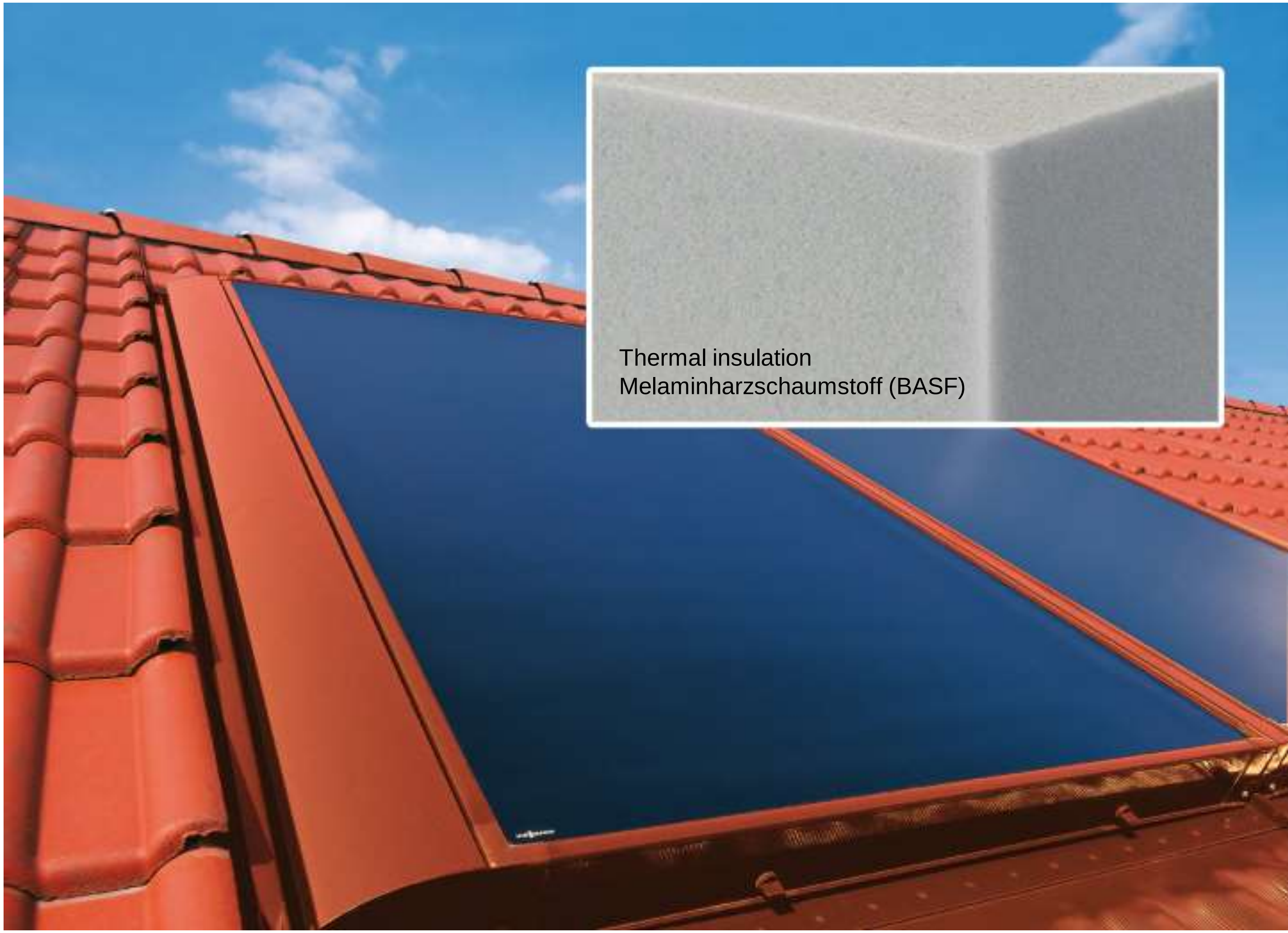
Flat plate collector
(casing)

Glasfibre reinforced plastics

Bosch Pressebild (AT)

Collector design: Replacing conventional materials with polymers (3)

Flat plate collector
Insulation


Thermal insulation
Melaminharzschaumstoff (BASF)

Viessmann Werke GmbH & Co KG (D)

Collector design: Replacing conventional materials with polymers (4)

Parabolic
trough collector
(supporting construction)

Parabolic trough, support, small components: PA, POM, PVC

Dr. Vetter, Gesellschaft für Med. Datentechnik, Bio- und Umwelttechnik mbH (D)

Collector design: Replacing conventional materials with polymers (5)

Vacuum pipe collector

Manifold header: PPS
Cover : PA66 30%GF

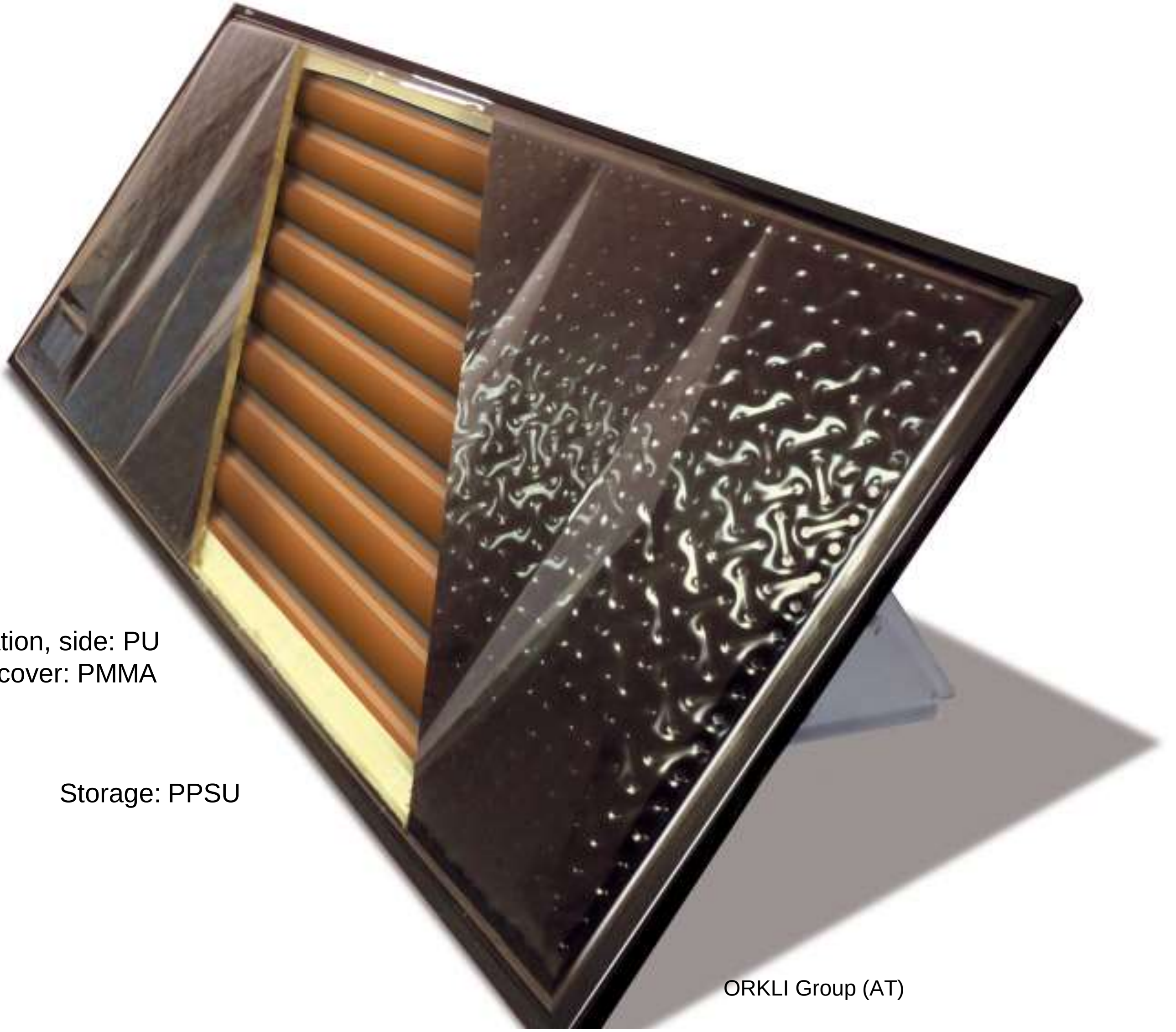
Kingspan Ltd. (UK)

ICS – Integrated Collector Storage (1)

Endcaps and
manifold header: PA

SOLCRAFTE Kioto Energy (AT)

ICS – Integrated Collector Storage (2)



Thermal insulation, side: PU
Collector cover: PMMA

Storage: PPSU

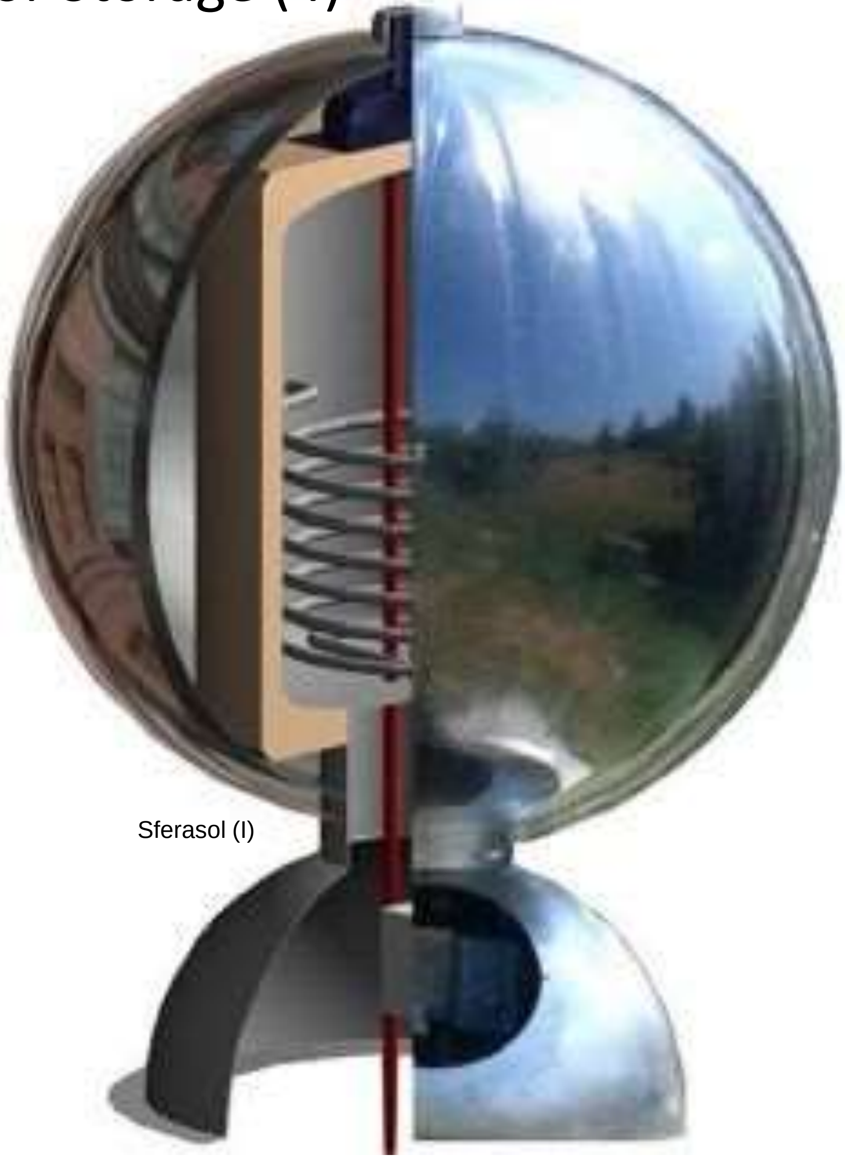
ORKLI Group (AT)

ICS – Integrated Collector Storage (3)

Solior, Itho Daalderop (NL)

ICS – Integrated Collector Storage (4)

Glazing: PMMA



Sferasol (I)

Polymeric air collectors

Glazing

PC Twin-wall sheet

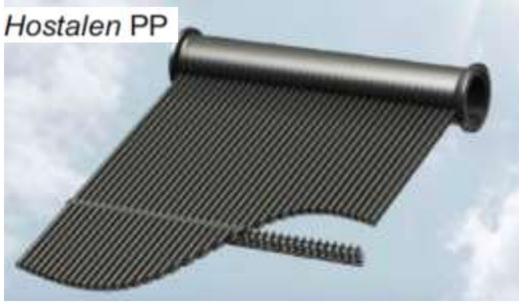
Solarventi (DK)

Perforated transparent glazing (PC)

Enerconcept (CA)

All-polymeric collectors (1)

Absorber: commoditive Plastics
with overheat protection



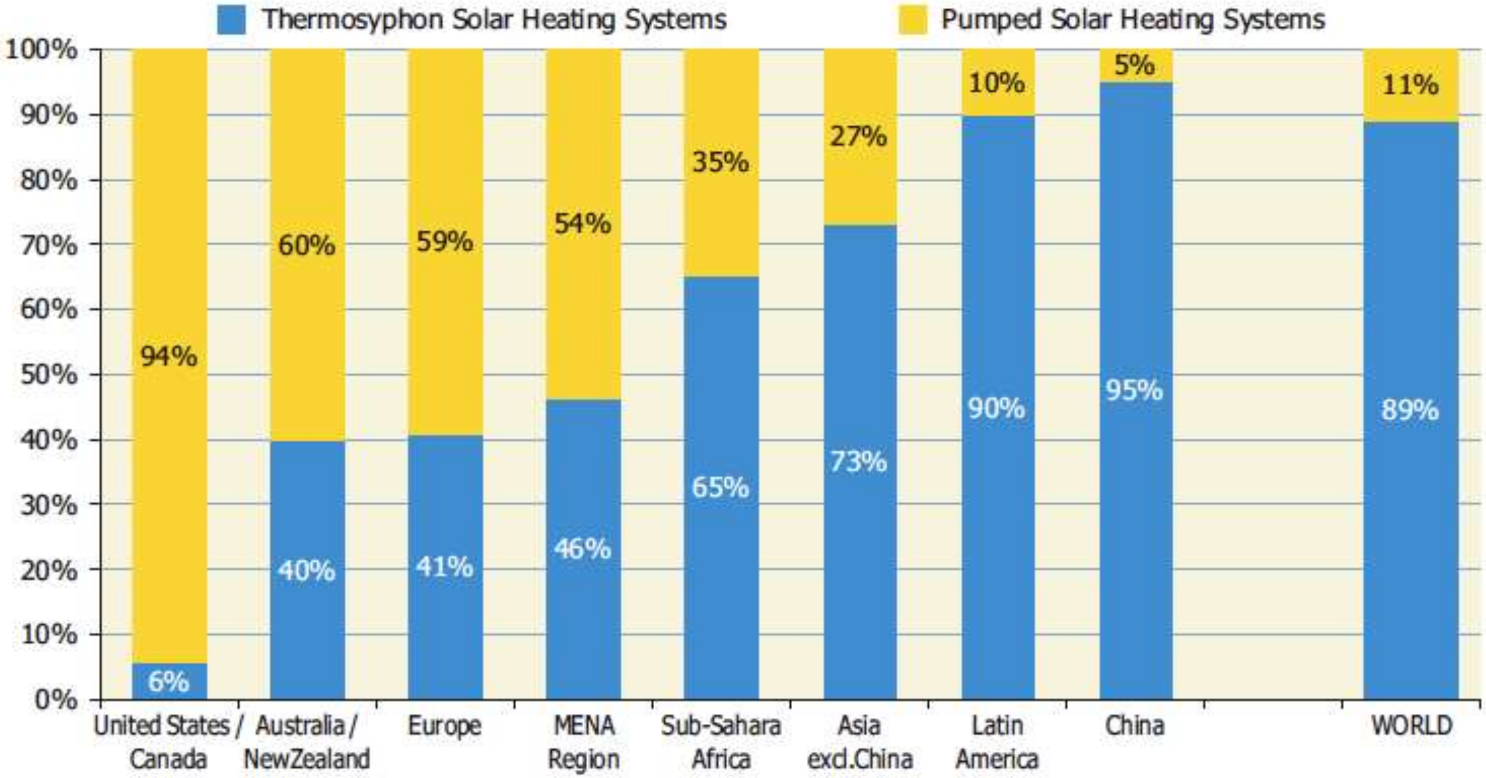

Magen Eco Energy (ISR)

All-polymeric collector (2)

Absorber: high temperature performance polymers

Aventa AS (N)

Polymers in Thermosiphon-collectors



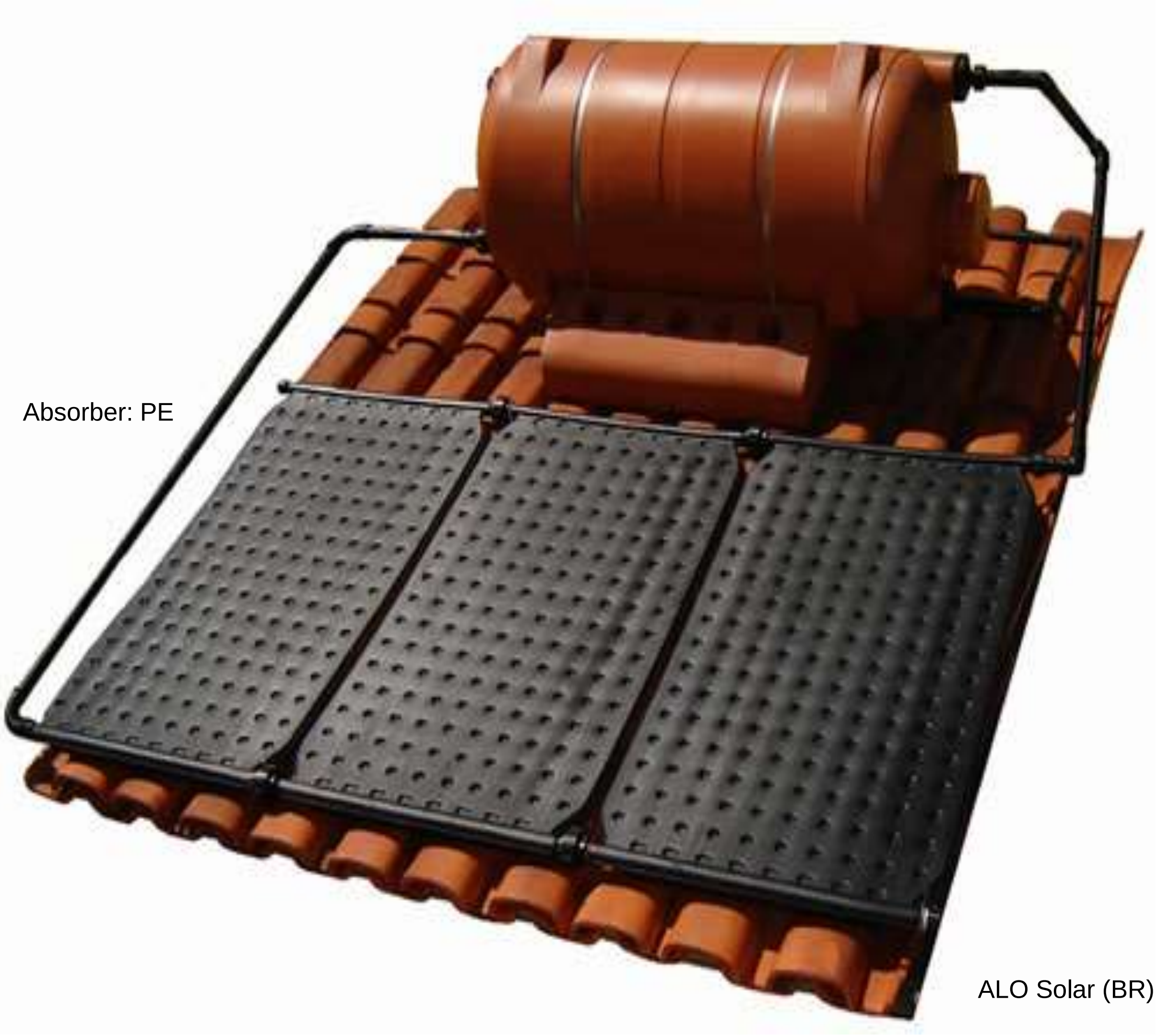
(Mauthner, Weiss, Solar Heat Worldwide, Edition 2013)

Polymers in Thermosiphon-collectors (1)

"Unibody": PU

Aguasol (DK)

Polymers in Thermosiphon-collectors (2)



Absorber: PE

ALO Solar (BR)

Polymers in Thermosiphon-collectors (3)

Absorber: PE

SOLCO (USA)

Polymers in Thermosiphon-collectors (4)

RhoTech Solar (USA)

*Prototype, not commercial (yet)

Thinfilm absorber & storage
: PE

Vaccum pipe collector integrated in roof tiles

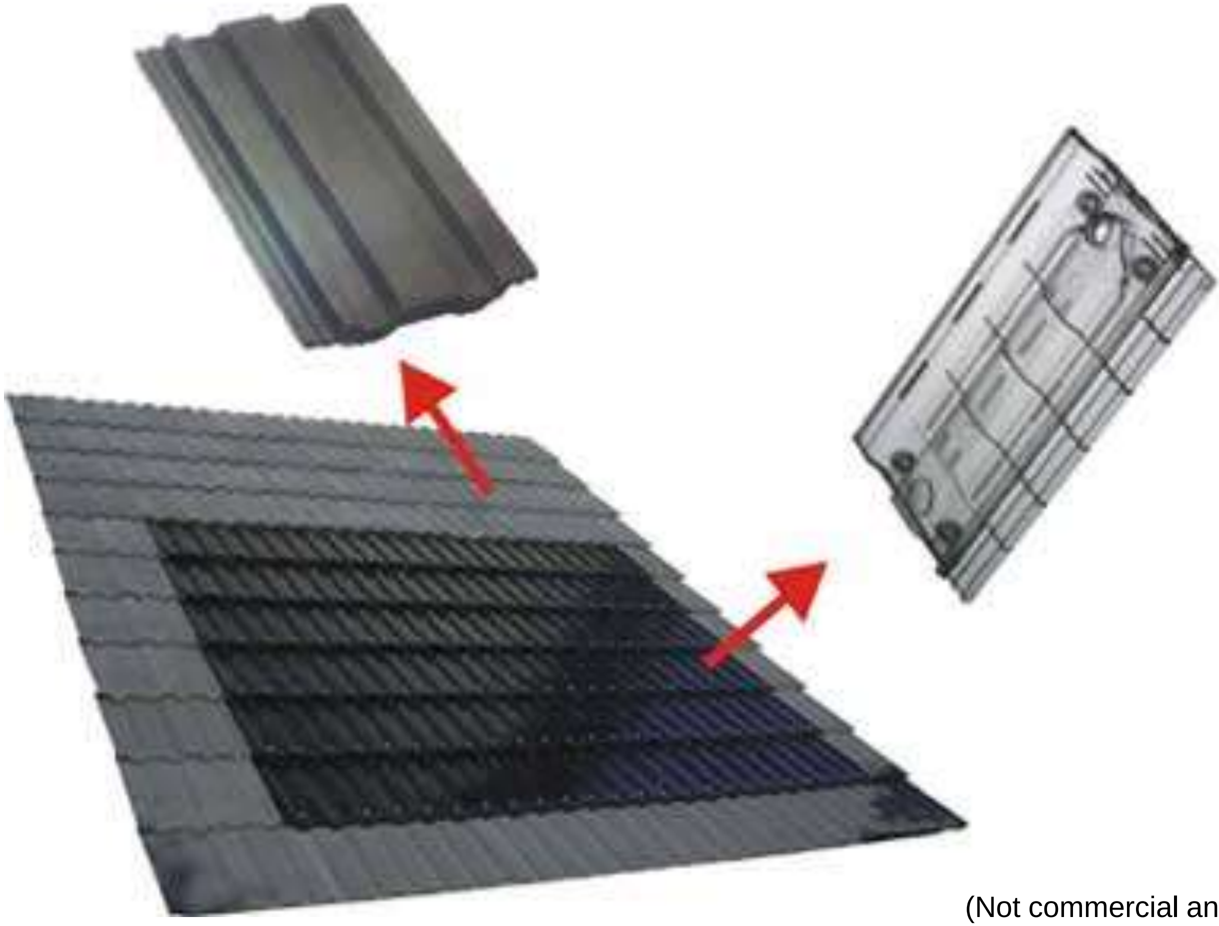
TECH TILE (IT)

Adapted collector design: Roof integration (1)

(Not commercial any longer)
www.solarcentury.com (UK)

Collector frame = glass fibre re-inforced plastics (UP+GD+MD)

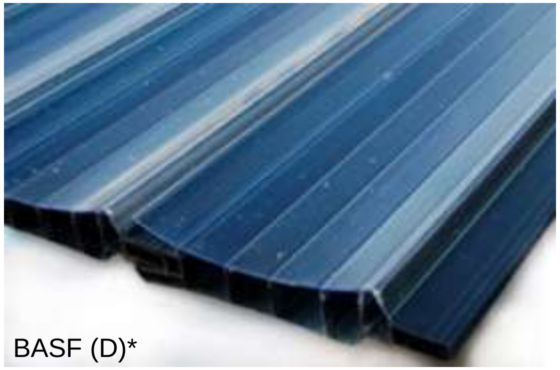
Adapted collector design: Roof integration (2)



(Not commercial any longer)
GeaSOL (SI)
Solari stresnik (Si)

Keyword: "Design freedom"

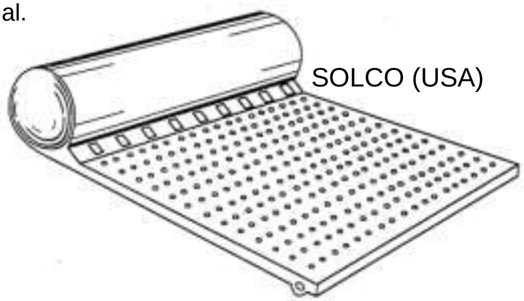
Roth Werke GmbH (D)



BASF (D)*

* not commercial.

Alo Solar (BR)



SOLCO (USA)

Polysolair (DE)

SOLCRAFTE Kioto Energy (AT)

Speedsolar (DE)

Keyword: “Integrated design”

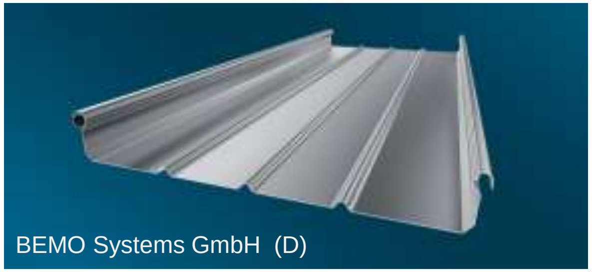

Enerconcept (CA)


Arcitects Dahle & Breitenstein (N)

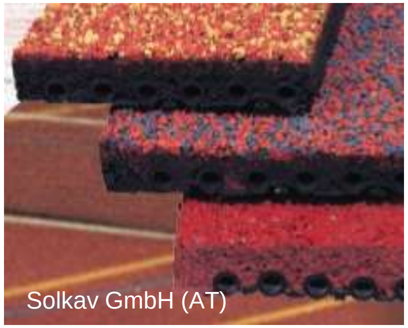

Birgit & Andreas Edelmann-Sigl (D)


Source: Purch GmbH (D),
not commercial any longer


BEMO Systems GmbH (D)


BEMO Systems GmbH (D)


SunnyFlex (DE)

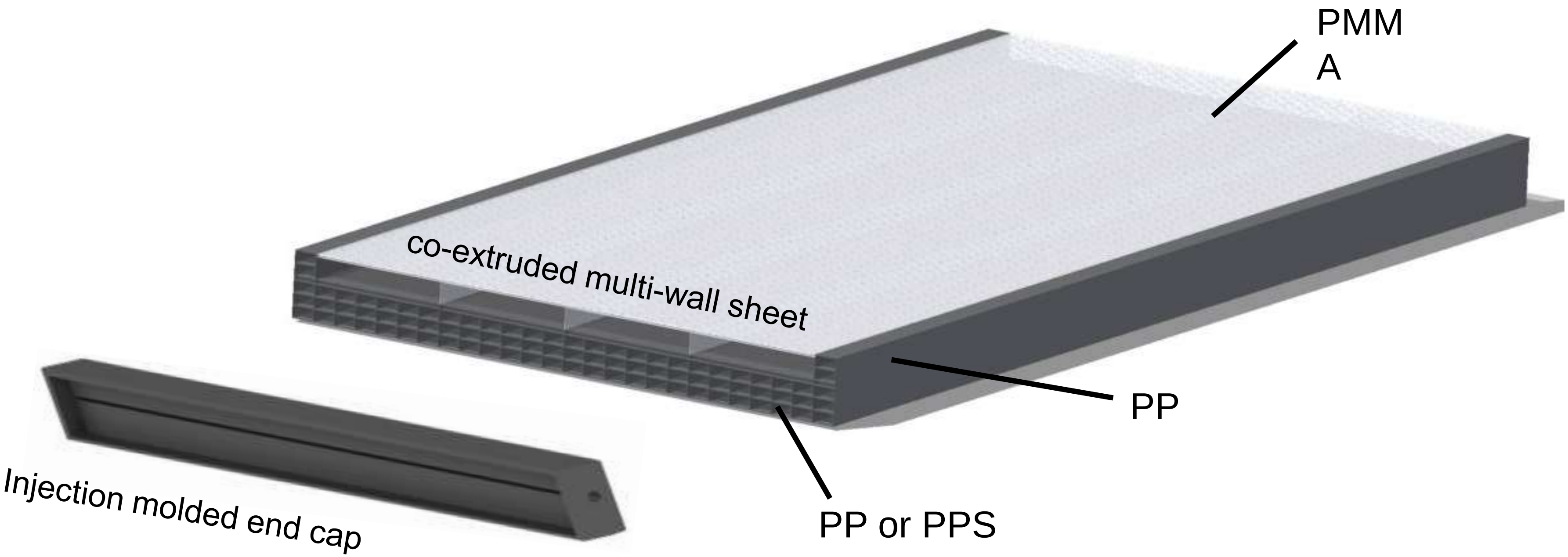

Solkav GmbH (AT)

38 selected examples on Task 39 website:

http://projects.iea-shc.org/task39/projects/default.aspx

Life Cycle Analysis of extruded polymeric collectors (1)

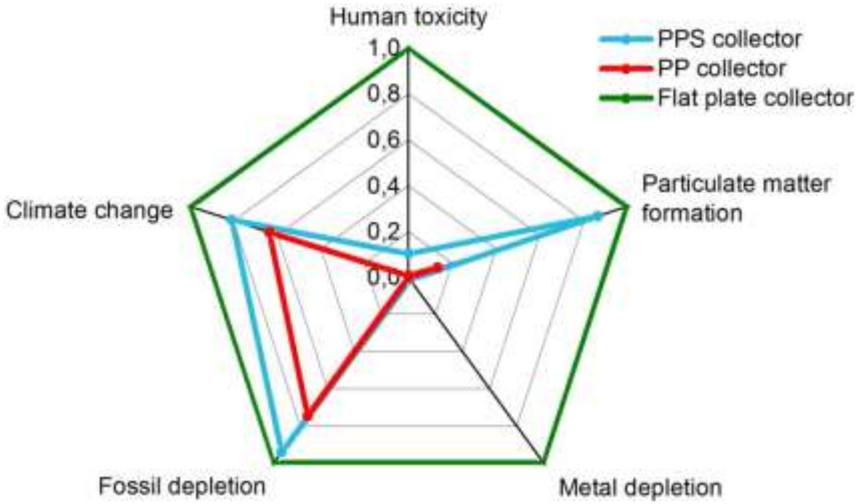
- PP collector concept
  - PP absorber
  - PP end caps
  - PMMA glazing
  - PP frame
  - 2.3 m², 22.0 kg
- PPS collector concept
  - PPS absorber
  - Selective coating
  - PPS end caps
  - PMMA glazing
  - PP frame
  - 2.3 m², 24.2 kg

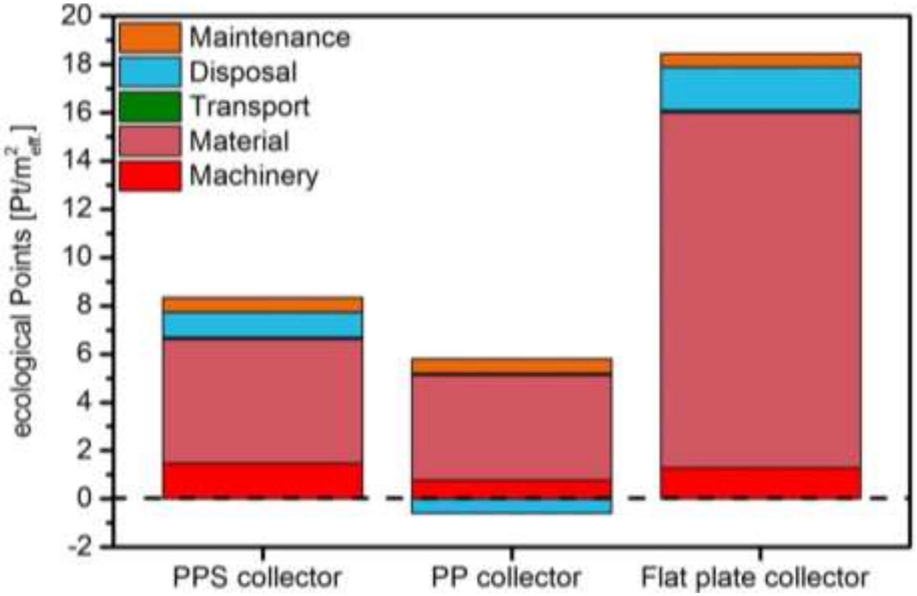


Ref.: Regine Weiss et. al. , Fraunhofer, ISE

Life Cycle Analysis of extruded polymeric collectors (2)

- Greatest impact in the production phase mainly due to materials
  - Impact metals > Impact plastics
- Transport has no significant impact
- Flat plate collector has the highest impact even with ~50% secondary metals
- Lower impact with polypropylene (PP) based collector
- Environmental gain due to incineration of PP



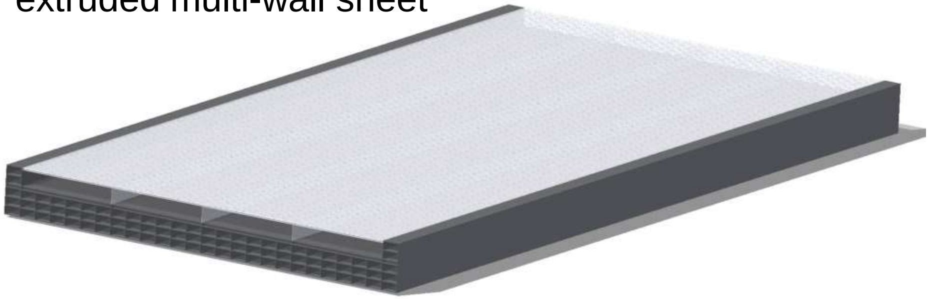


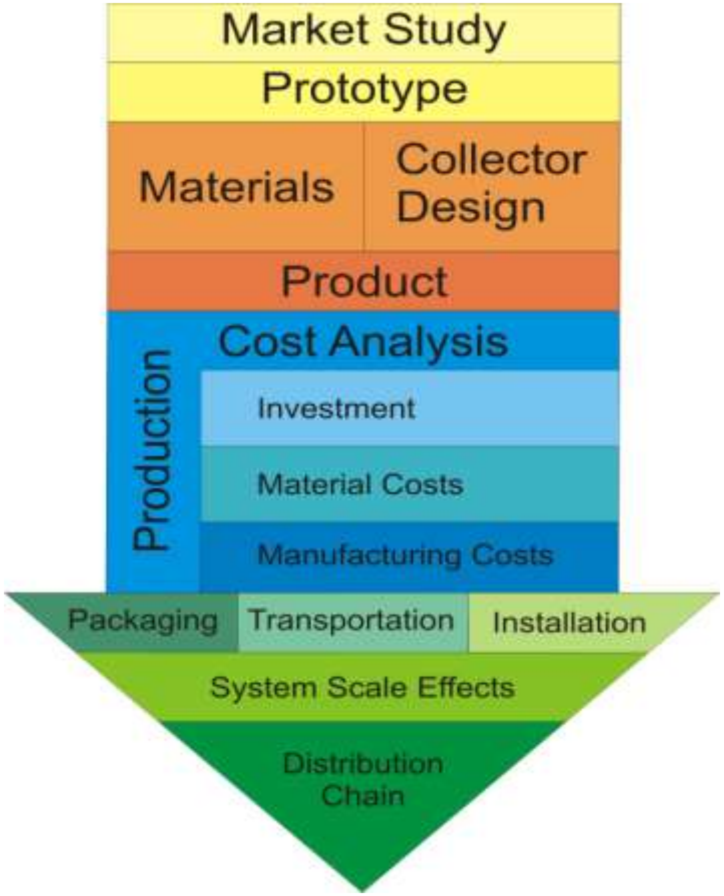
Ref.: Regine Weiss et. al. , Fraunhofer, ISE

Cost optimization: Extruded polymeric collectors (1)

- Concept study performed by Fraunhofer ISE BMU project ExKoll
- Market study => market size => volume
- Polymeric collector concept based on extrusion – compared to conventional flat plate collectors (metal, glass)

extruded multi-wall sheet



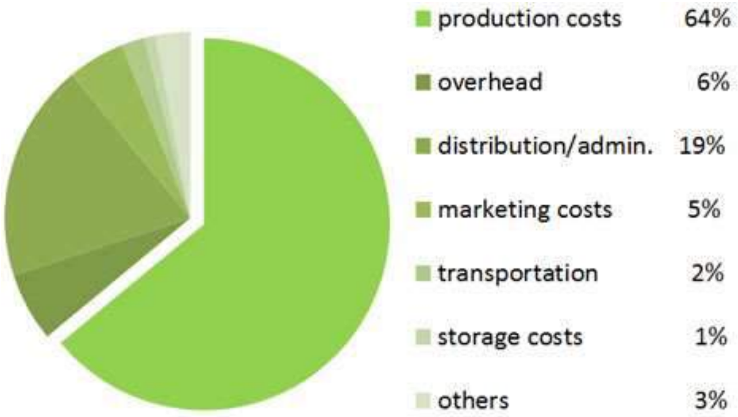


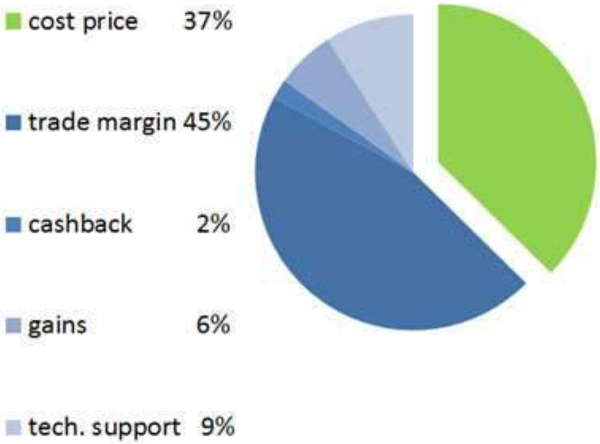
Market Study
Prototype
Materials
Collector Design
Product
Production
Cost Analysis
Investment
Material Costs
Manufacturing Costs
Packaging
Transportation
Installation
System Scale Effects
Distribution Chain

Ref.: Andreas Piekarczyk et. al. , Fraunhofer, ISE

Cost optimization: Extruded polymeric collectors (2)

- Optimisation towards production cost (labor, energy, machinery, scale effects on solar thermal systems, collector level; different collector efficiency, life times considered)
- Result of this study: 8-16% cost reductions on system level can be considered realistic.
- But: Extruded polymeric collector technology has much higher potential for cost reduction.
- Limiting factor: presently low share of production costs on the market





Ref.: Andreas Piekarczyk et. al. , Fraunhofer, ISE

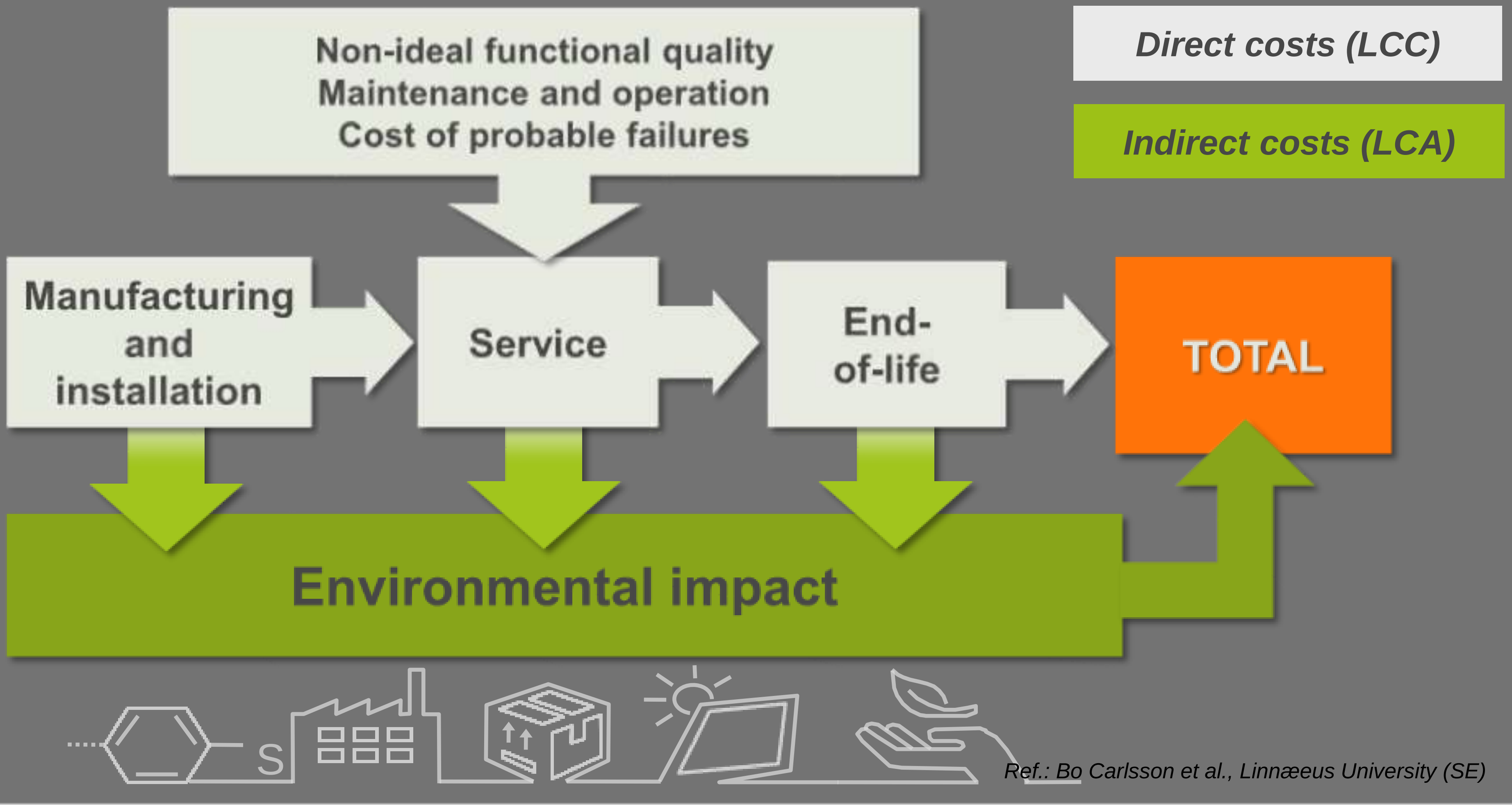
A total cost accounting approach in evaluation of polymeric based solar systems versus those of more traditional design

Direct costs (LCC)

Indirect costs (LCA)

Ref.: Bo Carlsson et al., Linnæeus University (SE)

A total cost accounting approach in evaluation of polymeric based solar systems versus those of more traditional design



Direct costs (LCC)

Indirect costs (LCA)

Non-ideal functional quality
Maintenance and operation
Cost of probable failures

Manufacturing and installation

Service

End-of-life

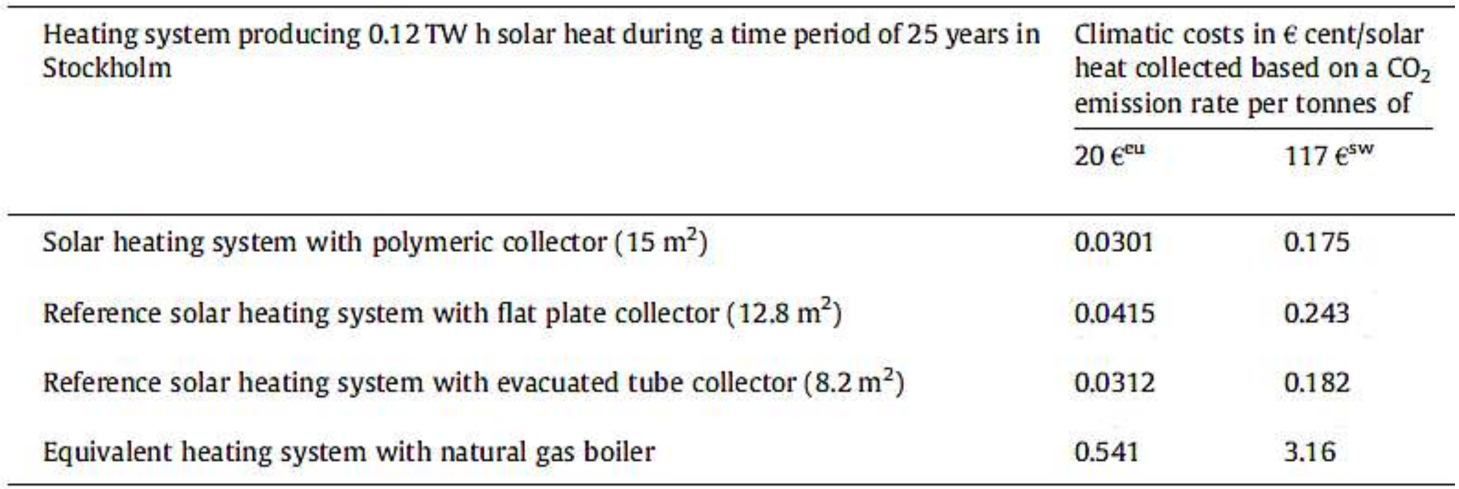
TOTAL

Environmental impact

Ref.: Bo Carlsson et al., Linnæeus University (SE)

