WACKER

CREATING TOMORROW'S SOLUTIONS

RENEWABLE ENERGY I SOLAR INDUSTRY

SILICONES FOR SOLAR APPLICATIONS

The Material of Choice for the Solar Age

“I’D PUT MY MONEY ON THE SUN AND SOLAR ENERGY. WHAT A SOURCE OF POWER! I HOPE WE DON’T HAVE TO WAIT UNTIL OIL AND COAL RUN OUT BEFORE WE TACKLE THAT.”

Thomas Edison, 1931

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Concentrated solar power

In the 21st century, our society faces the global challenges of climate protection and resource conservation while requiring more and more electrical power to drive industrial and consumer applications. Photovoltaics therefore plays an increasingly important role. To support the shift from conventional energy sources to renewable energy, WACKER offers high-quality silicone rubber grades.

ELASTOSIL® Silicones Are True Outdoor Specialists

Whether for encapsulating, sealing, adhesive bonding, molding or laminating, ELASTOSIL® Solar silicone grades from WACKER present the ideal long-lasting properties for outdoor applications:

- Long-term weathering resistance against:
  - High or low temperatures
  - UV radiation
  - Environmental impacts
- Water-repellency
- Low ion content for excellent electric insulation
- No embrittlement under outdoor conditions
- Good environmental compatibility

Putting Silicones in the Right Light

- **Standard solar modules**
  - Frame sealing
  - Bonding junction boxes and other components
  - Potting of junction box components
- **Additional possibilities for customized solar modules**
  - Encapsulation of solar cells
  - Lamination of flexible modules
- **Concentrator photovoltaics**
  - Molding of Fresnel lenses for highly concentrating PV (HCPV) modules
  - Optical coupling of secondary optical elements of HCPV modules
  - Thermal management of solar cells
  - Mirror bonding for solar concentrators
- **Concentrated solar power**
  - Bonding mirrors to the support structure
  - Silicone fluids as heat transfer media

Frame Sealing

Silicones can also be used for the assembly of solar collectors, e.g. for bonding the front glass to the frame structure.

STANDARD SOLAR MODULES

Frame Sealing and Bonding of Junction Boxes or Other Module Components

WACKER silicone rubber grades are ideal for bonding the PV laminate, usually comprising a front glass, encapsulation films in front of and behind the solar cells, and a back-sheet, to the aluminum frame. Silicones are also a reliable solution to fix system components, such as junction boxes.

Relevant benefits of ELASTOSIL® Solar silicones:

- Easy processing
- No release of corrosive volatiles
- Adhesion to typical PV substrates
- Long-term resistance to weathering and sunlight

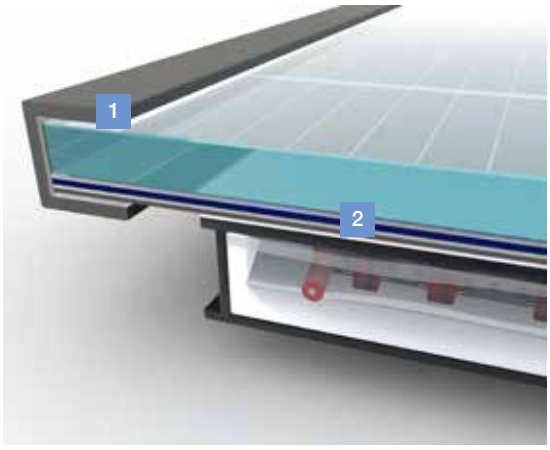
WACKER's dedicated silicone portfolio comprises one-part moisture curing silicones and two-part materials.

Potting of Junction Box Components

The potting of electronic and electrical components in the junction box requires reliable materials. Silicone gels offer the perfect protection.

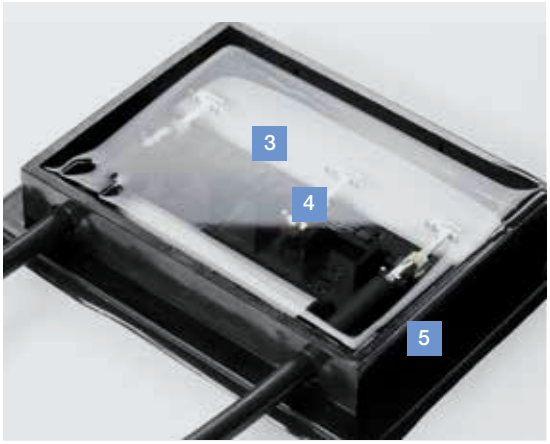
Relevant benefits of WACKER's silicone gels:

- Easy processing
- Productivity increase via UV curing (optional)
- No release of corrosive volatiles
- Perfect void-free potting of cavities and undercuts due to low viscosity
- Low thermomechanical stress due to high damping properties
- Intrinsic tackiness and thus excellent adhesion to surfaces
- Protection against water penetration, hence against corrosion



1 **Bonding of the PV laminate (composed of front glass, encapsulation films, solar cells and back-sheet) to the metal framing**

