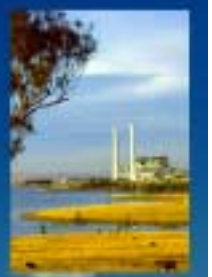


Australia and Europe
Partnerships for Sustainable Energy R&D

Solar Thermal Developments in Australia

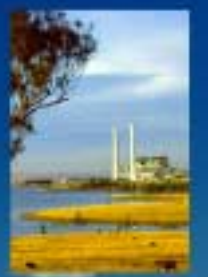
Wesley Stein

Sponsored by The Australian Academy of Technological Sciences and Engineering (ATSE) and CSIRO, Australia's National R&D organisation.

30 June 2002

ENERGY **TECHNOLOGY**



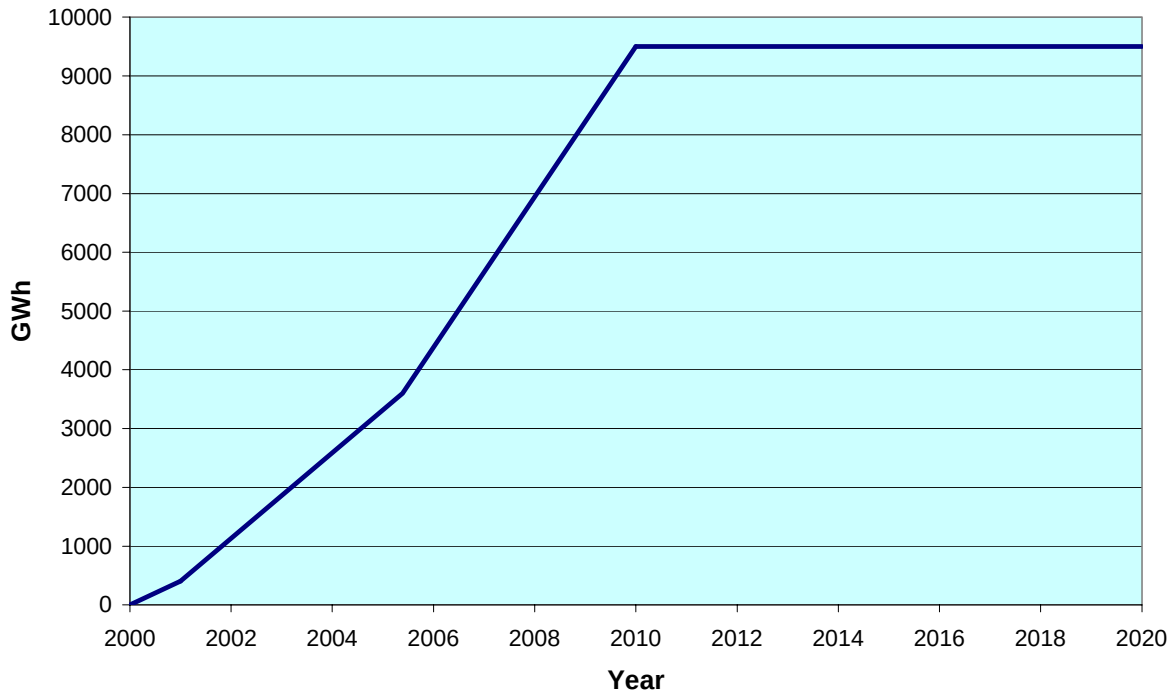



Drivers

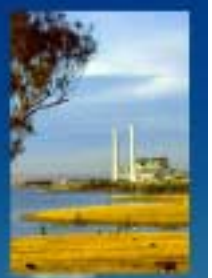
- *Renewable and sustainable energy incentives*
- *Solar is pure green*
- *Abundance of solar energy resource*
- *Compatibility with both existing and advanced energy technologies*
- *Distributed or large scale centralised*
- *New investment opportunity*

Australia's Mandatory Renewable Energy Target

- *9500GWh/yr of renewable energy required by 2010*



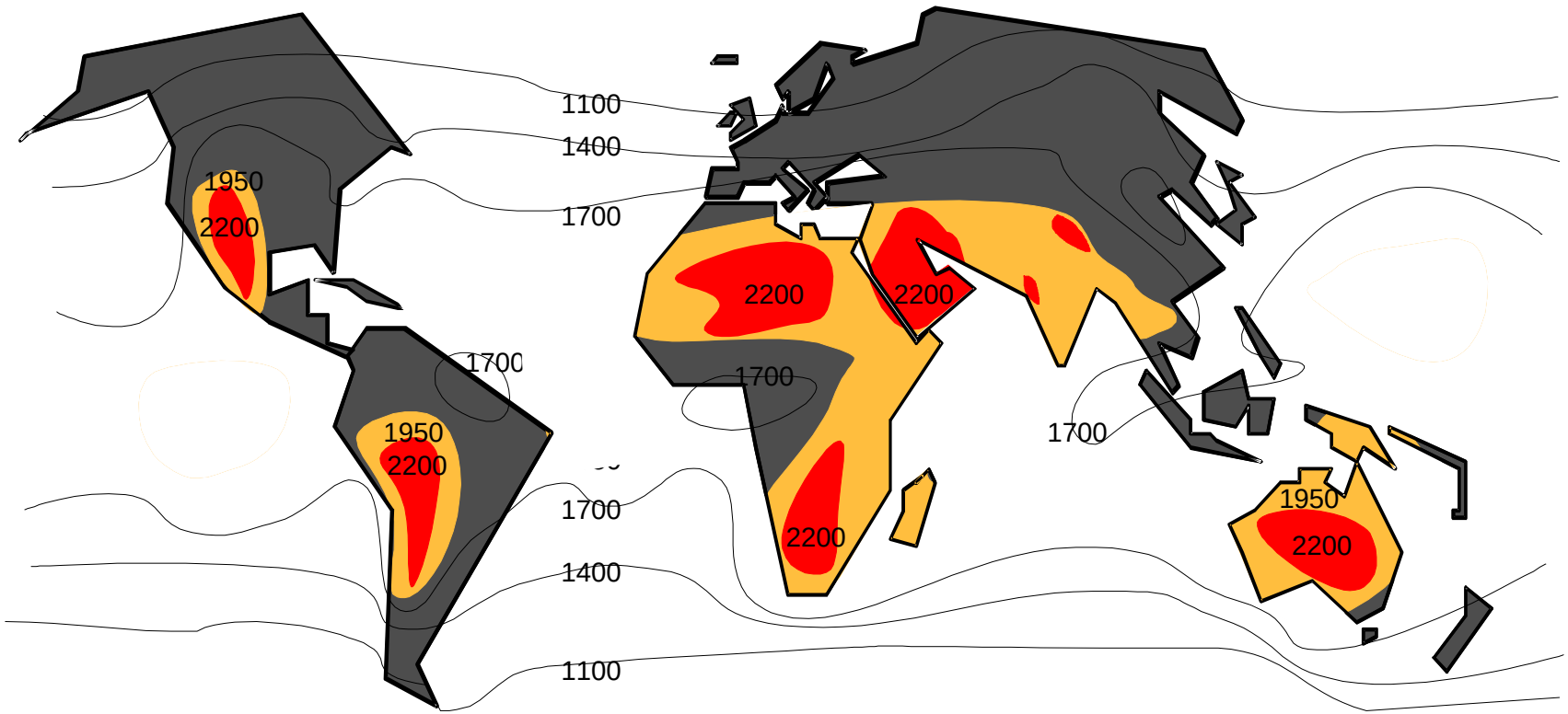


Australia's Mandatory Renewable Energy Target

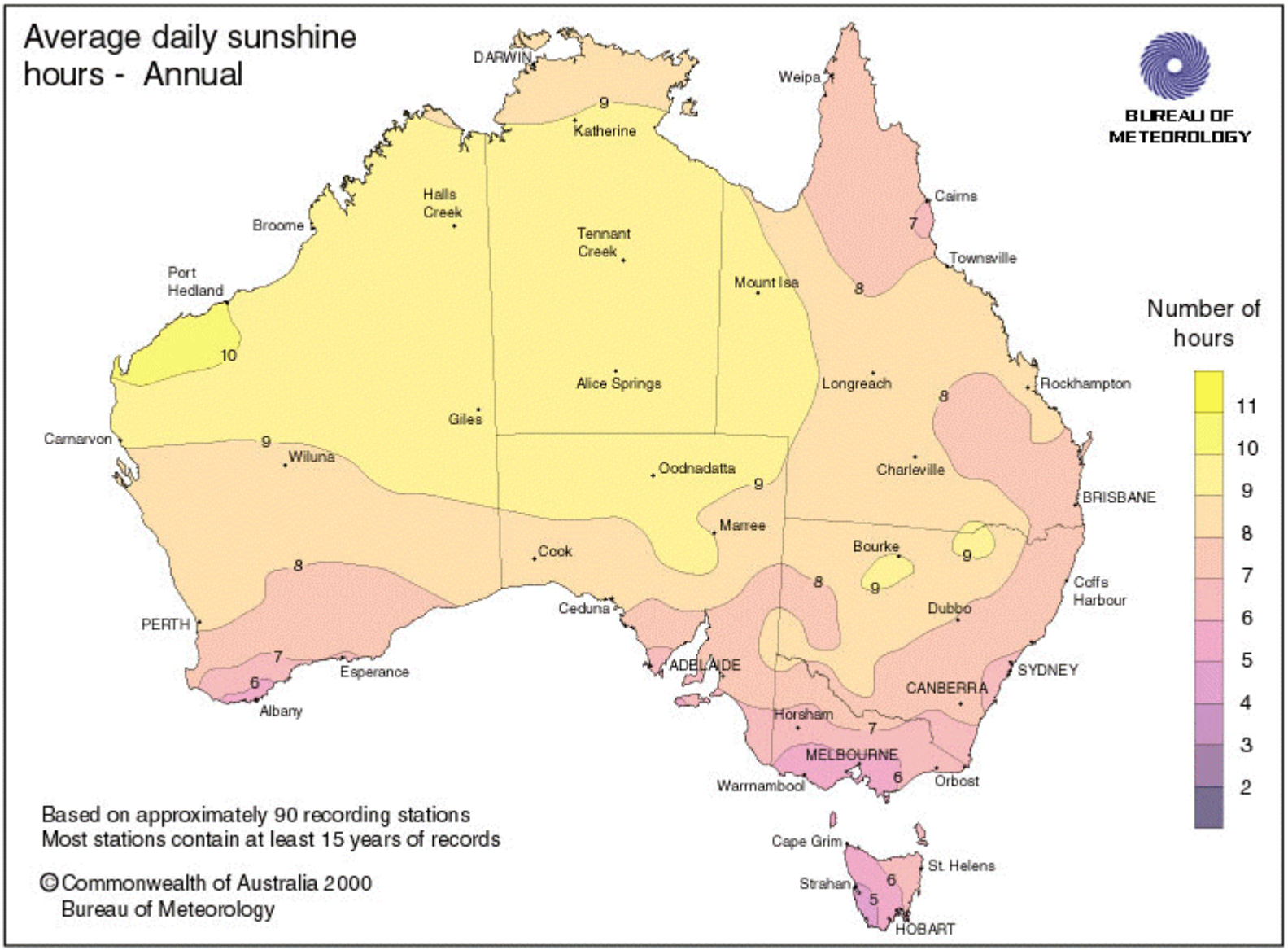
- *9500GWh/yr of renewable energy required by 2010*
- *Liability on electricity retailers*
- *Certificate trading system*
- *$40/MWh penalty for non-compliance*

Global Solar Radiation

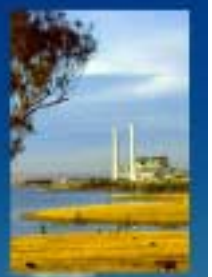


Qualification for Solar Electricity Generation

Solar Global Radiation > 2200 kWh/m²a		very good qualified
Solar Global Radiation > 1950 kWh/m²a		good qualified


Average daily sunshine hours - Annual
BUREAU OF METEOROLOGY
DARWIN
Katherine
Weipa
Halls Creek
Broome
Tennant Creek
Cairns
Townsville
Port Hedland
Mount Isa
Alice Springs
Longreach
Rockhampton
Giles
Carnarvon
Wiluna
Oodnadatta
Charleville
BRISBANE
Marree
Cook
Bourke
Coffs Harbour
Ceduna
Dubbo
PERTH
ADELAIDE
SYDNEY
Esperance
CANBERRA
Albany
Horsham
MELBOURNE
Warrnambool
Orbost
Cape Grim
St. Helens
Strahan
HOBART
Number of hours
11
10
9
8
7
6
5
4
3
2
Based on approximately 90 recording stations
Most stations contain at least 15 years of records
©Commonwealth of Australia 2000
Bureau of Meteorology

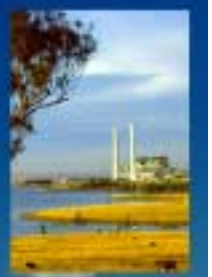


Solar thermal technologies

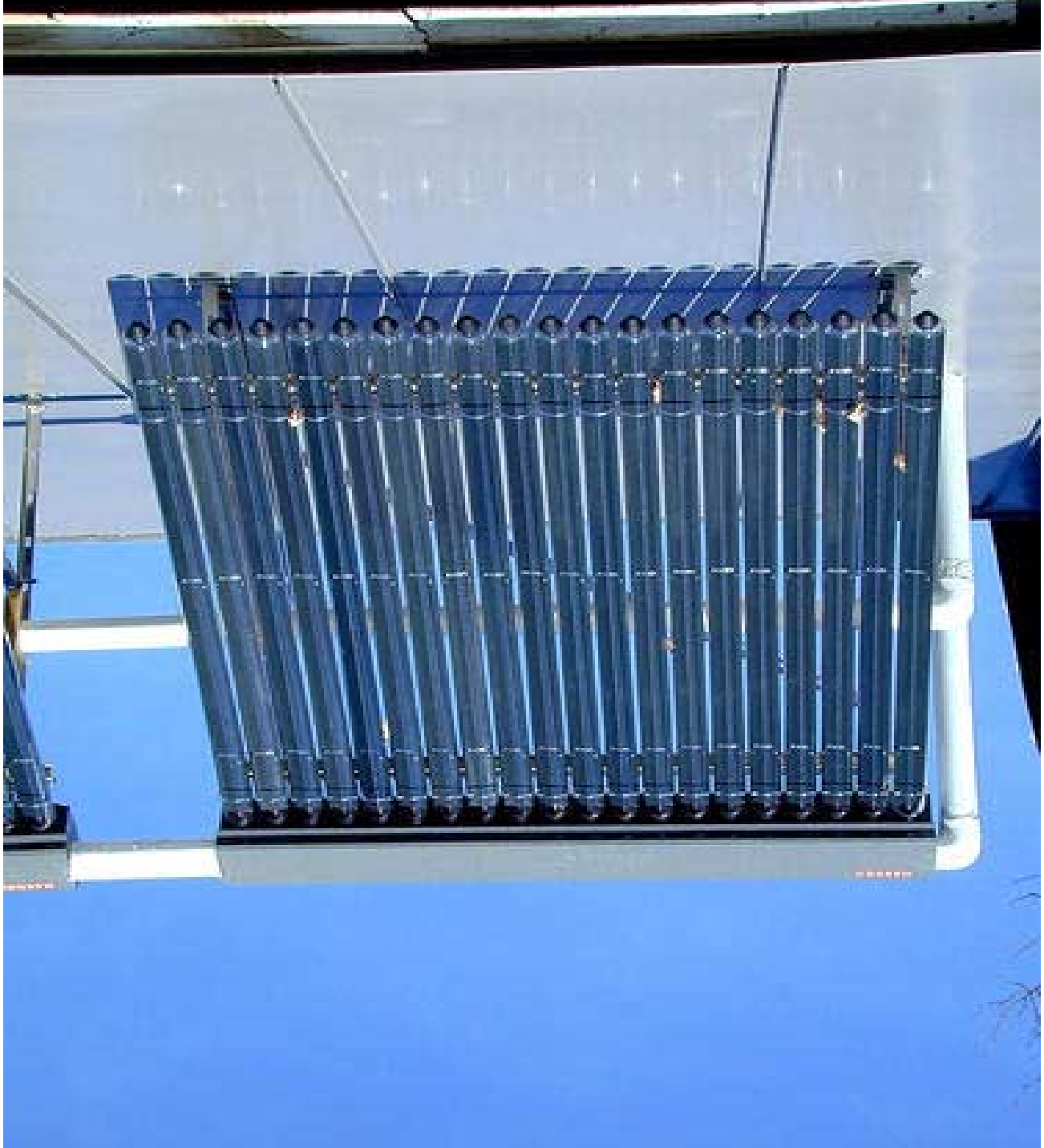
- *Solar hot water*
- *Solar tower*
- *Solar ponds*
- *Solar-assisted chilling*
- *Solar steam/ Rankine cycle*
- *Solar dish - Stirling or Brayton cycle*
- *Central Receivers*
- *Solar reforming or dissociation*



