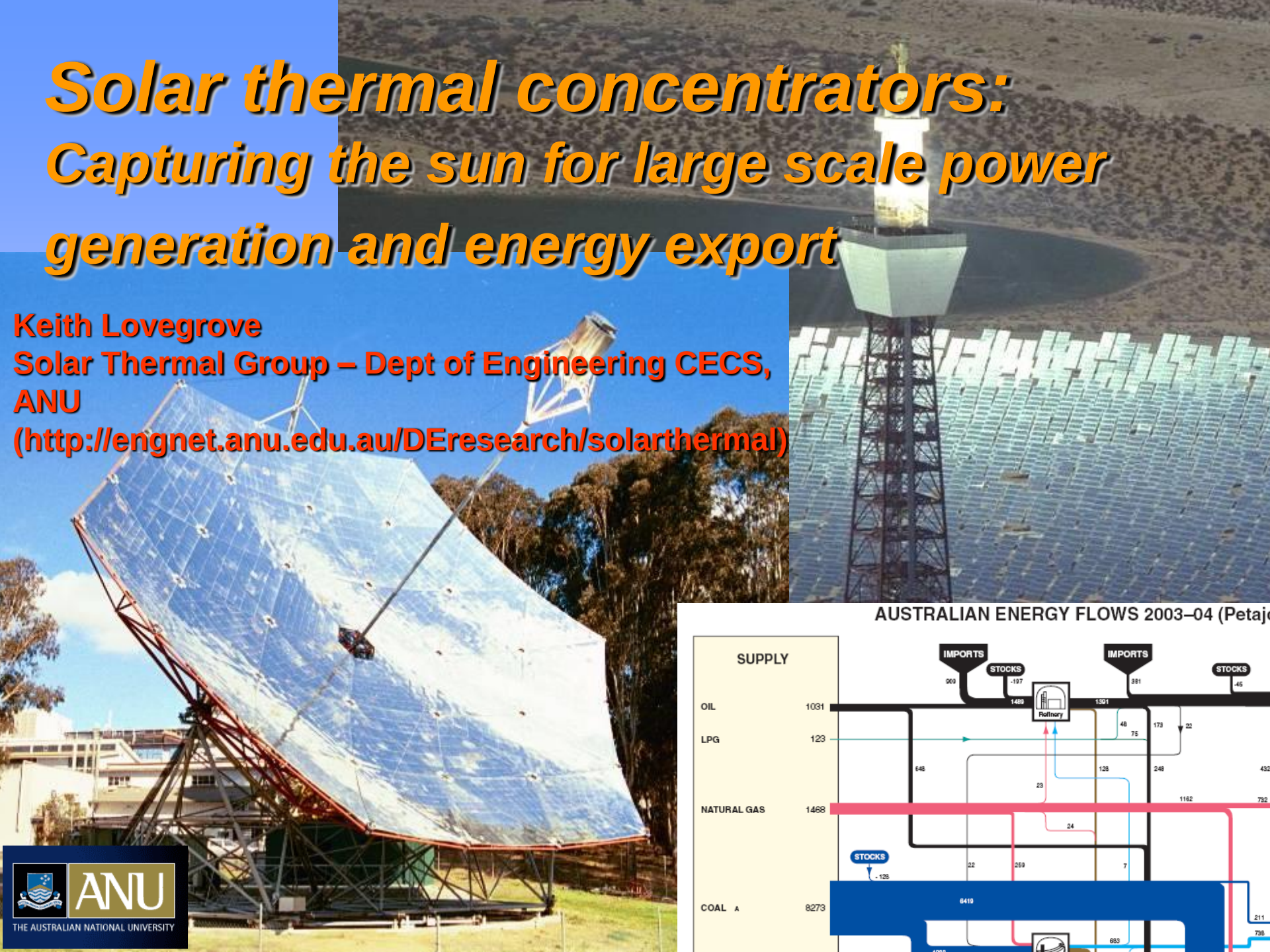
Solar thermal concentrators:
Capturing the sun for large scale power generation and energy export

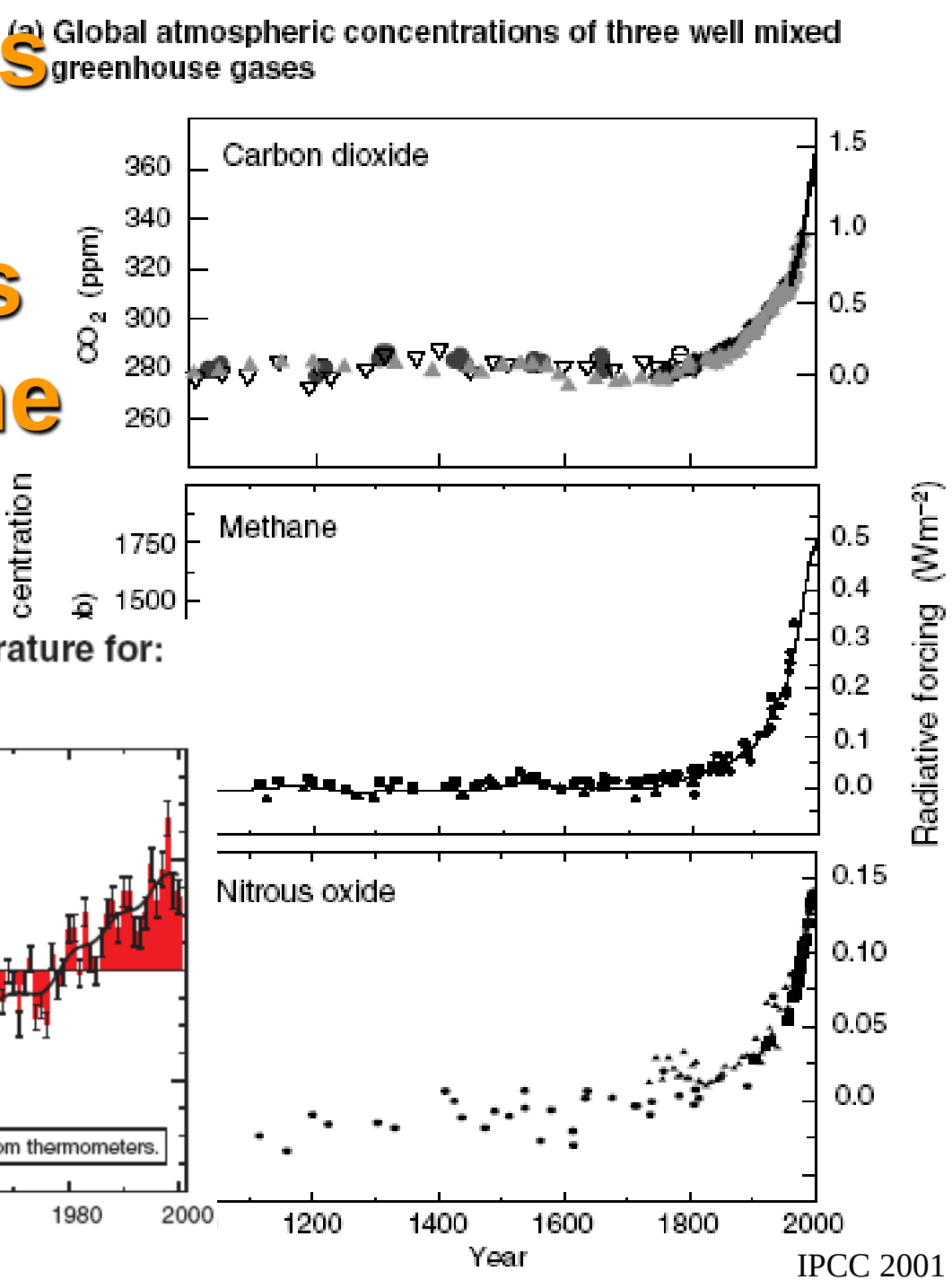
Keith Lovegrove
Solar Thermal Group – Dept of Engineering CECS, ANU
(http://engnet.anu.edu.au/DEresearch/solarthermal)



Concentrating Solar Power is:

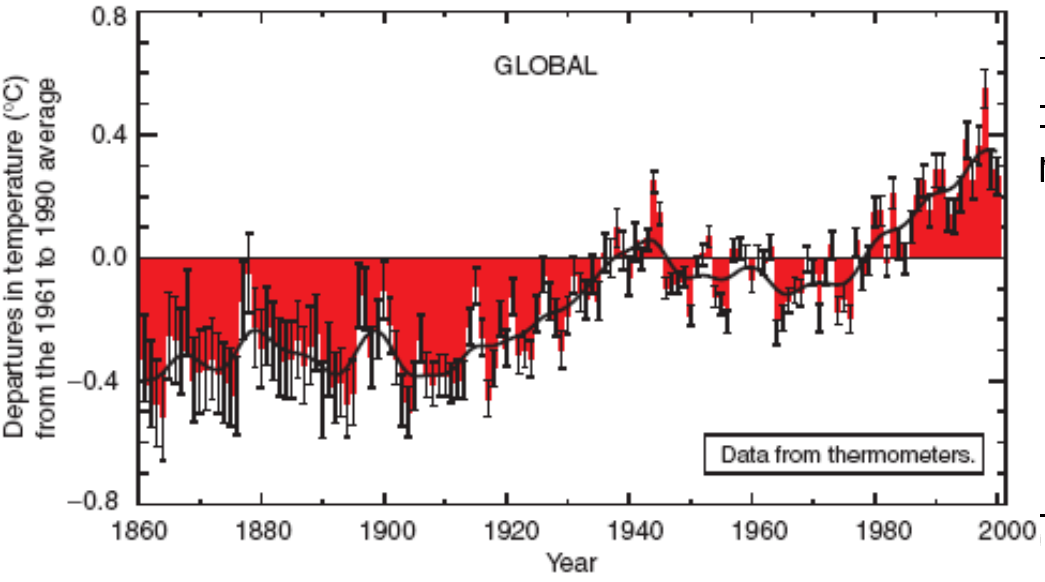
We are in the middle of an Energy Revolution

Human changes to GHG concentrations are changing the climate



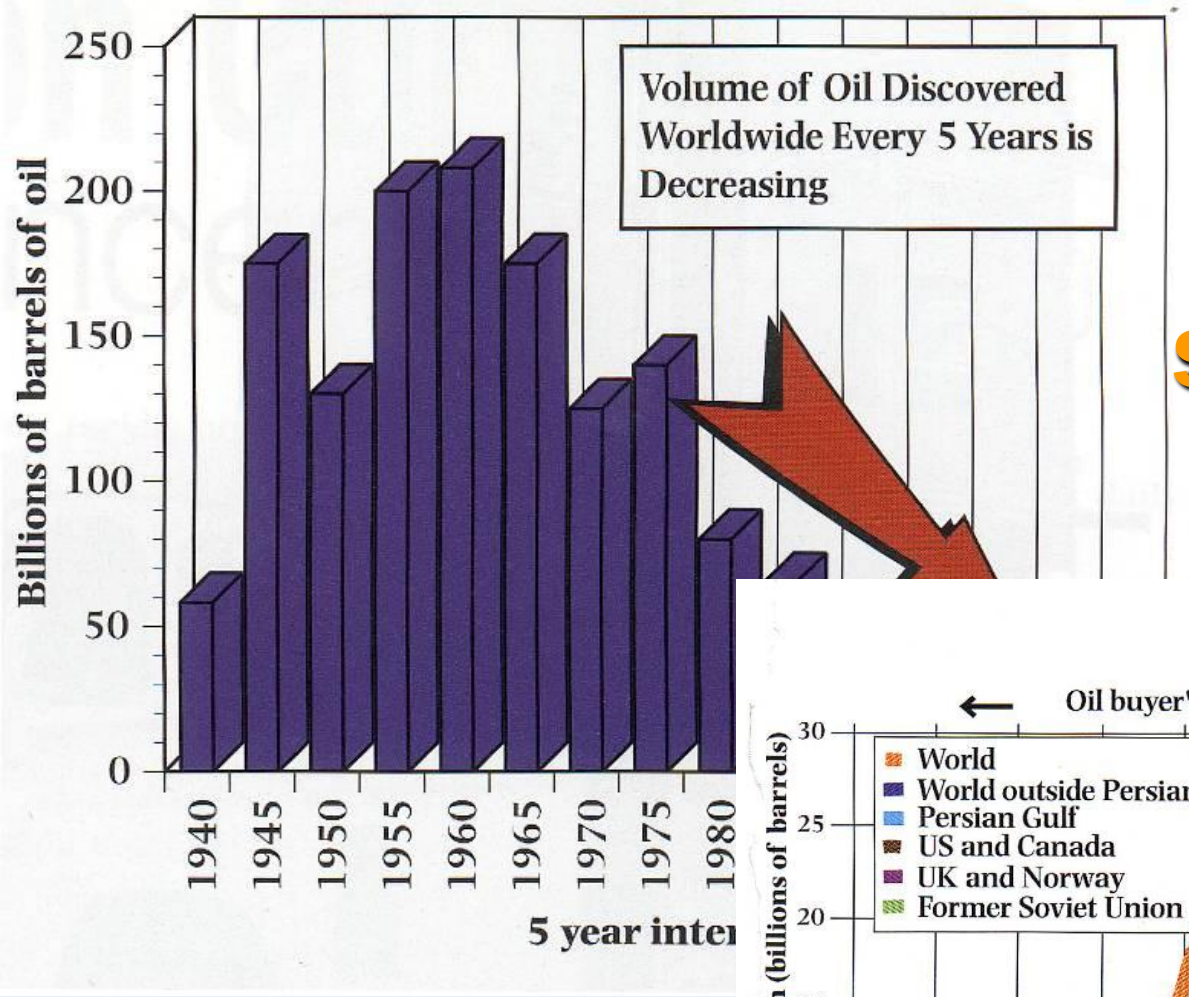
Variations of the Earth's surface temperature for:

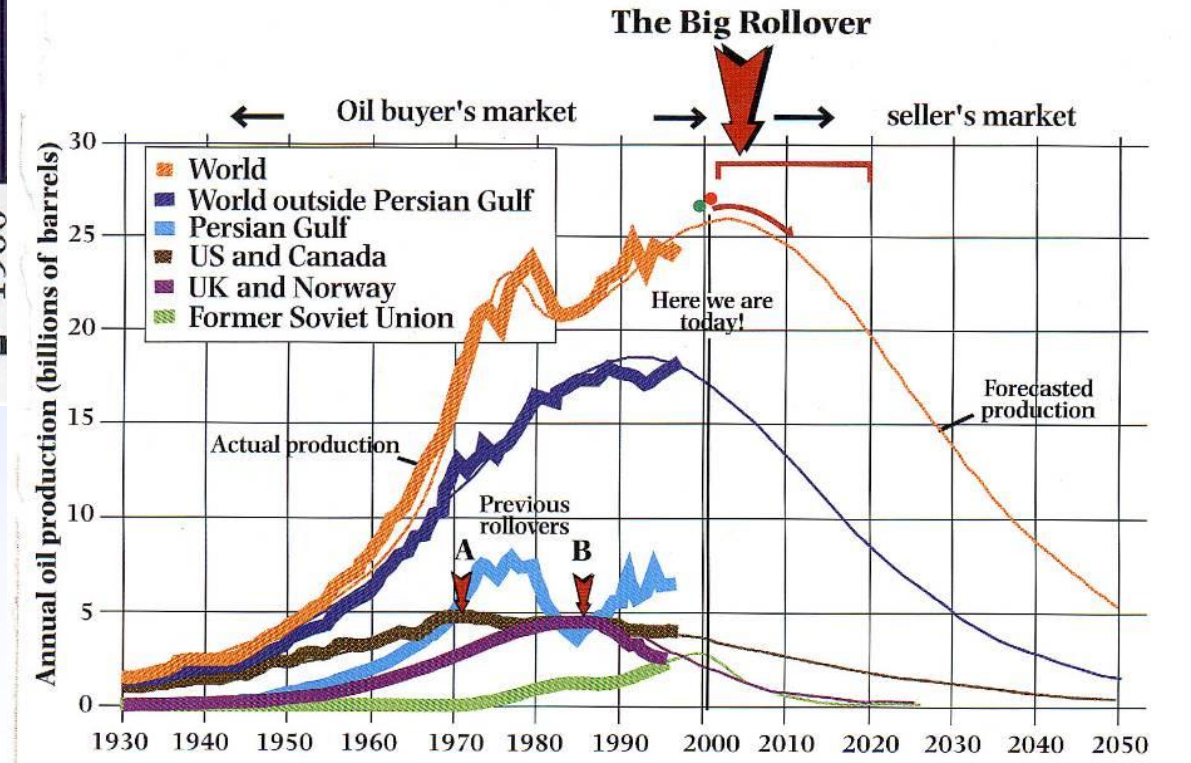
(a) the past 140 years



IPCC 2001

Demand exceeds supply for oil





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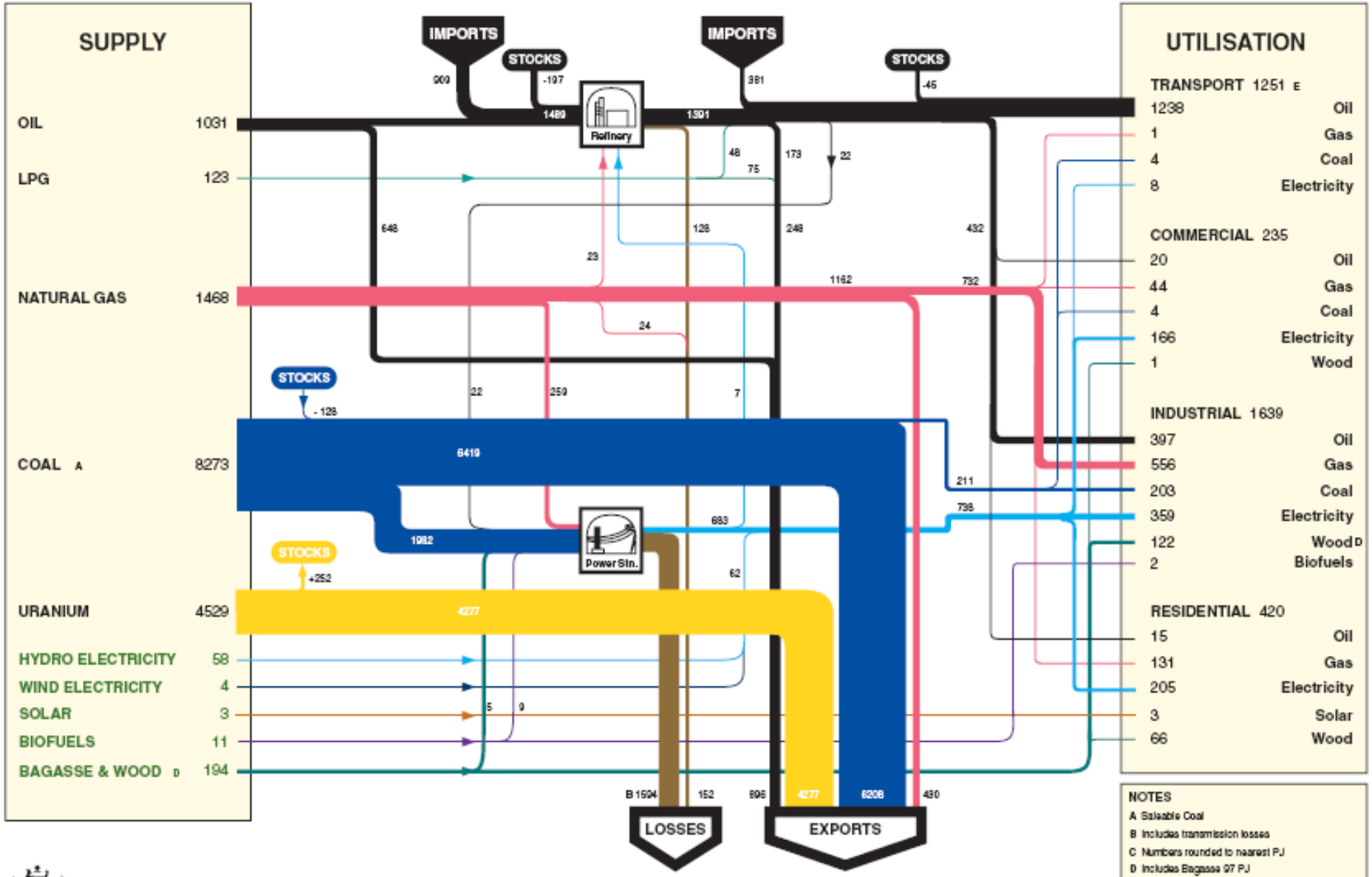
AUSTRALIAN ENERGY FLOWS 2003–04 (Petajoules)



NOTES
A Saleable Coal
B Includes transmission losses
C Numbers rounded to nearest PJ
D Includes Bagasse 97 PJ
E Transport includes 66 PJ LPG some imported
• Renewable supply sources coloured green
• Source: ABARE Code 13185

Total Primary Energy	Stock change & discrepancies	Imports	Losses	Exports	Total end-use
15694 =	+ 118	+ 1290	- 1746	- 11811	- 3545

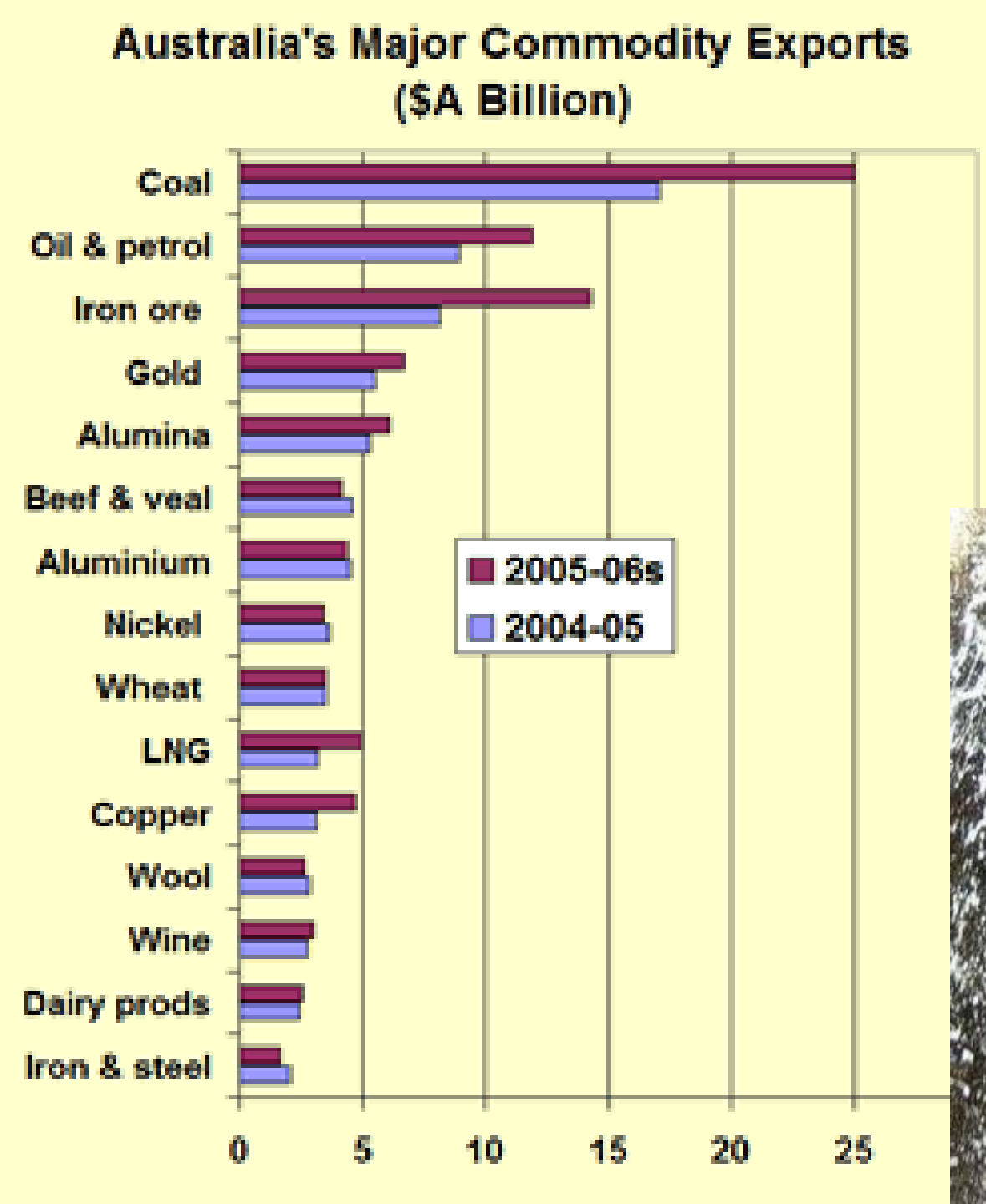
Australian Government
Office of the Renewable Energy Regulator
Geoscience Australia

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

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 totalling $17.6 million, under the federal Advance Electricity S to trial and dem efficient ways of st from renewable ener

The funding, annou by the federal Mi Environment and W Malcolm Turnbull, a Minister for Industr Resources, Ian McFar $2 billion Federal strategy to add change.

Electricity storage i by all renewable en worldwide and highlighted the bene of such systems.

"Demonstrating energy storage techn connected and rem supply application w

a strong base on which to grow its own industry and expand opportunities overseas," he said.

The ANU energy storage system is a large silver dish that concentrates the sun's rays into a chemical reactor, providing adequate heat to split ammonia into hydrogen and nitrogen gases.

These gases can be stored indefinitely and when power is required,

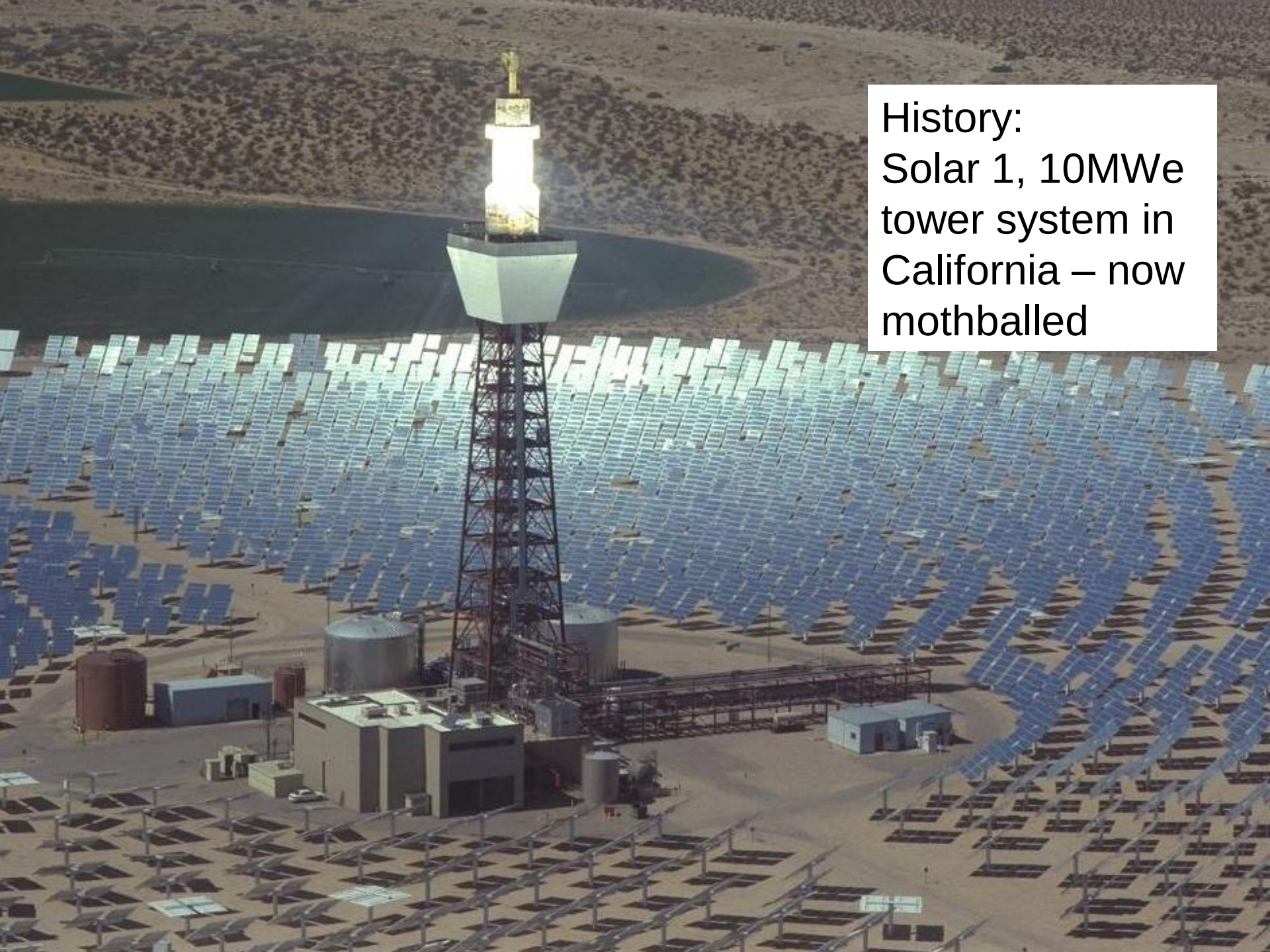
electricity and meet peak loads on-demand in the same way as coal, nuclear or gas fired power stations do," Dr Lovegrove said.