2 **Bonding of the junction box to the back-sheet**



3 **Potting material**

4 **Soldering tags for electrical components**

5 **Plastic housing**

Product Portfolio for Standard Solar Modules						
Application	**Frame Sealing, Bonding of Junction Boxes**			**Junction Box Potting**		
	ELASTOSIL® Solar 1101	ELASTOSIL® Solar 1109	ELASTOSIL® Solar 1200	ELASTOSIL® Solar 2202	ELASTOSIL® Solar 2203	ELASTOSIL® Solar 2205
Product type / curing system	1-part / moisture curing	1-part / moisture curing	2-part / room-temperature curing (base + catalyst*: 10:1)	2-part / platinum cure (A/B 1:1)	2-part / platinum cure (base + catalyst**: 10:1)	2-part / platinum cure (base + catalyst**: 10:1)
By-product during cure	Alcohol	Alcohol	Alcohol	None	None	None
Consistency	Paste-like	Paste-like	Paste-like	Low viscous (1,000 mPa·s)	Very low viscous (200 mPa·s)	Very low viscous (200 mPa·s)
Skin-forming time / potlife (at room temperature)	10 – 15 min.	20 – 35 min.	w/ curing agent T77: 15 – 20 min. w/ curing agent T77 PLUS: 5-10 min.	150 min.	Depending on curing catalyst used**	Depending on curing catalyst used**
Curing time (at room temperature)	Several days (curing speed: 1.5 mm/day)	Several days (curing speed: 1.0 mm/day)	Several hours (tack-free time: 30 – 60 min., depending on curing agent*)	Several hours	Several hours	Several hours
Color / aspect	Translucent	Black, white	Black	Transparent	Transparent	Transparent
Hardness	Sh A 30	Sh A 35	Sh A 36	N. a. (soft silicone gel)	N. a. (soft silicone gel)	N. a. (hard silicone gel)
Additional features			Curing speed tunable via mixing ratio and choice of curing catalyst*	High intrinsic tack	Curing mode (room temperature, UV) and curing speed tunable via choice of curing catalyst**	Curing mode (room temperature, UV) and curing speed tunable via choice of curing catalyst**

* Suitable curing catalysts: WACKER® Catalyst T 77 or WACKER® Catalyst T 77 PLUS
** Suitable curing catalysts: ELASTOSIL® CAT PT, ELASTOSIL® CAT PT-F or ELASTOSIL® CAT UV

ADDITIONAL POSSIBILITIES FOR CUSTOMIZED SOLAR MODULES

Whereas, in standard photovoltaic modules, silicones are limited to bonding and potting applications, their properties make them suitable for a wider range of applications in customized solar panels (e.g. building integrated photovoltaics), where they play an essential role in the generation of energy.

Encapsulation of Solar Cells

In order to improve a solar module's degree of efficiency, a transparent liquid silicone can be used to encapsulate the solar cells. This is particularly important for tailored solar panels that cannot be made by standard lamination processes, for instance.

Benefits of silicones:

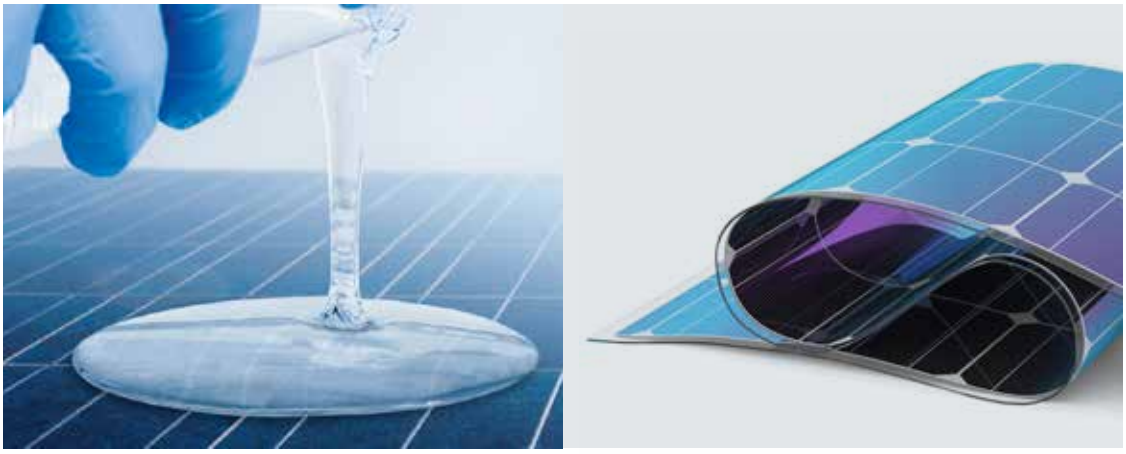
- Fast and void-free encapsulation
- No delamination thanks to long-term adhesion to typical substrates
- High module efficiency due to:
  - High transparency
  - No yellowing
  - Long-term resistance to sunlight

Lamination of Flexible Modules

Flexible modules are a special type of customized solar modules which are particularly common for organic photovoltaics (OPV). Silicones are the ideal laminating adhesives for the continuous roll-to-roll manufacture of such multilayer composite modules - typically comprising a cover-film, the organic solar cell layer embedded in a film laminate and a back-film.

