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Solar Energy RDI Roadmap for South Africa

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ABSTRACT

The national Departments of Science and Technology, and Energy, have jointly initiated a Solar Energy Technology Roadmap (SETRM) for South Africa. This paper focuses on one aspect of the SETRM, namely: the research, development and innovation (RDI) opportunities for the national system of innovation. It describes the overall approach, with process and output, which began with the completion of a baseline desktop study, followed by a number of workshops focused on the trends and market opportunities for South African RDI. These outputs were substantiated further and then underwent a process of strategic prioritisation to produce the basis on which the final RDI roadmap was developed.

INTRODUCTION

The Solar Energy Technology Roadmap (SETRM) has been finalised through a joint effort of the national Departments of Science and Technology (DST), and Energy (DoE) [1]. One chapter of the SETRM deals specifically with the research, development and innovation (RDI) opportunities for the South African national system of Innovation (NSI). The Solar Energy RDI Roadmap takes into consideration the energy RDI strategy drivers [1], which include universal access, economic growth, and environmental protection, to enable an emerging solar energy industry in the country. The Roadmap primarily aims to highlight key strategic RDI focus areas, and the required interventions by various role players to enable such RDI. The goal of the Roadmap is not to provide insight in terms of where the solar energy sector of South Africa should be heading, but where the NSI should place its emphasis to support and expand the emerging industry. The Roadmap focuses on the generic active solar technology platforms pertaining to both power and thermal as energy services; and specifically photovoltaic (PV) and concentrating solar power (CSP) systems – as summarised in Table 1.

ABBREVIATIONS

BoS	Balance of System
CSP	Concentrating Solar Power
DoE	Department of Energy
DST	Department of Science and Technology
NSI	National System of Innovation
PV	Photovoltaic
RDI	Research, Development and Innovation
SET	Science, Engineering, and Technology
SETRM	Solar Energy Technology Roadmap

THE APPROACH

A Roadmap is a needs-driven, and not a solutions-driven, approach. Subsequently, the process of developing the Solar Energy RDI Roadmap did not start with an end-point assumption that there will be a certain level of deployment of solar energy systems at some point in the future. Rather, the need and market potential for solar energy RDI in South Africa have been assessed, taking into account competing options in the NSI in which the RDI will take place.

Figure 1 shows how this study developed a national Solar Energy RDI Roadmap through a multi-stakeholder process.

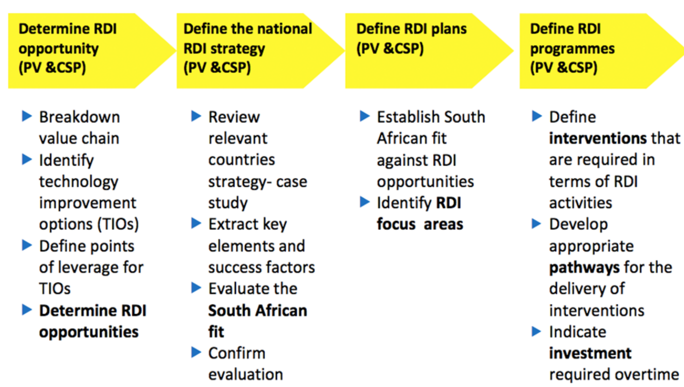

Figure 1 Process of developing the RDI Roadmap

Table 1 Classification of the active systems* that form part of the Solar Energy RDI Roadmap

System service	System market /application	System output		Generic technology platforms
Power	Singular households	Small	< 5 kW	Conventional without tracking photovoltaic
	Mini off-grid for small communities		< 200 kW	Conventional with / without tracking, or concentrated photovoltaic
	Commercial buildings / Agriculture sector	Medium	< 1 MW	Conventional, or thin film with / without tracking, or concentrated photovoltaic
	Industry sector	Large	> 1 MW	Concentrated, or thin film with tracking photovoltaic Concentrated (thermal) power
	Municipalities / commercial clusters		> 1 MW	Concentrated, or thin film with tracking photovoltaic / parks Concentrated (thermal) power
	National grid		> 1 MW	Concentrated, or thin film with tracking photovoltaic / parks Concentrated (thermal) power / parks
Thermal	Singular households / communities for water and space heating	Low	< 80ºC	Non-tracking collectors
	Singular households / communities for cooking		< 100ºC	Non-tracking collectors
	Commercial buildings / Agriculture sector for cooling (adsorption chillers)		60 - 90ºC	Non-tracking collectors
	Commercial buildings / Agriculture sector for cooling (adsorption chillers, single and double action)		75 - 115ºC	Non-tracking collectors
	Municipalities / commercial clusters / industry sector for multi effect desalination (MED)		< 70ºC	Non-tracking collectors
	Municipalities / commercial clusters / industry sector for desalination by membrane distillation		90 - 100ºC	Non-tracking collectors
	Commercial buildings / Agriculture sector / industry sector for cooling (adsorption chillers, single and double action)	Medium	130 - 180ºC	Concentrated thermal with tracking, specifically with a simple parabolic trough
	Municipalities / commercial clusters / industry sector for desalination by multi stage flash (MSF) distillation		90 - 120ºC	Non-tracking collectors, or concentrated thermal with tracking, specifically with a simple parabolic trough
	Industry sector for process heat		< 250ºC	Concentrated thermal with tracking, specifically with a simple parabolic trough and linear Fresnel
	Industry sector for process heat	High	< 500ºC	Concentrated thermal with tracking, specifically with a advanced parabolic trough and linear Fresnel
	Industry sector for thermochemistry and fuels		> 750ºC	Concentrated thermal with tracking, specifically with a central receiver

