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m5

Solar thermal power plants and their advantages

Cinema 2, Neelsie Student Centre

on Friday 18 October 2013

Prof Frank Dinter
Eskom Chair in CSP at Stellenbosch University and
Thermal Energy Research Group (STERG)

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About me

- Diploma work on Plataformasolar de Almeria (PSA) on "**Dual Medium Storage Tank** for Solar Thermal Acurex-field"
- PhD on **"Solar Thermal Energy Storage systems with concrete, liquid salt and phase change materials"** for SEGS plants in US
- **Different tasks and positions at RWE** e.g.
  - Head of R&D for fossil fired power plants
  - Head of product development at RWE Fuel Cells
  - Head of Solar at RWE Innogy
  - Technical Director of Andasol 3 (CSP Power Plant in Spain)
- **Now at Stellenbosch University**
  - Eskom Chair in Concentrating Solar Power
  - Member of STERG (Solar Thermal Energy Research Group)

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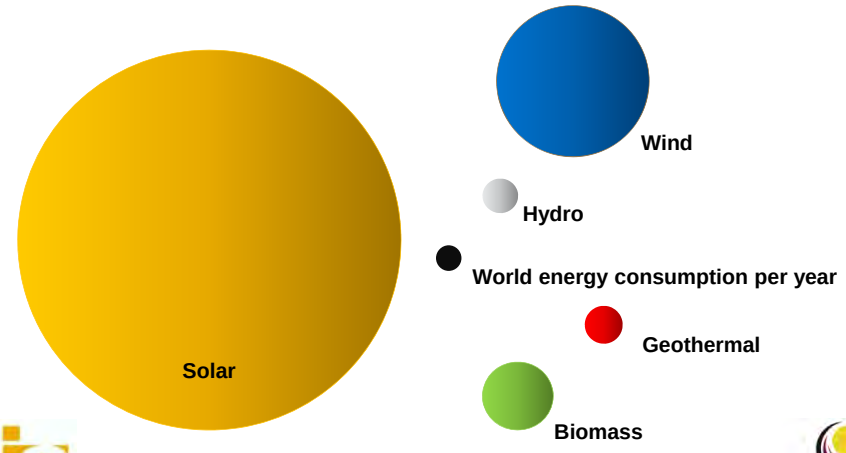
Slide 1

m5 Pick a title page according to affiliations
matti, 2013/09/10

Utilising the potential of the sun as source of energy I

Technical potential of renewable energy sources



Source: Fraunhofer ISE

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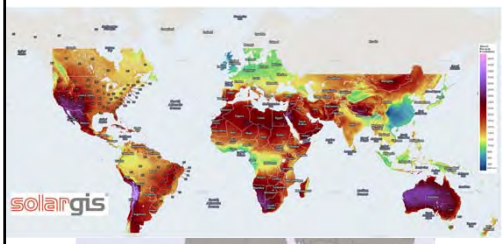
Utilising the potential of the sun as source of energy II



Area required to supply the world, the EU-25 or MENA with solar power from the Sahara. Source: Münchener Rück

- The sun is the world's largest source of energy
- The part of the earth directed to the sun is permanently exposed to a radiant power of $1.73*10^{11}$ MW which is equal to the capacity of 173 million big coal power plants
- Each year the sun sends over 1 billion TWh of energy to the earth which is equal to 60,000 times the world's electricity needs
- From a mathematical perspective, less than 3% of the surface area of the Sahara would be sufficient to meet the world's energy demand with solar power plants
- Unfortunately the utilisation of solar energy is not that easy due to the low power density

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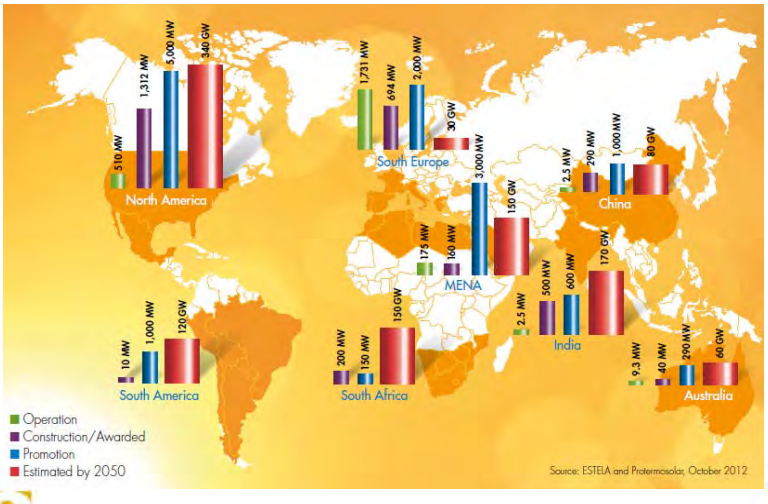
Utilising the potential of the sun as source of energy IV