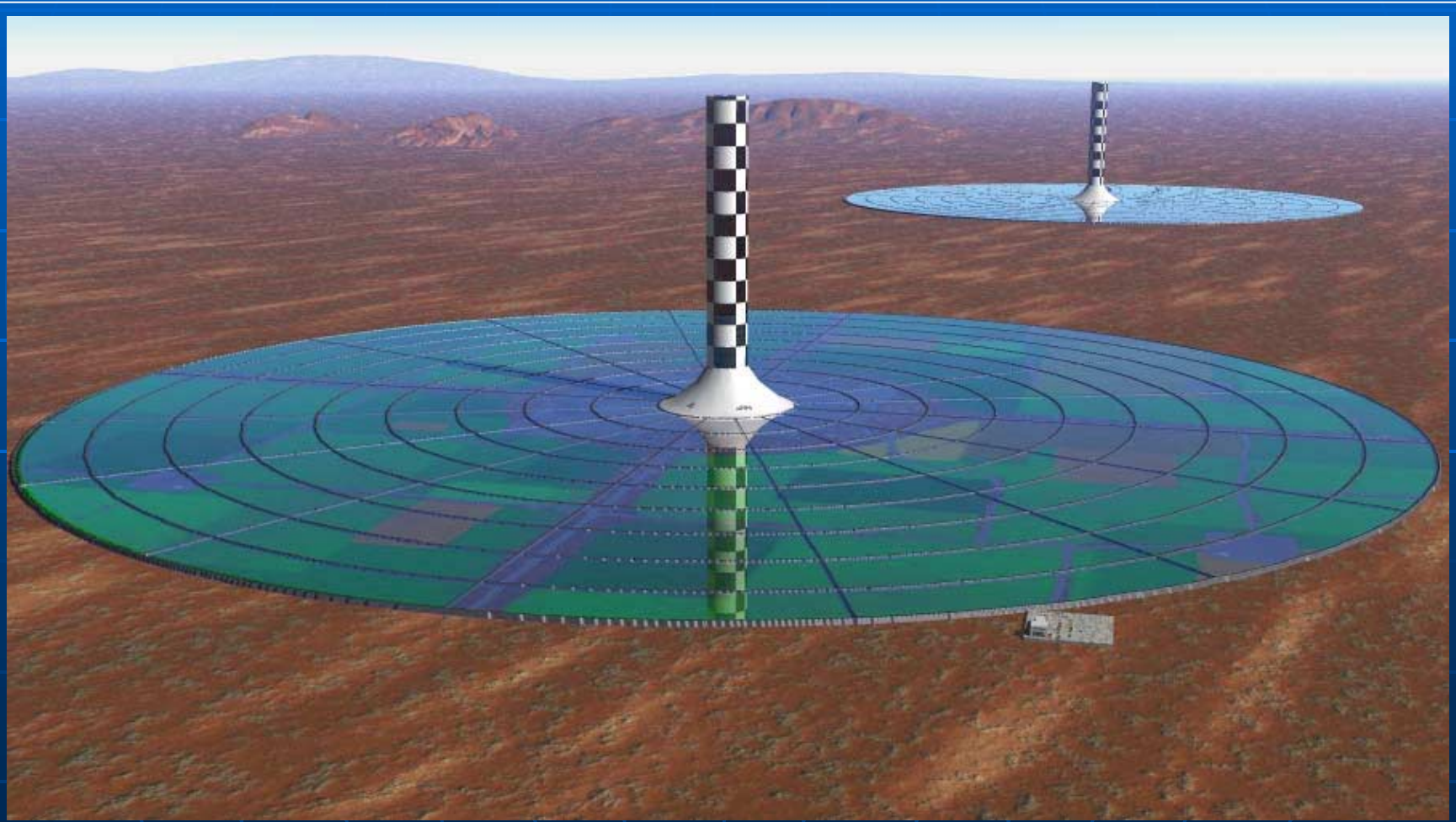



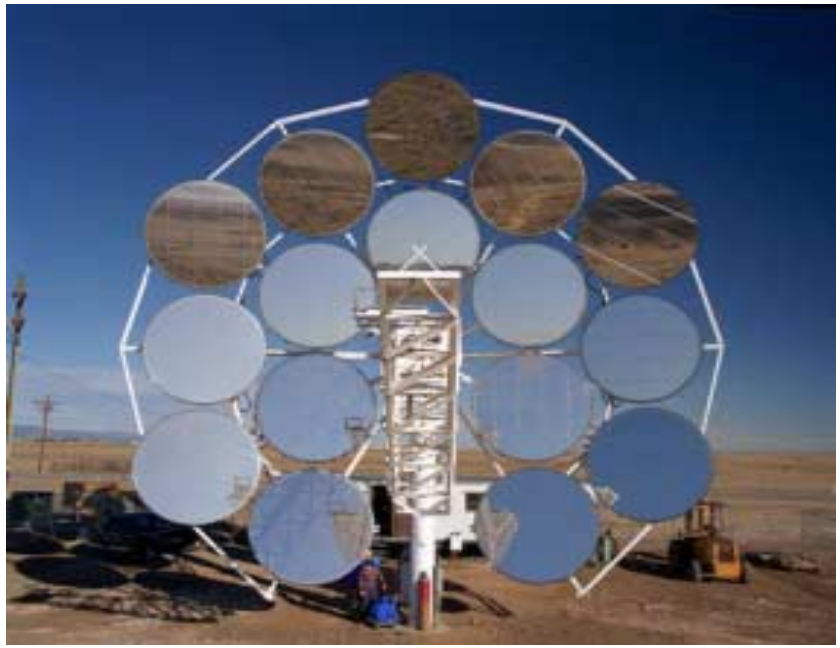
Solar thermal/biomass hybrids

- *Bioenergy and solar thermal both utilise the same thermodynamic cycles*
- *Each fuel offers advantages to the other*
- *Solar unlimited, biomass low cost (sometimes)*
- *No exotic material breakthroughs required*
- *Transitional*

