EMERGING OPPORTUNITIES IN SOLAR THERMAL

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UNIVERSITEIT
Solar Thermal Energy Research Group

Craig McGregor

Solar Thermal Energy Research Group (STERG)
Stellenbosch University

Photo by STERG

Photovoltaics (PV) is the most common form of solar energy

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PV produces direct current electricity directly

Solar thermal energy technologies convert solar irradiation into heat

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Non-concentrating solar collectors

Photo Genergy

Concentrating solar collectors

Photo Bokpoort CSP, EE Publishers

Solar Thermal Energy Research Group

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Over a decade of history in solar thermal energy research

- Staff
  - *Manager:*
    Prof. Craig McGregor
  - 8 active academic staff
  - 10+ affiliated academics
- Students
  - Cohort of 40 - 50 MSc and PhD students
  - 2 - 3 Interns
  - ~ 15 graduates per year

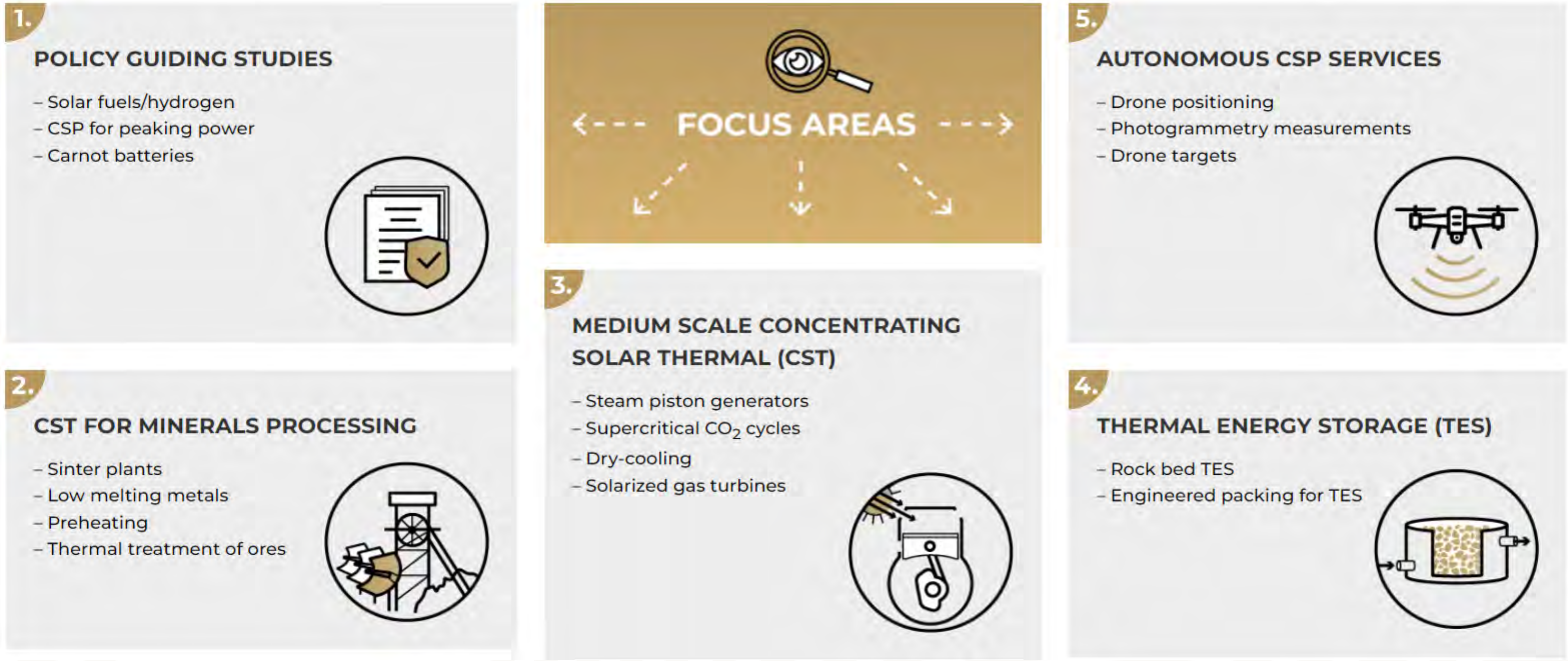




Photo by STERG

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Solar Heating of Industrial Processes (SHIP)

Opportunities in process heat

F Rozon, J Koke, M Owen

Photo of South African Breweries, Getty Images

SA's energy use is typical of an industrialised nation dependant on coal

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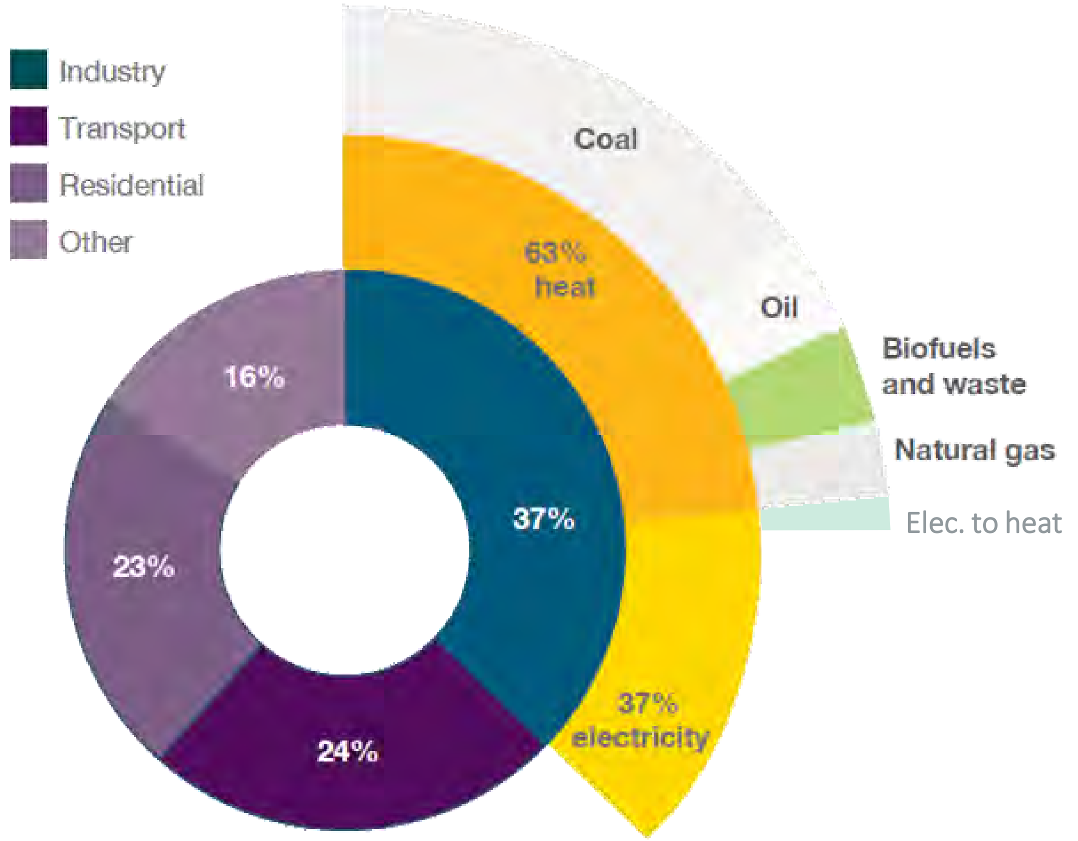
A significant portion (~70%) of energy use is for heat, particularly process heat for industry.

Solar thermal use has historically been limited to domestic hot water, and for electricity generation (CSP).

RSA thermal energy use is 204 TWh_{th} - equivalent to 30 million tonnes of coal (15% of annual coal production).



Final energy *consumption* for South Africa in 2015 (total: 3.13 EJ), IEA
Note: consumption is different to primary energy as it accounts for efficiencies

Solar Payback (2019)

Heat is a large fraction of SA beverage energy demand

Photo of South African Breweries, Moneyweb

Beverage categories	Production (mi ℓ)	Energy (kWh/ℓ)	Energy (GWh/a)	Electricity (%)	Heat (%)
Non-alcoholic ready-to-drink	6 980	0.10	675	59%	41%
Sparkling soft drinks	4 400	0.06	270	75%	25%
Juices and juice drinks	670	0.13	80	50%	50%
Packaged water	510	0.05	25	80%	20%
Value added dairy	370	0.27	100	25%	75%
Others	1 030	0.20	200	60%	40%
Alcoholic beverages	5 090	0.46	2 345	31%	69%
Beer	3 440	0.40	1 360	33%	67%
Cider	600	0.25	150	25%	75%
Wine	900	0.13	120	50%	50%
Spirits	150	4.8	715	25%	75%
Total RSA Beverages	12 070	0.25	3 020	38%	62%

Deployment of parabolic trough concentrators for industrial heat is accelerating

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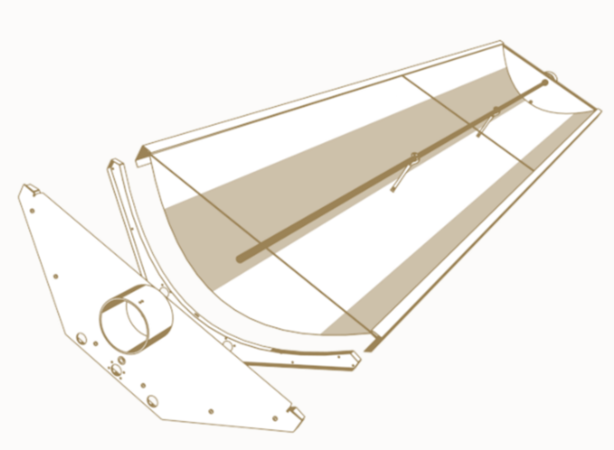
Absolicon's solar heat system will be manufactured in RSA soon