"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."

Canberra company Wizard Power is the research group's business

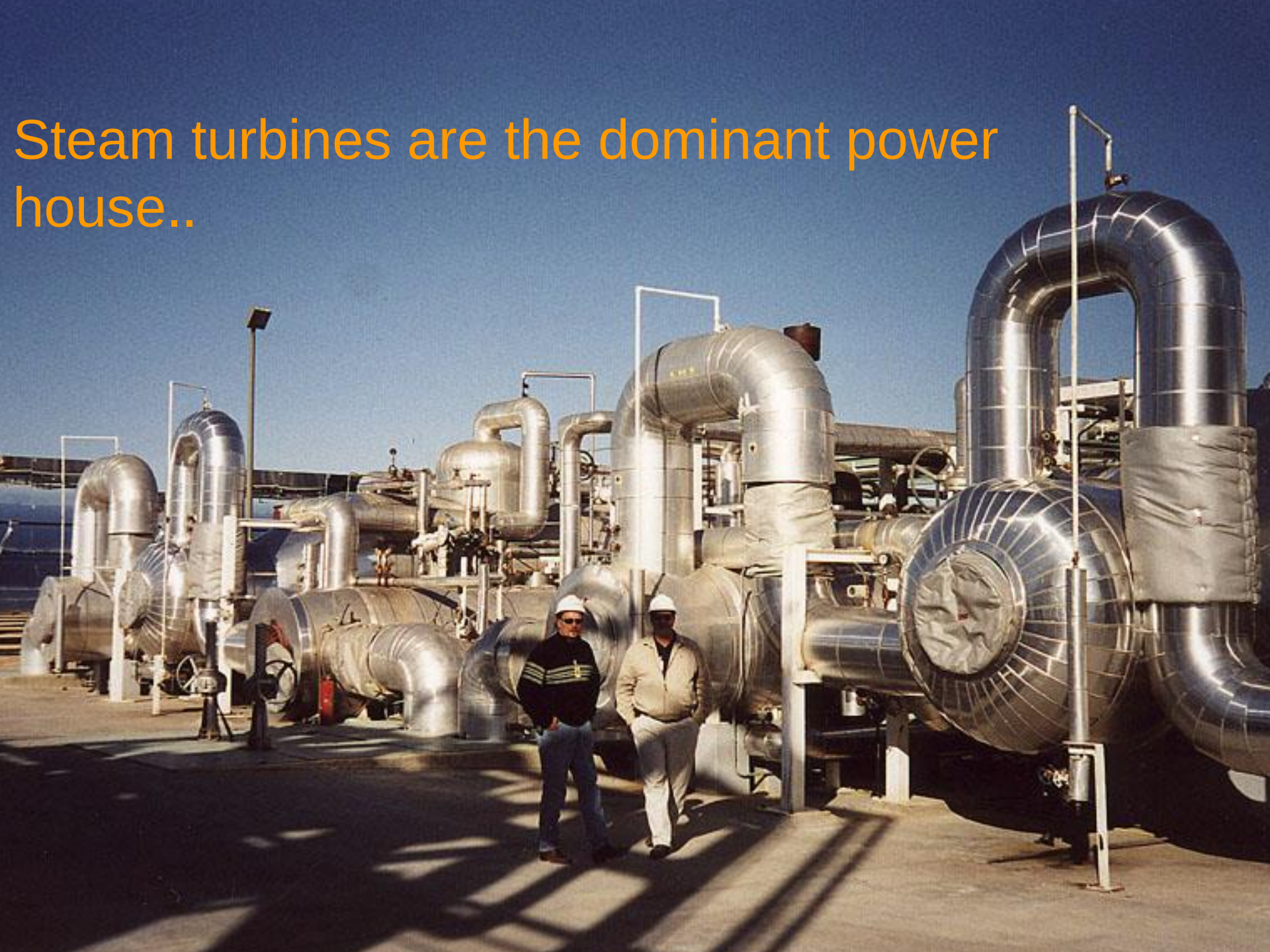
Today CSP makes Headlines on National Newspaper Cover Pages

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

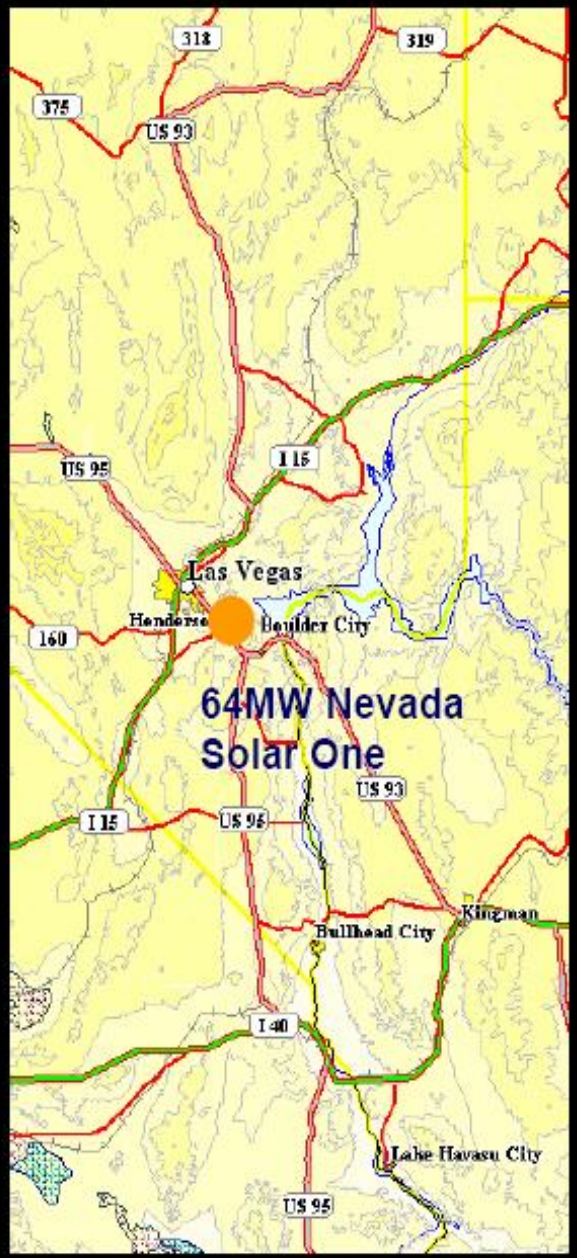
Steam turbines are the dominant power house..



Accionna; Nevada Solar One

- 64 MW_e
- Solar Field: 357200m^2
- Started Feb 06, Com-missioned 2June 07

Slide courtesy of R Buch, DLR Germany



USA: 64MW Nevada Solar One

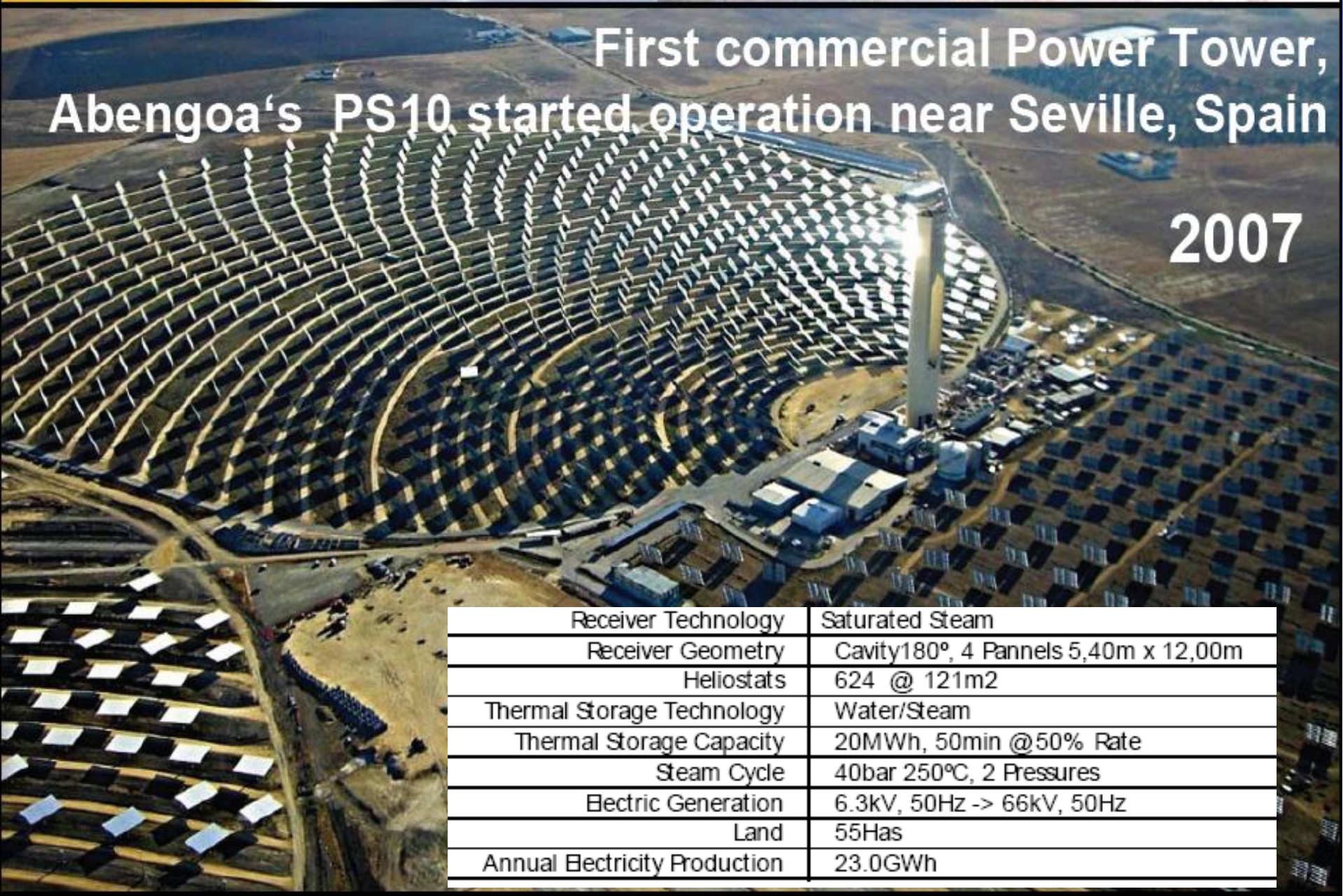
- 357.200m² Solar Field, 30 Minutes Storage
- No fossil fuel
- Long term Power Purchase Agreement signed with Nevada Power and Sierra Pacific
- 1st STARTUP June 2006

Slide courtesy of Michael Geyer

SolarPACES

First commercial Power Tower, Abengoa's PS10 started operation near Seville, Spain

2007



Receiver Technology	Saturated Steam
Receiver Geometry	Cavity180º, 4 Pannels 5,40m x 12,00m
Heliostats	624 @ 121m2
Thermal Storage Technology	Water/Steam
Thermal Storage Capacity	20MWh, 50min @50% Rate
Steam Cycle	40bar 250ºC, 2 Pressures
Electric Generation	6.3kV, 50Hz -> 66kV, 50Hz
Land	55Has
Annual Electricity Production	23.0GWh

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624 x 120m^2 Solucar heliostats

Slide courtesy of Michael Geyer

SolarPACES

- 510.120m² Solar Field and 7.5hours 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

Slide courtesy of Michael Geyer

SOLAR HEAT AND POWER

www.solarheatpower.de/

Compact Linear Fresnel Array (CLFR)

Aiming for 36.5MW$_e$ at Liddell power station in NSW

Ausra's 5MWe system
California, 23 Oct 2008

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PSA Test facility: Dish Array, front to back;

Eurodish x 2, Distal I, Distal II x 3

Solar Systems

www.solarsystems.com.au

- 130m^2 dish
- Photovoltaic receivers
- 480 x concentration
- 24kW$_e$
- Multiple units in central Australian remote communities

Under construction (if you believe Wikipedia)

http://en.wikipedia.org/wiki/List_of_solar_thermal_power_stations#cite_note-19 accessed 10/10/08

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'melHassi 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]