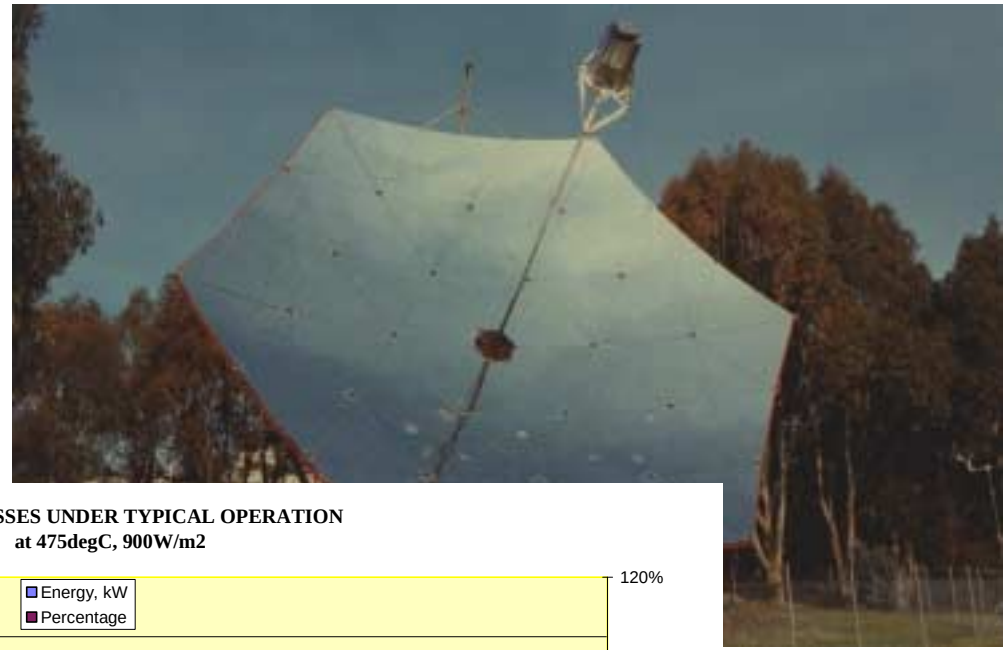


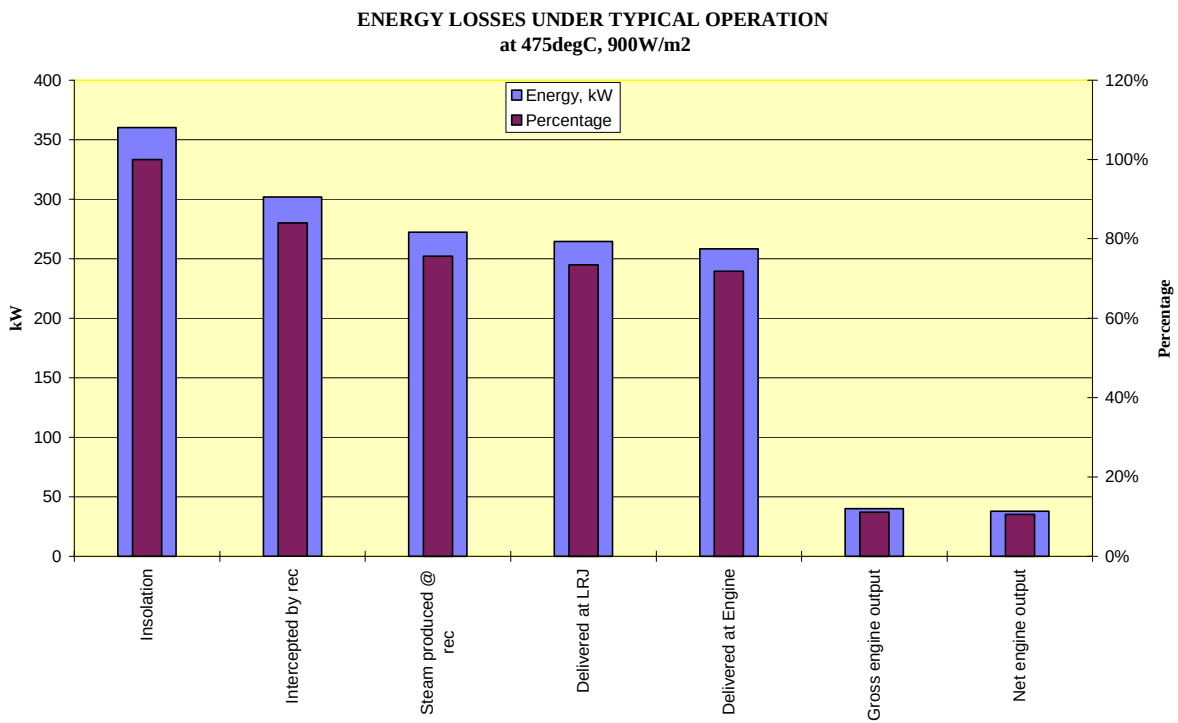
Solar Tower Project



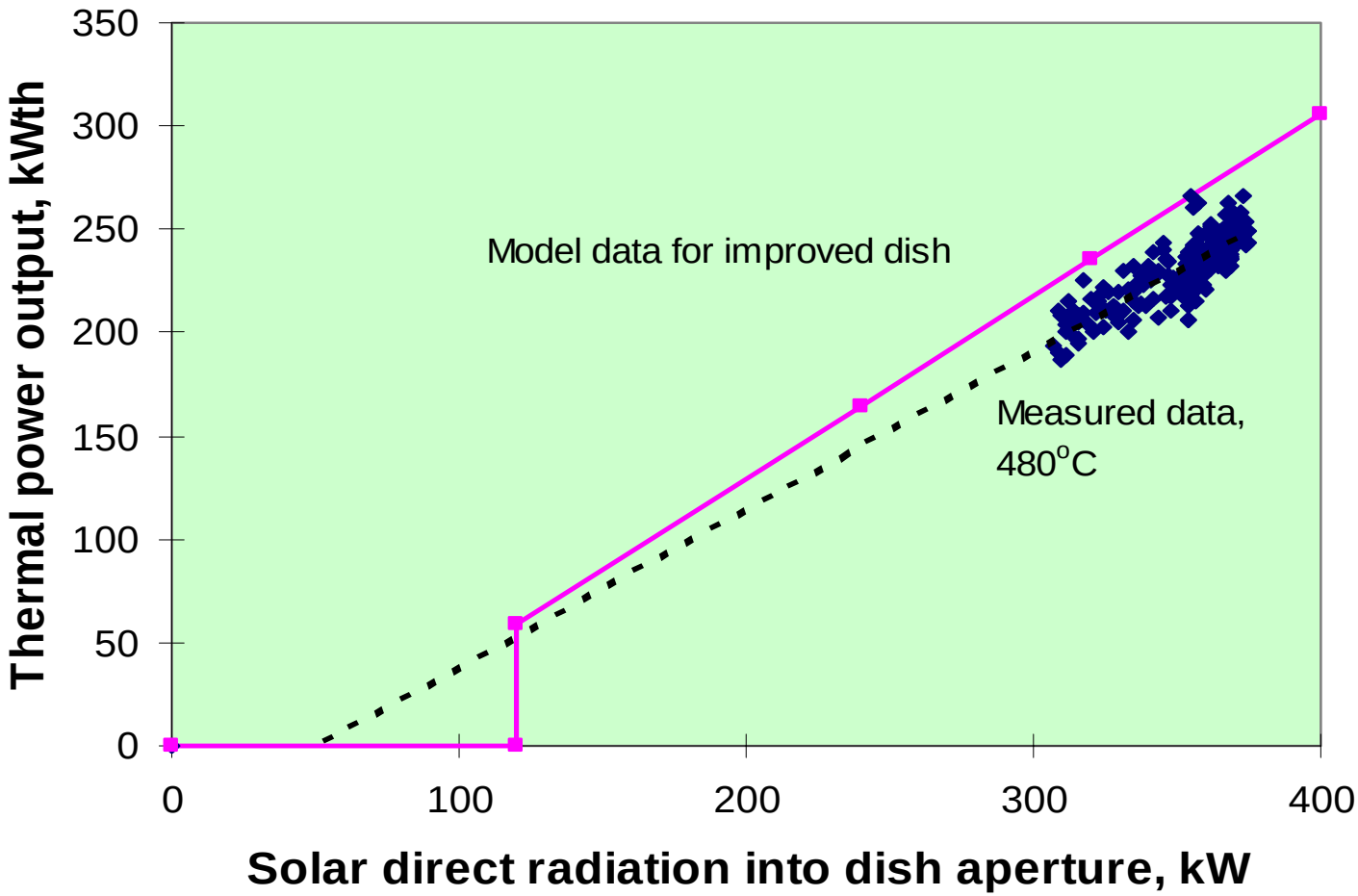


ENERGY **TECHNOLOGY**

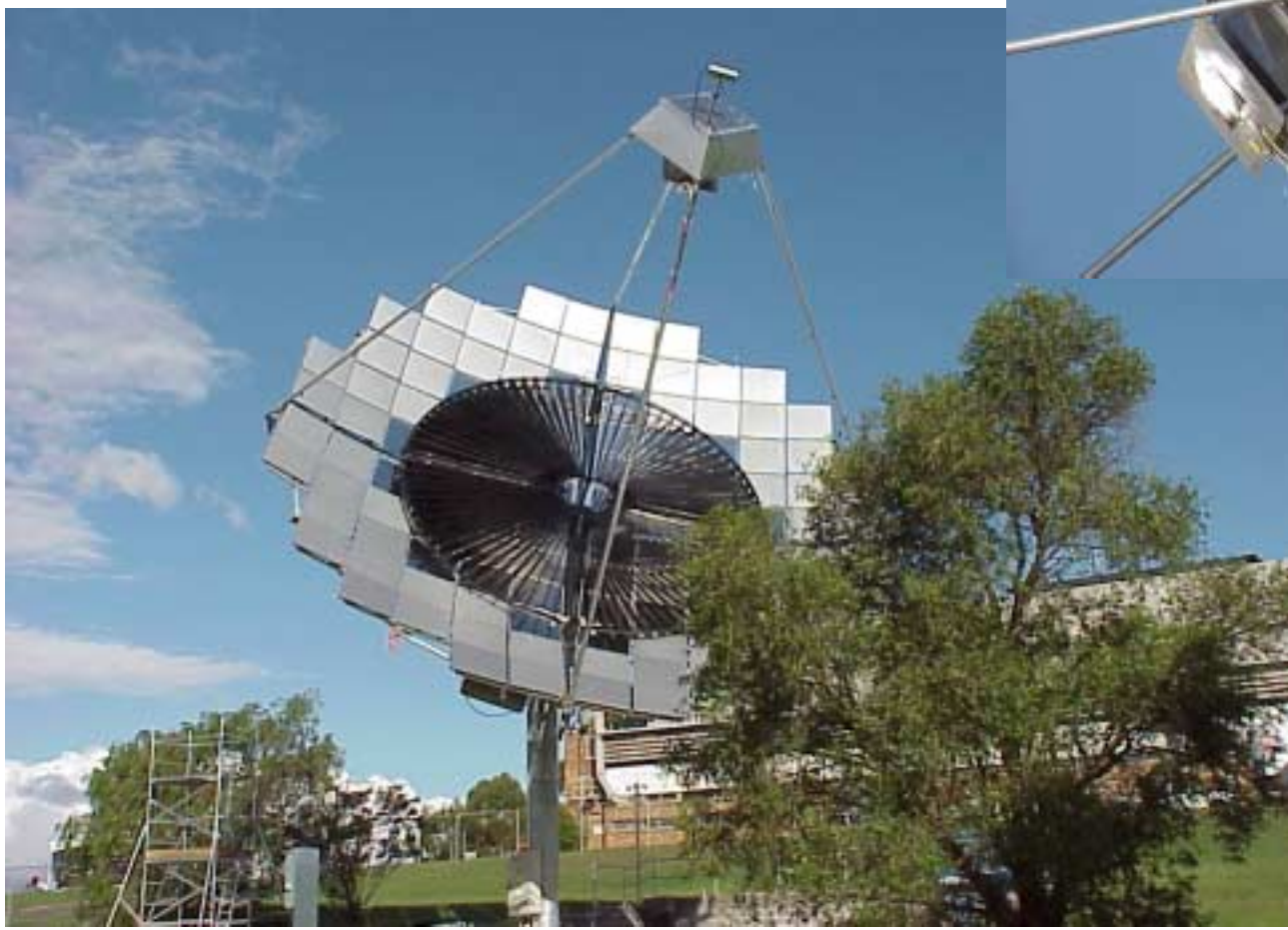


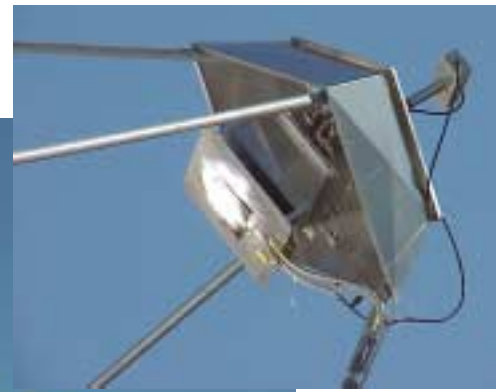


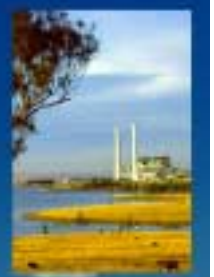
ENERGY **TECHNOLOGY**


Thermal power output, kWth
350
300
250
200
150
100
50
0
0
100
200
300
400
Solar direct radiation into dish aperture, kW
Model data for improved dish
Measured data,
480°C

The Dish and Collector



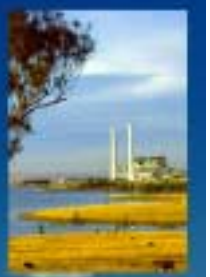




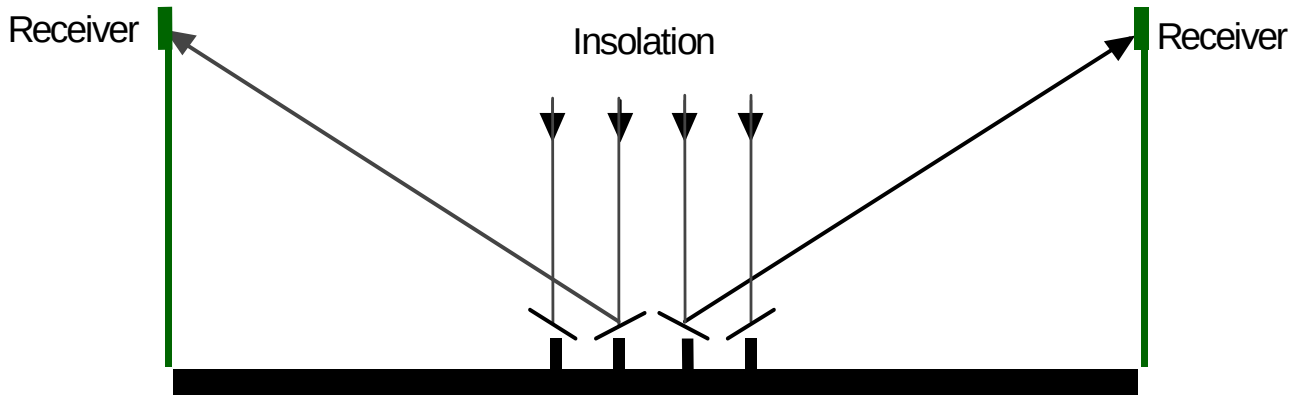
15 years of Australian Science
CSIRO

ENERGY **TECHNOLOGY**



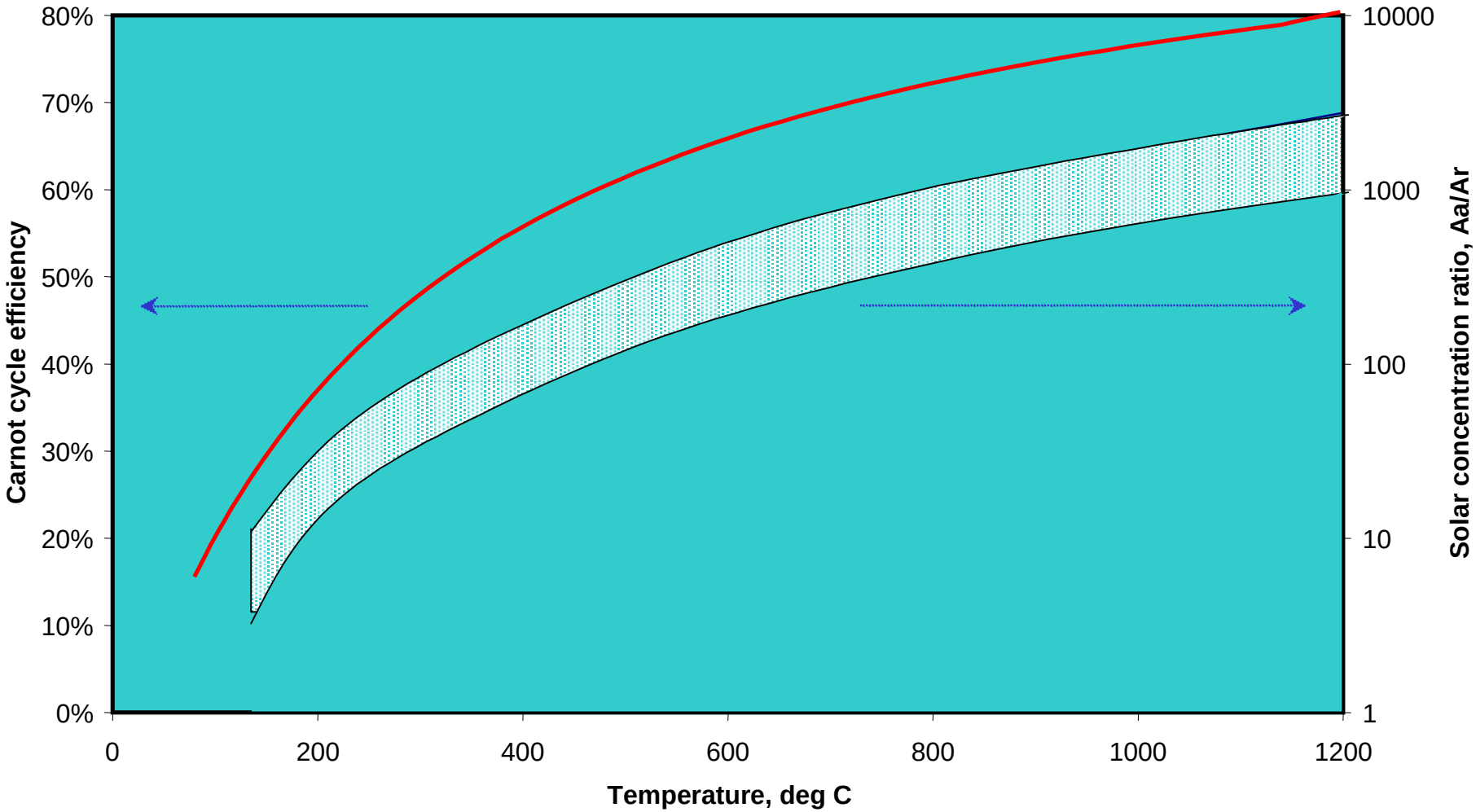



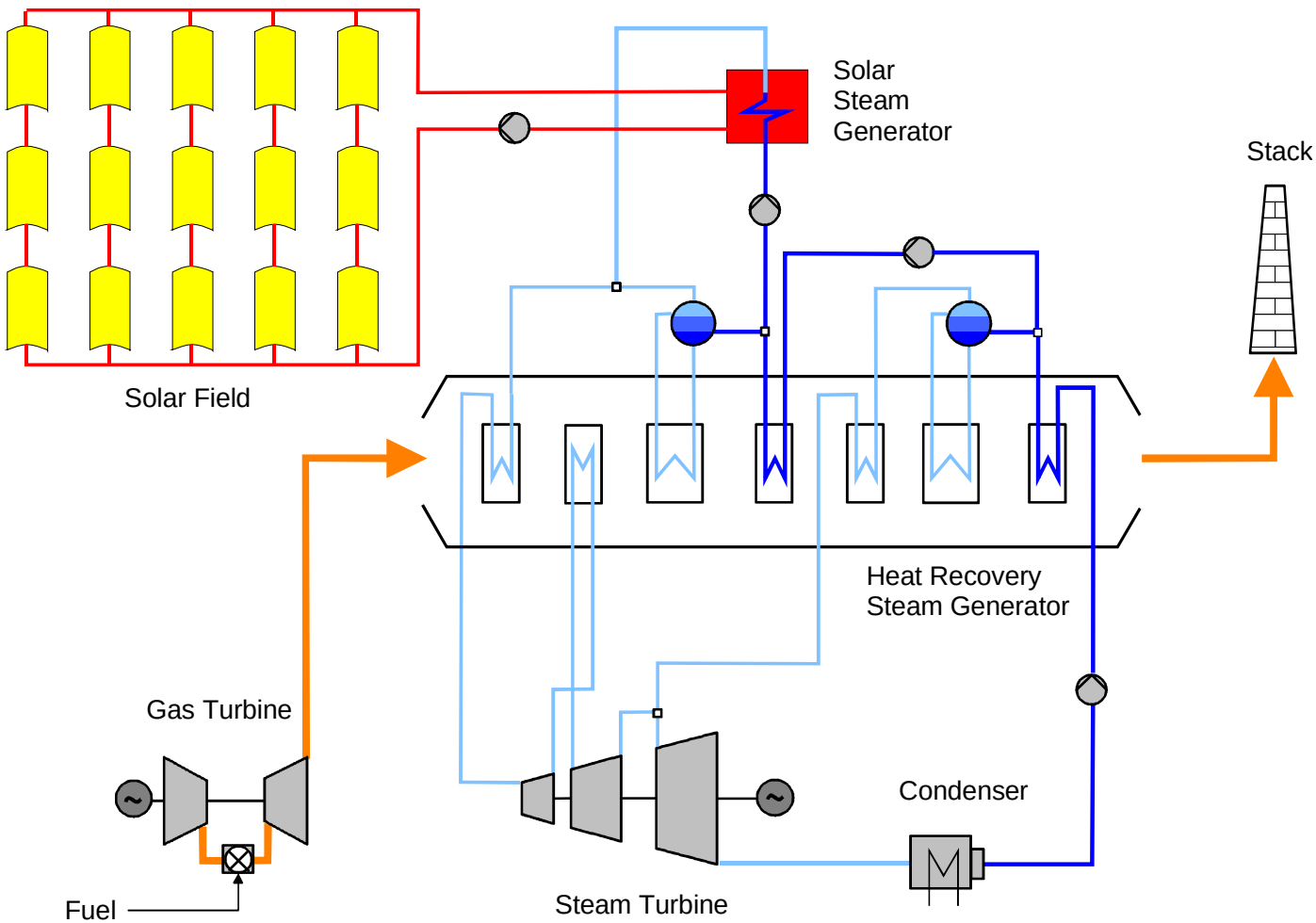
Multi-tower solar array
(University of Sydney)



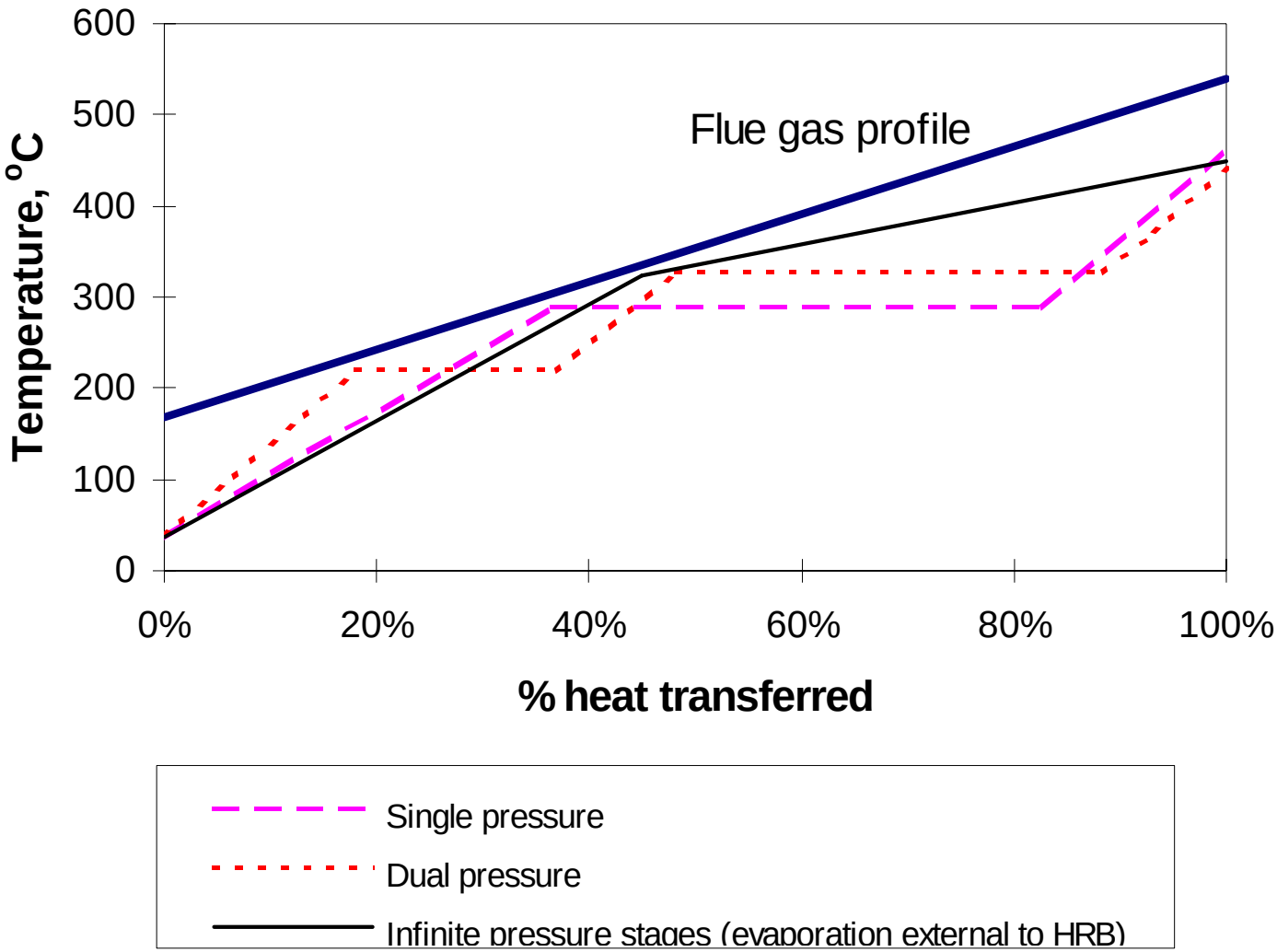
Reflector orientation patterns set up to allow avoidance of blocking of reflected radiation under close packing. This diagram applies schematically to the MTSA along two axes. Courtesy of Philippe Schramek and David Mills.