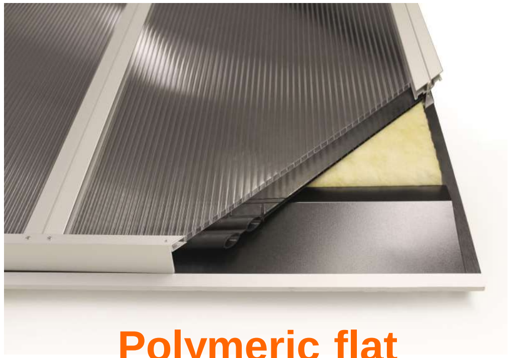
Importance of costs for geen house gas emission relative to total cost

Ref. B. Carlsson et al. / Applied Energy 125 (2014) 10–20

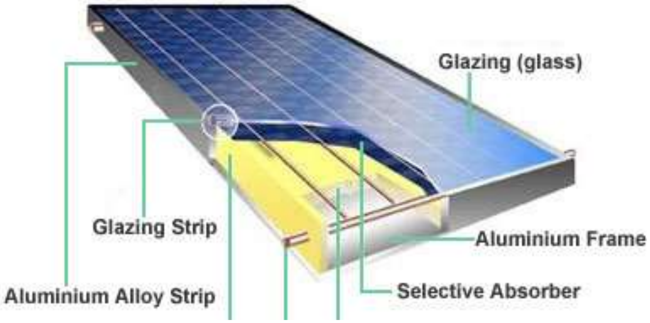


Heating system producing 0.12 TW h solar heat during a time period of 25 years in Stockholm	Climatic costs in € cent/solar heat collected based on a CO_2 emission rate per tonnes of	
	$20\ €^{eu}$	$117\ €^{sw}$
Solar heating system with polymeric collector (15 m^2)	0.0301	0.175
Reference solar heating system with flat plate collector (12.8 m^2)	0.0415	0.243
Reference solar heating system with evacuated tube collector (8.2 m^2)	0.0312	0.182
Equivalent heating system with natural gas boiler	0.541	3.16

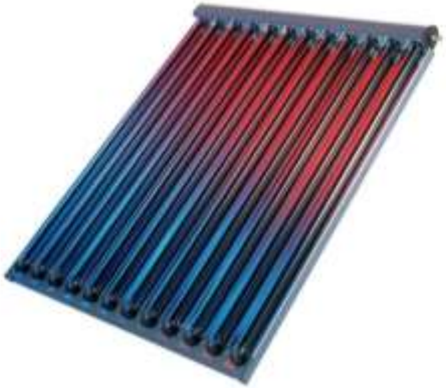
EU trade rate (2008); sw= Swedish general tax rate



Polymeric flat plate collector



Reference flat plate collector

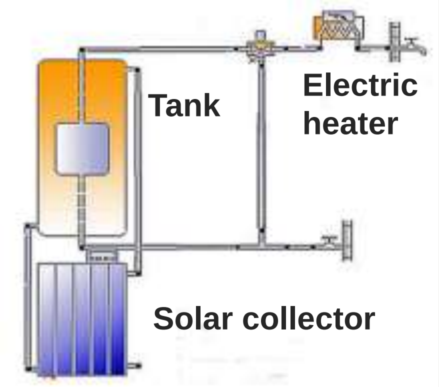


Reference evacuated tube collector

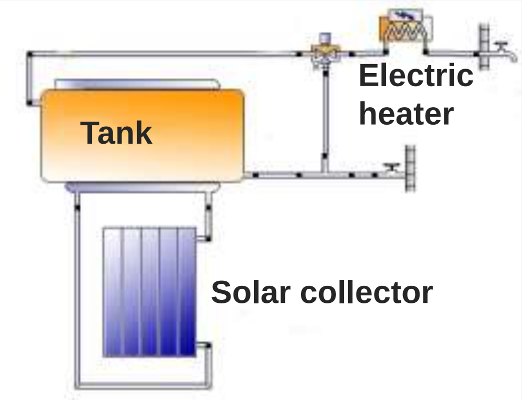
Present value life cycle based **Energy costs** for two thermosiphon systems placed in Athens, service time: 15 years

Ref.: Bo Carlsson et al., Linnæeus University (SE)

The Aventa polymeric based TSS



Reference TSS containing mainly metals



Costs related to the solar part of the TS systems

System	**Capital cost** (€cent/kWh)	**O&M cost*** (€cent/kWh)	**Climatic cost** (A) (€cent/kWh)	**Total cost** (€cent/kWh)
Reference TSS	11.9	1.8	0.06	13.8
Aventa TSS	7.9	1.2?	0.02	9.1
Difference	4.0	0.6	0.04	**4.6**

Costs related to the total useful produced heat by the TS systems

System	**Capital cost** (€cent/kWh)	**O&M cost*** (€cent/kWh)	**Climatic cost** (A) (€cent/kWh)	**Total cost** (€cent/kWh)
Reference TSS	9.3+X	7.2	0.77+Y	17.1+X+Y
Aventa TSS	5.7+X	8.5	0.99+Y	15.2+X+Y
Difference	3.6	-1.3	-0.22	**1.9**

X =End user cost of electric heater; Y = Climatic cost for producing electric heater;

Industry Dissemination Workshops

- **4 Industry workshops**

02-2008 in Leoben (AT) by PCCL Leoben + AEE INTEC

06-2011 in Linz (AT) by JKU Linz + AEE INTEC

05-2012 in Berlin (D) by HU Berlin + Fraunhofer ISE

10-2013 in Linz (AT) arranged by JKU Linz + AEE INTEC


Kunststoffe – die Wachstumsoption für die Solarthermie

Workshop
Chancen und Anforderungen für Kunststoffe in der Solarthermie

Programm

2. LEOBENER SYMPOSIUM

SOLARTECHNIK – Neue Möglichkeiten für die Kunststoffbranche

7. - 8. Februar 2008
Congress Leoben

POLYMERIC SOLAR MATERIALS

Einladung – Tagung

Kunststoffe als Wachstumsmotor für die Solarthermie

Neue Technologieoptionen auf Basis von Polymerwerkstoffen

Mittwoch, 6. Juli 2011
Johannes Kepler Universität Linz

Excursions: Production facilities and test laboratories (2006-2010)

- organised by local partners at experts meetings

- Sept. 2007: Excursion to solar heated brewery at Blumau Experts meeting, AT
- April 2008: Excursion to projects with polymeric ST collectors in Oslo, N
- Oct. 2008: Lab tour through LNEG at the Lisbon experts meeting, PT
- April 2009: Visit of test site of SPF during Rappersvil experts meeting, CH
- Oct. 2009: Lab tour through NREL during experts meeting at Golden, USA
- April 2010: Lab tour through INES during experts meeting at Aix-les-Bains, FR
- June 2010: Excursion to INTERSOLAR druing experts meeting in Munich, GE
- Sept 2010: Experts meeting in connection with EUROSUN 2010 in Graz, AT

NREL meeting, USA, 2009

INTERSOLAR meeting, Munich, 2010

Excursions: Production facilities and test laboratories (2011-2014)
- organised by local partners at experts meetings

- May 2011: Lab tour through NIC at Ljubljana experts meeting, SL
- Sept. 2011: Excursion to **Bosch TT's production site** at Aveiro experts meeting, PT
- Oct. 2012: Guided tour: Technological Institute and
  visit of **Fraunhofer ISE's outdoor test site** at Gran Canaria experts meeting, ES
- April 2014: Factory visit of **Magen Eco Energy** and
  excursion **to Fraunhofer ISE's outdoor test site** at the Ben Gurion University, ISR
- Oct. 2014: Guided tour to **projects with polymeric ST collectors** in Oslo, N


Bosch TT, PT, 2011


Sde Boquer, ISR, 2014


Magen, ISR, 2014

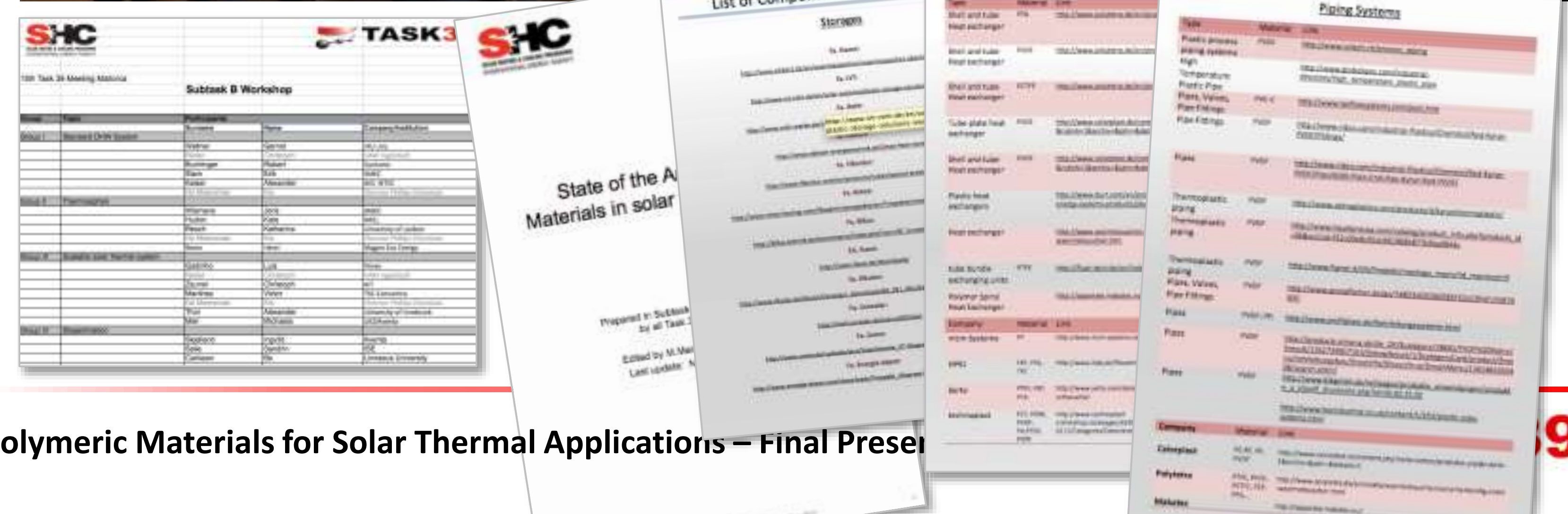

Pozo Izquierdo, ES, 2012

Task 39 Newsletters: Summary of Project meetings

- 14 Newsletters, IEA-SHC internal newsletters
- Task 39 Website, Task 39 Highlights

Dissemination: Task 39 Workshop → SHC2013 Exhibition

Workshop, April 2013, arranged within Subtask B leading to SHC 2013 exhibition



Subtask B Workshop

State of the A
Materials in solar

TASK39

List of Components & Manufac

Storages

Heat Exchangers

Piping Systems

Dissemination: Task 39 Workshop → SHC2013 Exhibition

Workshop, April 2013, arranged within Subtask B leading to SHC 2013 exhibition

SHC 2013
CONFERENCE
SEPTEMBER 23-25
FREIBURG, GERMANY

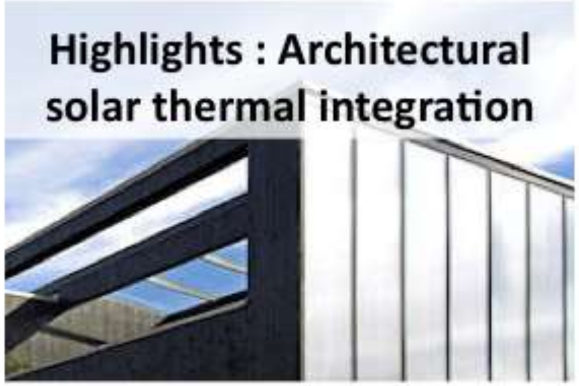
12 companies

Press release, Flyer

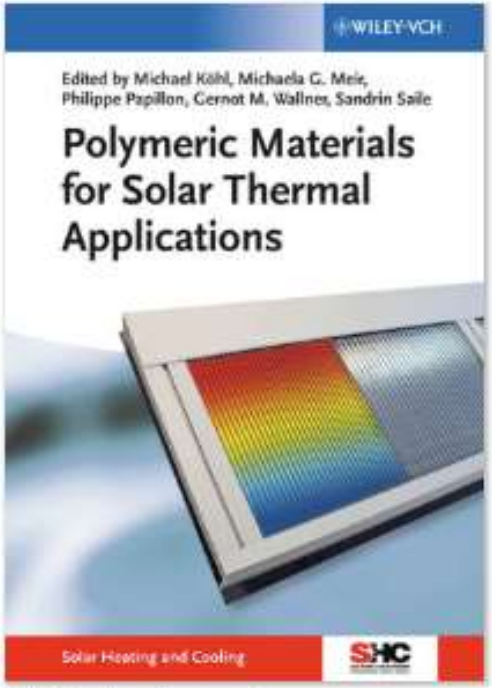
Major coodination effort
by Fraunhofer ISE, Freiburg

Final Task 39 Dissemination: Website

- Website: http://Task39.iea-shc.org



Final Task 39 Dissemination 2006-2010: Handbook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Edited by Michael Köhl, Michaela G. Meir, Philippe Papillon, Gernot M. Wallner, Sandrin Saile

Polymeric Materials for Solar Thermal Applications

Solar Heating and Cooling

Read an Excerpt

Polymeric Materials for Solar Thermal Applications

Michael Köhl (Editor), Michaela Georgine Meir (Editor), Philippe Papillon (Editor), Gernot M. Wallner (Editor), Sandrin Saile (Editor)

ISBN: 978-3-527-33246-5

418 pages
October 2012

Final Task 39 Dissemination 2011-2014: Info Sheets

- Subtask A : 7 - Subtask B : 16 - Subtask C : 10

TASK39

All polymeric thermosiphon system

Polymeric solar collectors and recycling

Market and cost

AventaSolar collector system

Standards, Certification and Regulations

Architecturally appealing

- A marketing tool in order to attract

Polymeric solar heating systems

Building integration and scalability of components

INFO Sheet B11

Case Study: twin wall sheet testing

Introduction

Twin wall sheets

Project presentations

Project presentations as pdf-files – 3-4 pages

Example: “One Task 39 success story”

- Experts met for the first time at Task 39 kick-off meeting in Ingolstadt in 2006

Example: “One Task 39 success story”

- Experts met for the first time at Task 39 kick-off meeting in Ingolstadt in 2006

Vanja Dobreva,
Chevron Phillips Chemicals

John Rekstad,
Aventa AS /
University of Oslo

Example: “One Task 39 success story”

- Experts met for the first time at Task 39 kick-off meeting in Ingolstadt in 2006

- Last Task 39 meeting in Norway: Excursion to row house project in Oslo: 34 passive houses heated with polymeric solar collectors

Example: “One Task 39 success story”

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Aventa AS (N)
Chevron Phillips Chemicals (B)
DS Smith Kaysersberg
University of Oslo

AEE INTEC
APC
Austrian Institute of Technology
Fraunhofer ISE
HTCO
ITW Stuttgart
J. Kepler University Linz
National Institute of Chemistry
PCCL
Prirev
University of Aveiro
University of Leoben

Example: “One Task 39 success story”

Thank you!

Polymeric Materials for Solar Thermal Applications

2006 – 2014

Subtask B: Collectors and Components

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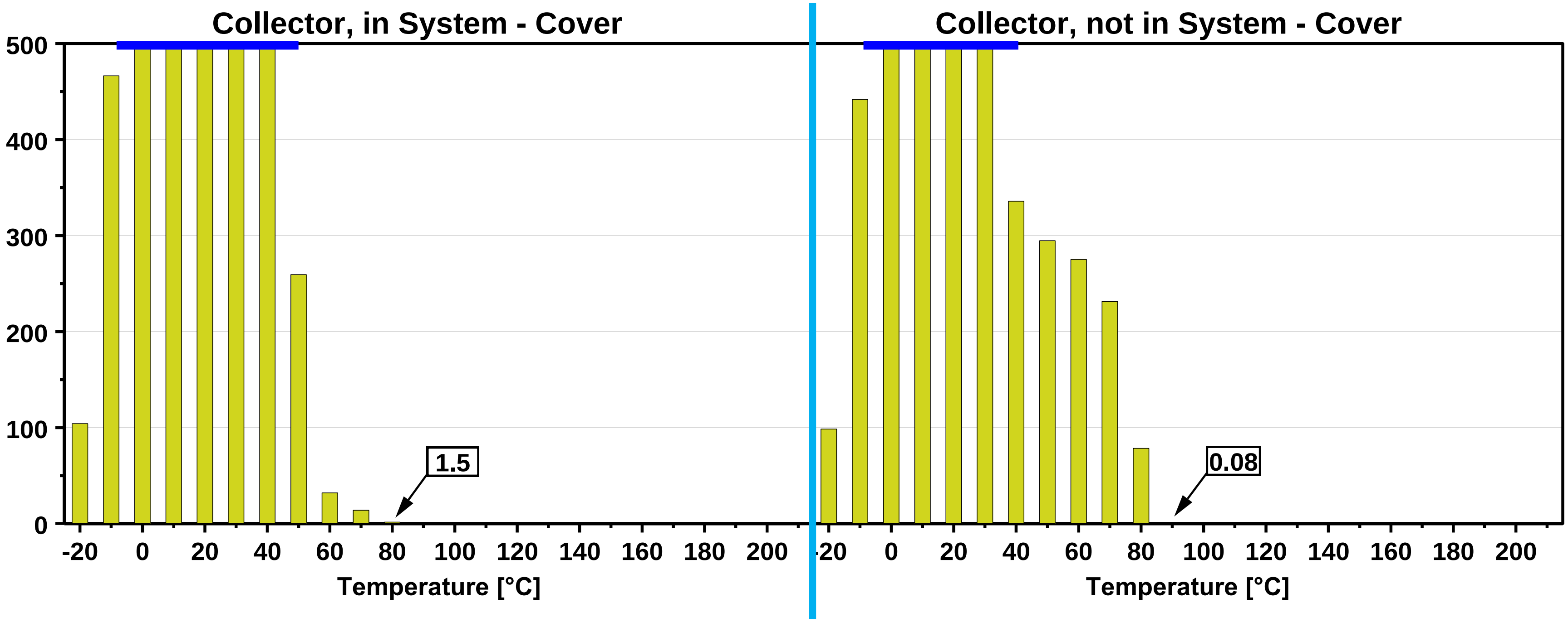
Content

- Thermal loads on solar collectors and components
- Overheating protection
- Selected products and concepts
- High lights, conclusion and outlook

Temperature transparent cover

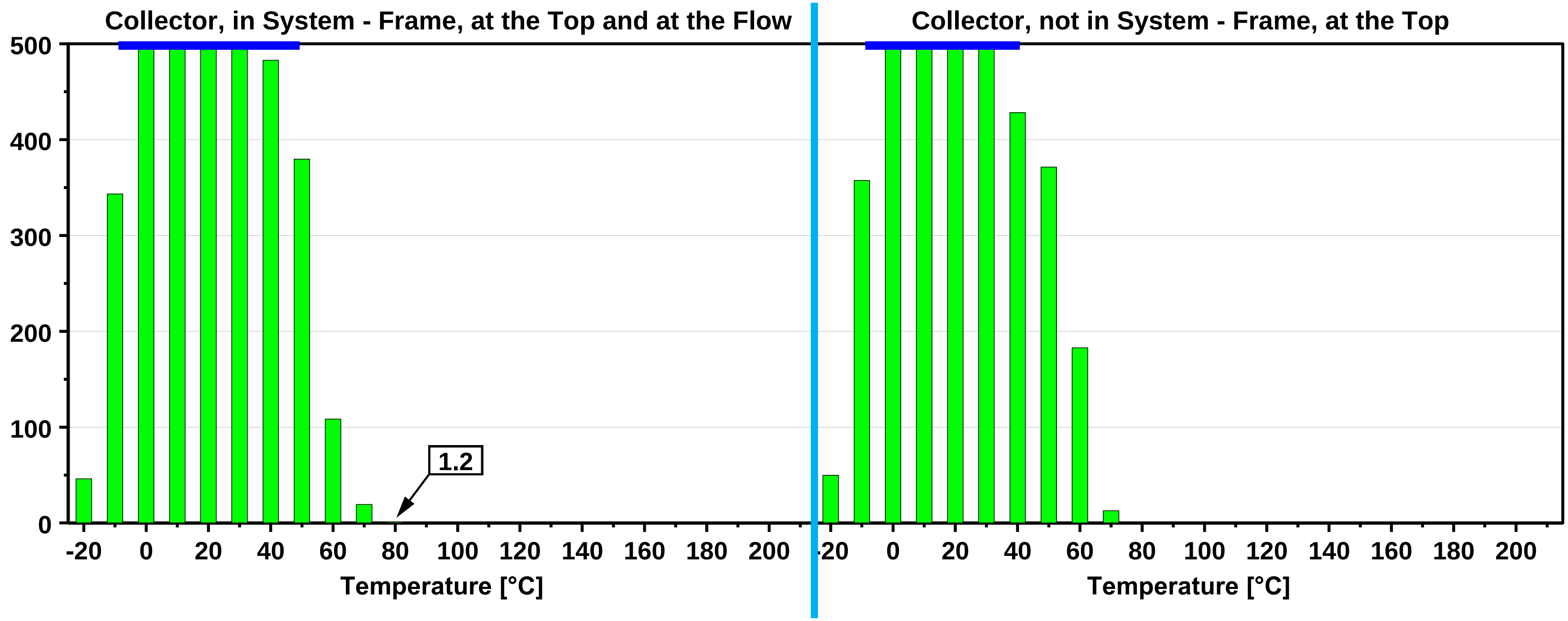
- Relatively Low Peak Temperatures (→ 86 °C)
- Only Short Durations at High Temperatures
- Most Low-Cost Polymers Useable



Source: Ch. Reiter, Ingolstadt University of Applied Sciences

Temperature collector frame

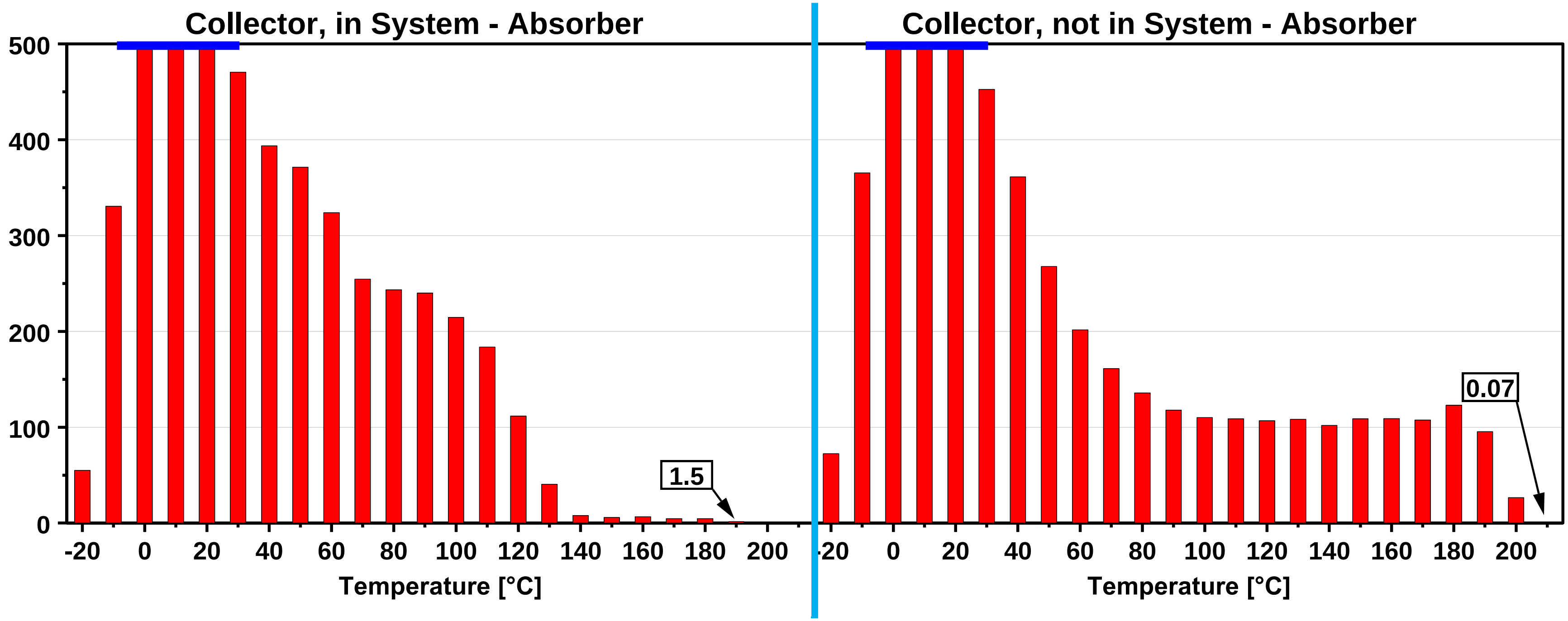
- Low Peak Temperatures (→ 79 °C)
- Temperature Mainly Below 65 °C
- Perfectly Suitable for the Use of Low-Cost Polymers



Source: Ch. Reiter, Ingolstadt University of Applied Sciences

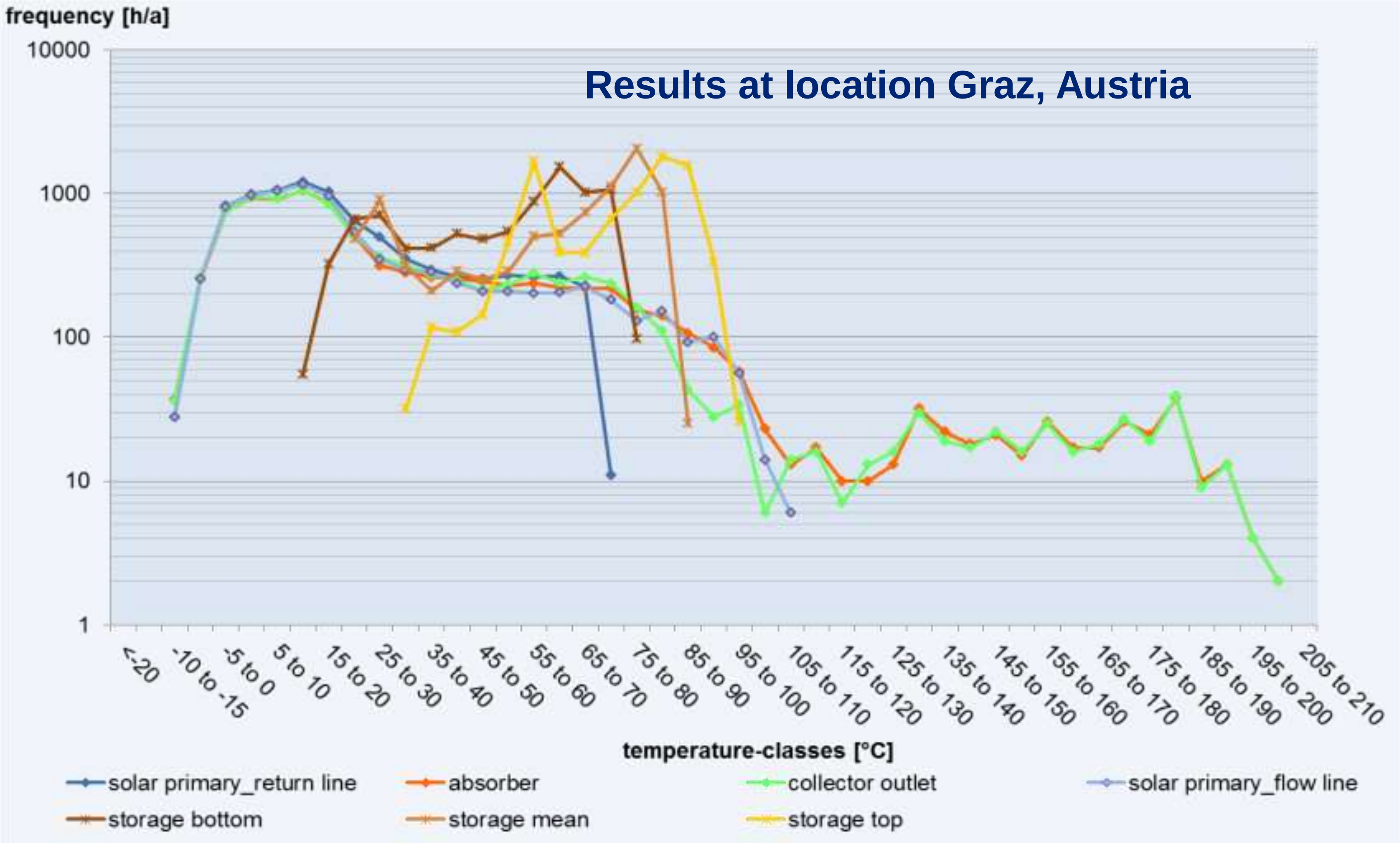
Temperature absorber

- Considerable Temperature Loads during Operation (→ 140 °C)
- Extreme Temperature Loads in Stagnation (→ 208 °C)



Source: Ch. Reiter, Ingolstadt University of Applied Sciences

Temperatures Solar thermal system



Source: D. Preiß, AEE – Institute for Sustainable Technologies

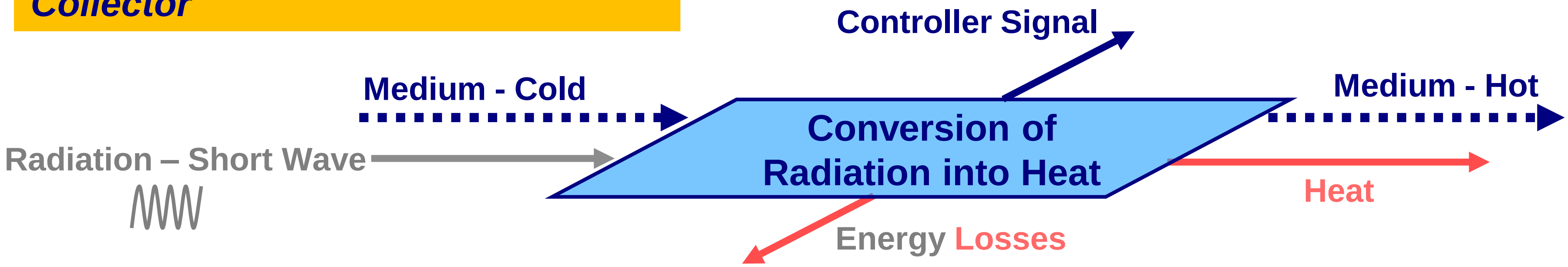
Consequences and solutions

- High performing (expensive) polymers
- Over heating protection

Source: A.. Thür, University of Innsbruck, Unit for Energy Efficient Buildings

Overheating protection measures

Basic Function Scheme of the Collector



Overheating Protection

Reduction of the Optical Efficiency

- Reduction of Transmission Properties
- Reduction of the Absorption Properties

Removal of Thermal Energy

- Raising of the Thermal Losses
- Active Cooling of Collector Parts

Source: Ch. Reiter, Ingolstadt University of Applied Sciences

Vents mechanism (MAGEN)

Active cooling

Vents

Patented unique venting mechanism builds from four ventilation orifices at the collector’s 4 corners that open and close, depending on temperature driven mechanism the casing structure, to eliminate the risk of overheating damage to the plastic absorber

Source: M. Plaschkes, Magen Eco-Energy

Measured absorber temperatures

a typical graph is shown : collector inclination 30 degrees. Red line: collector with closed slots/green line: collector with slots open

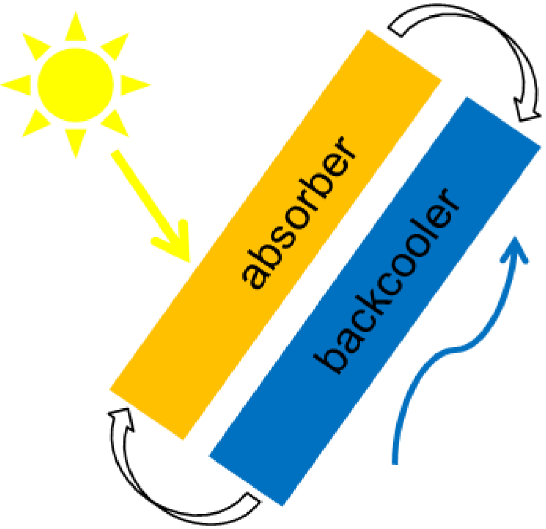
Source: M. Plaschkes, Magen Eco-Energy

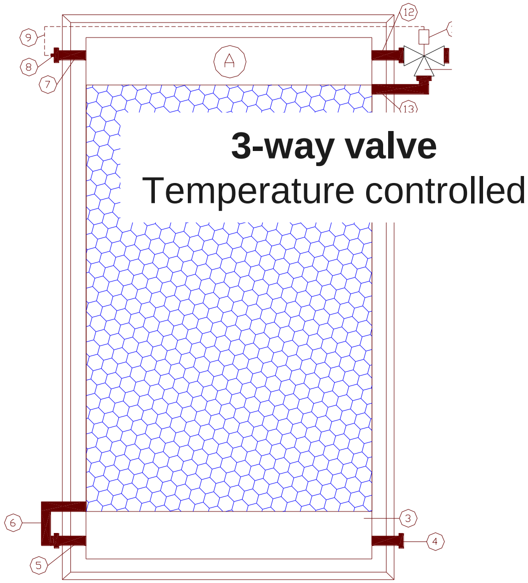
Back cooler (active cooling)

Goal	**Fail Safe Temperature Limited Plastic Collector** Maximum Temperature of ca. 90°C
Method	Concept, Material, Simulation, Production and Measurements of Modell-Collectors
Materials	Cheap Mass-Produced Plastics (Polyolefine)

Problem

Principle

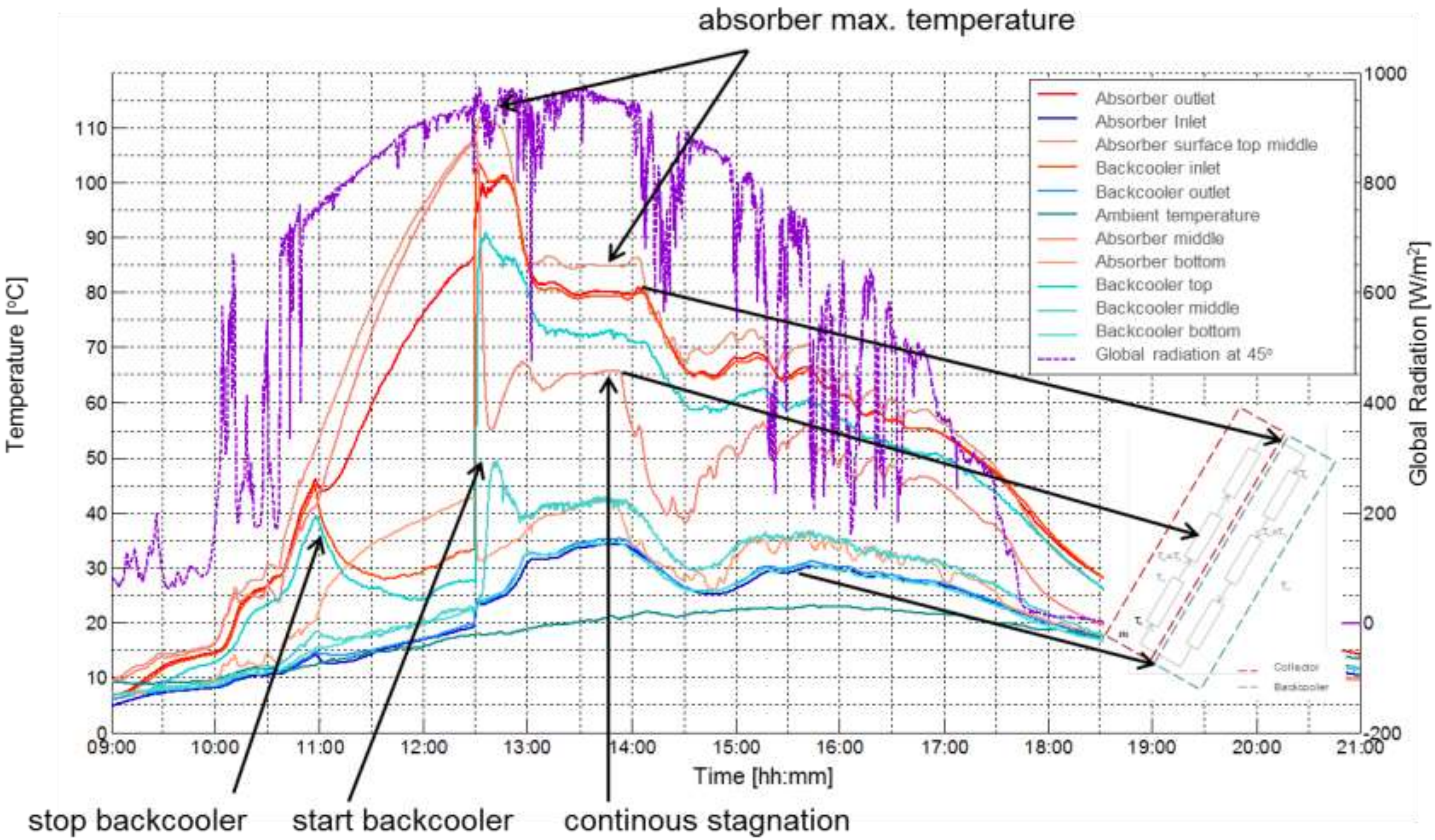




3-way valve
Temperature controlled

Source: A.. Thür, University of Innsbruck, Unit for Energy Efficient Buildings

Back cooler in operation



absorber max. temperature

stop backcooler

start backcooler

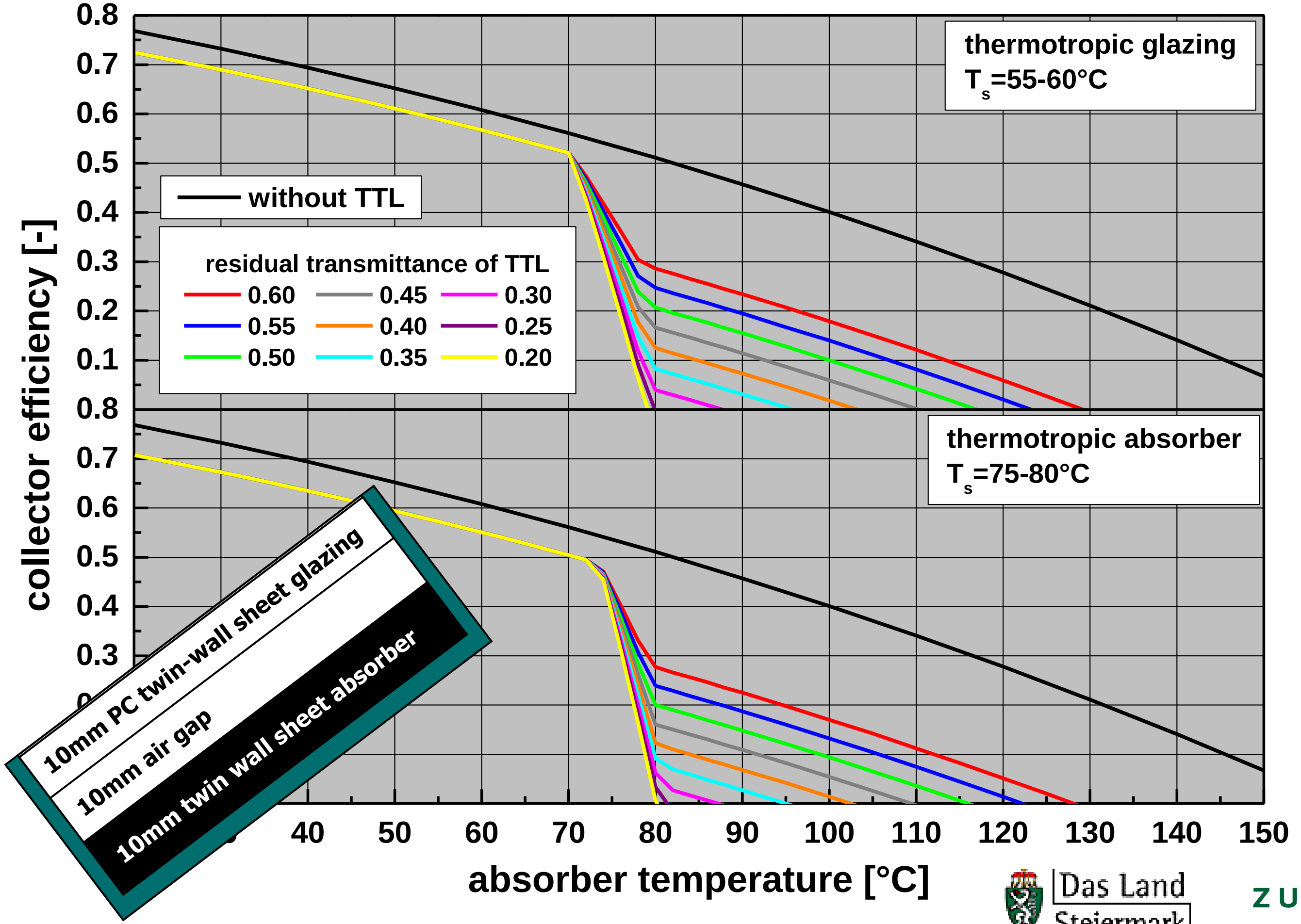
continous stagnation

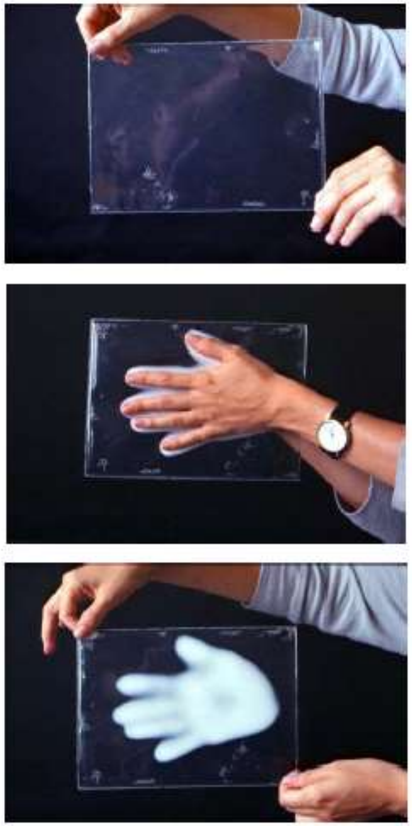
Source: A.. Thür, University of Innsbruck, Unit for Energy Efficient Buildings

Thermotropic Overheating Protection

Theoretical Potential and Material Requirements

Source: Wallner et al. (2008) Solar Energy Materials & Solar Cells





Source: Hartwig, 2003.

Thermotropic Overheating Protection

Application demonstrations in conventional solar thermal collectors

bmvit
HAUS der Zukunft

Source: Fraunhofer ISE.

Source: Austrian Institute of Technology.