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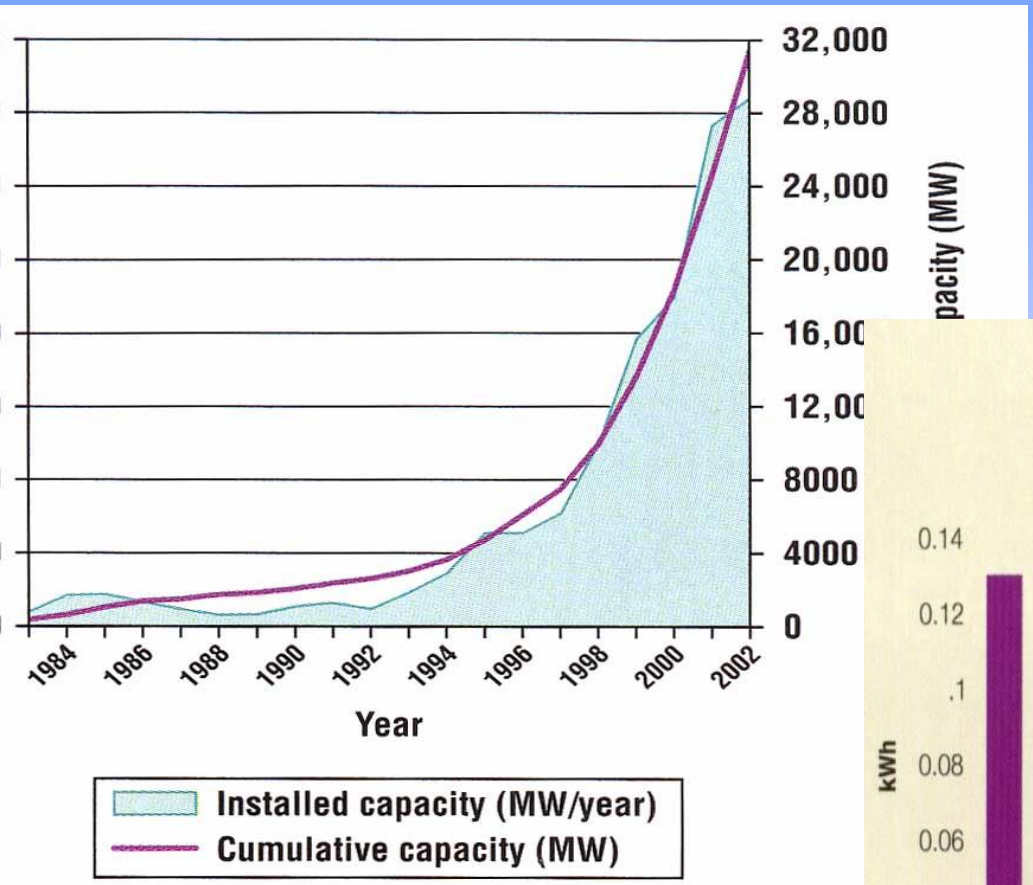
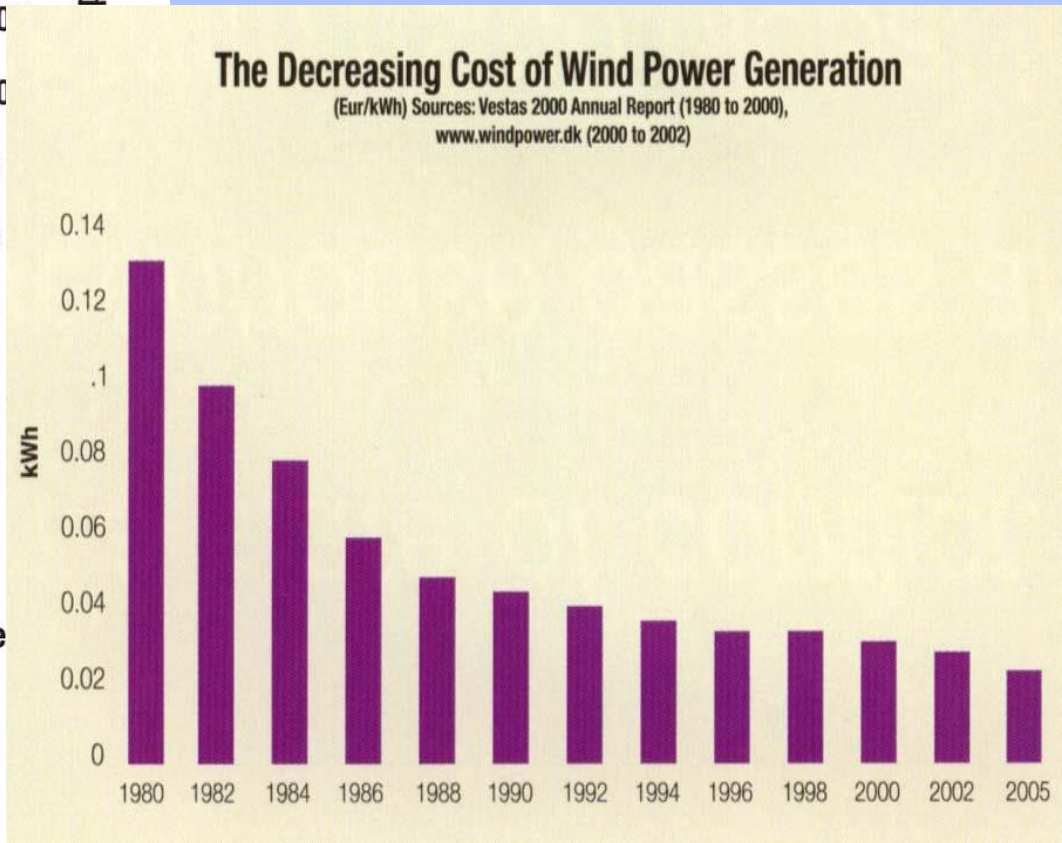
Future Prospects – lessons from wind



Annual and cumulative global wind energy developme
2. Source: BTM Consult ApS, March 2003



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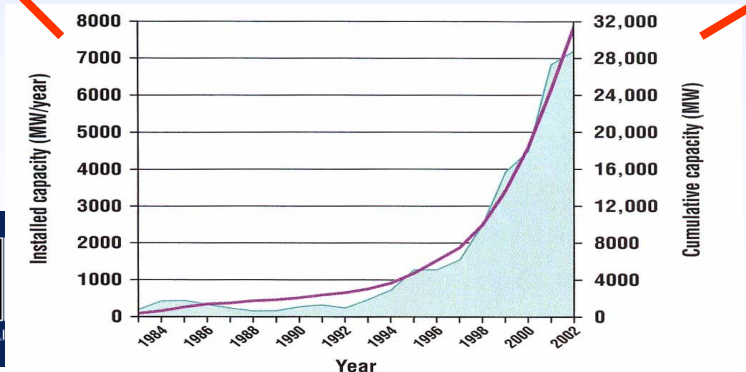
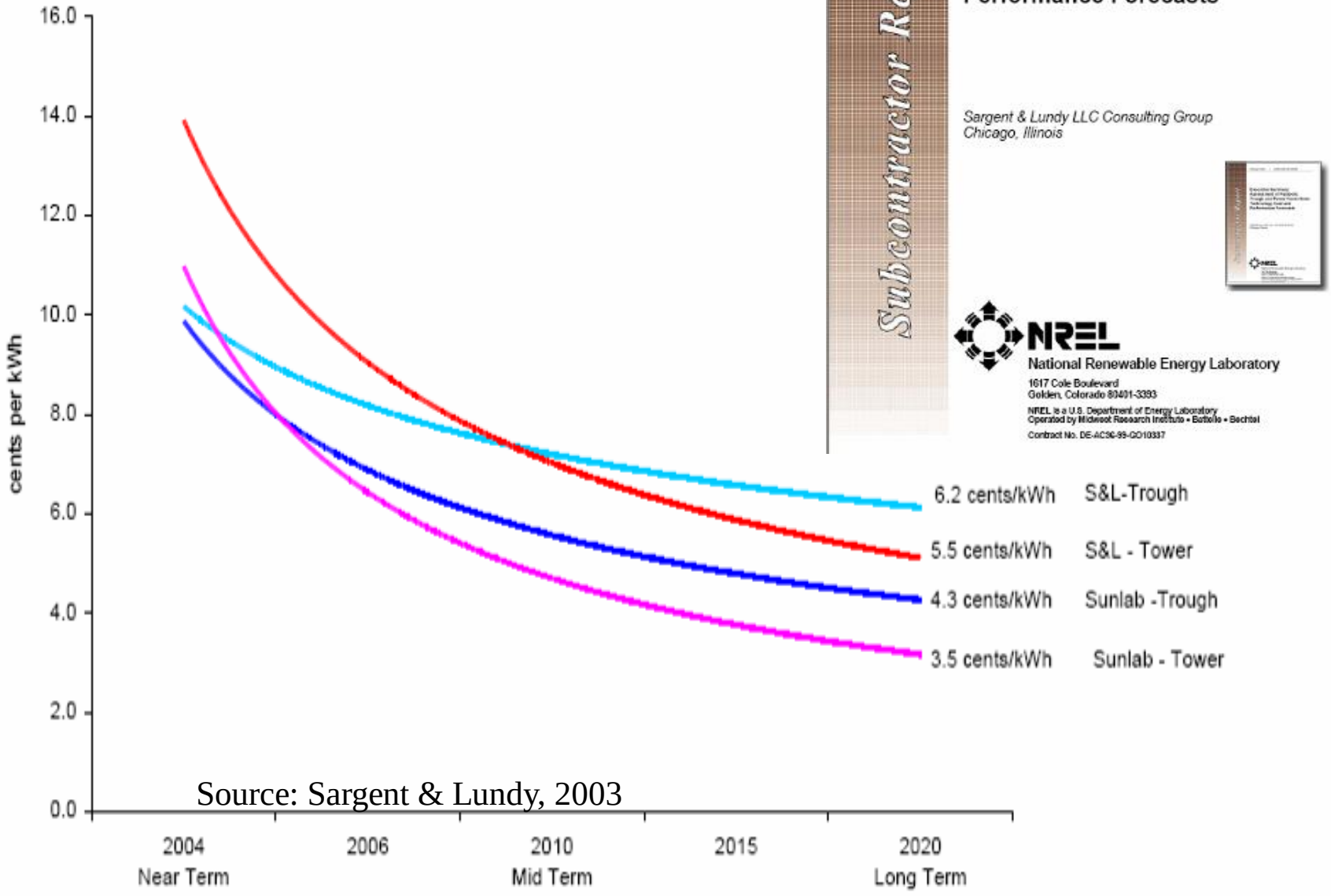


=1.3% global electricity



Source: Sargent & Lundy, 2003

October 2003 • NREL/SR-550-34440

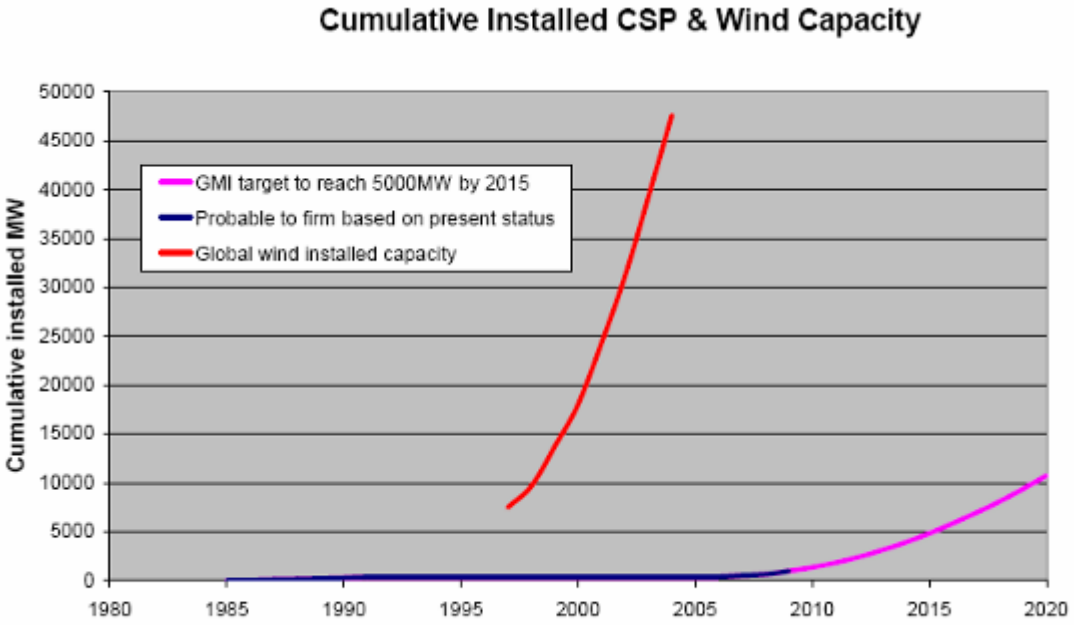
Subcontractor Report

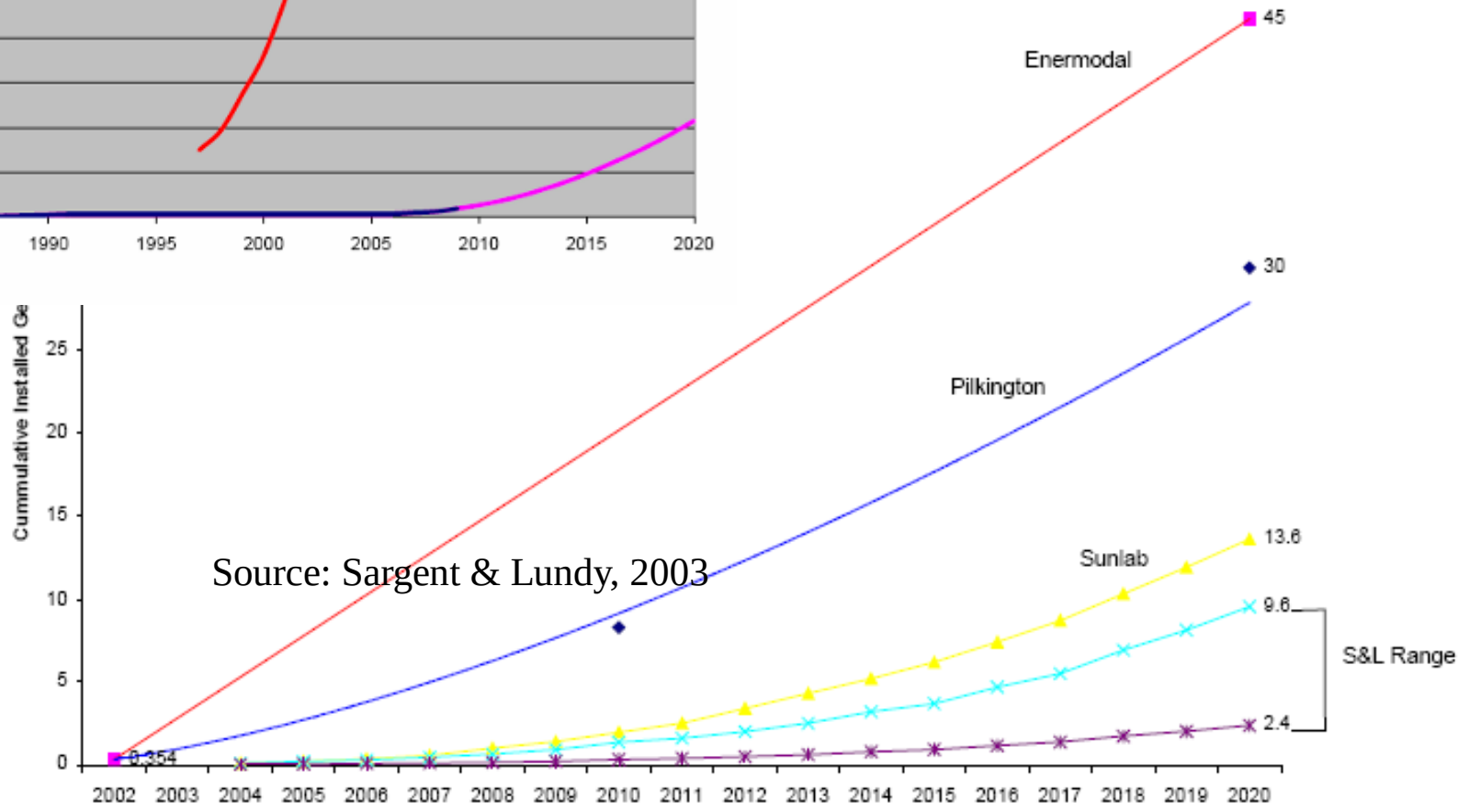
Assessment of Parabolic Trough and Power Tower Solar Technology Cost and Performance Forecasts

