On Prerequisites to Large Scale Rollout of CSP in Southern Africa: Models, Plants and Resources

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Dept. Mechanical & Mechatronic Research Lecture
22 November 2010
Agenda

• Background
• Research objective
  • Modelling
  • Plants
  • Resources
  • Risks
• Conclusions
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Where STERG Fits

Engineering Faculty

Mechanical and Mechatronic Engineering

Centre for Renewable and Sustainable Energy Studies

Solar Thermal Energy Research Group

Other Depts/Universities

DST

National Hub

Spokes etc.
Solar Thermal History at SU

- **1980 - 1989**
  - Solar Resource Station at SU
  - Solar Roof Lab Commissioned
  - Solar Chimney Research Commences
- **1990 - 1999**
  - Dry Cooling Research Commences
- **2000 – 2009**
  - National RE Centre Founded
- **2010 -**
  - SOLAR THERMAL ENERGY RESEARCH GROUP
  - SASTELA Research and Academic Committee Representative

~1970

First Parabolic Trough Research
STERG Research Structure

STERG Holistic/Multidisciplinary Research

- Social & Political Sciences
- Engineering
- Economic Sciences

SUNSTEL
Stellenbosch University Solar Thermal Electricity Project

System R&D (Modelling, Techno-economic, Resources, etc)

- SWH, Process Heat, Desalination etc.

Solar Resource Measure & R&D

Component R&D: Eg. Dry Cooling

Component R&D: Eg. Thermal Storage

Component R&D: Eg. Heliostats
STERG Infrastructure

- Primary sponsors: OSP/Hope Project, Sasol, DST
- Full time solar thermal energy researcher, engineer, technician (½)
- 15+ Staff and post-graduate students
- Extended solar roof lab (954m²)
- Solar & weather resource measurement station
- Multiple heat transfer and wind-tunnel labs.
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Research Objective

- **Title**: Techno-Economic Prerequisites to Large Scale Rollout of Concentrating Solar Power in Southern Africa
  - **Promoters**: Prof. T.W von Backström & Prof A.C. Brent (School of Public Leadership)
  - **Advisory**: Prof. D.G. Kröger, Prof. J.L. van Niekerk, [Dr.] H.C.R. Reuter
- **Objective**: Holistic project for SA to be “technology ready”. Covers:
  - Ability to model plants (from decision making to dispatch)
  - Understand technology asymptotes and 2050
  - Address the “we don’t know what we don’t know” through encouraging/building any and all research/pilot/demo plants
  - Build scenarios of the large scale rollout considering resources
Research Objective

• **Reason:** Early-stage for CSP in Southern Africa → Need macro level technology expertise for urgently needed planning at IRP (Integrated Resource Planning) level

• **Strategic & Appropriate:** CSP could be to 21st century South Africa what the Fischer–Tropsch process was to 20th century South Africa

• **Other:**
  - Fits well with STERG coordination
  - Past multidisciplinary experience
  - Aligns with sponsor goals
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# System Modelling for CSP Plants

<table>
<thead>
<tr>
<th>Tool</th>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
</table>
| System Advisor Model (SAM) by National Renewable Energy Lab (NREL) | • Quite easy  
• Good solver (TRNSYS)  
• Is validated | • Highly restrictive to built in configs |
| TRNSYS by University Wisconsin | • Good solver  
• Flexible use | • Very difficult to use for the untrained user |
| DLR consortium | • Hope for a standard | • Proprietary and hard to get in? |
| Flownex | • SA tool and support | • Doesn’t do any solar |
| Build own models and code | • Develop skills | • Will take time |
Proposal: Own Code for SUNSTEL

SUNSTEL (Stellenbosch University Solar Thermal Electricity Project)

SUNSTEL lite
High level system level tool for quick analysis of CSP plants

SUNSTEL design
Low level (detailed) system level tool for design analysis of CSP plants

SUNSTEL Dispatch
Tool for operating CSP plants

SUNSTEL Optical
Optical tool for CSP

SUNSTEL Power
Power block tool for CSP

SUNSTEL TES
Thermal energy storage tool for CSP

SUNSTEL Cool
Condenser tool for CSP

SUNSTEL ...
Any other components

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SUNSTEL Lite

- Approach per objective
  - Only the appropriate level of modelling for needs (Eg. Decision makers)
  - Looks at the big 5
    - Central Receiver
    - Parabolic Trough
    - Linear Fresnel
    - Dish Stirling
    - Solar Chimney (Special case)
  - Applies same rules to all (provide basis for comparison)
  - Uses hourly data for solar and weather (Day, Month, Hour, DNI, Ta, Wet bulb, Wind speed)
  - Quasi-transient analysis for
    - Energy balance
    - Chambadal-Novikov engine (Modified Carnot)
  - No operating fluids
SUNSTEL Lite: Only Necessary Plant Metrics