Benefits of silicones:

- High process efficiency due to rapid curing
- Fast and void-free lamination
- No delamination thanks to long-term adhesion to typical substrates
- High module efficiency through
  - High transparency
  - No yellowing
  - Long-term resistance to sunlight



The ELASTOSIL® Solar range comprises low-viscous and fast-curing silicones that are ideal for encapsulating rigid and flexible solar modules.

Product Portfolio for Customized or Flexible Solar Modules				
Application	**Encapsulation of Solar Cells**			**Lamination of Flexible Modules**
	ELASTOSIL® Solar 2202	ELASTOSIL® Solar 2203	ELASTOSIL® Solar 2205	ELASTOSIL® Solar 2200
Product type / curing system	2-part / platinum cure (A/B 1:1)	2-part / platinum cure (base + catalyst**: 10:1)	2-part / platinum cure (base + catalyst**: 10:1)	2-part / platinum cure (A/B 1:1)
By-product during cure	None	None	None	None
Consistency	Low viscous (1,000 mPa·s)	Very low viscous (200 mPa·s)	Very low viscous (200 mPa·s)	Self-leveling (30,000 mPa·s)
Potlife	150 min. (23 °C)	Depending on curing catalyst used**	Depending on curing catalyst used**	2 days (23 °C)
Curing time	Several hours (23 °C)	Several hours (23 °C)	Several hours (23 °C)	4 – 5 min. (120 °C)
Color / aspect	Transparent	Transparent	Transparent	Slightly translucent
Hardness	N. a. (soft silicone gel)	N. a. (soft silicone gel)	N. a. (hard silicone gel)	Sh A 35
Additional features	High intrinsic tack	Curing mode (room temperature, UV) and curing speed tunable via choice of curing catalyst	Curing mode (room temperature, UV) and curing speed tunable via choice of curing catalyst	Self-bonding to a wide range of substrates

** Suitable curing catalysts: ELASTOSIL® CAT PT, ELASTOSIL® CAT PT-F or ELASTOSIL® CAT UV

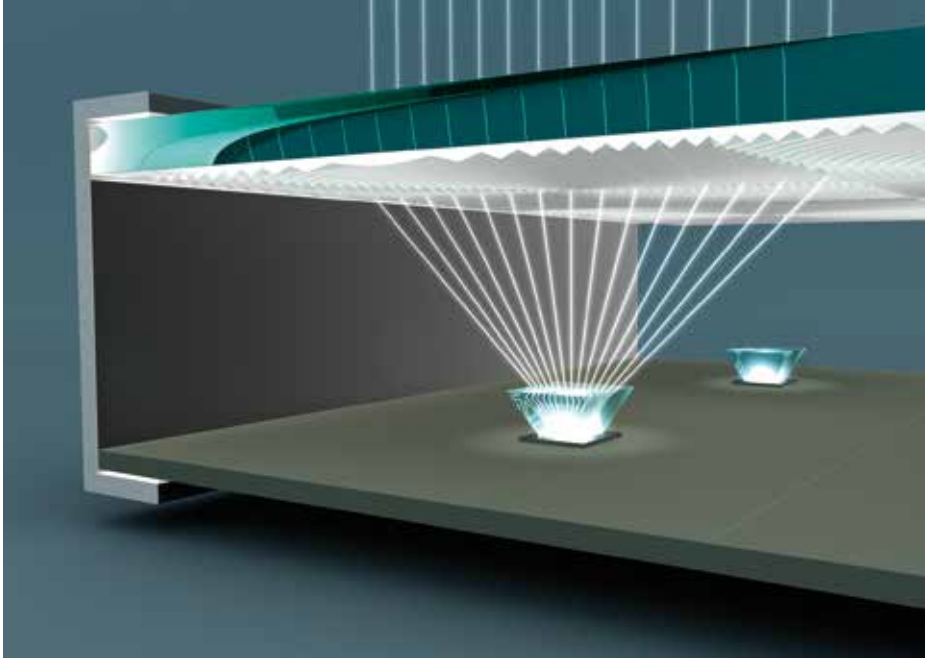
CONCENTRATOR PHOTOVOLTAICS

In regard to the construction of solar power plants, concentrator photovoltaics (CPV) represent an alternative to the classical standard module technology. Concentrator photovoltaics use optical elements (such as lenses or mirrors) to concentrate the sunlight and hence increase the power output per covered area. The CPV technology is thus more efficient than conventional PV arrays in terms of land consumption per kWh generated.

One way to concentrate sunlight is to use mirror systems like those found in parabolic trough power plants, where the concentrated sunlight is used to heat a heat-transfer fluid. Another option is Fresnel lens systems, which concentrate sunlight onto small but highly efficient solar cells (e.g. multiple-junction cells based on III-V semiconductors having an efficiency >40%).

Silicones are equally suitable for both technologies, and provide several advantages, for example:

- Excellent adhesion
- Long-term resistance to weathering and sunlight
- High transparency and no yellowing
- Easy processing
- No release of corrosive volatiles



Molding of Fresnel Lenses

By concentrating the sunlight, the solar cell area can be reduced to a fraction of the cell area that is required for a conventional solar module having a similar electricity output. The sunlight concentration factor is typical for each CPV system and usually ranges from hundreds to over 1000. Most compact module designs can be realized with highly concentrating Fresnel lenses placed in front of the solar cells.