Steam at 160°C



Images: Absolicon Solar Collector AB

The production profile of SA beverage manufactures matches the solar resource

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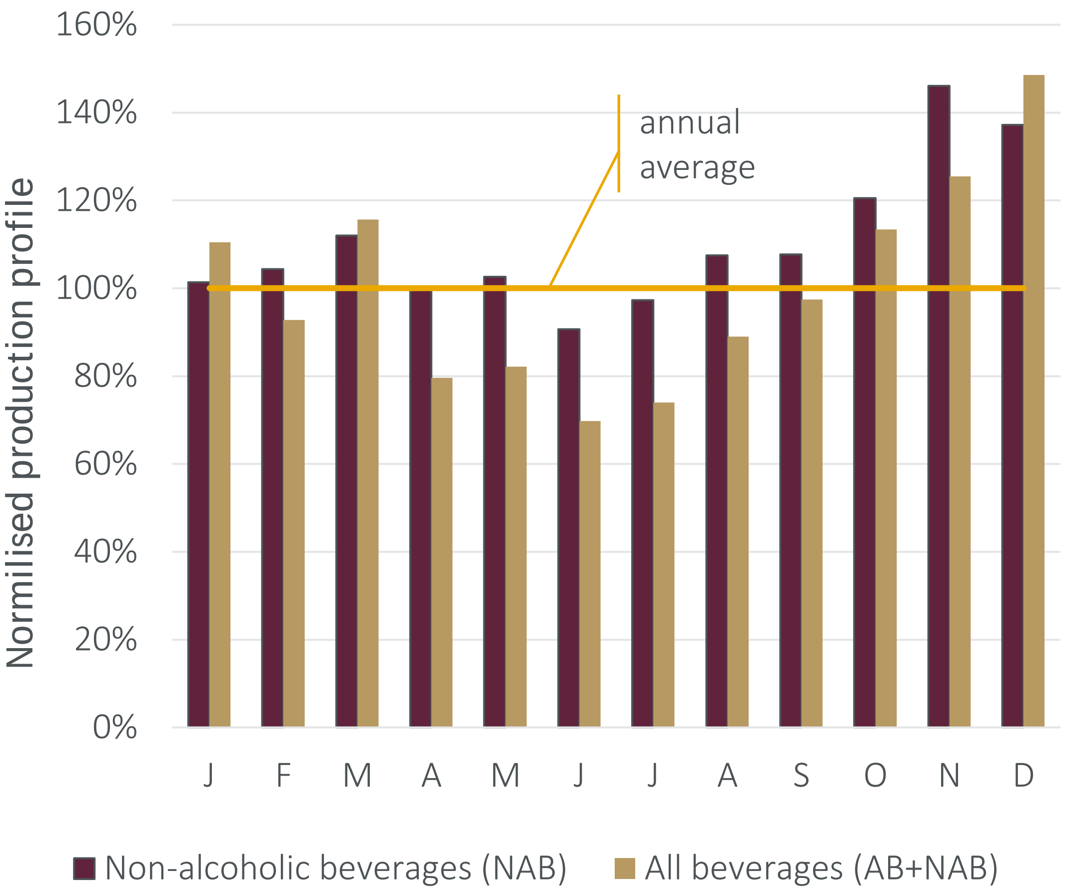
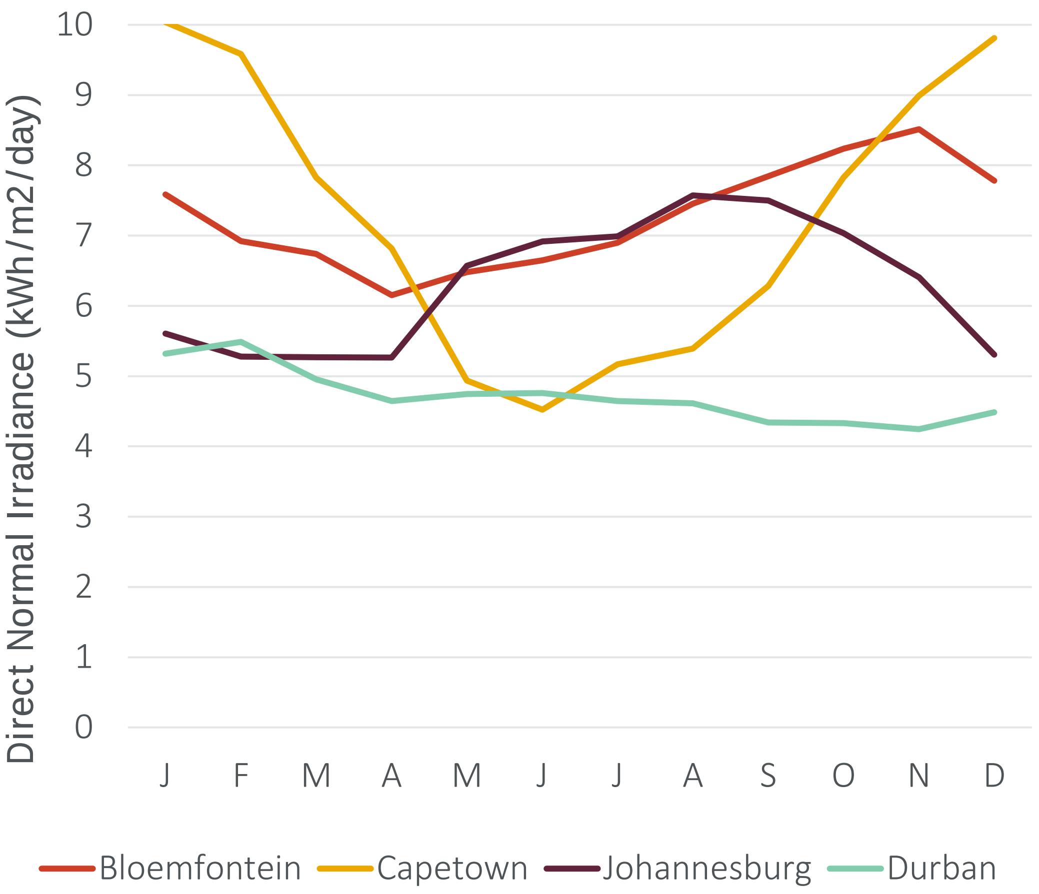
Input assumptions based on SA beverage industry figures





A full technical and economic assessment was developed for solar thermal heating

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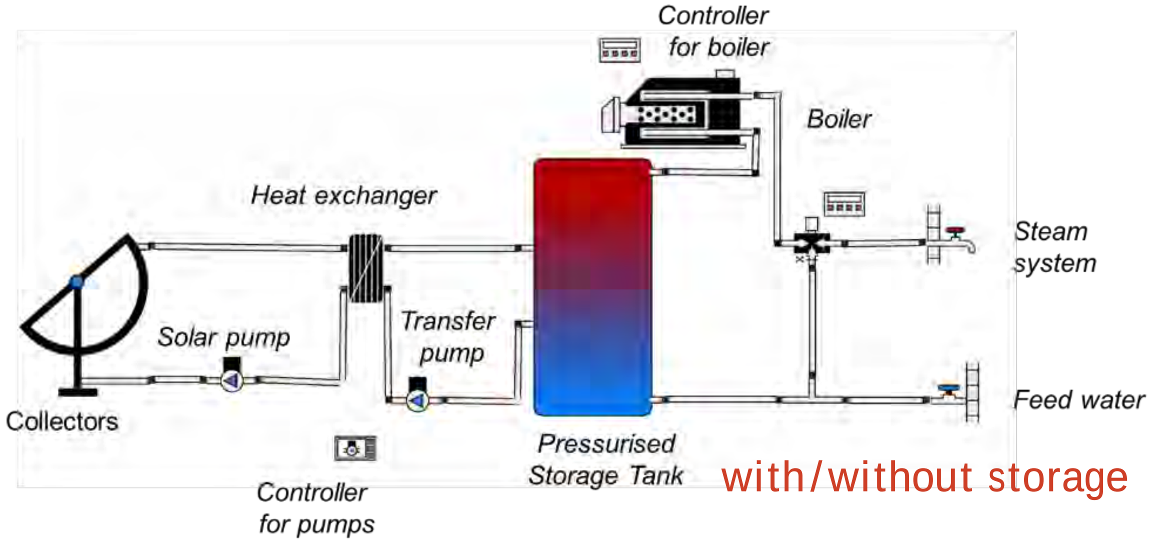
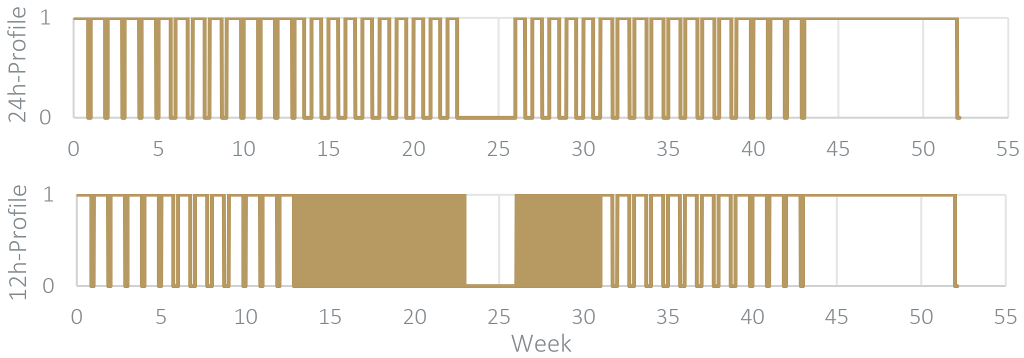
Modelling in Polysun™ as indirect solar steam generator with heat exchange

- Thermal load profiles:
  - Filling process for soft drinks
  - Washing and sterilizing glass
- Locations:
  - Cape Town (CPT)
  - Johannesburg (JHB)
- Plants:
  - RGB returnable glass bottles
  - RGB+PET combined glass and plastic
- Profiles:
  - 24h shifts
  - 12h in winter



with/without storage



High solar fractions can be achieved with a marginal increase in costs

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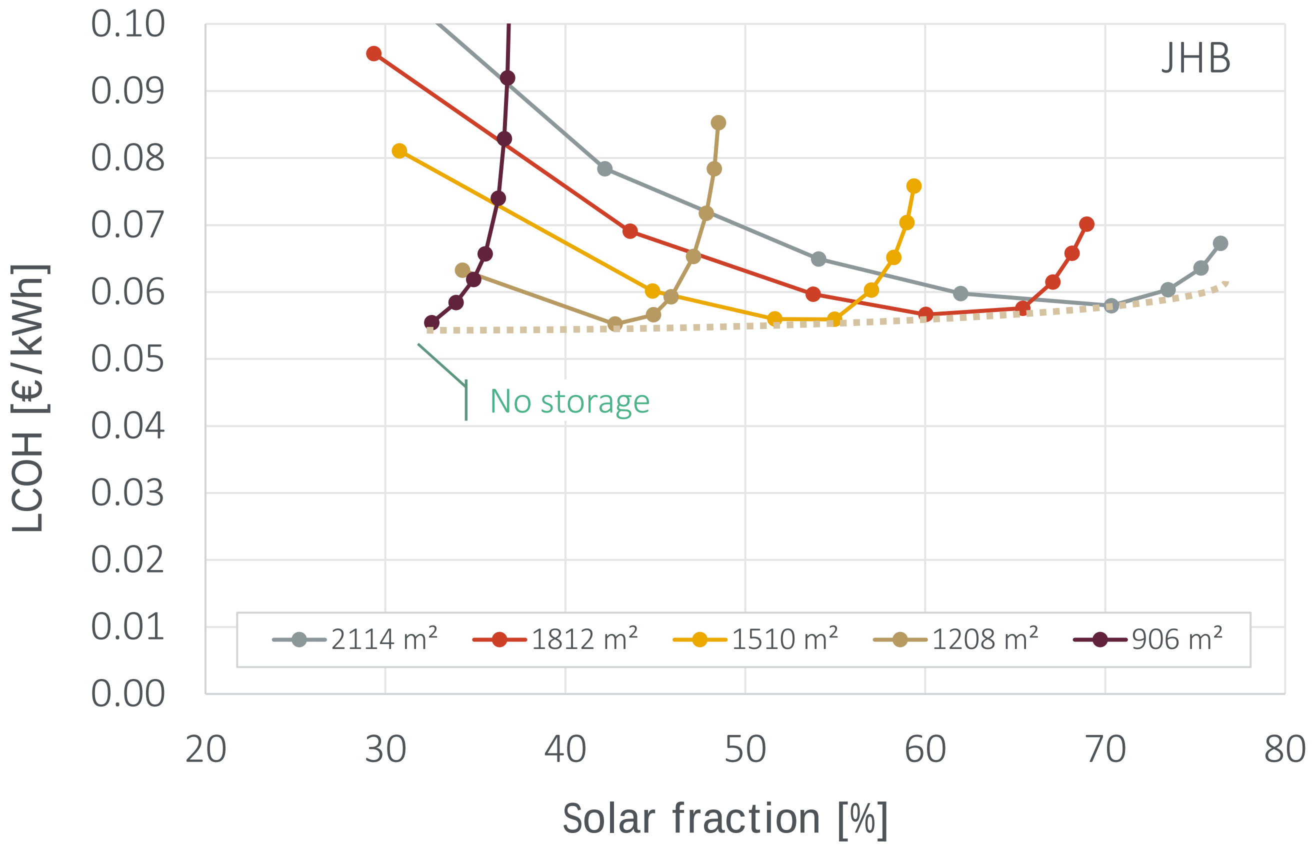
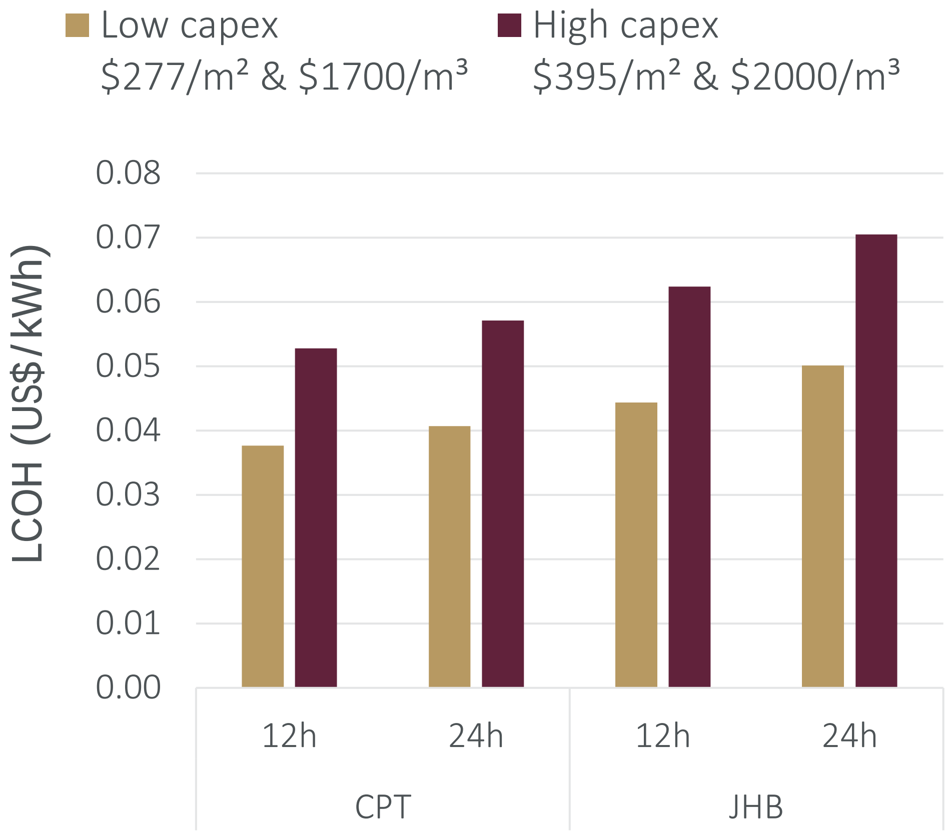
Results: technoeconomic modelling





