From scrap tyres to clean renewable energy

Dr Heinrich Badenhorst

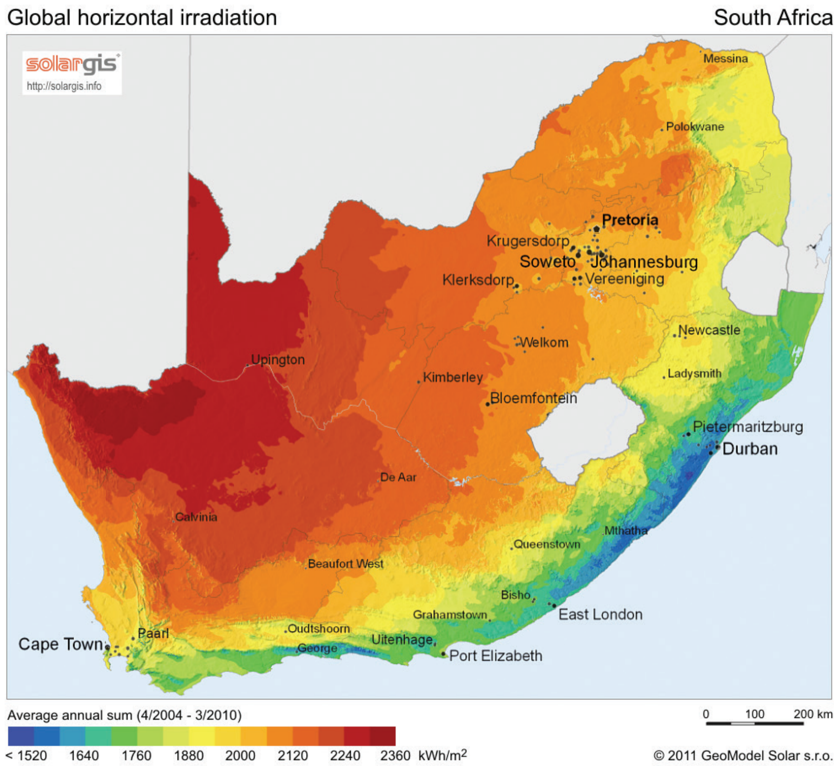
The University of Pretoria recently initiated a process designed to identify the unique research strengths of the institution and to support the development of strong multidisciplinary research groups clustered around the identified strengths. The University's Institutional Research Theme (IRT) on Energy focuses on all aspects of energy. One of these is the use of clean, renewable energy technologies, specifically solar energy.

Students of the South African Research Chair Initiative (SARChI) Chair in Carbon Materials and Technology in the Institute of Applied Materials are developing novel materials and creative new uses for old materials in this field. Carbon black reclaimed from recycled scrap tyres is being employed in a variety of solar collectors, while graphite nanoparticles are being drawn on as additives in solar energy storage devices.

The world is a very strange place when it comes to using energy. Each year, carbon, in the form of coal, is burnt at an efficiency of less than 30% in power stations around the globe. This carbon took millions of years to form. Apart from producing electricity in an inefficient manner, coal-fired power stations pump huge amounts of carbon dioxide into the atmosphere, potentially affecting the global climate negatively. When carbon is mentioned in an energy context, it usually has a negative connotation. At the SARChI Chair in Carbon Materials and Technology, a lot of hard work is going into changing this perception of carbon and carbon materials.

South Africa has some of the highest solar energy fluxes on the planet. To put it in perspective, the sun radiates enough solar energy onto the earth in one hour to provide all the energy consumed by humanity in a year. It is clear that this natural resource is underutilised.

In order to make use of this resource, it first has to be captured. This can be done by burning scrap tyres. Through a technique known



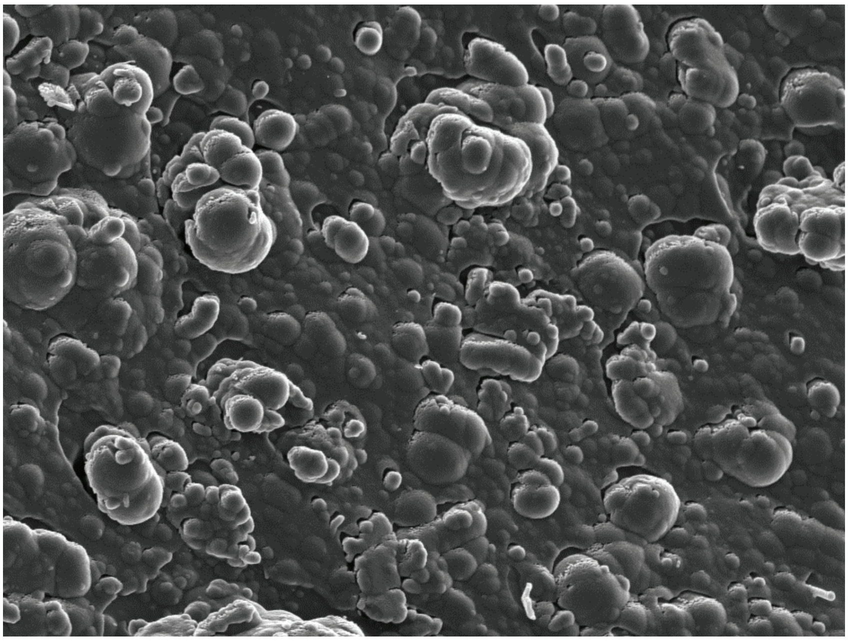
Solar irradiation map of South Africa.