Significiant reduction of maximum absorber temperatures (<90° C) with thermotropic layers

↓

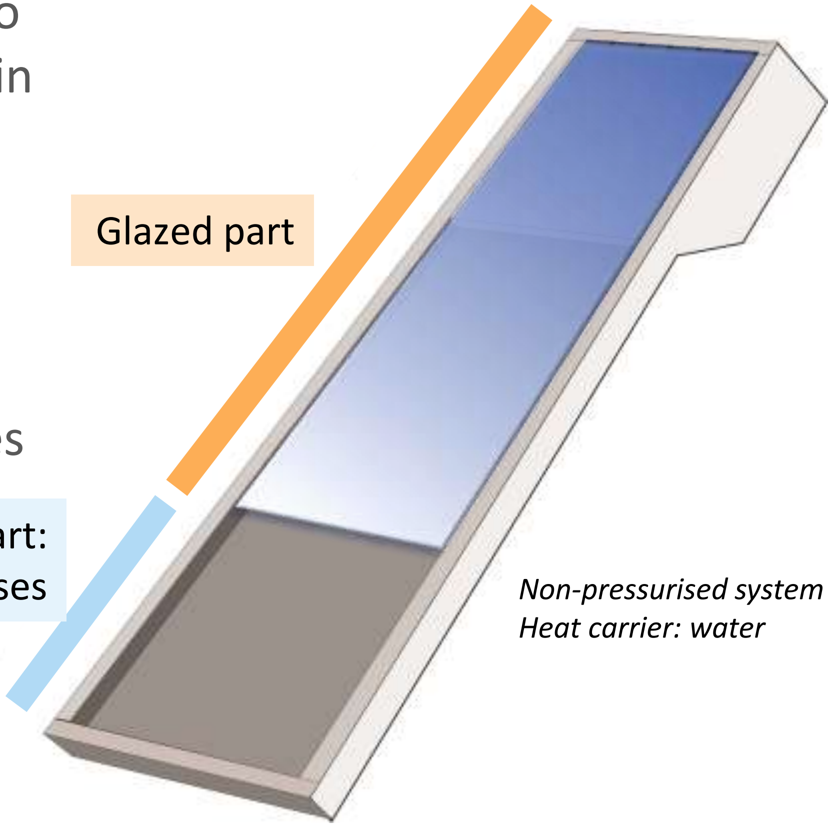
To do: **optimization of large scale manufacturing**

Das Land Steiermark
ZUKUNFTSfonds STEIERMARK

Source: K. Resch, Montanuniversität Leoben

Overheating protection by partial glazing for AventaSolar Thermosiphon system

- Tune the glazing fraction according to the climatic region and the demand in order to avoid overheating (boiling)
- Easy and flexible method
- Additional benefit
  Higher efficiency at low temperatures



Partly glazed thermosiphon collector

Glazed part

Unglazed part:
increased heat losses

Non-pressurised system
Heat carrier: water

Source: M. Meir, Aventa

Selected products and concepts

One world solar collector

|| The design concept:

|| functional - modern - trendy - smart - unique - intelligent - handy - practical

World premiere of One World Solar Collector at Fakuma fair 14th -15th October 2014 (www.fakuma-messe.de/en/fakuma/)

Source: R. Buchinger, Sunlumo

One world solar collector conceptional production line

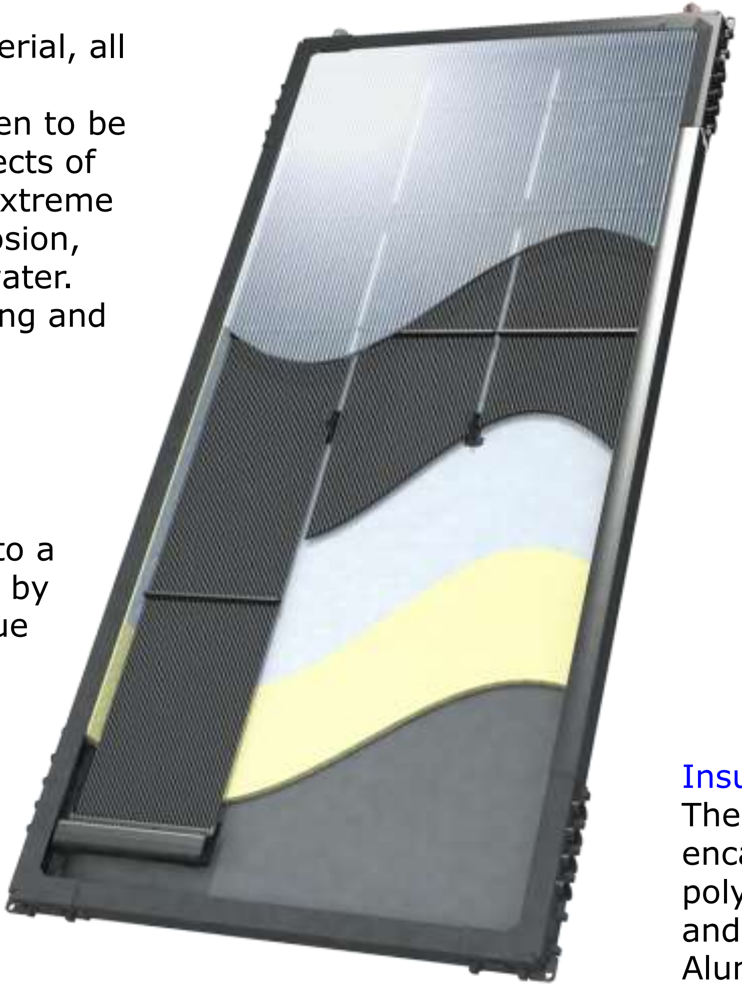
Fully automated modular factory

Source: R. Buchinger, Sunlumo

One world solar collector production line (prototype)

Source: R. Buchinger, Sunlumo

MAGEN Eco-Flare collector



Material
Specially formulated material, all plastic made, tested in authorized labs and proven to be stabilized against the effects of sustained UV radiation, extreme weather conditions, corrosion, limescale, salts and seawater. High resistance for freezing and pressures

Absorber
117 + Individual plastic tubes @6.5mm diameter, connected to a unique square manifold header by Over-Molding injection technique

Back Plate
UV stabilized Polypropylene back plate

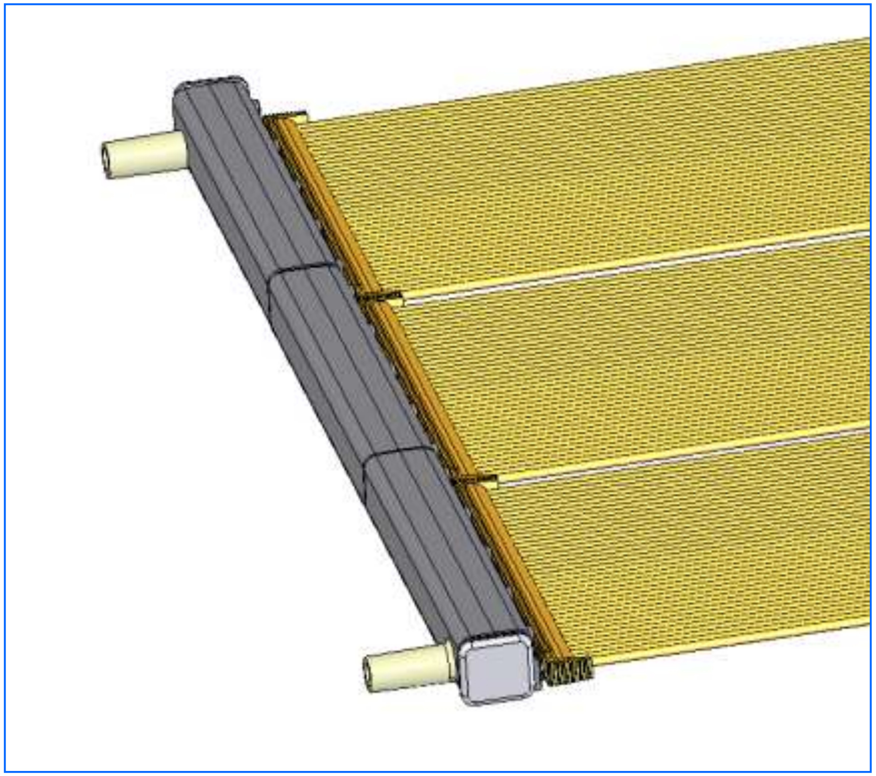
Casing & frame
Reinforced plastic and Aluminum components with a very light weight, for easy installation and minimal roof load

Glazing
Multiwall Polycarbonate glazing with additional UV blocking tissue. Light weight with extreme impact resistance (200 times more than glass)

Insulation
The collector is encased in polyurethane foam and Polyester coated Aluminum foil

Source: M. Plaschkes, Magen Eco-Energy

MAGEN Absorber and header



- Patent Pending
- Bursting Pressure: 50 bar
- Freeze Resistance: -18 °C
- Max. Operating Pressure: 5 bar @ 77 °C

Source: M. Plaschkes, Magen Eco-Energy

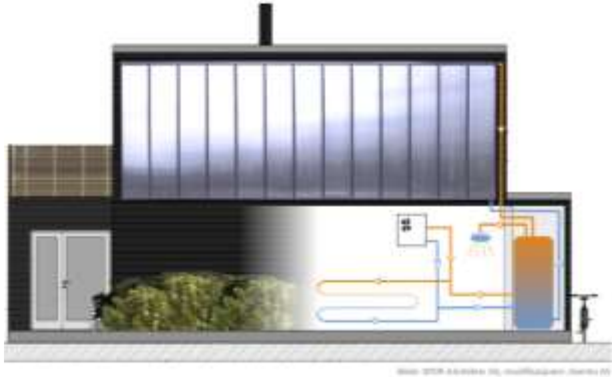
AventaSolar collector

- New collector concept based on extruded polymeric sheets (absorber and glazing)
- Collector design adopted to the use of polymers
  - Pure water as heat carrier
  - Non-pressurised collector loop
  - Solar loop with drain-back design
- Light weight with approx. 8 kg/m^2 : Easy handling, transport, installation

Source: M. Meir, Aventa

AventaSolar collector system

- Collector designed for building integration: Roof and facade integrated collectors replace conventional building materials
- Advantage: Modular collector design with various collector standard lenghts
- Simple system design: "Direct system”
- Favorable applications: Low- and midtemperature applications: Combisystems, low temperature heating systems, system with large DHW demand;



Source: M. Meir, Aventa

AventaSolar collector / system - New solutions overcome barriers for Solar Thermal

- Cost reduction by mass production (extrusion, IR welding)
- Replacing conventional building covers
- Modular concept & simple hydraulic design:
  Installation & distribution in collaboration with building industry instead of HVAC installers
- Building modules with well-known installation process:
  NorDan Solar window concept (NorDan, OSO Hotwater, Uponor)
- Mass-produced housing: AventaSolar in catalogue house programme

NorDan Solar

Collaboration with building industry, OBOS

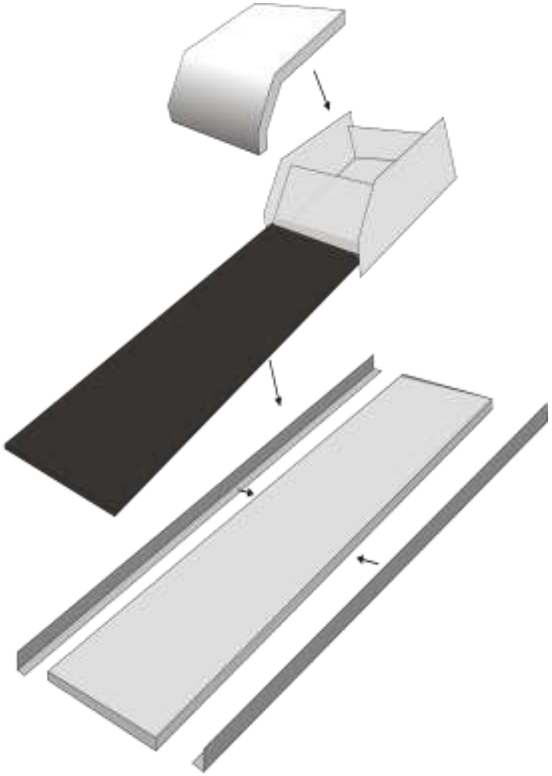
Catalogue house programme

NorDan Solar

Co-operation with building industry

AventaSolar Thermosiphon system

Illustration of the AventaSolar TSS. The flat design with integrated storage (left) consist of polycarbonate glazing, a twin-wall sheet absorber, rear and storage tank insulation and framing for façade or roof mounting (right).
Non-pressurised design.
Indirect system with immersed tank heat exchanger.

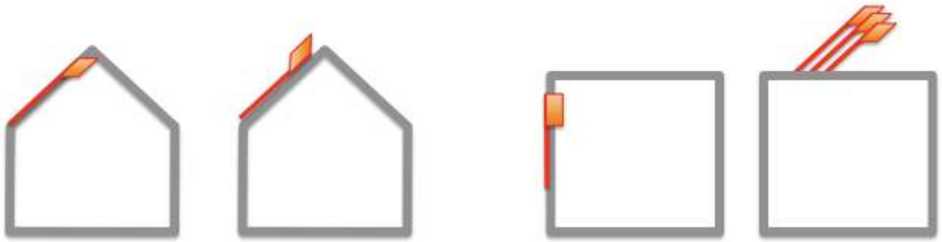


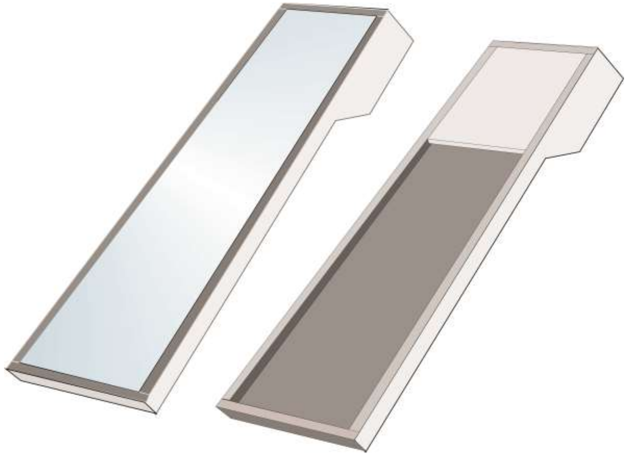
Advantages:

- Light-weight
- Low cost through mass production
- Integrated design (tank and collector)
- Option for easy integration

Source: M. Meir, Aventa

AventaSolar Thermosiphon system





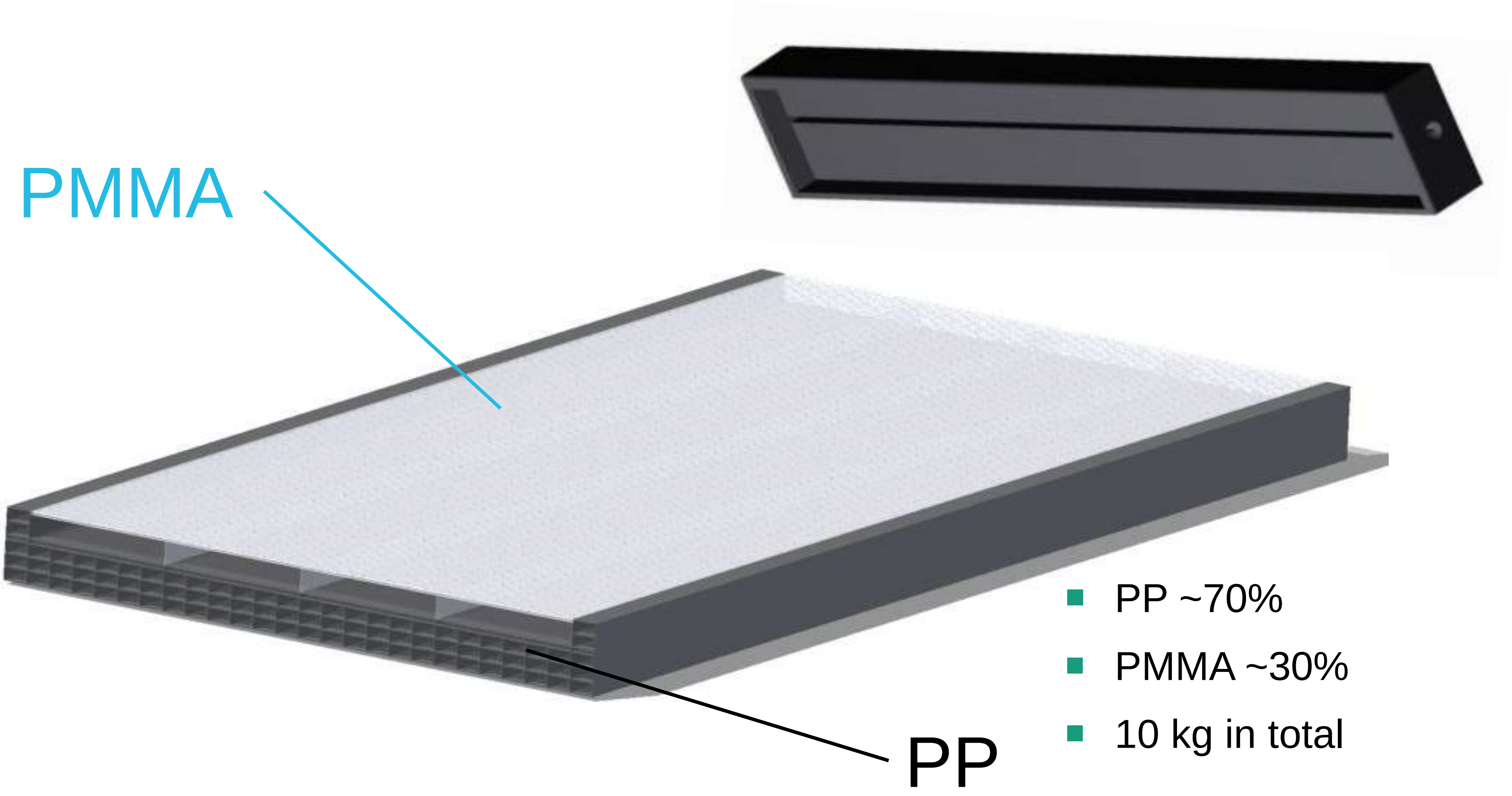
Storage tank behind:
Integrated design with flat-plate look

Storage tank in front:
Easy mounting on flat surfaces

Source: M. Meir, Aventa

Concept Study of a (Co-)Extruded PP Collector

Cost optimized modell

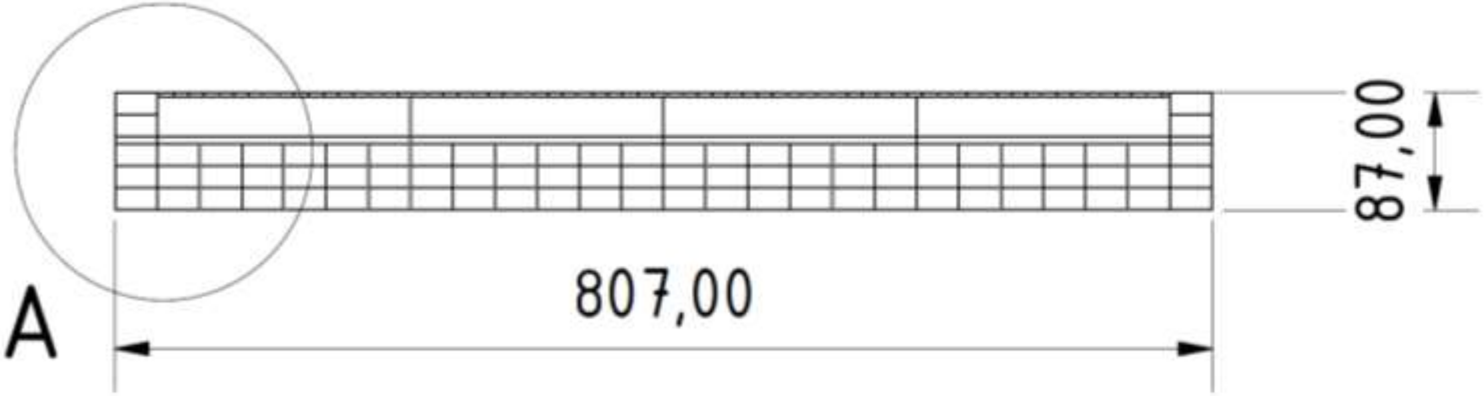


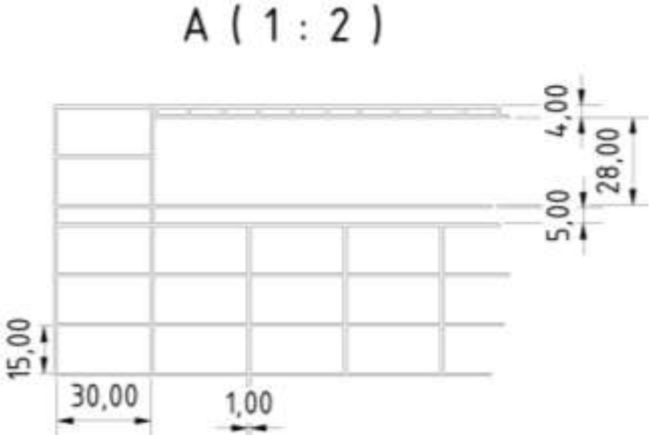
- PP ~70%
- PMMA ~30%
- 10 kg in total

Source: A. Piekarczyk, Fraunhofer ISE

PP-Collector

Extruded profile and injection molded end caps





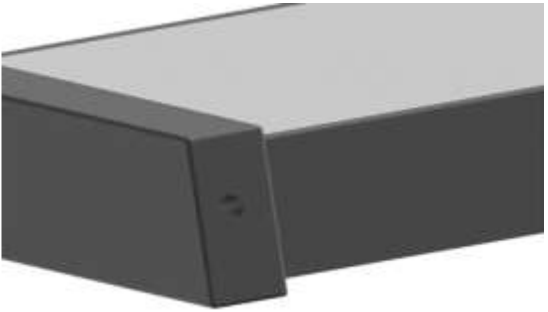
See: „Simulationsgestützte Qualifizierung neuer Konzepte zur Gestaltung von thermischen Solarkollektoren auf Polymerbasis“
Steffen Jack (2008)

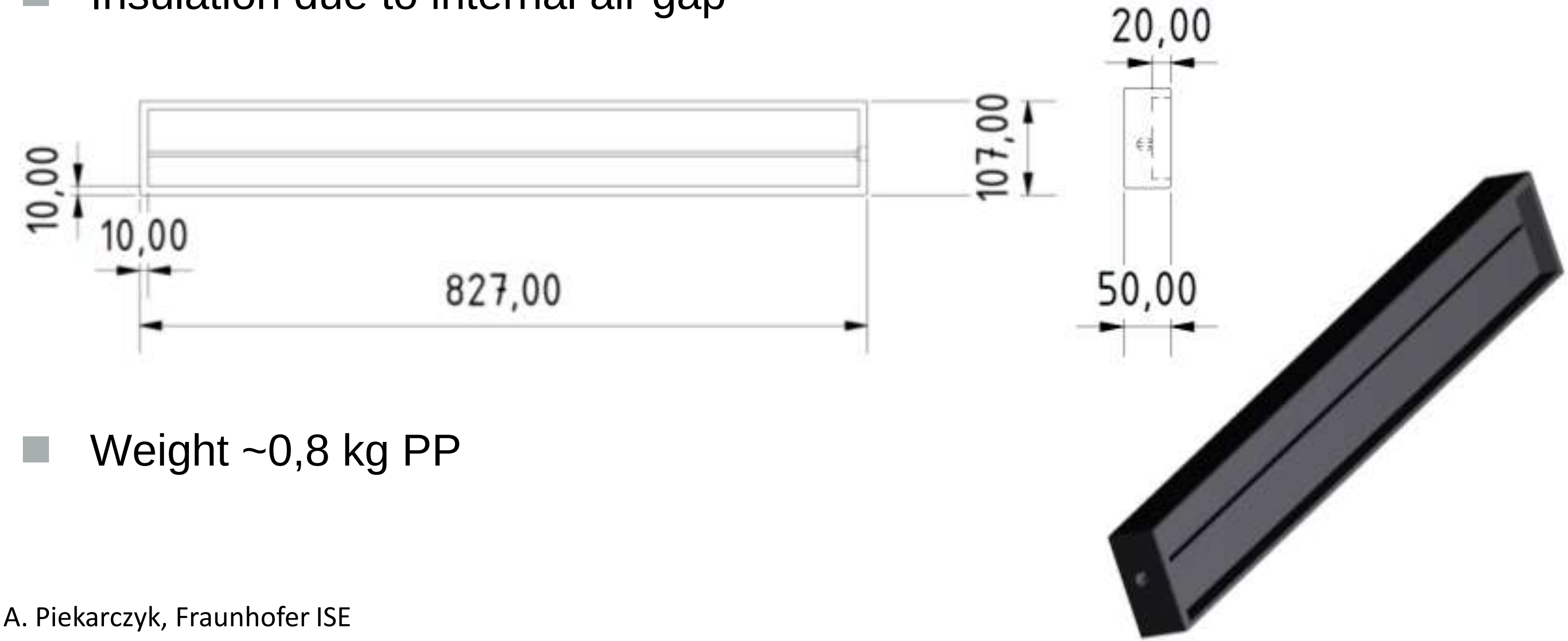
Source: A. Piekarczyk, Fraunhofer ISE

PP-Collector

Extruded profile and injection molded end caps

- End caps
  - Injection molded
  - Insulation due to internal air gap

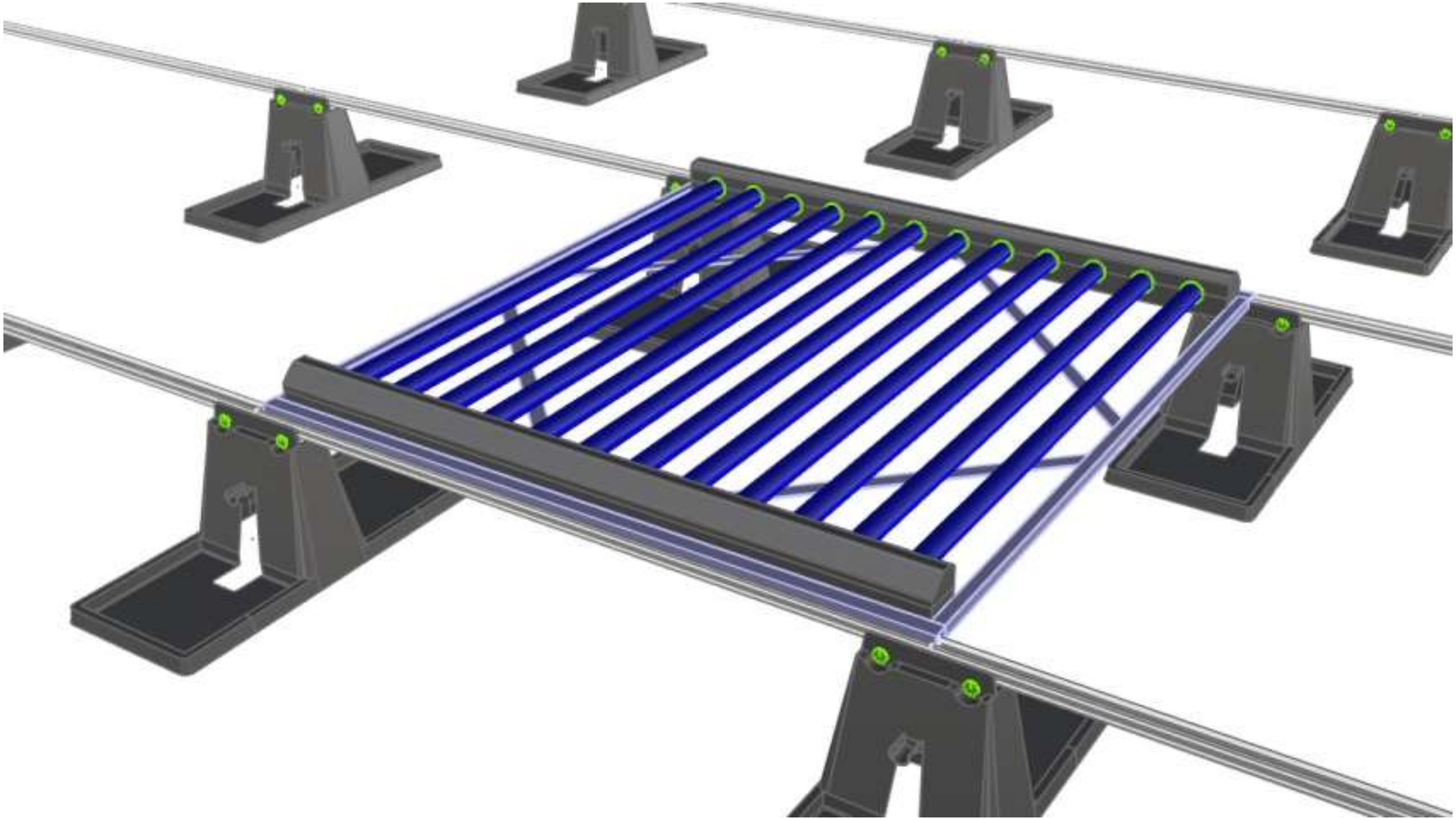




  - Weight ~0,8 kg PP

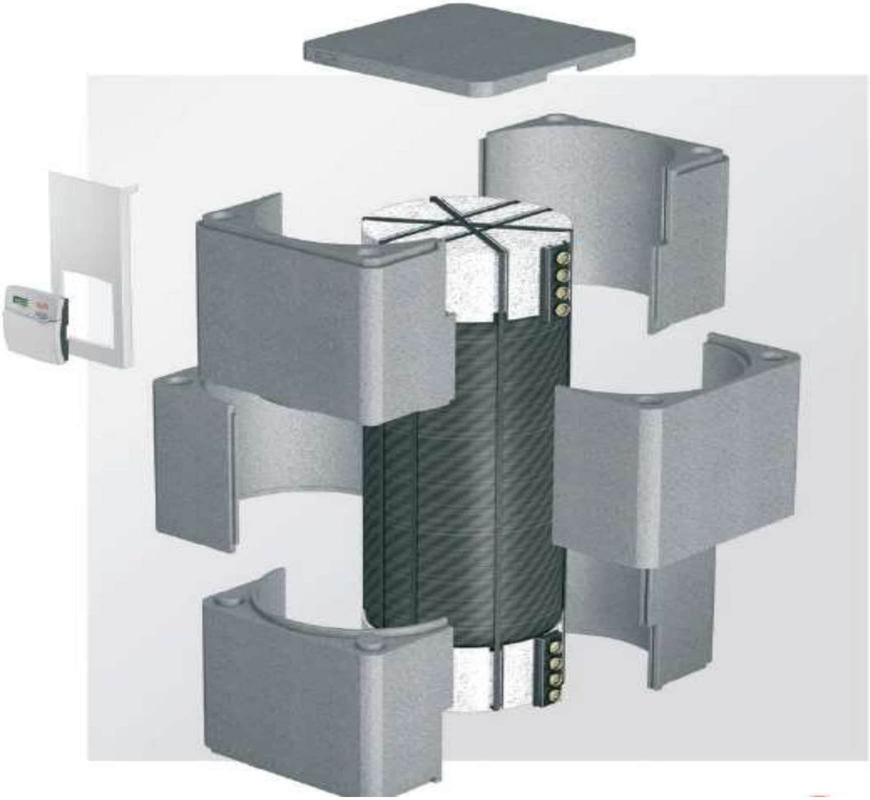
Source: A. Piekarczyk, Fraunhofer ISE

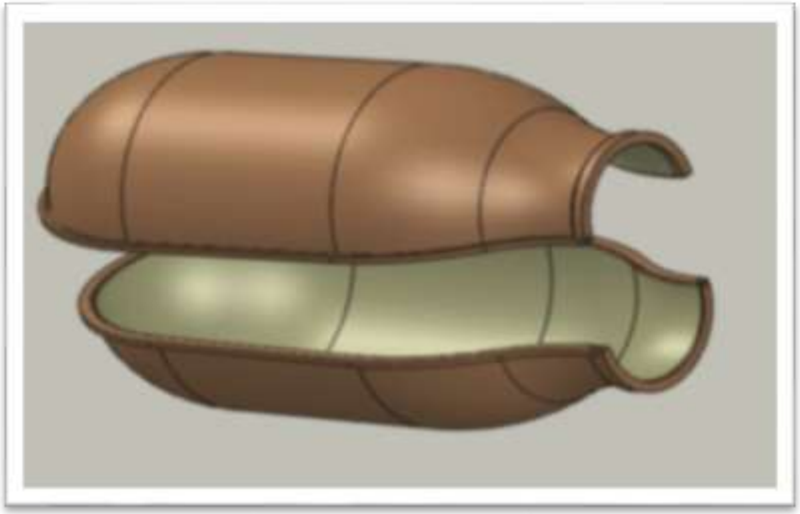
Collector support and framing



Source: R. Buchinger, Sunlumo

Thermal storage





Injection moulding of two half shells made from glass reinforced engineering materials (Concept Magen)

Thermo-tank QUADROLINE by ROTH WERKE GmbH

Fibre / Plastic composite and EPS blocks

High lights, conclusion and outlook

- Solar thermal has been brought to another level due to the participation and interest of big plastic producing companies (BASF, Chevron Phillips Chemicals, Du Pont, Borealis, Sabic, EMS, Solvay)
- First profil extruded with PPS
- First mass production of polymer collector in sight
- Collectors made from polymers pushed Norvegien solar thermal market
- Promising products for emerging markets

High lights, conclusion and outlook

- World market is and will increase this is why the big companies are interested
- Market development was not supportive (Europe)
- Lacking processing capacity
- Solar thermal industry is not yet interested in plastic production
- Investment for production line is very high compared to conventional production and will only be pay back with mass production

High lights, conclusion and outlook

Plastics are the future for solar thermal

- Real mass production is possible
- Cheaper products can be realised
- Higher freedom in design and building integration is possible

Tailor-made polymeric materials for collectors and heat storages

Prof. Dr. Gernot M. Wallner
Subtask Leader C

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Institute of Polymeric Materials and Testing
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Presentation Outline

Introduction and Background

- Development of Polymeric Materials
- Main Fields of Application and Success Factors

Subtask C: Structure, Partners and Selected Results

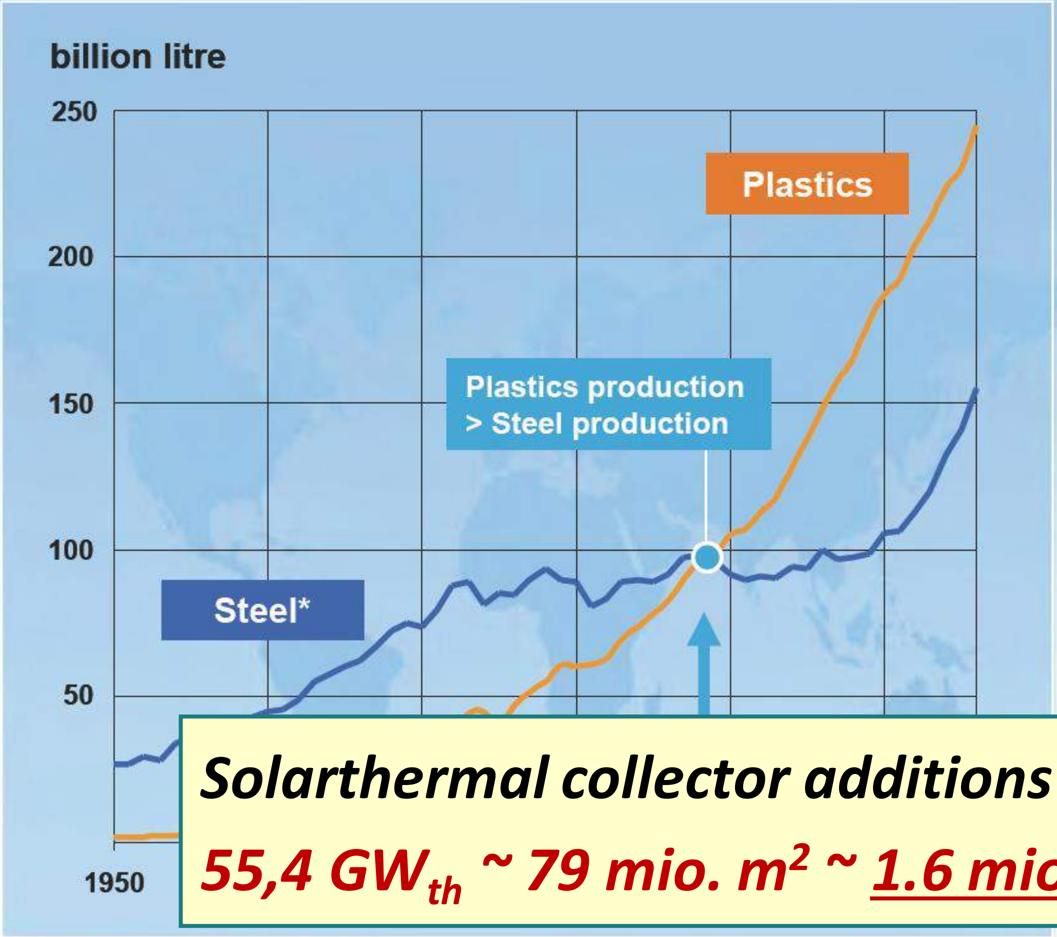
- Main Topics and involved Partners
- 3 selected Case Studies on Plastics for:
  - Overheating controlled flat-plate collectors
  - Drainback flat-plate collectors
  - Heat storage liner materials

Summary and Outlook

- Solarthermal Market Development
- Material Demand

The importance of the polymer industry

Development of plastics and steel worldwide (in terms of volume)



- **Plastics**
  in 1989, passed steel production by volume

Production worldwide 2007

- **Plastics:**
  260 Mio t =
  260 billion litre
- **Steel:**
  1,345 Mio t =
  168 billion litre

el:
tre

Solarthermal collector additions in 2012:

55,4 GW_{th} ~ 79 mio. m^2 ~ 1.6 mio. t material !!!

e, D (2008)

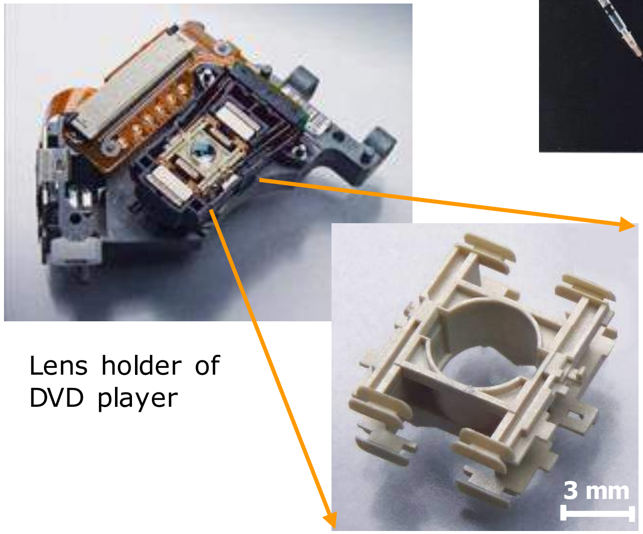
Plastics - most widely used material class

- **Tele-communication**

- **Medical technologies**

- **Civil & infrastructure engineering (B&C)**

- **Automotive engineering**

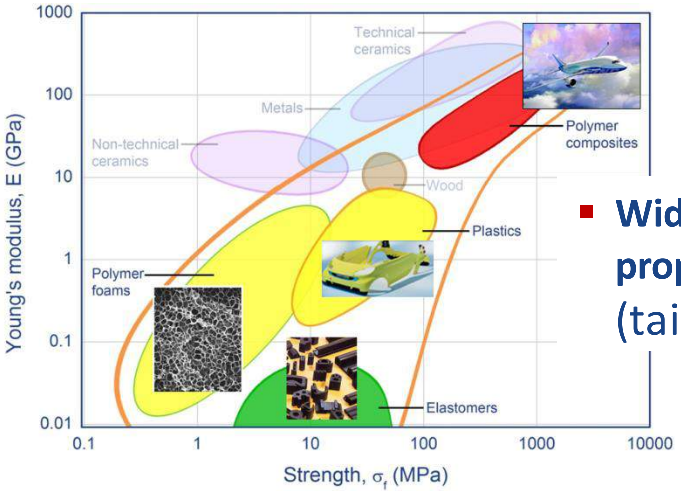


Lens holder of DVD player

- **Precision engineering & mechatronics**

- **Packaging**

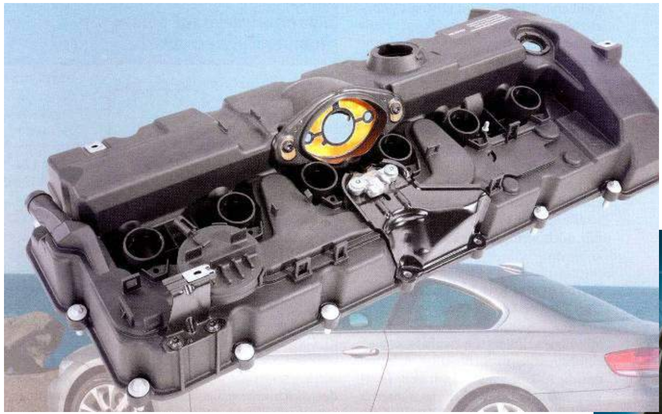
Plastics - main features and success factors



- **Wide range: property/performance** (tailor-made materials)

LED optics

- **Freedom of design**

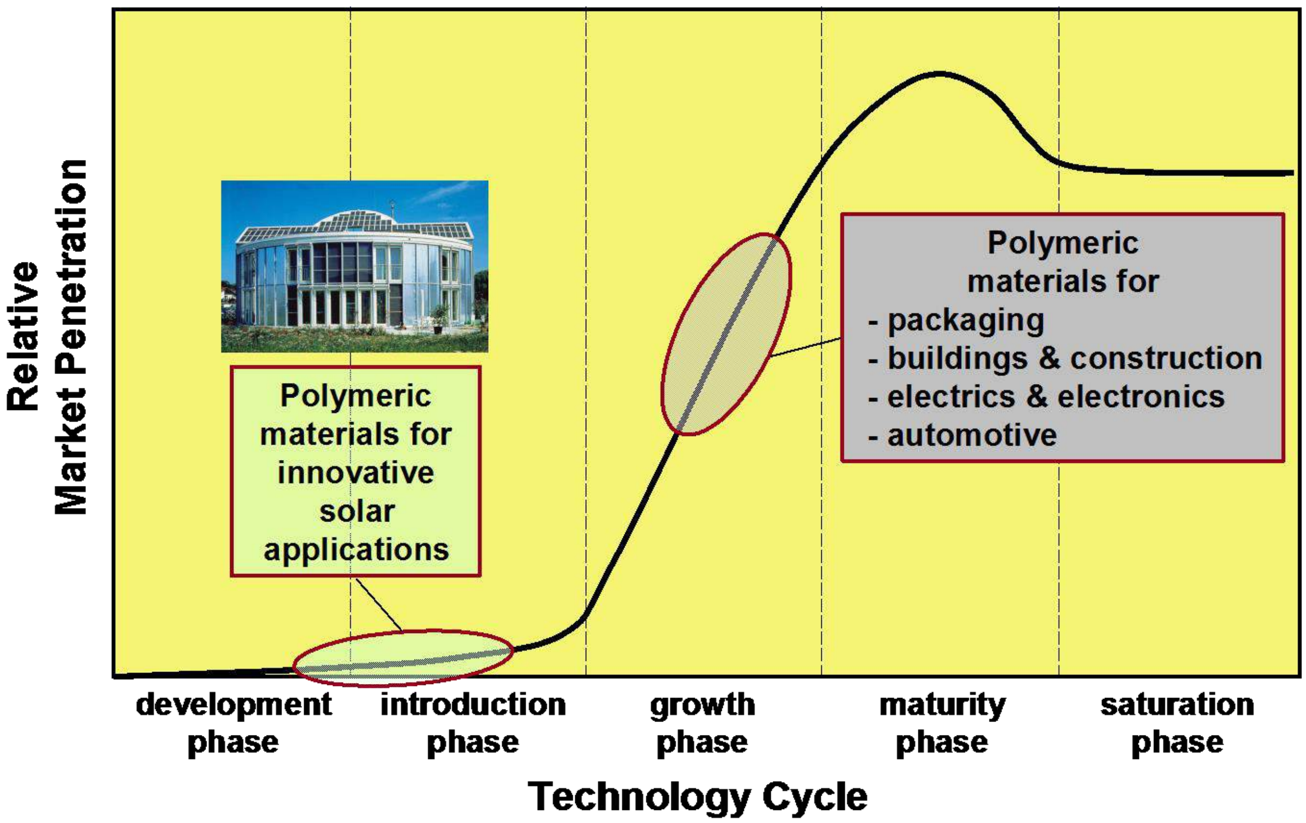


- **Multifunctional integration**

- **Combination of process technologies**

- **Composites & hybrid materials**

Plastics - Market penetration



Polymeric materials for innovative solar applications

Polymeric materials for
- packaging
- buildings & construction
- electrics & electronics
- automotive

4 main prerequisites for market acceptance:

- *improved performance (functionality)*
- *enhanced cost effectiveness*
- *guaranteed quality and durability*
- *attractive/multi-functional design*

What needs to be done to accelerate innovation & market penetration?