Levelised cost of heat (LCOH) calculated according to VDI6002; economic analysis for low and high Investment costs (CAPEX); variation of collector field and storage to determine the lowest LCOH

Solar thermal for medium heat is competitive in SA for all sources except coal

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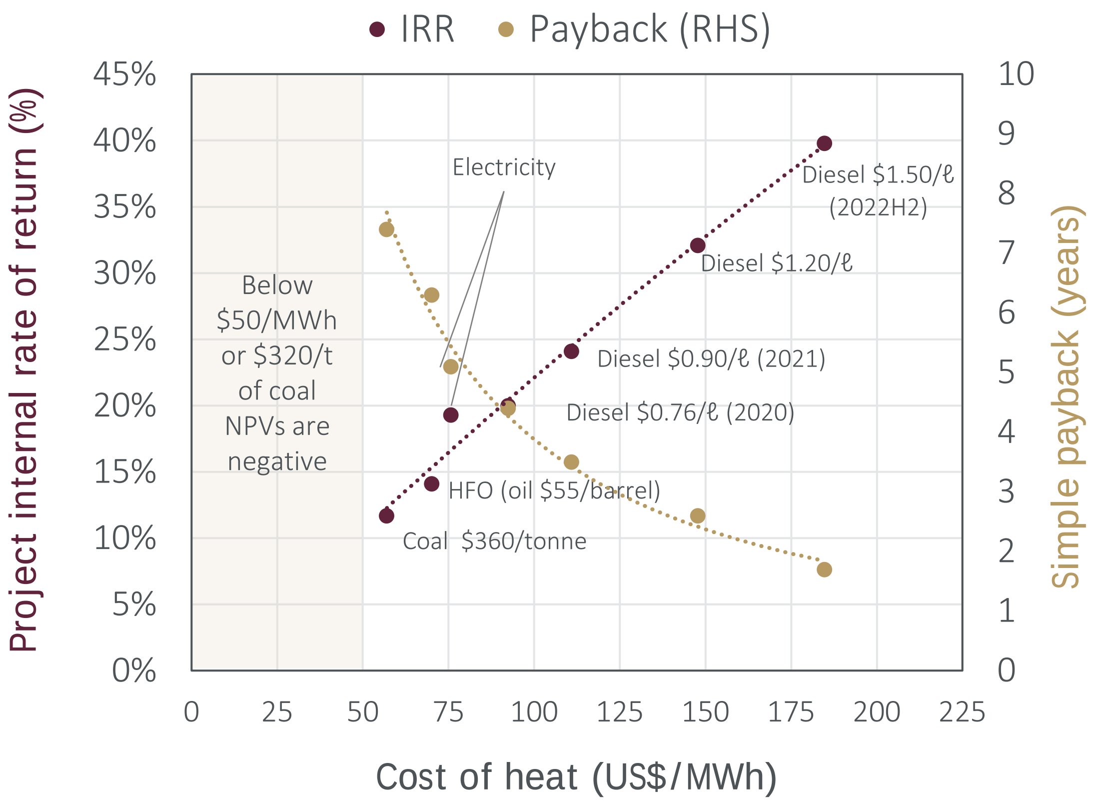
Results: benchmark against fossil fuels

Fuel	**Heat cost** (US$/MWh)
Coal (GP)	20 – 60
Coal (WC)	20 – 80
Reticulated gas (GP/KZN)	40 – 50
Solar thermal	50 – 70
Electricity (average Megaflex variable)	80 +
Heavy fuel oil	50 – 90
Diesel 0.05%	120 – 180

Real WACC @ 6.5%, opex at 2% of capex pa, collector price 277 $/m² – 395 $/m², economy of scale exponent 0.85, electricity tariff growth 3% real, 20 year lifetime



Solar thermal process heating is already viable for many SA businesses

Conclusions

- Parabolic trough collectors are well suited for integration into existing steam heating networks
- In areas with high levels of irradiation, the low heat costs ($0.038…$0.058/kWh in CPT) are attractive, particularly for smaller manufacturers who use oil or electricity for heat
- Thermal supply in South Africa is normally† dominated by cheap coal and solar thermal is not yet competitive
- Systems without storage are cheapest, but the renewable fraction is low (25-30%)
- The economics can still be improved by lowering the steam operating temperature, since the production processes usually take place at temperatures <100°C

† current coal spot prices during the energy crisis could swing this, but unlikely to justify capital expenditure without additional considerations such as decarbonisation

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Opportunities in solar thermal electricity

A Attieh, J Pretorius

Concentrating Solar Power (CSP)

Image: Vast Solar

In concentrating solar power (CSP) thermal energy is converted to electricity

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Central receiver CSP plant with hybrid PV plant

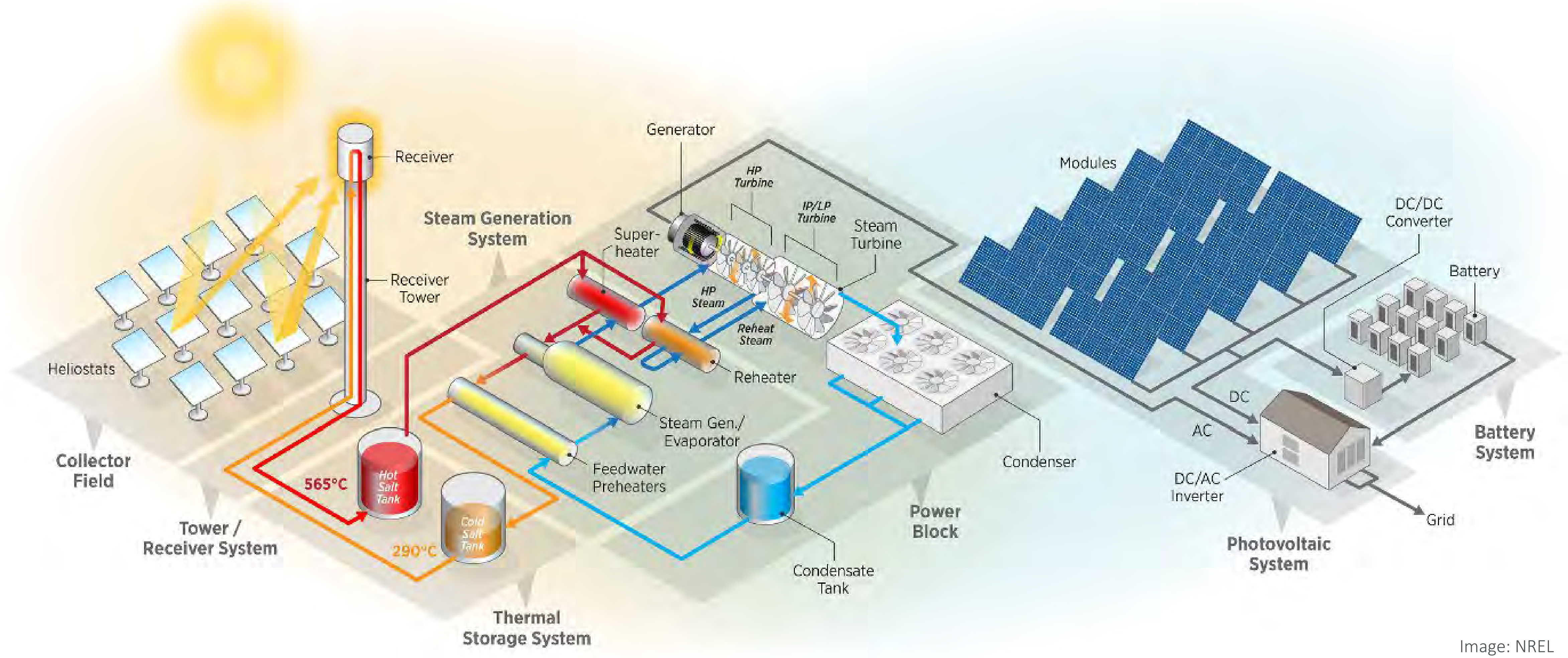

Image: NREL

Parabolic trough is the predominant technology of CSP plants deployed to date

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Bokpoort Parabolic Trough CSP Plant, 100 MW