The ESTELA CSP world forecast



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The CSP technologies have a different level of technological maturity

Parabolic Trough	Solar Tower	Dish Stirling	Linear Fresnel

Higher: large-scale systems in place — **Level of technological maturity** — Lower: large-scale deployment not yet proven

- Uses parabolic mirrors to concentrate solar radiation on linear tube receiver
- Is a long-term, commercially proven technology
- Has high maturity level, operational experience, modularity and a large number of providers
- Provides heat storage capabilities

- Concentrates solar radiation on a point receiver at the top of a tower
- Enables operation at high temperature level
- Has high net solar to electrical efficiency and is a commercially proven technology
- Provides heat storage capabilities

- Uses parabolic dish to concentrate solar radiation on a Stirling engine
- Has high net solar to electrical efficiency with low water consumption
- Is highly modular and suitable for both small stand-alone, decentralized off-grid power systems and large grid-connected power systems

- Uses flat mirror design to concentrate sun, enabling simpler production and installation
- Enables other industrial uses such as steam processing
- Has high land-to-electricity ratio due to linear design and the usability of space below support structure
- Provides heat storage capabilities

Source: A.T. Kearney

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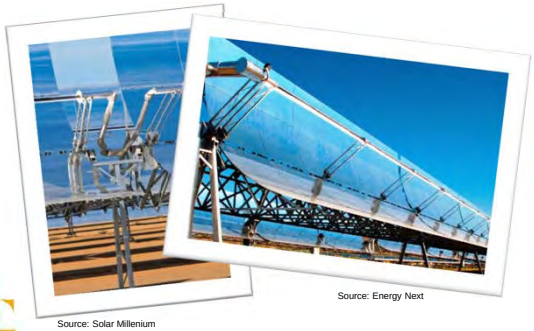
CSP technologies I

Parabolic Trough

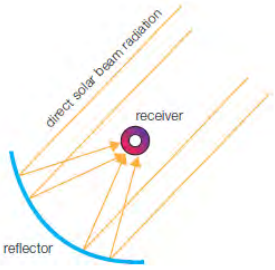
> Uses parabolic mirrors to concentrate solar radiation on linear tube receiver
> Is a long-term, commercially proven technology
> Has high maturity level, operational experience, modularity and a large number of providers
> Heat storage possible

Source: Solar Millenium



Source: Solar Millenium

Source: Energy Next



Source: German Aerospace Center

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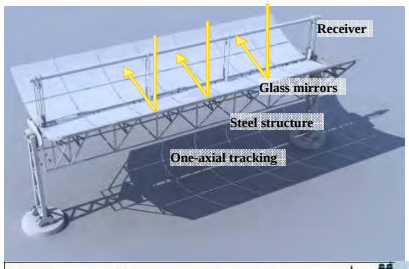
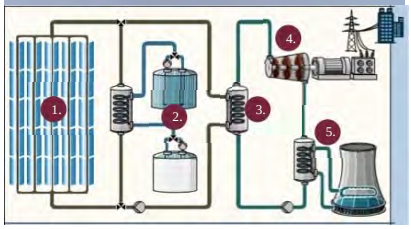
How parabolic trough power plants work





1. Solar field, 2. Storage, 3. Heat exchanger, 4. Steam turbine, 5. Condenser

Source: Solar Millennium

- Trough-like mirrors of the solar field concentrate the incident solar radiation
- The solar beams are concentrated 80-fold on the receiver tube in the collector's focal line
- A heat transfer fluid runs through the tubes which is heated up to 400°C by the sunlight
- The hot fluid passes through heat exchangers to generate steam in a central unit
- As in a conventional power plant the steam powers a steam turbine with electricity generator
- The integration of a heat store permits electricity generation almost around the clock