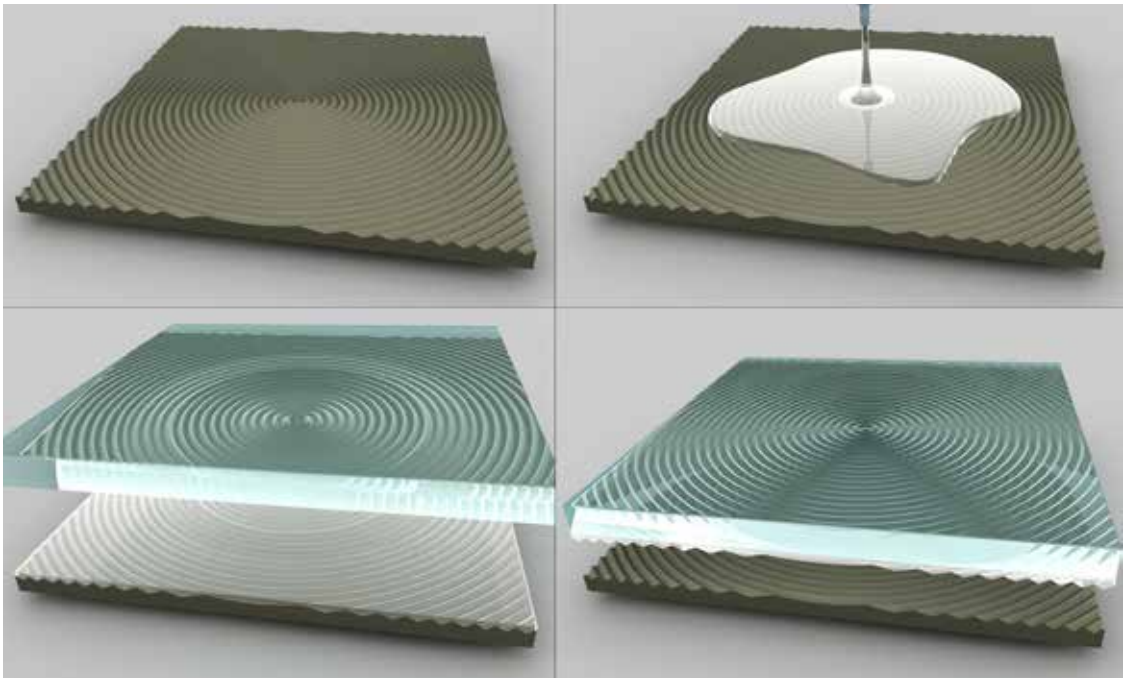
Fresnel lenses can be made of glass, transparent thermoplastics (such as polycarbonate and polymethyl methacrylate) or silicone, which is molded onto a glass substrate in a process called silicone-on-glass (SOG) technology. Usually, several single lenses are combined side-by-side to form a parquet of Fresnel lenses, which is placed in front of the solar cell array.

The SOG Fresnel lenses offer the best combination of:

- Design flexibility
- Easy, cost-efficient processing
- Weight reduction
- High transparency and high light transmission
- Long-term resistance to abrasion, sunlight and weathering

In collaboration with leading CPV companies, WACKER has developed specific silicones to meet all relevant requirements of this industry, namely:

- Low viscosity for quick filling of large molds
- Highly precise reproduction of lens details
- Very high light transmission from 250 nm to >1100 nm
- No change in light transmission on long term light-exposure



The precisely formed Fresnel lenses are manufactured from a highly transparent silicone specifically designed for optical applications.

Optical Coupling of Secondary Optical Elements

Normally and in most cases, Fresnel lenses are already quite sufficient to concentrate the sunlight. In some specific cases however, the Fresnel lens parquet – considered as the primary optical element – is combined with glass prisms as secondary optical elements, which are placed between the SOG structure and the solar cells, guiding the concentrated sunlight to the cells.

The main requirements for the optical bonding silicone that connects the glass prism with the solar cell, are:

- Transparency
- Resistance to sunlight
- Non-yellowing
- Fast curing to allow short process time
- Ideally thixotropic and easy to apply

Thermal Management of Solar Cells

As the complete sunlight spectrum, including the infrared part, is focused on the solar cells, effective heat dissipation is a key factor to prevent overheating of the solar cells and, hence, to guarantee an optimum conversion of light into electricity. For an effective thermal management WACKER has developed thermally conductive grades that keep their properties even at permanently high temperature and over a lifetime of the CPV panel.