Image credits: ACWA Power

By concentrating solar irradiation, we can generate high temperature heat

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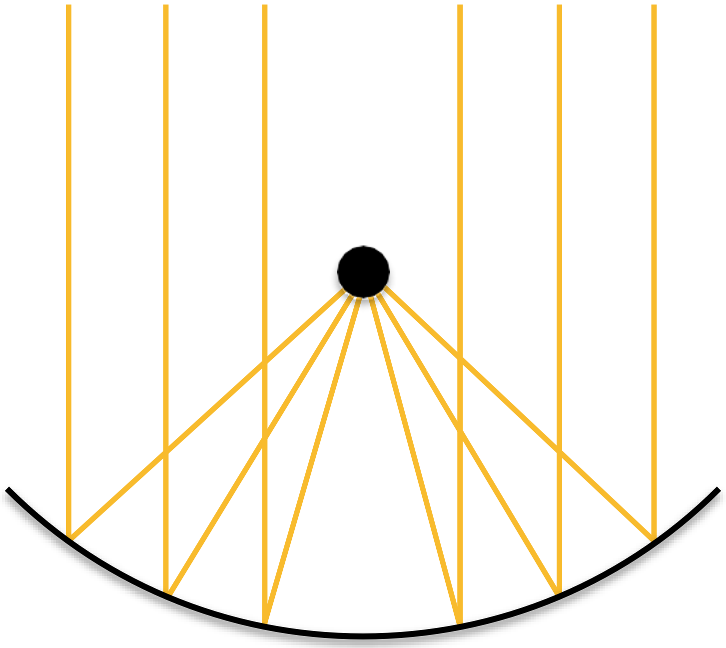
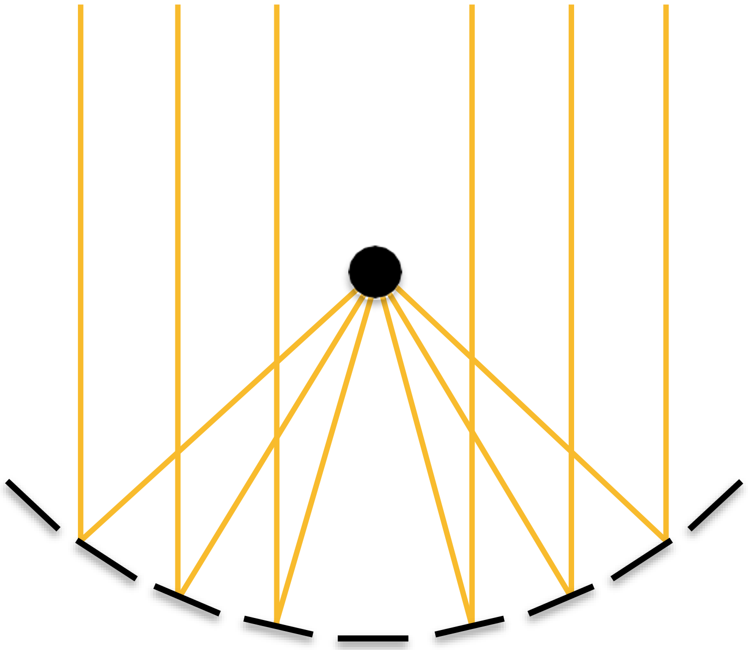
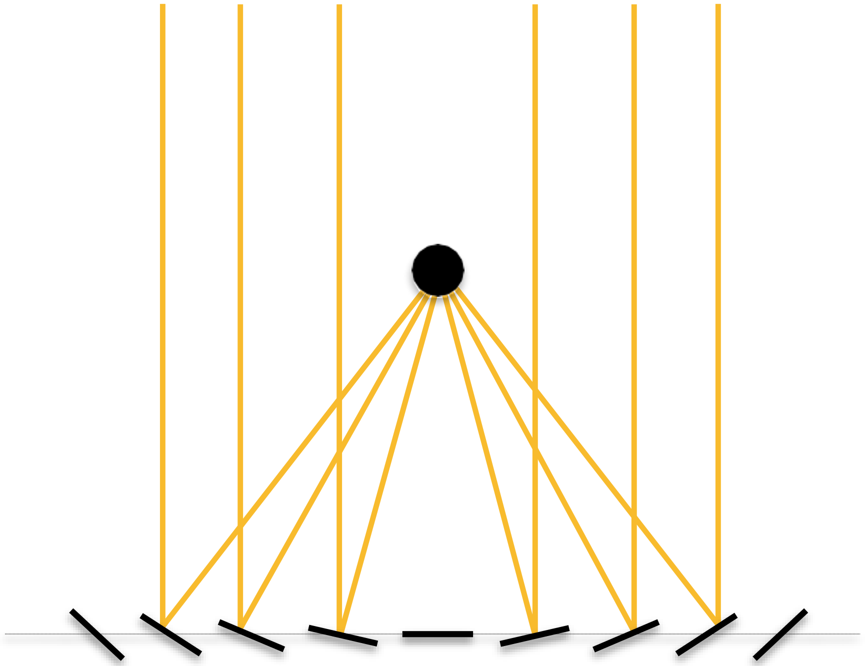
Breaking a reflector into segments



parabolic concentrator



parabolic concentrator, segmented

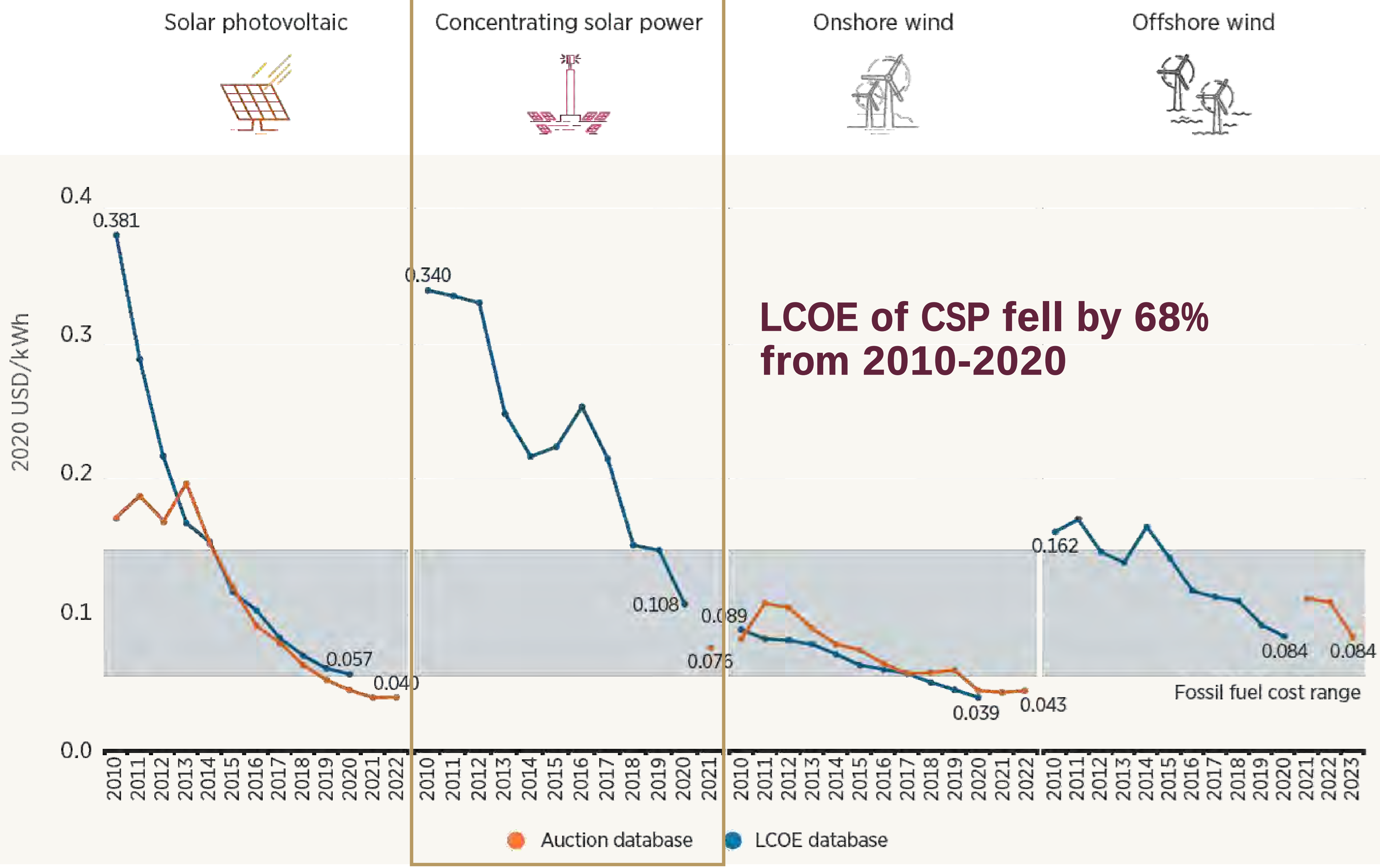


Fresnel concentrator or heliostat field

Solar Towers are emerging as the technology of choice due to high efficiency

Hami Central Receiver CSP plant (China), 50 MW


Images: HELIOCSP



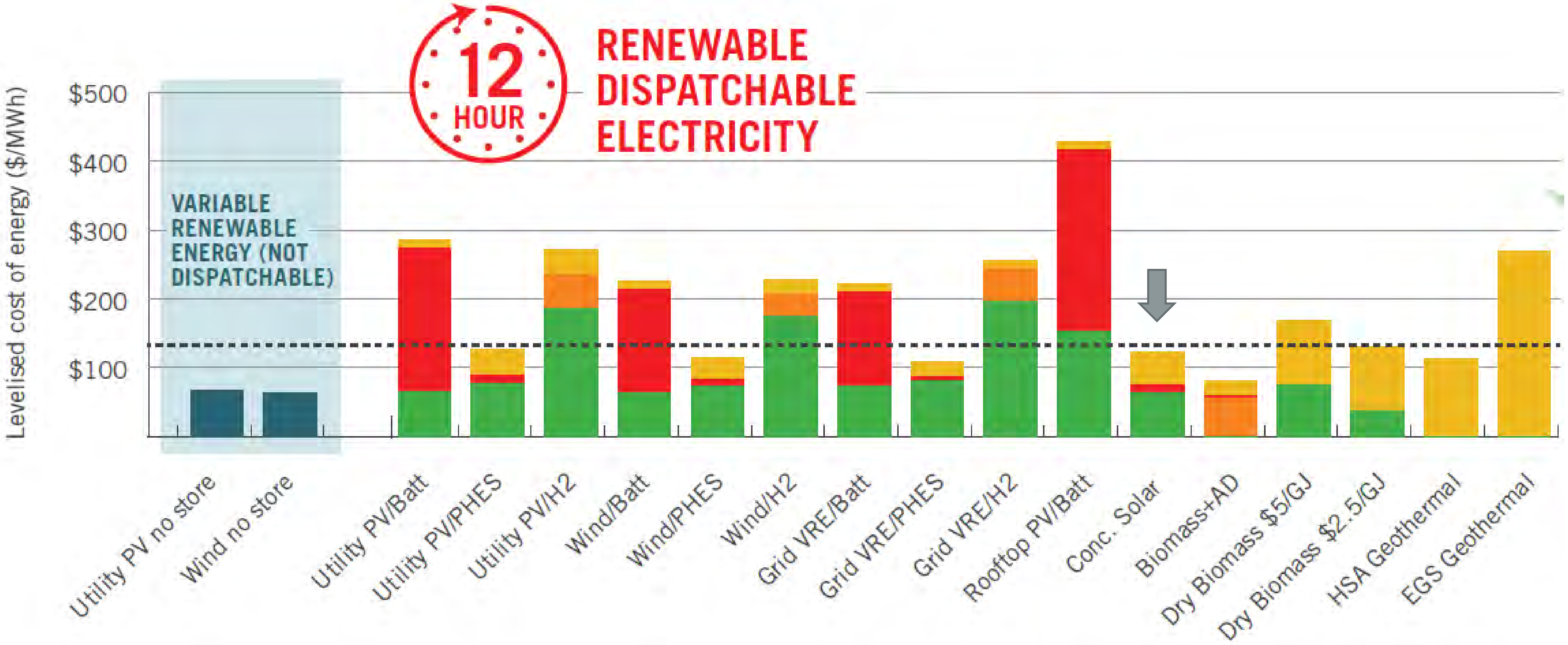
LCOE of CSP fell by 68% from 2010-2020

Image credit: IRENA. 2020. Renewable Power Generation Costs in 2020

CSP* is cheapest *dispatchable* option with 12 hour storage

* excl. pumped hydro (PHES)

ARENA comparison of dispatchable RE options for Australia



Lovegrove, K., et al. 2018. Comparison of dispatchable renewable electricity options. *Australian Renewable Energy Agency*.