Sargent & Lundy LLC Consulting Group
Chicago, Illinois

NREL
National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, Colorado 80401-3393
NREL is a U.S. Department of Energy Laboratory
Operated by Midwest Research Institute • Battelle • Bechtel
Contract No. DE-AC36-99-GO10337

CSP Market Outlook





Source: Sargent & Lundy, 2003

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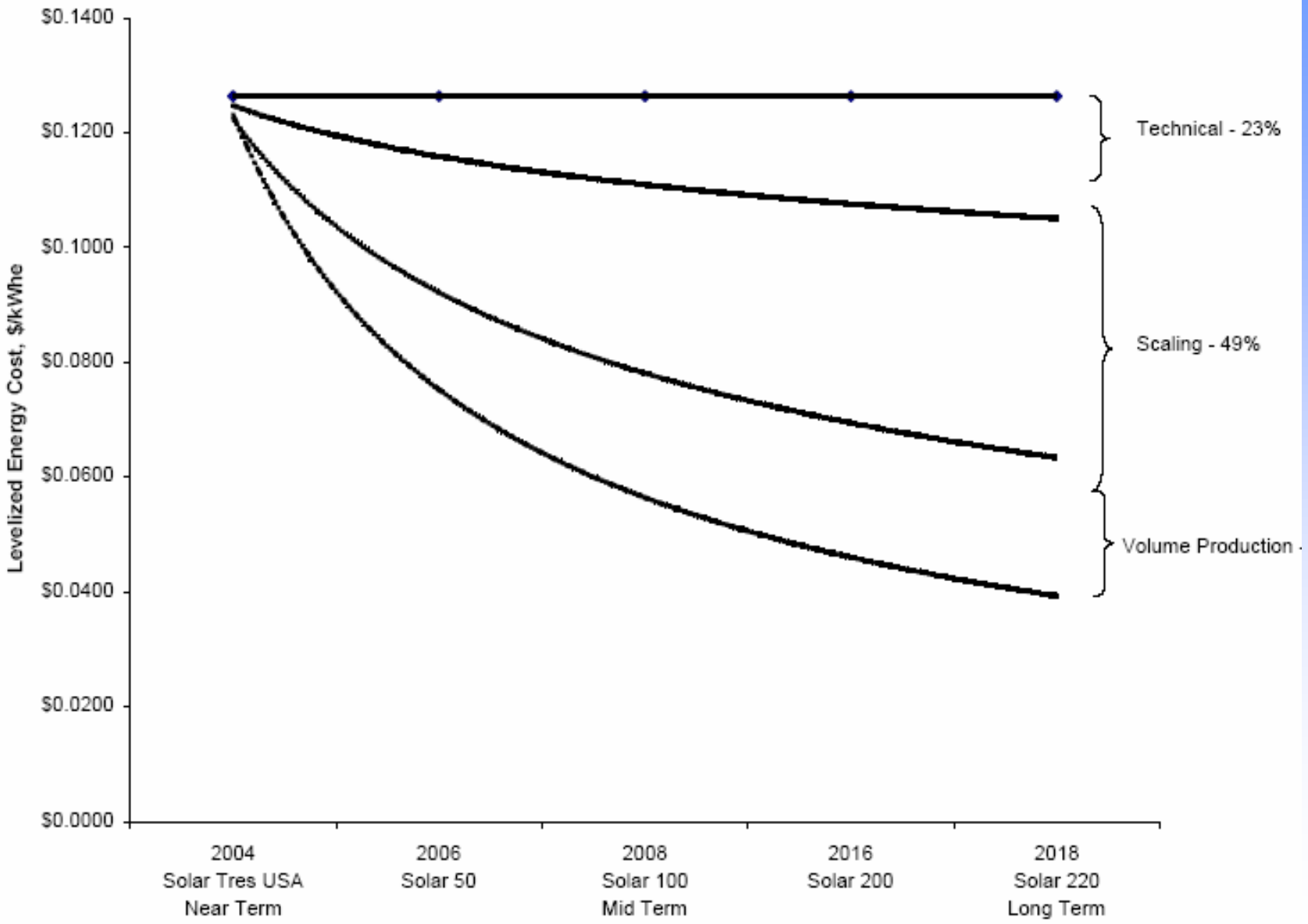
Energy costs will decline as market penetration increases from:



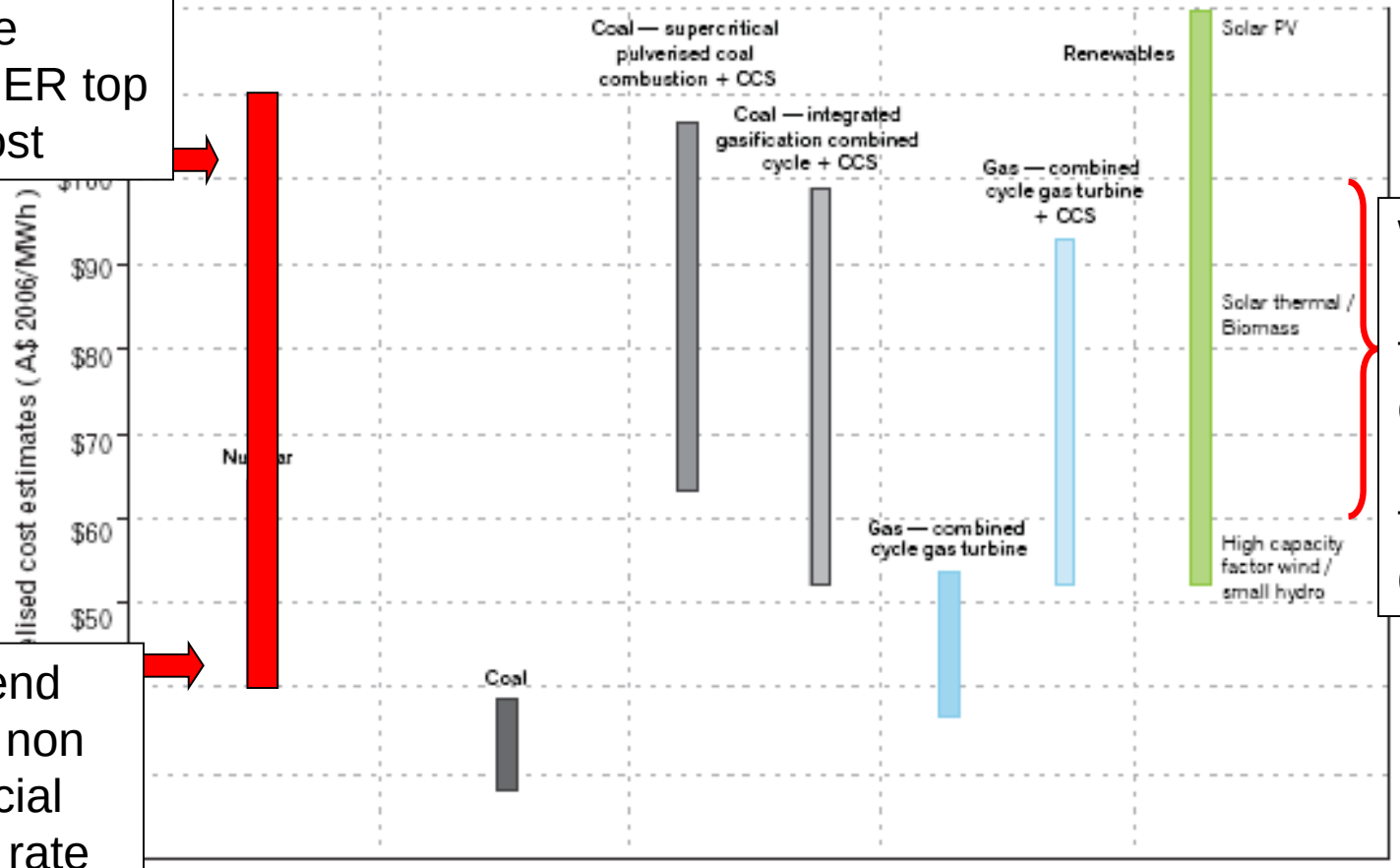
Costs from UMPNER

Include UMPNER top end cost

Bottom end includes non commercial discount rate

Wizard Power's target cost range for big dish

Figure 4.7 Levelised cost ranges for various technologies



uclear costs are settled down costs for new plant
CCS estimates are indicative only
Renewables have large ranges and substantial overlaps

MWh = megawatt hours; PV = photovoltaic

Source: EPRI study[74]

From UMPNER

THE AUSTRALIAN NATIONAL

Solar Thermal at ANU

Our history – White Cliffs 14 dish system

ANU 400m² Big Dish concentrator

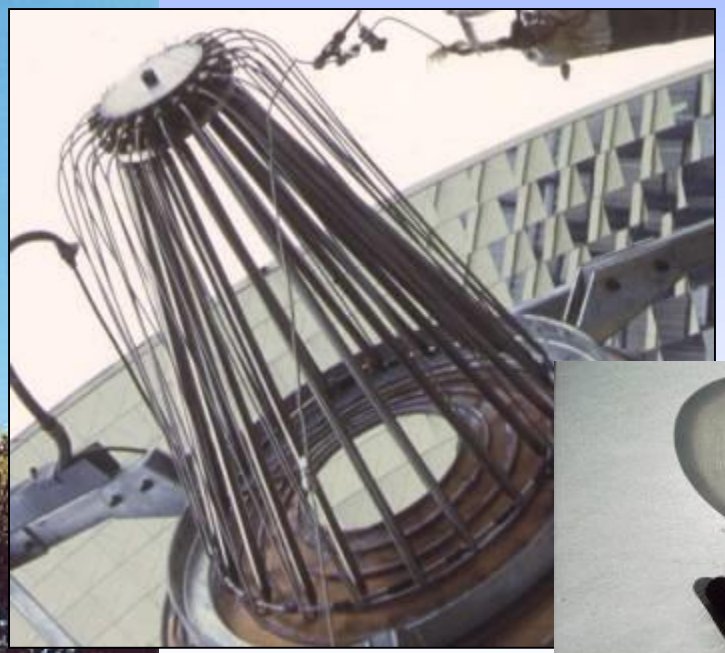
Rim angle:	**46.6°**
Focal length:	**13.1 m**
Concentration ratio:	**>1000**
Weight: 19t (dish) 50t (foundation)	
Output:	**320 kWth @ 500°C; 5MPa**

Why Dishes?

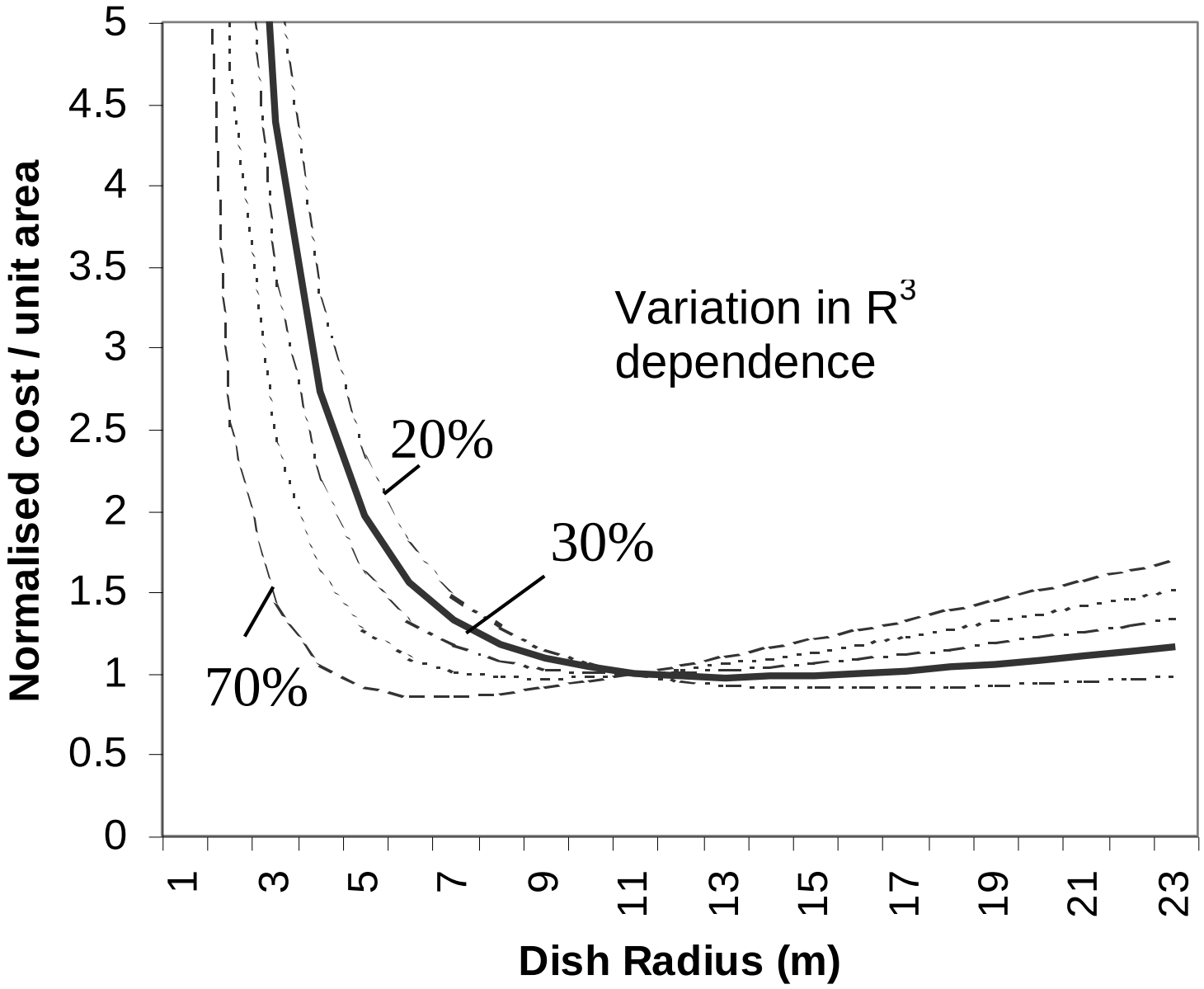
	Trough	**Tower**	
System	SEGs VI	SolarTres	Dish 10
	Serg&Lund	Serg&Lund	ANU
Size	30MWe	13.6MWe	10MWe
Solar Field Optical Efficiency	0.533	0.56	0.85
Receiver thermal efficiency	0.729	0.783	0.9
Transient effects			0.92
Piping loss efficiency	0.961	0.995	0.961
Storage Efficiency	1	0.983	1
Turbine power cycle efficiency	0.35	0.405	0.35
Electric loss efficiency	0.827	0.864	0.86
Power plant availability	0.98	0.92	0.94
Annual Solar to Electric Eff	**10.59%**	**13.81%**	**19.14%**

Why Dishes II?