These highly filled materials present the following properties:

- Thermal conductivity up to 1 W/m·K
- Shear thinning and optimized rheology for easy processing
- Reliable surface contact under permanent thermal stress

Frame Sealing and Bonding

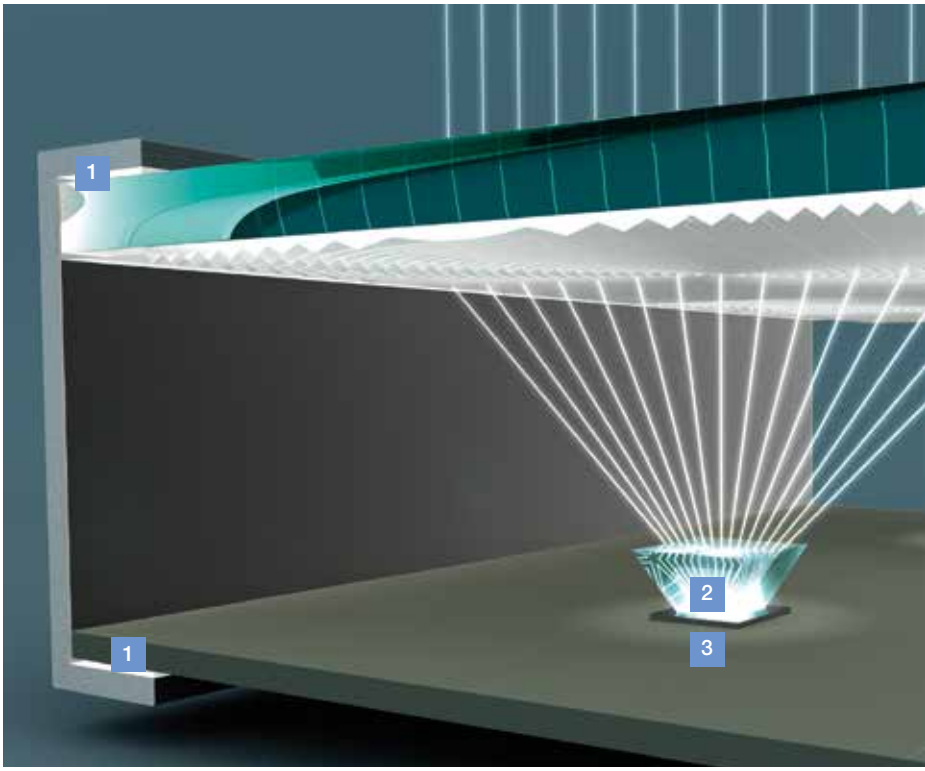
As with standard PV modules, the WACKER silicone rubber grades are ideal for bonding system components of CPV modules, such as the backplate, the Fresnel lens parquet, the metal frame structure, junction boxes, etc.

Benefits of silicones:

- Easy processing
- No release of corrosive volatiles
- Adhesion to typical PV substrates
- Long-term resistance to weathering and sunlight

Note

WACKER's dedicated silicone portfolio comprises one-part moisture curing silicones and two-part materials.



1 **Frame sealing and bonding**
2 **Optical coupling of secondary optical elements**
3 **Thermal management of solar cells**

Product Portfolio for Concentrator Photovoltaics				
Application	**Molding of Fresnel Lenses**			**Optical Coupling of Secondary Optical Elements**
	ELASTOSIL® Solar 3210	ELASTOSIL® Solar 3211	ELASTOSIL® Solar 3201	SEMICOSIL® 988 1K
Product type / curing system	2-part / platinum cure (A/B 9:1)	2-part / platinum cure (base + catalyst*: 10:1)	2-part / platinum cure (base + catalyst**: 10:1)	1-part / heat curing
By-product during cure	None	None	None	None
Consistency	Low viscous (3,500 mPa·s)	Low viscous (2,300 mPa·s)	Low viscous (1,600 mPa·s)	Paste-like
Potlife	Approx. 100 min. (23 °C)	Depending on curing catalyst used*	30 – 40 min. (23 °C)	9 months (23 °C)
Curing time	Approx. 20 min. (70 °C)	Approx. 20 min. (50 °C)	Approx. 100 min. (50 °C)	60 min. (130 °C)
Color / aspect	Crystal clear	Crystal clear	Crystal clear	Translucent
Hardness	Sh A 45	Sh A 52	Sh A 42	Sh A 35
Additional features	Very high light transmission in the range of 250 nm to 1100 nm	Very high light transmission in the range of 250 nm to 1100 nm. Curing mode (room temperature, UV) and curing speed tunable via choice of curing catalyst*	Very high light transmission in the range of 250 nm to 1100 nm. Self-bonding on low-iron glass.	Self-bonding on many substrates (no surface pretreatment necessary)

Application	**Frame Sealing Bonding of Junction Boxes**			**Bonding of Heat Sink / Thermal Management**	
	ELASTOSIL® Solar 1101	ELASTOSIL® Solar 1109	ELASTOSIL® Solar 1200	ELASTOSIL® TC 9800	WACKER® Silicone Paste P12
Product type / curing system	1-part / moisture curing	1-part / moisture curing	2-part / room temperature curing (base + catalyst***: 10:1)	1-part / moisture curing	1-part (non-curable silicone paste)
By-product during cure	Alcohol	Alcohol	Alcohol	Alcohol	N. a. (non-curable silicone paste)
Consistency	Paste-like	Paste-like	Paste-like	Slightly self-leveling paste	Paste
Skin forming time / potlife (at room temperature)	10 – 15 min	20 – 35 min.	w/ curing agent T77: 15 – 20 min. w/ curing agent T77 PLUS: 5 – 10 min.	5 – 15 min.	N. a. (non-curable silicone paste)
Curing time (at room temperature)	Several days (curing speed: 1.5 mm/day)	Several days (curing speed: 1.0 mm/day)	Several hours (tack-free time: 30 – 60 min., depending on curing agent***)	Several days (curing speed: 1.0 mm/day)	N. a. (non-curable silicone paste)
Color / aspect	Translucent	Black, white	Black	White	White
Hardness	Sh A 30	Sh A 35	Sh A 36	Sh A 70	N.a. (silicone paste)
Additional features			Curing speed tunable via mixing ratio and choice of curing catalyst***	Thermal conductivity: 0.85 W/(m·K)	Thermal conductivity: 0.8 W/(m·K)