Modular CST offers several deployment advantages in South Africa

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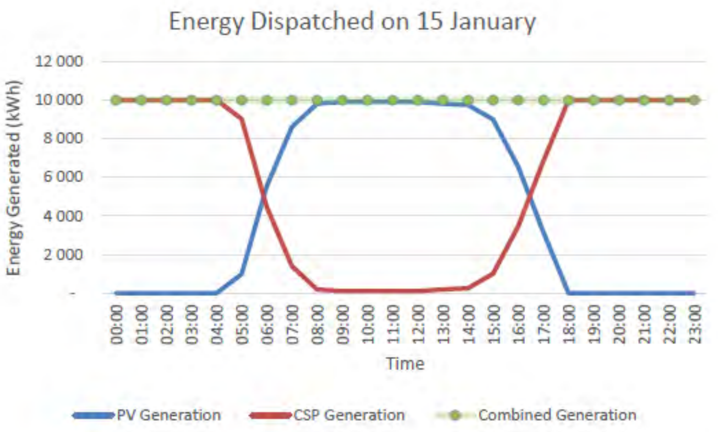
Advantages of modular concentrating solar thermal

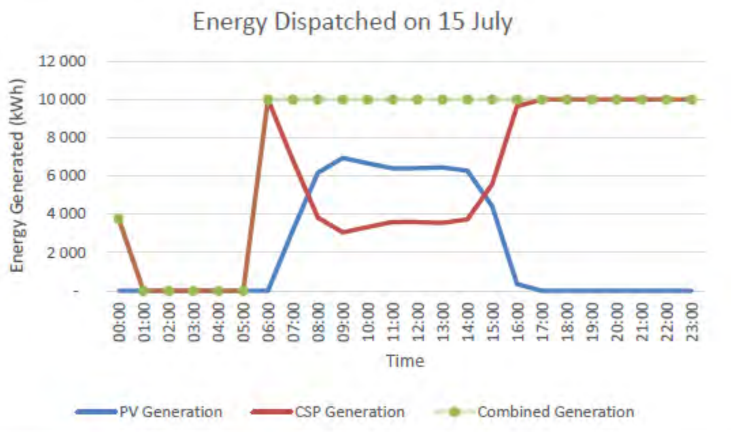
Monolithic CSP : 50-100 MW
Economy of scale benefit
High capital ($800 mil) – hard to finance

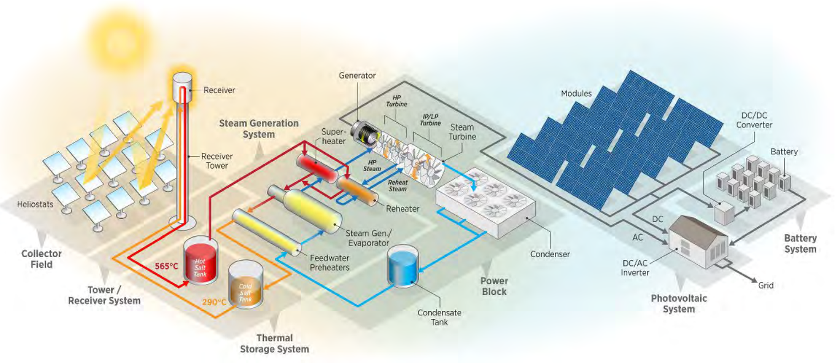
Modular CSP : 5-10 MW
Better optics – high solar to thermal efficiency
Lower capital cost ($80 mil) – simpler finance
Repeatable – justifies investment in local manufacturing
Expandable – grow to form energy parks

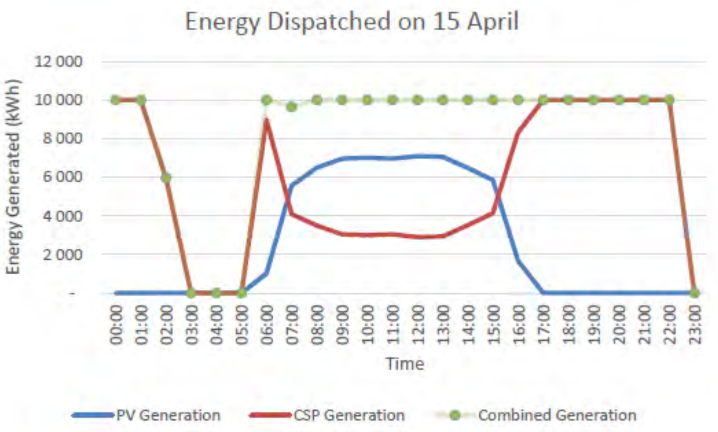
A full technical and economic assessment was developed for a 10 MW CSP/PV hybrid

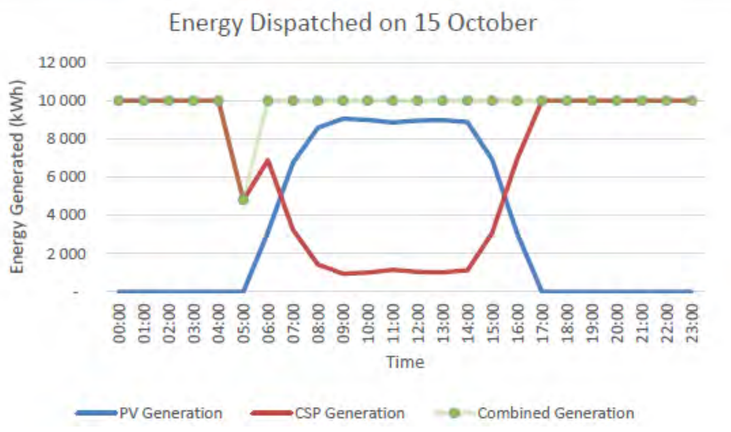
Account for economy of scale effects; time effects (resource, optimised dispatch and ToU tariffs), and optimise the CSP plant configuration

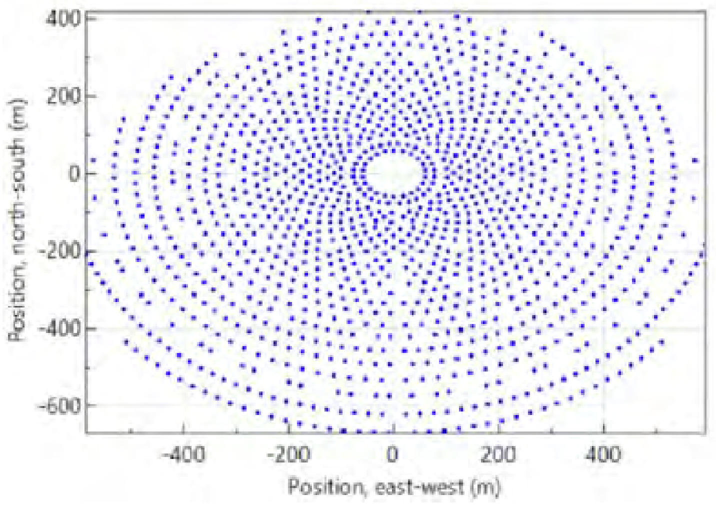












Medium scale CSP/PV hybrids are competitive in good solar resource locations

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Results: 10MW CSP/PV

PV: R0.70/kWh

CSP: R1.75/kWh

Blended: R1.30/kWh

Megaflex R2-R2.25/kWh*

NPV @ 13% = R500 mi (nominal) over 20y PPA

Capital costs and exchange rates reflect 2021

Megaflex, FY21/22, given at average of Peak and Std ToU for 10MW user. Most expensive rate for ≥500V <66kV, Transmission Zone >900km

Megaflex tariffs increasing at at CPI + 3.5% for NPV and IRR

Tariffs calculated based on 15% Equity IRR Hurdle Rate

	Unit	Value
PV Generation	kWh	28 110 770
PV Tariff	ZAR/kWh	0.686
Cost of PV Energy Delivered	ZAR	19 283 988

SM	FLSH (hrs)	1st Year CSP Tariff @ 15% Equity IRR Hurdle Rate (ZAR/kWh)	CSP Energy Delivered (kWh)	Total Energy Delivered (kWh)	%PV	%CSP	Blended Tariff (ZAR/kWh)
1.6	9	1.8200	33 490 705	61 601 475	46%	54%	1.3025
	10	1.7850	35 448 970	63 559 740	44%	56%	1.2989
	11	1.7600	37 039 041	65 149 811	43%	57%	1.2966
	12	1.7450	38 404 189	66 514 959	42%	58%	1.2974
	14	1.7350	40 194 856	68 305 626	41%	59%	1.3033
	16	1.7650	40 339 358	68 450 128	41%	59%	1.3219
2	9	1.8900	36 278 247	64 389 017	44%	56%	1.3644
	10	1.8400	38 923 087	67 033 857	42%	58%	1.3561
	11	1.7900	41 335 531	69 446 301	40%	60%	1.3431
	12	1.7550	43 531 103	71 641 873	39%	61%	1.3355
	14	1.7200	46 476 422	74 587 192	38%	62%	1.3303
	16	1.7450	46 769 964	74 880 734	38%	62%	1.3474

CSP/PV hybrids are at grid parity in SA and offer the lowest cost dispatchable power

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Strengths

1. The CSP/PV plant blended tariffs are competitive due to PV's low cost and low-risk profile.
2. The hybrid plant is fully dispatchable and can perform load-following and arbitrage for energy security and cost savings.
3. The PV capacity de-risks a portion of the capital expenditure and operating costs, making the hybrid's CSP portion more appealing to lenders and investors.
4. A medium-scale plant simplifies the development and construction of CSP and permits a modular approach where additional capacity units can be added as required.
5. A reduced CSP component also permits shorter construction, making it more competitive with respect to other technologies.

Weaknesses

1. The perception of elevated technology risk and the aspect of affordability continue to exist in the market.
2. Due to the impact of technology risk and off-taker risk on project funding and bankability, the pool of potential off-takers is small.
3. Due to the large capital and funding costs, the PPA contract duration must be at least 20 years. This is in a market where private off-takers are hesitant to sign PPAs longer than 10 to 12 years.
4. The operation and maintenance of CSP facilities is extremely complex.