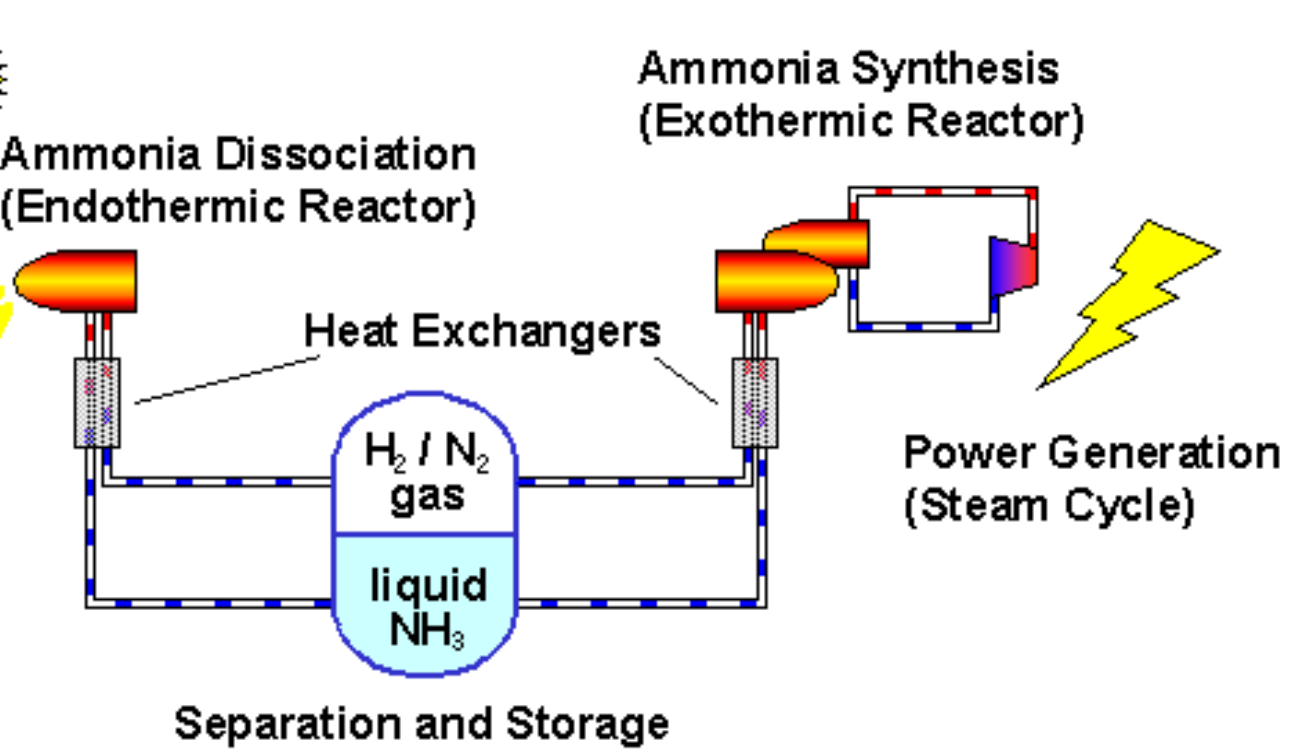
- 1500+ suns = high temperatures = solar driven chemical reactions



Why Big Dishes?



ANU's Thermochemical Energy Storage System



$$NH_3 + 66.8kJ/mol \rightleftharpoons 1/2N_2 + 3/2H_2$$

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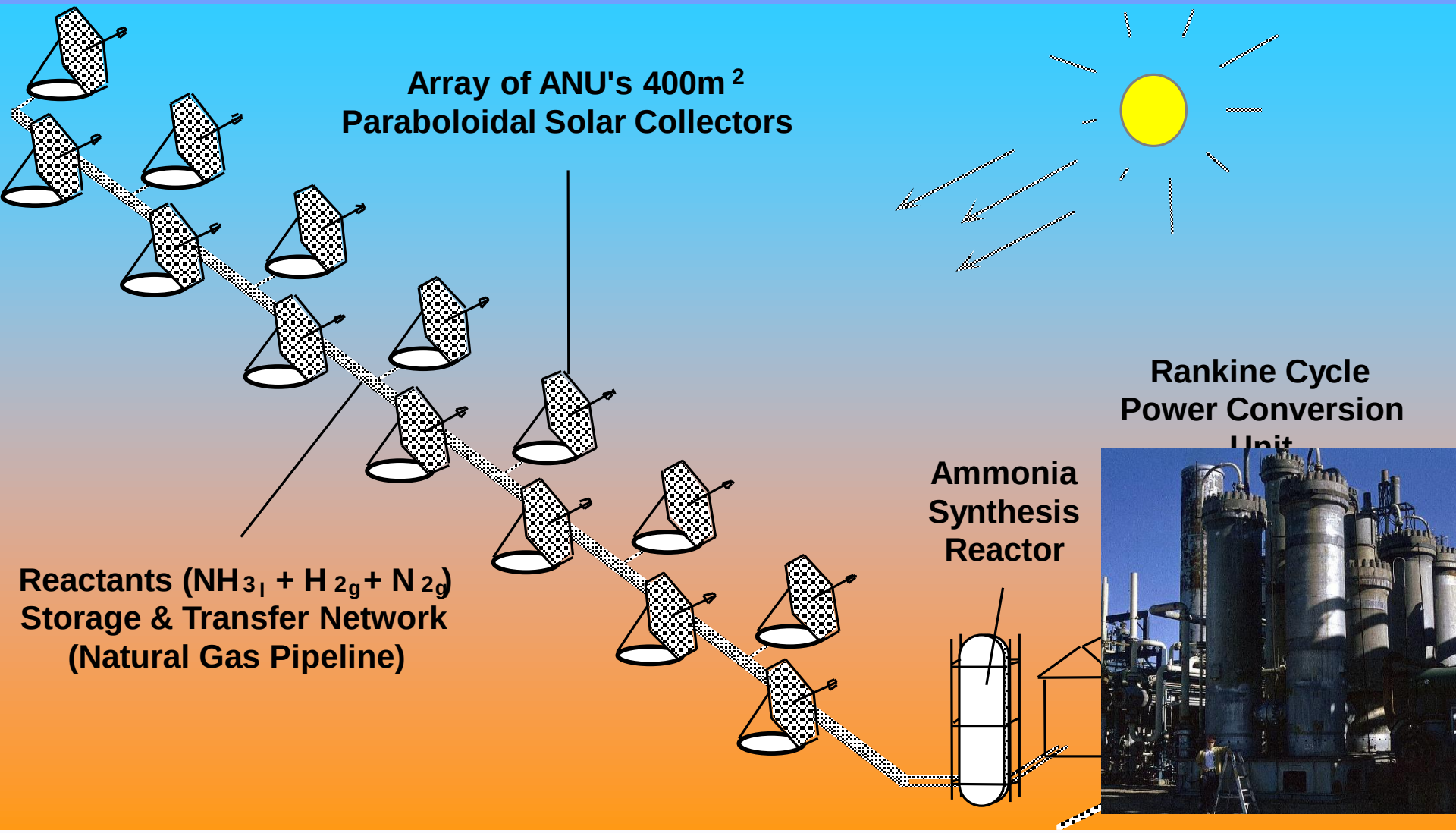
……For 24 Hour Solar Power



Builds on 100 Years of industrial ammonia production

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Wizard Power and ANU

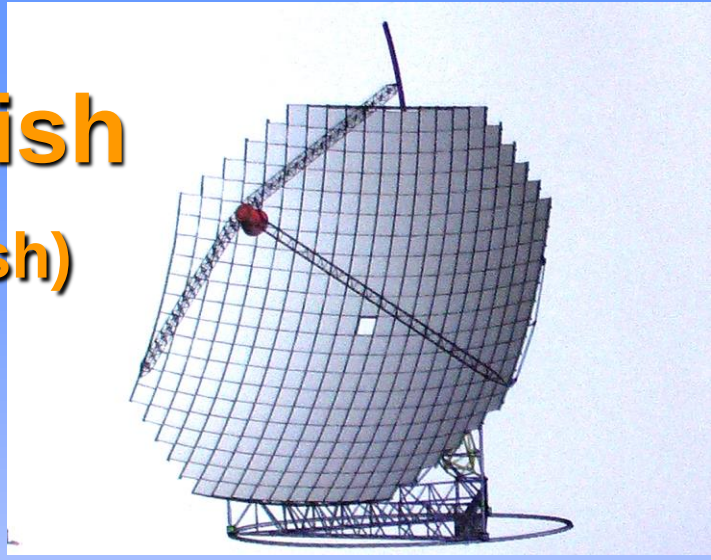
- **Wizard Power Pty Ltd established 2005**
- **Exclusive licence to ANU dish technology**
- **AusIndustry REDI project:**
  - **$3.5m to a $7m project**
  - **Build new dish (x2), progress business, move gasification and ammonia R&D forward**
- **Australian Greenhouse Office AEST project:**
  - **$7.4m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

ANU THE AUSTRALIAN NATIONAL UNIVERSITY

威圣能源 Wizard Power Delivering Solar Energy 24*7

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

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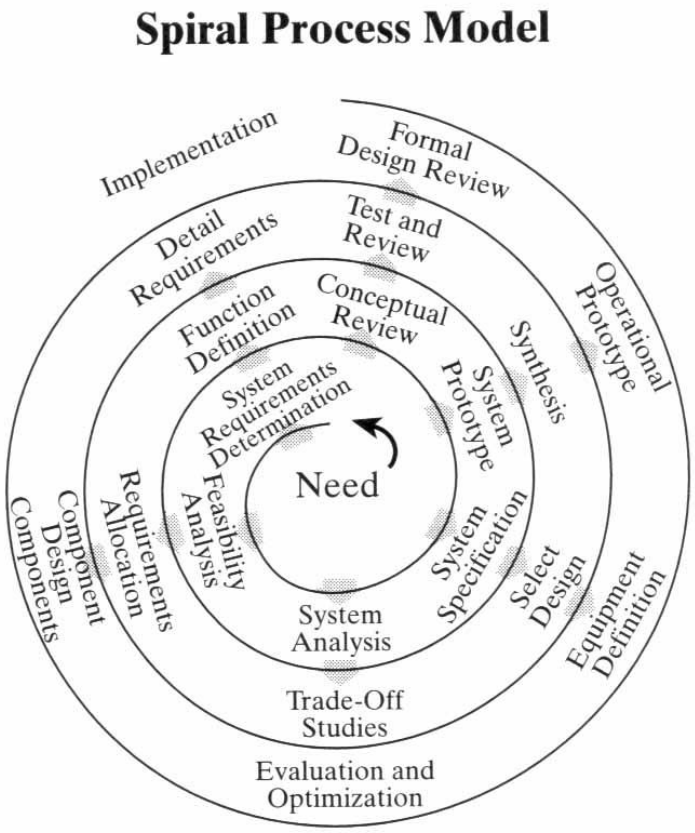
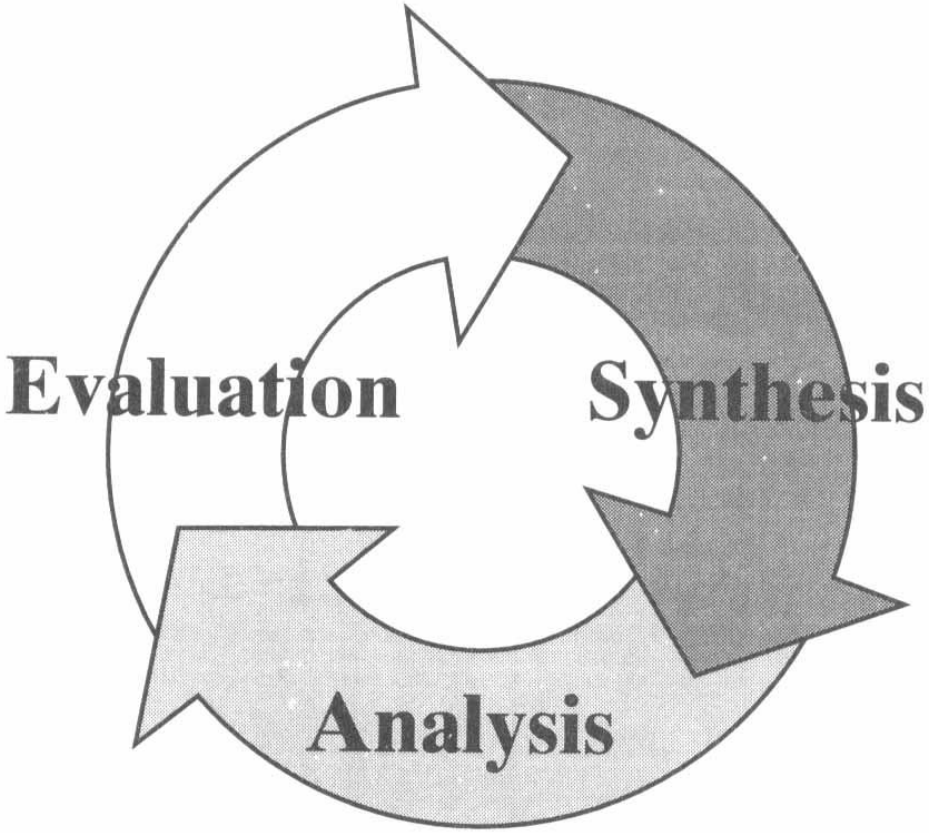
Systems design begins with Customer Needs

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….