Projects of Subtask C on Materials

Project	Title	Focus
C1	**Multi-Functional Polymeric Materials**	• Materials for „All-polymeric“ Collectors • Materials for System Components incl. Heat Storages
C2	**Processing and Evaluation of Components**	• Extrusion and Injection Moulding of Components • Joining techniques
C3	**Methods for Testing and Characterization**	• Quality assurance • Aging and durability characterization

Partners of Subtask C on Materials

10 Countries	13 Company partners	10 Scientific partners
Austria, Belgium, Brasil, Germany, Netherlands, Norway, Portugal, Slovenia, Switzerland, USA	BOREALIS SHAPING the FUTURE with PLASTICS SOLVAY سابك sabic EMS EMS-GRIVORY BASF The Chemical Company Chevron Phillips Chemical Company LP DU PONT DS Smith agru Worldwide Competence in Plastics APC advanced polymer compounds BBT THERMOTECHNIK Roth save Color	JKU JOHANNES KEPLER UNIVERSITÄT LINZ AIT PCCL Fraunhofer ISE HUMBOLDT-UNIVERSITÄT ZU BERLIN Fachhochschule Osnabrück University of Applied Sciences SPF UiO : Department of Physics University of Oslo Solar Energy Laboratory

Overheating controlled collectors

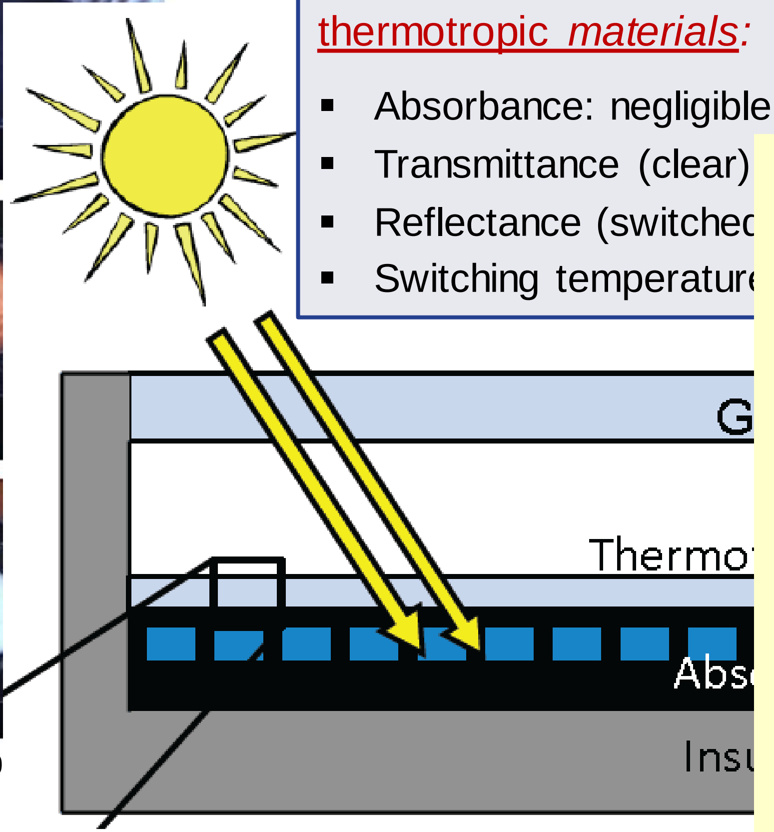
Thermotropic materials – Requirements and Achievements

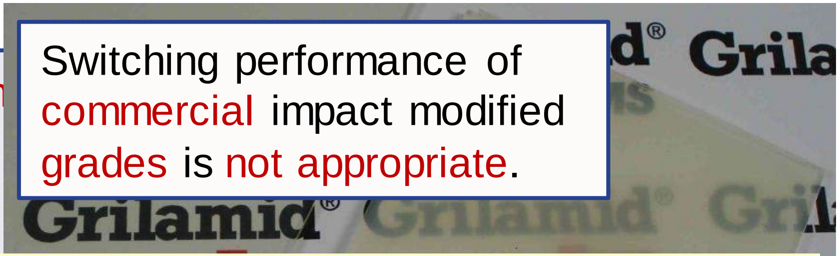
(Univ. of Leoben (Austria); Univ. of Minnesota (USA); EMS (Switzerland))

Source: Hartwig, 20

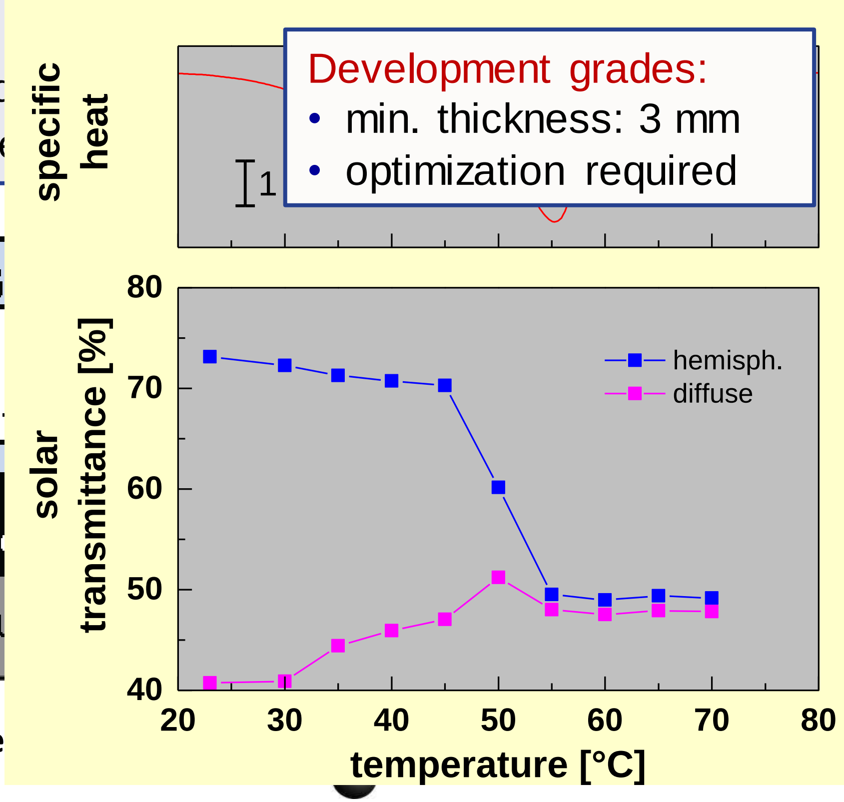
Key-property requiremen
thermotropic materials:

- Absorbance: negligible
- Transmittance (clear)
- Reflectance (switchec
- Switching temperature





Switching performance of commercial impact modified grades is not appropriate.



Development grades:

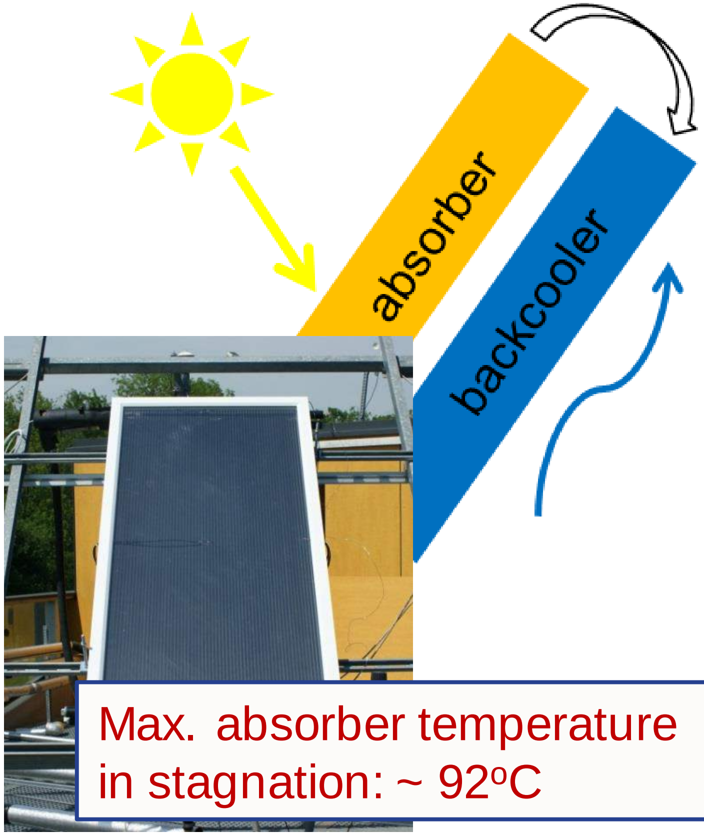
- min. thickness: 3 mm
- optimization required

Overheating controlled collectors

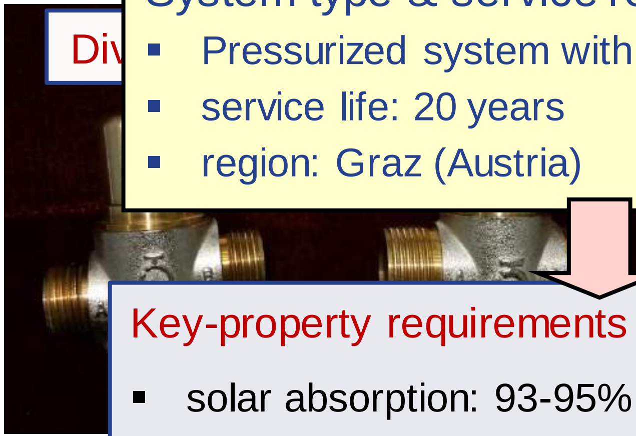
Absorber materials for overheating protected collectors

(Borealis, Univ. of Linz, AEE INTEC, Univ. of Innsbruck (Austria))

Overheating control by backcooling



Max. absorber temperature in stagnation: ~ 92°C



System type & service requirements

- Pressurized system with overheating protection
- service life: 20 years
- region: Graz (Austria)

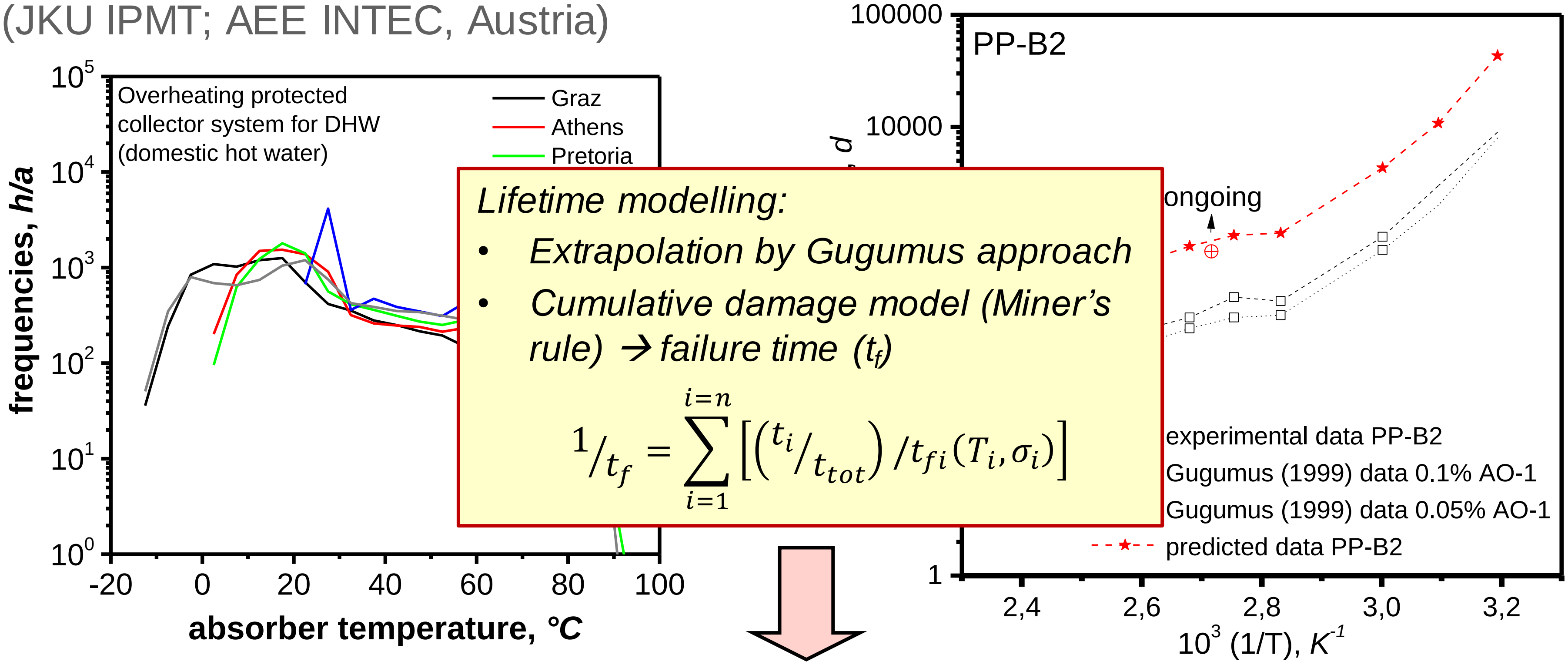
Key-property requirements for *absorber materials*

- solar absorption: 93-95%
- thermal stability: >100°C
- low temperature capability: -30°C
- long-term stability in water/glycol:
  - 75-100°C: > 3,500 h (DHW)
> 7,000 h (SH)
  - 0-75°C: > 150,000 h
- pressure: max. 1,5 bar

Overheating controlled collectors

Development and lifetime estimation for PP absorber materials

(JKU IPMT; AEE INTEC, Austria)



Lifetime modelling:

- *Extrapolation by Gugumus approach*
- *Cumulative damage model (Miner's rule) → failure time (t_f)*

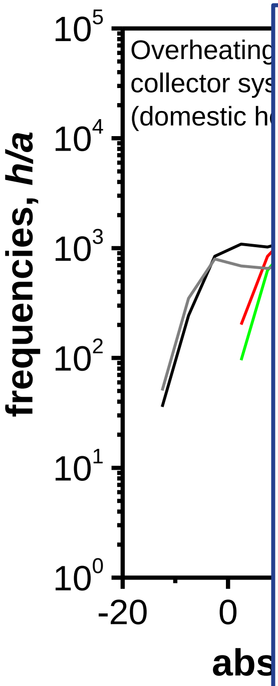
$$ {}^{1}/_{t_f} = \sum_{i=1}^{i=n} \left[\left({}^{t_i}/_{t_{tot}} \right) / t_{fi}(T_i, \sigma_i) \right] $$

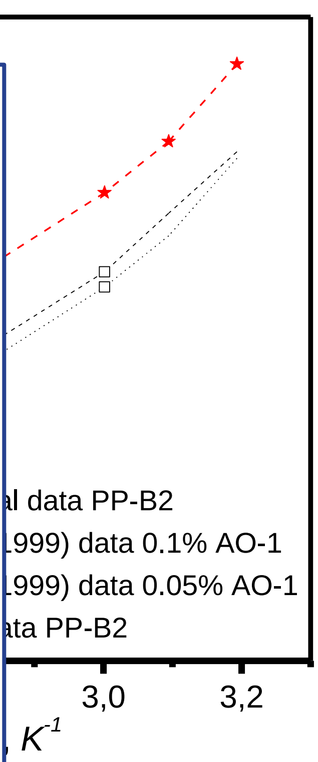
Lifetime, years	Graz, AT	Athens, GR	Pretoria, RSA	Fortaleza, BR	Beijing, CHN
PP-B1	**21**	**15**	**14**	**8**	**23**
PP-B2	**32**	**25**	**24**	**15**	**34**

Overheating controlled collectors

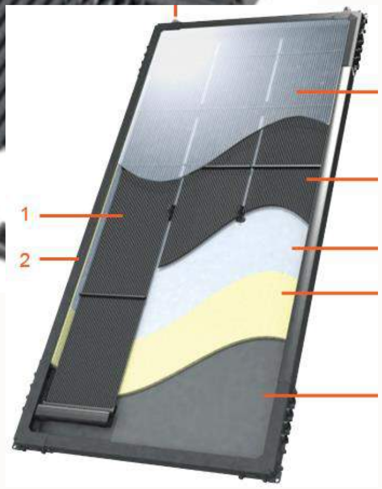
Development and lifetime estimation for PP absorber materials

(Univ. Linz, Borealis, AEE INTEC (Austria))





Novel material PP-B2 is now used commercially!



MAGEN eco-ENERGY
(Israel, Kibbuz Magen)

www.magen-ecoenergy.com

Lifetime, years					Beijing, CHN
PP-B1					23
PP-B2	**32**	**25**	**24**	**15**	**34**

Drainback flat-plate collectors

Requirements for absorber materials in drainback collectors

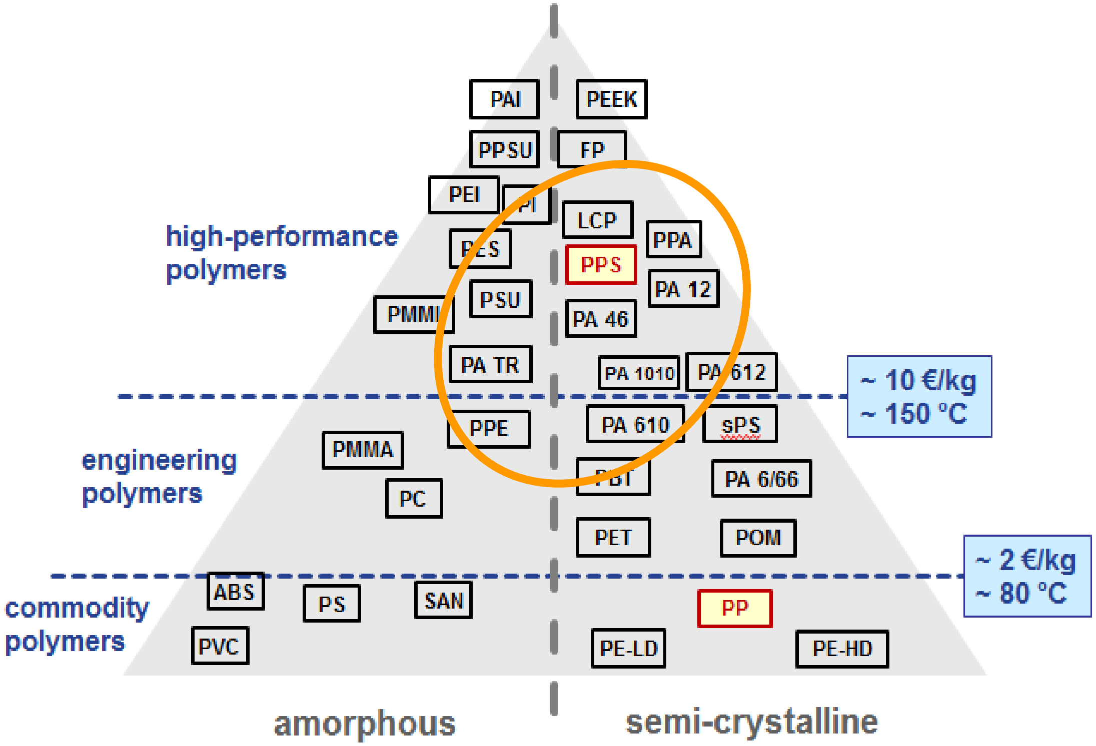
(Univ. Oslo, Aventa (Norway))

System type

- low-pressu
- service life
- region: Os

Key-property
absorber ma

- solar abso
- thermal st
- long-term
  - < 80°C: > 100,000 h
- short-term
  - 80-150
- no pressu



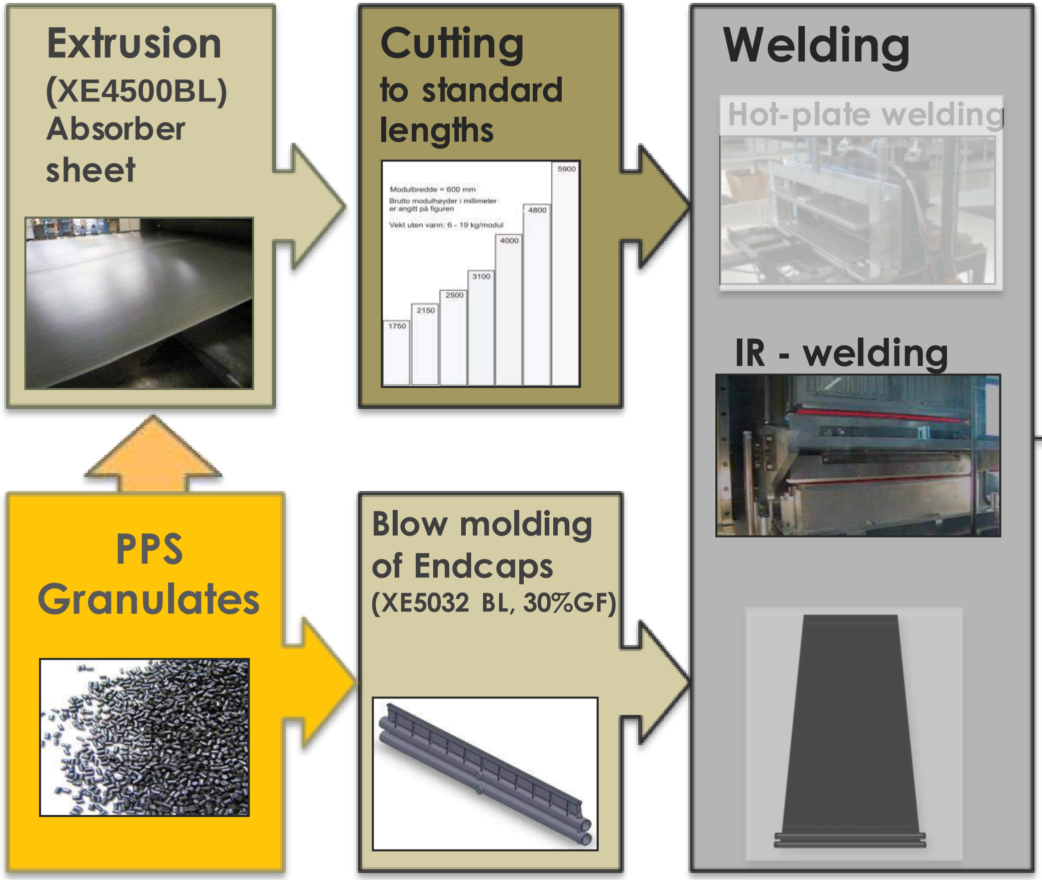
High performance plastics required; focus on:

- Polyphenylenesulfide (PPS)
- Polyphenyleneether (PPO)

Drainback flat-plate collectors

Processing, testing and lifetime estimation of PPS

(Univ. Oslo, Aventa (Norway), Chevron Philips (Belgium), DS Smith (France), ISE (Germany))



Extrusion
(XE4500BL)
Absorber sheet

Cutting
to standard lengths

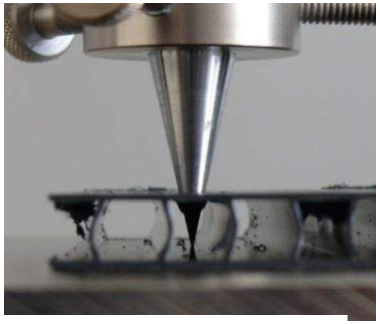
Welding

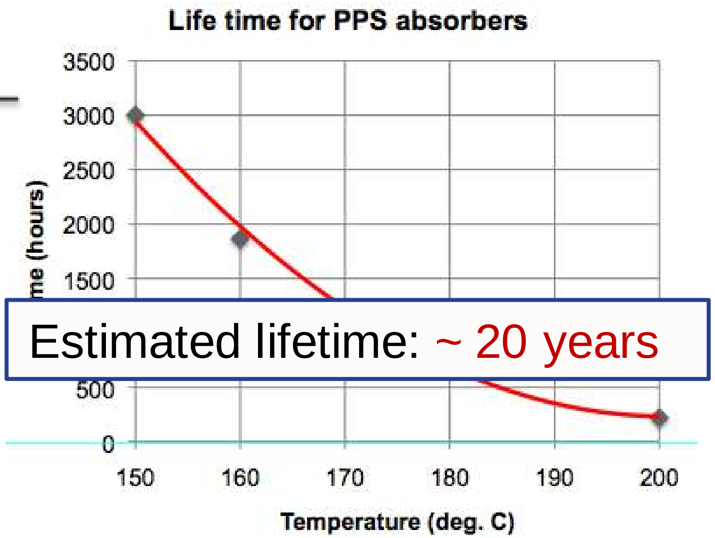
Hot-plate welding

IR - welding

PPS Granulates

Blow molding of Endcaps
(XE5032 BL, 30%GF)





Life time for PPS absorbers

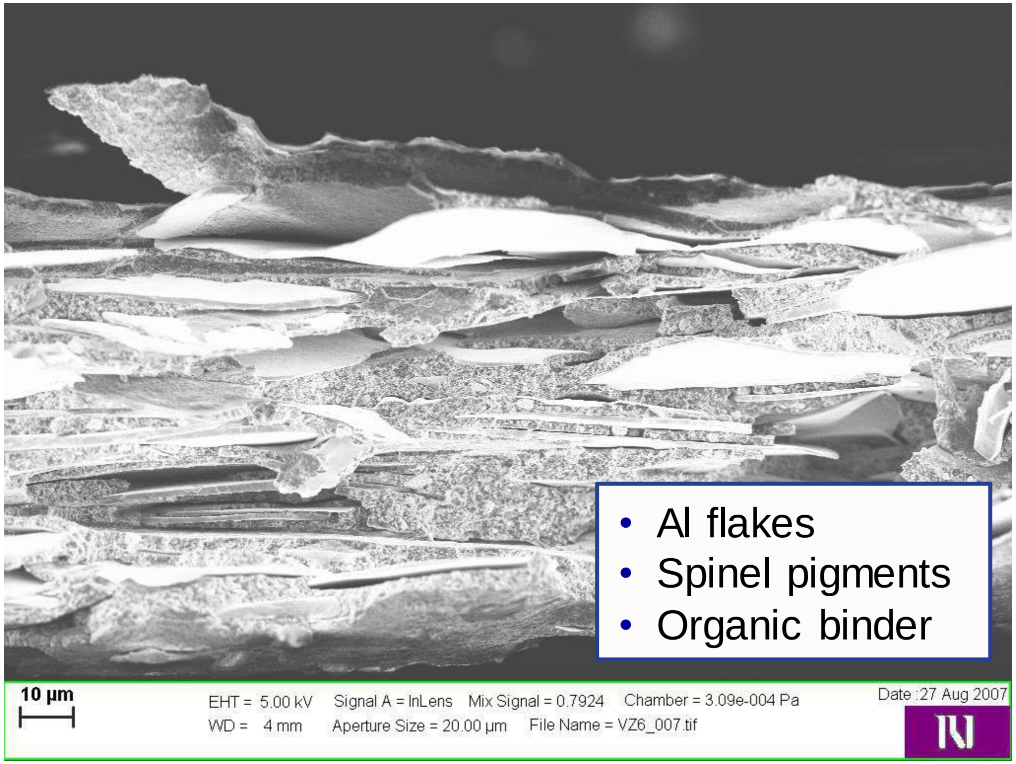
Estimated lifetime: ~ 20 years

Drainback flat-plate collectors

Multifunctional coatings for PPS absorbers

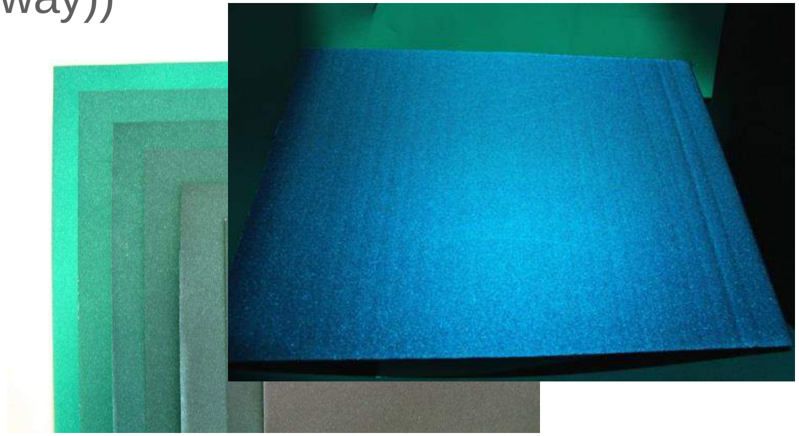
(NIC, Color (Slovenia), Univ. Oslo, Aventa (Norway))

Thickness Insensitive Spectrally Selective (TISS) paints

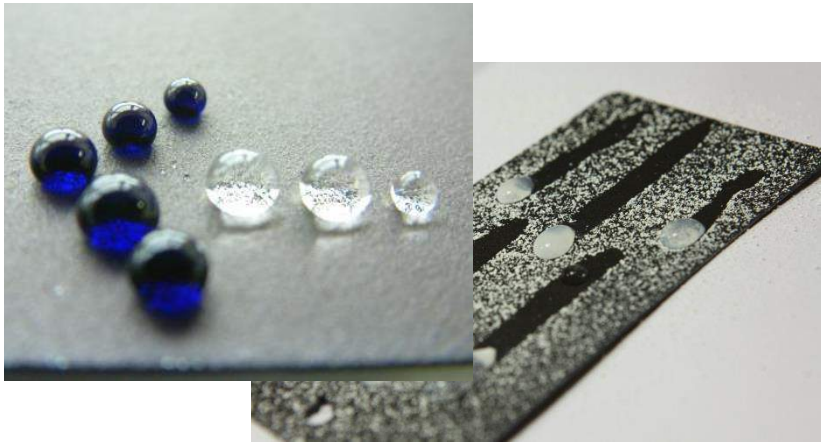


- Al flakes
- Spinel pigments
- Organic binder

Estethic colors



Self-cleaning capability



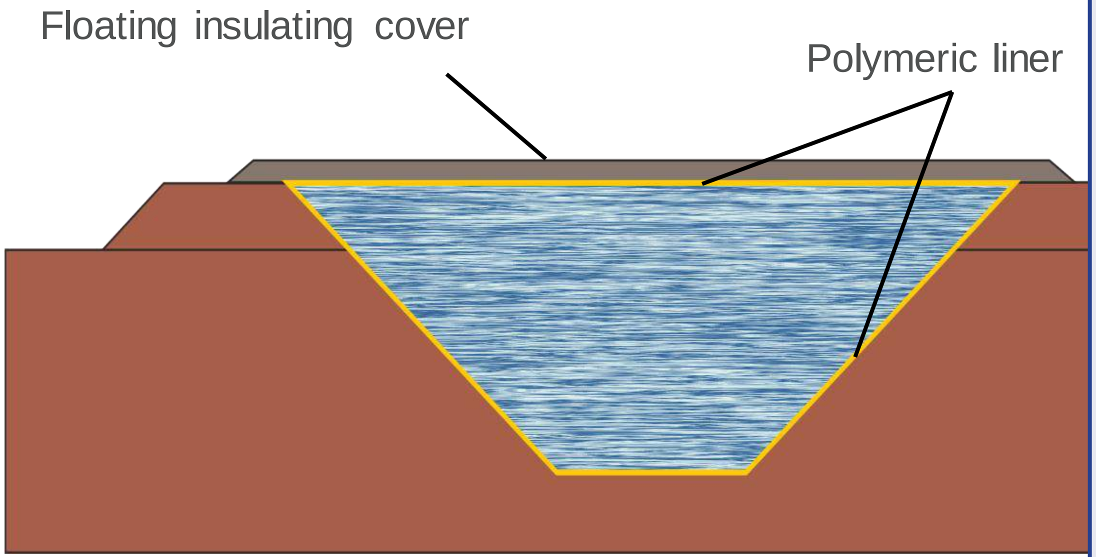
Heat storage liner materials

Liner materials for seasonal hot water storages

(AGRU, Univ. of Linz (Austria))

Example

SUNSTORE4, Marstal, DK (75 000 m³ water)



Dimensions:

- *Volume: 1.000 – 100.000 m^3*
- *Demand of liner: 250 – 25.000 m^2*

Criteria for *liner materials*:

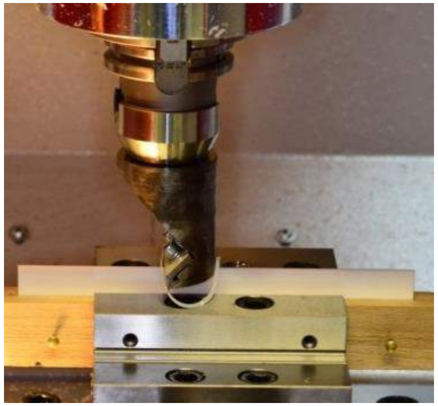
- Flexibility for easy installation:
  - E ≈ 600 MPa (at RT)
  - Liner thickness: ≈ 2 mm
- Key requirements:
  - Tmax = 95°C
  - 4,000 h/a ≈ 65-85°C
  - 4,000 h/a ≈ 30-60°C
- Environment:
  - Water heat carrier
  - Air / water vapor
  - Soil chemistry (minerals)
- Service lifetime: ≥ 30 years

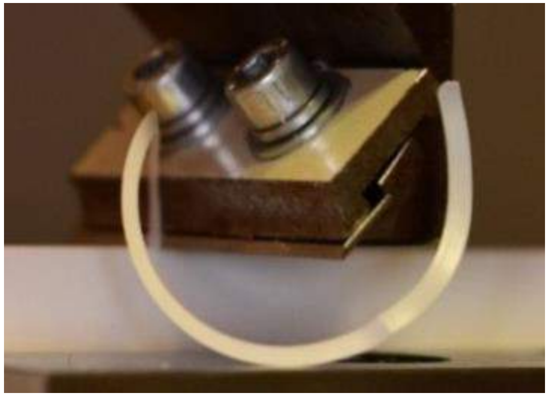
Heat storage liner materials

Accelerated aging characterization by Specimen Miniaturization

(Univ. of Linz (Austria))

Automized production of micro-sized specimen





Aging equipment (air, water water vapor)

Aging characterization and indicators

Mechanics (Tensile Testing):

- Strain at break (ε_B)

Spectroscopy:

- Carbonyl index (C.I.)

Thermoanalytical Methods:

- Oxidation onset temperatur (OOT)

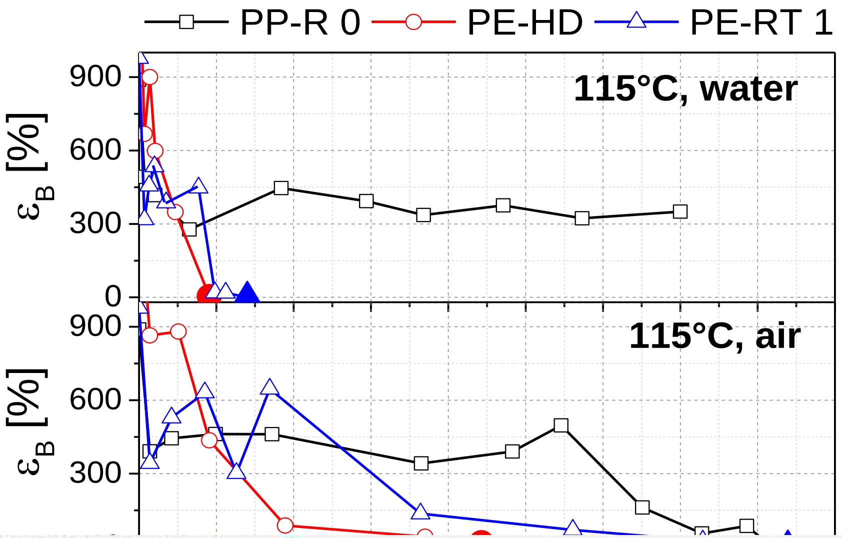
Chromatography:

- Content of stabilizers (esp. antioxidants)

Heat storage liner materials

Durability of polyolefin compounds (benchmark vs. novel grades)

(Univ. of Linz, AGRU, APC (Austria))



<u>Polyethylene (PE) grades:</u>

- Ranking: PE-RT 2 > PE-RT 1 > PE-HD

Water aging more severe than air aging.

<u>Novel polypropylene (PP) exhibit a better durability.</u>

<u>Lifetime estimation</u>

- No embrittlement for all gr
exposure in hot air and wa
900d (2.5 years).

→ Continuation of expe

Spin-off:

News > Latest News > High Temperature Resistant Geomembrane

agru

Worldwide Competence in Plastics

High Temperature Resistant Geomembrane

07.01.2014 LINING SYSTEMS - General - Research

AGRU for many years has supplied PE pipes for hot water applications. With this vast knowledge and experience AGRU developed the first high temperature resistant (HTR) PE geomembrane in the marketplace. It looks, feels and welds like every other HD-PE geomembrane. Additionally it offers an outstanding

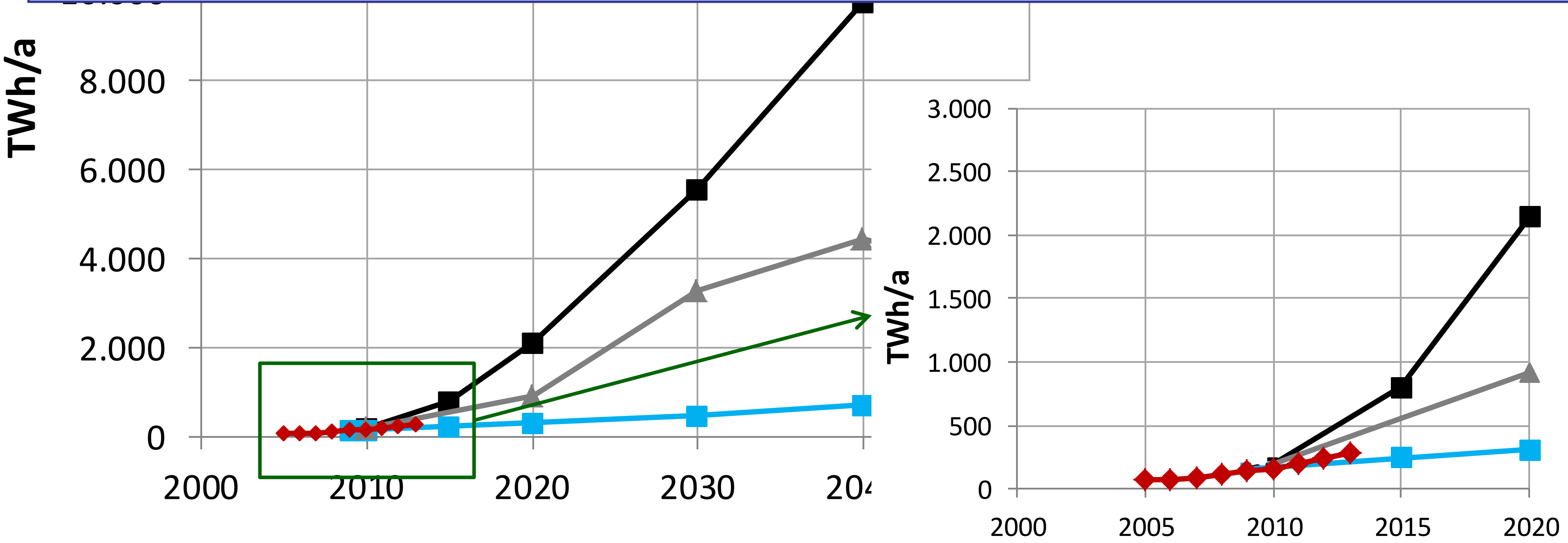
Summary and Outlook

Global Solar Thermal Heat based on 100% Renewable Energy Scenarios

(1) To keep up with the ambitious 100% scenarios, and

(2) to strengthen (or even maintain) its position as a main component in a future solar technology mix,

the solar-thermal industry needs a strong innovation push by enhanced R&D efforts.



Source: K. Holzhaider (2014)

Summary and Outlook

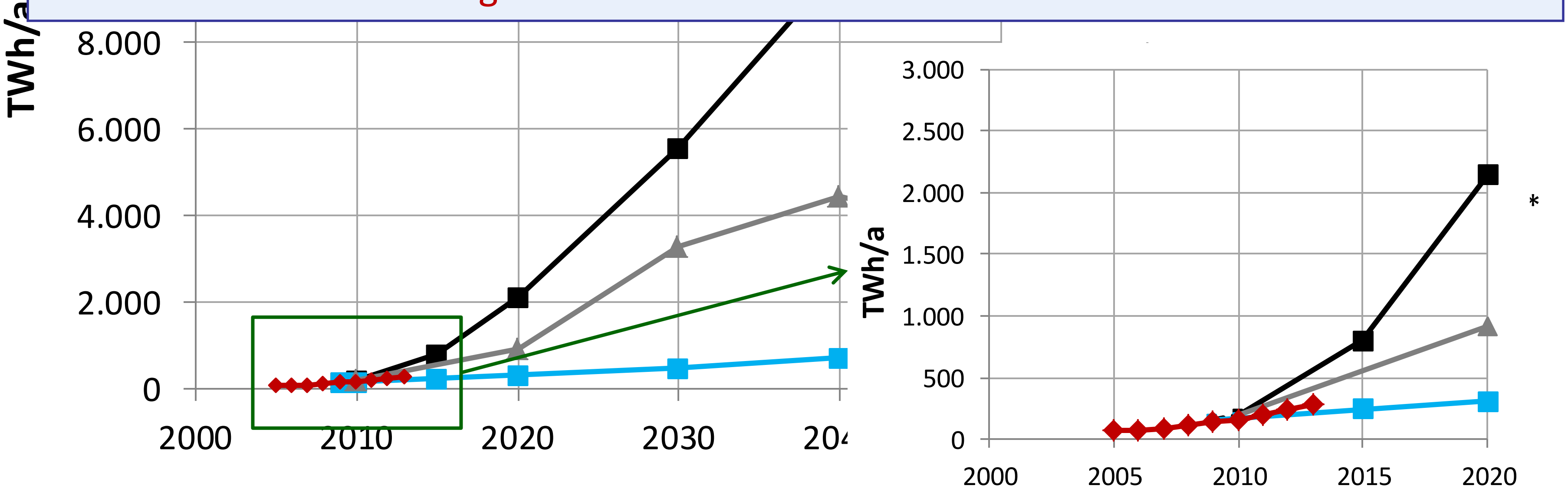
Global Solar Thermal Heat based on 100% Renewable Energy Scenarios

(1) To keep up with the ambitious 100% scenarios, and

(2) to strengthen (or even maintain) its position as a main component in a future solar technology mix,

the solar-thermal industry needs a strong innovation push by enhanced R&D efforts.

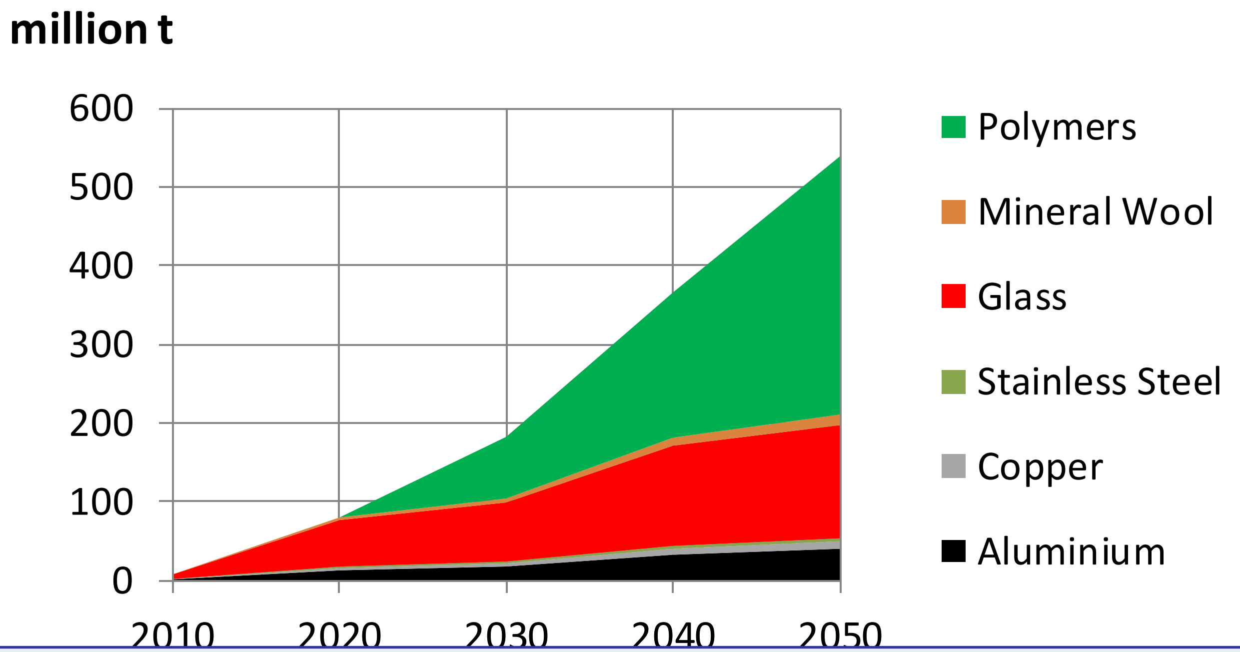
(3) Apart from significant polymer-induced innovations, there is no other single innovation driver in sight to achieve the more ambitious scenarios.



Source: K. Holzhaider (2014)

Summary and Outlook

Global Cumulative Material Demand for Polymer Based Solar Thermal Systems



(1) Low temperature heat supply is currently based on fossil (carbon) fuels.

(2) To achieve 100% renewable energy scenarios an average annual plastics demand of 8.2 million t/a would be needed.

→ Highly attractive market perspective for the oil/gas and plastics industry.

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UNIVERSITÄT LINZ | JKU

ipmt Institute of
Polymeric Materials
and Testing

Renewable Energy Scenarios and Potentials for Plastics in Solar Thermal and Photovoltaic Systems

MASTERARBEIT

zur Erlangung des akademischen Grades

Master of Science

im Masterstudium

UMWELTSYSTEMWISSENSCHAFTEN – PHYSIK

der KF Universität Graz

Eingereicht von:
Klaus Holzhaider, BSc., BSc.

Angefertigt am:
Institut für Polymerwerkstoffe, JKU Linz

Begutachtung:
Ao. Univ.-Prof. Dipl.-Ing. Dr. mont. Gernot Wallner

Linz, November 2014

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Eidesstattliche Erklärung

Ich erkläre an Eides statt, dass ich die vorliegende Masterarbeit selbstständig und ohne fremde Hilfe verfasst, andere als die angegebenen Quellen und Hilfsmittel nicht benutzt bzw. die wörtlich oder sinngemäß entnommenen Stellen als solche kenntlich gemacht habe.

Die vorliegende Masterarbeit ist mit dem elektronisch übermittelten Textdokument identisch.

Klaus Holzhaider, November 2014

Abstract

The aim of this master's thesis was to estimate the future material demand for solar thermal and photovoltaic systems and derive potentials for plastics based on 100% renewable energy scenarios. First, scenarios that aim for 100% renewable energy by 2050 were analysed and compared to market scenarios. Assumptions on the material input for different technologies were made and the future material demand of solar thermal and photovoltaic systems was estimated. While assumptions on solar thermal collectors were entirely based on literature, in case of photovoltaic modules an experimental analysis of typical solar modules was made, additionally. The cumulative plastics demand for solar thermal systems until 2050 was estimated to be between 90 and 330 million t, which is at the same time a great challenge and potential for the plastics industry and strongly suggests the usage of cost-efficient commodity plastics such as polyolefins. In case of photovoltaics the estimated material demand is lower by roughly a factor of ten, yet still considerable.

