I would like to cover

• Concentrating Solar Power technologies – the types
• The context – our solar resource
• Current developments around the world
• ANU’s concentrator technology
• Commercial prospects
• Commercialisation of ANU’s technologies

But first an advertisement....
Concentrating Solar Power

Parabolic Trough

International links via SolarPACES
(http://www.solarpaces.org)

Paraboloidal Dish
The latest technology.....
The Context

Yearly Insolation, kWh/m²

The Solar Resource
The Solar Resource

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

Compliments wind
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 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
Land Area for a Solar Future

• Assume:
  
  5000Wh/m²/day average insolation
  
  5000PJ = 5 \times 10^{18} \text{J} \text{ required per year}
  
  Conversion of solar energy at 20\% efficiency

• 5000Wh/m²/day \times 365\text{days} \times 0.2 = 1314\text{MJ/m²/year}

• \frac{(5 \times 10^{18} \text{J/\text{year}})}{(1.314 \times 10^9 \text{J/m²/\text{year}})} = 3.81 \times 10^9 \text{m}^2
  
  =3805\text{km}^2 = 61.7\text{km} \times 61.7\text{km}

• Allowing for spacing between collectors:
  
  @ 10\% coverage; 38052\text{km}^2 = 195\text{km} \times 195\text{km}
  
  @ 20\% coverage; 19026\text{km}^2 = 138\text{km} \times 138\text{km}
The Missing Solar Energy

• “Conventional” statistics essentially only measure fossil contributions to energy needs

• Count 200W per person for food grown with 2% efficiency, solar gain to existing houses, clothes lines etc.

• we are > 50% solar already!
100% Renewable Energy Achievable with today’s technology
Passive Solar Houses...

No extra energy needed for heating or cooling – solar hot water universal
Biofuels - The “Canola Corolla” - 5.3litre/100km on fish and chip oil
Solar / Electric / Hybrid cars

How far will you go to save the planet?

About 566 miles per tank.*
A Portfolio of Renewables for Power
Concentrating Solar Power developments around the world
- 130m$^2$ dish
- Photovoltaic receivers
- 480 x concentration
- 24kW$_e$
- Multiple units in central Australian remote communities
## Solar Thermal Power Plants under construction

<table>
<thead>
<tr>
<th>Project</th>
<th>Location</th>
<th>Initiator</th>
<th>Type</th>
<th>Component suppliers</th>
<th>Status</th>
<th>Design electrical output</th>
</tr>
</thead>
<tbody>
<tr>
<td>PS10</td>
<td>Sevilla (Spain)</td>
<td>Solúcar Energia</td>
<td>Saturated steam CRS</td>
<td>Abengoa</td>
<td>Start of operation 2006</td>
<td>11 MW</td>
</tr>
<tr>
<td>Saguaro Power Plant</td>
<td>Red Rock Arizona (USA)</td>
<td>Arizona Power Services</td>
<td>Parabolic Trough with ORC</td>
<td>Solargenix, Schott, Flabeg, Ormat</td>
<td>Start of operation 2006</td>
<td>1 MW</td>
</tr>
<tr>
<td>Solargenix</td>
<td>Nevada (USA)</td>
<td></td>
<td>Parabolic Trough with steam cycle</td>
<td>Solargenix, Schott, Flabeg</td>
<td>Erection started</td>
<td>64 MW</td>
</tr>
<tr>
<td>CLFR Liddell</td>
<td>Liddell (Australia)</td>
<td>Solar Heat and Power</td>
<td>Preheating for a coal power station; linear Fresnel collectors</td>
<td>Solar Heat and Power</td>
<td>First stage in operation (1 MW&lt;sub&gt;th&lt;/sub&gt;)</td>
<td>38 MW in the final stage of extension</td>
</tr>
</tbody>
</table>
PS10: the first new plant in Spain

- 11 MWe (gross) Solar tower plant near Seville is growing
- Total cost 36 Mio. Euro; EPC by ABENGOA group.
- Start of operation scheduled for summer 2006

Slide courtesy of R Buch, DLR Germany
PS10: the first new plant in Spain

- Conservative design: saturated steam receiver 250°C
- 50 min operation from storage at 50% load (Ruths type storage)
- Projected efficiencies: design 20%; mean annual value 15%
- 624 heliostats with 121 m²
Solargenix Nevada

Solargenix Project
"Nevada Solar One Power Project"

- 64 MW
- Solar Field: 357200m$^2$

Groundbreaking: February 2006

Slide courtesy of R Buch, DLR Germany
Aiming for 36.5MW e at Liddell power station in NSW

Compact Linear Fresnel Array (CLFR)

www.solarheatpower.de/
## Other current projects (1)