* Active solar technologies are employed to convert solar energy into usable heat or electricity, cause air-movement for ventilation or cooling, or store heat for future use. Active solar systems use electrical or mechanical equipment, such as pumps and fans, to increase the usable heat in a system.

Passive solar technologies convert sunlight into usable heat, cause air-movement for ventilation or cooling, or store heat for future use, without the assistance of other energy sources.

OUTCOMES: CSP SYSTEMS

The analyses reveal the R&D focus areas for CSP (parabolic trough, central/power tower, and linear Fresnel) systems as follows:

Systems analysis (performance, design & analysis)

- Build and operate a world-class test facility for CSP technologies.
- Designing and modelling capability (and capacity) for system and plant optimisation relating to conventional CSP and to efficient hybridisation (retrofitting, boosting, new build).

Optical (reflector)

- Achieve leadership in the design and development of next generation reflectors, via collaboration with selected world leaders.

Thermal (receiver, heat transfer fluids, thermal energy storage)

- Receiver technology is an identified point of excellence for South Africa; since the environment allows for rigorous testing.
- Focus on and exploitation of locally available materials, systems and component concepts for HTFs and TES that are appropriate for South Africa.

Cooling

- Extend South African leadership in (dry) cooling and leverage to become suppliers of advanced cooling technology to CSP owners, EPC contractors and component manufacturers.

Electrical (power block)

- Investigate non-Rankine power systems for improved efficiency and lower water consumption (with no intent to do power plant development).

To enable a coordinated research programme for CSP systems, four strategic intervention areas have been defined:

1. Enablement of a South African up-stream industry producing optical, thermal, cooling, electrical elements components and applications-optimised systems, targeted at on-grid and off-grid power generation in utility, commercial and industrial segments.
2. Enablement of a South African down-stream CSP industry in the areas of systems deployment, operations, maintenance and performance improvement.
3. Export CSP know-how and technology in the form of hardware, blueprints, intellectual property and advisory services (technical and commercial) to targeted markets including, initially, Southern Africa, Australia, South America and MENA.
4. Aligned and strengthened capability and capacity in RDI and production for CSP technologies.

The outputs for the four key intervention areas are:

- World-class test facilities for the design, deployment, operation and performance improvement of CSP systems, components and applications; for application- and context-optimised CSP systems.
- Modelling, simulation and optimisation (technical and economic) of designs, elements, components, whole projects and operational performance (recognising local conditions).
- Establishment of an entity focused on the guidance, coordination and support of initiatives to commercialise (market, sell and deliver) of South Africa's know-how, technology and services.
- An aligned human capacity development plan for the development and strengthening of science, engineering and technical skills relating to modelling, analysis and design; materials science; mechanical and mechatronic control; and chemical engineering, with an emphasis on thermo-dynamics and heat transfer.

The pathways and required investment for the interventions are summarised in Table 2.

OUTCOMES: PV SYSTEMS

In terms of PV systems the focus will be on two R&D streams: one relating to materials, cells and modules; and the other to systems and application integration – for the following technologies: silicon (mono- or multi-crystalline); thin film (amorphous Si, CIGS, CIS, CdTe, DSSC); concentrator PV (CPV) (high efficiency Si or crystalline multi-junction thin film); and organic PV. Less R&D focus will be on the materials and cells of crystalline and concentrator PV systems but aspects that required attention include: PV module configurations; advanced characterization tools that will also be developed and utilised (e.g. standard and solar solar-LBIC, device parameter extraction); and degradation and failure analyses.