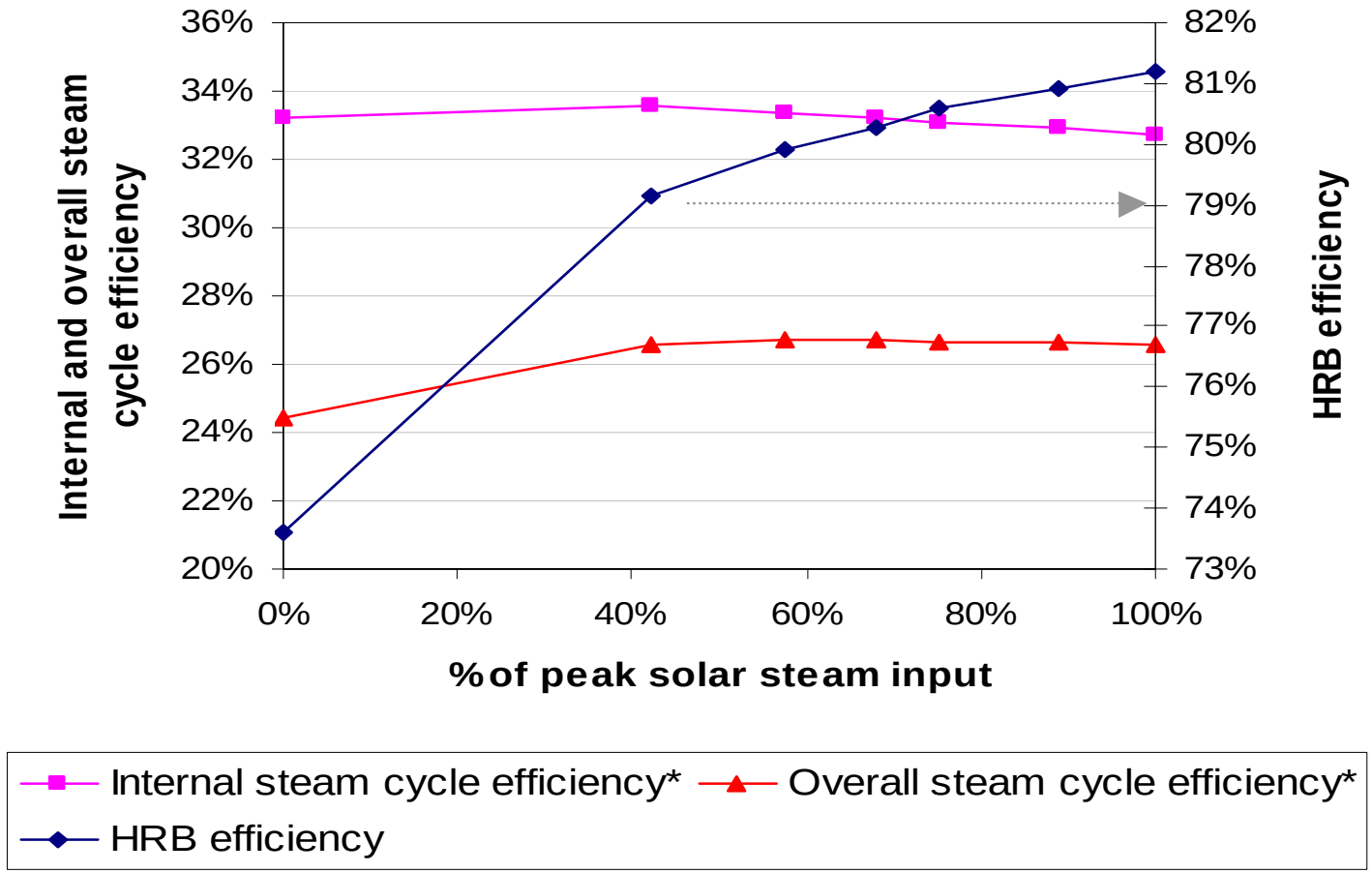
CARNOT CYCLE EFFICIENCY AND SOLAR CONCENTRATION RATIO

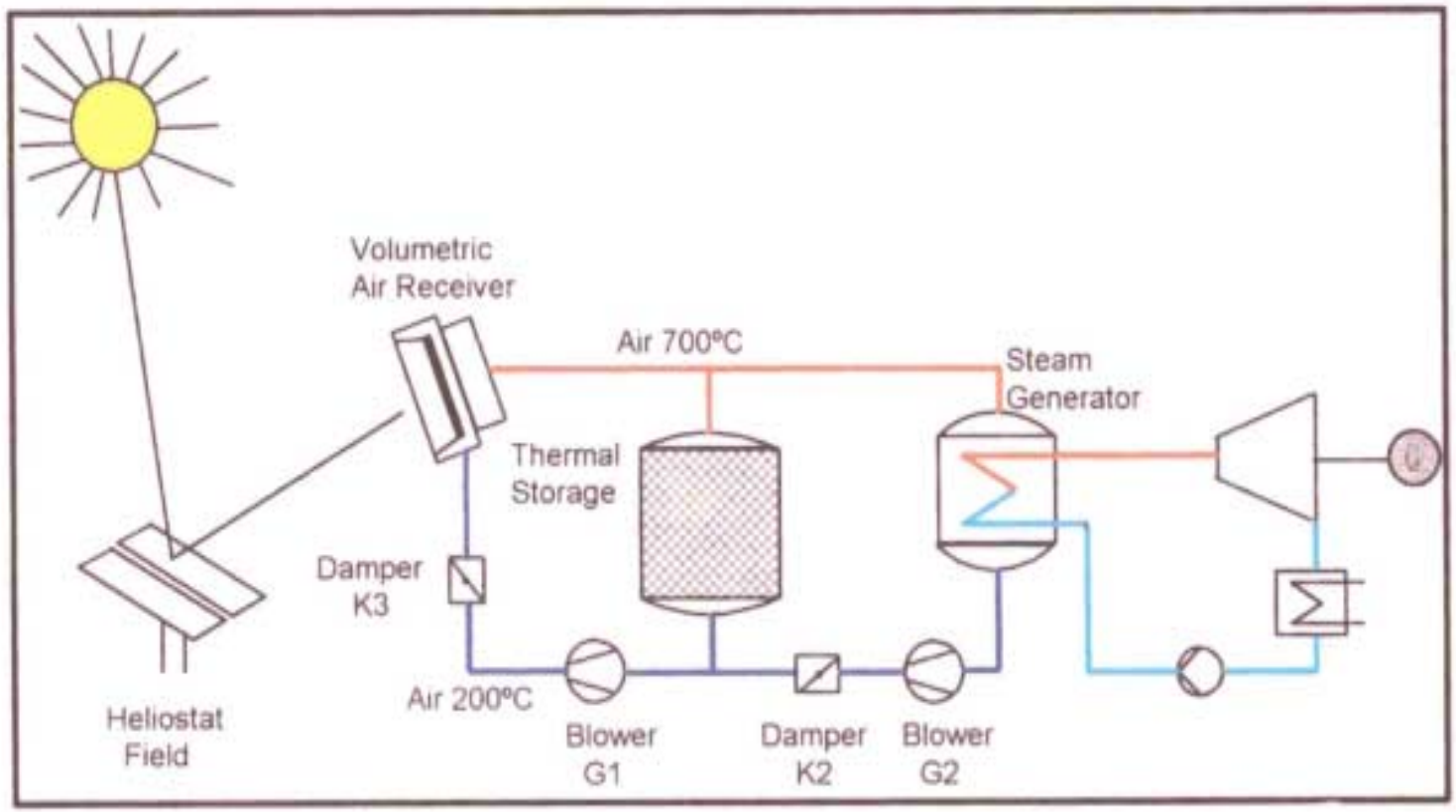




ENERGY **TECHNOLOGY**

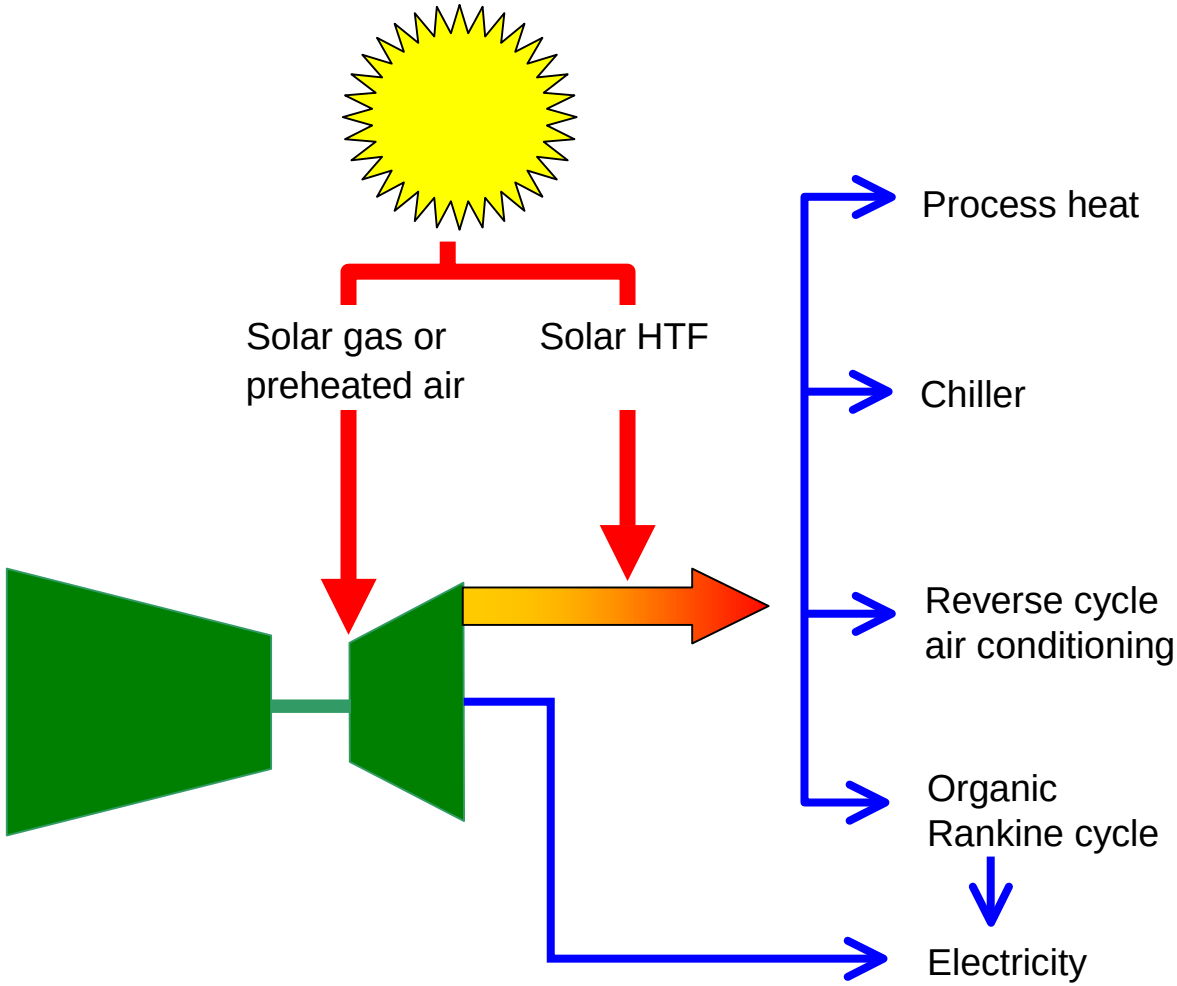

Flue gas profile
Temperature, °C
600
500
400
300
200
100
0
0%
20%
40%
60%
80%
100%
% heat transferred
Single pressure
Dual pressure
Infinite pressure stages (evaporation external to HRB)

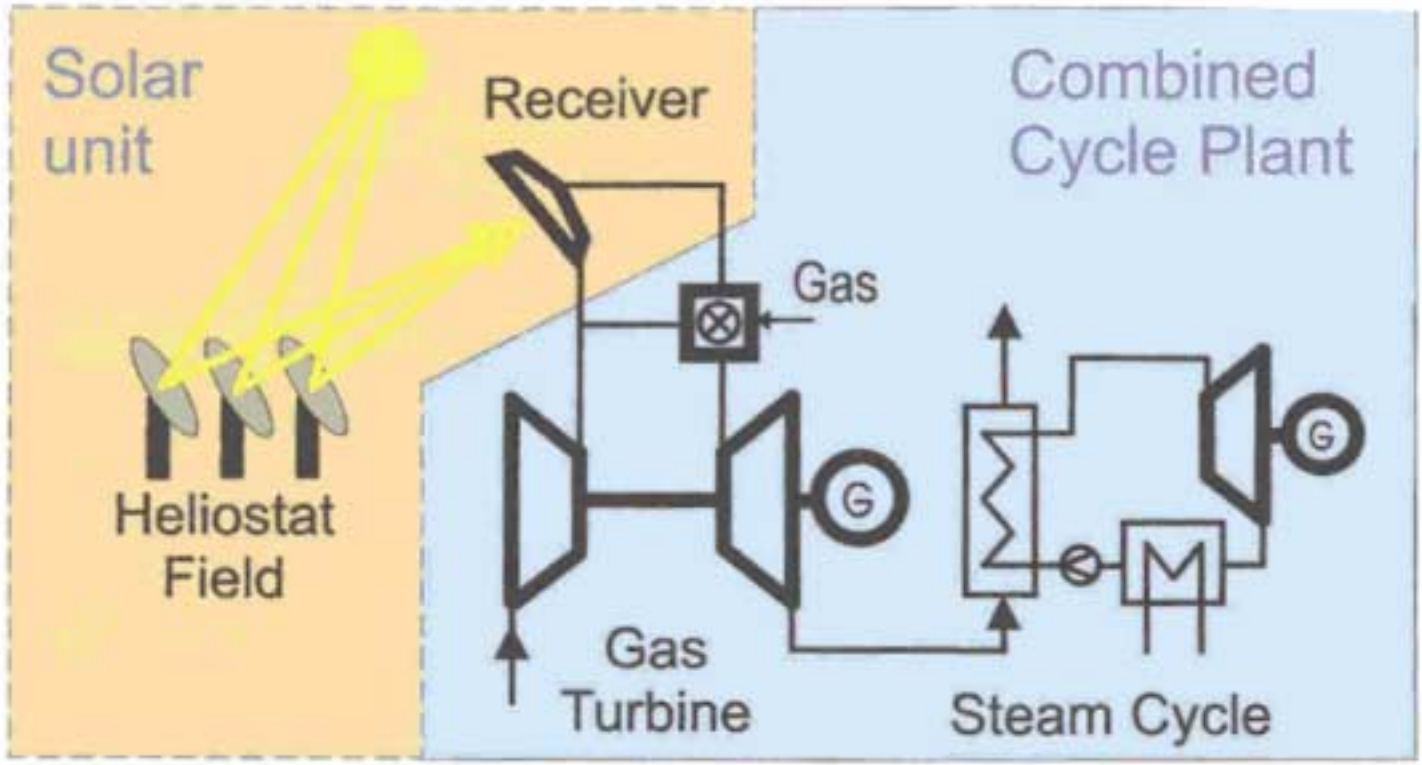

Internal and overall steam cycle efficiency
HRB efficiency
36%
34%
32%
30%
28%
26%
24%
22%
20%
82%
81%
80%
79%
78%
77%
76%
75%
74%
73%
0%
20%
40%
60%
80%
100%
% of peak solar steam input
Internal steam cycle efficiency*
Overall steam cycle efficiency*
HRB efficiency