* Suitable curing catalysts: ELASTOSIL® CAT PT, ELASTOSIL® CAT PT-F or ELASTOSIL® CAT UV
** Suitable curing catalysts: ELASTOSIL® CAT CPV or ELASTOSIL® PT-F
*** Suitable curing catalysts: WACKER® Catalyst T 77 or WACKER® Catalyst T 77 PLUS

CONCENTRATED SOLAR POWER

Bonding Mirrors to the Support Structure

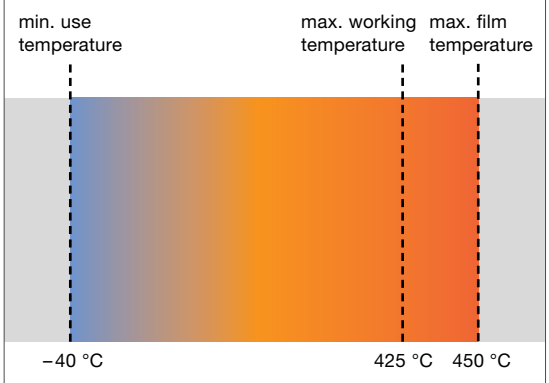
WACKER silicone adhesives are ideal for bonding the mirror panes of solar concentrators used at concentrated solar power plants. The fast curing, non-slumping silicone grades allow the precise fixing of mirrors on the support structure and a fast installation process. The silicone rubbers' resilience to thermal cycling and their resistance to permanent thermal stress, makes them a reliable bonding solution for concentrated solar power plants.

Benefits of silicones:

- Easy processing
- Fast curing
- No release of corrosive volatiles
- Adhesion to glass, metal and painted surfaces
- Long-term resistance to heat, weathering and sunlight

WACKER's dedicated silicone portfolio comprises one-part moisture curing silicones and two-part materials.

Operating Temperature of HELISOL® Heat Transfer Fluids



Recommended working temperature:
–40 °C to 425 °C

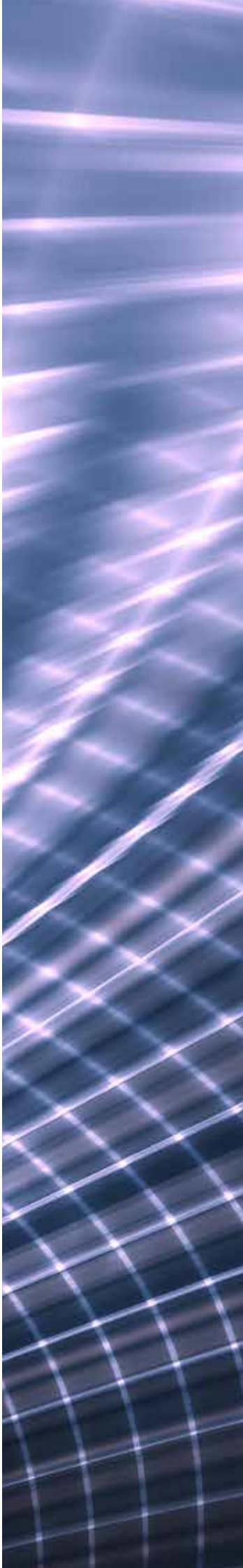
Silicone Fluid as Heat Transfer Medium

Durable heat transfer fluids are key components of concentrated solar power (CSP) systems. Long-term resistance to extreme thermal stress, excellent heat transfer properties and a stable level of viscosity over the fluid's lifetime are key factors for the highly economical and reiiable running of a CSP plant.