Kurzfassung

Ziel dieser Masterarbeit war die Abschätzung des zukünftigen Materialbedarfs für solarthermische und photovoltaische Systeme und die Ableitung möglicher Potenziale für Plastik, basierend auf 100% erneuerbare Energie Szenarien. Zunächst wurden Szenarien, die 100% erneuerbare Energie bis 2050 zum Ziel haben, analysiert und mit Marktszenarien verglichen. Annahmen für den Materialeinsatz verschiedener Technologien wurden getroffen und der zukünftige Materialbedarf für solarthermische und photovoltaische Systeme berechnet. Während die Annahmen im Fall der Solarthermie alleine auf der Literatur beruhen, wurde im Fall der Photovoltaik zusätzlich eine Materialanalyse typischer PV-Module durchgeführt. Der kumulierte Plastikbedarf bis 2050 wurde zwischen 90 und 330 Mio. t berechnet. Dies ist zugleich eine große Herausforderung, wie auch ein großes Potenzial für die Kunststoffindustrie und legt die Verwendung von kostengünstigen und leicht verfügbaren Massenkunststoffen wie Polyolefinen nahe. Im Fall der Photovoltaik lag der abgeschätzte Materialbedarf um etwa einen Faktor zehn darunter, war aber dennoch beträchtlich.

Table of Contents

ABBREVIATIONS

BHJ	Bulk heterojunction
CdS	cadmium sulphide
CIGS	copper indium gallium selenide
c-Si	crystalline silicon
E[R]	Energy [R]Evolution
EPIA	European Photovoltaic Industry Association
EREC	European Renewably Energy Council
ESTIF	European Solar Thermal Industry Federation
EU	European Union
EVA	Ethylenvinylacetat Copolymer
GaInAs	gallium indium arsenide
GaInP	gallium indium phosphide
Ge	germanium
GWEC	Global Wind Energy Council
IEA	International Energy Agency
IPCC	International Panel on Climate Change
ITO	indium tin oxide
NEP	New Energy Policy
OMA	Office for Metropolitan Architecture
PE-LD/HD	Polyethylene - low denstity/high density
PMMA	Poly(methyl methacrylate)
PV	Photovoltaic
PVB	Polyvinylbutyral
PVF	Polyvinylfluorid
TCO	Transparent conductive layer
TER	The Energy Report
TF	Thin film
WWF	World Wide Fund for Nature
ZnO	zinc oxide

1. INTRODUCTION AND SCOPE

The growing amount of natural disasters and extreme weather phenomena the world has experienced in recent years shows that global warming is becoming an increasing threat for people around the world. At the same time, however, both the usage of and subsidies for fossil fuels keep increasing[1]. As reserves become scarcer, more and more unconventional and environmentally controversial methods such as fracking have to be used. Also, the accident in Fukushima in 2011 showed that nuclear power is not a safe alternative. Thus, an energy revolution with a shift to renewable energies is inevitable to ensure a sustainable energy future and secure adequate living conditions for generations to come. Renewable technologies have seen an enormous increase of installed capacity in recent years. However, they will have to overcome many more obstacles before becoming the main (and eventually only) player on the energy market.

This master's thesis analyses what it takes to realise such an energy revolution. It compares different pathways towards 100% renewable energies by 2050. In order to achieve this, new scales will have to be set in many ways. One of those issues is the material demand resulting from the necessary increase of installed capacity. Using conventional materials will be expensive and in some cases not feasible any more. Thus the development of new, cost-effective materials for renewable technologies such as plastics is one key to success. In this thesis we look at the impacts of 100%-scenarios on the material demand and the resulting potential of plastics in the renewable technology sector, focusing on solar thermal and photovoltaic (PV) systems. These two technologies are not the only applications for polymeric materials within the renewable sector but are especially well suited. Including more technologies would have gone beyond the scope of this master's thesis.

We confine ourselves to the basic elements of the systems. In case of solar thermal energy we only consider the collector and do not include any other system elements such as the mounting system, hot water tank, tubes, pumps etc. In case

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[1] Available: http://www.worldenergyoutlook.org/resources/energysubsidies and http://www.scientificamerican.com/article/fossil-fuel-use-continues-to-rise (5th August, 2014).

of PV, similarly, we look at the modules only and don't include the mounting system, batteries, cables, inverter etc.

After this brief introduction, chapter 2 gives an overview of scenarios aiming for 100% renewable energy until 2050 on a global and European scale. This includes their assumptions and results for both the expected demand and the technology mix of the energy supply. As we focus on solar thermal and PV, heat and electricity are of special interest in this context. Furthermore, we have a look at existing market scenarios of the involved industries and compare them with the “100%-scenarios”.

Chapter 3 is dedicated to the future material demand of solar thermal systems. We start by describing the methodology as well as the assumptions and data the calculations are based on. Then we present the results, i.e. the expected cumulative and annual material demand as well as the corresponding growth rates of the different materials. The chapter is concluded by considerations on the effects of such a development on the plastics industry.

Chapter 4 follows a similar structure as chapter 3 but regards PV systems. In the same way we look at methodology, the underlying assumptions, the results of the calculation and the possible effects on the plastics industry.

Finally, chapter 5 summarizes the results and gives an outlook on possible future research in the field.

2. RENEWABLE ENERGY SCENARIOS

Before starting to describe the so-called 100%-scenarios it is important to clarify what is meant by the term “scenario”. The International Panel on Climate Change (IPCC) defines a scenario as *“[…] a coherent, internally consistent and plausible description of a possible future state of the world. It is not a forecast; rather, each scenario is one alternative image of how the future can unfold.”* [2] Further clarification is given in “RE-thinking 2050”: *“Long-term scenarios are to be considered as analytical tools for reflection, highlighting choices and opportunities, rather than predicting the future”* (Zervos et al., 2010). A scenario therefore largely depends on the underlying assumptions and parameters that can be varied in order to get information about possible outcomes of events under varying circumstances.

2.1 History of 100%-Scenarios

The concept of covering the global or regional energy demand by 100% renewable energies is not new. Already in 1975 a scenario was made aiming for the entire energy demand of Sweden to be covered by renewables (Scheer, 2012). The non-profit European Association for Renewable Energy EUROSOLAR also has pursued the goal of completely substituting nuclear and fossil energy by renewables since its foundation in 1988. It continues to organize 100% renewable energy conferences such as the IRENEC 2014 in Turkey. Their aim was long considered impossible by many experts. In recent years, however, a vast amount of scientifically well-grounded studies and scenarios were published on the topic for different regions around the world as well as on a global scale.

Renowned environmental organisations such as Greenpeace (“Energy [R]Evolution”), World Wide Fund for Nature (WWF, “The Energy Report”) or the European Climate Foundation (“Roadmap 2050”, cooperating, amongst others, with the consultancy McKinsey & Company) have worked on 100%-scenarios. Likewise, more and more government-related organizations and official institutions have picked up the topic, such as the “Energieziel 2050: 100% Strom aus

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[2] Available: http://www.ipcc-data.org/guidelines/pages/definitions.html (6th May 2014).

erneuerbaren Quellen"[3] (Klaus et al., 2010) by the German "Umweltbundesamt", aiming for 100% renewable electricity until 2050. In August 2014 Stefan Bofinger, head of the department of Large-Area Energy Supply Structures at Fraunhofer Institute for Wind Energy and Energy Systems Technology, Kassel, said 100% renewable energy by 2050 is possible at the Technology Symposium Alpbach[4].

The hypothesis that 100% renewable energy is technologically feasible seems no longer unrealistic. In fact, many authors (e.g. Edenhofer, 2012; Jacobson and Delucchi, 2011) don't see technological but rather social or political issues as the limiting factors. This is also in line with all scenarios we chose to analyse for this thesis.

Despite the great number of existing scenarios, few of them can be used for our purposes. The scenarios vary in terms of their goals (not all scenarios that call themselves "100%" truly aim for an entire renewable energy system), the scope (included technologies, region etc.) and timeframe. In our case we are looking for scenarios on a global and European scale, with a timeframe until 2050, including solar thermal and PV technology. Only few 100%-scenarios are detailed and consistent enough to fulfil our criteria. In the following section we give an overview of the scenarios we chose for our calculations and give reasons for the selection.

2.2 100% - Renewable Energy Scenarios

Global

On a global scale the selection was not difficult as options were few. The only scenarios we found that meet our criteria are

1. ***Energy [R]Evolution – A Sustainable World Energy Outlook*** by Greenpeace, Global Wind Energy Council (GWEC) and European Renewable Energy Council (EREC) and
2. ***The Energy Report – 100% Renewable Energy by 2050*** by WWF International, ECOFYS and the Office for Metropolitan Architecture (OMA).

The target of *Energy [R]Evolution* (E[R]) is to provide 94% of the electricity demand and 91% of the heat demand with renewable energy by 2050. The former

---

[3] Energy goal 2050: 100% electricity from renewable sources

[4] Available: http://science.orf.at/stories/1743348 (5th August 2014).

E[R] edition published in 2010 was chosen as one out of four illustrative benchmark scenarios for climate change mitigation scenarios for IPCC's Special Report on Renewable Energy and Climate mitigation (Edenhofer et al., 2012). As such it is very detailed in terms of used technologies, regions, energy sectors etc. One advantage of this scenario is that, apart from the global scenario, it specifies detailed results for different regions, including OECD Europe. Thus we can use it in both global and European calculations.

In the same timeframe *The Energy Report* (TER) targets to provide 95% of the total energy demand by renewable energies. It also includes all energy sectors (electricity, heat and transport), regions and common technologies.

Other global scenarios such as the „Technology Roadmap – Solar Heating and Cooling" of the International Energy Agency (IEA, 2012) have less ambitious aims and therefore are not suitable for our purposes.

Europe

On a European scale more 100%-scenarios exist. However, here in particular we face the problem of varying scopes. For example some scenarios include the former EU-27 countries (e.g. RE-thinking 2050), others include OECD-Europe (e.g. Energy [R]Evolution). While the difference in terms of installed capacity is only around 1% for PV[5] (Masson et. al, 2013), in case of installed capacity of solar thermal collectors[6] there is a difference of around 27% (ESTIF 2013; Mauthner and Weiss, 2013). The difference is mainly due to Turkey whose installed capacity of 10.2 GW_{th} is only outnumbered by the European market leader Germany (11.2 GW_{th}). Turkey is included in OECD-Europe but not in EU-27.

As European scenarios we chose:

1. ***Energy [R]Evolution – A Sustainable World Energy Outlook*** by Greenpeace, GWEC and EREC and
2. ***RE-thinking 2050 – A 100% Renewable Energy Vision for the European Union*** by EREC

---

[5] EU-27: 69.1 GW, OECD-Europe 68.4 GW, cumulated installed capacity in 2012

[6] EU-27: 27.5 GW_{th}; OECD-Europe: 37.7 GW_{th} (values from 2012 except Iceland, Norway and Switzerland (2011))

The former is consistent with the global E[R]-scenario with the same advantages as listed above. The latter allows a comparison with the scenarios of the European Solar Thermal Industry Federation (ESTIF) which also take EU-27 as a basis. It includes electricity, heat and transport and considers all common technologies. Furthermore it includes estimations on the share of renewable technologies depending on the oil price development. Other scenarios only cover the time until 2030 (e.g. “Renewable Energy: a 2030 scenario for the EU” by ECOFYS) or are confined to certain energy or geographic sectors (e.g. “100% renewable electricity - A roadmap to 2050 for Europe and North Africa” by PriceWaterhouseCoopers (a.o.)).

Austria

Our initial plan was to include Austrian scenarios into our calculations. However, on an Austrian scale there exist no suitable 100%-scenarios. The feasibility-study *Energieautarkie für Österreich 2050* by Streicher et. al. (2010) targets 100% renewable energies in Austria until 2050. However, only possible potentials for different technologies in the year 2050 are presented but no scenarios are calculated that describe the pathway towards 2050. This makes continuous calculations impossible. The study *Energy [R]Evolution – 2050 Österreich* by Bliem et. al. (2011) aims for 80% renewable energies until 2050 but here, too, the results are estimations of potentials rather than scenarios. Besides, there is no separate scenario for solar thermal technology. Furthermore, the potentials were taken from literature and underlie no independent calculations. As no suitable scenarios were found for Austria we decided not to include national 100%-scenarios in our calculations.

2.2.1 Energy [R]Evolution – A Sustainable World Energy Outlook

Greenpeace published a first “Energy [R]Evolution” scenario for Europe in 2005. Further (already global) scenarios followed in 2007, 2008, 2010 and 2012, the latter being the one we are working with in this thesis. It “*provides a consistent fundamental pathway for how to protect the climate: getting the world from where we are now to where we need to be by phasing out fossil fuels and cutting* CO_2 *emissions while ensuring energy security*.” (Teske et al., 2012).

Authors:

Greenpeace, GWEC and EREC

Targets:

The E[R] scenario has a key target to keep the average global temperature increase below 2℃. In order to achieve this, the annual CO_2-emission needs to be kept below 4 Gt by 2050. A second goal is to phase out the usage of nuclear power. The targets until 2050 for each sector are:

- 94.3% renewably electricity,
- 90.7% renewable heat generation,
- 71.5% renewable transport and
- 82.3% renewably primary energy.

Note: The report envisages 46.4% of the final energy demand of OECD Europe to be covered by renewables in the year 2030. In July 2014, the European Commission set the target of 27% renewable energies by 2030[7]. While the EU and OECD Europe are not directly comparable, the difference of almost 20 percentage points cannot be neglected.

Scenarios

The report describes two scenarios: a reference scenario (REF) which assumes a continuation of current trends and policies and the E[R] scenario which shows potential achievements following major policy-induced changes.

The reference scenario is based on the Current Policies scenario of the World Energy Outlook, which was published by the IEA in 2011. For the timeframe between 2035 and 2050, which is not covered by IEA's scenario, an interpolation was used.

The current Energy [R]Evolution scenario is more ambitious than those in earlier editions. The implementation of the scenario is based on three steps:

1. Energy savings by increasing efficiency and reduction of consumption.

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[7] Available: www.industriemagazin.at/a/energieziele-eu-kommission-will-30-prozent-energieeinsparung-bis (24th July 2014).

2. Extensive use of decentralized power supply (including cogeneration) as well as large scale renewables.
3. Transformation of the energy system, in order to be able to accommodate the significantly higher shares of renewable energies (e.g. smart grids).

Key characteristics include, amongst others:

- Usage of currently available best practice technology.
- All cost-effective renewable energy sources are used for heat and electricity generation as well as the production of biofuels.
- Shift within the renewables from power to heat.
- A fast expansion of solar and geothermal heating systems.
- Particularly in developing countries a short lifetime was assumed for coal power plants (20 years) to allow a faster development of renewable energy.

Demand projection

One of the key components of an energy scenario is the demand projection, which defines the necessary energy supply and influences the energy mix. It includes social and technical factors such as population growth, GDP development or energy efficiency. In our case, the (low temperature) heat demand for solar thermal systems and electricity demand for PV are of special interest. Figure 2-1

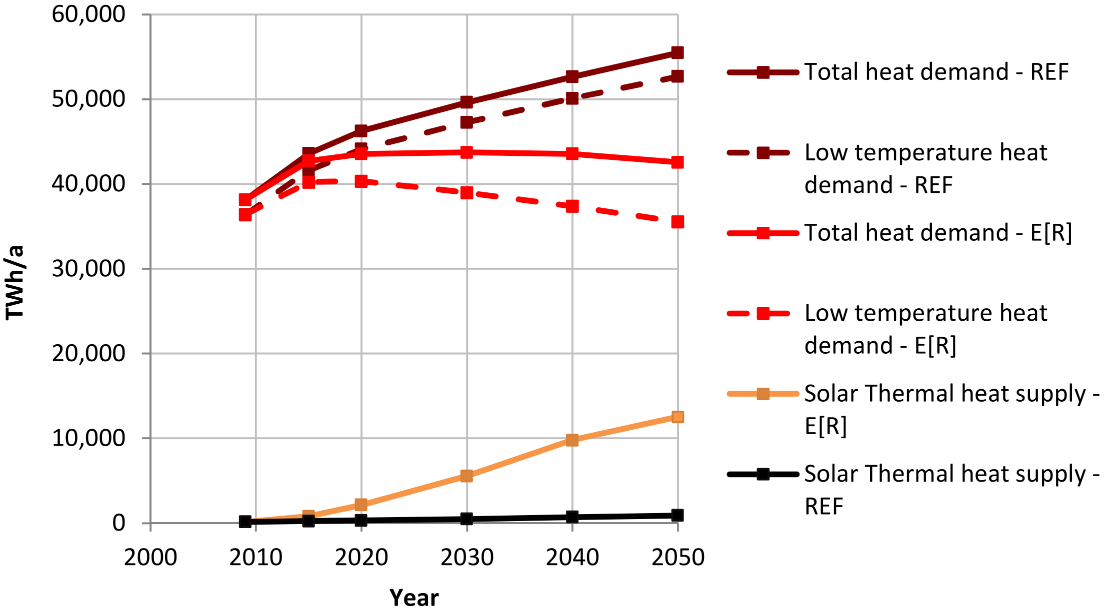

Figure 2-1 Global heat demand and supply by solar thermal systems, Energy [R]Evolution

shows the global heat demand and the low temperature heat demand[8] for both scenarios. In the E[R]-scenario, 35.2% of the low temperature heat demand and 29.4% of the total heat demand would be covered by solar thermal heat supply with fossil fuels below 10% of the total share. While fossil fuels experience a drastic decrease and shares of biomass heating remain similar between 2009 (24.8%) and 2050 (26.3%), the shares of solar thermal collectors and geothermal heat rise from 0.4% to 29.4% and 0.25 to 31.0% respectively. This partly reflects the current trend towards heat pumps in combination with PV in central Europe. Solar thermal heat supply share would be 1.6% in the reference scenario (while fossil fuels would account for more than 75%).

While 2050's heat demand in the E[R]-scenario is comparable with today's values, the electricity demand increases significantly (mainly due to an increasing usage of heat pumps and electric cars). The demand in 2050 is more than double the demand of 2010. Figure 2-2 shows the projected electricity demand as well as the electricity supplied by PV. The PV share of the electricity supply in 2050 would be 1.5% in the reference scenario (non-renewables would account for more than 75 %) and 15.6% in the E[R] scenario (non – renewables in this case make up only 5.7%). For detailed assumptions on the scenario see Appendix A – Scenario Details.

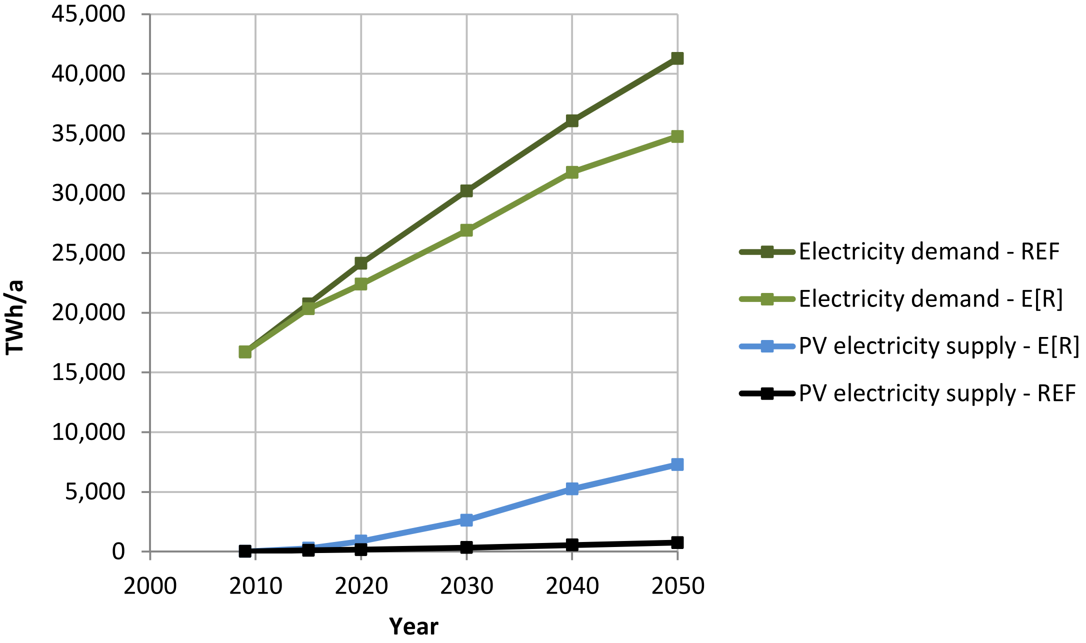

Figure 2-2 Global electricity demand and supply by PV systems, Energy [R]Evolution

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[8] Solar thermal heat is usually used in the low temperature sector

2.2.2 The Energy Report – 100% Renewable Energy by 2050

The Energy Report is a co-production between WWF International, ECOFYS and OMA and describes a “possible pathway to a global, sustainable energy system” (Singer et al., 2011) until 2050. The scenario itself was created by the sustainable energy-consultancy ECOFYS. The key question of the report is: Is an almost fully sustainable global energy system possible by 2050? The answer here, too, is that it is technically and economically feasible.

<u>Authors:</u>

WWF International, ECOFYS and OMA

<u>Targets:</u>

The main target is to achieve an energy system by 2050 which sources 95% of its energy from sustainable sources.

<u>Scenario</u>

The “ECOFYS Energy Scenario” presented in TER considers all energy sectors, regions and major renewable technologies. It is based on three pillars:

1. Reducing energy demand to the minimum required to provide energy services. Energy efficiency is a main key for this goal.
2. Providing energy by renewable, where possible, local sources first. As electricity is easily available from renewable resources, electrification is crucial for the scenario.
3. Providing the remaining energy from ‘traditional’ energy sources as cleanly as possible.

First, the energy demand was estimated, based on the population development and GDP growth (see Appendix A – Scenario Details for details). The demand is split into different sectors (electricity, heat and fuel). In a second step, this demand is filled up by the different supply technologies that are available[9]. First, non-bioenergy technologies are used, where possible. Then, bioenergy options are used to cover the rest. If necessary, conventional energy sources are used to fill

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[9] The report uses, wherever possible, only existing technologies

up the residual demand. Figure 2-3 shows the assumed energy demand pear year and how the demand is covered by the different energy sources.

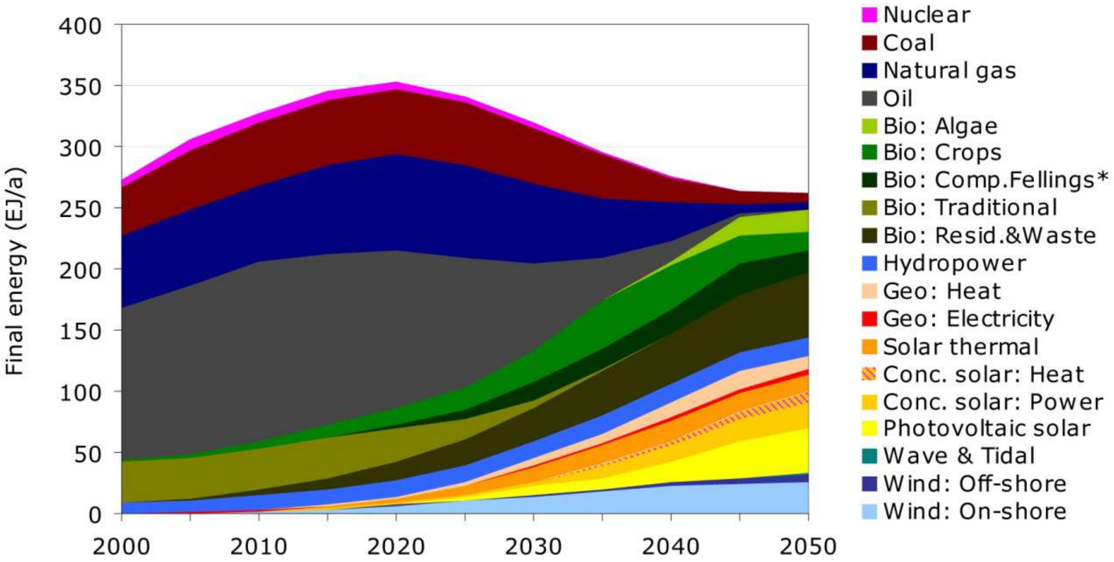

Figure 2-3 Global final energy demand and supply by technology, The Energy Report; Source: Singer et al., 2011

<u>Demand projection</u>

With 261.4 EJ/a in 2050 the TER total global energy demand is around 17% lower than E[R]'s 316.2 EJ/a. This overall demand reduction can be achieved by using the most efficient technologies and thus reducing the energy intensity. It does not imply a reduction in activity of the consumer. In contrary, the ECOFYS scenario "*is founded on an assumption of increasing living standards and continuing economic development*" (Singer et al., 2011). Still, both population by 2050 and GDP growth rates until 2050 are lower than in case of E[R] (see Appendix A – Scenario Details). With respect to the heat demand (see Figure 2-4) the reductions are even more drastic. Especially the low temperature heat demand undergoes a strong decrease, starting in 2020, with buildings being the major player of this sector. The scenario assumes, amongst other things, an increase in floor space per capita, an average annual building retrofit rate of 2,5% until 2050 (with a 60%-reduction of heating needs of retrofitted buildings) and all new buildings being built in the near-zero energy use standard[10] by 2030. The low temperature heat demand can be reduced by almost 75% compared to today's values. More than half of 2050's low

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[10] Comparable to passive house standards in Germany with a heat demand lower than 15kWh/m^2 per year

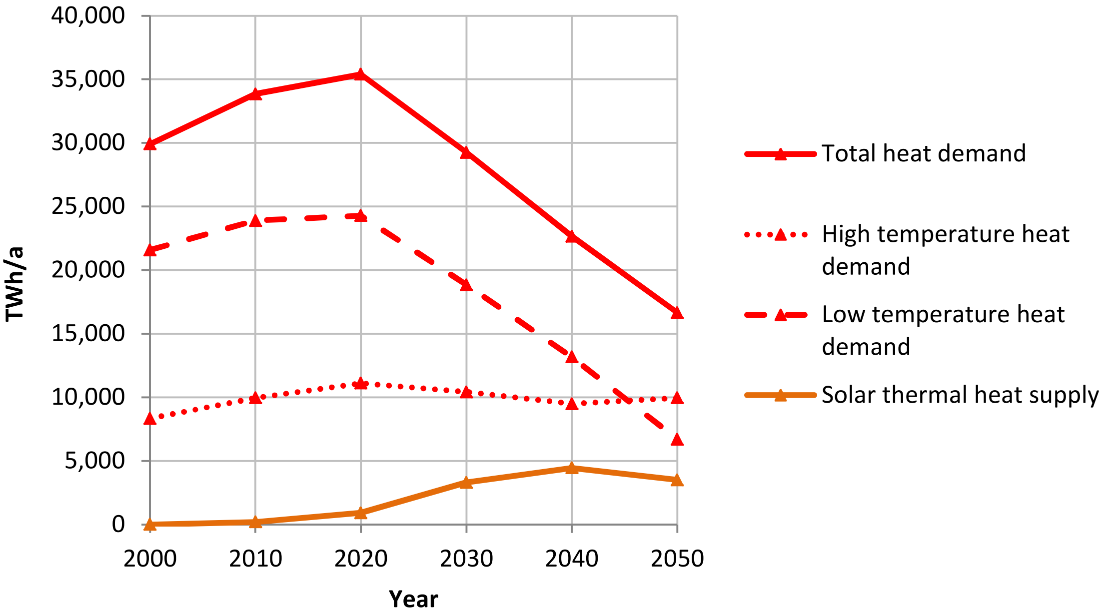

Figure 2-4 Global heat demand and supply by solar thermal systems, The Energy Report

temperature heat demand is covered by solar thermal heat supply in the ECOFYS scenario.

Similar to E[R], the electricity demand increases significantly (see Figure 2-5). Additionally to the increased usage of heat pumps and the electrification of transport like in the E[R] report, increased cooling and appliances are given as reasons for the increase.

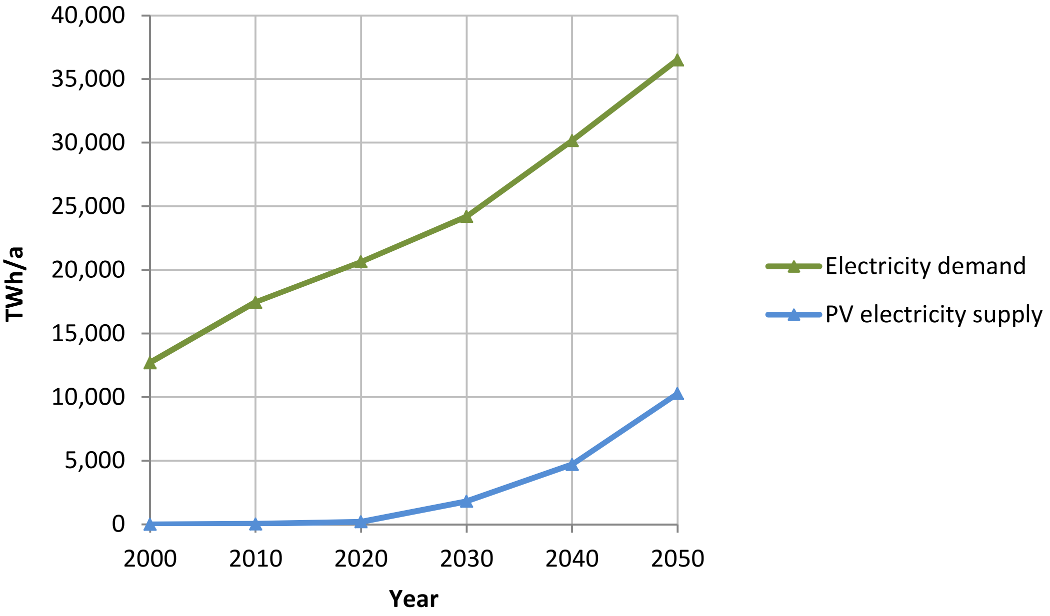

Figure 2-5 Global electricity demand and supply by PV systems, The Energy Report

2.2.3 RE-thinking 2050 – A 100% Renewable Energy Vision for the European Union

This report was made by EREC (see chapter 2.3), representative of the European renewable energy industry. It outlines a pathway towards 100% renewable energy by 2050. The scenario is based on the projections of the EREC member associations for the different renewable technologies as well as on the "New Energy Policy" (NEP) scenario by the European Commission. Rather than trying to describe the exact energy mix of the individual technologies the focus lies on the common goal of achieving 100% renewable energies. It includes the former EU-27 countries.

Author:

EREC

Targets:

The main target of the report is to outline a pathway towards an energy system of the European Union which is entirely based on renewable energy sources. It also analyses economic, environmental and social benefits that are likely to come with such a development.

Scenarios

The scenarios work with the economic potential which is the proportion of the technically feasible potential that can be realized economically. It "takes into account cost levels which are considered to be competitive" (Zervos et al., 2010). As stated above, the projected developments of the different technologies are based on the individual member associations of EREC. PV and wind are considered the main electricity suppliers by 2050, while biomass will dominate the heating and cooling section as well as the non-electric part of transportation.

Demand projection

The assumptions on the future energy demand as well as population and GDP development are based on the NEP by the European Commission (see Appendix A – Scenario Details). Two cases are considered: a high oil price scenario and a moderate oil price scenario. The higher oil price leads to a lower overall energy demand. There is only one scenario for the supply of renewable energy by the different technologies but two demand-scenarios. This results in a range of possible renewable energy shares until 2050, depending on the demand.

The heating demand is expected to decrease in both scenarios (see Figure 2-6). However, only in the “aggressive efficiency” scenario the decrease continues after 2030. Solar thermal systems would cover 25.8% of the entire heat demand of 2050 in case of the moderate price scenario and 36.8% in case of the high price aggressive efficiency scenario.

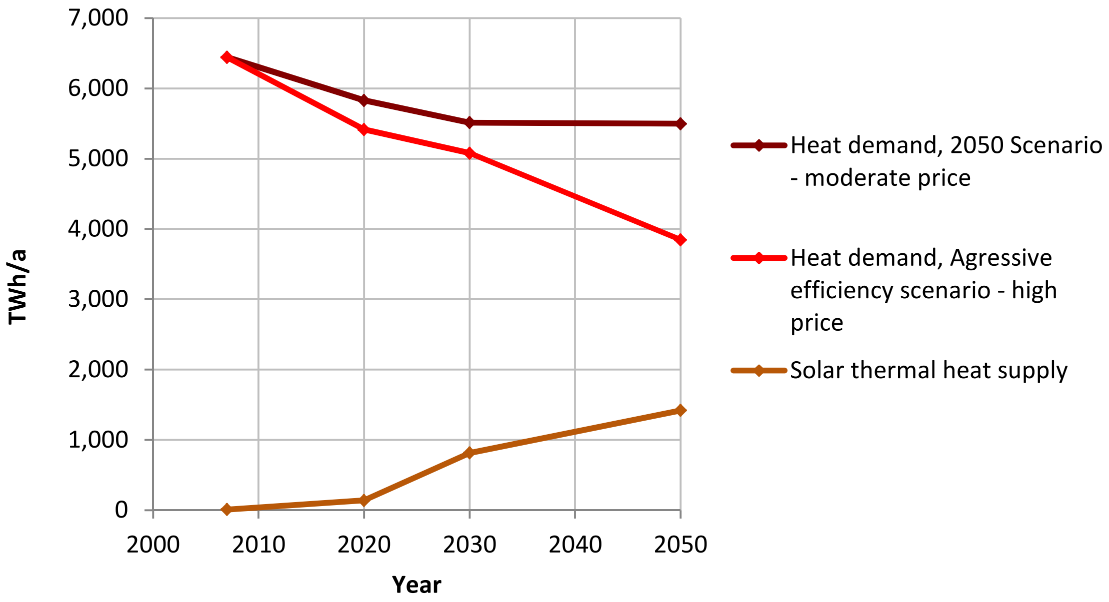

Figure 2-6 European (EU-27) heat demand and supply by solar thermal systems, RE-thinking 2050

In line with the other reports, RE-thinking 2050 expects an increase of the electricity demand, mainly due to the increased usage of heat pumps as well as the electrification of transport. This increase is projected to take place primarily between 2030 and 2050. The report also points out Europe’s chances for renewables in the electricity sector, coming with a large number of ageing power plants that need to be replaced by 2020. It states that “*approximately 330 GW of new power capacity needs to be built by 2020, which represents 42% of the current EU capacity*” (Zervos et al., 2010). Figure 2-7 shows the projected electricity demand of the two scenarios and the development of electricity supplied

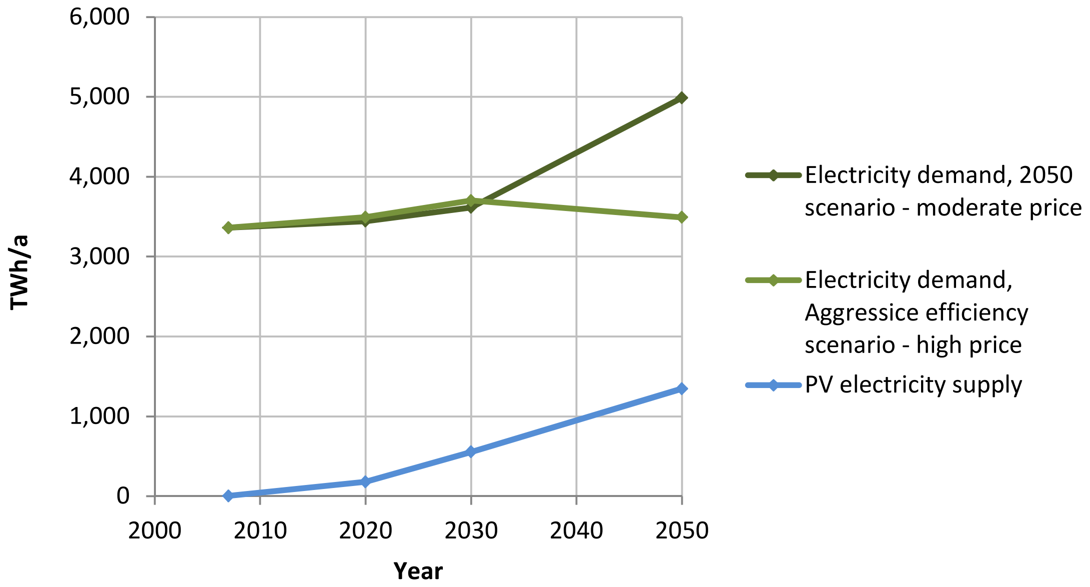

Figure 2-7 European (EU-27) electricity demand and supply by PV systems, RE-thinking 2050

by PV, which would cover 27.0% of the moderate price scenario demand and 38.6% of the high price “aggressive efficiency” scenario demand.

2.3 Market Scenarios

The 100%-scenarios of chapter 2.2 describe what would have to happen for the entire energy demand to be covered by renewable energy supplies. They do include potentials and barriers for the renewable energy technologies and even market developments. Still, it is interesting to compare pathways described in the 100%-scenarios with the market projections of the renewable energy industries. This can give us some information whether they are within a realistic growth margin that also the industry deems possible.

The renewable energy industry in Europe is represented by the **European Renewable Energy Council (EREC)** which was founded in 2002. It describes itself as an “*umbrella organisation of the European renewable energy industry, trade and research associations active in the sectors of photovoltaics, small hydropower, solar thermal, bioenergy, geothermal, solar thermal electricity and ocean energy*”[11]. Among the members are the **European Solar Thermal Industry Federation (ESTIF)** and **European Photovoltaic Industry Association (EPIA)**, representing the technologies covered in this thesis.

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[11] Available: www.erec.org, “About EREC” (16th April 2014).

2.3.1 Solar Thermal Industry Scenarios

In case of the solar thermal industry no suiting worldwide market scenario was available. The most detailed and comprehensive study for Europe is the report “**Potential of Solar Thermal in Europe**” (Weiss and Biermayr, 2009) that was commissioned by ESTIF. Potentials in five countries were investigated in detail and an extrapolation was made for the entire European potential (former EU-27 member states).

Weiss and Biermayr developed a model to determine the future heat demand, based on the “EU 20% renewable goal” and estimation on energy efficiencies, renovation rates etc.

The development of solar thermal systems is based on three scenarios:

1. Business as Usual (BAU):
    a. no reduction of heating and cooling demand,
    b. moderate political support mechanisms,
    c. low research and development (R&D) rate, and
    d. focus on solar thermal systems for hot water preparation.
2. Advanced Market Deployment (AMD):
    a. Moderate reduction of heating demand compared to 2006 (-20% by 2050),
    b. solar obligations for all new residential buildings and subsidies for existing buildings or constantly moderately rising energy prices of fossil energy,
    c. medium R&D rate, and
    d. focus on solar combisystems[12], medium solar fraction from 2020 (20-50%).
3. Full R&D and Policy Scenario (RDP)
    a. Significant reduction of the heat demand compared to 2006 (-30% by 2050),
    b. full political support mechanisms (solar obligations for all new and existing buildings or high energy prices of fossil energy),

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[12] Systems for both, hot water preparation and space heating

c. high R&D rate, and
d. focus on solar combisystems, high solar fraction from 2020 (50 – 100%).

Figure 2-8 shows the results of the different ESTIF-scenarios for EU-27.

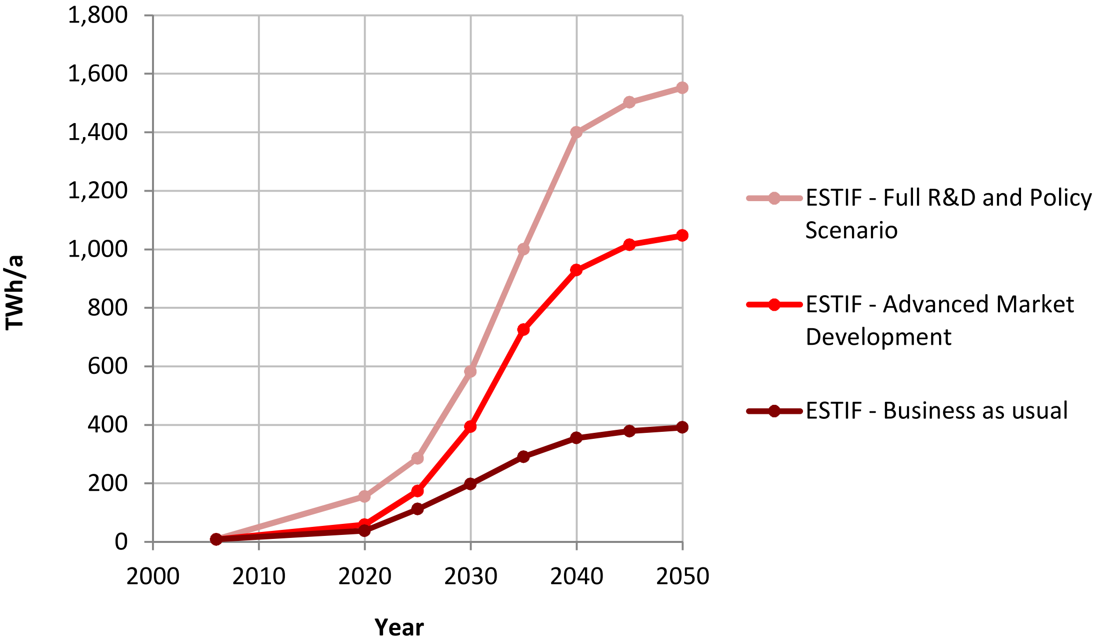

Figure 2-8 European (EU-27) scenarios for solar thermal heat supply; Potential of Solar Thermal in Europe, ESTIF

2.3.2 Photovoltaic Industry Scenarios

In case of photovoltaic technology, EPIA has published a variety of global as well as European scenarios. In the report "Solar generation 6 - Solar Photovoltaic Electricity Empowering the World", EPIA[13] describes three global scenarios for PV until 2050. Its most ambitious so-called "paradigm shift" scenario is almost as ambitious as the E[R] scenario. It represents the technical potential of PV for the coming decades which EPIA describes as "ambitious, but also feasible" (Teske et. al., 2011). In the "accelerated growth" scenario PV technology is deployed faster than it has been in recent years but political support mechanisms continue as they are today. Just like in the E[R], the reference scenario is based on the reference scenario of IEA's World Energy Outlook (2009). Figure 2-9 shows the three scenarios.

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[13] In collaboration with Greenpeace

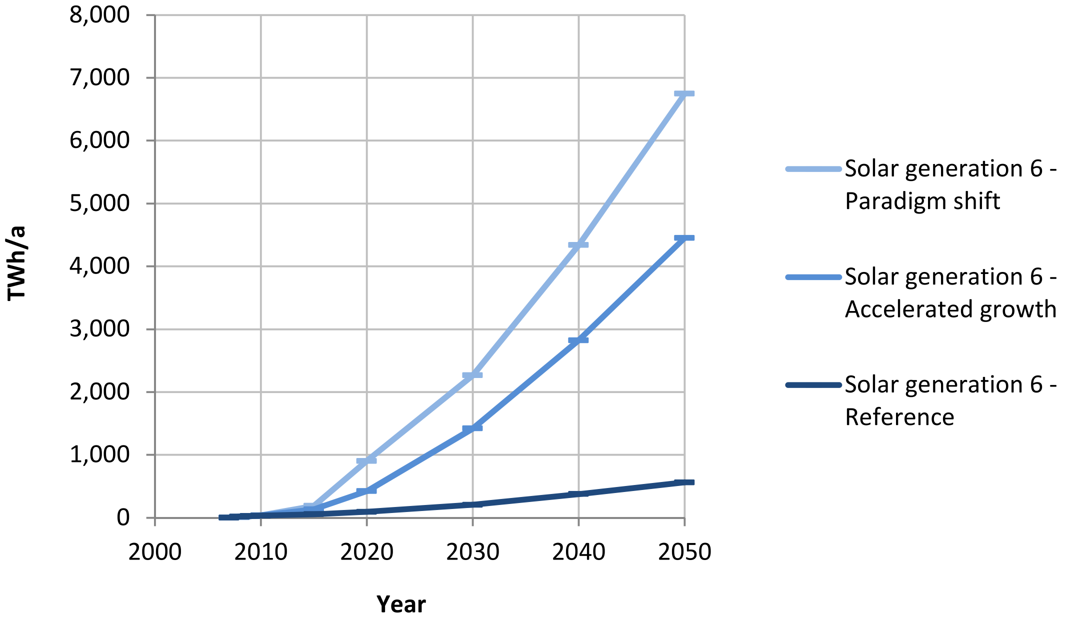


Figure 2-9 Global PV electricity generation scenarios, Solar Generation 6, EPIA

For Europe, only scenarios until 2030 were found. Apart from annual publications (such as the "Global Market Outlook"), EPIA published a variety of scenarios in recent years. While "Solar Generation 6" covers OECD Europe, other reports such as "Set for 2020" or "Connecting the Sun – Solar Photovoltaics on the Road to Large-scale Grid Integration" (EPIA, 2012) include the former EU-27 countries, Turkey and Norway (as well as Switzerland in the first case). Just like "Solar Generation 6", they show three scenarios, a baseline scenario (business as usual), an accelerated growth scenario (according to current market trends) and a paradigm shift scenario (assuming that all barriers are lifted). "Connecting the Sun" was published in 2012, three years after "Set for 2020". The PV industry experienced an extremely rapid growth after 2009, reaching the 100 GW installed capacity mark in 2012 and 139 GW in 2013, as the latest global futures report (REN21, 2014) showed recently. 2012's value was the target for around 2015 in the most ambitious (paradigm change) scenario in the earlier "Set for 2020" report. Therefore it is not surprising that in "Connecting the Sun" the targets are revised upward. The scenarios of the two reports are shown in Figure 2-10.