Significant potential for CSP exists in South Africa in a least cost electricity grid

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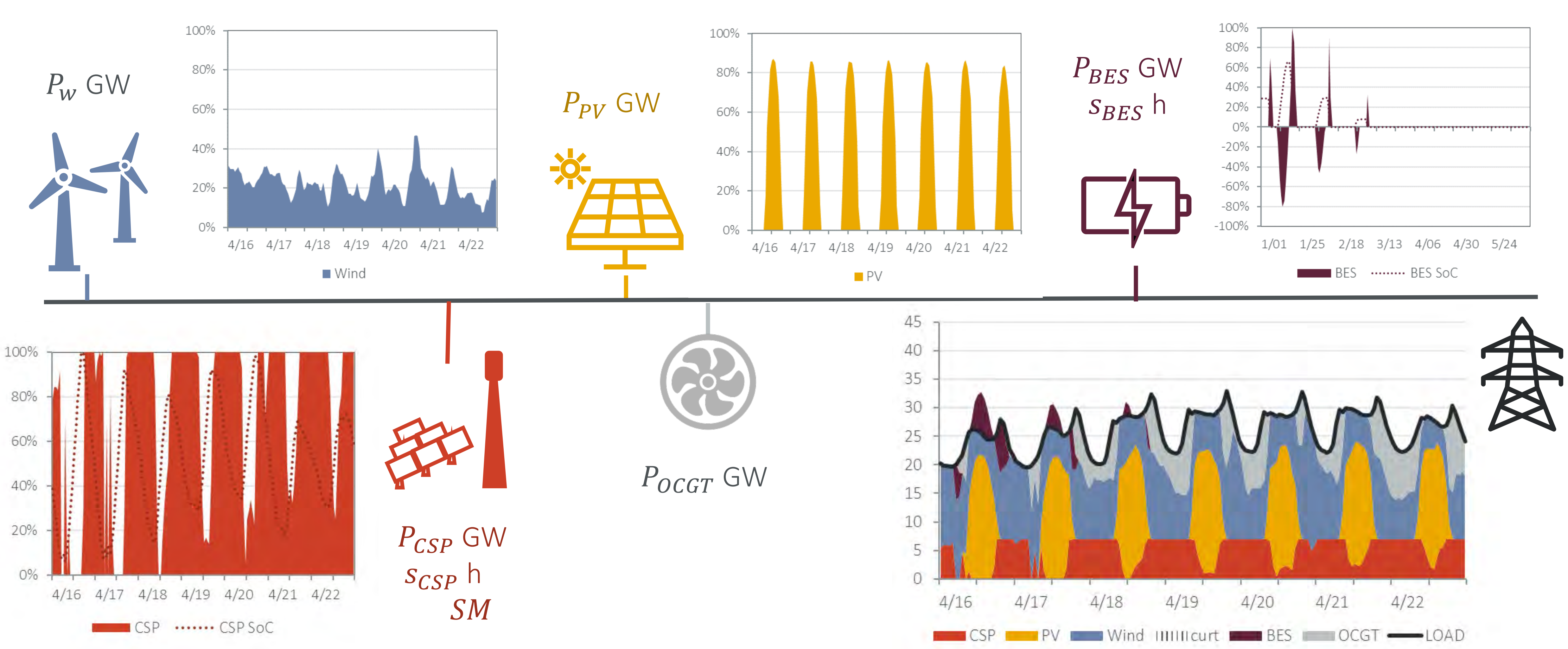

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Thank you
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CONTACT DETAILS:
Prof Craig McGregor
Solar Thermal Energy Research Group
Stellenbosch University, South Africa
STERG@sun.ac.za

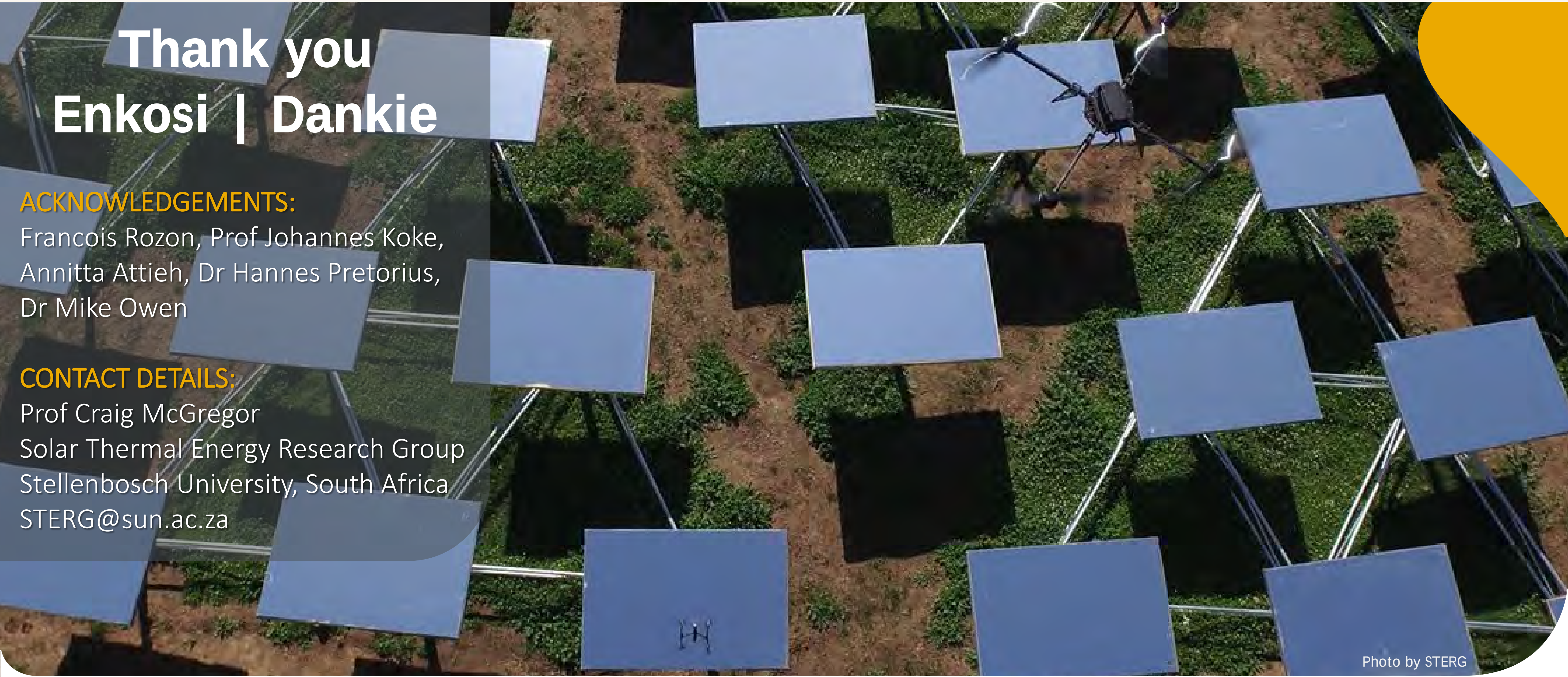

Photo by STERG

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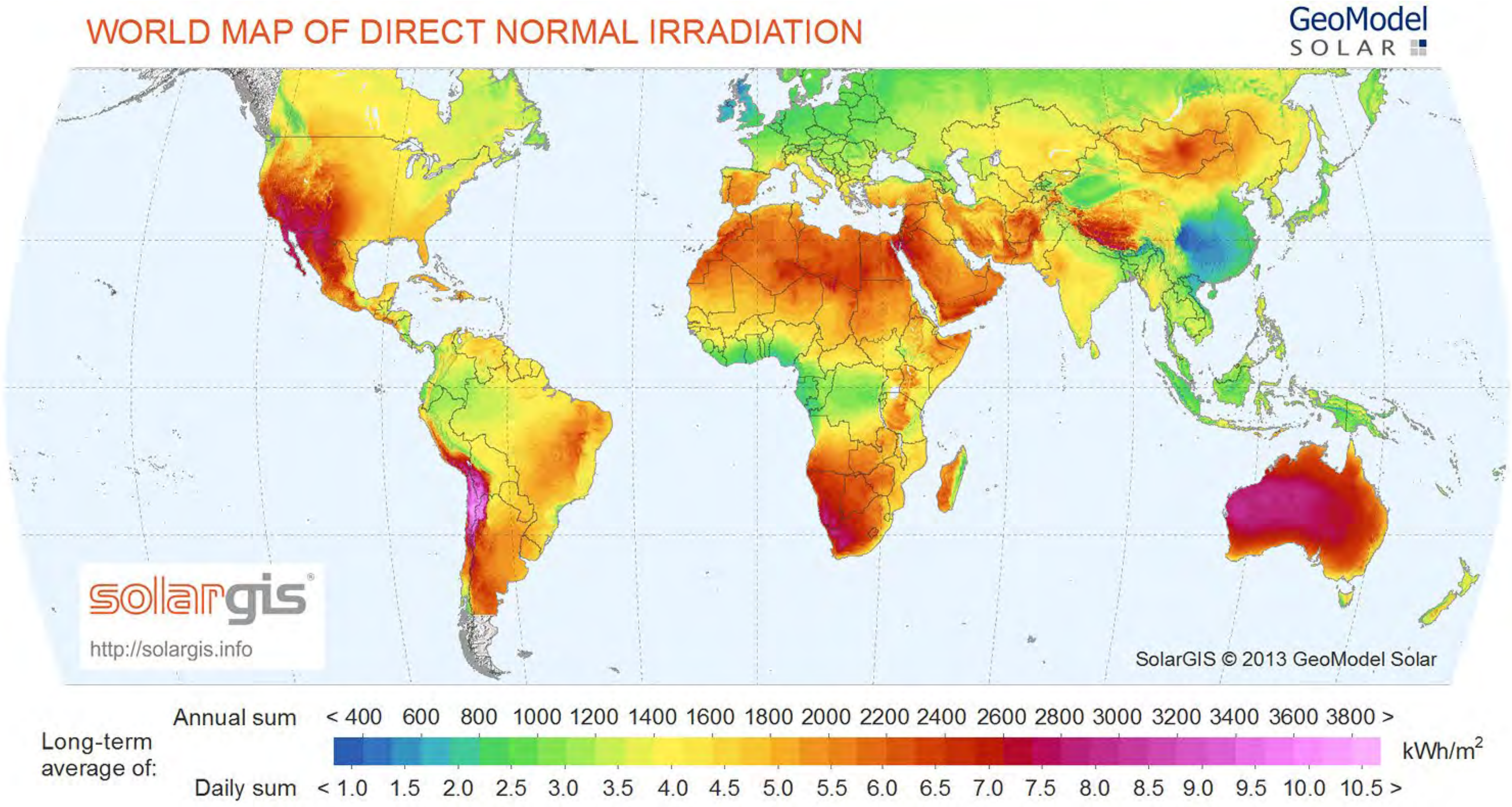
Backup slides