<table>
<thead>
<tr>
<th>Initiator</th>
<th>Location</th>
<th>Type and design power</th>
<th>Status</th>
<th>Planned start of operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar Millennium</td>
<td>Granada (Spain)</td>
<td>Parabolic trough 2 * 50 MW</td>
<td>Approval procedure completed</td>
<td>2008 / 2009</td>
</tr>
<tr>
<td>Solùcar Energia</td>
<td>Sevilla (Spain)</td>
<td>CRS: 2 * 20 MW, Parabolic trough: 3 * 50 MW</td>
<td>Land and grid connection ensured</td>
<td>CRS: 2007/08 Troughs: 2009/10</td>
</tr>
<tr>
<td>Israel Electric Company</td>
<td>Ashalim (Israel)</td>
<td>Parabolic trough 100 MW</td>
<td>Government has agreed to allocate the additional cost on the electricity price</td>
<td>n. a.</td>
</tr>
<tr>
<td>Stirling Energy Systems</td>
<td>Southern California (USA)</td>
<td>Dish / Stirling 850 MW</td>
<td>Power purchase agreement signed</td>
<td>1 MW in 2006 850 MW by 2010</td>
</tr>
<tr>
<td>Neal</td>
<td>Hassi R‘Mel (Algeria)</td>
<td>Parabolic trough 25 MW combined with 105 MW fossil PP</td>
<td>Request for proposal released</td>
<td>2008</td>
</tr>
</tbody>
</table>
## Other current projects (2)

<table>
<thead>
<tr>
<th>Initiator</th>
<th>Location</th>
<th>Type and design power</th>
<th>Status</th>
<th>Planned start of operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iranian Power Development Company</td>
<td>Yazd (Iran)</td>
<td>ISCCS: Parabolic trough 67 MW and 363 MW CC</td>
<td>Feasability study started</td>
<td>2009</td>
</tr>
<tr>
<td>World Bank</td>
<td>Sonora (Mexico)</td>
<td>ISCCS: Parabolic trough 30 MW and 470 MW fossil PP</td>
<td>Waiting for the approval by the Mexican Ministry of Finance</td>
<td>2009</td>
</tr>
<tr>
<td>World Bank</td>
<td>Kuraymat (Egypt)</td>
<td>ISCCS 150 MW: Parabolic trough 110 MW&lt;sub&gt;th&lt;/sub&gt; and CC</td>
<td>Request for prequalification released</td>
<td>2009</td>
</tr>
<tr>
<td>Eskom</td>
<td>Upington (South Africa)</td>
<td>CRS (molten salt) 100 MW</td>
<td>Feasability study completed</td>
<td>n.a.</td>
</tr>
</tbody>
</table>

Slide courtesy of R Buch, DLR Germany
### Other current projects (3)

<table>
<thead>
<tr>
<th>Initiator</th>
<th>Location</th>
<th>Type and design power</th>
<th>Status</th>
<th>Planned start of operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>World Bank</td>
<td>Mathania (India)</td>
<td>ISCCS: Parabolic trough 30 MW and 120 MW CC</td>
<td>Waiting for the commitment of the Indian government</td>
<td>2009</td>
</tr>
<tr>
<td>Stadtwerke Jülich</td>
<td>Jülich (Germany)</td>
<td>1.5 MW Solar Tower with open volumetric receiver</td>
<td>Waiting for the commitment of public authorities</td>
<td>2008</td>
</tr>
<tr>
<td>SENER</td>
<td>Spain</td>
<td>15 MW molten salt Solar Tower</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IBERDROLA</td>
<td>Almeria (Spain)</td>
<td>5 MW parabolic trough with direct steam generation</td>
<td>Project preparation</td>
<td></td>
</tr>
</tbody>
</table>
Our history – White Cliffs 14 dish system
ANU 400m² 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
System for BGU, Sde Boquer Israel
Glass on metal mirrors for troughs and dishes
Dish mirror panels

- Change from 54 to 216 identical mirror panels
- Design for mass production
Lunar Flux Mapping

The ANU 400m² Dish
PC with image capture card
and EPIX software
CCD VDO Camera
Flux mapping Target
Receiver
PV cell (radiometer)
DC
DC power supply
(LED light)
HP Digital Multi-meter
(measure voltage across the PV cell)
PC with image capture card and EPIX software

The ANU 400m² Dish

CCD VDO Camera

Flux mapping Target

PV cell (radiometer)
Investigation of Receiver Convection Loss

Virginia Magnitude (m/s)  Temperature (K)

φ=0°  φ=0°  φ=30°  φ=30°
Comparison of natural convection heat loss through the aperture for 400 m² dish receiver.
Transient System Modeling

Weather Data

Incident Radiation

User Input Table

Dish Component

Ambient Temperature

Dish Power

Receiver Aperture Diameter

Receiver Component

Temp_in, Flowrate_in, Pressure_in

Receiver Temp.