There are approximately 60 million scrap tyres in South Africa.

as pyrolysis, the tyres are "burned" in the absence of oxygen. This produces a gas that can be used to heat the ovens in which the pyrolysis takes place, which means the process does not consume energy. A liquid that can be used as a fuel oil in industrial burners or that can be further refined into other petrochemicals is also released. In addition to these products, the process creates a solid residue very similar in appearance to the charcoal used by millions of South Africans over weekends. The residue is called carbon black and has a unique property; it is an excellent absorber of electromagnetic radiation, such as sunlight. This material is so effective that the American military uses it to coat stealth planes. Carbon black absorbs any incoming radio waves, making it virtually undetectable to radar.

To recycle the millions of scrap tyres in the country, the South African government recently implemented the Integrated Industry Waste Tyre Management Plan. This means that a large amount of low-quality carbon black will soon be produced. If this material can be utilised to capture solar energy, it will not only generate clean, renewable energy, but will solve a major waste problem at the same time.

Carbon black can collect solar energy in a variety of ways. The first is in pressed sheets that are similar to the solar panels on roofs. Carbon black is mixed with exfoliated graphite and pressed



→ *Carbon black film.*

→ *The new parabolic trough design.*

onto a suitable substrate. In a preliminary investigation, this mixture was pressed onto a small copper disc. The disc was connected to an insulated water reservoir through tubing, which created a small solar geyser. The system was left in the sun to collect energy, and the temperature of the water was monitored. At its peak shortly after midday, the water temperature had risen to 45 °C. This meant that around 4 $kW.hr.m^{-2}$ of solar energy had been collected. This was an excellent result, since the average expected irradiation is around 6 $kW.hr\ m^{-2}$, which implies an efficiency of around 75%. The use of carbon black is currently being tested in many other applications.

The first promising application that is being tested is a central collection tube in a new version of the so-called parabolic trough collectors. Traditional trough concentrators use a single mirror shaped in a parabola to concentrate sunlight onto a central receiver. There are two significant drawbacks to this approach. Large mirrors tend to break or crack, and the manufacture of these mirrors is limited worldwide. Thus, it is not possible to procure these mirrors in South Africa. They have to be imported at great cost and a risk of breakage.

Pieter de Bruin, a local engineer from the Western Cape, has come up with an innovative solution to the problem of finding suitable parabolic mirrors in South Africa. He has developed a segmented mirror design in which the large single mirror has been broken down into roughly 100 smaller mirrors. If any single mirror breaks, it can easily be replaced at a low cost. Furthermore, the parabolic steel framework is cheap and easy to manufacture. Therefore, it is possible to manufacture the framework locally from readily available materials with little or no input from international suppliers.

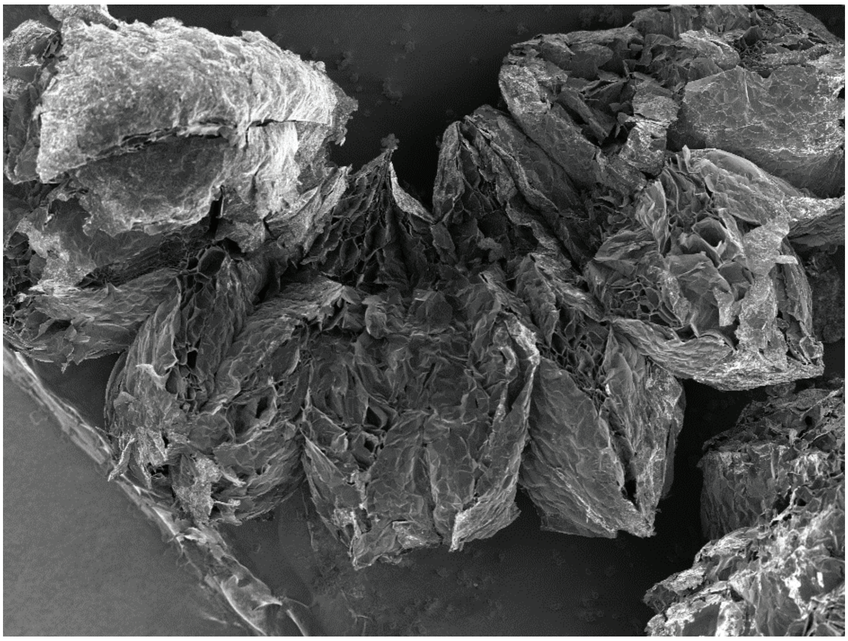
Another innovation is the stationary collector tube. In traditional assemblies, expensive flexible couplings are required to link the ends of the tube to the fixed piping system. Furthermore, the segmented design allows better airflow. Consequently, the construction is far less susceptible to wind damage. Once operational, carbon black will be used to optimise the central receiver that harvests the solar energy and maximises, for example, steam production, which can be used to generate electricity.