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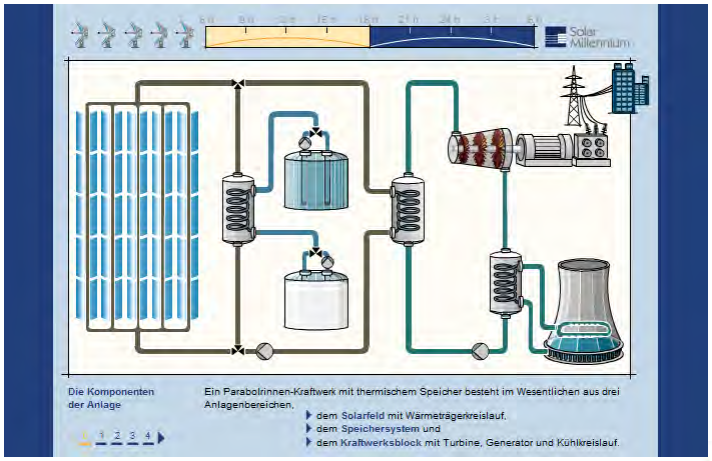
Parabolic trough power plant with thermal energy storage

Animation



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Parabolic trough power plants: More than two decades of experience

- Up to now the only large power plant technology that has been tested over a longer period of time
- The technology has been in commercial use in California since the 1980's

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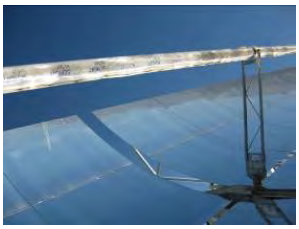
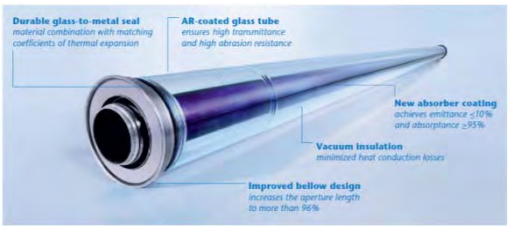
Receiver tubes heat up heat transfer fluid

- Multiply coated stainless steel tube with 95% absorption level
- Max. 14% heat radiation is emitted
- Steel tube sheathed in vacuum-insulated jacket tube that lets 96% of sunlight through
- Metal bellows compensate thermal expansion





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World´s biggest Trough Plant with TES

Solana Generating Station

> **Owners**: Abengoa Solar
> **Location**: near Gila Bend, Arizona, USA
> **Technologie**: Parabolic Trough
> **Power**: 280 MW
> **Commission date:** 2013

Source: Abengoa Solar

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World´s biggest Trough Plant with TES

Film

Solana (Abengoa) now in operation
280 MW, 6 hours storage (molten salt), Solar field 2.2 M m^2, Area 1200 ha, 980 GWh annual energy production.

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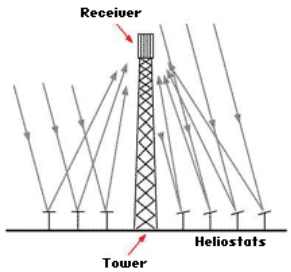
CSP technologies II

Solar Tower

- Concentrates solar radiation on a point receiver at the top of a tower
- Enables operation at high temperature level and provides heat storage capabilities
- Has high net solar to electrical efficiency and is a commercially proven technology
- Different heat transfer media (HTM) possible
- Heat storage possible