ENERGY **TECHNOLOGY**

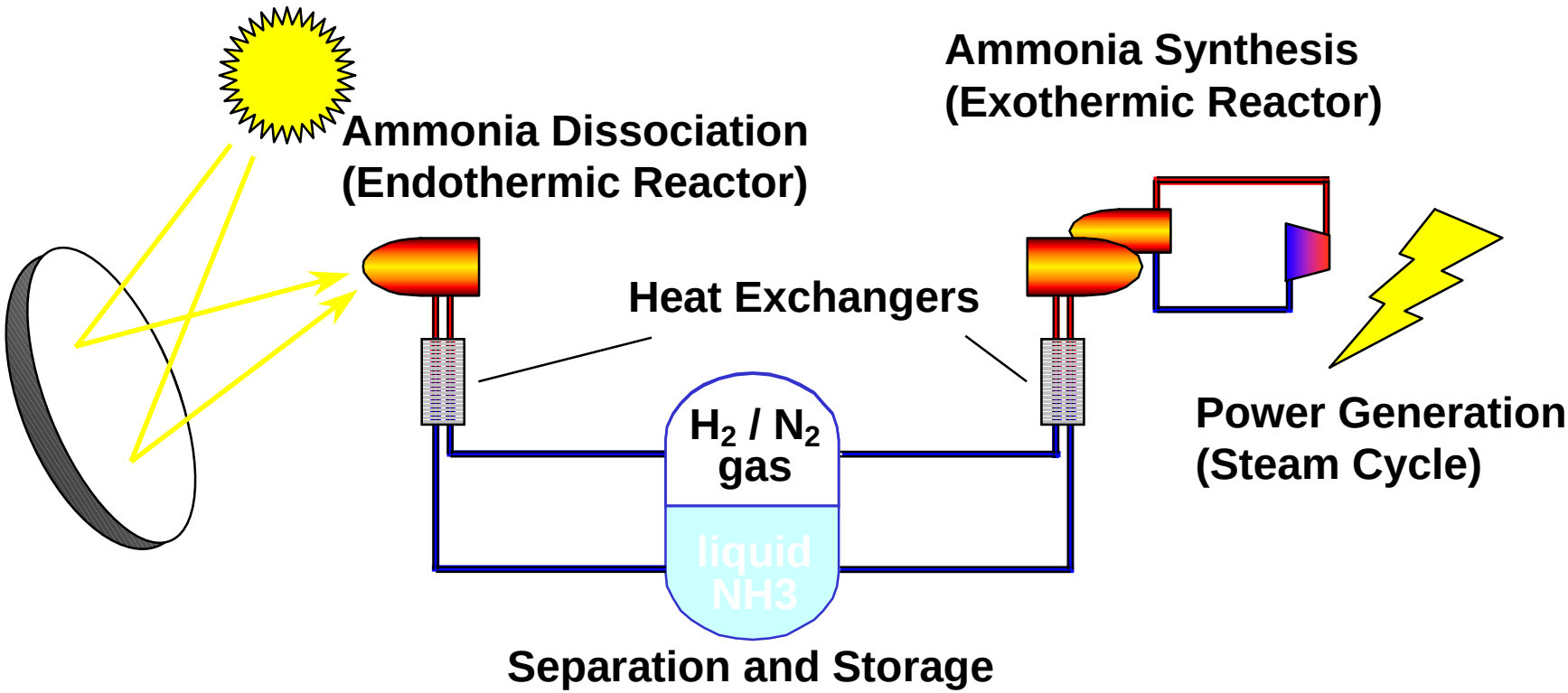
CO/TRI-GENERATION FOR DISTRIBUTED ENERGY APPLICATIONS





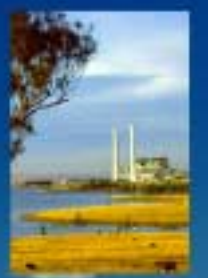
ENERGY **TECHNOLOGY**

Thermochemical Energy Storage



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

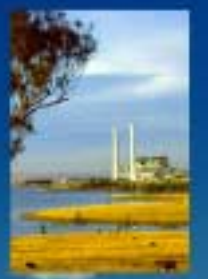


Towards Sustainable Energy – CSIRO solar reforming

- **Aim:** demonstrate a solar thermal – fossil energy hybrid concept for high efficiency / low CO_2 power generation and appropriate for Australian conditions

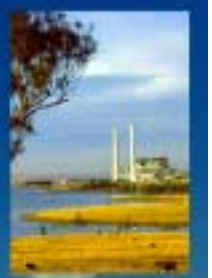


Project Drivers

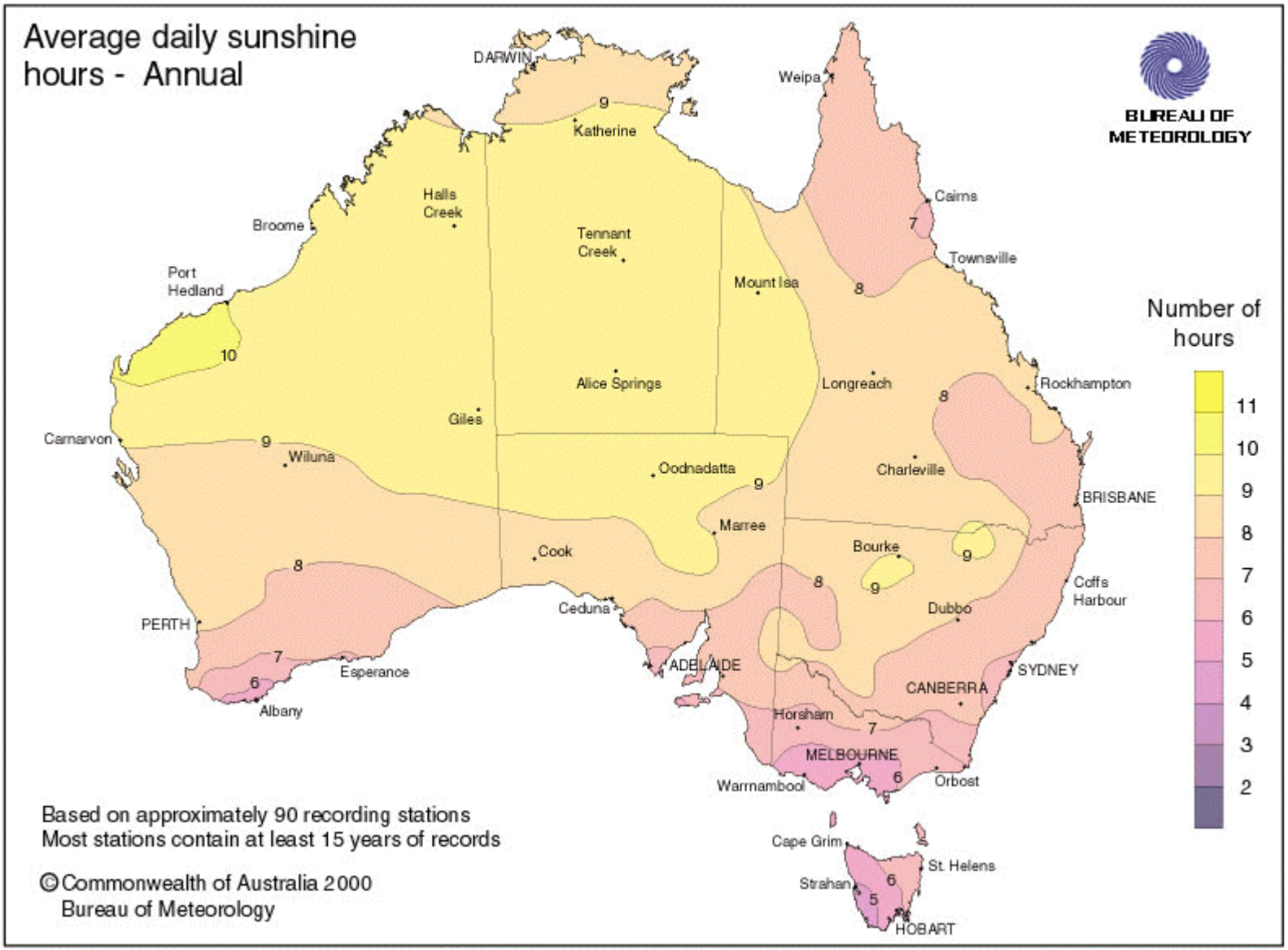
- Deregulation of electricity and gas supply industries
- Move towards smaller-scale power generation based on gas
- By 2010 an additional 9,500 GWh pa to be sourced from new renewable energy
- Introduction of renewable energy accreditation schemes by which electricity generated from renewable sources attracts a premium
- Legislation requiring distributors to sell electricity with reduced Greenhouse gas emissions
- **Need for Greenhouse gas mitigation strategies to go beyond more efficient fossil energy technologies and fuel substitution**



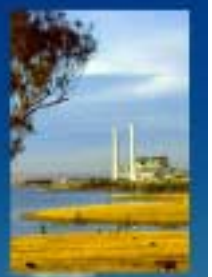



Project Drivers (cont.)

- No exotic material breakthroughs required
- Thermal and chemical processes well understood
- Simple integration with existing thermodynamic cycles and energy processes
- **Coincidence of high levels of solar and gas**
- **Storage of solar energy in chemical form**


Average daily sunshine hours - Annual
BUREAU OF METEOROLOGY
DARWIN
Katherine
Weipa
Halls Creek
Broome
Tennant Creek
Cairns
Townsville
Port Hedland
Mount Isa
Alice Springs
Longreach
Rockhampton
Giles
Carnarvon
Wiluna
Oodnadatta
Charleville
BRISBANE
Marree
Cook
Bourke
Coffs Harbour
Ceduna
Dubbo
PERTH
ADELAIDE
SYDNEY
Esperance
CANBERRA
Albany
Horsham
MELBOURNE
Warrnambool
Orbost
Cape Grim
St. Helens
Strahan
HOBART
Number of hours
11
10
9
8
7
6
5
4
3
2
Based on approximately 90 recording stations
Most stations contain at least 15 years of records
©Commonwealth of Australia 2000
Bureau of Meteorology

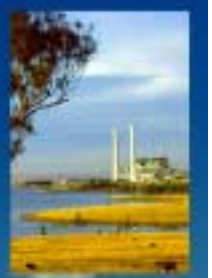


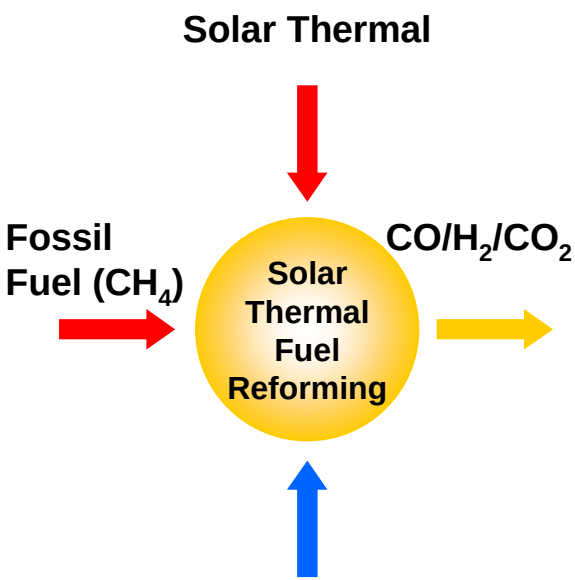
Operational Modes / Products 1

- Green syngas for electricity generation
- Production of synthesis gas as precursor for gas-to-liquids production (potential “bottled sunshine”)
- Closed loop heat generation (methanation) (zero GHG emission)



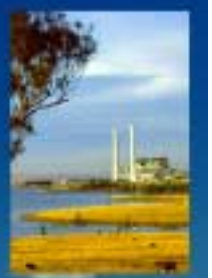



The Concept



$$CH_4 + H_2O(l) + 250\ KJ \rightarrow CO + 3H_2$$

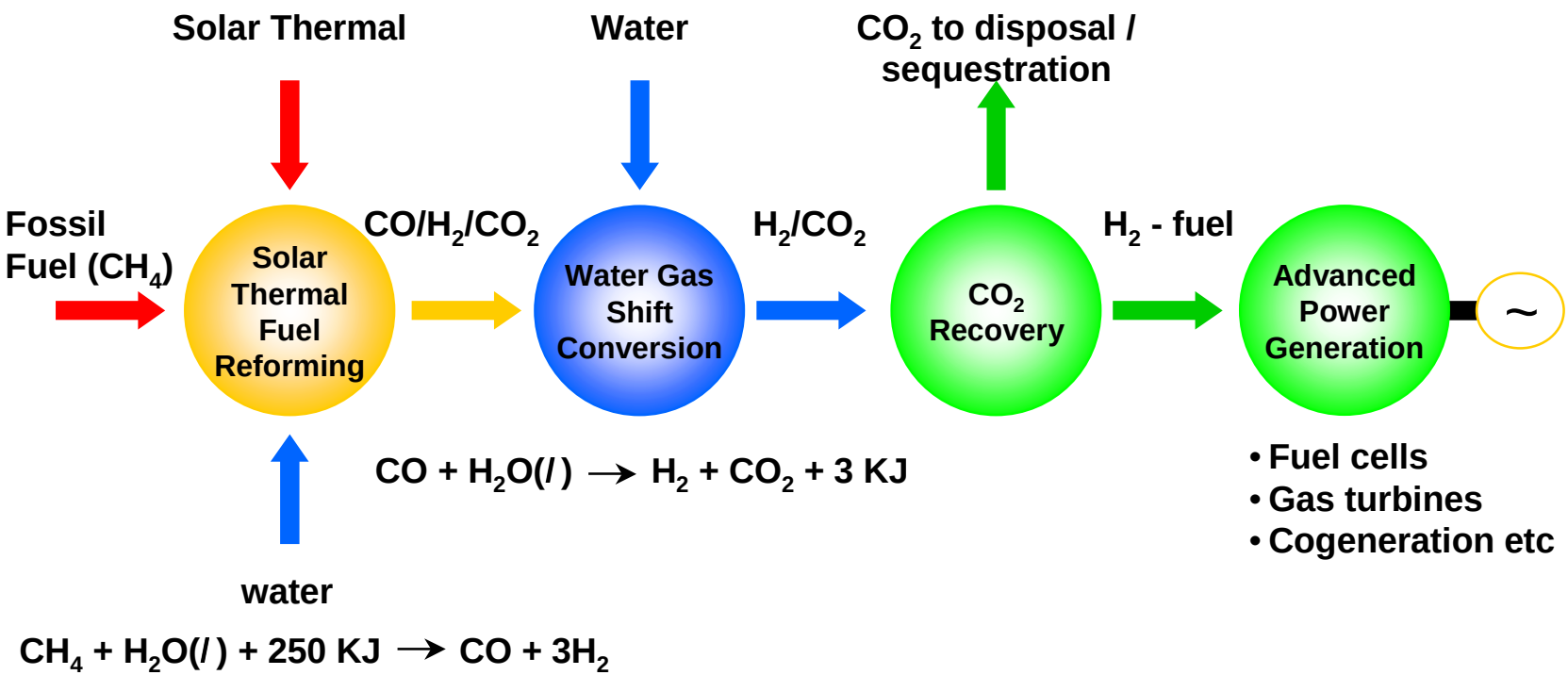


Operational Modes / Products 2

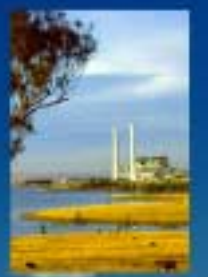
- Hydrogen production with CO_2 capture/sequestration
- Fuel cell electricity generation from hydrogen
- Hydrogen for refining of heavier crude oils