The second application that is being tested is very unusual and involves solar distillation. Work is underway to treat the carbon black in a way that modifies the surface, making it easy to disperse in water. The carbon black still absorbs the sunlight and heats up the water. Two prototypes are being tested. The first uses a thin film technique to evaporate the water under non-equilibrium conditions. This approach is very simple and may result in an inexpensive system that operates with little supervision and low maintenance.

The second trial combines the carbon black dispersed in water with a low-cost solar concentrator (a Fresnel lens). This compound lens can be used to focus the sunlight onto a very small focal point. In fact, the process is so effective that it can almost immediately induce microscopic boiling. Both techniques can be used to desalinate seawater or to purify brackish water. Once these concepts have been proven on a laboratory scale, they will be taken to the pilot level.

A significant drawback is that there is no sunshine during the night or when it rains. The key to the effectiveness of solar systems on an industrial scale is the efficient storage of the collected energy. There are several solutions to this problem, but one is becoming increasingly widespread: phase change materials. These are materials that undergo a phase change and store the energy in that way, for example, ice that melts to form water. Commonly used materials in the solar field are salts that either melt at low (-50 °C) or high (300 °C) temperatures, depending on the application. Regrettably, these salts generally have a very low thermal conductivity, meaning that it is difficult to transfer the energy into them, and they take a very long time to melt. However, there is another form of carbon – graphite – that has excellent thermal conductivity. It is a natural mineral that can be mined in the form of small flakes. To make the most of the available graphite, it has to be converted into graphite nanoparticles.

The first step in this process is to intercalate the graphite. This process uses a variety of techniques to insert foreign atoms in between the layers of graphite. Upon heating, these atoms are liberated and explode into the gas phase, making the graphite pop into an exfoliated form that looks very similar to a stretched accordion. This is known as the exfoliated graphite mentioned earlier.

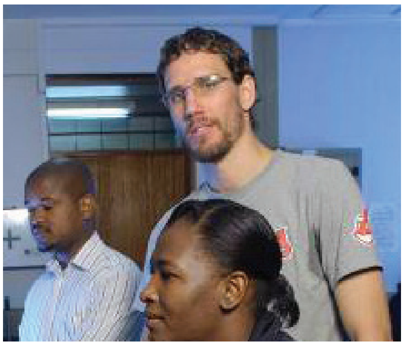


→ *Exfoliated graphite.*

It is extremely light and quite flexible, so it can be used together with carbon black to make sheets, or it can be broken into nanoparticles through sonication. This method uses ultrasonic vibrations to create microbubbles that tear the graphite layers apart. The research group associated with the Chair is currently investigating a variety of techniques to find the most efficient and effective way of producing these graphite nanoparticles or nanoplatelets.

These nanoplatelets can be added directly to the salts to enhance their thermal conductivity. Preliminary testing has shown that the time needed to melt low-temperature salts can be reduced by up to 80%. An experimental rig that allows the testing of this additive together with salts at much higher temperatures has been built. A combination of sodium nitrate and potassium nitrate is being used to test the thermal stability of the composite at temperatures around 300 °C.

Ultimately, the aim is to incorporate the carbon black directly into the salt/nanoplatelet composites. This will enable the direct melting of the salt, drastically reducing the losses and costs associated with conventional systems, where the heat must be transferred from collection to storage. Scientists hope to extend this work to include so-called seasonal energy storage. In this case, the harvested solar energy is stored in the form of a chemical reaction. When the energy is needed, the reaction is reversed and the energy is released for use. This process works much like a battery. In this way, all aspects of solar energy harvesting, storage and use are being explored, while using local resources and expertise to solve the issues that prevent a truly renewable energy-based society.



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