The strategic interventions of the PV RDI programme is defined as follows:

1. Recognised expertise and capacity in solar energy materials and engineering development.
2. A South African up-stream industry producing materials, cells and modules for targeted on-grid and off-grid energy generation applications in residential, industrial, commercial and utility segments.
3. Enabled South African down-stream industry in the areas of systems deployment, maintenance and performance improvement.
4. Aligned and strengthened capability and capacity in RDI and production for PV energy technologies.

The outputs of the key four interventions are envisaged to be as follows:

- Higher performance solar conversion materials; and more cost effective production processes and technologies.
- Application-optimised solar energy generation systems (cells, modules, systems, application integration); and modelling and simulation of systems for design, production and operations optimisation and performance improvement (recognising local environmental conditions).
- Higher performance BoS components (durability, stability, maintenance and cost); and established and standardised tools and techniques for production quality control and operational performance optimisation.
- SET skills relating to materials science, engineering, nanotechnology, modelling, production.

The pathways and required investment for the interventions are summarised in Table 3.

Table 2 Pathways and investments for CSP interventions

	Y1	Y2	Y3
Objective	**Plan an build a SA Solar R&D Centre** **Build 2 to 3 small special regional centres**	**Build SA Solar R&D centre** **First testing in small centres**	**Overtake from project phase to operation** **Operate South African Solar R&D Centre and small regional centres**
Focus	▶ Plan and build a SA Solar R&D centre for CSP technologies (system analysis, optical, thermal, cooling and electrical) in the Northern Cape ▶ Build 2 to 3 small special regional centres which are already planned by SU and CSIR (maybe another by NWU)	▶ Build South African Solar R&D centre and first operating year ▶ Build and operate	▶ Testing of reflectors, receivers, HTF, TES, cooling systems, electrical equipment and power block unit ▶ System analysis ▶ Teaching of solar material
Capacity	▶ South African Solar R&D Centre: Tower with 3 platforms Trough with salt as HTF Different storages and heat exchangers: a) Salt/water b) air/water ▶ CSIR 500 kW_{th} (700 m^2), 19 m tower with Gas turbine 100 kW_{el} ▶ SU: 300 kW_{th} (400 m^2), 23 m tower		
Capabilities		▶ People: organizers, project manager, researchers, employees	▶ People: organizers, project manager, more researchers, teachers, employees
Investment	▶ South African Solar R&D Center: 150 mR ▶ CSIR: 25 mR + operation 50 mR/year ▶ SU: 20 mR + operation 5 mR/year ▶ Third small test facility: 25 mR	▶ South African Solar R&D Center: 150 mR + operation 25 mR/year ▶ CSIR: operation 50 mR/year ▶ SU: operation 5 mR/year ▶ Third small test facility: 25 mR + operation 5 mR/year	▶ South African Solar R&D Center: operation 50 mR/year ▶ CSIR: operation 50 mR/year ▶ SU: operation 5 mR/year ▶ Third small test facility: operation 5 mR/year

Table 3 Pathways and investments for PV interventions

	Short Term 2014-2016	Medium Term 2017-2019	Long Term 2020-2023
Material, Cell and Module	▶ Develop materials synthesis techniques. ▶ Continue research on 2nd generation (thin-film) technologies. ▶ Investigate new generation PV devices. ▶ Seek cost-effective and appropriate encapsulant technologies. ▶ Development of characterisation techniques for cells and modules.	▶ Integrate new materials into PV devices. ▶ Scale up manufacturing of 2nd generation technologies. ▶ R&D on new generation PV devices and modules. ▶ R&D on standard processing for cells and modules. ▶ Implementation of advanced characterisation tools.	▶ Produce new generation PV cells and modules. ▶ Scale up standard processing.
Systems, Application Integration	▶ PV yield optimisation models – development and verification ▶ PV system characterisation for PV optimisation and improved plant operation ▶ Develop optimised BoS components.	▶ Implementation of models for optimisation and improved PV plant efficiency. ▶ Local manufacture of BoS components – pilot.	▶ Implementation of models for optimisation and improved PV plant efficiency ▶ Scale up BoS manufacturing.

CONCLUSION

While the Solar Energy RDI Roadmap aims to provide an outlook of the developments in the solar sector, it is by no means comprehensive. Instead, the roadmap should be used as a guide to envisage the direction of technological trends and evolution, its enablers and inhibitors to adoption, so that effective strategies can be devised to adapt to landscape changes. To this end, the project team would like to thank all the stakeholders in the process for their contributions, insights and feedback, and suggestions, as well as charting the directions for the next phase of the South Africa's solar energy RDI journey, which is summarised in Table 4. The table indicates the areas where South Africa should focus its R&D over the next five year, but other areas, over a longer time frame are defined in the SETRM [1].