Source: European Commission

Source: Abengoa Solar

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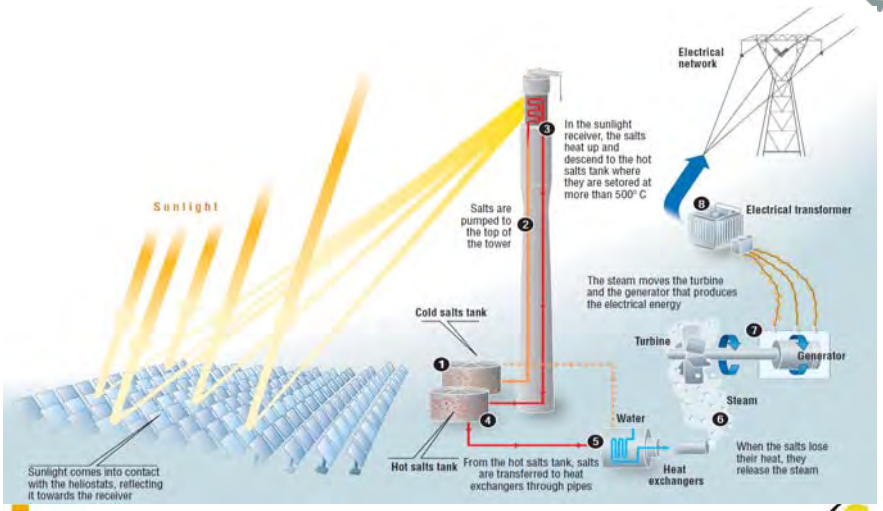
Solar tower power plant with liquid salt as heat transfer medium



Source: torresolenergy

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Gemasolar Tower plant, 15 h storage 19.9 MW (Torresol Energy)

World´s largest Solar Tower plants

Film

Ivenpah Solar Power

> **Owners**: NRG Energy, Google and BrightSource
> **Location**: Mojave Desert in California, USA
> **Technologie**: Solar power tower
> **Power**: 3 x 130 MW
> **Commission date:** 2013

Source: Ivanpah

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First Solar Tower plant in South Africa

Khi Solar One

> **Owners**: Abengoa solar and IDC
> **Location**: Upington, South Africa
> **Technologie**: Solar power tower
> **Power**: 50 MW
> **Commission date:** 2014

Source: Abengoa Solar

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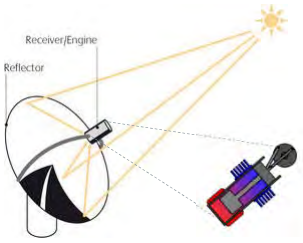
CSP technologies III

Dish Stirling

> Uses parabolic dish to concentrate solar radiation on a Stirling engine
> Has high net solar to electrical efficiency with low water consumption
> Is highly modular and suitable for both small stand-alone, decentralized off-grid power systems and large grid-connected power systems



Source: Stirling Energy Systems

Source: Stirling Energy Systems

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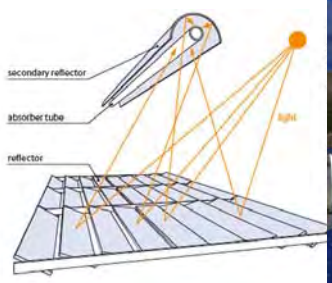
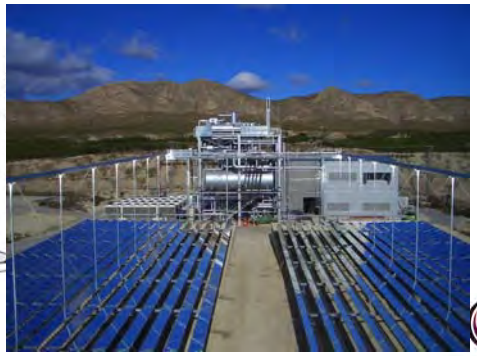
CSP technologies IV

Linear Fresnel

> Uses flat mirror design to concentrate sun, enabling simpler production and installation
> Enables other industrial uses such as steam processing
> Has high land-to-electricity ratio due to linear design and the usability of space below support structure
> First test with liquid salts soon



Source: Solarpraxis.de / M. Römer



Source: Novatec Solar

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Solar boosting with Fresnel

Kogan Creek – Solar boost

> **Owners**:CS Energy
> **Location**: Brigalow, Queensland, Australia
> **Technologie**: Linear Fresnel - solar addition
> **Power**: 44 MW

