Solar thermal concentrators: Capturing the sun for large scale power generation and energy export

Keith Lovegrove
Solar Thermal Group – Dept of Engineering CECS, ANU
(http://engnet.anu.edu.au/DEresearch/solarthermal)
Concentrating Solar Power is:

- Parabolic Trough
- Paraboloidal Dish
- Central Receiver
- Linear Fresnel
We are in the middle of an Energy Revolution
Human changes to GHG concentrations are changing the climate.

Variations of the Earth's surface temperature for:

(a) the past 140 years

Data from thermometers.

 IPCC 2001
Demand exceeds supply for oil
Where will future energy come from?

- Gas
- Nuclear Fission
- Nuclear Fusion
- Clean Coal
- Biomass
- Wind
- Hydro
- Wave
- Tidal
- Solar
- Other
Where will future energy come from?

- Gas – Reserves are finite
- Nuclear Fission – Waste, weapons and supply issues
- Nuclear Fusion – Always decades away!
- Clean Coal – When and at what cost?
- Biomass – Land and food constraints
- Wind – The success story of the last 2 decades
- Hydro – Ecological and social effects
- Wave – limited
- Tidal - limited
- Solar - ?????
- Other - ?
The real debate Australia needs to have.
Concentrating Solar Power

Parabolic Trough

Paraboloidal Dish

Central Receiver

Linear Fresnel
Five Years Ago CSP and SolarPACES were almost Declared Dead

Big Dish snares $7m ray of sunshine

By Jessica Wright

The Federal Government's efforts to tackle climate change have produced a $7 million grant based on a revolutionary solar power storage system developed at the Australian National University.

Five projects have received Australian Government grants totaling $75.6 million, under the Commonwealth Government's Advance Electricity Storage scheme. The funding, among others, will help assess and develop storage technologies that will enhance reliability, reduce costs and carbon emissions and provide a strong base on which to grow its own industry and expand opportunities overseas, he said.

"The ANU energy storage system is a large solar dish that concentrates the sun's rays into a chemical reaction, providing adequate heat to split water into hydrogen and nitrogen gases. These gases can be stored indefinitely and when power is required, electricity can be made from the hydrogen using a fuel cell in the same way as coal, nuclear or gas fuelled power stations do," Dr Lovegrove said.

"It is emission-free power generation on a large scale. The system is comparable to wind turbine energy production, but the energy can be kept.

Solar company Wizard Power is the research group's business partner.

Today CSP makes Headlines on National Newspaper Cover Pages

Slide courtesy of Michael Geyer
History: Solar 1, 10MWe tower system in California – now mothballed
History II: 354MWe “SEGS” plants going strong after 20 years
Steam turbines are the dominant power house.
Accionna; Nevada Solar One

- 64 MW$_e$
- Solar Field: 357200m$^2$
- Started Feb 06, Commissioned 2 June 07

Slide courtesy of R. Buch, DLR Germany
USA: 64MW Nevada Solar One

- 357,200 m² Solar Field, 30 Minutes Storage
- No fossil fuel
- Long term Power Purchase Agreement signed with Nevada Power and Sierra Pacific
- 1st STARTUP June 2006
First commercial Power Tower, Abengoa’s PS10 started operation near Seville, Spain in 2007.

<table>
<thead>
<tr>
<th>Technology</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Receiver Technology</td>
<td>Saturated Steam</td>
</tr>
<tr>
<td>Receiver Geometry</td>
<td>Cavity 180°, 4 Panels: 5.40m x 12.00m</td>
</tr>
<tr>
<td>Heliostats</td>
<td>624 @ 121m²</td>
</tr>
<tr>
<td>Thermal Storage Technology</td>
<td>Water/Steam</td>
</tr>
<tr>
<td>Thermal Storage Capacity</td>
<td>20MWh, 50min @ 50% Rate</td>
</tr>
<tr>
<td>Steam Cycle</td>
<td>40bar 250°C, 2 Pressures</td>
</tr>
<tr>
<td>Electric Generation</td>
<td>6.3kV, 50Hz -&gt; 66kV, 50Hz</td>
</tr>
<tr>
<td>Land</td>
<td>55HAs</td>
</tr>
<tr>
<td>Annual Electricity Production</td>
<td>23.0GWh</td>
</tr>
</tbody>
</table>
624 x 120m² Solucar heliostats
and PS20 is now under construction
- 510,120m² Solar Field and 7.5 hours Storage
- 176 GWh annual production, 12% gas
- EPC Cost 260Mio Euro first Plant
- 5Mio EU Grant for AndaSol-1
- Financial Closure 31.5.2006, NTP 1.7.2006
- 1st STARTUP SCHEDULED 1.7.2008
Compact Linear Fresnel Array (CLFR)