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Subsystems

Mirrors

Receiver

Structure

Conversion

Foundations

Actuation

Geometry options included..

ANU
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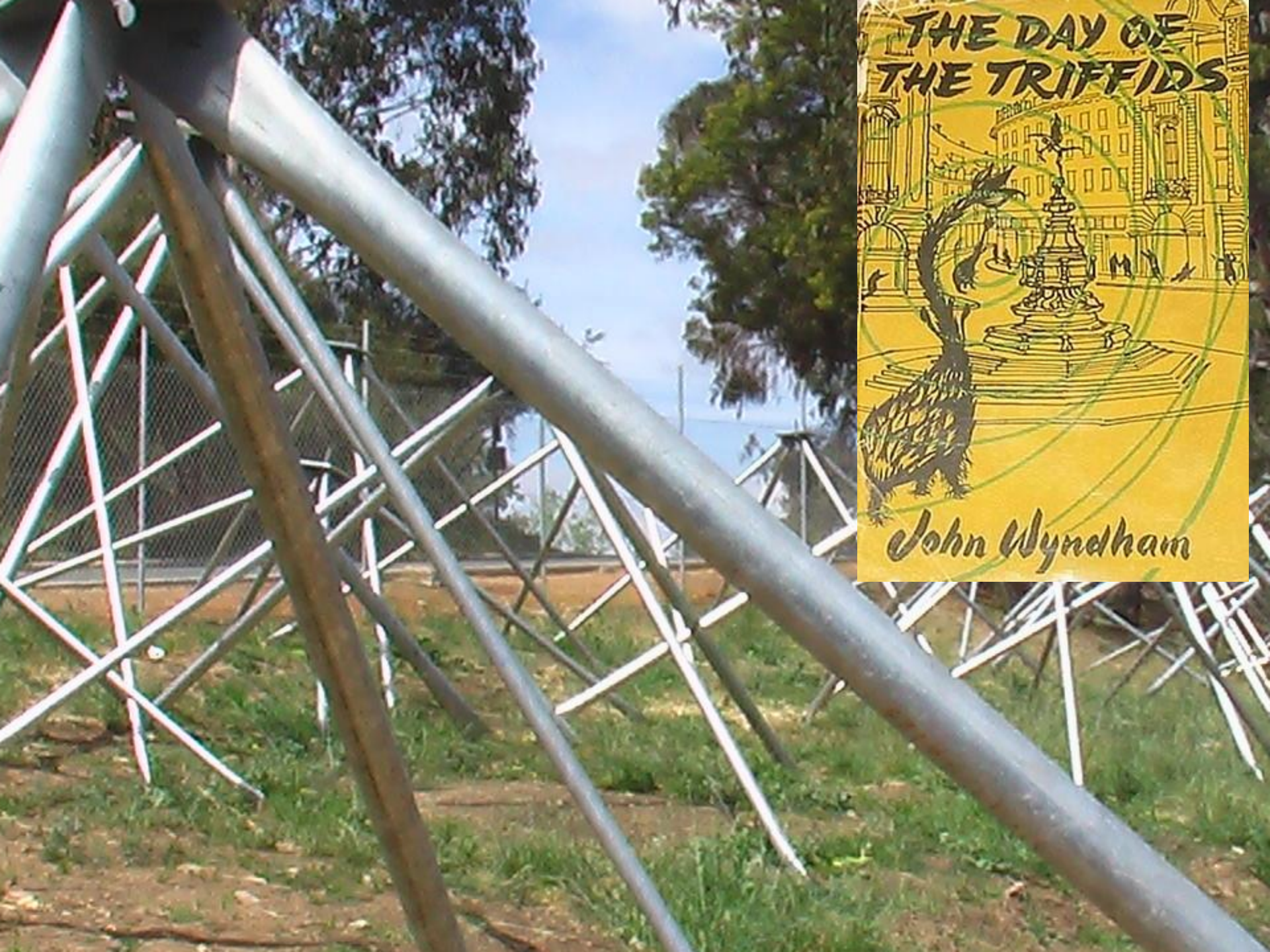
Site works started Feb 08…


This bit because all of North Canberra's sewage passes through a pipe under here


P&R


THE DAY OF THE TRIFFIDS
John Wyndham

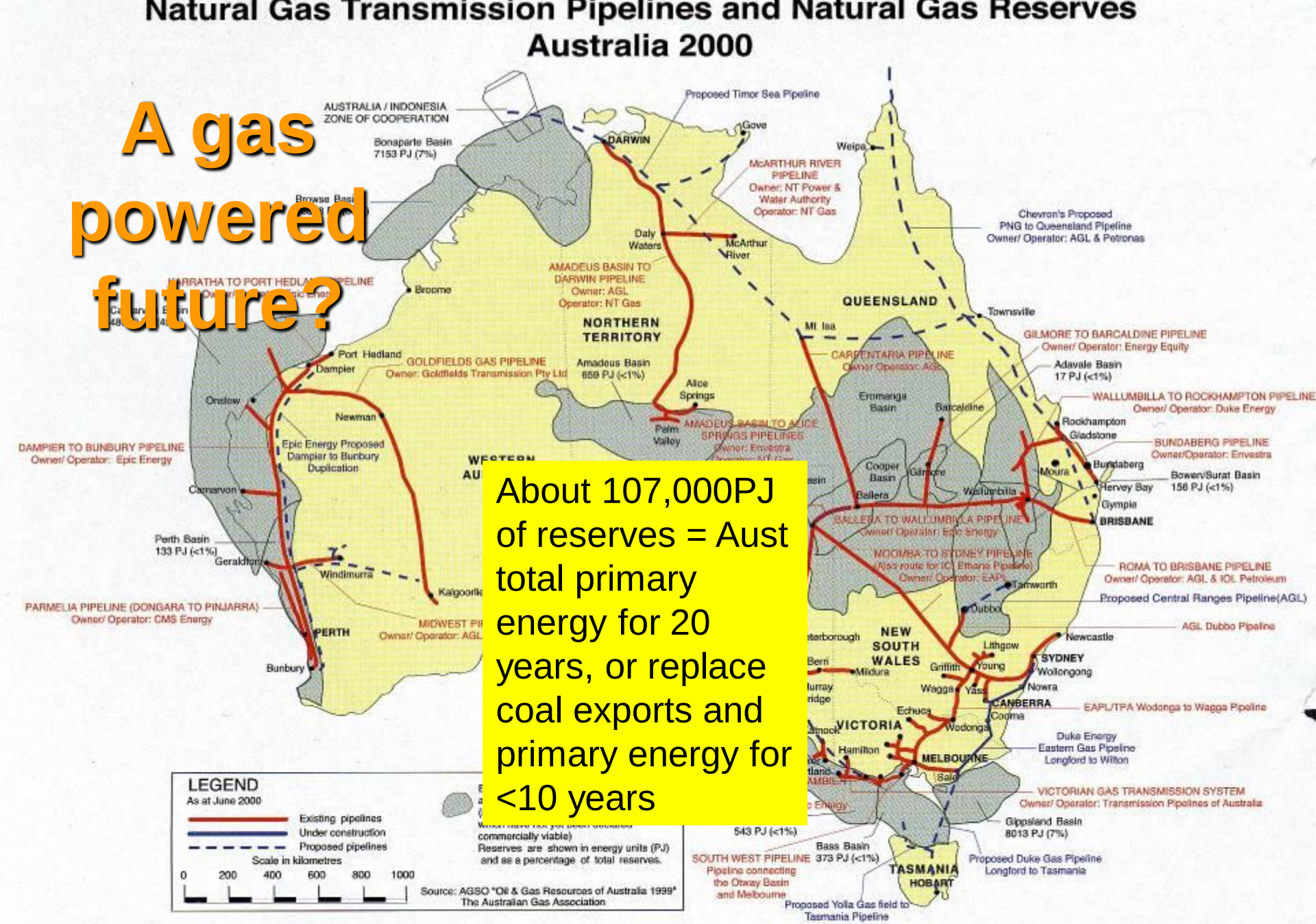
THE AUSTRALIAN NATIONAL UNIVERSITY


TUMBLER


RUMBLES
RUMBLES
RUMBLES

Getting back to the subject of exports….

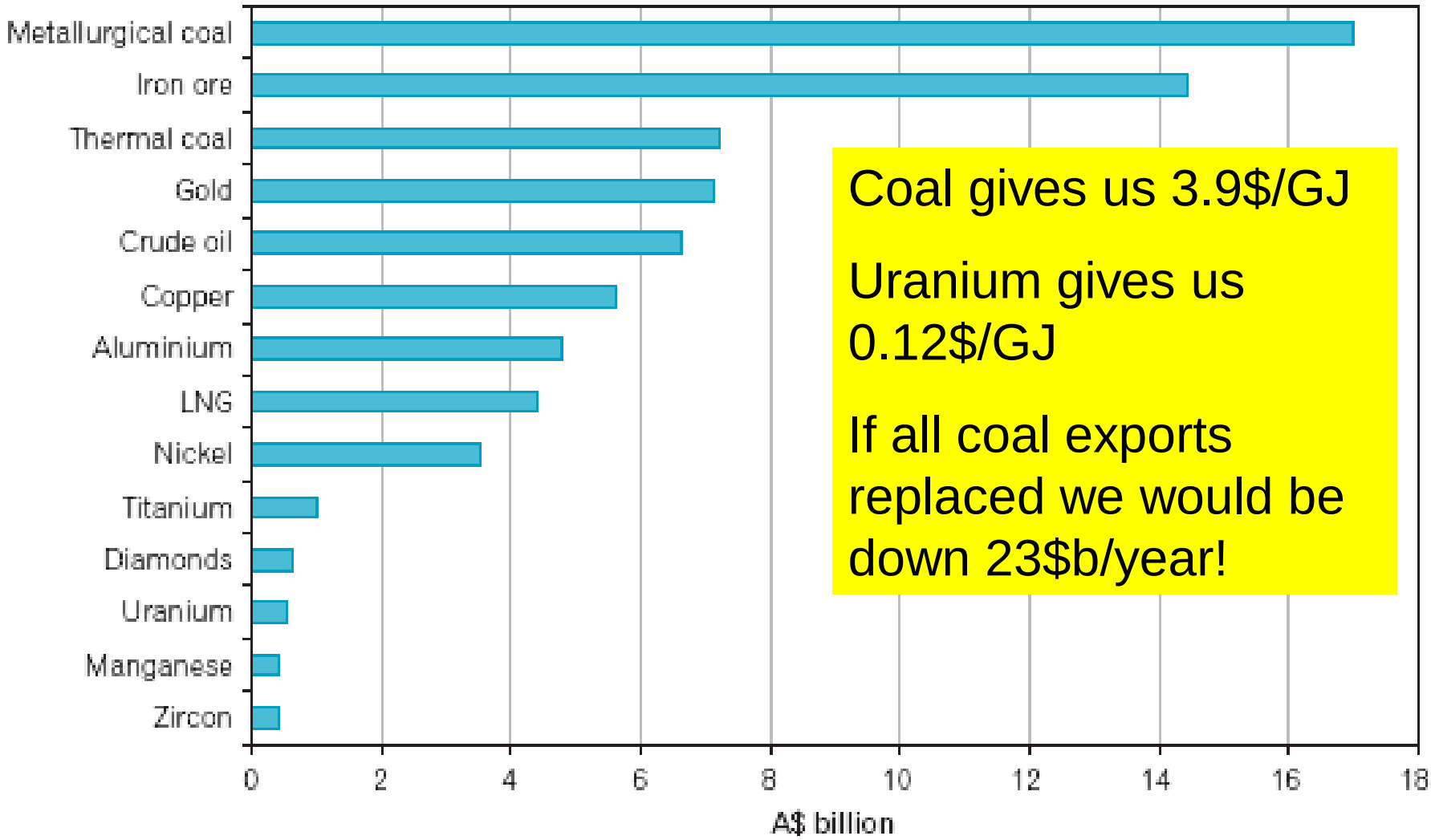
A gas powered future?



About 107,000PJ of reserves = Aust total primary energy for 20 years, or replace coal exports and primary energy for <10 years

A Uranium powered future?