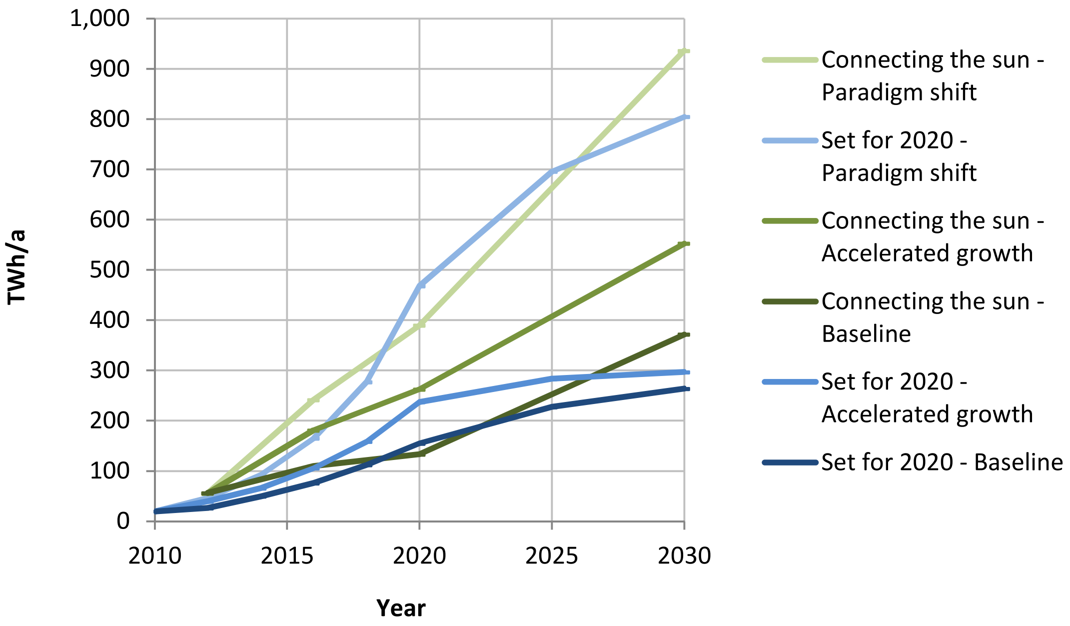


Figure 2-10 European PV electricity generation scenarios, EPIA

2.4 Comparison of 100% Renewable Energy- and Market Scenarios

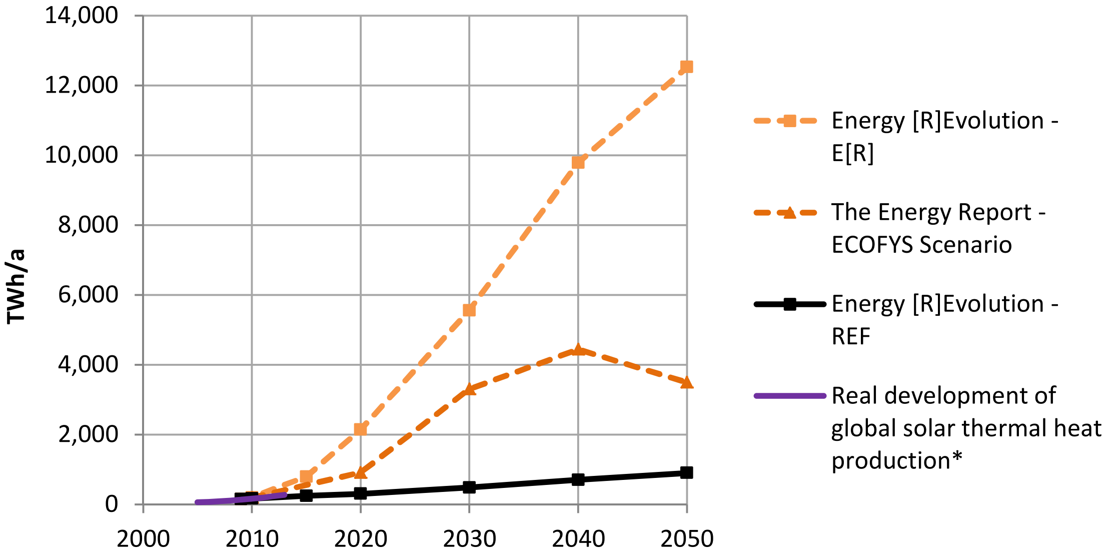
Before starting to compare the 100%-scenarios with the scenarios developed by the different industrial associations we want to point out that often there exist dependencies and collaborations between representatives of the renewable industries (see chapter 2.3) and NGOs such as Greenpeace or WWF that are reflected in the scenarios. It is therefore impossible to draw a clear line between the two groups, making a comparison difficult. E[R] was produced by Greenpeace, EREC and GWEC together, to mention only one example. In the following sections we show global and European graphs, with 100%-scenarios (dashed lines) and market scenarios for solar thermal (red) and photovoltaics (green and blue).

2.4.1 Solar Thermal Scenarios

Global

The scenarios for solar thermal heat production (see Figure 2-11) show a wide range of results. In case of E[R] the solar thermal heat supply increases continuously, reaching more than 12,000 TWh/a in 2050. In the TER scenario the growth is slower and even reaches negative values after 2040, falling to 3,500 TWh/a in 2050. This is largely due to the big difference in the expected development of the heat demand (see Figure 2-1 and Figure 2-4). It also shows the difficulty of long term projections, depending on a large variety of different parameters and assumptions. This is especially true for global scenarios. For a global scale no market scenario is available that could be used as a comparison.

The violet line in Figure 2-11 shows the real development of the global solar thermal heat production. It lies only slightly above the reference scenario and significantly below both 100%-scenarios. Thus, efforts need to be increased, if the goal of 100% renewable energy by 2050 is to be reached and solar thermal heat is to play its part in it.



* Source : Solar heat worldwide (2007 – 2013) and REN, Global Futures report (2012 & 2013).

Figure 2-11 Global comparison of different scenarios for solar thermal heat production; no market scenarios available.

Europe

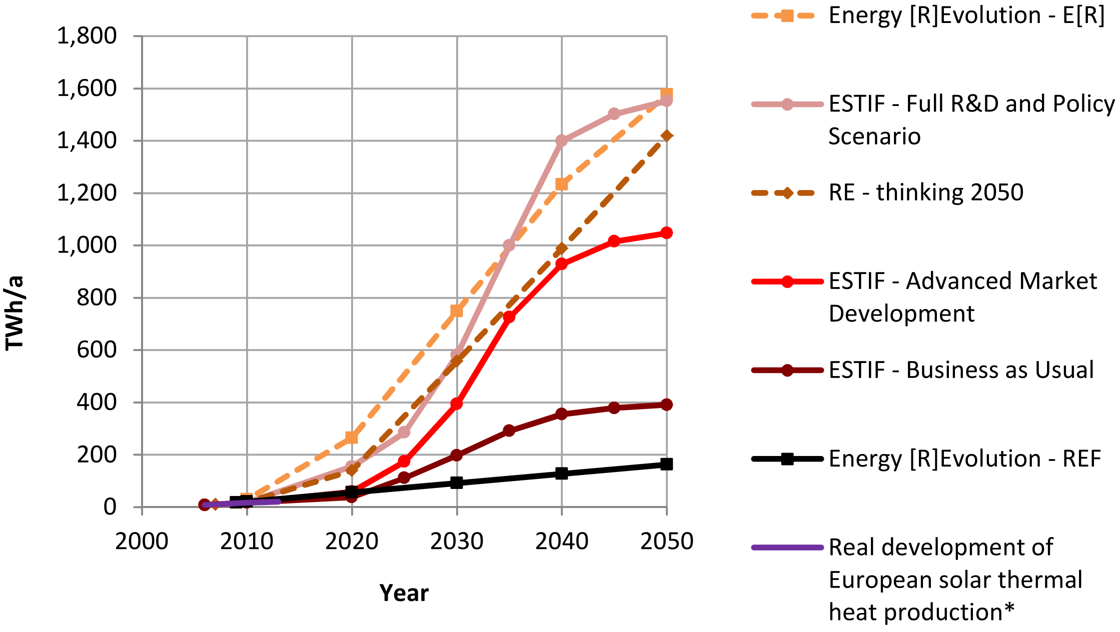
At a European scale, scenarios match much better. First of all, the smaller the region, the easier it is to define parameters (such as GDP, population, market development etc.). Furthermore, in this case there is a dependency between the different authors. RE-thinking 2050 is directly based on the ESTIF – scenarios of “Potential of Solar Thermal in Europe”. Also, the E[R] report was co-written by EREC, which is, of course, closely linked to ESTIF.

It is interesting to see that the 100%-scenarios are somewhere between the FULL R&D scenario and the Advanced market development of ESTIF. This is in line with the expectations that 100% renewable energy by 2050 is feasible, given that the full R&D potentials are used and policies develop accordingly.

Note that the ESTIF scenarios and RE-thinking 2050 include the former EU-27 countries, while E[R] includes OECD Europe (see footnote 6 for further information). The total installed solar thermal capacity of EU-27 is around 27% below OECD Europe's, which means that E[R] values would have to be reduced by this amount for a direct comparison.

Also on a European scale the real development of the heat production by solar thermal systems is significantly below the 100%-scenarios. It is even slightly below the reference / business as usual scenarios. More measures need to be taken if the 100%-scenarios were to be reached. There is still time until 2050, but ever increasing growth rates (see chapter 3.2) become more and more difficult to achieve, the longer it takes for the technology to take off.

The real development of the solar thermal yield and the scenarios are depicted in Figure 2-12.



* Source : Solar Thermal Markets in Europe (20010 – 2013).

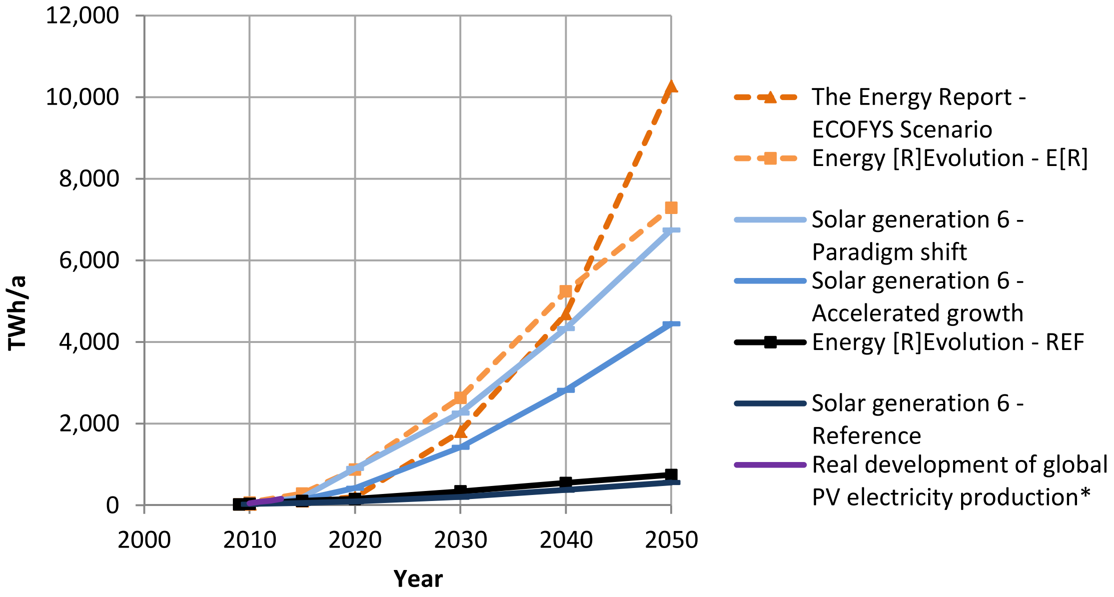
Figure 2-12 European comparison of different scenarios of the solar thermal heat production

2.4.2 Photovoltaic Scenarios

Global

A comparison of the different global scenarios (see Figure 2-13) shows that the 100%-scenarios and the Paradigm shift market scenario lie within 1,000 TWh/a (or 17.3%) until 2040. Only the sharp rise in TER after 2040 leads to a 3,500 TWh/a (or 34.3%) spread by 2050. Values are much closer than in the global solar thermal scenarios. Unlike the heat demand scenarios, the electricity demand projections are very similar[14]. The “Paradigm shift” scenario in “Solar generation 6” by EPIA, representing the technical potential of PV, is slightly below the 100%-scenarios. This means that the entire technical potential (and theoretically more) of PV has to be used in order for PV to fulfil its part in the 100%-scenarios.

However, in case of PV the real development of installed systems is in the range of the 100%- and Paradigm shift scenarios. Thus, this technology is currently in a better position to achieve the 100%-renewable energy targets than the solar thermal technology.



* Source : Global market outlook for PV (2011 – 2014).

Figure 2-13 Global comparison of different scenarios of the PV electricity generation

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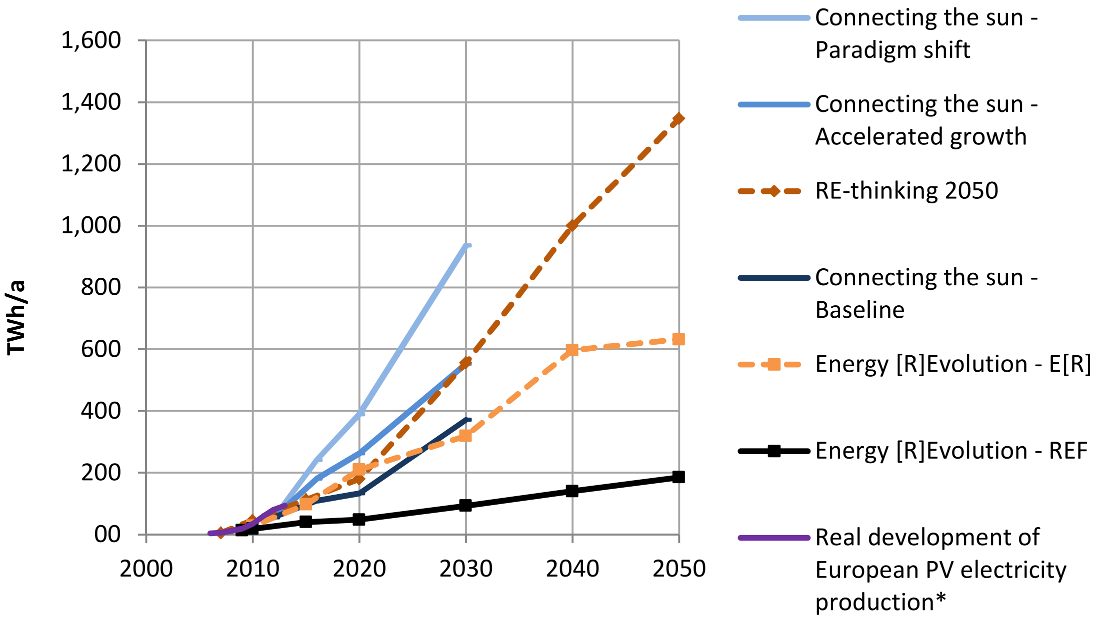
[14] E[R]: 34.7 GWh/a, The Energy Report: 36.5 GWh/a for 2050

Europe

The PV market scenarios for Europe run until 2030 only. We expand the timeframe up to 2050, in order to be able to compare the different 100%-scenarios (see Figure 2-14). Unlike the global situation, in Europe 100%-scenarios are in the range of accelerated growth- or even baseline market scenarios. One possible explanation for this is the currently installed worldwide capacity. In 2012, 68.6% of the total PV capacity was installed in Europe (Masson et al., 2013). The only other region with comparable values for installations per capita (138 W/habitant) is Australia (105 W/habitant). Europe is already using a higher share of their potential than the rest of the world. Thus, continuing this development with some (comparably small) modifications will suffice for PV to play its part in the 100% renewable pathway. While the difference between EU-27 and OECD Europe was significant in case of solar thermal systems, it is neglectable with PV. Installed capacity in the EU-27 countries is 1.1% above the installed capacity of OECD Europe (see footnote 5).

Also on a European scale the real development of solar thermal heat production is in the range of 100%- and Paradigm shift scenarios and prospects seem good. It



* Source : Global market outlook for PV (2012 – 2014).

Figure 2-14 European comparison of different scenarios of the PV electricity generation. Note: Only the more recent "Connecting the sun" values are taken for market scenarios for a better comparability

is, however, interesting to see that while global growth rates have been increasing in recent years, in Europe growth rates have been declining since 2011.

Finally, we make a direct comparison between the yield of solar thermal and PV systems. On a global scale we see that the scenarios for both technologies are in a similar order, ranging between around 3,500 and 12,500 TWh/a (see Figure 2-15). While heat and electrical energy are not directly interchangeable, this still shows that the magnitude in the development of the systems is similar.

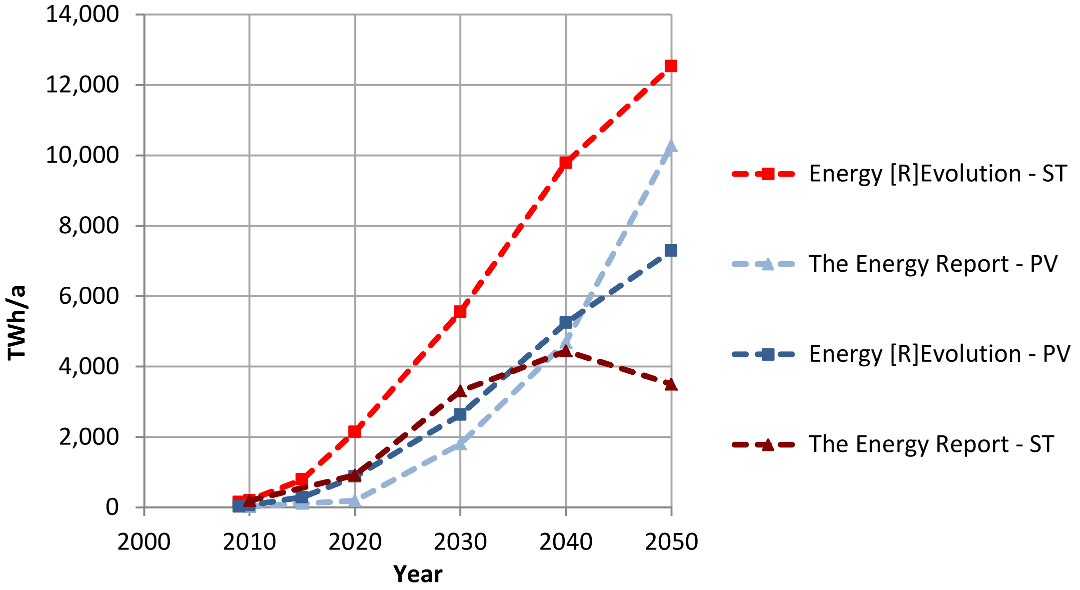


Figure 2-15 Comparison of the yield of ST and PV systems, Energy [R]Evolution, global

In terms of **collector area** for solar thermal systems this corresponds to a total of **36.0 billion m^2 (24.7 billion m^2 without replacements due to lifetime considerations) for E[R] and 13.8 billion m^2 (6.9 billion m^2) for TER** until 2050. In case of PV the calculations are more complex as the module area is different for different technologies and efficiencies. However, for comparison’s sake we calculate the module area with a standard c-si module with 15% efficiency. This would lead to a **total module area of 45.9 billion m^2 (33.5 billion m^2) for E[R]** and **55.9 billion m^2 (47.3 billion m^2) for TER** until 2050.

In the following chapters we will show the effect of these scenarios on a possible material demand. Based on the 100%-scenarios we will calculate the materials needed for solar thermal and PV systems.

3. FUTURE MATERIAL DEMAND FOR SOLAR THERMAL HEAT

3.1 Calculations

Based on the 100%-scenarios described in chapter 2.2 we now calculate the resulting material demand for solar thermal applications. From the scenarios we can extract the yield, i.e. the heat produced by solar thermal applications in TWh/a. Information we need to find in order to be able to calculate the future material demand based on the yield are

1. data on used materials of typical existing collectors in kg/m^2 for pumped and non-pumped (thermosiphon)systems,
2. the development of the share between pumped and non-pumped systems until 2050 and
3. the collector yield per area [TWh/m^2].

We differentiate between global and European data as well as temporal development between 2010 and 2050 in steps of 10 years.

The information about the mass and type of material used per collector area of flat plate collectors is based on experimental data provided by AEE – Institute for Sustainable Technologies (AEE - INTEC). The information on the material demand of non-pumped systems was provided by “Sunlumo Technology GmbH”. All other data is based on literature research.

Based on the results for collectors with conventional materials we calculate the potentially used polymeric material by defining a certain factor that gives the average mass of polymeric collectors compared to conventional collectors. For the development of the polymeric material demand we define two different cases:

Case 1: The entire solar thermal heat supply is covered by conventional collectors.

Case 2: The “Business as usual” demand is covered by conventional collectors and the residual part is covered by polymeric collector systems (beginning in 2020).

The following section gives an overview over the data and assumptions that we used for the calculations.

- Material Input

In order to be able to calculate the material demand for solar thermal systems we define a standard flat plate collector as a reference for pumped systems and a standard vacuum tube collector with integrated storage tank as a reference for thermosiphon systems. As a standard flat plate collector we use a typical frame-collector with an aluminium absorber. The material demand was kindly provided by AEE INTEC[15]. In 2011 76% of the total installed global solar thermal capacity were thermosiphon systems. The majority of them (72.5%) were installed in China. Therefore we use a standard vacuum-tube collector that is typically used in China as a reference for the material demand of thermosiphon systems. The material demand was kindly provided by Sunlumo Technology GmbH[16]. The material input for both reference collector types is shown in Table 1.

Table 1 Material input for a flat plate collector in a standard pumped solar thermal system and a vacuum tube collector in a standard thermosiphon system

Material	Selective Flat Plate frame-collector, aluminium absorber Mass [kg/m^2]	Vaccum tube collector Mass [kg/m^2]
Aluminium	4.7	2.2
Copper	1.2	0.4
Glass	8.4	16.4
Mineral wool	2.1	0.2
Stainless steel	-	0.7
Total	**16.4**	**19.9**

- Share between pumped and thermosiphon systems

Global: On a global average, in 2011 76% of the installed capacity were thermosiphon systems and 24% pumped systems (Mauthner and Weiss, 2013). Currently there is a trend towards the cheaper thermosiphon systems, which is understandable considering the tense global financial situation. However, in the long run we expect the pumped systems and combi-systems[17] in particular to become more widespread. Especially with reduced costs and with the wider application possibilities (e.g. space heating) pumped systems will become

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[15] Hausner Robert, E-mail from Nov. 19th, 2013

[16] Buchinger Robert, E-mail from April 15th, 2014

[17] Combined hot water and space heating with solar thermal applications

increasingly attractive. Therefore, we assume that the share of pumped and non-pumped systems will reach 50% each by 2050.

Europe: Our assumptions for Europe are based on two current trends in the European solar thermal industry. On one side the "*solar combi-systems market share is continually growing and in some countries, such as Germany, it is already around 50%*" (Stryi-Hipp et al., 2012). Especially in northern and central European countries this share is expected to rise further. On the other hand, in the years of the recent financial crisis, the share of pumped systems fell from 73% in 2008 to 60% in 2011 (Mauthner and Weiss, 2010; Mauthner and Weiss, 2013). One of the reasons for this development is the lower cost of (non-pumped) thermosiphon systems. Considering both trends we define that the share of pumped and non-pumped systems remains 60% and 40% respectively until 2050. Europe's solar irradiation is smaller than the world's average and thus favours pumped systems.

- Collector yield

The collector yield[18] depends on several factors such as

- Annual global horizontal solar irradiation at the collector location [kWh/(m^2·a)],
- collector type,
- application field,
- collector efficiency as well as
- tilt and orientation.

In order to make solar thermal systems more comparable to other energy sources, in 2004 an international team of experts[19] agreed upon an average "area to capacity conversion factor" of **0.7 kW/m^2**. Together with the yield per capacity this conversion factor allows us to calculate the necessary collector area for a certain yield. In our case we define the yield value as the average of several literature sources. The resulting **global value** is **0.725 TWh/(GW·a)**. For **Europe**, the assumed yield value is **0.608 TWh/(GW·a).** No further specification is made

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[18] produced heat energy per collector area and year, kWh/(m^2·a)

[19] Representatives of the IEA Solar Heating and Cooling Programme, ESTIF, Austria Solar a.o. For further Information see: http://www.estif.org/st_energy/area_to_energy_conversion_method/ (13th May 2014).

between different collector types. For a detailed list of the literature values, see Appendix B – Yield Assumptions.

A yield of **1 TWh/a corresponds to 0.152 million m^2 collector area**. However, the yield cannot be directly compared to the collector area, as the lifetime and thus replacement of modules increases the necessary collector area.

These values apply to conventional systems. The yield of the polymeric equivalent is assumed to be 90% for the conventional collector in case of flat plate collectors and 100% in case of the thermosiphon systems.

- Conventional and polymeric collectors

Usually the achieved mass reduction by using polymeric instead of conventional materials is between 20 to 40%. As an average value we define:

$$\text{Mass}_{\text{pol}} = 0.7 \cdot \text{Mass}_{\text{conv}}$$

where “pol” denotes the polymeric collector and “conv” denotes the conventional collector.

- Collector lifetime

In order to calculate the cumulative material demand over several decades, the collector lifetime plays a crucial role. In literature, values for the lifetime of solar thermal systems are typically around 15 to 25 years (e.g. Stryi-Hipp et al., 2012; Mauthner and Weiss, 2013). We assume a **collector lifetime of 20 years**. Within the calculated time period (2010 – 2050) the replacement of old systems results in an increase of the material demand of 40 to 100%[20].

- Calculation procedure

These assumptions are then processed in the actual calculations. We combine the data of the 100%-scenarios (see chapter 2.2) and of the material demand to perform the calculations. They follow the following procedure:

1. Define yield [TWh/a] at 10-year intervals for the 100%-scenarios (with interpolations, where necessary),

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[20] Depending on the growth rate over the four decades

2. include the necessary replacements due to lifetime considerations (add stock from 20 years before, that need to be replaced, to the current stock),
3. convert the yield values into a corresponding collector area [million m^2],
4. define development of material demand [kg/m^2 collector area] for every decade and every material (according to the evolution of the share of pumped and thermosiphon systems) and
5. calculate the corresponding material demand for each decade and material.

3.2 Results and Discussion

In this chapter we show the results of the calculations of the estimated future material demand of solar thermal systems based on the 100% renewable energy scenarios. The graphs for the cumulative and annual material demand as well as tables of the annual growth rates can be found at the end of the chapter.

3.2.1 Global Material Demand of Solar Thermal Collectors

Energy [R]Evolution

Greenpeace's "Energy [R]Evolution" report presents two scenarios, a reference scenario and the Energy [R]Evolution scenario. According to chapter 3.1 we divide the calculations into two cases. In case 1 the entire demand is covered by conventional materials. Glass, being of major importance in both, pumped and thermosiphon systems, is by far being used most, with a cumulative material demand of 447.4 Million t until 2050. In case 2 the business as usual scenario (here: "reference scenario") is covered by collectors made of conventional materials, the residual part to the paradigm shift (here E[R] scenario) is covered by polymeric collectors. As the amount of currently installed polymeric collectors is negligible and within the next few years no significant increase is expected, we assume that the take-off of polymeric collector production will take place in 2020. **By 2050 the cumulative demand of polymeric materials would reach 328.1 million t**. Due to the possibility to reduce the total mass by using polymeric materials, the total material demand of case 2 is 116 million t less than in case 1. Figure 3-2 shows the cumulative and average annual material demand. The main materials used in case 1 are glass and aluminium while in case 2 the amount of glass needed is reduced drastically after 2020 due to the increased usage of polymeric materials. When looking at the feasibility of such a development, annual growth rates (see Table 2) are essential. They are also based on an average value over one decade[21]. Even though in absolute terms, more material is needed between 2030 and 2050, growth rates are much higher before 2030. **Especially between 2010 and 2020 annual growth rates are extremely high, reaching almost 30%.** In case 2, growth rates of conventional materials are smaller than in case 1, due to the substitution by plastics. Considering that the market growth of flat plate and evacuated tube collectors was around 20% p.a. on average between 2000 and 2011 (Mauthner and Weiss, 2013) this is a very ambitious, yet feasible scenario.

As plastics are only considered from 2020 onwards, growth rates can be calculated only after 2030. However, the biggest step for polymeric materials lies between 2020 and 2030, where there is a demand for polymeric materials of almost 8 million t/a annually, compared to zero until 2020. This decade will be the key challenge for polymeric collectors.

The Energy Report

The Energy Report only contains one scenario, a paradigm shift scenario called “ECOFYS scenario” in the report. Therefore we use the E[R] reference scenario as the baseline for case 2. Figure 3-3 shows the results for TER.

Due to the drastically lower energy demand of this scenario (see chapter 2.2.2) compared to E[R], the material demand is accordingly low. **The cumulative plastic demand until 2050 is 94.8 million t**, which is only 28.9% of the corresponding E[R]-value. This shows the great uncertainty of the energy scenarios themselves in our calculations, not even considering other uncertainties such as technology developments, yield, lifetime etc.

The general material share, however, is similar, with glass dominating case 1 and plastics and glass equally dominating case 2. As the reference scenario takes up a higher share in TER than in the E[R] (see Figure 2-11), the share of polymeric materials is generally lower in this scenario. While polymeric materials cover 60.9% of the total material demand by 2050 in the E[R] in case of TER the share is

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[21] Growth rates of 20-30% p.a. red, 10-20% p.a. orange, 5-10% p.a. yellow and 0-5% p.a green

only 43.7%. Looking at the average annual material demand we see a similar development as in E[R] with glass being dominant in case 1 and plastics in case 2. However, annual growth rates (Table 3) are considerably smaller and tend to decrease towards 2050. They don't exceed 20% p.a. and are in general lower than in the E[R] scenario.

3.2.2 European Material Demand of Solar Thermal Collectors

Europe accounted for 16.7% of the total installed solar thermal capacity worldwide in 2011 (Mauthner and Weiss, 2013). Its overall share of the global market has been sinking recently. This is mainly due to the enormous market growth in China, which accounted for 83.9% of the newly installed capacity in 2011 while Europe (being the world's second biggest market) accounted for only 8.2%. This trend is depicted in Figure 3-1, which shows the extreme growth rates of the Chinese solar thermal industry in the first decade of the 21st century. All other regions besides China and Europe have stayed below 1,000 MW_{th}/a of newly installed capacity and therefore don't contribute significantly to the world market.

As described in chapter 3.1 and in contrary to the global average the majority of the systems are pumped. Furthermore, there is a tendency towards combi-systems (19% of all installed systems in Europe in 2011 compared to 4% worldwide).

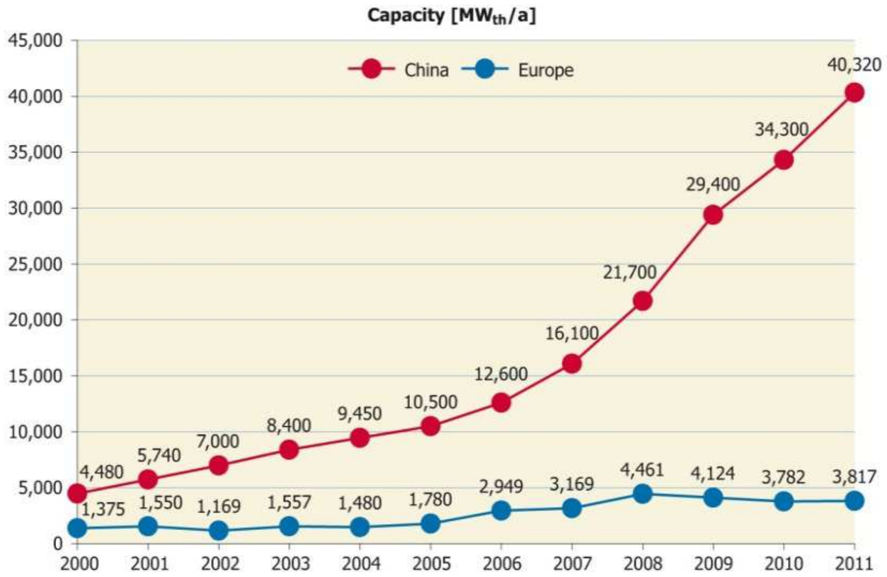

Figure 3-1 Annual installed capacity of flat plate and evacuated tube collectors in China and Europe
Source: Mauthner and Weiss, 2013.

Energy [R]Evolution

The results for E[R] Europe are shown in Figure 3-4. Apart from the scale it is very similar to the global scenario (see Figure 3-2). The **cumulative polymeric material demand until 2050 is 48.2 million t**, which is almost equal to the total European plastics demand of 47 million t in 2011 (PlasticsEurope, 2012). Also the annual material demand and growth rates are similar to the global case, beside the scale. For Europe, too, the key decade lies between 2010 and 2020 with a growth rate of 24.5% for all materials.

RE-thinking 2050

Just like in TER there is no baseline scenario in RE-thinking 2050. Therefore we take the “Business as usual” scenario from ESTIF (see Figure 2-8) as a reference. The reason for taking the ESTIF scenario and not E[R] in this case is that, just like RE-thinking 2050, it also refers to the EU-27 countries which allows a direct comparison. The results are shown in Figure 3-5. **The total cumulative plastics demand is 34.7 million t**. Compared to E[R] (see Figure 3-4), there is only a small difference compared to the vast difference in the two global scenarios. While E[R] and TER were produced by completely different authors, in both E[R] and RE-thinking 2050, EREC was involved, which could be one explanation for the similarity of the results. Also, within Europe considerations are confined to a much smaller region, which reduces possible uncertainties.

Even so, the cumulative demand for polymeric materials ranges from 34.7 million t in RE-thinking 2050 to 48.2 million t in E[R], which is a significant difference of 28.0%. This difference can be explained by looking at the regional scope of the different scenarios. E[R] is calculated for OECD Europe while RE-thinking 2050 considers the former EU-27 countries. EU-27’s capacity is 27.0% lower, as shown in chapter 2.2, which almost perfectly fits to the difference in the material demand. In case of the average annual material demand values are naturally also lower than in case of E[R]. The highest annual growth rates (Table 5) lie between 2010 and 2020 (22.3% for both cases) as well as 2020 and 2030 (15.2% in case 1 / 9.8% in case 2). In case of Europe the values are the same for all materials, as the proportion of pumped and thermosiphon systems does not change.

Energy [R]Evolution – Global – Solar Thermal

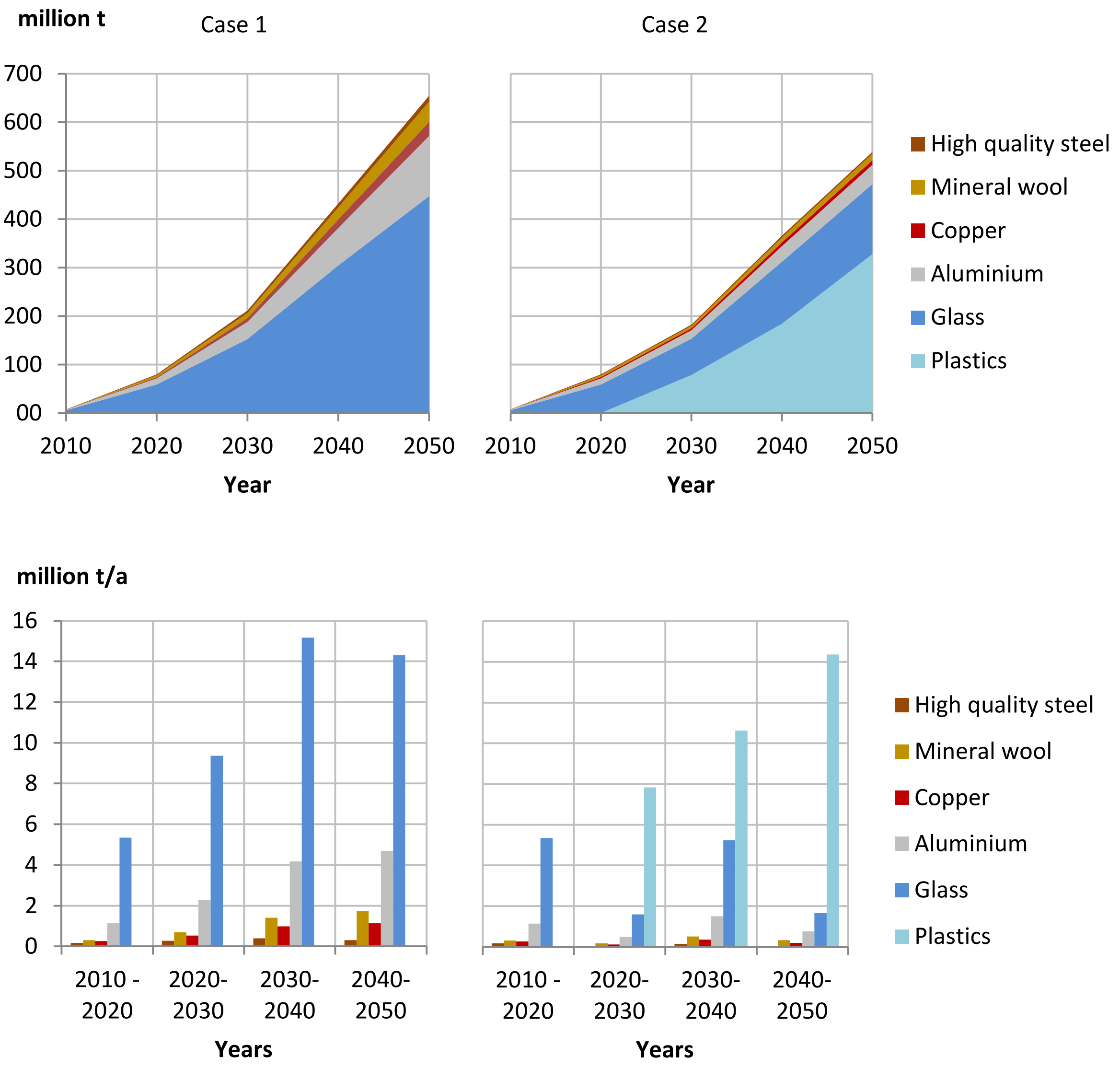

Figure 3-2 Global material demand of solar thermal collectors, Energy [R]Evolution; Top: Cumulative material demand; Bottom: Annual material demand, average over 10 years

Table 2 Annual growth rates in %, average over 10 years; Energy [R]Evolution (global)

Timeframe	Aluminium		Copper		Stainless steel		Glass		Mineral wool		Plastics	
Case	1	2	1	2	1	2	1	2	1	2	1	2
2010 – 2020	27.5	27.5	27.8	27.8	25.7	25.7	26.3	26.3	28.9	28.9	-	-
2020 – 2030	11.0	3.4	11.2	3.5	9.3	1.8	10.0	2.4	12.0	4.3	-	-
2030 – 2040	8.1	6.4	8.3	6.6	6.4	4.7	7.1	5.4	8.9	7.2	-	8.9
2040 – 2050	4.9	2.1	5.0	2.3	3.1	0.4	3.9	1.2	5.5	2.8	-	5.9

The Energy Report – Global – Solar Thermal

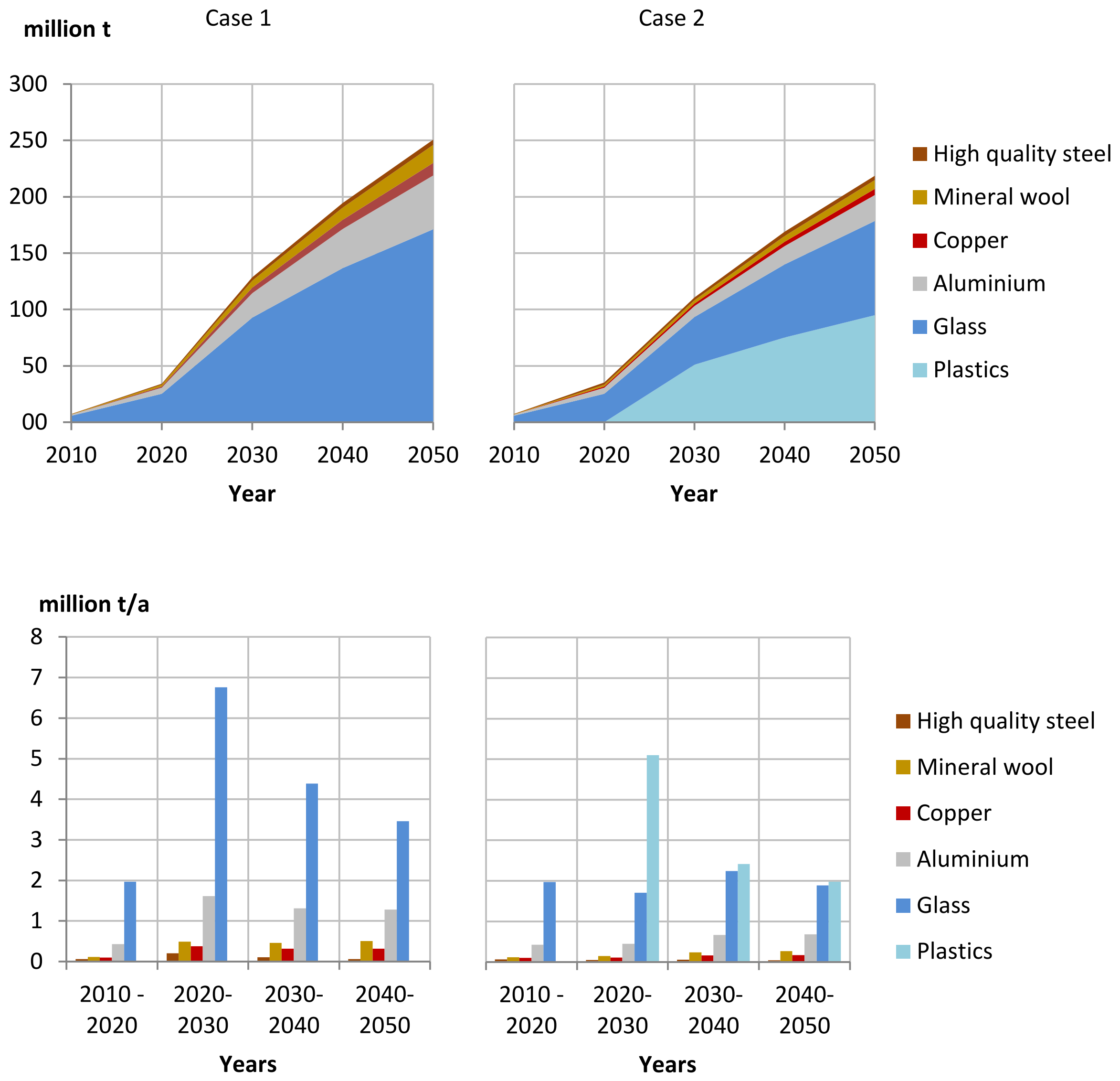

Figure 3-3 Global material demand of solar thermal collectors, The Energy Report;
Top: Cumulative material demand; Bottom: Annual material demand, average over 10 years

Table 3 Annual growth rates in %, average over 10 years; The Energy Report

Timeframe	Aluminium		Copper		Stainless steel		Glass		Mineral wool		Plastics	
Case	1	2	1	2	1	2	1	2	1	2	1	2
2010 – 2020	17.4	17.4	17.7	17.7	15.7	15.7	16.3	16.3	18.7	18.7	-	-
2020 – 2030	15.0	6.3	15.2	6.5	13.2	4.7	13.9	5.3	16.0	7.2	-	-
2030 – 2040	4.9	5.3	5.1	5.5	3.2	3.6	3.9	4.3	5.7	6.1	-	3.9
2040 – 2050	3.2	3.5	3.3	3.7	1.5	1.8	2.3	2.6	3.9	4.2	-	2.4