Aiming for 36.5\textsubscript{e}MW\textsubscript{e} at Liddell power station in NSW

www.solarheatpower.de/
PSA Test facility: Dish Array, front to back;
Eurodish x 2, Distal I, Distal II x 3
- 130m² dish
- Photovoltaic receivers
- 480 x concentration
- 24kWₑ
- Multiple units in central Australian remote communities
Andasol 1, Granada, Spain, 50 MW with heat storage, parabolic trough
Andasol 2, Granada, Spain, 50 MW with heat storage, parabolic trough
Andasol 3, Granada, Spain, 50 MW with heat storage, parabolic trough
La Risca 1, Spain, 50 MW, parabolic trough
Solnova 1, Spain, 50 MW, parabolic trough
Solnova 3, Spain, 50 MW, parabolic trough
Energia Solar De Puertollano SA, Spain, 50 MW, parabolic trough
Extresol 1, Spain, 50 MW, parabolic trough
Hassi R'mel, Hassi R’mei, Algeria, 20 MW steam input for gas powered plant, parabolic trough
PS20 solar power tower, Spain, Seville, 20 MW, power tower design
Beni Mathar Plant, Morocco, 20 MW for hybrid power plant, technology unknown
Solar Tres Power Tower, Spain, 17 MW with heat storage, power tower design
Keahole Solar Power, Hawaii, 1 MW, MicroCSP parabolic trough design [12]

Under construction (if you believe Wikipedia)
http://en.wikipedia.org/wiki/List_of_solar_thermal_power_stations#cite_note-19 accessed 10/10/08
Future Prospects – lessons from wind

Annual and cumulative global wind energy development.


The Decreasing Cost of Wind Power Generation
Assessment of Parabolic Trough and Power Tower Solar Technology Cost and Performance Forecasts

Sargent & Lundy LLC Consulting Group
Chicago, Illinois

Source: Sargent & Lundy, 2003
CSP Market Outlook

Source: Sargent & Lundy, 2003
Energy costs will decline as market penetration increases from:
Include UMPNER top end cost

Bottom end includes non-commercial discount rate

Wizard Power’s target cost range for big dish

Costs from UMPNER
Solar Thermal at ANU
Our history – White Cliffs 14 dish system
ANU 400m$^2$ Big Dish concentrator

Rim angle: 46.6°
Focal length: 13.1 m
Concentration ratio: >1000
Weight: 19t (dish) 50t (foundation)
Output: 320 kWth @ 500°C; 5MPa
## Why Dishes?

<table>
<thead>
<tr>
<th></th>
<th>Trough</th>
<th>Tower</th>
<th>Dish 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>System</td>
<td>SEGs VI</td>
<td>SolarTres</td>
<td>Serg&amp;Lund</td>
</tr>
<tr>
<td></td>
<td>Serg&amp;Lund</td>
<td>Serg&amp;Lund</td>
<td>ANU</td>
</tr>
<tr>
<td>Size</td>
<td>30 MWe</td>
<td>13.6 MWe</td>
<td>10 MWe</td>
</tr>
<tr>
<td>Solar Field Optical Efficiency</td>
<td>0.533</td>
<td>0.56</td>
<td>0.85</td>
</tr>
<tr>
<td>Receiver thermal efficiency</td>
<td>0.729</td>
<td>0.783</td>
<td>0.9</td>
</tr>
<tr>
<td>Transient effects</td>
<td>0.961</td>
<td>0.995</td>
<td>0.92</td>
</tr>
<tr>
<td>Piping loss efficiency</td>
<td>1</td>
<td>0.983</td>
<td>1</td>
</tr>
<tr>
<td>Storage Efficiency</td>
<td>1</td>
<td>0.983</td>
<td>1</td>
</tr>
<tr>
<td>Turbine power cycle efficiency</td>
<td>0.35</td>
<td>0.405</td>
<td>0.35</td>
</tr>
<tr>
<td>Electric loss efficiency</td>
<td>0.827</td>
<td>0.864</td>
<td>0.86</td>
</tr>
<tr>
<td>Power plant availability</td>
<td>0.98</td>
<td>0.92</td>
<td>0.94</td>
</tr>
<tr>
<td><strong>Annual Solar to Electric Eff</strong></td>
<td><strong>10.59%</strong></td>
<td><strong>13.81%</strong></td>
<td><strong>19.14%</strong></td>
</tr>
</tbody>
</table>
Why Dishes II?

• 1500+ suns = high temperatures = solar driven chemical reactions
Why Big Dishes?