Figure 2.2 Value of selected Australian mineral and energy exports, 2005–2006



Coal gives us 3.9$/GJ

Uranium gives us 0.12$/GJ

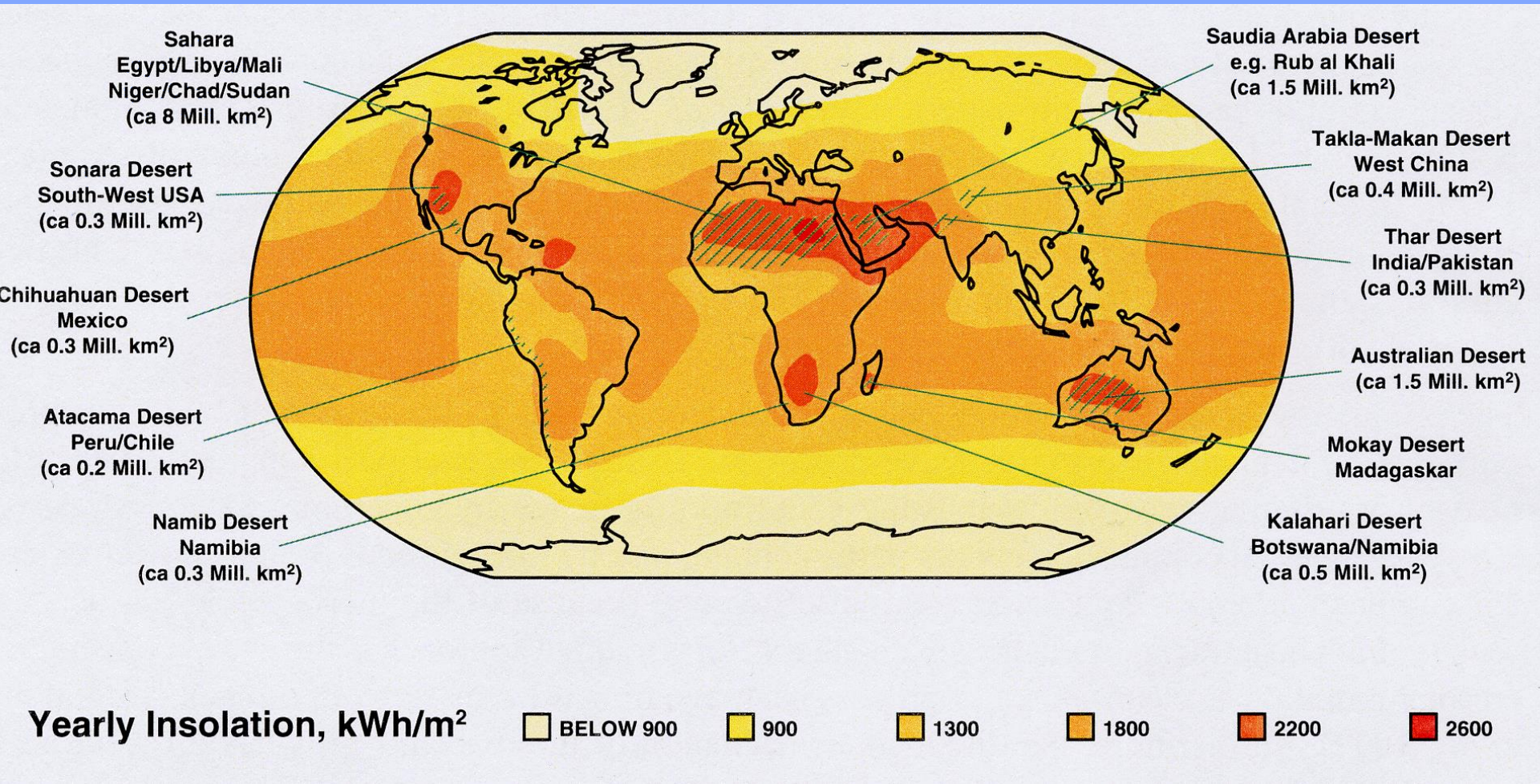
If all coal exports replaced we would be down 23$b/year!

Note: Mineral and energy exports were worth more than A$91 billion in 2005–2006.

Australia as the future manufacturing powerhouse of the world?

mmmm……

Surely we have something to offer?



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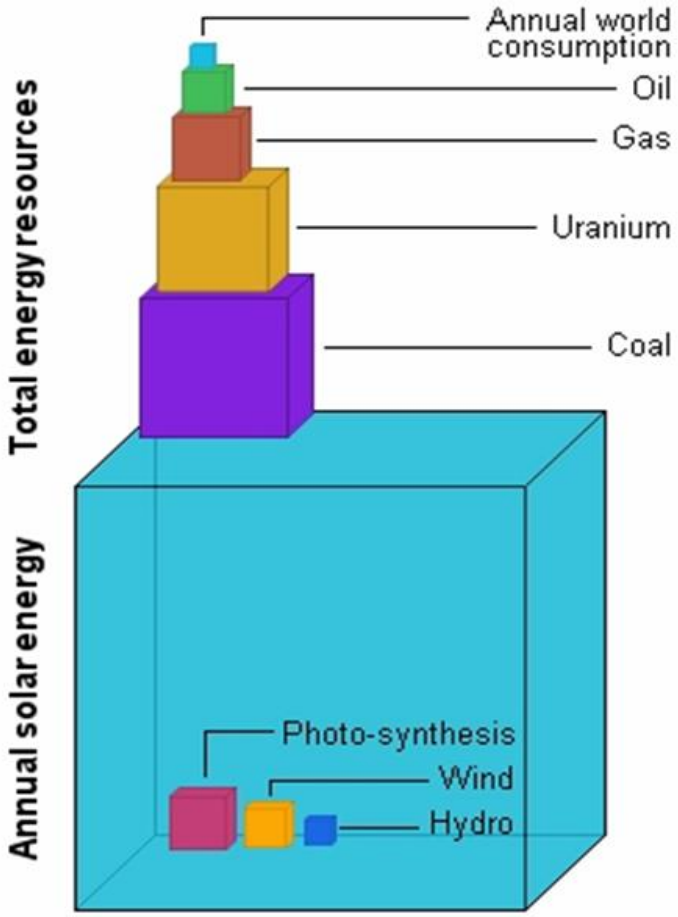
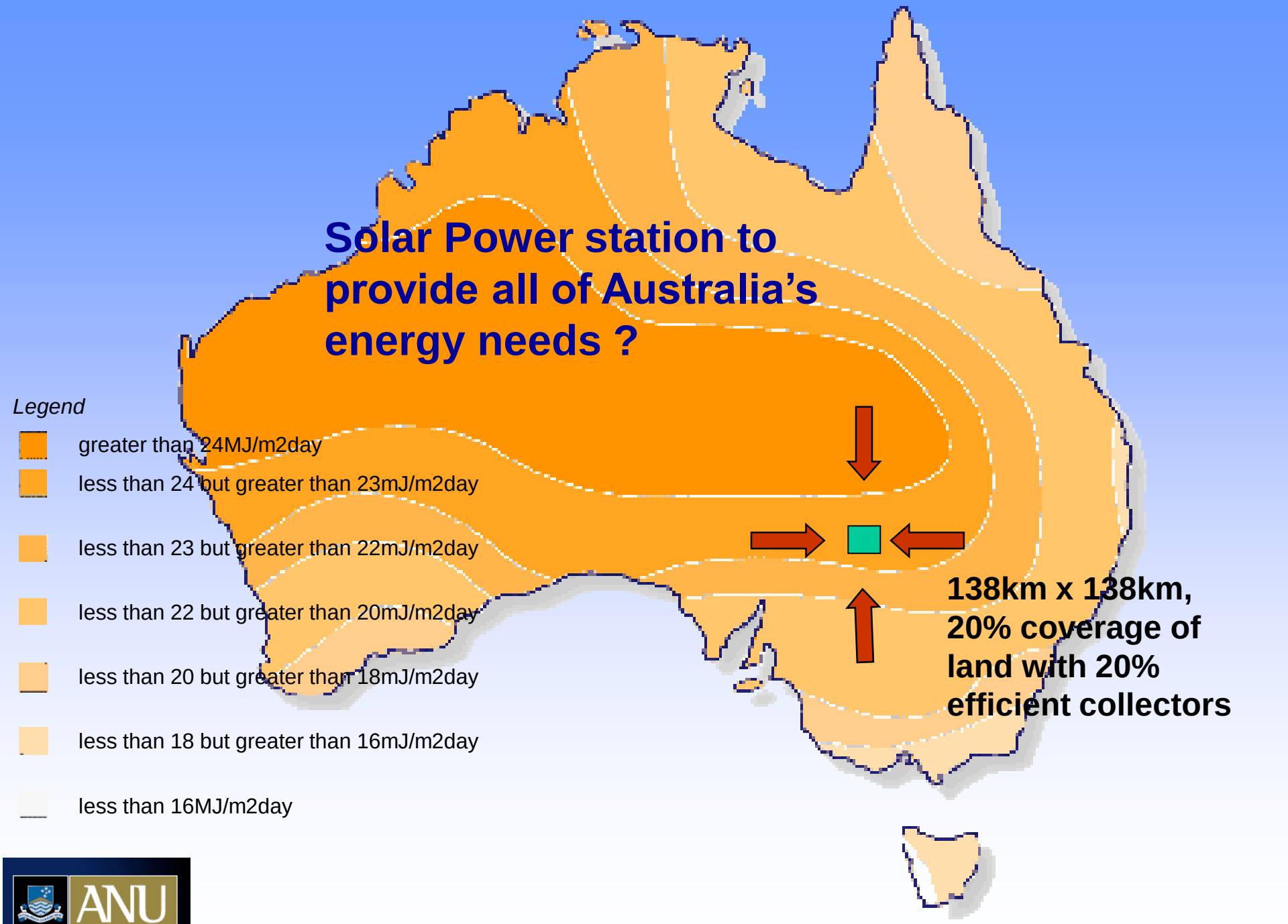
World Energy Council
CONSEIL MONDIAL DE L'ENERGIE

Order of Magnitude of Energy Resources



"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 ?



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

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Solar Gasification

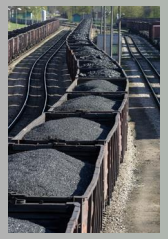
- $C+2H_2O \leftrightarrow CO_2 + 2H_2$
  take 176kJ/mol from solar energy
- The hydrogen can be burnt / oxidized
  $2H_2 + O_2 \leftrightarrow 2H_2O$ giving off 570 kJ/mol
- Compared to just burning coal
  $C+O_2 \leftrightarrow CO_2$ giving off 394kJ/mol
- Ie solar enhanced gas is 176/570 = 30% solar energy,
- Other hydrocarbons are gasified according to:

$$C_xH_y + XH_2O \leftrightarrow XCO + (X+Y/2)H_2$$

The Future - Exporting Solar Energy to the World

Solar Powered Transition to Hydrogen & Emission Free Liquid Fuels

2012+



Coal & Gas

2015+

Crops & Algae

2020+

Water

Exports

Coal & Gas To Liquid Fuels

Biomass to Liquid Fuels

Thermochemical Water Splitting

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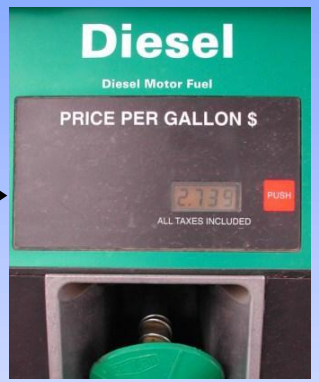
Big Dish solar thermal concentrators used to produce hydrogen and liquid fuels (e.g. methanol) from high temperature solar conversion of coal, gas & biomass

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



Australian Thermal Coal Exports 2005-06:

114.8 Million Tonnes
$7,668 Million

Converted to

Australian Liquid Fuel Exports:

229.6 Million Barrels
$22,997 Million
based on average Australian wholesale diesel cost $0.63/Litre

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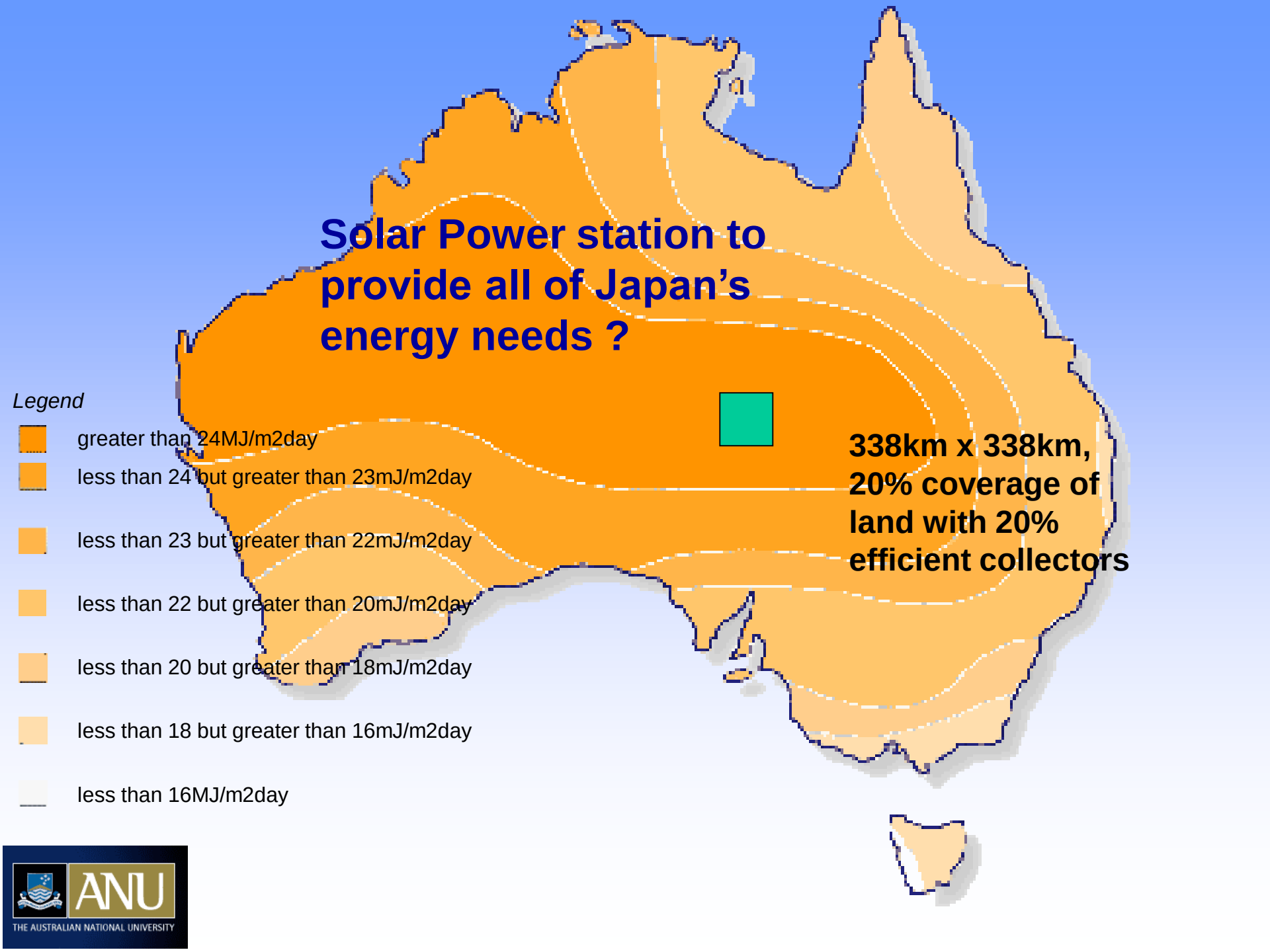
Solar Power station to provide all of Japan's energy needs ?
Legend
greater than 24MJ/m2day
less than 24 but greater than 23mJ/m2day
less than 23 but greater than 22mJ/m2day
less than 22 but greater than 20mJ/m2day
less than 20 but greater than 18mJ/m2day
less than 18 but greater than 16mJ/m2day
less than 16MJ/m2day
338km x 338km, 20% coverage of land with 20% efficient collectors
ANU
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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

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