Energy [R]Evolution – OECD Europe – Solar Thermal

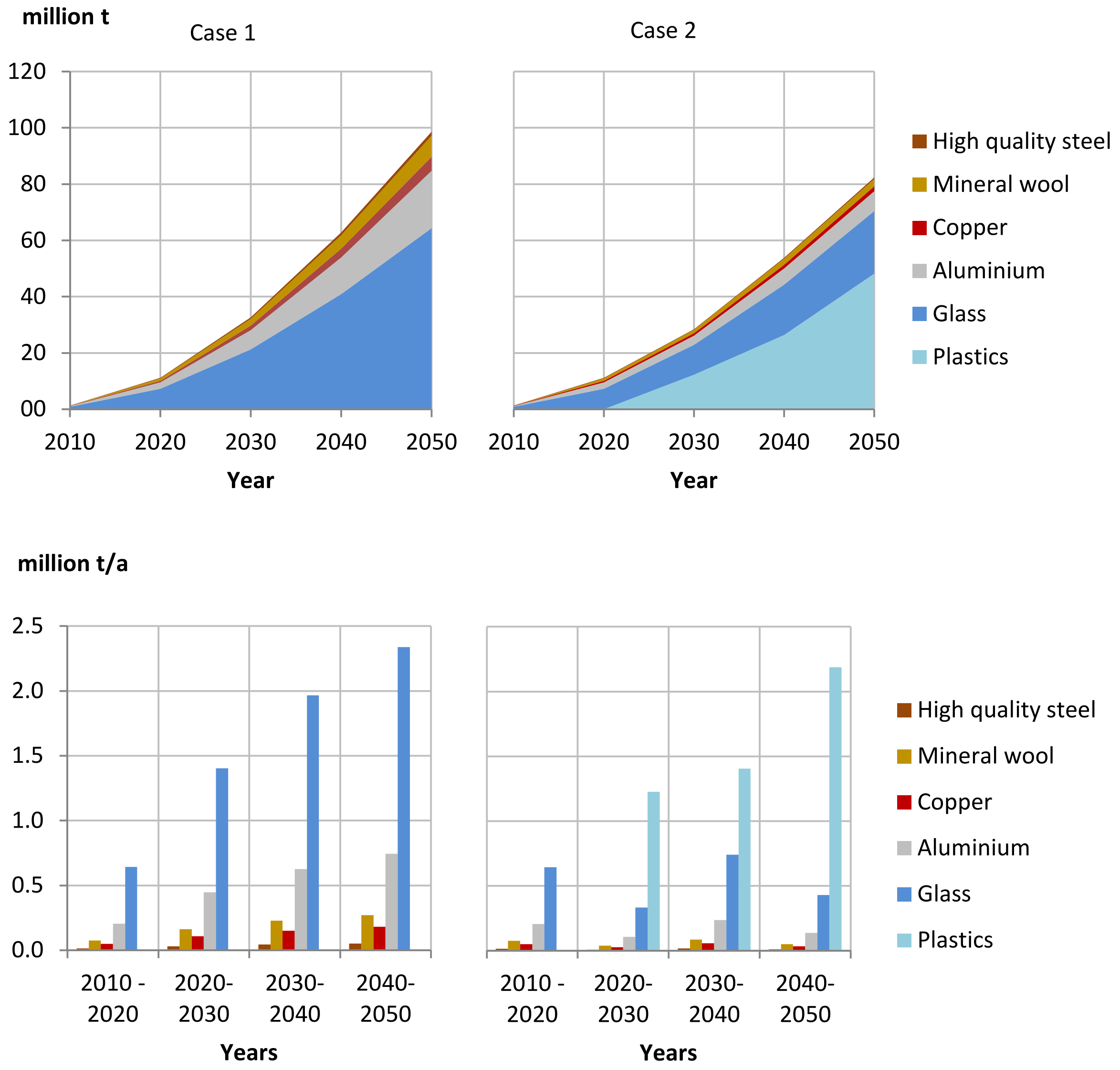

Figure 3-4 European (OECD) material demand of solar thermal collectors, Energy [R]Evolution; Top: Cumulative material demand; Bottom: Annual material demand, average over 10 years

Table 4 Annual growth rates in %, average taken over 10 years; Energy [R]Evolution (OECD Europe)

Timeframe	Aluminium		Copper		Stainless steel		Glass		Mineral wool		Plastics	
Case	1	2	1	2	1	2	1	2	1	2	1	2
2010 – 2020	24.5	24.5	24.5	24.5	24.5	24.5	24.5	24.5	24.5	24.5	-	-
2020 – 2030	11.4	3.9	11.4	3.9	11.4	3.9	11.4	3.9	11.4	3.9	-	-
2030 – 2040	6.8	5.4	6.8	5.4	6.8	5.4	6.8	5.4	6.8	5.4	-	7.9
2040 – 2050	4.6	2.2	4.6	2.2	4.6	2.2	4.6	2.2	4.6	2.2	-	6.2

RE-thinking 2050 – EU-27 – Solar Thermal

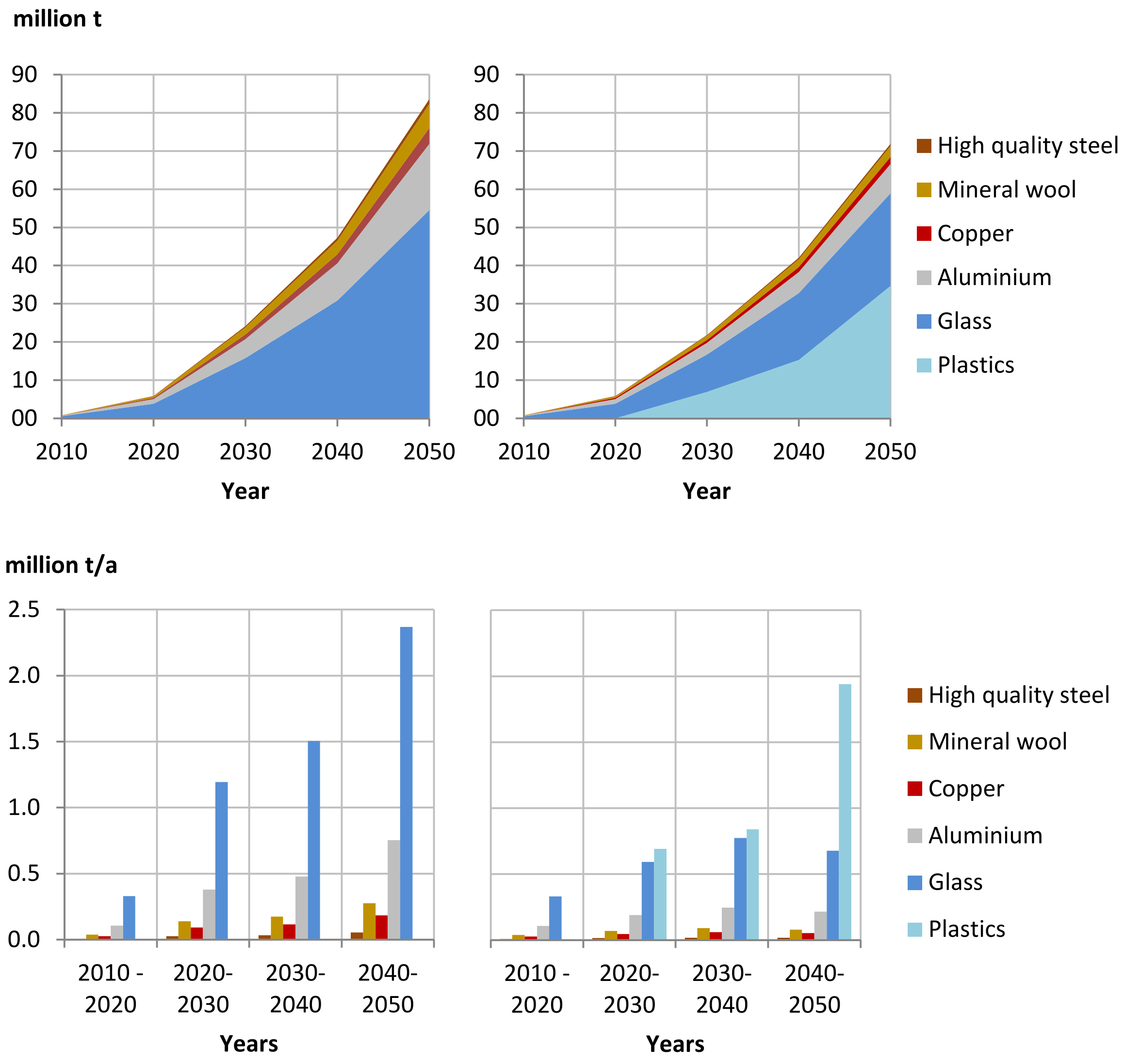

Figure 3-5 European (EU-27) material demand of solar thermal collectors, RE-thinking 2050; Top: Cumulative material demand; Bottom: Annual material demand, average over 10 years

Table 5 Annual growth rates in %, average over 10 years; RE-thinking 2050

Timeframe	Aluminium		Copper		Stainless steel		Glass		Mineral wool		Plastics	
Case	1	2	1	2	1	2	1	2	1	2	1	2
2010 – 2020	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3	-	-
2020 – 2030	15.2	9.8	15.2	9.8	15.2	9.8	15.2	9.8	15.2	9.8	-	-
2030 – 2040	6.9	6.0	6.9	6.0	6.9	6.0	6.9	6.0	6.9	6.0	-	8.3
2040 – 2050	5.9	3.3	5.9	3.3	5.9	3.3	5.9	3.3	5.9	3.3	-	2.4

3.3 Conclusions for the Plastics Industry

The realization of 100%-scenarios has a big impact on all renewable energy technologies, including solar thermal heat production. With such a drastic increase in installed capacity, also the consequences on the material demand have to be thought of. New materials like plastics need to be used to reduce production costs and increase collector efficiencies (Stryi-Hipp et al., 2012). If the solar thermal industry is to cover their share in the 100%-scenarios and furthermore all installations additional to the baseline are to be covered by polymeric materials (case 2), the demand for plastics becomes huge. Assuming that the E[R] scenario case 2 becomes true, this means that until 2050 a total of 328.1 million t of polymeric materials has to be provided. The worldwide annual plastics production in 2012 of 288 million t (PlasticsEurope, 2013) was only a little below this value. In terms of application sectors, solar thermal collectors best fit into the category Building and Construction". At the moment a fraction of about 20.3% of the European plastics production is used in the "Building and Construction" sector (see Figure 3-6), which would correspond to an annual global plastic production of about 58 million t. It would take over five years of today's entire building and construction production volume to provide the necessary amount of plastics up to 2050. Thus, the focus should be put onto easily available plastics. In this market sector, anyway cost-efficient commodity plastics (e.g., polyolefins) are dominating. Polypropylene and Polyethylene (PE-LD, PE-LLD and PE-HD[22]) covered 48% of

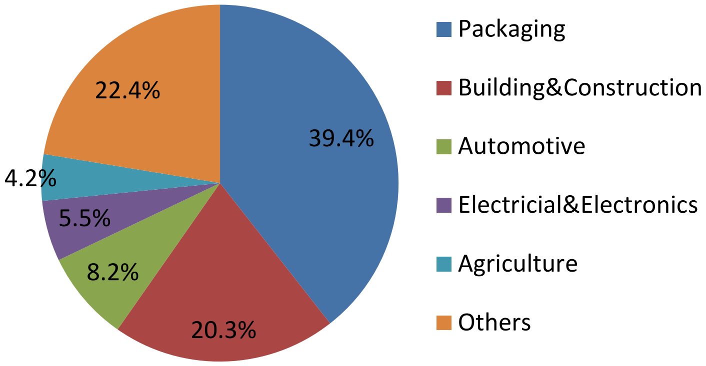

Figure 3-6 European plastic demand per segment
Source: PlasticsEurope, 2013.

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[22] PE-LD: Polyethylene low-density, PE LLD: Polyethylene linear low-density, PE-HD: Polyethylene high-density

the plastics production in 2012 (PlasticEurope, 2013) and are cost-efficient in production.

Assuming the global E[R] scenario becomes reality, an additional annual quantity of about 8.2 million t/a of plastic has to be provided for the solar thermal industry. This figure clearly indicates the high attractiveness of solar thermal technologies for the plastics industry.

The global plastics production grew by 3.2% on average between 2002 and 2012. While this growth is expected to continue, the available oil reserves are predicted to decrease after 2015 – 2025 (see Figure 3-7). Currently only ~5% of the worldwide oil reserves are used for the plastics production but this share could increase drastically within the next decades. Depending on the growth rates of plastic and the development of the oil reserves, by 2050 the plastics production could account for 20 – 50% of the available oil. It is therefore likely that in the future fossil fuels will be used primarily as feedstock for materials, which implies reduced availabilities for energy production. A significant benefit of solar thermal energy supply is therefore the saving of fossil resources in terms of low temperature heat production.

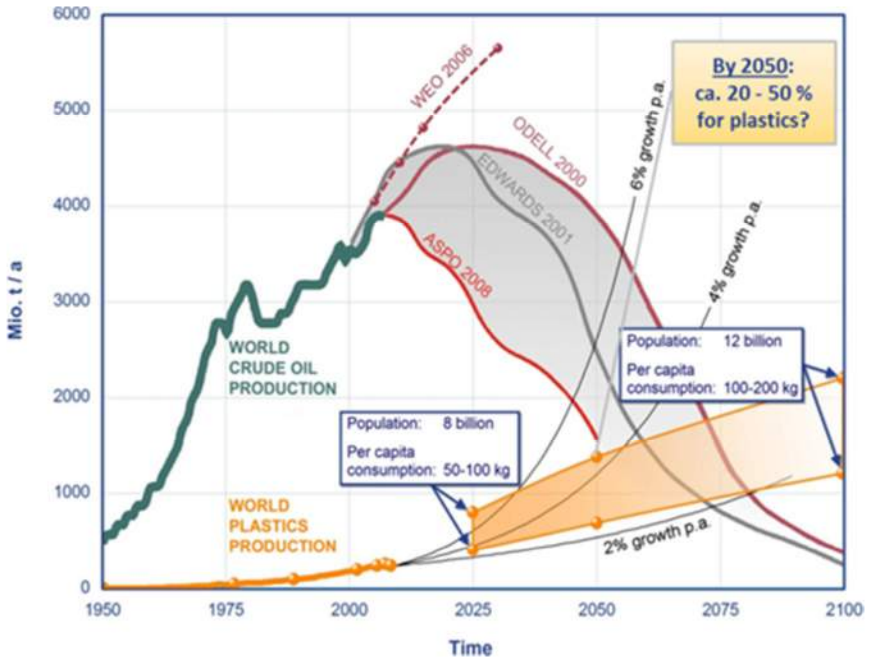

Figure 3-7 Plastics growth scenarios vs. development of the oil reserves. Depending on both factors, the share of plastics could increase to 20 – 50% of the available oil reserves by 2050. Source: R. W. Lang and H. Kicker (2010).

4. FUTURE MATERIAL DEMAND FOR PHOTOVOLTAIC MODULES

4.1 Calculations

Similar to the considerations of chapter 3 we now estimate the future material demand of photovoltaic systems, again based on the 100%-scenarios. The scenarios give us information about the yield, i.e. the electricity produced by photovoltaic systems in TWh/a. Additionally, we need to find the following information in order to calculate the future material demand:

1. Data on the masses and materials of typical existing solar modules [kg/m^2] for all three generations[23],
2. market outlook and the development of the share of different technologies,
3. efficiencies and the corresponding necessary areas per capacity, and
4. yield factor for future solar modules.

In this case we don’t differentiate between global and European data but do consider the temporal development of the different parameters between 2010 and 2050. We use experimental methods additionally to the literature research to define the material usage of typical solar modules of the three generations. Principally, we use literature values of typical modules of each technological generation. In addition we took one sample module from each technological generation and analysed the thickness and material composition of the different layers. The experimental results were then used to compare with the literature values. When no literature values were found we used these results. However, we want to point out that the experimentally analysed solar modules were small-scale modules and are of limited suitability for calculating typical material compositions as they are not representative for the commonly installed module types.

All other values (market outlook, efficiencies, share of technologies and yield factors) are entirely based on literature research.

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[23] 1st generation: conventional c-Si solar cells, 2nd generation: thin film solar cells, 3rd genaration: emerging technologies such as OPV or CPV

- Experimental analysis

In order to be able to verify literature values of typical soar modules we conducted experimental analyses on the material composition of solar modules of the different technological generations. Table 6 shows data on the selected solar cells and modules.

Table 6 Selected solar cells and modules for experimental analysis of material usage

Technology	Module designation	Nominal Power [W_p]	Module area [m^2]	Specific capacity [W/m^2]
1st generation poly-Si	TPS-103 2W	1.35	0.01	112.50
2nd generation TF (a-Si)	Solarmodul 9V / 150 mA	1.18	0.05	33.52
3rd generation OPV	Konarka PP 120	1.30	0.09	13.98

First we cut parts of the solar cells into small pieces. We then embedded the samples in a methacrylate resin and polished the surface with a Struers Tegramin Polishing machine.

In a next step we used an optical microscope to measure the thicknesses of the various layers of the samples. While crystalline Silicion (c-si) and thin film (TF) modules have a total thickness in the range of a few mm (2.8 mm and 3.2 mm respectively), the organic solar cell only has a total thickness in the scale of 10^2 µm (419 µm).

After the optical analysis, we use both, fourier-transform infrared microscopy (or simply: “IR-microscopy”) and Raman microscopy to analyse the material composition of the different layers. IR-microscopy was useful only in case of c-Si and organic solar cells. The TF sample could be analysed with the Raman microscope. The recorded spectrums were compared with the standardized data bank. Further information on the measurements and an example of the IR analysis is shown in Appendix C – Experimental Results.

Layer structure and material composition

Polycrystalline Silicon (p-Si): The 1st generation p-Si solar cell was analysed using IR and Raman microscopy.

Thin film: The 2nd generation TF solar cell was analysed by the Raman microscope. As the thickness of the active layer of TF solar cells (~1 µm) is below the resolution of the Raman microscope, only the back sheet layer and the front side glass could be analysed.

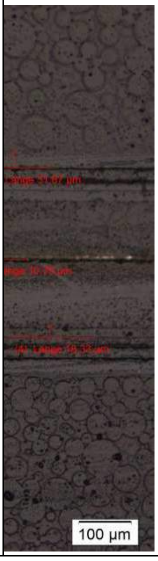
Organic Solar Cell: The "Konarka" organic solar cell is flexible and only 419 µm thin. Under the optical microscope 11 layers were identified. Here, too, the active layer is too thin to be analysed with either IR or Raman microscopy. The analysis was performed using both microscopes and the results matched well. However, the Tedlar Polyvinylfluorid (PVF) layers in the laminate with Polyethylenterephthalat (PET) are too polar to have significant bands in the Raman spectrum and were only measured by the IR Microscope.

Images of the modules, images of the cross sections with optical microscopes as well as the layer thicknesses and composition are shown in Table 7.

- Market Outlook

Before having a look at the different technologies in detail we need to know the expected development of the share of the technologies. However, it is very difficult, if not impossible to estimate the market development for more than a few years. In its fact sheet on Materials Availability, EPIA makes clear that "*It is not useful to speculate on the market share breakdown of each PV technology beyond 2020*" (EPIA, 2013). Therefore, any assumptions have to be considered as scenarios and not as predictions. Figure 4-1 shows the historical development of the market share as well as estimations until 2020. It shows that there are big differences in the literature concerning the expected development of the market share, even within the next few years.

Table 7 Image and cross section of the analysed PV modules

Cell type	Image of analysed PV module	Cross-section and material composition
1st generation Polycrystalline Silicon		 **Layer 1**: 145 µm, PET **Layer 2**: 27 µm, unknown, possibly glue **Layer 3**: 1,034 µm, Ethylenvinylacetat (EVA) **Layer 4**: 189 µm, Silicon **Layer 5**: 29 µm, Silicon substrate **Layer 6**: 1,437 µm, Epoxy resin with glass fibre reinforcement
2nd generation Thin film		 **Layer 1**: 3,085 µm, Glass **Layer 2**: 69 µm, PET
3rd generation Organic Photovoltaic Cell		 **Layers 1-4**: 88.9 µm, PET/ fluoropolymer laminate **Layer 5**: 104.2 µm, Ethylene-Copolymer **Layer 6**: 10.8 µm, unknown (active layer) **Layer 7**: 126.6 µm, PET **Layers 8-11**: 88.6 µm, PET / fluoropolymer laminate

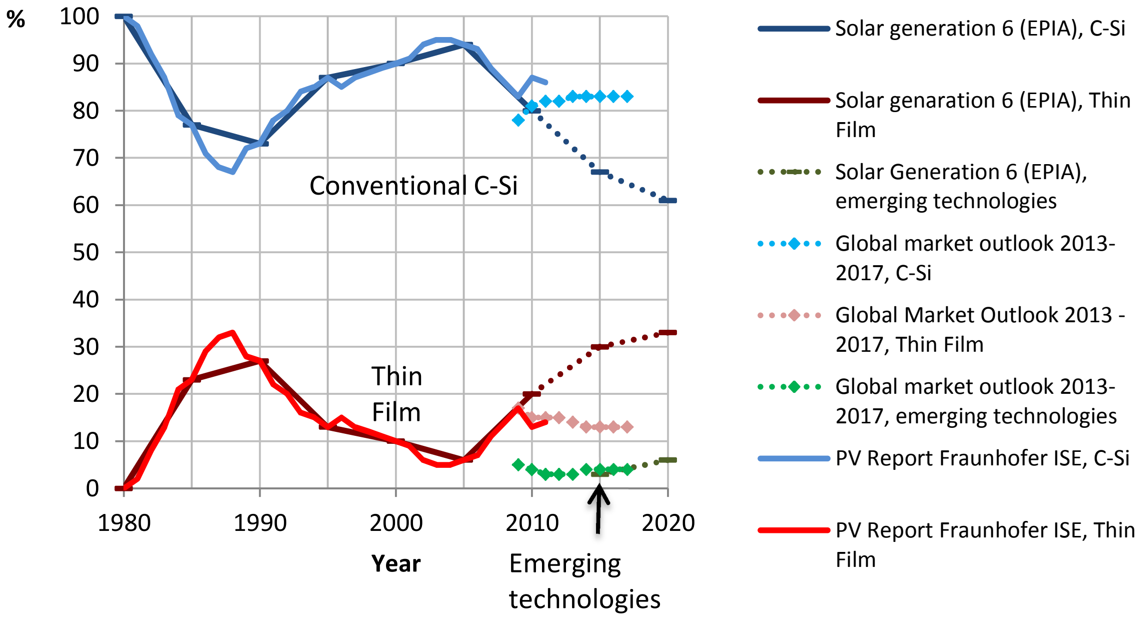


Figure 4-1 Development of the market share of different PV technologies [%]. Dashed lines show the expected development in the future.

The chosen market development primarily follows the forecast of the “Solar Generation 6” (EPIA) until 2020, taking into account also other sources such as “Renewables, Global Futures Report 2013” (REN21, 2013)[24] or the “Technology Roadmap – Solar Photovoltaic Energy” (*Frankl and Nowak*, 2010)[25]. No forecast beyond 2020 was found in the reviewed literature. Conservative assumptions were made with 1st generation technology (c-Si) remaining dominant but with increasing shares of both 2nd (thin film) and 3rd generation (Organic Photovoltaics (OPV) and Concentrating Photovoltaics (CPV)) technologies until 2050. High efficiencies, large material availability and the technological experience (due to the broad usage of silicon in various electronic applications) make it likely for c-Si to remain an important player on the global market. However, low material usage as well as low cost and an expected increase of efficiency could see TF technologies rise its market share. The future of 3rd generation “emerging technologies” such as OPV and CPV is very uncertain. Estimations of their development are very difficult. However, due to certain unsolved issues and limitation to special applications of

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[24] Thin film: 30-40% by 2020, OPV: good alternative after 2020

[25] C-si: dominant until at least 2020, forecasted market share by 2020 is 50%; Thin film: significant increase of market share until 2020

both OPV[26] and CPV[27], we don't expect a market share higher than 10% by 2050. Figure 4-2 shows the assumed development of the PV market until 2050. These numbers serve as a basis for the calculations.

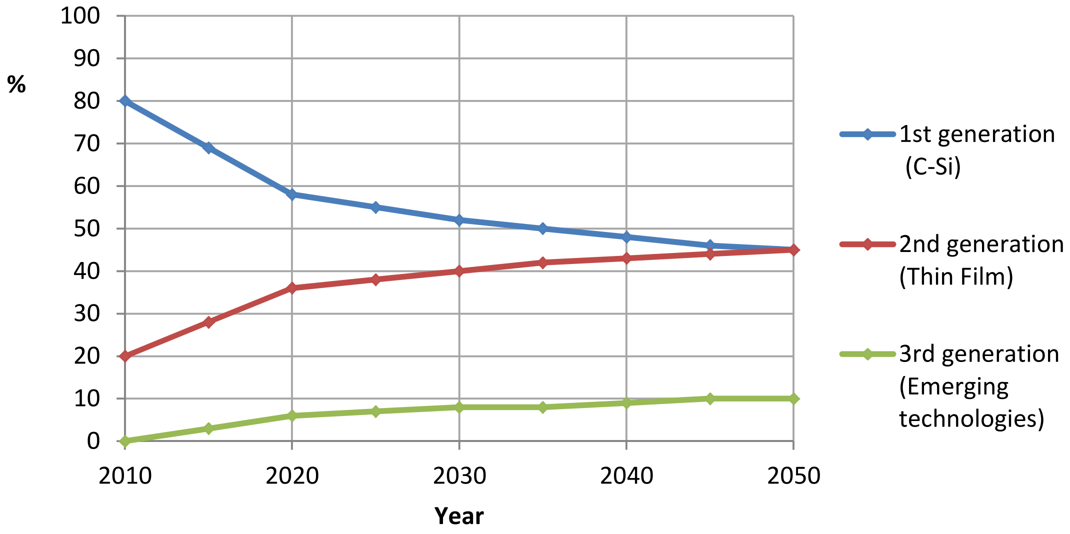

Figure 4-2 Assumed market development of the different PV technology generations

- Efficiency[28]

The necessary module area (and the corresponding material demand) to produce a certain amount of electricity largely depends on the efficiency of the PV system. The higher the efficiency, the lower the material demand becomes. Not the entire spectrum of the sun can be absorbed by semiconductors. Photons with energies below the band gap energy E_g cannot be excited into the conduction band. Photons with a higher energy than the band gap usually only excite one electron to the conduction band, the residual energy is lost in the form of heat energy transmitted to the crystal lattice of the semiconductor. In case of a small band gap, most of the photons have enough energy to excite electrons from the valence band to the conduction band. The gained energy due to the charge separation is, however, small. In case of a large band gap, the gained energy would be higher, but less photons have enough energy to excite electrons above the band gap. The ideal band gap lies around 1.1 eV (Wesselak and Voswinckel, 2012). Its

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[26] i.a. low efficiencies, low stability over time

[27] i.a. high costs, necessity of a precise tracking and cooling systems, only direct sunlight usable

[28] Ratio of the generated electrical power to the incoming solar radiation.

corresponding theoretical efficiency is around 30%. Silicon’s 1.12 eV band gap lies very close to this optimum, which is one of the reasons why the usage of this semiconductor material is so widespread in PV technology. When concentrating the light or combining different semiconductor materials with different band gaps, higher efficiencies can be obtained. The theoretical limit of non-concentrated and concentrated systems with the corresponding band gaps is shown in Figure 4-4.

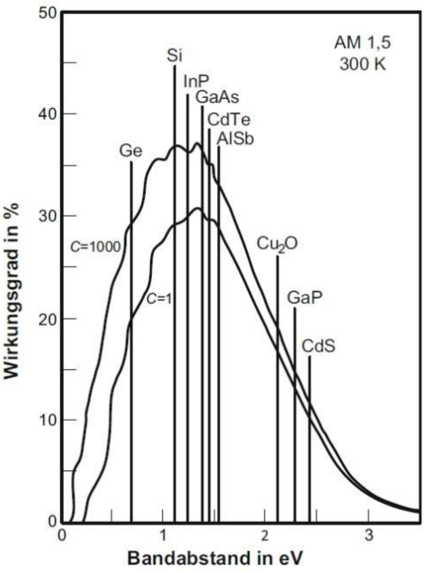

Figure 4-4 Theoretical efficiencies of different band gaps in PV cells. Lower curve: no concentration; Upper curve: concentrating factor 1000. AM = Air mass.
Source: Kaltschmitt et al. (2013).

As shown in Figure 4-5, the efficiencies of solar cells have continuously increased since the 1970s and are expected to continue to rise. The targeted commercial efficiency of polycrystalline silicon cells in the long run is 21%, for mono crystalline silicon cells it is 25% (IEA-ETSAP and IRENA, 2013 and IEA, 2010b). With currently around 4-12%, TF cell efficiencies are

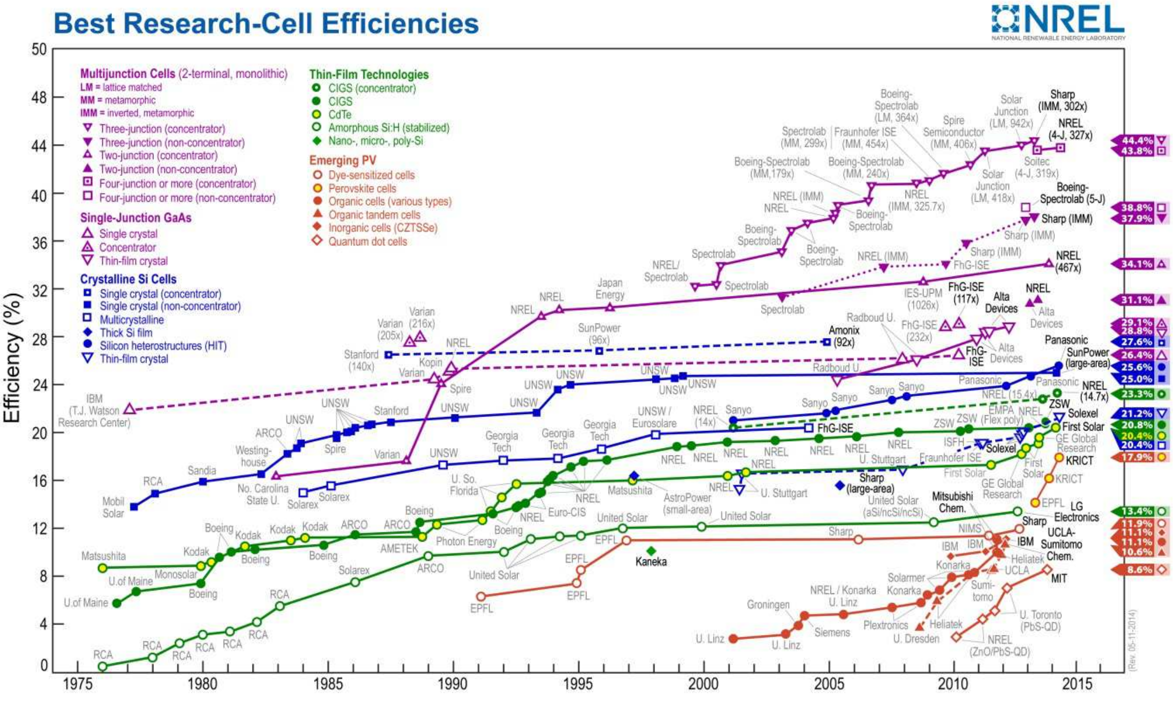

Figure 4-3 History of the best lab-efficiencies of different PV cell technologies.
Source: www.nrel.gov/ncpv (12^{th} November 2014).

significantly below those of c-Si but are expected to increase to 15 - 18% by 2030. We assume efficiencies of around 20% by 2050 in our calculations. As the 3rd generation technologies like OPV and CPV are less mature than 1st and 2nd generation solar cells, projections are even more difficult than for c-Si and TF. No numbers are given beyond 2020 for OPV, where IEA-ETSAP and IRENA (2013) expect commercial efficiencies of 10% and lab efficiencies of 15%. We assume that OPV will reach 20% by 2050. CPV on the other hand has significantly higher efficiencies, using mostly multi-junction cells. Commercial efficiencies are expected to be higher than 45% in the long run (IEA-ETSAP and IRENA, 2013 and IEA, 2010b). Table 8 summarizes the assumed development of the efficiencies of the different PV technologies until 2050.

Table 8 Assumed development of efficiencies of the different technologies [%]

	C-Si	TF	Emerging Technologies - OPV	Emerging Technologies - CPV
2010	15	8	4	20
2020	18	13	10	30
2030	20	16	15	35
2040	23	18	18	40
2050	25	20	20	45

- Material input for PV modules

Defining the used materials for each technology is the most crucial part of the assumptions. Both, typical literature values and the experimental analysis of three solar modules were combined to define the material usage [kg/m^2] for each technological generation. Considering the vast amount of technologies (even within one technological generation) this selection can only be seen as one possible choice that takes into account general trends and common solar cells but cannot be considered exhaustive. It should be noted that the material demand is calculated for solar modules, i.e. a certain amount of solar cells that are connected and encapsulated. The literature review shows that *"Thin sheets of EVA or PVB*[29] *are used to bind cells together and to provide weather protection. The modules are normally enclosed between a transparent cover (usually glass) and a weatherproof*

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[29] Polyvinylbutyral

backing sheet (typically made from a thin polymer). […] Thin Film modules are usually encapsulated between two sheets of glass […].” (Teske et al., 2011).

Crystalline-Silicon: The front cover usually consists of a 3.2 mm low iron solar-glass. The active layer is made of silicon with a typical thickness of 180-200 µm (Mertens, 2013; IEA-ETSAP and IRENA, 2013), which is in agreement with the experimental results. The EVA sheets typically are 500 µm thick which makes a total of 1000 µm, which also is consistent with the measurements. Back sheets are typically made from a PVF-Polyester-PVF laminate. We use the 325 µm PVF/PET/PVF laminate of the company “Dunmore” for our calculations. The typical c-Si module cross section is shown in Figure 4-5 and the resulting material demand is shown in Table 9.

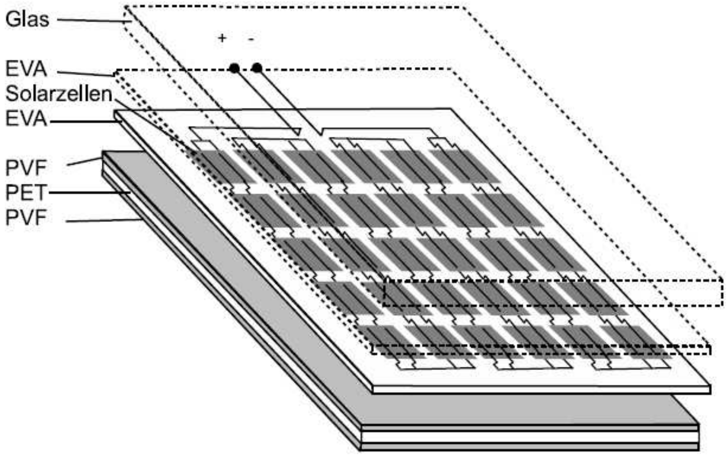
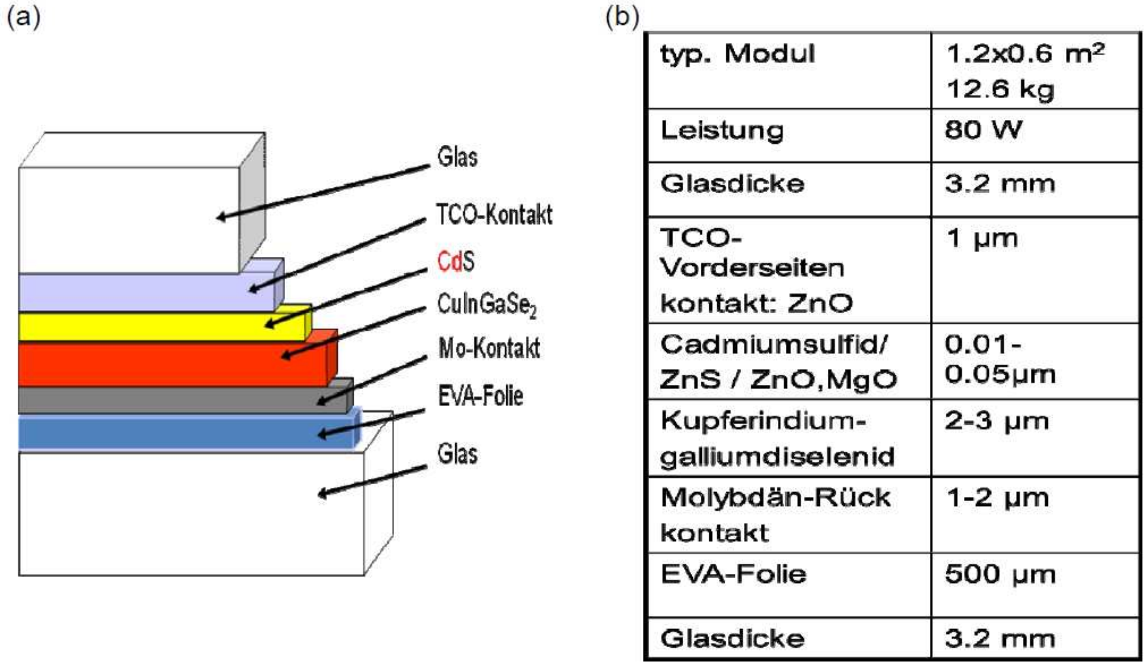


Figure 4-5 Standard c-Si module cross section. Source: Wesselak and Voswinckel, 2012.

Table 9 Assumed material demand for a typical c-Si solar module

Material	Thickness [µm]	Material density [kg/m^3]	Mass per area [kg/m^2]	Mass per capacity [kg/kW]
Glas	3,200	2,500	8.00	53.33
EVA	1,000	945	0.95	6.30
Silicon	200	2,330	0.47	3.11
TPT (Tedlar PVF - PET - Tedlar PVF)	325	1,445	0.47	3.13
Total	**4,725**		**9.88**	**65.86**

Thin film: TF Modules are either produced with a superstrate[30], substrate[31] or both. For our calculations we assume the latter. The principal structure of the module is similar in all common TF technologies, only the semiconductor material of the thin active layer (a few µm) differs from type to type. We use a copper indium gallium selenide (CIGS) module, being representative for the thin film technology. In 2011, around 24% of the produced TF modules and around 3% of the worldwide PV production were CIGS modules (Fraunhofer ISE, 2012). Beneath the upper glass layer there is a transparent conductive oxide (TCO) layer such as indium tin oxide (ITO) or zinc oxide (ZnO). The next layer is made of cadmium sulphide (CdS) and is a so-called window layer with a very high band gap, letting through most of the light and only absorbing high-energy light. The window-layer is followed by the actual semiconductor, in this case CIGS, the backside contact, typically made of molybdenum, an EVA layer and the backside glass layer. Figure 4-6 depicts a typical cross section of a CIGS-TF module with the corresponding layers. The resulting material demand is shown in Table 10.



typ. Modul	1.2x0.6 m^2 12.6 kg
Leistung	80 W
Glasdicke	3.2 mm
TCO-Vorderseiten kontakt: ZnO	1 µm
Cadmiumsulfid/ ZnS / ZnO,MgO	0.01-0.05µm
Kupferindium-galliumdiselenid	2-3 µm
Molybdän-Rück kontakt	1-2 µm
EVA-Folie	500 µm
Glasdicke	3.2 mm

Figure 4-6 (a) Cross section of a typical CIGS TF module. (b) materials and thickness of the different layers.
Source: Fischer et al., 2012.

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[30] Usually a glass layer on top of the cell, oriented towards the sun

[31] Usually a glass layer at the bottom of the cell on which the cell is built

Table 10 Assumed material demand for a typical CIGS TF module

Material	Thickness [µm]	Material density [kg/m^3]	Mass per area [kg/m^2]	Mass per capacity [kg/kW]
Glass	2,000.0	2,500	5.00	62.50
ZnO	1.00	5,606	0.01	0.07
CdS	0.05	4,826	0.00	0.00
CIGS	1.50	5,700	0.01	0.11
Molybdene	0.50	10,280	0.01	0.06
EVA	500.00	945	0.47	5.91
Glass	2,000.00	2,500	5.00	62.50
Total	**4503.05**		**10.49**	**131.15**

Organic PV: In case of OPV we mostly use the results of our own measurements. Only assumptions on the thin active layer (<1µm) are entirely based on literature. Polymeric layers of PET/fluoropolymer and Ethylene Copolymer as well as PET and PET/fluoropolymer are a protection above and below the active layer. With only polymeric materials as a substrate, the solar cell is flexible. ITO and aluminium layers act as electrodes. "Amongst various material, P3HT:PCBM[32] Bulk Heterojunction (BHJ)[33] is the most commonly used and well-optimized active layer used in OSC[34]s" (Wallace, 2013). The PEDOT:PSS layer "improves the extraction properties between the ITO and the P3HT and to smooth out the ITO film" (Kraner, 2011). Figure 4-7 shows the cross section of a typical BHJ organic solar cell. The resulting material demand is shown in Table 11.

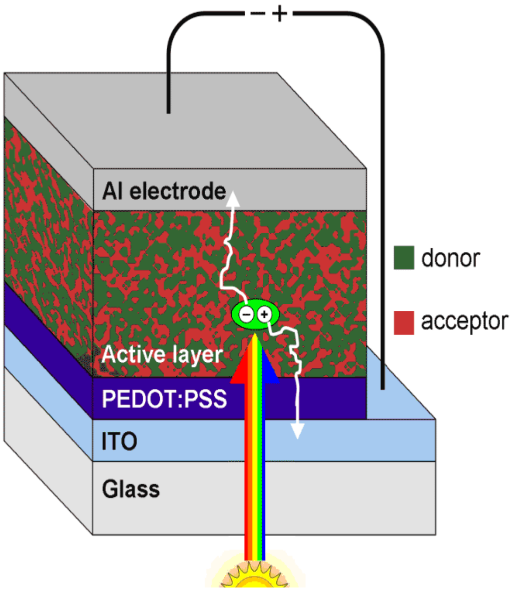

Figure 4-7 Cross section of a typical Bulk Heterojunction organic solar cell. Donor and acceptor layers are mixed. The substrate glass is often substituted by a plastic foil.
Source: Verploegen, 2010.

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[32] P3HT: Poly(3-hexylthiophene-2,5-diyl), conjugated polymere donor-molecule; PCBM: Phenyl-C61-butyric acid methyl ester, fullerene based acceptor-molecule

[33] Bulk Heterojunction, one of the most important breakthroughs for OPV development, where donor and acceptor are mixed in order to avoid the problem of the low diffusion lengths of excitons (only ~10 nm) in organic materials

[34] Organic solar cell

Table 11 Assumed material demand for a typical Organic BHJ solar cell

Material	Thickness [µm]	Material density [kg/m^3]	Mass per area [kg/m^2]	Mass per capacity [kg/kW]
PET/fluoropolymer	88.90	1,445	0.13	3.21
Ethylene Copolymer	104.20	925	0.10	2.41
Aluminium	0.10	2,700	0.00	0.01
P3HT:PCBM	0.10	1,300	0.00	0.00
PEDOT:PSS	0.05	1,011	0.00	0.00
ITO	0.10	7,140	0.00	0.02
PET	126.60	1,380	0.17	4.37
PET/fluoropolymer	88.60	1,445	0.13	3.20
Total	**408.65**	**17,346**	**0.53**	**13.22**

Figure 4-9 Amonix 7700 CPV system, 53 kW$_p$, aperture area of 267 m^2, triple-junction high efficient solar cells. Source: amonix.com

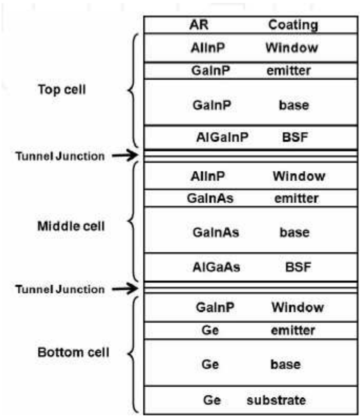

Figure 4-8 Structure of a typical multijunction solar cell used for CPV systems. Source: Lin et.al, 2013.

Concentrated PV: CPV is a special case in various ways. Highly efficient multijunction cells are used that are too expensive to be produced for large areas. Furthermore, a concentrating and tracking system is needed to always ensure that the sunlight is used at maximum. Only direct sunlight can be used for this kind of technology. In this case we use an existing example of a running CPV-system to define the material demand. Several of these so-called Amonix 7700 CPV solar power systems[35] (see Figure 4-9) by Arzon Solar are installed in the South West of the United States. For the active layer of multijunction cells typically the semiconductors gallium indium phosphide (GaInP) (top cell) gallium indium arsenide (GaInAs) (middle cell) and germanium (Ge) (bottom cell) are used (see Figure 4-8). Each semiconductor has a different band gap, allowing the cell to absorb a bigger part of the solar spectrum. 7560

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[35] 53kW$_p$, 500:1 concentration, 0.855cm^2 cells, aperture area = 267m^2 with 7,560 focal spots, 37% Efficiency

cells with Fresnel lenses for concentration form one module with 53 $kW_{p.}$ In the material demand table (see Table 12) we include the cell materials as well as those components that have to be used in CPV and are not necessarily used in other technologies: lenses, tracking system and heat sink.

Table 12 Assumed material demand for a multijunction CPV system

Material	Thickness [µm]	Material density [kg/m^3]	Mass per area [kg/m^2]	Mass per capacity [kg/kW]
GaInP	0.52	4,470	0.00	0.00
GaInAs	3.6	5,500	0.02	0.00
Germanium	150.3	5,323	0.80	0.01
PMMA				20.48
Aluminium				55.30
Steel				48.82
Total	**154.42**		**0.82**	**124.61**

- Yield

Despite the fact that with 1,000 kWh/m^2 the average annual solar irradiation in Europe is much lower than the global average of 1,700 kWh/ m^2 (Teske et al., 2012), in the reviewed literature no significant regional difference could be found in terms of yield per capacity [kWh/(a·kW_p)] as is shown in Table 13[36]. Even within Europe, there is a big difference of irradiation values. In southern Spain, southern Italy and Greece irradiation values can reach almost 2,000 kWh/(m^2·a) while most parts of Great Britain and Scandinavia don’t even reach 1,000 kWh/(m^2·a).

Table 13 Yield – capacity ratios, global and Europe, today’s values

Source	Region	Yield [TWh/a]	Capaci-ty [GW]	Conversion [kWh/(a·kW_p)]
Renewable Energy Sources and Climate Change Mitigation, IPCC	Global	26	22	**1,181.8**
Global Market Outlook 2013 –	Global	102	110	**1,078.4**
RE-thinking 2050	Europe	5.4	4.9	**1,102.0**
Solar generation 6	Europe	1,400.0	1,500	**933.3**

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[36] The absolute values themselves are of no relevance here as we are only interested in the resulting ratio of kWh/(a·kW_p)

Figure 4-10 shows literature values of the development of this ratio in Europe (blue) and on a global scale (red) and the ratio taken for the calculations (green). Zervos et al. (2012) explain that "*With the expected evolution of technologies such as concentrated PV and nanotechnologies, even higher efficiency and output performances can be expected*".