The Concept



$CH_4 + H_2O(l) + 250\ KJ \rightarrow CO + 3H_2$

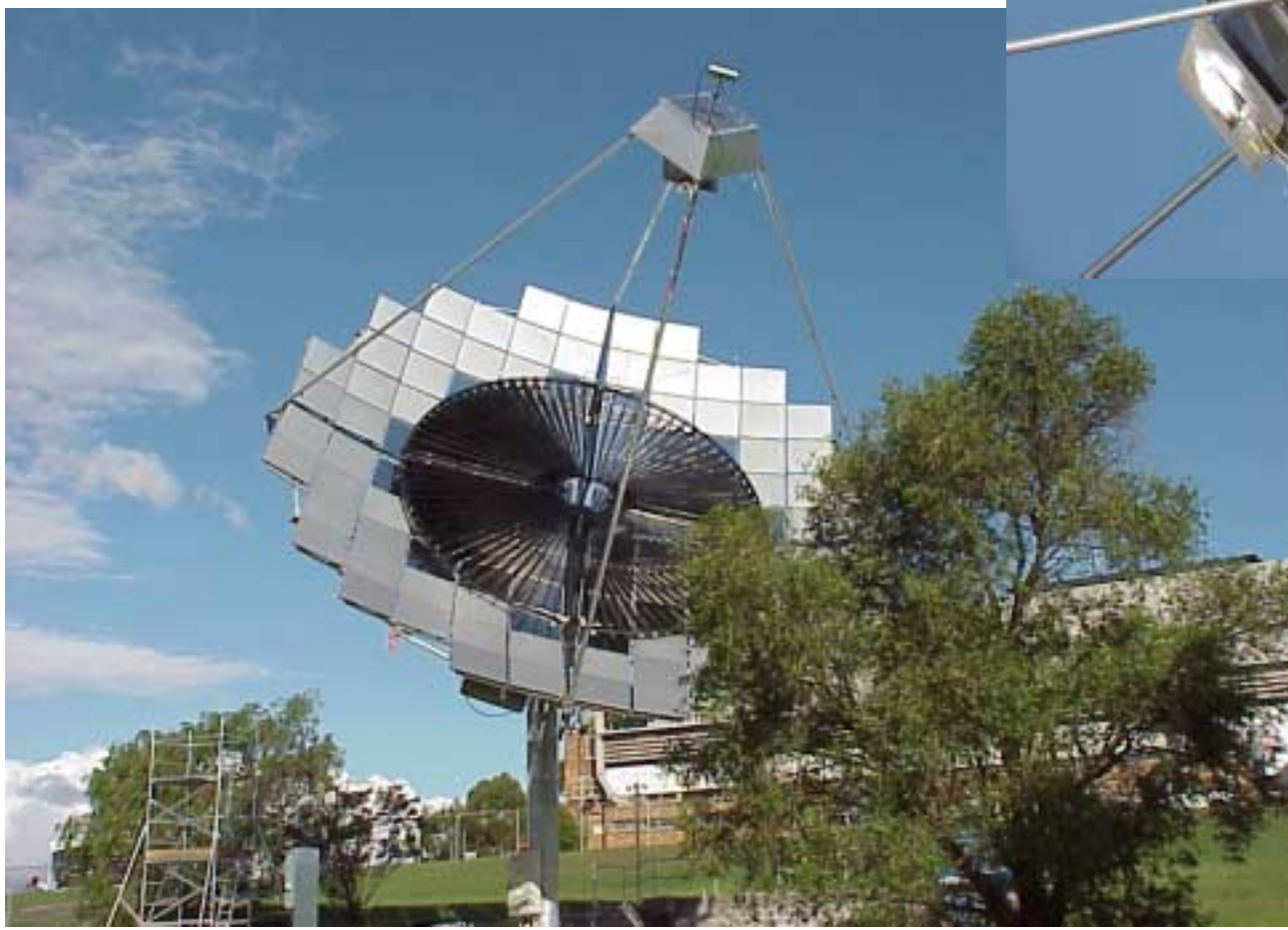


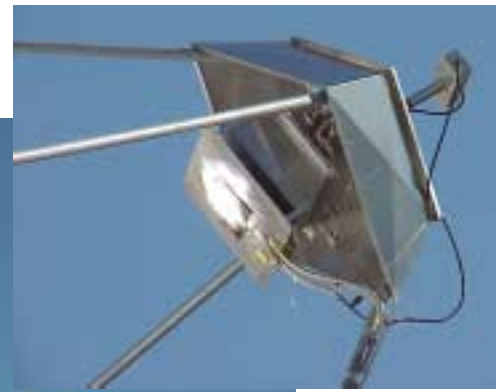



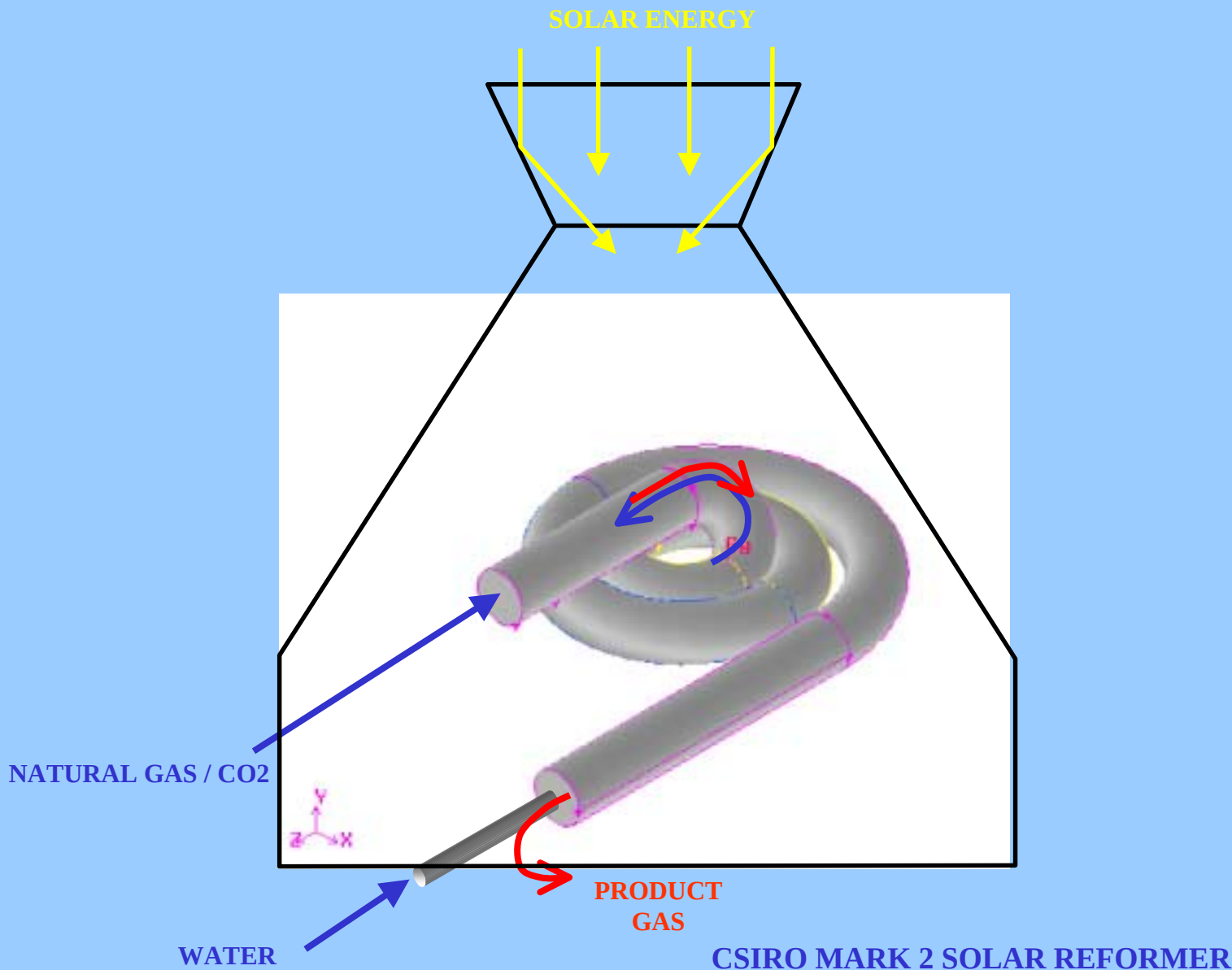
The CSIRO Demonstration Facility

- A 107m^2 twin axis tracking solar dish
- Catalytic gas reforming reactors
- Receiver and flux modifier at focal point
- Absorption-based H_2/CO_2 separation units
- A 10 kWe polymer electrolyte membrane fuel cell (unavailable)
- Complete integrated operation has been successfully demonstrated - H_2 has CO levels low enough for PEM fuel cell operation

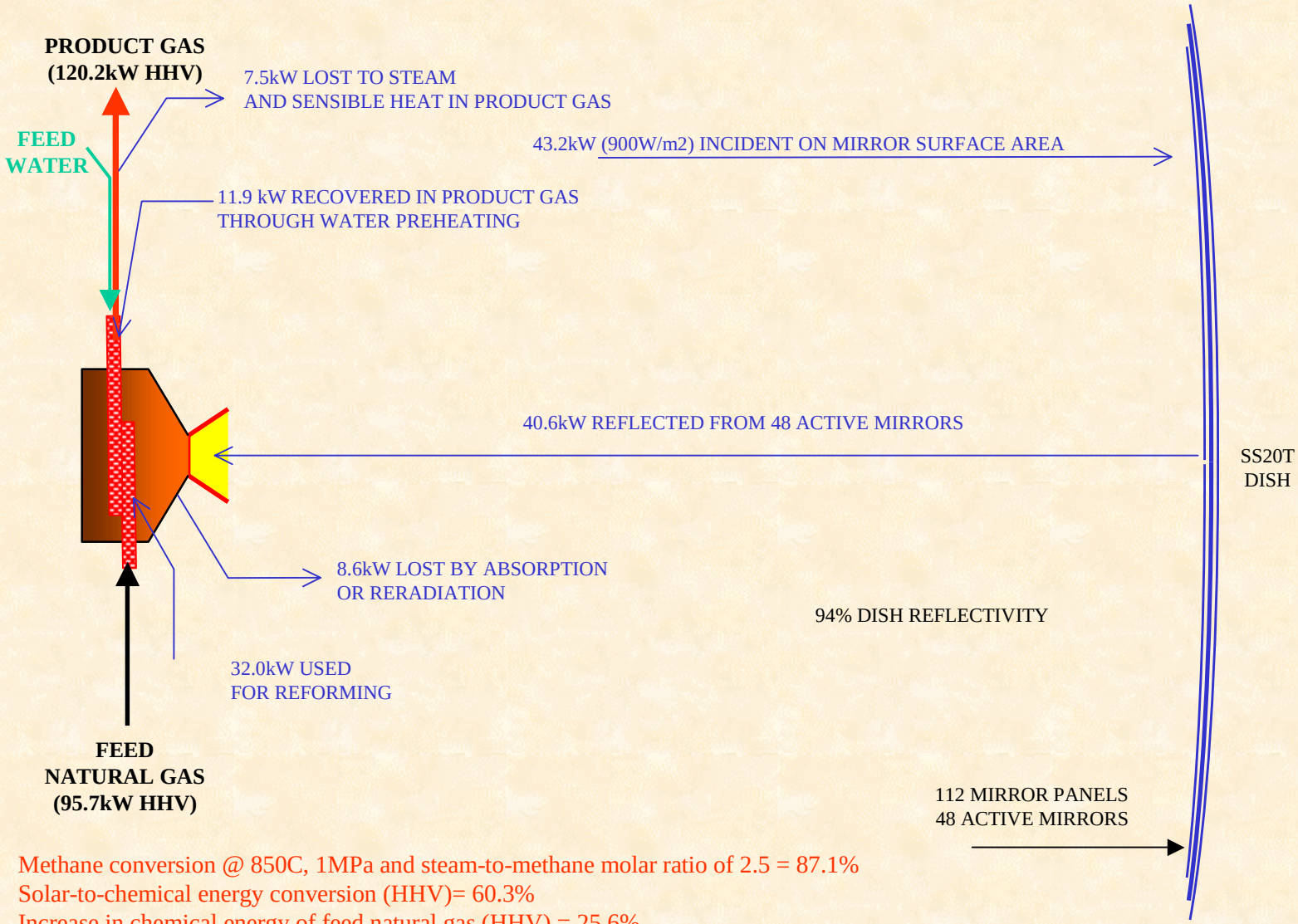
The Dish and Collector





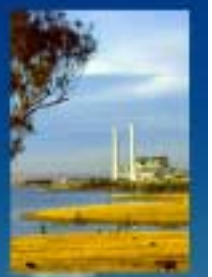

SOLAR ENERGY
NATURAL GAS / CO2
WATER
PRODUCT GAS
CSIRO MARK 2 SOLAR REFORMER

PREDICTED THERMAL PERFORMANCE OF CSIRO MARK II SOLAR REFORMER WITH 900W/M2 DIRECT SOLAR ENERGY



Methane conversion @ 850C, 1MPa and steam-to-methane molar ratio of 2.5 = 87.1%
Solar-to-chemical energy conversion (HHV)= 60.3%
Increase in chemical energy of feed natural gas (HHV) = 25.6%