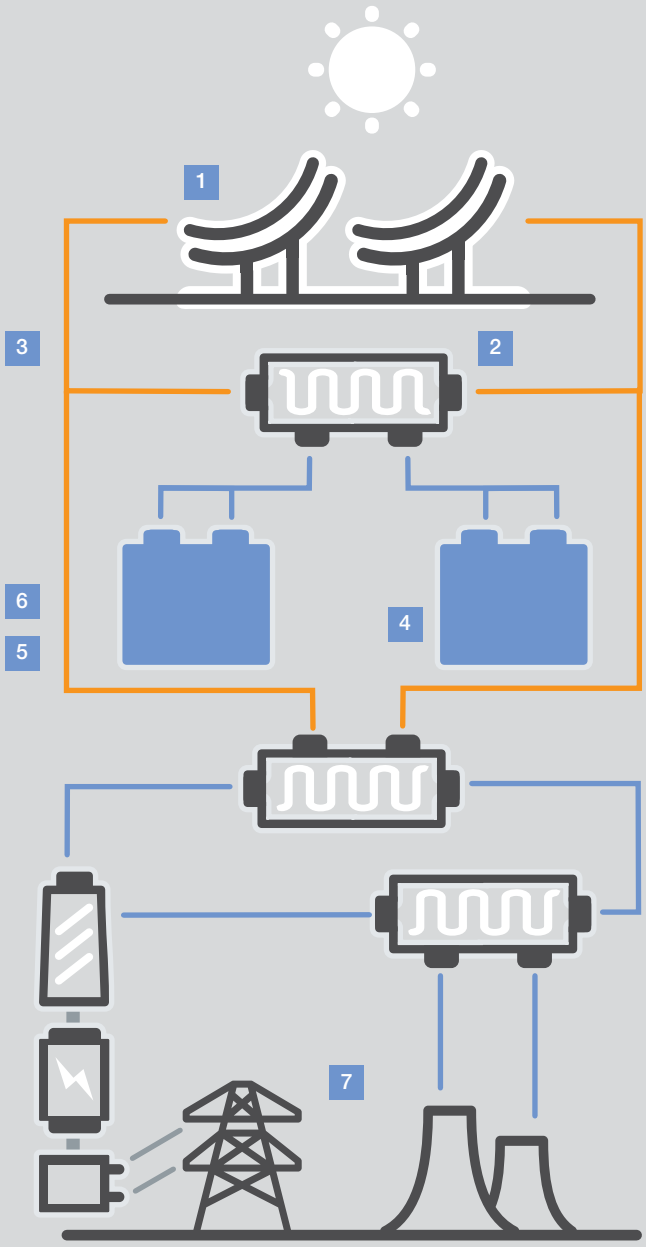
To meet the specific requirements of parabolic trough power plants, WACKER has developed a range of specialized silicone fluids which provide significant advantages over conventional heat transfer media. HELISOL® fluids are purely silicone-based and offer valuable benefits that are prerequisites for highly efficient and cost-effective energy conversion:

- High thermal stability, up to 425 °C, and even in the long term, resulting in a high level of operational reliability
- A very low viscosity level for an optimized material flow in the CSP plant's pipelines, minimizing the build-up of pressure
- A very low pour point keeping the fluid liquid down to even -40 °C, making anti-freeze measures obsolete
- Good heat transfer for a high power-block efficiency
- Non-corrosive and no critical degradation products, such as hydrogen, allowing a long lifetime of both the heat fluid receivers and the heat exchangers
- No risk of fouling
- Non-toxic, very low environmental impact, thus easy disposal of used or spilled fluid in an environmentally friendly way

Furthermore HELISOL® heat transfer fluids can be filled in the piping system irrespective of limitations due to ambient temperature. This allows system maintenance regardless of weather conditions at virtually any time.