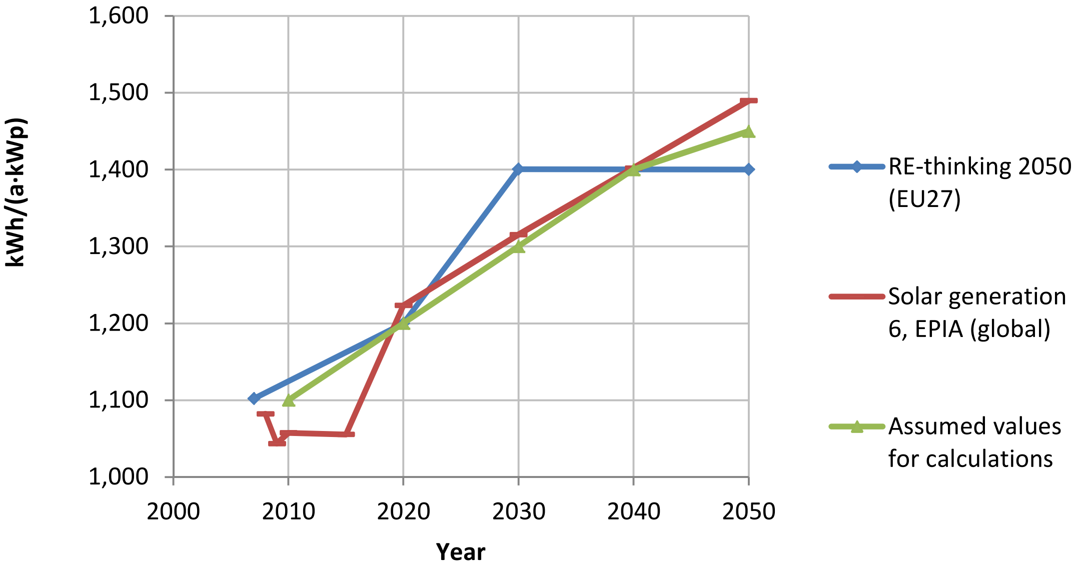

Figure 4-10 Development of the yield - capacity ratios in Europe (blue) and global (red). The green line shows the assumed ratio for the calculations for both regions.

- Calculation procedure

In a next step we combine the data of the 100%-scenarios (see chapter 2.2) and of the material input in PV modules described above to perform the calculations. They follow the following procedure:

1. Define yield [TWh/a] at 10-year intervals for the 100%-scenarios,
2. define necessary cumulative installed capacity, including the necessary replacements due to lifetime considerations (add stock from 20 years before, that need to be replaced, to the current stock) as well as changes in the necessary installed capacity to achieve the targeted yield [GW_p]
3. define development of material demand [t/GW_p] for every decade and each used material (taking into account the changing market share as well as the increase of efficiency) and
4. calculate the corresponding material demand for each decade and material.

4.2 Results and Discussion

In this chapter we show the results of the calculations of the estimated future material demand of PV modules based on the 100% renewable energy scenarios. The graphs for the cumulative and annual material demand of the five most used materials as well as tables of the cumulative material demand of the other materials by 2050 and the annual growth rates of all materials can be found at the end of the chapter.

4.2.1 Global Material Demand of Photovoltaic Modules

Energy [R]Evolution

Given the assumptions of the previous chapter come true, glass would remain by far the most dominant material used for PV systems, followed by plastics. It should be noted, however, that the calculations only consider the modules, not the mounting systems, inverters etc. E[R] expects a rather constant increase of installed capacity. **The total polymeric material demand until 2050 is 25.8 million t** while the glass demand is 176.7 million t. This does not, however, consider possible replacements of some parts of the module (like the cover) with other materials. In case the glass cover was to be replaced by plastics, these numbers would, of course, change drastically. Figure 4-11 shows the cumulative and annual material demand of the five most used materials which make up 99.9% of the entire material demand. The share of the cumulative demand of other materials (denoted as “Others” in the diagram) until 2050 is shown in Table 14. Of this list, only indium (in ITO) is considered critical by EPIA (2013) in terms of long term availability.

The steady increase mentioned above is also reflected in the average annual material demand, which increases only moderately between 2010 and 2050. Like in chapter 3, we have a look at annual growth rates, which is an important factor for the feasibility of the projected development. Table 15 shows the annual growth rates. Also here, the critical time period is in the current decade (2010 – 2020), where in some cases an increase of more than 30% per year would be needed over an entire decade to cover the needed demand.

As any assumption of the development of the market share until 2050 is subject to great uncertainties, we repeat the calculations for the global Energy [R]Evolution scenario with a different market share development. It shows how sensible the data is to this parameter. If the market share of c-Si remains above 80% until 2050, TF market share reduces to around 10-15% and emerging technologies reach 6%, the cumulative plastic demand would be 34.0 million t. In case of a take-off of emerging technologies, reaching 45% market share in 2050, with c-Si reducing to 35% and TF remaining around 20%, the plastic demand would be 21.0 million t. Thus, the uncertainty of the market development has a significant influence on the development of the plastic material demand. However, even when considering such uncertainties, the results remain considerably lower than in case of solar thermal systems.

The Energy Report

In contrast to the E[R] scenario, calculations with the ECOFYS scenario from TER show a rapidly increased growth of the material demand over the next decades (see Figure 4-12). **The cumulative material demand reaches 31.2 million t by 2050**. Until 2040 the expected demand is lower than in case of E[R]. From 2040 to 2050 an absolute growth of 145.7 million t within one decade leads to a 21.2% higher material demand than E[R] by 2050. GDP and population growth is higher in E[R] while the expected electricity demand is 4.8% lower. However, E[R] assumes only 16% of the electricity demand to be covered by PV systems by 2050, while TER assumes 29%, which accounts for the high material demand. Interestingly, the assumed electricity generation of TER in 2050 is 40.9% higher than in case of E[R]. However, the lower installed capacity in earlier decades leads to fewer necessary replacements later on which results in only 21.2% higher cumulative material demand by 2050. The absolute growth is also mirrored in the diagram of the annual material demand, which grows from 0.65 million t/a in 2010 to 14.55 million t/a in 2050 (combining all materials). Again, glass is the main player followed by plastics. Looking at the relative growth rates (see Table 16) shows that the crucial decades are both 2010 to 2020 and 2020 to 2030. All materials would experience an annual growth in demand of more than 20% between 2020 and 2030.

4.2.2 European Material Demand of Photovoltaic Modules

Energy [R]Evolution

The European (OECD Europe) electricity demand in the E[R] scenario increases from 3,457 TWh/a in 2009 to 4,225 TWh/a in 2050. 77% of the demand growth happens in the periods 2009 – 2015 and 2020 – 2030. This is reflected also in the cumulative material demand of PV systems that is shown in Figure 4-13. The most important increase happens in the first and third considered decade. This development is not seen on a global scale. No specific reason for this varying demand is given in the report. **The cumulative polymeric material demand is moderate, with 2.53 million t until 2050**. The average annual material demand also shows the dominance of the decades 2010 to 2020 and 2030 to 2040. Even the glass demand, being by far the highest of all materials, stays below 1 million t/a for Europe. The relative growth rate per year (see Table 17) shows that only the current decade is critical. Beyond 2020 the growth rates don't reach 10% anymore, so no problems are to be expected.

RE-thinking 2050

RE-thinking 2050 includes the former EU-27 countries. Unlike the solar thermal systems, the difference in terms of installed capacity to OECD Europe is neglectable (~1%). The electricity demand of 4,987 TWh/a by 2050 is also comparable to E[R]'s 4,225 TWh/a (+18%). However, the material demand of PV systems is significantly higher in case of RE-thinking 2050. The reason for this lies in the 2050 electricity mix of the scenarios, where PV covers 15.0% in case of E[R] and 27.0% in RE-thinking. This results in **almost exactly twice the total plastic material demand of the latter until 2050, namely 5.0 million t** (see Figure 4-14). The lower contribution of PV in E[R] is mostly covered by a higher share of wind energy (+4.03 percentage points compared to RE-thinking 2050) and hydro power (+5.34 percentage points). This is a good example for the differences that occur in distinct 100%-scenarios, just due to varying technology mixes. In case of RE-thinking 2050, the material demand is fairly constant throughout the four decades. The average annual polymeric material demand is around 0.1 to 0.2 million t /a. In terms of growth rates, this scenario is more feasible, with a maximum annual growth rate of 15% (see Table 21) for some materials between 2010 and 2020.

Energy [R]Evolution – Global – Photovoltaics

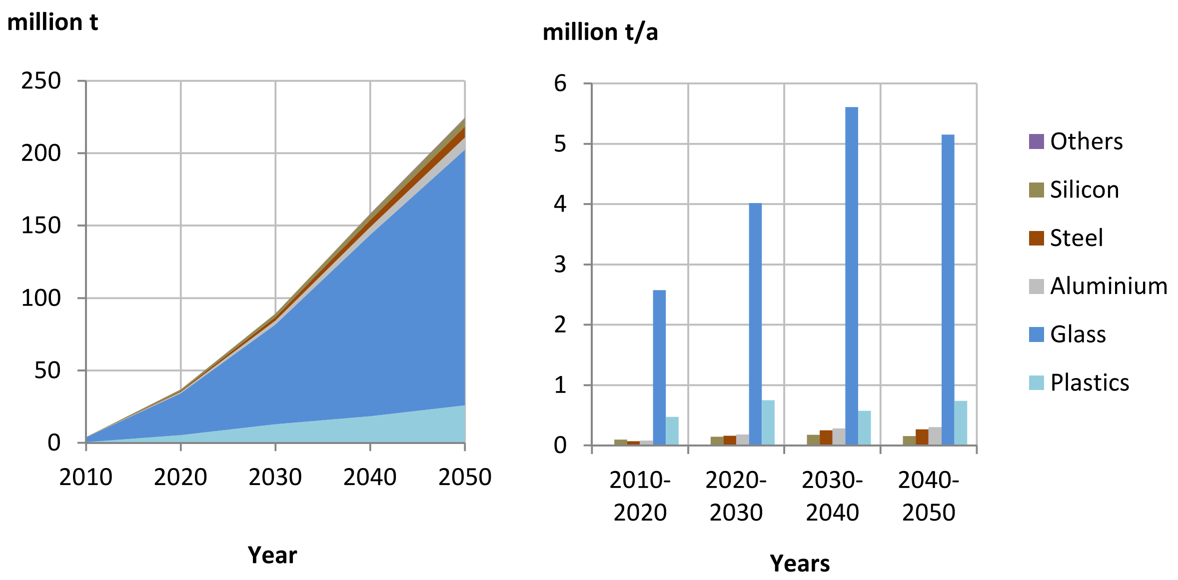

Figure 4-11 Global material demand of photovoltaic modules, Energy [R]Evolution; Left: Cumulative material demand; Right: Annual material demand, average over 10 years

Table 14 Cumulative demand of materials until 2050 denoted as "Others" in Figure 4-11

Material	Demand (million t)
Other semiconductor materials	0.13
Zinc Oxide (ZnO)	0.09
Molybdenum	0.08
Cadmium Sulphide (CdS)	0.004
Indium Tin Oxide (ITO)	0.001
P3HT:PCBM	0.0002

Table 15 Annual growth rates in %, average over 10 years; Energy [R]Evolution (global)

Timeframe	Glass	Silicon	ZnO	CdS	Other SC	Mo	Al	P3HT: PCBM	ITO	Steel	Plastics
2010 – 2020	24.5	22.3	30.0	30.0	30.1	30.0					26.1
2020 – 2030	9.1	8.6	9.9	9.9	9.9	9.9	12.5	9.7	9.7	12.5	9.3
2030 – 2040	6.1	5.4	7.2	7.2	7.2	7.2	7.6	7.0	7.0	7.6	3.8
2040 – 2050	3.5	3.1	4.0	4.0	4.0	4.0	4.5	4.7	4.7	4.5	3.4

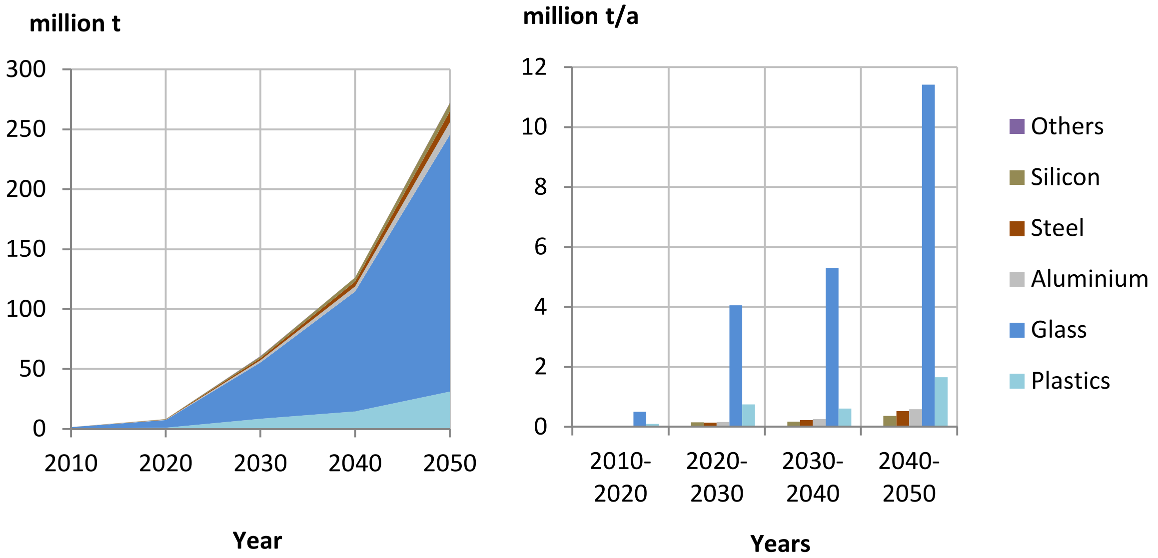

Figure 4-12 Global material demand of photovoltaic modules, The Energy Report; Left: Cumulative material demand; Right: Annual material demand, average over 10 years

Table 16 Cumulative demand of materials until 2050 denoted as “Others” in Figure 4-12

Material	Demand (million t)
Other semiconductor materials	0.16
Zinc Oxide (ZnO)	0.10
Molybdenum	0.09
Cadmium Sulphide (CdS)	0.004
Indium Tin Oxide (ITO)	0.001
P3HT:PCBM	0.0003

Table 17 Annual growth rates in %, average over 10 years; The Energy Report

Timeframe	Glass	Sili-con	ZnO	CdS	Other SC	Mo	Al	P3HT: PCBM	ITO	Steel	Plast-ics
2010 – 2020	16.5	14.5	21.7	21.7	21.8	21.7					18.0
2020 – 2030	22.0	21.5	22.9	22.9	22.9	22.9	25.8	22.7	22.7	25.8	22.3
2030 – 2040	7.9	7.1	9.0	9.0	9.0	9.0	9.3	8.8	8.8	9.3	5.5
2040 – 2050	7.9	7.5	8.5	8.5	8.5	8.5	9.0	9.1	9.1	9.0	7.8

Energy [R]Evolution – OECD Europe – Photovoltaics

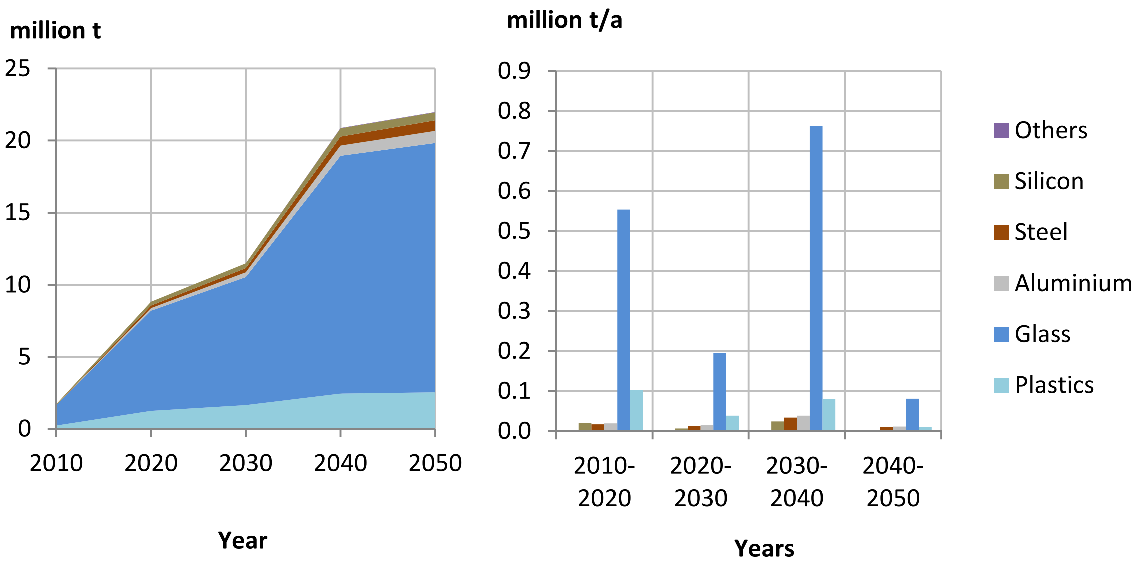

Figure 4-13 OECD Europe - material demand of photovoltaic modules, Energy [R]Evolution Left: Cumulative material demand; Right: Annual material demand, average over 10 years

Table 18 Cumulative demand of materials until 2050 denoted as “Others” in Figure 4-13

Material	Demand (million t)
Other semiconductor materials	0.013
Zinc Oxide (ZnO)	0.008
Molybdenum	0.008
Cadmium Sulphide (CdS)	0.0004
Indium Tin Oxide (ITO)	0.0001
P3HT:PCBM	0.00002

Table 19 Annual growth rates in %, average over 10 years; Energy [R]Evolution (OECD Europe)

Timeframe	Glass	Silicon	ZnO	CdS	Other SC	Mo	Al	P3HT: PCBM	ITO	Steel	Plastics
2010 – 2020	17.4	15.4	22.6	22.6	22.7	22.6					18.9
2020 – 2030	2.5	2.1	3.2	3.2	3.3	3.2	5.7	3.1	3.1	5.7	2.7
2030 – 2040	6.4	5.7	7.5	7.5	7.5	7.5	7.8	7.3	7.3	7.8	4.1
2040 – 2050	0.5	0.1	1.0	1.0	1.0	1.0	1.5	1.6	1.6	1.5	0.4

RE-thinking 2050 – EU-27 – Photovoltaics

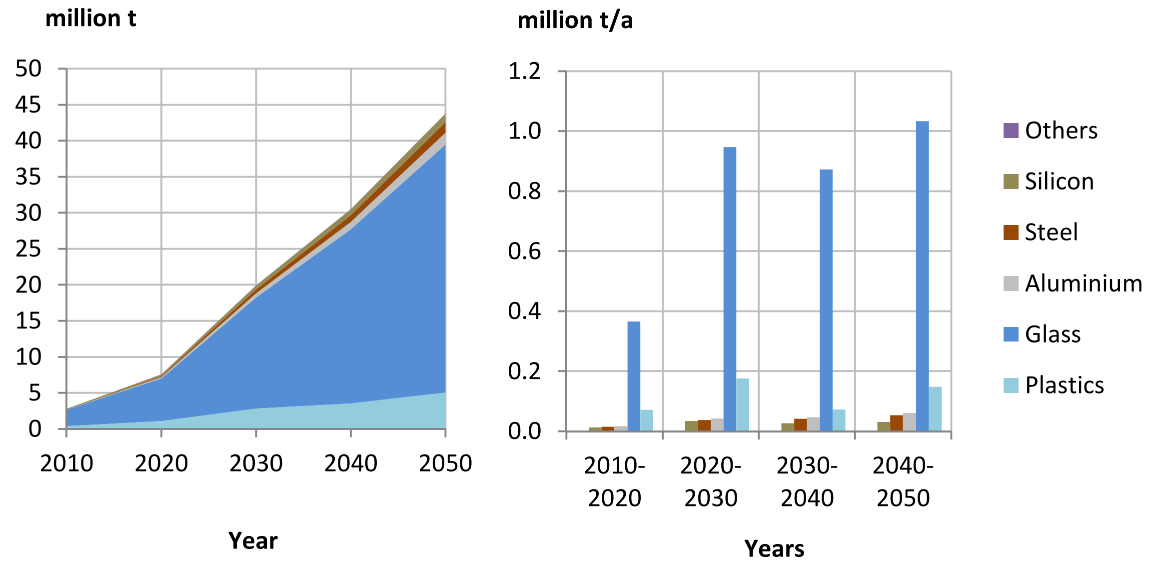

Figure 4-14 EU27 - material demand of photovoltaic modules, RE-thinking 2050
Left: Cumulative material demand; Right: Annual material demand, average over 10 years

Table 20 Cumulative demand of materials until 2050 denoted as "Others" in Figure 4-14

Material	Demand (million t)
Other semiconductor materials	0.03
Zinc Oxide (ZnO)	0.02
Molybdenum	0.02
Cadmium Sulphide (CdS)	0.001
Indium Tin Oxide (ITO)	0.0002
P3HT:PCBM	0.00004

Table 21 Annual growth rates in %, average over 10 years; RE-thinking 2050

Timeframe	Glass	Silicon	ZnO	CdS	Other SC	Mo	Al	P3HT: PCBM	ITO	Steel	Plastics
2010 – 2020	10.0	8.1	14.9	14.9	15.0	14.9					11.4
2020 – 2030	10.0	9.6	10.8	10.8	10.8	10.8	13.4	10.6	10.6	13.4	10.2
2030 – 2040	4.6	3.9	5.7	5.7	5.7	5.7	6.0	5.5	5.5	6.0	2.3
2040 – 2050	3.6	3.2	4.2	4.2	4.2	4.2	4.6	4.8	4.8	4.6	3.5

4.3 Conclusions for the Plastics Industry

While the impact and potential for the plastics industry was huge in case of solar thermal systems, the results would suggest that PV is not likely to play a dominant role in the plastics industry. Compared to the plastic demand of around 8 million t per year for solar thermal systems, 1 million t/a for the most ambitious global PV scenario is relatively low. However, even if the plastics material demand is lower by a factor of 10, it is still significant.

Furthermore, rather than posing interesting quantitative perspectives, PV might still provide interesting R&D fields and demand for special polymeric applications such as the encapsulation or packaging. The latter is one of the main R&D issues for TF technologies in the future (Frankl and Nowak, 2010). Also the field of organic solar cells can become an interesting specialized application field for polymeric materials if the concept proves successful.

5. SUMMARY AND OUTLOOK

In this master's thesis we analysed global and European scenarios that aim for a 100% renewable energy supply until 2050. A comparison with market scenarios of the solar thermal and photovoltaic industry showed that the 100%-scenarios are mostly in the range of "paradigm shift" market scenarios or even below. This means that the energy revolution is feasible, but only with the combined effort of all involved parties (politics, industry, R&D etc.).

Furthermore, we calculated the resulting cumulative and annual material demand for solar thermal collectors and photovoltaic modules with a focus on plastics. The results show a big band width of different scenarios and therefore large uncertainties, also in the cumulative material demand. Even though no prediction is possible based on these numbers, the results can be used to estimate expected scales of the necessary masses and can also serve as a basis for cost calculations and decisions on material selections.

In case of solar thermal systems we found that the potential for the plastics industry is huge. Given that from 2020 onwards only the business as usual demand is covered by conventional systems and the residual part of the 100%-scenarios is covered by plastic collectors (case 2), **an average of 8.2 million t/a of polymeric material has to be provided annually until 2050** in case of the most ambitious scenario (Energy [R]Evolution, Greenpeace). This results in a **cumulative demand of 328.1 million t until 2050**. Even in the ECOFYS scenario of The Energy Report (WWF) 2.3 million t/a of polymeric material (94.8 million t cumulative until 2050) is necessary. On a European scale, the E[R]-scenario results in an annual demand of 1.2 million t of polymeric materials (48.2 million t until 2050) while the RE-thinking 2050 scenario leads to an annual demand of 0.9 million t of plastics (34.7 million t until 2050).

This imposes an enormous challenge for the plastic industry to provide such quantities (which strongly suggests the usage of commodity plastics such polyolefins) but also for the R&D sector to achieve mass production of polymeric collectors. On the other side such a production volume is a big chance for the plastics industry.

In case of photovoltaics the estimated potential is smaller. Polymeric materials are already used in photovoltaic modules (encapsulation, back sheets etc.) but the potential for replacement of other materials is smaller than in solar thermal collectors. In the most ambitious global scenario (The Energy Report, WWF), **0.8 million t/a of polymeric materials are necessary each year on average (31.2 million t until 2050)**. In the Energy [R]Evolution scenario the potential is even lower. An annual demand of 0.6 million t/a (25.8 million t until 2050) would be necessary. In case of Europe, the Energy [R]Evolution scenario leads to an annual demand of less than 0.1 million t/a (2.5 million t until 2050) and RE-thinking 2050 (EREC) results in an annual demand of 0.1 million t/a (5.0 million t until 2050). Even if quantitatively photovoltaic is not as attractive as solar thermal systems, special applications for solar cells may still make the field interesting for the plastics industry.

This master’s thesis included only the most basic elements of solar thermal and PV systems, namely the collector and the solar module respectively. In a further step one could include other system parts. For solar thermal systems these include the mounting system, hot water tank, pipes and pumps. In typical solar thermal combisystems, for example, collectors only account for 43% of the mass; the other 53% are composed of the hot water tank (45%), mounting system (6%), control and pump unit (4%) and the pipes (2%) (Fischer et al., 2012). For PV, other system parts include the mounting system, cables, batteries, inverters and possibly a tracking system. Furthermore, one could analyse other renewable technologies such as wind energy or small hydro power. There are applications for plastic materials in practically all renewable technologies.

It would be also interesting to analyse the uncertainties and to create a tool that allows calculating different results depending on varying parameters more easily. This could give further insight on the relative importance of distinct parameters (such as the yield, the efficiency, the lifetime etc.). At the same time one could, of course, go into more detail with the parameters themselves (e.g. define the PV yield more regionally rather than taking one global average value).

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APPENDICES

Appendix A – Scenario Details

Energy [R]Evolution

Population growth:

- global population growth between 2009 and 2050: 0.8% p.a.
- global population development (billion): 2009: 6.82; 2030: 8.37; 2050: 9.47
- OECD Europe population development (million): 2009: 555; 2030: 593; 2050: 600

Economic growth:

- The decoupling of energy demand and GDP growth is a prerequisite for the Energy [R]Evolution as economic growth has been a key driver for energy demand
- The economic development assumptions of the E[R] scenario are based on World Energy Outlook (WEO) 2011. After the WEO timeframe (until 2035), the projections for 2035 - 2050 are based on own estimates.
- GDP growth in all regions is expected to slow gradually over the coming decades.
- Average annual GDP growth rates between 2009 and 2050:
    - World: 3.1%
    - OECD Europe: 1,6%

Cost projections:

- Oil and gas price projections:
    - Crude oil imports: 2010: 78 \$/barrel, 2050: 152 \$/barrel
    - Natural gas: US: 24.04 \$/GJ, Europe: 26.37 \$/GJ, Japan LPG: 29.77 \$/GJ
- Renewables:
    - PV (including additional costs for grid integration of up to 25% of the PV investment): Investment costs [\$/KW$_p$]: 2009: 3000, 2030: 1280,

2050: 1060; Operation and maintenance [$/(kW·a)]: 2009: 43, 2030: 15, 2050: 15

- Solar thermal: Yield (and therefore the costs) strongly depends on the location, differences of 100%. In less sun-intensive regions the economies of scales can reduce prices. Investment costs [$/kW]:
  - Low tech solar collectors: 2015: 140, 2030: 140, 2050: 140
  - Small solar collector systems: 2015: 1170, 2030: 1010, 2050: 750
  - Large solar collector systems: 2015: 950, 2030: 810, 2050: 610
  - Solar district heating (without network): 2015: 1080, 2030: 920, 2050: 690

The Energy Report

Population growth:

- global population growth between 2007 and 2050: 0.75% p.a.
- global population development [billion]: 2007: 6,67; 2025: 8,01; 2050: 9,19

Economic Growth

- Global GDP Growth [trillion EUR]: 2010: 65, 2030: 112, 2050: 188 (error margin: 2 trillion EUR)
- Average global annual GDP growth rates between 2010 and 2050**:** 2.7%

Cost projections

- Oil price:

2005: 6.22 EUR/GJ; 2030 ~ 11.8 EUR/GJ; 2050: ~ 18.6 EUR/GJ which corresponds to:

2005: 45.54 US$ / barrel; 2030: 86.39 US$/barrel; 2050: 136.18 US$ / barrel [37]

- Gas:

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[37] Conversion US$ - EUR 2005: Average value 2005: 1 EUR = 1.245 US$ (http://www.oanda.com/lang/de/currency/historical-rates/) 1 l = 37 MJ -> 1 barrel = 158,98 l = 5,882.26 MJ -> 1 barrel = 5.882 GJ (http://www.oekosystem-erde.de/html/energieeinheiten.html)

2005: 3.15 EUR / GJ, 2030 ~ 6.6 EUR/GJ, 2050: ~ 12 EUR/GJ which corresponds to:

2005: 3.92 US$ / GJ; 2030 ~8,22 US$/GJ; 2050: ~ 14.94$/GJ

- Renewable Energies:

No specific data available on solar thermal or PV cost developments.

RE-thinking 2050

No details are given on population or GDP developments

Cost projections

- Oil price development:

Moderate oil price: 2020: 61 $/barrel, 2030: 63 $/barrel, 2050: n/a

High oil price: 2010: 82 $/barrel, 2020: 100 $/barrel, 2030: 120 $/barrel, 2040: 150 $/barrel, 2050: 200 $/barrel.

CO_2 price development:

2020: 41 €/t CO_2 , 2030: 45 €/t CO_2, 2050: 100 €/t CO_2

No specific (comparable) data available on solar thermal or PV cost developments.

Appendix B – Yield Assumptions

Assumed yield factor – underlying literature values:

Global

Source	Region	Year	Collector Area [million m^2]	Produced heat [PJ/a]	Conversion factor, million [m^2/(PJ/a)]
Renewables 2013 – Global status report	Global	2011	318.6	696	**0.458**
Potential of Solar Thermal in Europe	Global	2006	183	128	**0.659**
Solar Heat Worldwide – Markets and Contribution to the Energy Supply 2011	Global	2011	335.1	704	**0.476**
IEA Technology Roadmap – Solar Heating and Cooling	Global	2050	9,857	16,500	**0.597**
Average					**0.547**

Europe

Source	Region	Year	Collector Area [million m^2]	Produced heat [PJ/a]	Conversion factor, million [m^2/(PJ/a)]
Solar Thermal Markets in Europe	EU 27 + CH	2012	40.5	72	**0.563**
Potential of Solar Thermal in Europe	EU 27	2006 2050	20.25 970	30.6 1407.6	**0.662** **0.689**
Solar Heat Worldwide – Markets and Contribution to the Energy Supply 2011	Europe	2011	56.14	120.3	**0.467**
IEA Technology Perspectives[38]	OECD Europe	2006 2050			**0.771** **0.77**
Average					**0.653**

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[38] Average values for different installations (varying building sizes and application)

Appendix C – Experimental Results

Example: OPV, FT-IR microscopy measurements

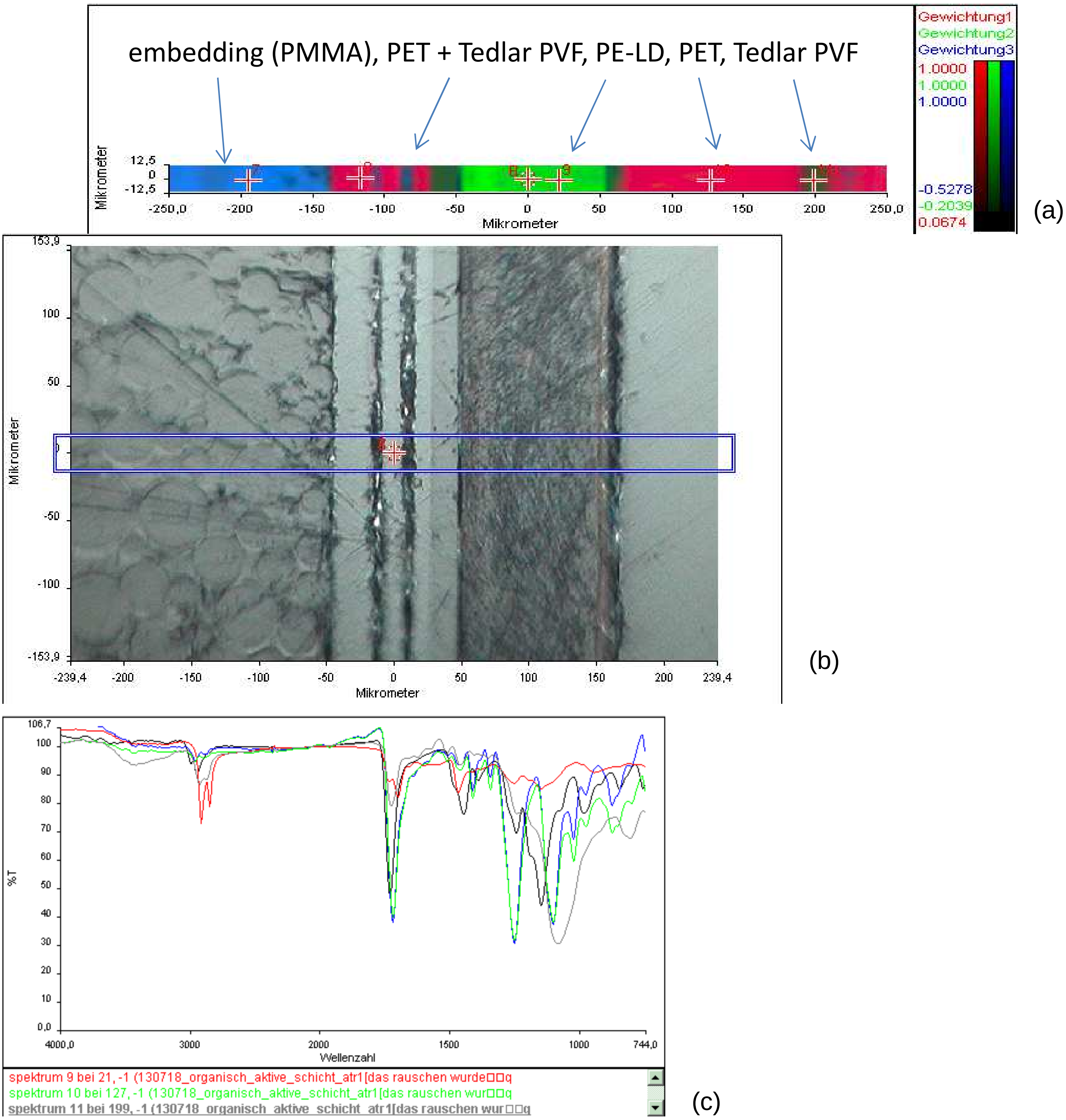

Figure 0-1 IR analysis of the organic solar cell: (a) IR cross section with the points where the transmission spectrum was analysed (b) optical image of the analyzed region (c) transmission spectrum of different layers

Figure 0-1 (c) shows different FT-IT spectrums with their vibrational peaks. Spectrum 10 (green), for example, is typical for PET with vibrational peaks at wavenumbers 1720 cm^{-1} (ester carbonyl bond C=O stretching), 1470-1350 cm^{-1} (ethylene glycol), 1235 cm^{-1} (ester group) and 1090 cm^{-1} (methylene group) (Chen et al., 2013).

Results for c-Si

	Thickness [µm]	Material	Material density [kg/m^3]	Mass per module [kg]	Mass per area [kg/m^2]	Mass per capacity [kg/W]
Layer 1	145	PET	1,380	0.0024	0.2001	0.0018
Layer 2	1,034	EVA	945	0.0117	0.9771	0.0087
Layer 3	189	Silicon	2,330	0.0053	0.4404	0.0039
Layer 4	29	Silicon	2,330	0.0008	0.0676	0.0006
Layer 5	1,437	Epoxy	1200	0.0207	1.7244	0.0153
Layer 6	27	unknown (possibly glue)				
Total	**2,861**			**0.0409**	**3.4096**	**0.0303**

Results for TF

	Thickness [µm]	Material	Material density [kg/m^3]	Mass per module [kg]	Mass per area [kg/m^2]	Mass per capacity [kg/W]
Layer 1	3085	Glass	2,500	0.3949	7.7125	0.2301
Layer 2	69	PET	1,380	0.0049	0.0952	0.0028
Total	**3,154**			**0.3998**	**7.8077**	**0.2330**

Results for OPV

	Thickness [µm]	Material	Material density [kg/m^3]	Mass per module [kg]	Mass per area [kg/m^2]	Mass per capacity [kg/W]
Layer 1	31.9	PET	1,380	0.0041	0.0440	0.0031
Layer 2	21.9	PET	1,380	0.0028	0.0302	0.0022
Layer 3	15.4	PET	1,380	0.0020	0.0213	0.0015
Layer 4	19.7	PET	1,380	0.0025	0.0272	0.0019
Layer 5	104.2	Ethylen Copolymer	925	0.0090	0.0964	0.0069
Layer 6	10.8	unknown		0.0000	0.0000	0.0000
Layer 7	126.6	PET	1,380	0.0162	0.1747	0.0125
Layer 8	18.3	PET	1,380	0.0023	0.0253	0.0018
Layer 9	16.8	PET	1,380	0.0022	0.0232	0.0017
Layer 10	22.7	PET	1,380	0.0029	0.0313	0.0022
Layer 11	30.8	PET	1,380	0.0040	0.0425	0.0030
Total	**419.1**			**0.0480**	**0.5160**	**0.0369**

Appendix D – Results of Calculations

Cumulative material demand in million t

Solar Thermal

Global E[R]	Year	Aluminium	Copper	High Quality Steel	Glass	Mineral Wool	Plastics	Total
Global: E[R]								
Case 1	2010	1.1	0.2	0.2	5.7	0.3	0.0	7.5
	2020	12.5	2.8	1.9	59.1	3.4	0.0	79.8
	2030	35.4	8.2	4.7	152.7	10.4	0.0	211.4
	2040	77.2	18.1	8.7	304.3	24.4	0.0	432.7
	2050	124.1	29.5	11.8	447.4	41.8	0.0	654.6
Case 2	2010	1.1	0.2	0.2	5.7	0.3	0.0	7.5
	2020	12.5	2.8	1.9	59.1	3.4	0.0	79.8
	2030	17.4	4.0	2.3	75.1	5.1	78.3	182.2
	2040	32.3	7.6	3.7	127.4	10.2	184.6	365.8
	2050	39.9	9.5	3.8	143.9	13.4	328.1	538.6
Global: TER								
Case 1	2010	1.1	0.2	0.2	5.6	0.3	0.0	7.3
	2020	5.3	1.2	0.8	25.3	1.4	0.0	34.1
	2030	21.5	5.0	2.9	92.9	6.3	0.0	128.5
	2040	34.7	8.1	3.9	136.7	11.0	0.0	194.4
	2050	47.5	11.3	4.5	171.3	16.0	0.0	250.6
Case 2	2010	1.1	0.2	0.2	5.6	0.3	0.0	7.3
	2020	5.3	1.2	0.8	25.3	1.4	0.0	34.1
	2030	9.8	2.3	1.3	42.3	2.9	51.0	109.5
	2040	16.4	3.9	1.9	64.8	5.2	75.1	167.2
	2050	23.2	5.5	2.2	83.6	7.8	94.8	217.1
Europe: E[R]								
Case 1	2010	0.3	0.1	0.0	0.8	0.1	0.0	1.2
	2020	2.3	0.6	0.2	7.2	0.8	0.0	11.1
	2030	6.8	1.6	0.5	21.3	2.5	0.0	32.6
	2040	13.0	3.2	0.9	40.9	4.7	0.0	62.8
	2050	20.5	5.0	1.5	64.3	7.5	0.0	98.7
Case 2	2010	0.3	0.1	0.0	0.8	0.1	0.0	1.2
	2020	2.3	0.6	0.2	7.2	0.8	0.0	11.1
	2030	3.4	0.8	0.2	10.6	1.2	12.3	28.5
	2040	5.7	1.4	0.4	18.0	2.1	26.3	53.8
	2050	7.1	1.7	0.5	22.2	2.6	48.2	82.3

Europe: RE-thinking 2050

Case 1	2010	0.2	0.0	0.0	0.5	0.1	0.0	0.8
	2020	1.2	0.3	0.1	3.8	0.4	0.0	5.8
	2030	5.0	1.2	0.4	15.8	1.8	0.0	24.2
	2040	9.8	2.4	0.7	30.8	3.6	0.0	47.3
	2050	17.3	4.2	1.2	54.5	6.3	0.0	83.6
Case 2	2010	0.2	0.0	0.0	0.5	0.1	0.0	0.8
	2020	1.2	0.3	0.1	3.8	0.4	0.0	5.8
	2030	3.1	0.7	0.2	9.7	1.1	6.9	21.8
	2040	5.6	1.3	0.4	17.5	2.0	15.3	42.1
	2050	7.7	1.9	0.5	24.2	2.8	34.7	71.8

Photovoltaics

Global: E[R]

Year	Glass	Plastics	Aluminium	Steel	Silicon	Other semiconductor materials
2010	3.25	0.51	0.00	0.00	0.15	1.26E-03
2020	28.99	5.22	0.81	0.71	1.10	1.75E-02
2030	69.13	12.70	2.62	2.32	2.52	4.48E-02
2040	125.19	18.42	5.44	4.80	4.25	9.02E-02
2050	176.69	25.77	8.47	7.47	5.78	1.34E-01

	ZnO	Molybdenum	CdS	ITO	P3HT: PCBM	Total
2010	8.26E-04	7.57E-04	3.56E-05	0.00E+00	0.00E+00	3.91
2020	1.14E-02	1.04E-02	4.89E-04	1.57E-04	2.85E-05	36.87
2030	2.91E-02	2.67E-02	1.25E-03	3.95E-04	7.20E-05	89.38
2040	5.85E-02	5.37E-02	2.52E-03	7.80E-04	1.42E-04	158.30
2050	8.69E-02	7.97E-02	3.74E-03	1.23E-03	2.24E-04	224.48

Global: TER

Year	Glass	Plastics	Aluminium	Steel	Silicon	Other semiconductor materials
2010	1.39	0.22	0.00	0.00	0.06	5.40E-04
2020	6.42	1.16	0.18	0.16	0.24	3.87E-03
2030	46.96	8.62	1.78	1.57	1.71	3.05E-02
2040	100.01	14.71	4.35	3.84	3.40	7.21E-02
2050	214.23	31.25	10.27	9.06	7.01	1.62E-01

	ZnO	Molybdenum	CdS	ITO	P3HT: PCBM	Total
2010	3.54E-04	3.24E-04	1.52E-05	0.00E+00	0.00E+00	1.68
2020	2.52E-03	2.31E-03	1.08E-04	3.47E-05	6.32E-06	8.17
2030	1.98E-02	1.81E-02	8.51E-04	2.69E-04	4.89E-05	60.72
2040	4.68E-02	4.29E-02	2.01E-03	6.23E-04	1.13E-04	126.46
2050	1.05E-01	9.66E-02	4.53E-03	1.49E-03	2.71E-04	272.18

Europe: E[R]

Year	Glass	Plastics	Aluminium	Steel	Silicon	Other semiconductor materials
2010	1.40	0.22	0.00	0.00	0.06	5.41E-04
2020	6.93	1.25	0.19	0.17	0.26	4.18E-03
2030	8.88	1.63	0.34	0.30	0.32	5.76E-03
2040	16.51	2.43	0.72	0.63	0.56	1.19E-02
2050	17.31	2.53	0.83	0.73	0.57	1.31E-02

	ZnO	Molybdenum	CdS	ITO	P3HT: PCBM	Total
2010	3.55E-04	3.25E-04	1.53E-05	0.00E+00	0.00E+00	1.68
2020	2.72E-03	2.49E-03	1.17E-04	3.75E-05	6.83E-06	8.82
2030	3.74E-03	3.43E-03	1.61E-04	5.08E-05	9.25E-06	11.49
2040	7.72E-03	7.08E-03	3.32E-04	1.03E-04	1.87E-05	20.87
2050	8.51E-03	7.81E-03	3.67E-04	1.20E-04	2.19E-05	22.00

Europe: RE-thinking 2050

Year	Glass	Plastics	Aluminium	Steel	Silicon	Other semiconductor materials
2010	2.29	0.36	0.00	0.00	0.10	8.88E-04
2020	5.94	1.07	0.17	0.15	0.23	3.58E-03
2030	15.41	2.83	0.59	0.52	0.56	9.99E-03
2040	24.14	3.55	1.05	0.93	0.82	1.74E-02
2050	34.47	5.03	1.65	1.46	1.13	2.61E-02

	ZnO	Molybdenum	CdS	ITO	P3HT: PCBM	Total
2010	5.82E-04	5.34E-04	2.51E-05	0.00E+00	0.00E+00	2.76
2020	2.33E-03	2.14E-03	1.00E-04	3.21E-05	5.85E-06	7.56
2030	6.49E-03	5.95E-03	2.79E-04	8.81E-05	1.60E-05	19.93
2040	1.13E-02	1.03E-02	4.86E-04	1.50E-04	2.74E-05	30.52
2050	1.70E-02	1.55E-02	7.30E-04	2.40E-04	4.37E-05	43.79