Source:CS Energy

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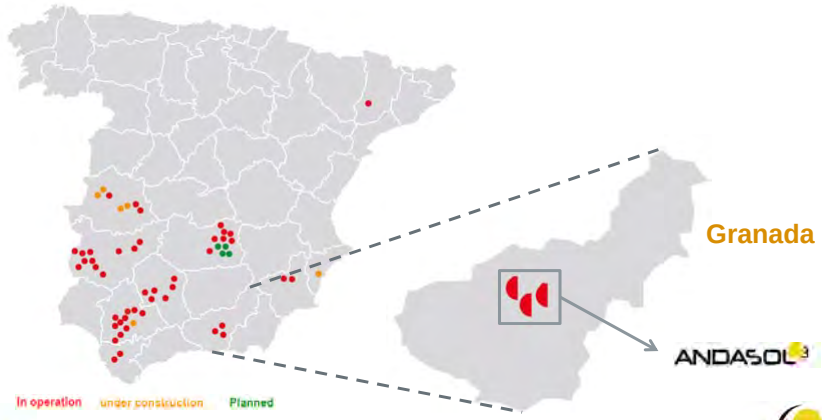
More than 2 GW of STE plants in Operation in Spain



Source: Protermosolar

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Andasol is one of Europe's largest solar energy sites

Film

Andasol 3: Facts & Figures

- Owner: Marquesado Solar S.L.
- Location: Aldeire/La Calahorra (Granada, Spain)
- Technology: Parabolic trough incl. 7.5h molten salt storage
- Capacity: 50 MW_{el}
- Size of the collector area: ~ 500,000 m²
- Forecasted electricity production: ~200 GWh/a
- Annual CO_2 savings: 150,000 tonnes
- Commissioning in autumn 2011
- Investors:
- EPC contractor: UTE

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Technical data of Andasol 3

Solar field	
Size of solar field	497,040 m²
No. of parabolic mirrors	204,288 mirrors (each mirror is 12m long and 6m wide)
No. of receivers (Dewar tubes)	21,888 tubes, each 4m long
No. of sensors	608 units
Annual direct normal irradiation (DNI)	2,136 kWh/m²a
Altitude above sea level	1,100 m
Thermal storage	
Storage capacity of heat store	28,500 t salt, 7.5 full load hours
Power plant output	
Turbine output	49.9 MW
Annual operating hours	approx. 4,000 full load hours
Forecast gross electricity generated	approx. 200 GWh/a
Estimated service life	At least 40 years

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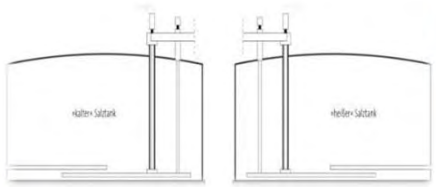
Thermal storage system of Andasol 3

- The entire storage system is designed for total 1010 MWh useful storage capacity, this corresponds to 7.5 full load hours
- The system is equipped with two molten salt storage tanks (cold tank: 286°C / hot tank: 386°C)
- Due to the system's design the steam turbine can be operated between 10 MW_e (approx. 36h) to around 45 MW_e (121 MW_{th} for approx. 8.3 h) gross power output from thermal storage in discharge mode
- Storage medium is a molten salt mixture (60/40) of sodium nitrate ($NaNO_3$) and potassium nitrate (KNO_3)



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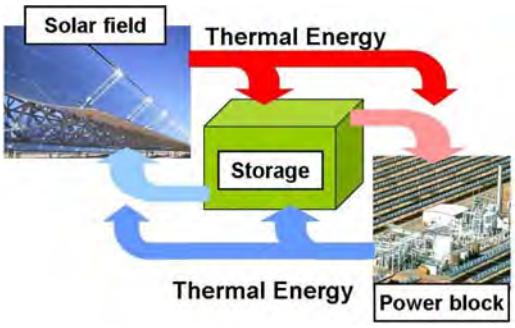
Advantages of CSP with thermal energy storage

The main advantage of CSP technology against other RES as PV or wind power is the capability to provide dispatchable power by storing solar energy through thermal energy storage



Flexible and predictable electricity generation on demand

Source: DLR

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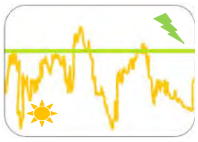
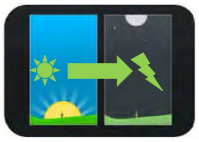
Advantages of CSP with thermal energy storage

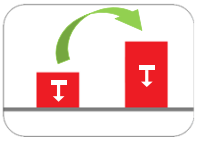
Flexible and predictable electricity generation



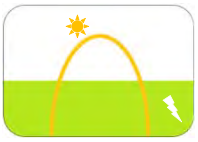
Avoidance of production interruptions resulting from the intermittency of solar radiation