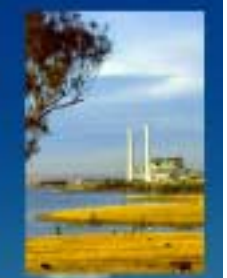


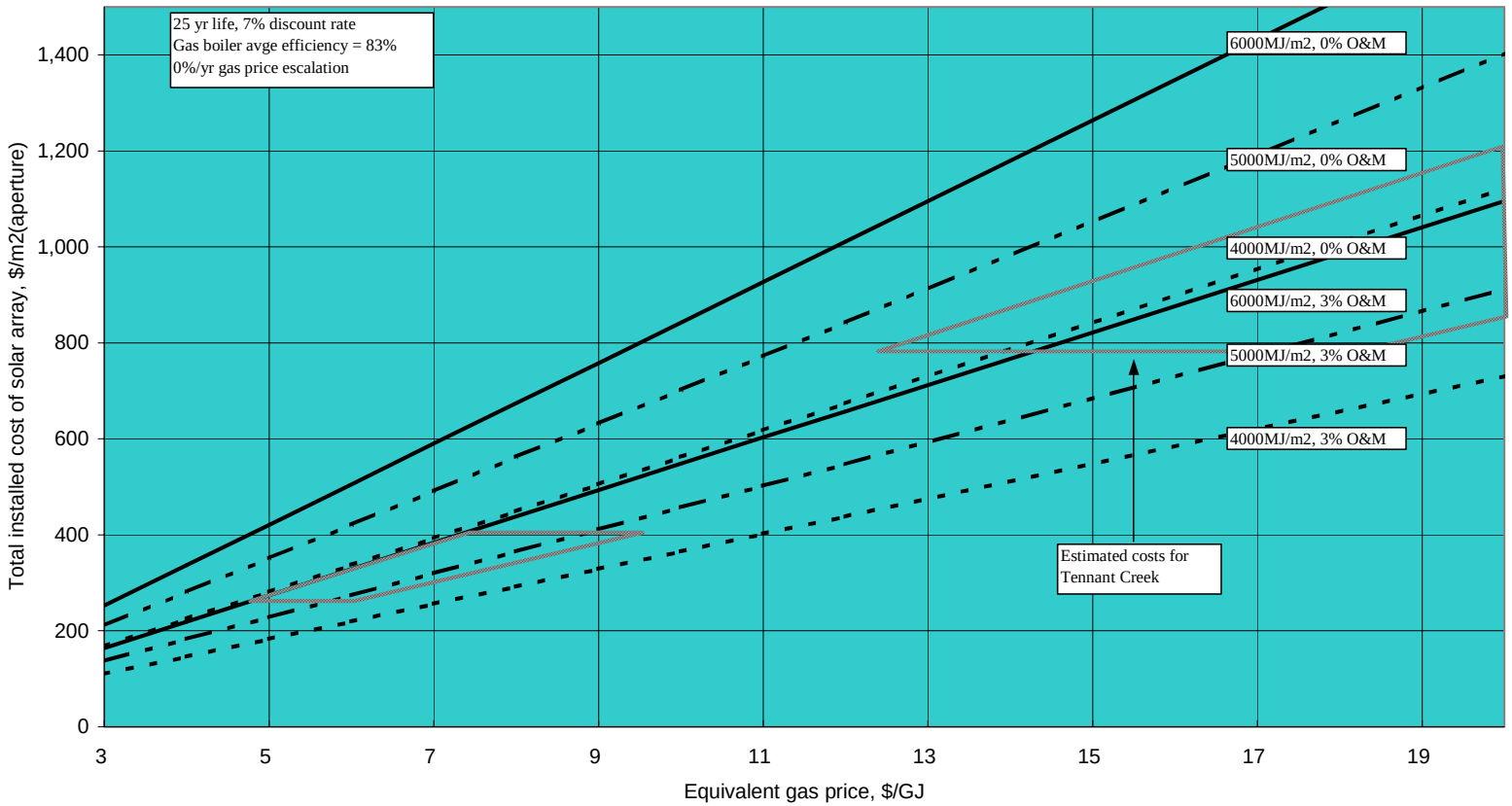



Future Plans & Outlook for CSIRO solar reforming

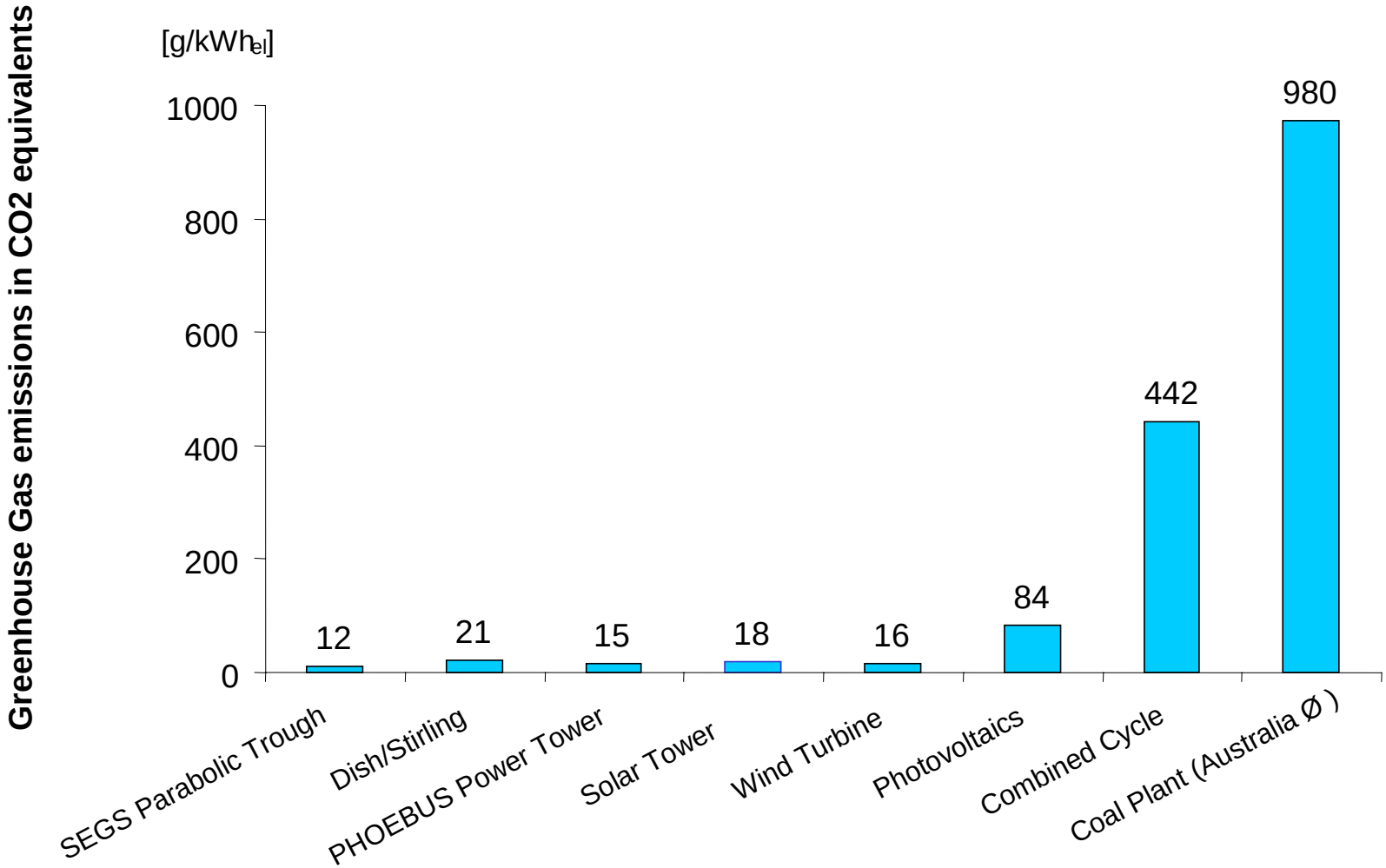
- Commercial prospects being evaluated
- Demonstration facility establishing proof of concept being pursued
- Appropriate solar concentrator is required
- Industrial partners being sought to move into a commercial implementation phase



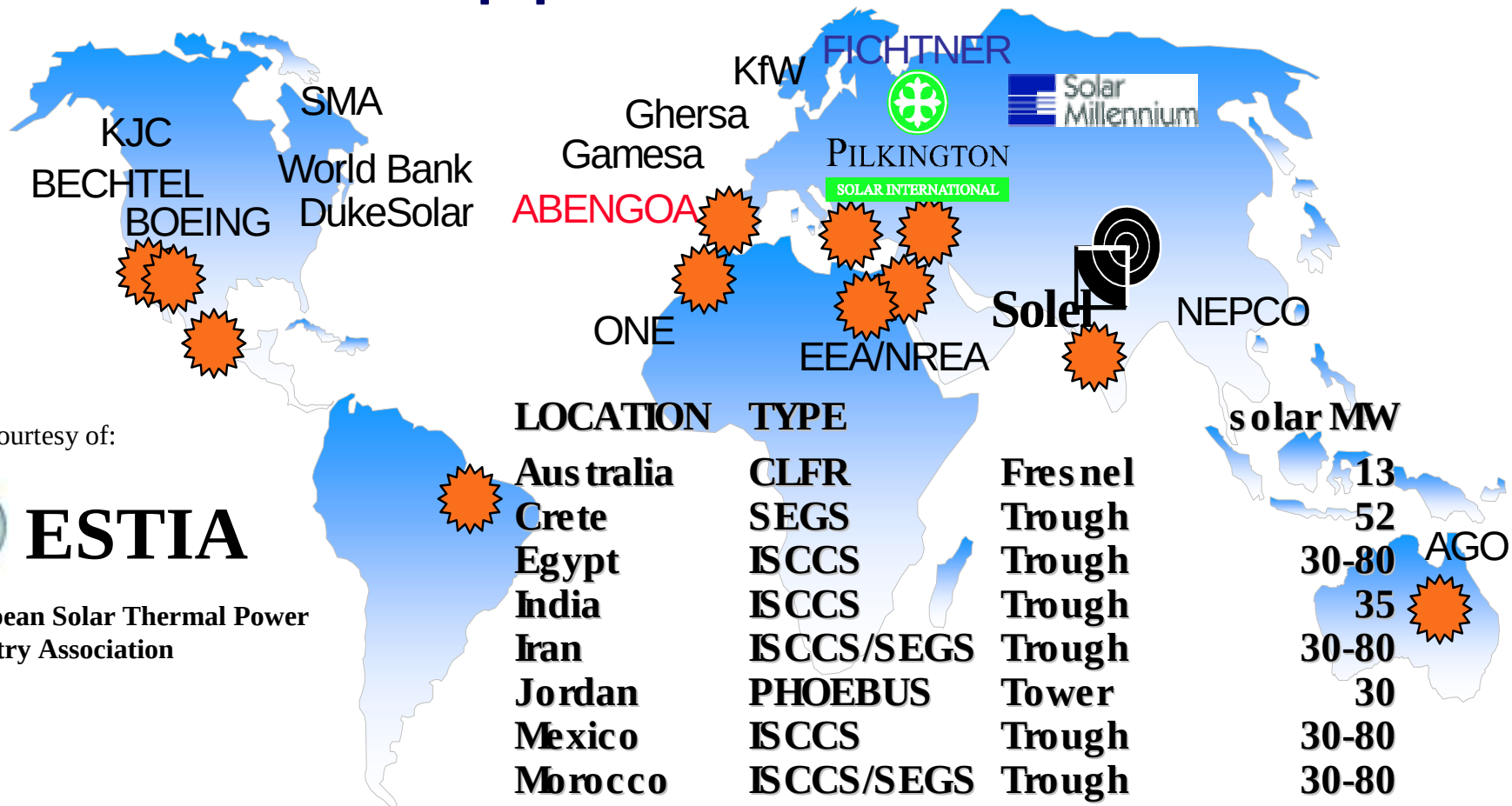

25 yr life, 7% discount rate
Gas boiler avge efficiency = 83%
0%/yr gas price escalation
6000MJ/m2, 0% O&M
5000MJ/m2, 0% O&M
4000MJ/m2, 0% O&M
6000MJ/m2, 3% O&M
5000MJ/m2, 3% O&M
4000MJ/m2, 3% O&M
Estimated costs for Tennant Creek
Total installed cost of solar array, $/m2(aperture)
0
200
400
600
800
1,000
1,200
1,400
3
5
7
9
11
13
15
17
19
Equivalent gas price, $/GJ

Greenhouse gas emissions



Source: Weinrebe, G.: ”Greenhouse Gas Mitigation with Solar Thermal Power Plants”, Proceedings of the PowerGen Europe 1999 Conference, Frankfurt, Germany, June 1-3

International Opportunities



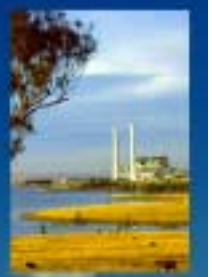
LOCATION	TYPE		solar MW
Australia	CLFR	Fresnel	13
Crete	SEGS	Trough	52
Egypt	ISCCS	Trough	30-80
India	ISCCS	Trough	35
Iran	ISCCS/SEGS	Trough	30-80
Jordan	PHOEBUS	Tower	30
Mexico	ISCCS	Trough	30-80
Morocco	ISCCS/SEGS	Trough	30-80
Spain	SEGS, SP10	Trough,Tower	10-50
USA	SEGS	Trough	354

Slide courtesy of:

ESTIA

European Solar Thermal Power Industry Association

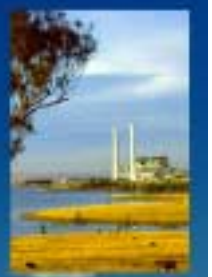


Where to from here?

- *A number of technology types opening up many different opportunities.*
- *Major hurdle at present is capital cost of the collector / concentrator.*
- *Apart from mirrors, manufacturing and civil works similar to wind turbines so could follow same cost reduction curve.*
- *Opportunity to link the best technologies of Europe and Australia to produce flexible solar thermal driven packages that can be customised for specific applications.*

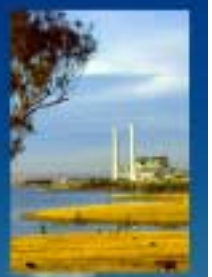


Required steps

- *Demonstration plants at pre-commercial level are critical. Problem-free operation is possibly more crucial to technology confidence than cost at this time.*
- *Such plants should be installed in hybrid configurations (with reliable back-up fuel such as gas) and in parallel so that seamless operation can be demonstrated*
- *They should operate in a commercial environment (whether or not they are producing commercially-competitive energy) so that real experience is gained and investors see real solutions emerging*

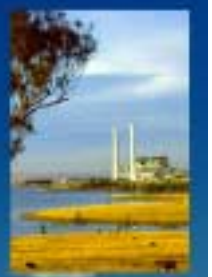


Collaborative opportunities

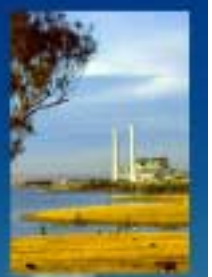
- *Alliance with European partners sought for various aspects*
- *Collaboration could be:*
  - *Technical R&D*
  - *Modelling*
  - *Product development*
  - *Product demonstration and testing*