Rooftop industrial process heat in Turkley, Image: Solar Thermal World

Southern Africa is blessed with solar resources



RE/BES are cheapest dispatchable options with 1 hour storage

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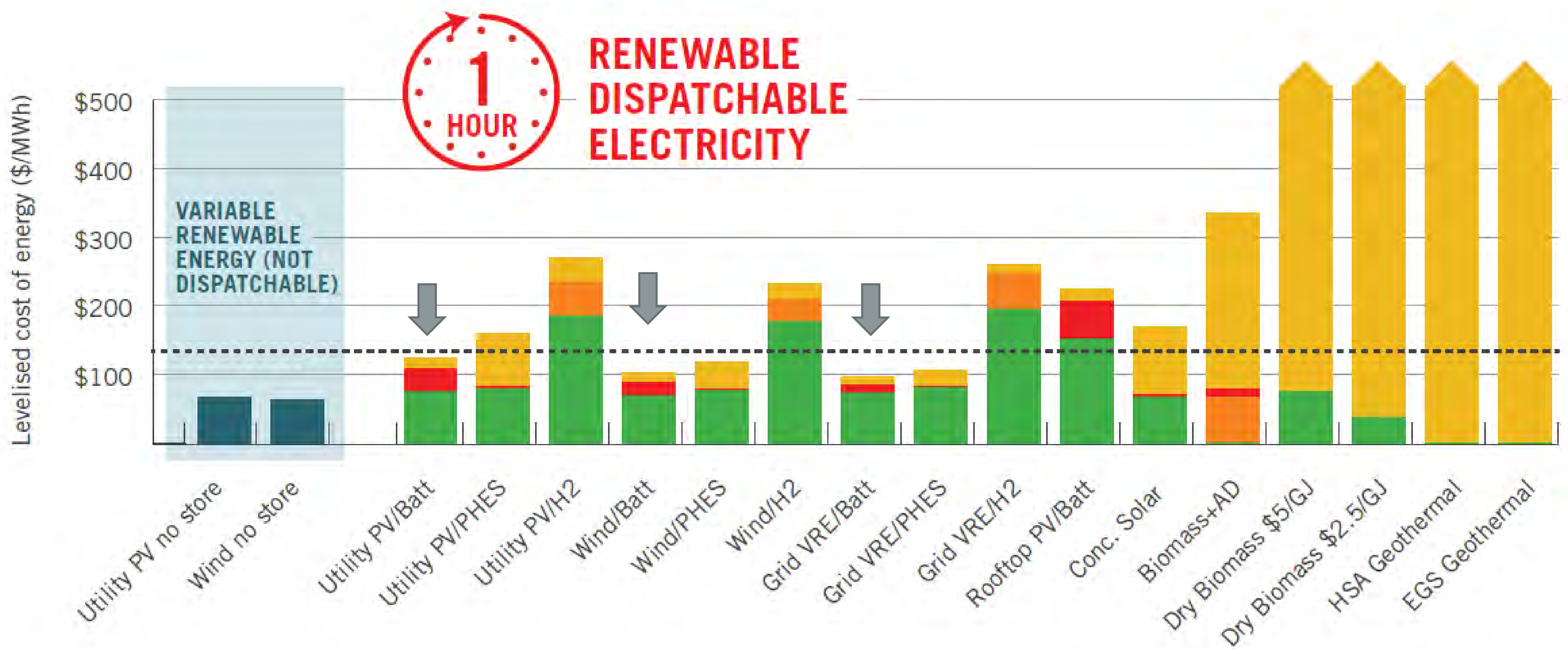
ARENA comparison of dispatchable RE options for Australia



Lovegrove, K., et al. 2018. Comparison of dispatchable renewable electricity options. *Australian Renewable Energy Agency*.

CSP* is cheapest dispatchable option with 12 hour storage

* excl. PHES

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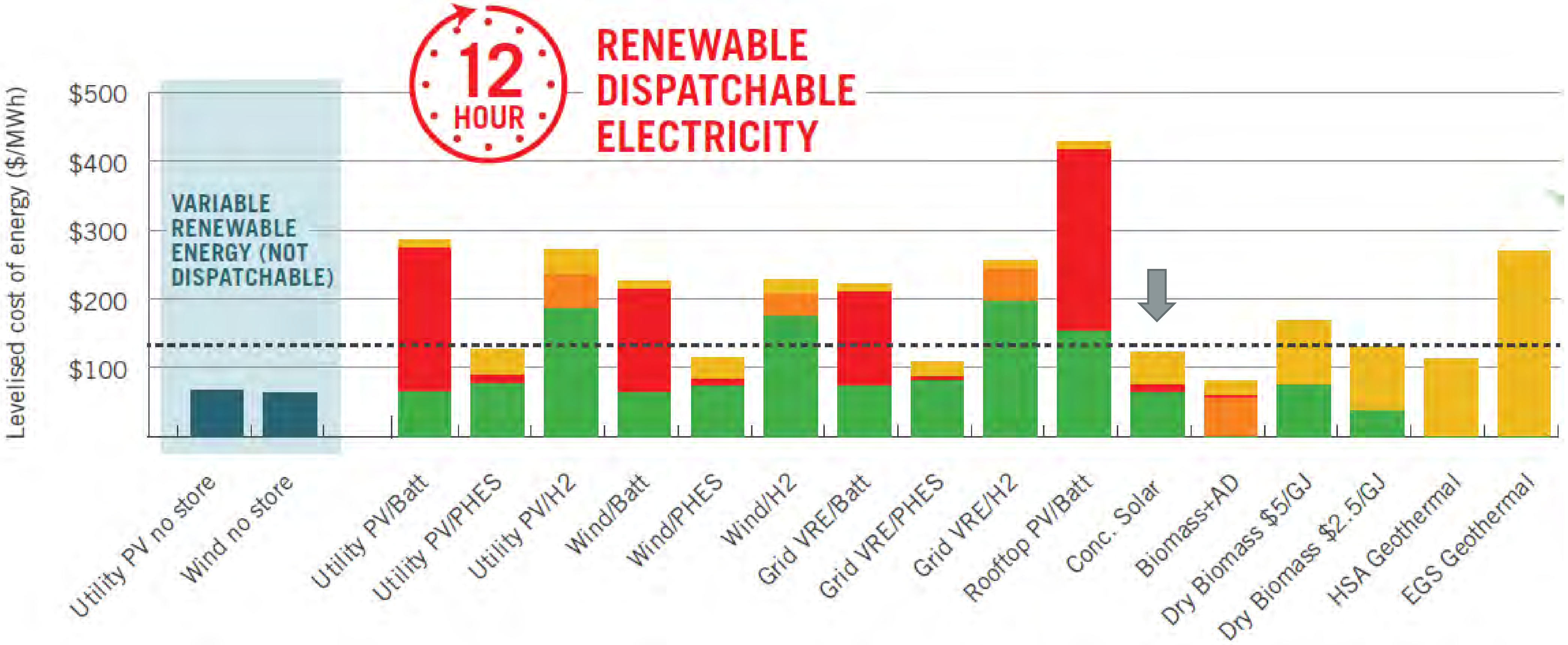
ARENA comparison of dispatchable RE options for Australia



Lovegrove, K., et al. 2018. Comparison of dispatchable renewable electricity options. *Australian Renewable Energy Agency*.

Solar thermal system costs will continue to drop as systems are deployed

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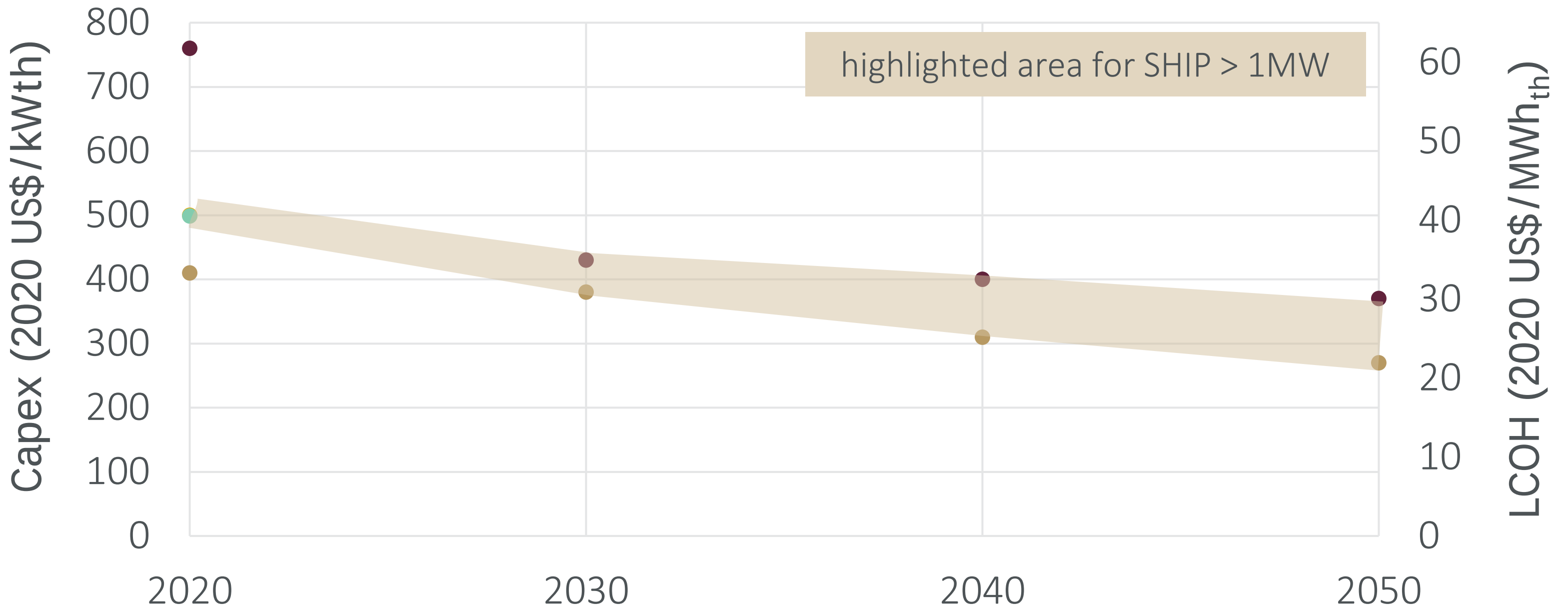
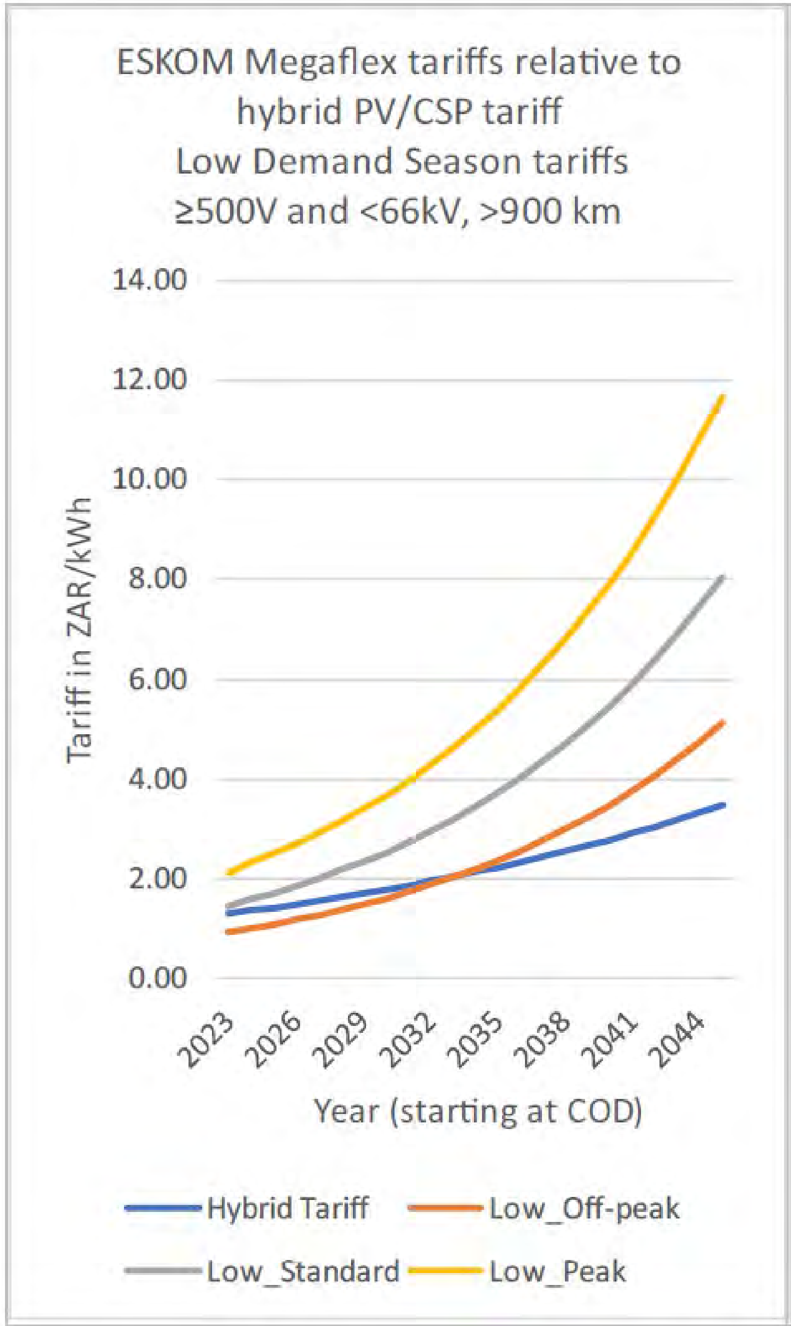
Cost reduction projections range from -1% to 3% per annum