Variation in $R^3$ dependence

Normalised cost / unit area

Dish Radius (m)
ANU’s Thermochemical Energy Storage System

\[ \text{NH}_3 + 66.8\text{kJ/mol} \rightleftharpoons \frac{1}{2}\text{N}_2 + \frac{3}{2}\text{H}_2 \]
Array of ANU's 400m² Paraboloidal Solar Collectors

Reactants (NH$_3$ + H$_2$ + N$_2$)
Storage & Transfer Network (Natural Gas Pipeline)

Builds on 100 Years of industrial ammonia production

......For 24 Hour Solar Power
Wizard Power and ANU

- Wizard Power Pty Ltd established 2005
- Exclusive licence to ANU dish technology
- AusIndustry REDI project:
  - $3.5m to a $7m project
  - Build new dish (x2), progress business, move gasification and ammonia R&D forward
- Australian Greenhouse Office AEST project:
  - $7.4m to a $14.8m project over 4 years,
  - Demo 4 dishes with ammonia based energy storage
  - Siting in Whyalla
The Gen II Big Dish
(the slightly bigger dish)

- A 494m$^2$, 13.4m focal length, Altitude Azimuth tracking dish
- Completely re-engineered for mass production
- 380 identical spherical 1.17m x 1.17m mirror panels
- Formed on an accurate jig
- Space-frame based on circular pipe with simple welded joins
Systems design begins with Customer Needs

The Dish / Solar concentrator

- Provides electricity and other energy services sustainably
- Generates with the lowest possible Levelised Energy Cost
- Is reliable
- Has minimal risk of failure in first system
- Is inspiring
- Attracts investors
- Allows land to be used for other purposes
- Can be operated with minimal training
- Is safe
- Can be applied to a range of uses
Iterative nature of the system design process....

Spiral Process Model

Need

- Requirements
- Function Definition
- System Requirements Determination
- System Analysis
- Trade-Off Studies
- Evaluation and Optimization

- Design
- Select
- Equipment Definition
- System Specification
- System Prototype
- Conceptual Review
- Test and Review
- Formal Design Review
- Implementation

Evaluation

Synthesis

Analysis
Subsystems

- Mirrors
- Structure
- Foundations
- Actuation
- Receiver
- Conversion
Geometry options included..

Balanced dish

3 pole hanging dish

Mushroom dish

Rolling dish

Polar Equatorial dish
Site works started Feb 08...
This bit because all of North Canberra’s sewage passes through a pipe under here.
Getting back to the subject of exports....
A gas powered future?

About 107,000 PJ of reserves = Aust total primary energy for 20 years, or replace coal exports and primary energy for <10 years.
Coal gives us 3.9$/GJ
Uranium gives us 0.12$/GJ
If all coal exports replaced we would be down 23$b/year!
Australia as the future manufacturing powerhouse of the world?

mmmm........
Surely we have something to offer?

**Yearly Insolation, kWh/m²**

- Below 900
- 900
- 1300
- 1800
- 2200
- 2600
In one hour, the amount of sunlight falling upon the earth is close to the total energy used by the world’s population in one year.
Solar Power station to provide all of Australia’s energy needs?

Legend
- greater than 24MJ/m²/day
- less than 24 but greater than 23MJ/m²/day
- less than 23 but greater than 22MJ/m²/day
- less than 22 but greater than 20MJ/m²/day
- less than 20 but greater than 18MJ/m²/day
- less than 18 but greater than 16MJ/m²/day
- less than 16MJ/m²/day

138km x 138km, 20% coverage of land with 20% efficient collectors
Solar Gasification

- \( C + 2H_2O \leftrightarrow CO_2 + 2H_2 \)
  take 176kJ/mol from solar energy
- The hydrogen can be burnt / oxidized
  \( 2H_2 + O_2 \leftrightarrow 2H_2O \) giving off 570 kJ/mol
- Compared to just burning coal
  \( C + O_2 \leftrightarrow CO_2 \) giving off 394kJ/mol
- Le solar enhanced gas is \( \frac{176}{570} = 30\% \) solar energy,
- Other hydrocarbons are gasified according to:
  \[ C_xH_y + XH_2O \leftrightarrow XCO + (X+Y/2)H_2 \]
Big Dish solar thermal concentrators used to produce hydrogen and liquid fuels (e.g. methanol) from high temperature solar conversion of coal, gas & biomass. In the long term achieved by the thermochemical splitting of water.
Value-adding with Solar-Coal-to-Liquid Fuels
delivering an ultra clean liquid fuel with 30% energy content coming from solar

Solar Steam

Coal

Gasification +
Fischer-Tropsch Synthesis

Australian Thermal
Coal Exports
2005-06:
114.8 Million Tonnes
$7,668 Million

Australian Liquid
Fuel Exports:
229.6 Million Barrels
$22,997 Million
based on average Australian wholesale diesel cost $0.63/Litre
Solar Power station to provide all of Japan’s energy needs?

Legend

- greater than 24MJ/m²/day
- less than 24 but greater than 23MJ/m²/day
- less than 23 but greater than 22MJ/m²/day
- less than 22 but greater than 20MJ/m²/day
- less than 20 but greater than 18MJ/m²/day
- less than 18 but greater than 16MJ/m²/day
- less than 16MJ/m²/day

338km x 338km, 20% coverage of land with 20% efficient collectors
Conclusions

• CSP technology offers attractive route to large scale solar thermal power and solar fuels.

• ANU / Wizard Power Generation II Big dish nearing completion.

• Australia’s export income must evolve as world moves to low carbon future

• Uranium and Gas offer little prospect of replacing revenue from coal

• Our Solar resource is a major asset and liquid hydrocarbons may be the way to export it