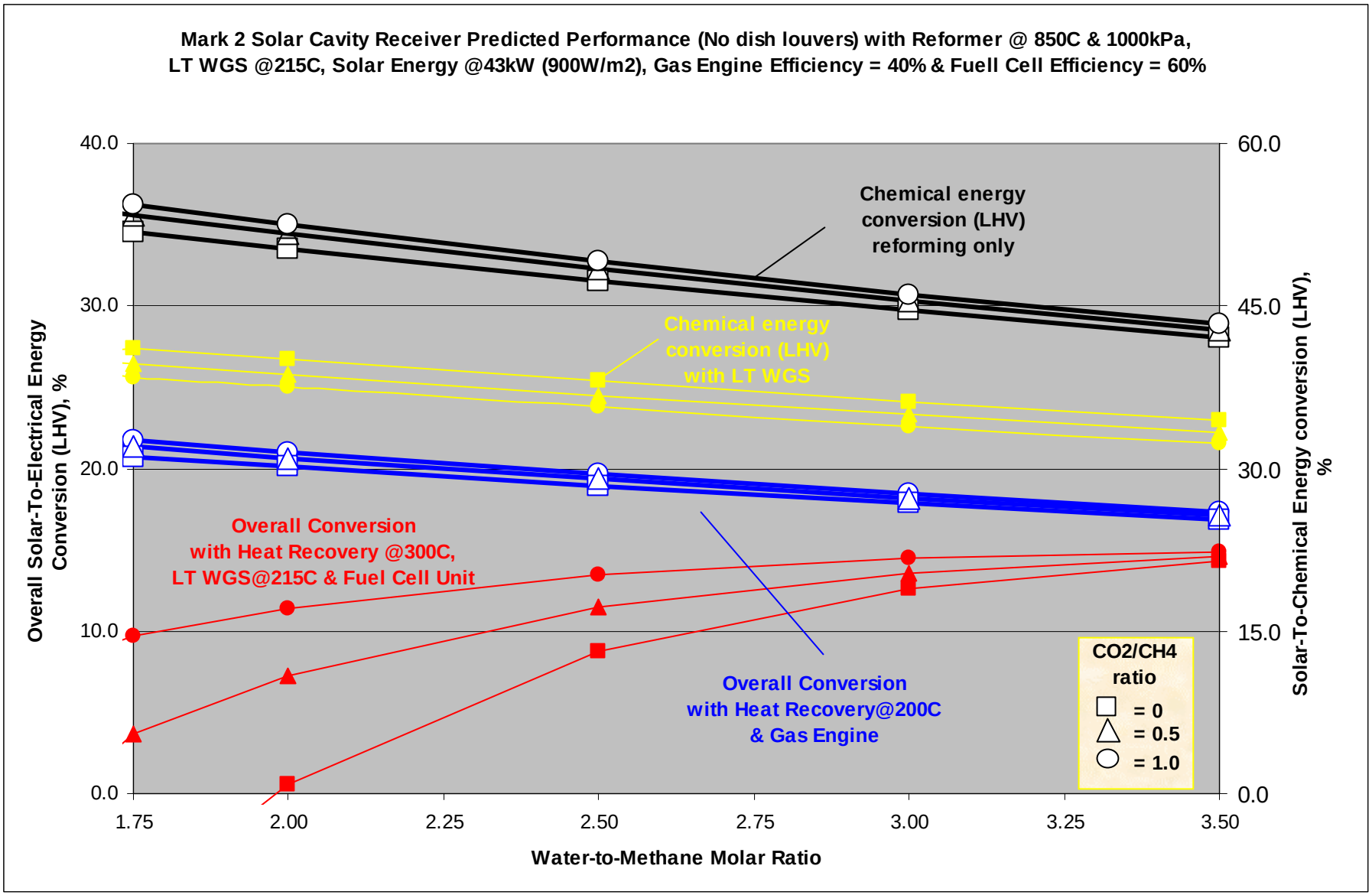
Collaborative opportunities

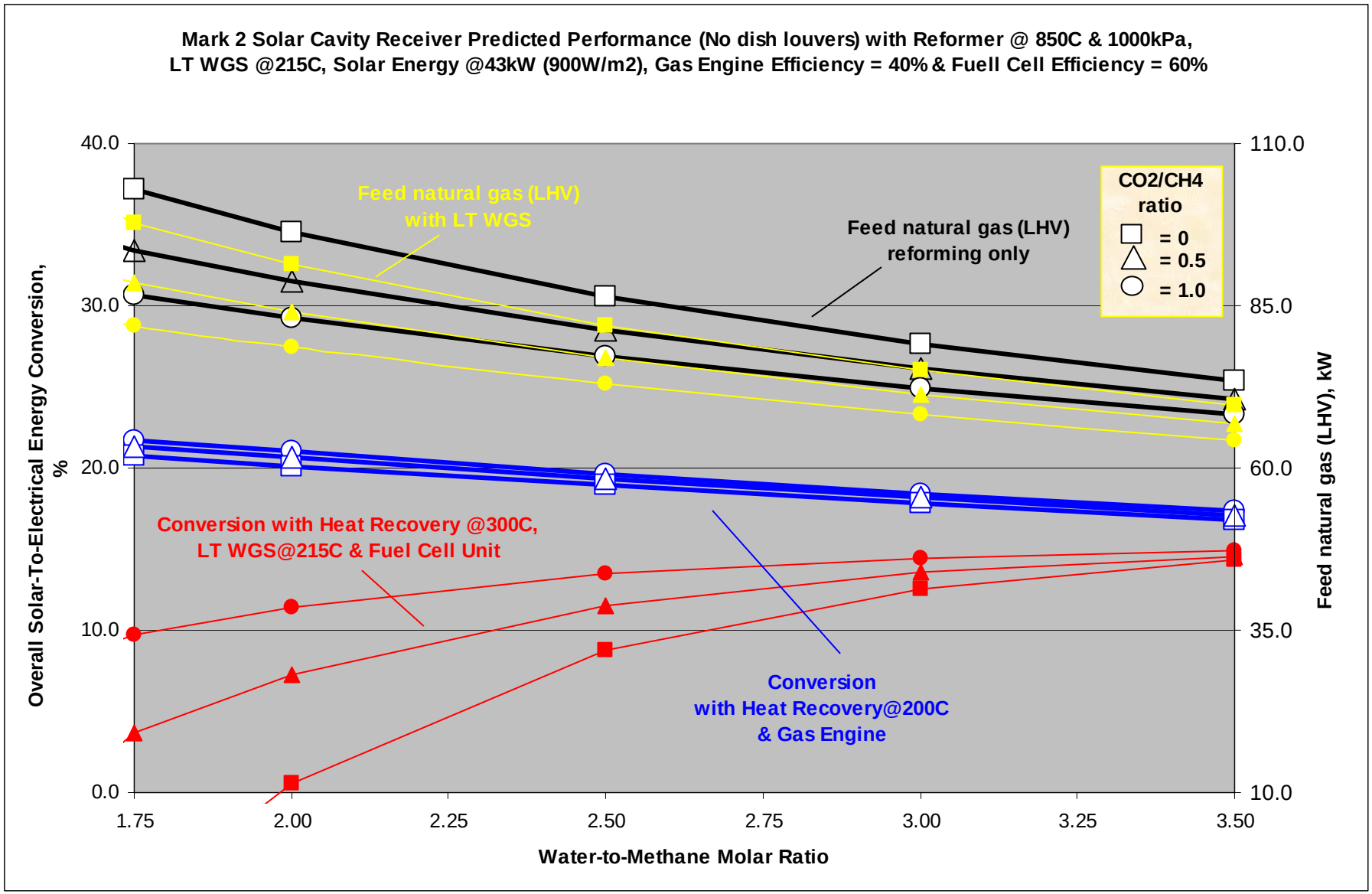
- *Some immediate areas of interest:*
  - *Solar/gas hybrid Brayton cycle*
  - *Solar thermal supplementation of distributed generation plants, especially cogen and trigen*
  - *Solar steam Rankine cycle integration*
  - *Solar reformed methane*
  - *Solar biomass hybrids*
- *Work also required on associated equipment, for example:*
  - *Small heat engines utilising medium temperature steam*
  - *Organic Rankine Cycles*
  - *Absorption cycle chilling*

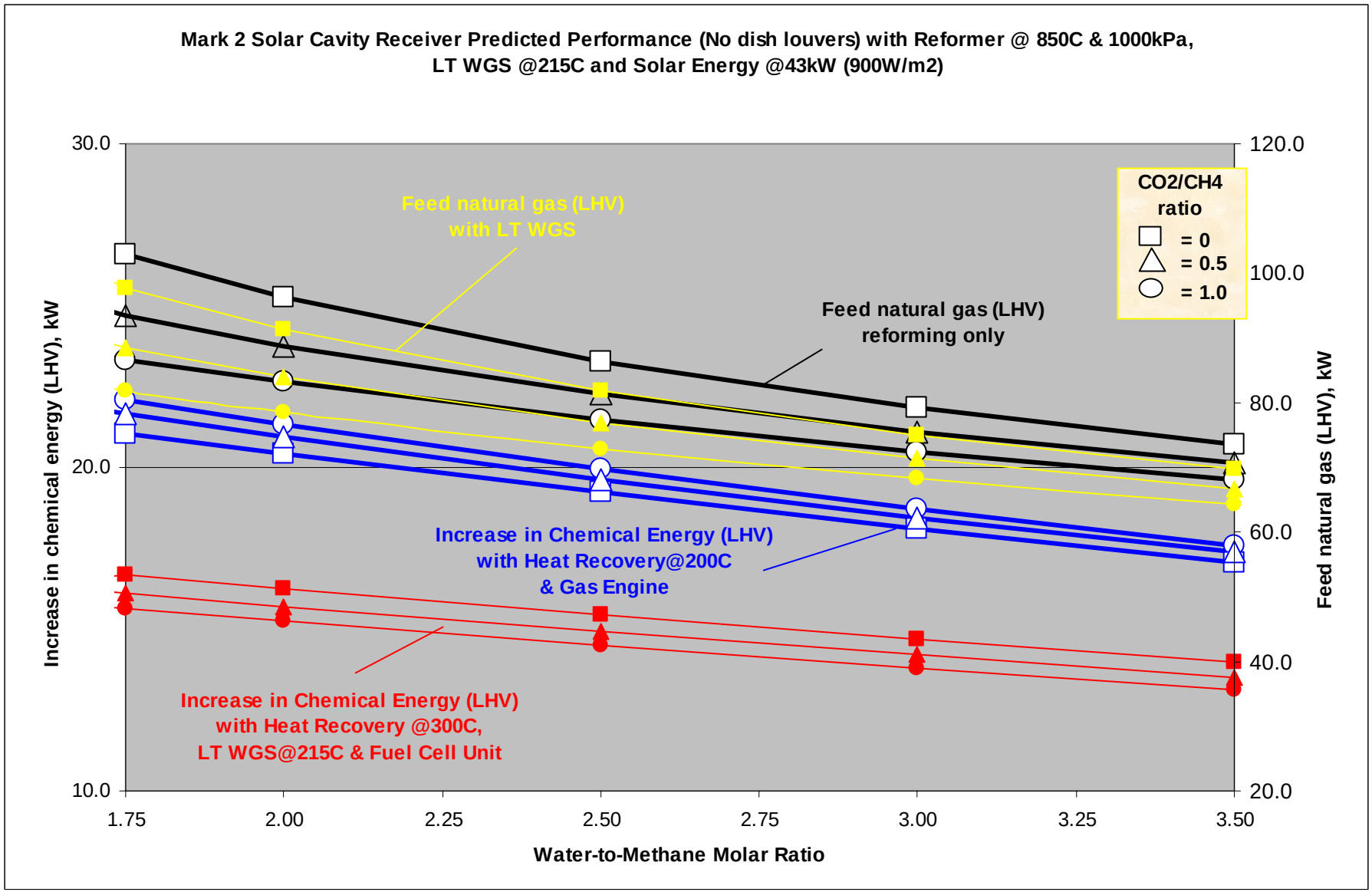


THANK YOU

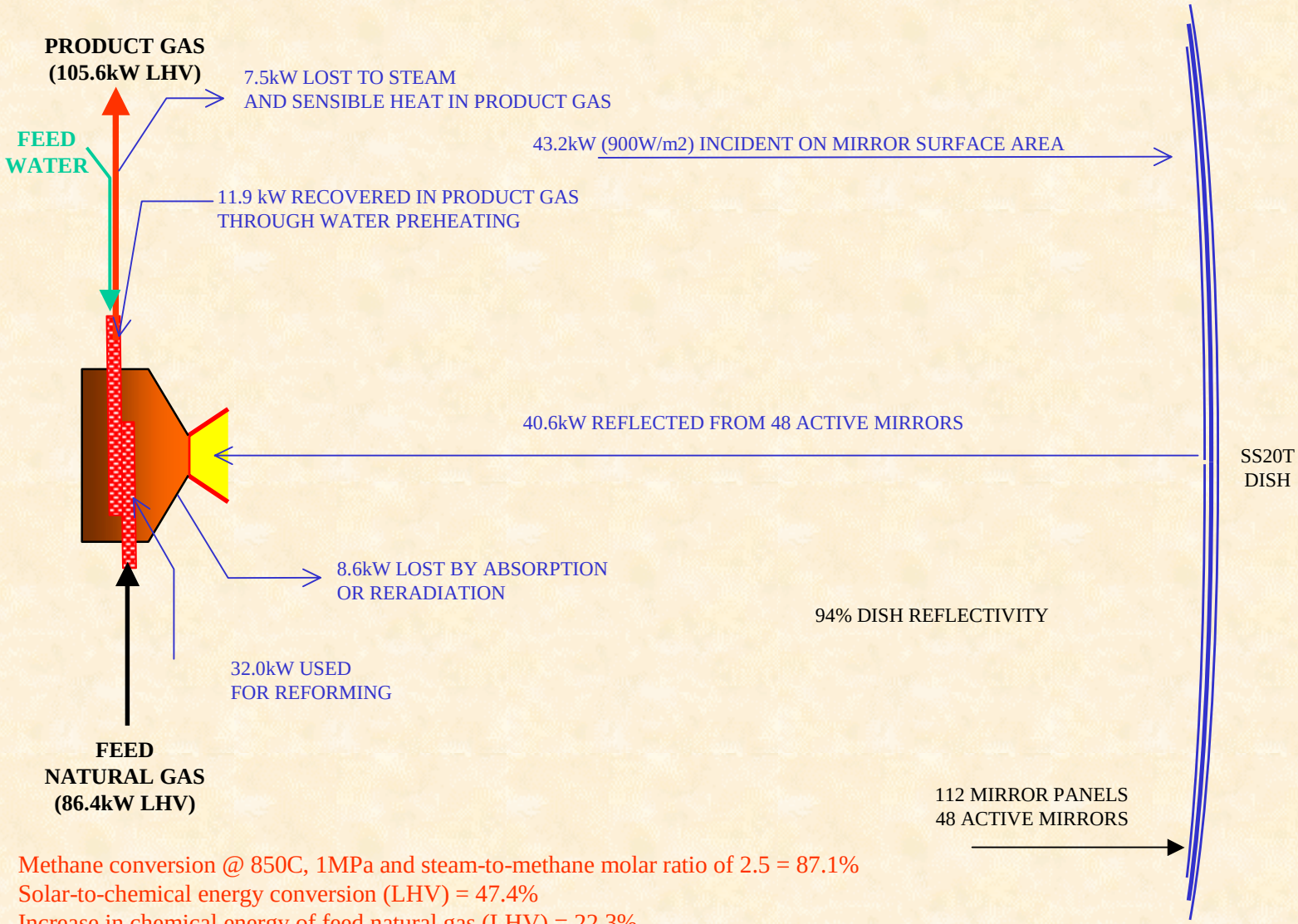
ENERGY **TECHNOLOGY**


Mark 2 Solar Cavity Receiver Predicted Performance (No dish louvers) with Reformer @ 850C & 1000kPa,
LT WGS @215C, Solar Energy @43kW (900W/m2), Gas Engine Efficiency = 40% & Fuell Cell Efficiency = 60%
Overall Solar-To-Electrical Energy Conversion (LHV), %
Solar-To-Chemical Energy conversion (LHV), %
Water-to-Methane Molar Ratio
40.0
30.0
20.0
10.0
0.0
60.0
45.0
30.0
15.0
0.0
1.75
2.00
2.25
2.50
2.75
3.00
3.25
3.50
Chemical energy conversion (LHV) reforming only
Chemical energy conversion (LHV) with LT WGS
Overall Conversion with Heat Recovery @300C, LT WGS@215C & Fuel Cell Unit
Overall Conversion with Heat Recovery@200C & Gas Engine
CO2/CH4 ratio
= 0
= 0.5
= 1.0


Mark 2 Solar Cavity Receiver Predicted Performance (No dish louvers) with Reformer @ 850C & 1000kPa,
LT WGS @215C, Solar Energy @43kW (900W/m2), Gas Engine Efficiency = 40% & Fuell Cell Efficiency = 60%
Overall Solar-To-Electrical Energy Conversion, %
Feed natural gas (LHV), kW
Water-to-Methane Molar Ratio
40.0
30.0
20.0
10.0
0.0
110.0
85.0
60.0
35.0
10.0
1.75
2.00
2.25
2.50
2.75
3.00
3.25
3.50
Feed natural gas (LHV) with LT WGS
Feed natural gas (LHV) reforming only
CO2/CH4 ratio
= 0
= 0.5
= 1.0
Conversion with Heat Recovery @300C, LT WGS@215C & Fuel Cell Unit
Conversion with Heat Recovery@200C & Gas Engine


Mark 2 Solar Cavity Receiver Predicted Performance (No dish louvers) with Reformer @ 850C & 1000kPa,
LT WGS @215C and Solar Energy @43kW (900W/m2)
Feed natural gas (LHV)
with LT WGS
Feed natural gas (LHV)
reforming only
CO2/CH4
ratio
= 0
= 0.5
= 1.0
Increase in Chemical Energy (LHV)
with Heat Recovery@200C
& Gas Engine
Increase in Chemical Energy (LHV)
with Heat Recovery @300C,
LT WGS@215C & Fuel Cell Unit
Increase in chemical energy (LHV), kW
Feed natural gas (LHV), kW
Water-to-Methane Molar Ratio
30.0
20.0
10.0
120.0
100.0
80.0
60.0
40.0
20.0
1.75
2.00
2.25
2.50
2.75
3.00
3.25
3.50

PREDICTED THERMAL PERFORMANCE OF CSIRO MARK II SOLAR REFORMER WITH 900W/M2 DIRECT SOLAR ENERGY



Methane conversion @ 850C, 1MPa and steam-to-methane molar ratio of 2.5 = 87.1%
Solar-to-chemical energy conversion (LHV) = 47.4%
Increase in chemical energy of feed natural gas (LHV) = 22.3%