Generation of solar power decoupled from weather conditions and time

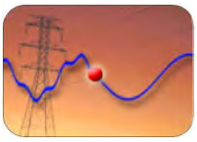


Shifting of power generation to periods of highest demand



24 h/d continuous production capability

Regulation and frequency response



Support for power quality

Contribution to system flexibility supporting the integration of other RE sources

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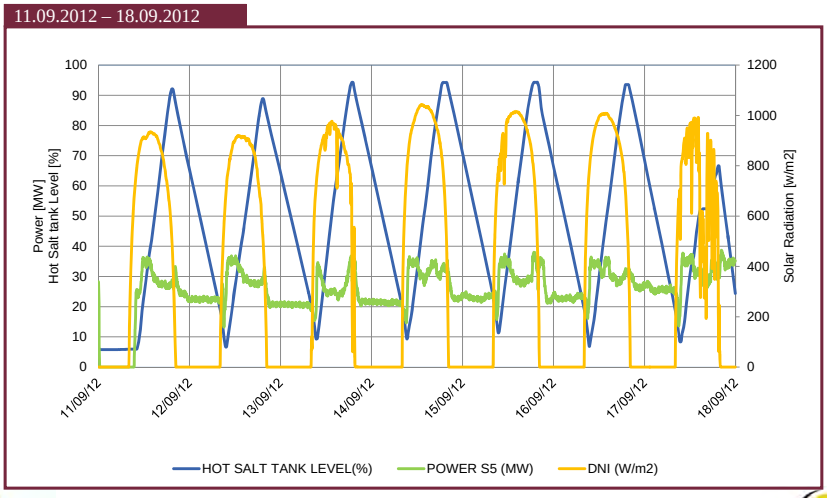
Continuous generation 24 h/d

11.09.2012 – 18.09.2012



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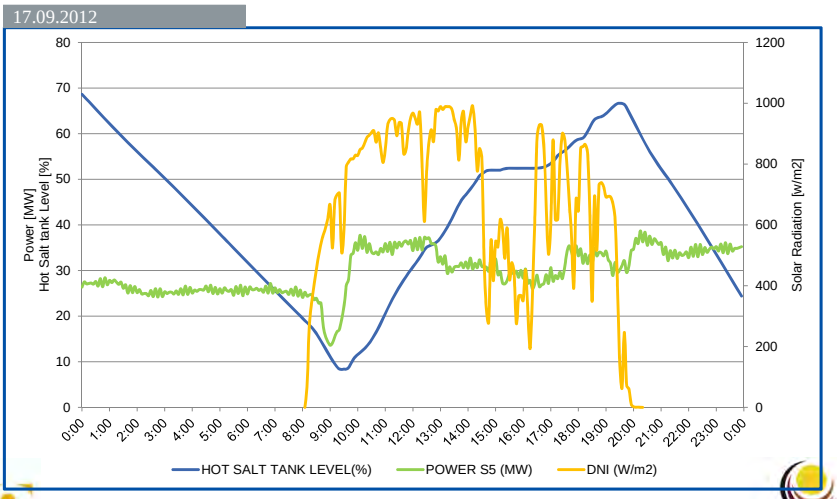
Continuous generation 24 h/d



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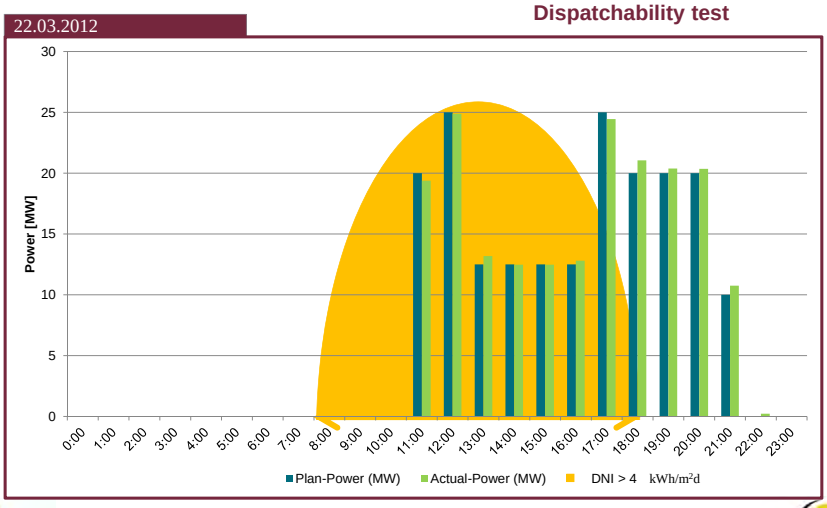
Dispatchable generation