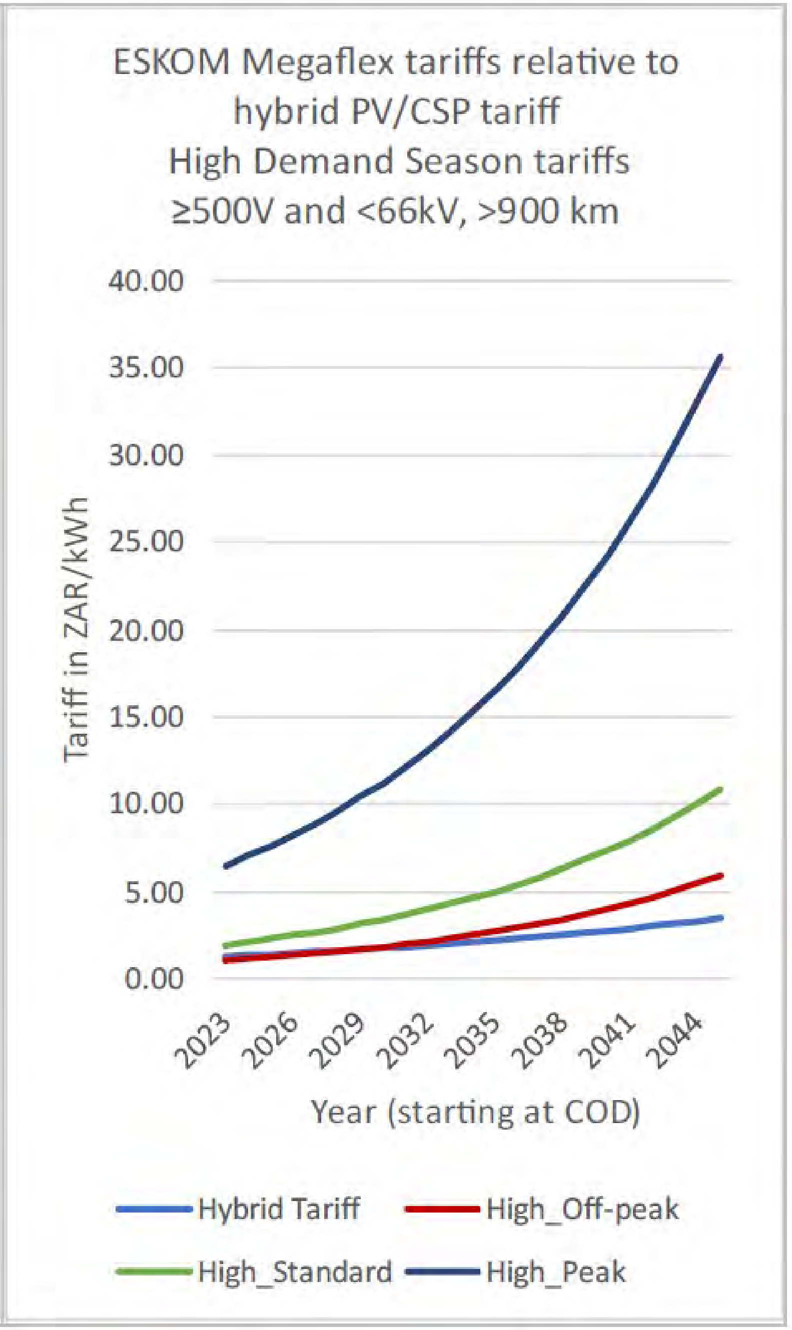


Assumptions

		Low CAPEX	High CAPEX
Gross Collector area	m²	6.04	
Specific collector price (for reference size)	$/m²	277	395
Reference solar field size corresponding to cost	m²	2000	
Economy of scale exponent		0.85	
Storage	$/m³	1700	2000
Average system life	years	20	
WACC		6.5%	
OPEX	% of Capex	2.0%	
Inflation		0%	
Electricity tariff increases above inflation		3%	

Results for 10MW CSP/PV against Megaflex





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CONTACT DETAILS:
Author
Solar Thermal Energy Research Group
Stellenbosch University
South Africa
STERG@sun.ac.za
sterg.sun.ac.za

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Rooftop industrial process heat in Turkley, Image: Solar Thermal World


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Faculty of Engineering
Photo by Stefan Els

Solar Thermal Energy Research Group is the largest in Southern Africa in the field

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Staff

- *Director:*
  Prof. Craig McGregor
- *Admin officer:*
  Leigh van der Merwe
- 8 active academic staff:
  Prof J van der Spuy, Prof J Hoffmann, Dr H Pretorius, Dr W Smit, Dr M Owen, Prof C McGregor, Prof C Meyer
- 10+ affiliated academics

Students

- 40 - 50 MSc and PhD
- 2 - 3 Interns

An introduction to the lecturer

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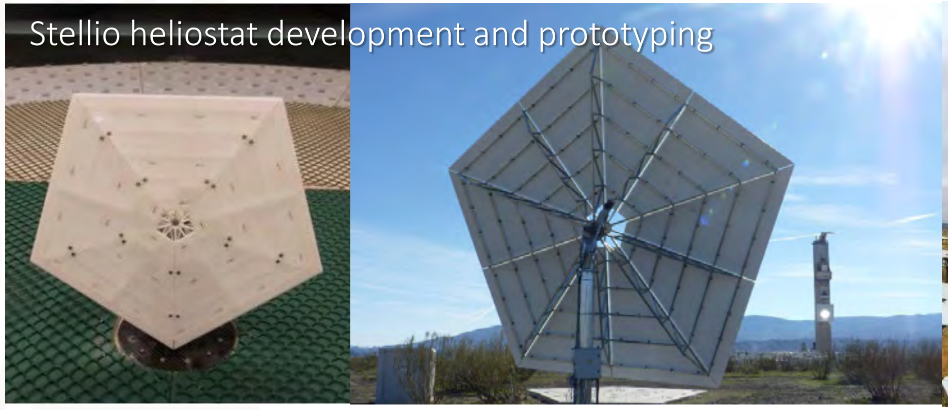
Sasol R&D facilities in Sasolburg

Image credit: SASOL



Stellio heliostat development and prototyping

Image credit: Balz, Göcke, Keck, von Reeken, Weinrebe & Wöhrbach (2016). Stellio – development, construction and testing of a smart heliostat. 1734. 020002. 10.1063/1.4949026.

Hami CSP Plant with Stellio heliostat

Image credit: CSPFocus

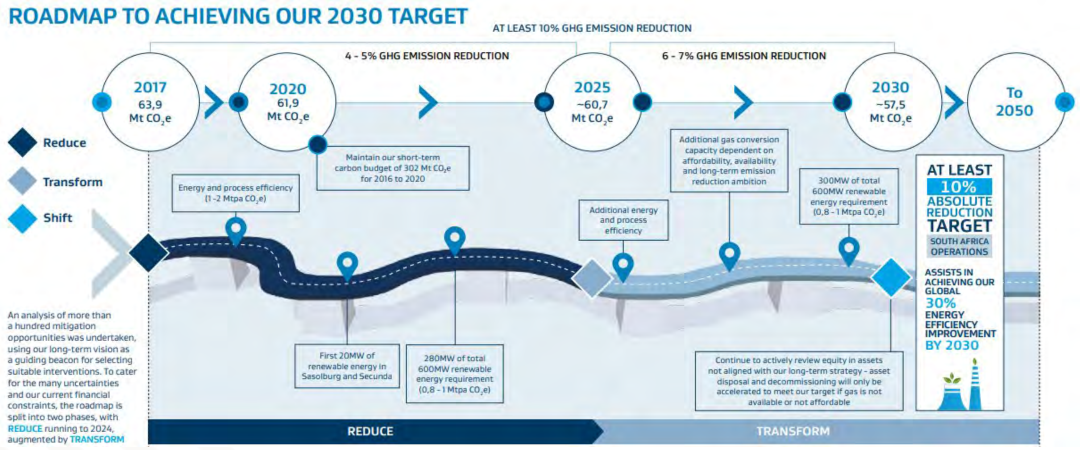


Image credit: SASOL Climate Change Report (2020)

- PhD is Process Engineering
- 10 years in chemical and energy research in industry
- 5 years in CSP research, includes Stellio heliostat
- 5 years on Sasol's carbon reduction roadmap
- Director of STERG at SU since 2019

The Solar Thermal Energy Research Group has over a decade of history in CST

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2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
7 – 15 people	~ 30 people	~ 45 people					~ 100 people						

SOLAR ENERGY RESEARCH

Eskom chair and centre of excellence

NRF solar thermal spoke 2013 - 17

SASEC

Sasol 40 m² heliostat field (Helio40)

SolarPACES 2015 in Cape Town

HELIO100

EU H2020 partner MinWaterCSP

Paul Gauché becomes head of CSP division

DSI solar thermal spoke 2018 >

PREMA EU H2020 partner

Global Challenges Research Fund partner

SASOL-NRF CSP grants

Imperial College London Photo-electric reactors


Solar roof lab expansion

Helio100 field at Mariendahl


2017: New rock-bed storage test facility at Mariendahl


Diesel engine converted to steam expander


STERG technical tours resume after Covid

DSI-Solar Thermal Spoke studies areas of national interest

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FOCUS AREAS

1. POLICY GUIDING STUDIES

- Solar fuels/hydrogen
- CSP for peaking power
- Carnot batteries

2. CST FOR MINERALS PROCESSING

- Sinter plants
- Low melting metals
- Preheating
- Thermal treatment of ores

3. MEDIUM SCALE CONCENTRATING SOLAR THERMAL (CST)

- Steam piston generators
- Supercritical CO_2 cycles
- Dry-cooling
- Solarized gas turbines

4. THERMAL ENERGY STORAGE (TES)

- Rock bed TES
- Engineered packing for TES

5. AUTONOMOUS CSP SERVICES

- Drone positioning
- Photogrammetry measurements
- Drone targets

Solar Thermal Energy Research Group

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STERG: infrastructure & resources

Thank you
Enkosi | Dankie

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Add text

CONTACT DETAILS:

Author
Solar Thermal Energy Research Group
Stellenbosch University
South Africa
STERG@sun.ac.za
sterg.sun.ac.za

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