Thermal Losses

Useful Thermal Energy

Temp_out, Flowrate_out, Pressure_out

Temp_out, Pressure_out, Flowrate_out

Thermal Losses

Pipe Temp.

Steam Line Component

Temp_out, Pressure_out, Flowrate_out

Thermal Losses

Pipe Temp.

Steam Line Component
Transient System Modeling

Essential for business planning for large plants
Thermochemical Energy Storage

NH₃ + 66.8kJ/mol ⇌ 1/2N₂ + 3/2H₂
Array of ANU's 400 m² Paraboloidal Solar Collectors

Reactants (NH₃ + H₂ + N₂)
Storage & Transfer Network (Natural Gas Pipeline)

Ammonia Synthesis Reactor
Rankine Cycle Power Conversion Unit

......For 24 Hour Solar Power
Builds on 100 Years of industrial ammonia production
Commercial prospects for CSP – lessons from wind
S&L: “..CSP technology is a proven technology for energy production and that significant cost reductions are achievable assuming reasonable deployment of CSP technologies occurs.”
CSP Market Outlook

Cumulative Installed CSP & Wind Capacity

Source: Sargent & Lundy, 2003
Potential Cost Reductions

Energy costs will decline as market penetration increases from:

• Technical improvements
• Economies of scale and performance improvement with scale up
• Volume production
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Troughs</td>
<td>6.2 cents/kWh</td>
<td>2.8 GWe</td>
<td>4.3 cents/kWh</td>
<td>4.9 GWe</td>
</tr>
<tr>
<td>Towers</td>
<td>5.5 cents/kWh</td>
<td>2.6 GWe</td>
<td>3.5 cents/kWh</td>
<td>8.7 GWe</td>
</tr>
</tbody>
</table>
Levelised Energy Cost Curve & Path to Market

- Creation of technical and institutional experience
- Generation of a CSP market
- Early CSP mass market
- Near competitive and competitive market

LEC (cUS/kWh)

- 2005 to 2025

- CSP
- Fossil alternatives
## Commercialisation – Why Dishes?

<table>
<thead>
<tr>
<th>System</th>
<th>Trough</th>
<th>Tower</th>
<th>Dish</th>
<th>Dish 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>SEGs VI</td>
<td>SolarTres</td>
<td>Dish now</td>
<td>ANU</td>
<td>ANU</td>
</tr>
<tr>
<td>Size</td>
<td>30MWe</td>
<td>13.6MWe</td>
<td>1MWe</td>
<td>10MWe</td>
</tr>
<tr>
<td>Solar Field Optical Efficiency</td>
<td>0.533</td>
<td>0.56</td>
<td>0.85</td>
<td>0.85</td>
</tr>
<tr>
<td>Receiver thermal efficiency</td>
<td>0.729</td>
<td>0.783</td>
<td>0.85</td>
<td>0.9</td>
</tr>
<tr>
<td>Transient effects</td>
<td></td>
<td></td>
<td>0.92</td>
<td>0.92</td>
</tr>
<tr>
<td>Piping loss efficiency</td>
<td>0.961</td>
<td>0.995</td>
<td>0.961</td>
<td>0.961</td>
</tr>
<tr>
<td>Storage Efficiency</td>
<td>1</td>
<td>0.983</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Turbine power cycle efficiency</td>
<td>0.35</td>
<td>0.405</td>
<td>0.27</td>
<td>0.35</td>
</tr>
<tr>
<td>Electric loss efficiency</td>
<td>0.827</td>
<td>0.864</td>
<td>0.86</td>
<td>0.86</td>
</tr>
<tr>
<td>Power plant availability</td>
<td>0.98</td>
<td>0.92</td>
<td>0.94</td>
<td>0.94</td>
</tr>
<tr>
<td>Annual Solar to Electric Eff</td>
<td><strong>10.59%</strong></td>
<td><strong>13.81%</strong></td>
<td><strong>13.94%</strong></td>
<td><strong>19.14%</strong></td>
</tr>
<tr>
<td>ITEM</td>
<td>% Cost</td>
<td>Change for trough</td>
<td>Change for Central Receiver</td>
<td></td>
</tr>
<tr>
<td>-----------------------------</td>
<td>--------</td>
<td>-------------------</td>
<td>-----------------------------</td>
<td></td>
</tr>
<tr>
<td>Foundations</td>
<td>17.15%</td>
<td>0.5</td>
<td>2</td>
<td>34.30%</td>
</tr>
<tr>
<td>Baseframe</td>
<td>9.31%</td>
<td>0.5</td>
<td>1</td>
<td>9.31%</td>
</tr>
<tr>
<td>Centre hub</td>
<td>0.42%</td>
<td>0</td>
<td>1</td>
<td>0.42%</td>
</tr>
<tr>
<td>Horizontal pivots</td>
<td>0.86%</td>
<td>1</td>
<td>1</td>
<td>0.86%</td>
</tr>
<tr>
<td>Bogies</td>
<td>1.79%</td>
<td>0</td>
<td>1</td>
<td>1.79%</td>
</tr>
<tr>
<td>Dish Spaceframe</td>
<td>18.37%</td>
<td>0.5</td>
<td>1</td>
<td>18.37%</td>
</tr>
<tr>
<td>Mirror panels</td>
<td>22.54%</td>
<td>1.2</td>
<td>1</td>
<td>22.54%</td>
</tr>
<tr>
<td>Hydraulic system</td>
<td>12.74%</td>
<td>0.5</td>
<td>1</td>
<td>12.74%</td>
</tr>
<tr>
<td>Steam generating receiver</td>
<td>5.14%</td>
<td>1</td>
<td>0.5</td>
<td>2.57%</td>
</tr>
<tr>
<td>Rotary joints</td>
<td>1.64%</td>
<td>0.5</td>
<td>0</td>
<td>0.00%</td>
</tr>
<tr>
<td>Feedwater and steam lines</td>
<td>2.69%</td>
<td>1</td>
<td>0</td>
<td>0.00%</td>
</tr>
<tr>
<td>Instrumentation</td>
<td>7.35%</td>
<td>1</td>
<td>0.5</td>
<td>3.68%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100.00%</strong></td>
<td><strong>72.69%</strong></td>
<td><strong>106.58%</strong></td>
<td></td>
</tr>
</tbody>
</table>
Why Big Dishes?