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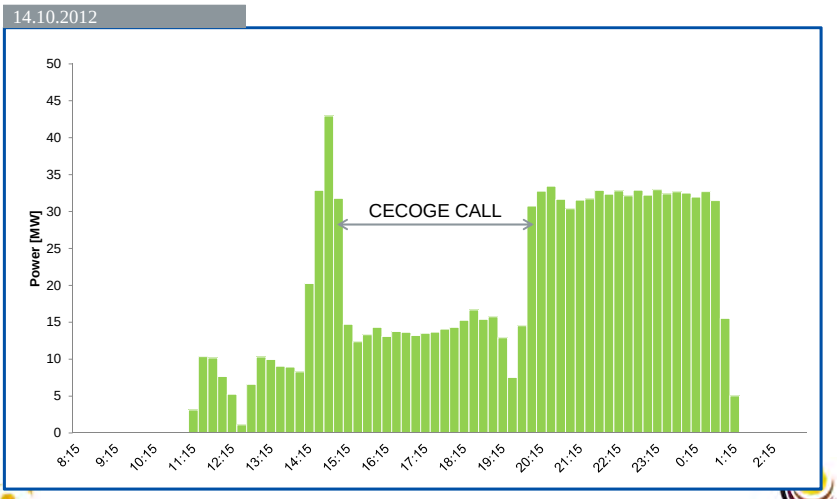
Dispatchable generation

CECOGE: Tech minimum request 14.10.2012



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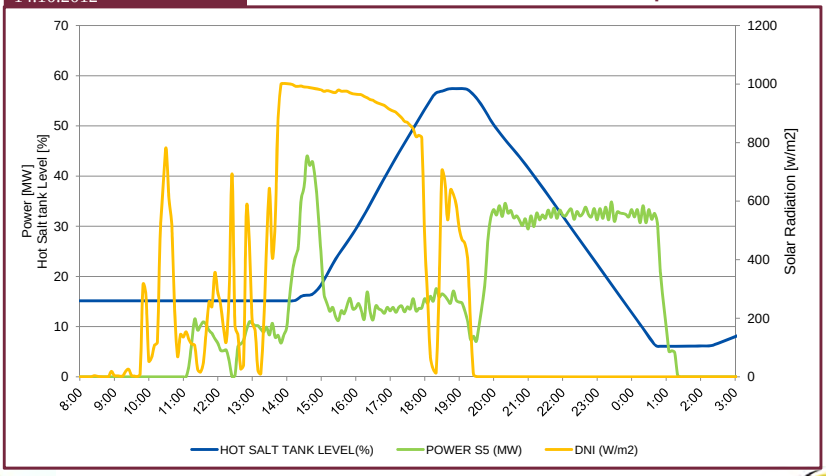
Dispatchable generation

14.10.2012

CECOGE: Tech minimum request 14.10.2012



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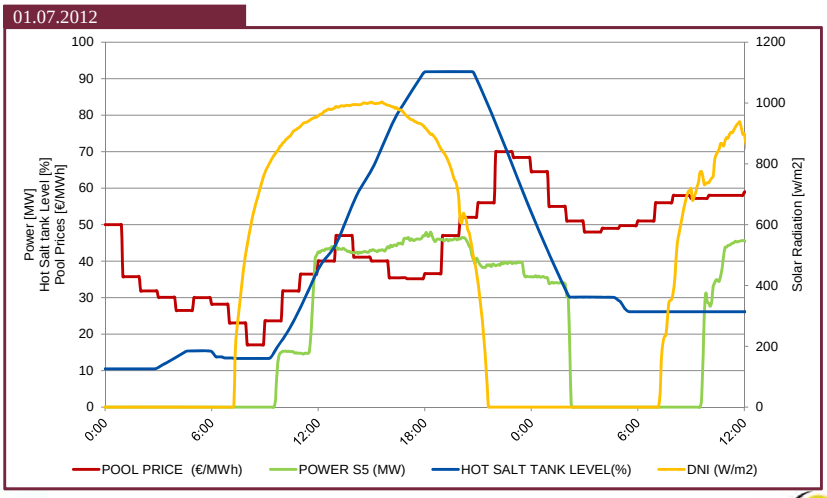
Economic value of dispatchable generation