Central receiver Example

- Receiver Width/Diameter
- Receiver Height
- Heliostat Field for 1 Module
- Tower Height
- Min Heliostat Distance
- Tower Zone (No Heliostats)
- Maximum Heliostat Distance
- Heliostat Field Width/Length
- Heat Engine

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Calculates Solar Physics for Plant Sizing

- Reflection angle (T)
- Heliostat Distance to Tower
- Tower Height
Small Reflector (~infinitesimal)

*Subtending angle of the sun. Casts Ø 9.3m image per 1,000m focal distance

Perfectly Curved Square Reflector

Perfectly Flat Square Reflector
Normal Image Outline
Perfectly Flat Square Reflector

Normal Image Outline
Real Flat Square Reflector

Angled Image Outline on Receiver
Real Flat Square Reflector

Shape and Size Impact

Stretching Due to reflection Angle
Conceptual Modelling Approach

Solar Energy In Based on multiple efficiencies

Solar Reflected

Thermal Radiation Loss

Thermal Convection Loss

Thermal Energy Out

Flow rate set for power block $T_{max}$

$T_{rec} = \text{MEAN}(Th-Ta)$

Power = $1 - \sqrt{Th-Ta}$

$Th = T_{max}$

$Ta = \text{Dry bulb or wet bulb}$
Example of DNI – 10 Days in Upington

Gn (DNI)

Hours of the Year

DNI [W/m²]
10 Days of Power – 2.5MWe plant

Energy and Power

Energy or Power [W]

Hours of the Year

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Annual Production – 2.5MWe Upington Plant

GWh cumulative

Days of the Year

Cumulative Power [GWh]

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Research – Pilot – Demo Plants

- We don’t know what we don’t know
- Need to take small steps and grow skills locally
  - Design
  - Build
  - Model
  - Run
  - Debug
  - Improve
  - Build local industry
  - …
- Any and all sizes & types
  - Small (3kWe) troughs and LFRs
  - Pilot sized central receivers at 5MWe
  - Anything in between
Plants

- SUNSPOT high efficiency combined cycle concept – Prof Kröger concept
  - May have an excellent chance to do something like this with an industrial partner
Plants

- Solar Thermal Group (STG) Organic Rankine CSP system for Spier
Plants

- Other opportunities
  - Technology vendors looking for places to put pilots
  - Spier to go carbon neutral by 2017 → 1-2MWc CSP plant
    - Has many constraints
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Need to Comprehend the Resource
Rollout Model taking Resource Into Account

Mockup on Models of Rollout

Location of Plants

Annual average solar irradiation (DNI) [Wh/m²/d]

- < 5600
- 5600 - 6500
- 6500 - 7000
- 7000 - 7500
- 7500 - 8000
- > 8000

Andasol

Hail

Data Source: SWERA, 2008

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# Risks (SWOT)

<table>
<thead>
<tr>
<th>Strengths</th>
<th>Weakness</th>
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<tbody>
<tr>
<td>✓ Multidisciplinary and holistic research</td>
<td>✓ Lacks in-depth fundamental research in one particular area</td>
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<tr>
<td>✓ Covers system technology and reviews state of art at system level – applicable in SA where the technology and industry is new</td>
<td>✓ Inability to perform laboratory experiments</td>
</tr>
<tr>
<td>✓ Close match to job description and sponsor interests</td>
<td>✓ May be wider in scope than any one promoter can comfortably handle</td>
</tr>
<tr>
<td>✓ Close match with candidate experience</td>
<td></td>
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<table>
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<tr>
<th>Opportunities</th>
<th>Risks</th>
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<tr>
<td>✓ Highest level of knowledge transfer to the public (and University)</td>
<td>✓ University acceptance of multidisciplinary research topic</td>
</tr>
<tr>
<td>✓ High level of learning about CSP for the candidate – good level of employability</td>
<td>✓ Harder to constrain the work – volume could spiral – risk of completion</td>
</tr>
<tr>
<td>✓ May help to broaden solar thermal energy research group into multidisciplinary realm</td>
<td>✓ Validation and experimentation is either abstract or requires significant financial investment or is of timeframe not in PhD realm</td>
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✓: Addressed in planning
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Conclusions

• Looking towards 2050 – For SA to take the opportunity
• Macro level research – has risks
• Work starting with models – showing good promise
• Ability to simulate is important for SA – many topics!
• We believe the small steps approach and getting plants built is critical
• Appropriate technology, skills, locations for the rollout

• Feedback Welcome
Thank You