Schematic of a Parabolic Trough Plant – Advantages of HELISOL®



1 Operating temperatures up to 425 °C and thus much higher efficiency levels and energy yields

2 Longer lifetime of receivers due to less hydrogen generation

3 Excellent low-temperature behavior (can be used down to -40 °C); no need for freeze protection

4 Higher working temperature allows reduced storage volume

5 Cold weather independent maintenance increases the degree of utilization

6 Improved economics, reliability and profitability of CSP plants

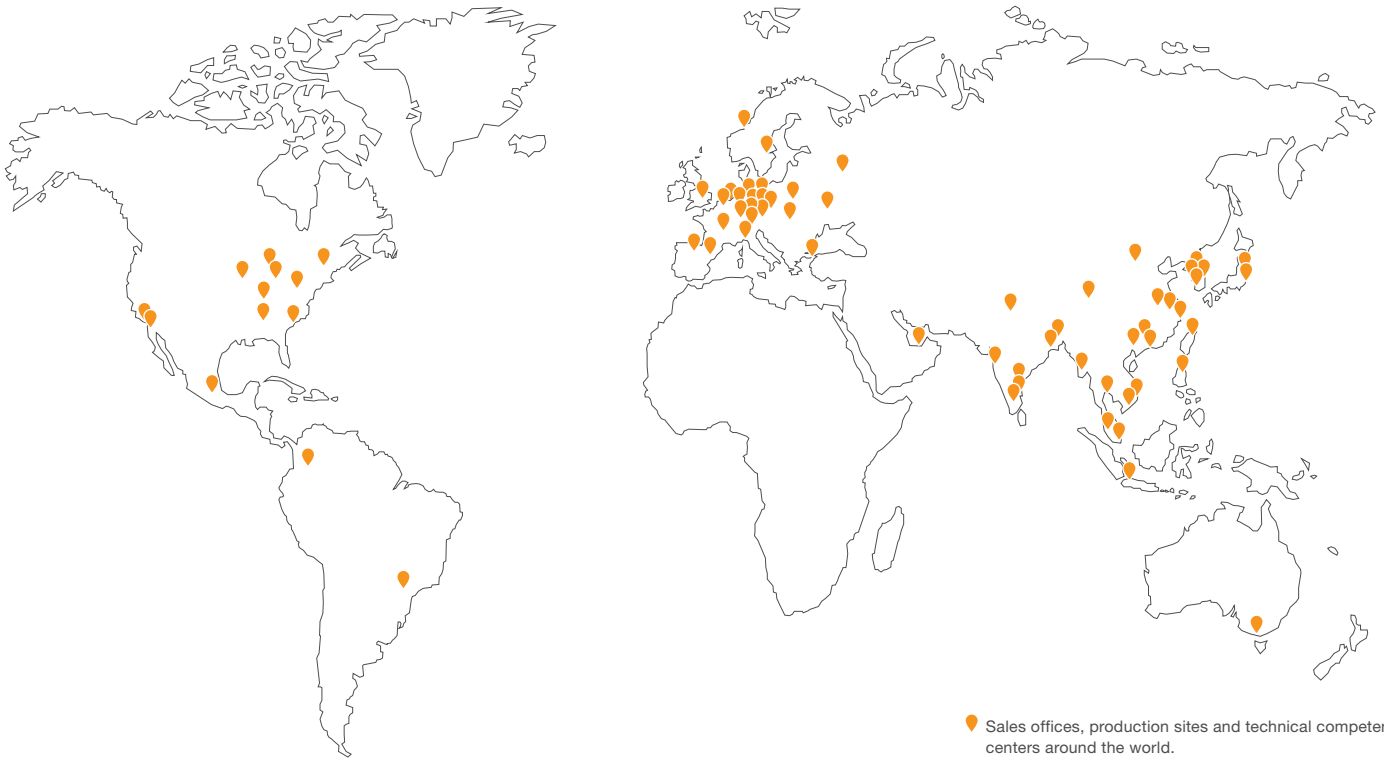
7 Potential 5% LCOE reduction

Product Portfolio for Concentrated Solar Power			
Application	**Bonding of Mirrors to the Support Structure**		
	ELASTOSIL® Solar 1101	ELASTOSIL® Solar 1109	ELASTOSIL® Solar 1200
Product type / curing system	1-part / moisture curing	1-part / moisture curing	2-part / room-temperature curing (base + catalyst*: 10:1)
By-product during cure	Alcohol	Alcohol	Alcohol
Consistency	Paste-like	Paste-like	Paste-like
Skin forming time / potlife (at room temperature)	10–15 min	20–35 min.	w/ curing agent T77: 15–20 min. w/ curing agent T77 PLUS: 5 – 10 min.
Curing time (at room temperature)	Several days (curing speed: 1.5 mm/day)	Several days (curing speed: 1.0 mm/day)	Several hours (tack-free time: 30–60 minutes, depending on curing agent*)
Color / aspect	Translucent	Black, white	Black
Hardness	Sh A 30	Sh A 35	Sh A 36
Additional features			Curing speed tunable via mixing ratio and choice of curing catalyst*

Application	**Heat Transfer Fluids**			
	HELISOL® 5A	HELISOL® 10A	HELISOL® XA	HELISOL® XLP
Pour point (in use) **	< -55 °C	< -55 °C	-36 °C	-45 °C
Density at 25 °C	0.92 g / cm^3	0.93 g / cm^3	0.94 g / cm^3	0.95 g / cm^3
Vapor pressure at 425 °C (in use)**	20 bar	16.3 bar	15.9 bar	12.6 bar
Viscosity at 25 °C	~5 mPa·s	~10 mPa·s	~20 mPa·s	~35 mPa·s
Flash point (ISO 2719)	120 °C	175 °C	225 °C	222 °C

* Suitable curing catalysts: WACKER® Catalyst T 77 or WACKER® Catalyst T 77 PLUS
** In use = 720 hours at 425 °C

EXPERTISE AND SERVICE NETWORK ON FIVE CONTINENTS



Sales offices, production sites and technical competence centers around the world.

WACKER is one of the world's leading and most research-intensive chemical companies, with total sales of €6.21bn. Products range from silicones, binders and polymer additives for diverse industrial sectors to bioengineered pharmaceutical actives and hyperpure silicon for semiconductor and solar applications. As a technology leader focusing on sustainability, WACKER promotes products and ideas that offer a high value-added potential to ensure that current and future generations enjoy a better quality of life, based on energy efficiency and protection of the climate and environment.

Spanning the globe with 4 business divisions, we offer our customers highly-specialized products and comprehensive service via 26 production sites, 23 technical competence centers, 14 WACKER ACADEMY training centers and 52 sales offices in Europe, North and South America, and Asia – including a presence in China. With a workforce of some 14,400, we see ourselves as a reliable innovation partner that develops trailblazing solutions for, and in collaboration with, our customers. We also help them boost their own success. Our technical competence centers employ local specialists, who assist customers worldwide in the development of products tailored to regional demands, supporting them during every stage of their complex production processes, if required.

WACKER e-solutions are online services provided via our customer portal and as integrated process solutions. Our customers and business partners thus benefit from reliable service and comprehensive information to enable projects and orders to be handled fast, reliably and highly efficiently.

Visit us anywhere, anytime around the world at: **www.wacker.com**

All figures are based on fiscal 2021.

WACKER

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