Variation in $R^3$ dependence

Dish Radius (m)

Normalised cost / unit area

Series3
Series6
Series9
Series12
Series15

20%
30%
70%
First Dish Demo Plant

- Single row of dishes
- Commercial steam turbine or engine
- $100kW_e$ per dish
Wizard Power

★ Established in 2005

★ Partnership with ANU and an exclusive licence to:
  ★ The Big Dish solar thermal concentrator
  ★ Ammonia solar energy storage system
  ★ Mirror panel technology

★ A sister company of Wizard Information Services:
  ★ Design and delivery of comprehensive Information Technology solutions
  ★ More than 200 skilled personnel
  ★ Exports to Asia, Europe and North America
Mission Statement

To deliver solar power to the nation through open integrated solar energy solutions that incorporate agricultural, domestic and industrial systems.

Wizard Power is a division of Wizard Information Services. Wizard Power’s focus is to provide the integration services necessary to facilitate the development of integrated solar energy solutions to deliver solar power to the nation.

These integrated solar energy solutions involve the development of infrastructures that combine big dish solar energy collection systems with industrial and agricultural technologies.

These industrial and agricultural technologies include, desalination, sewerage treatment, chemical extraction, town heating, horticulture and aquaculture.

On a larger scale these integrated infrastructures can also include broad acre farming activities such as, fuel production from biomass, salinity reduction, alternative agricultural practices and products.

Wizard Power’s role includes the commercialisation of Australian best practice solar research. The Australian National University and Wizard have entered into an arrangement that will see the ANU's world leading research into big dish solar energy collection and storage systems incorporated in integrated solar energy solutions. More information on ANU's solar research is available in the Solar Technology section.
Wizard’s Goals

- Multi-megawatt baseload and peak power storage & generation - 10s MW ➔ GWs
  - Large arrays of dishes
  - Thermochemical energy storage

- Levelised energy cost competitive with wind

- Strategic R&D – eg. thermochemical gasification of hydrocarbons, gas turbine systems
Current Activities

★ Big Dish development (2005-2008)
  ★ 2nd Generation Big Dish with improvements in efficiency, manufacturability, maintainability (2005-2008)
  ★ $7 m project, supported by AusIndustry

★ Commercial demonstration prospects (2006-2010)
  ★ Integrated Big Dish power desalination project
  ★ Technical and commercial demonstration of a full scale ammonia storage system

★ Establishing partnerships and relationships
  ★ Dish manufacture and component supply
  ★ Project delivery
  ★ Financing and investment
Conclusions

• Concentrating Solar Power has strong future prospects
• ANU large dish technology offers attractive route to large scale solar thermal power.
• Ongoing R&D leading to performance improvements for dishes and troughs
• Thermochemical storage offers 24 hr operation in the future.
• ANU dish designs, ammonia system and dish mirrors licenced to Wizard Power