01.07.2012



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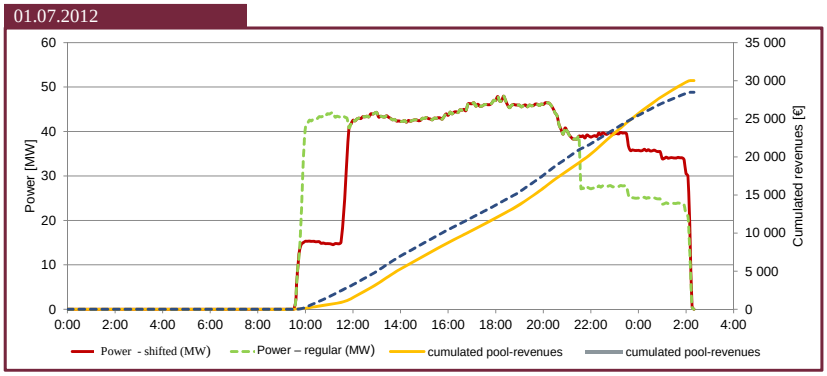
Economic value of dispatchable generation

01.07.2012



Energy output	633 MWh	
Energy shifted	50 MWh	8%
ΔRevenues	1.500€	5,3%

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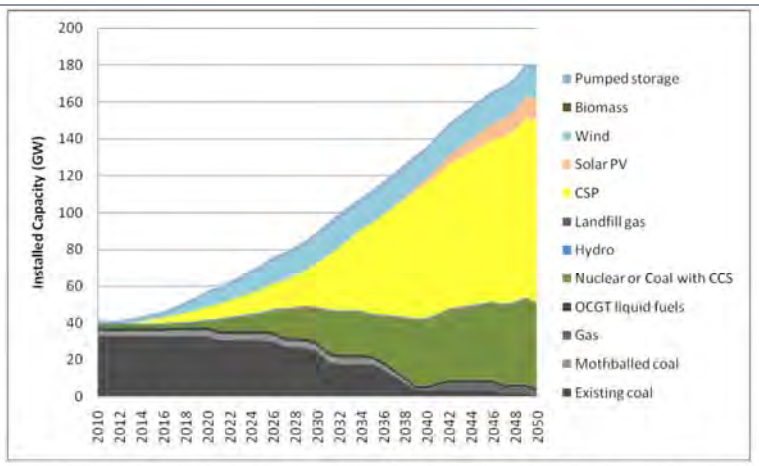
What could be possible with CSP in SA?



Electricity generation capacity projected for South Africa to achieve near carbon-neutral electricity generation by 2050

Source: Winkler (2007)

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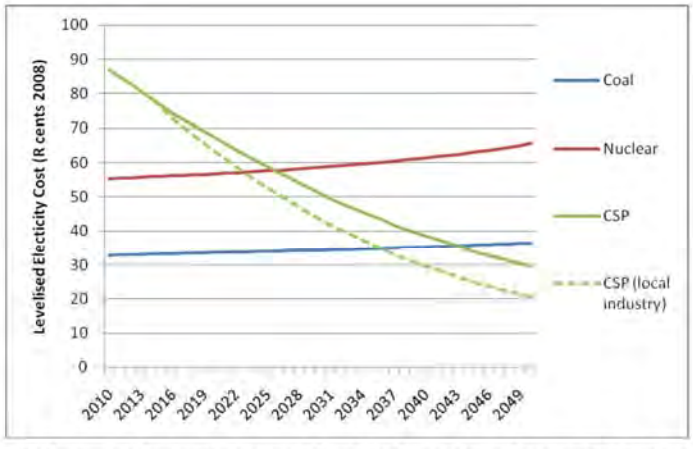
Main Research on cost reduction in CSP technology



Projections of the levellised costs of electricity from coal, nuclear and CSP in South Africa

Source: adapted from Marquard et al. (2008)

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Thank you for your attention and any "???"
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