REFERENCES

[1] Department of Science and Technology, Department of Energy, *Solar Energy Technology Roadmap (SETRM)*, Pretoria, 2014.

Table 4 Global challenges, options, readiness and economic benefits of technologies

Technologies	Global challenges	Options	Technology readiness	Economic benefits
PV systems				
Crystalline silicon	Increasing efficiency/performance	Improved solar resource capturing with improved materials and system design	Near-commercial; many competitors but also collaboration opportunities	Capitalisation on existing competencies; and expansion of current industry base
		Improve the quality of the units through the fabrication of low-defect silicon, and defect characterisation	Fabrication still in development, but defect characterisation is commercial	Reduced financial losses in the economic system through defect characterisation
Thin films	The reduction of material cost (CIGS)	Processes for high speed deposition of functional layers	In development by competitors, but collaboration is possible	Could improve the competitiveness of a future South African industry
		Alternative 'low cost' deposition methods for CIGS absorber		
	Reducing production costs (CdTe)	Development of advanced deposition technologies with reduced materials and energy input	In development by competitors, but collaboration is possible	Could improve the competitiveness of a future South African industry
	Increasing efficiencies (organic PV)	Fundamental understanding of the physics of dye and full-organic solar cells including the effect of nanomorphology and order on the electrical transport and exciton transport and dissociation	In development by competitors, but collaboration is possible	Could position South Africa for future niche markets
	Thermo-chemical energy storage materials	Development of new materials	In development by competitors	No benefits to pursue this option in South Africa
	Higher temperature storage materials (at least 600 ºC)	Development of new materials, thermal properties, any technology		
	Steels/composites/ liners for piping and tank structures	Long-term resistance to internal corrosion and thermal strains		

Technologies	Global challenges	Options	Technology readiness	Economic benefits
CSP systems				
Absorbers	Metals	Long-term resistance to corrosion, increase temperature	In development by competitors, with collaboration	Could position South Africa for future niche markets
	Porous ceramic and metal structures for central receivers	Higher mechanical stability, higher temperatures, and better performance	In development by competitors, with collaboration	Could position South Africa for future niche markets
	Insulation materials	Improved resistance to environmental loads	In development by competitors, with collaboration	Could position South Africa for future niche markets
	Transparent receiver cover	Allow for high temperature closed receiver/reactors at 800 °C	In development by competitors, with collaboration is	Could position South Africa for future niche markets
Reflectors	Mirror protective coatings	Improved anti-soiling function	In development by competitors, but existing R&D capabilities does position SA to collaborate or develop own IP	Could position South Africa for future niche markets
	Mirror surface degradation for non-glass mirrors	Degradation processes in different climatic conditions and under abrasion, improved accelerated ageing tests		
	All mirror technologies (e.g. flexible aluminium sheets with a silver covering and polymer thin films)	Higher reflectance and/or specularity, and cost reduction,		
	Low-iron glass	Reduced transmission losses; methods for recycling/treatment of raw materials to reduce iron content		
	Low-lead solutions	Zero lead or minimum lead contents		
	Steels, aluminium, fibre	Improved stiffness and stability for larger collector structures		
	Composites	Improved manufacturing processes to lower cost		
	Fibre composites	New concepts for low cost and precise components		
	Hardened steels or others	Improved precision, low wear, high reliability in mechanical parts		
	Ceramics or alloys	Increase temperatures; reduce cost		
	Structural materials	Decrease cost, optimization for different HTF		
	Higher temperature storage materials (at least 600 ºC)	Development of new materials, thermal properties, any technology		
Structural components	Low-lead solutions	Zero lead or minimum lead contents	In development by competitors, but existing R&D capabilities does position SA to collaborate or develop own IP	Could position South Africa for future niche markets
	Steels, aluminium, fibre composites	Improved stiffness and stability for larger collector structures; improved manufacturing processes to lower cost		
	Fibre composites	New concepts for low cost and precise components		
Heat storage materials	Solid ceramic particles, high-temperature phase change materials, solid ceramic particles, graphite, etc.	Thermal properties and reduced costs	In development by competitors, but existing R&D capabilities does position SA to collaborate or develop own IP	Could position South Africa for future niche markets
	Thermo-chemical energy storage materials	Development of new materials		
	Higher temperature storage materials (at least 600 ºC)	Development of new materials, thermal properties, any technology		
	Steels/composites/ liners for piping and tank structures	Long-term resistance to internal corrosion and thermal strains		