Photovoltaics in Australia
Technology, Markets & Performance

Dr Muriel Watt
Senior Lecturer
School of Photovoltaics & Renewable Energy Engineering
UNSW

IEAust, August 2006

UNSW } ENGINEERING
THE UNIVERSITY OF NEW SOUTH WALES

Outline

- The world PV market
- The Australian PV market
- PV technologies
- Australian PV research
- Net energy and ghg impacts
- Australian PV applications
- Government support for PV
- Where to from here?

The World PV Market

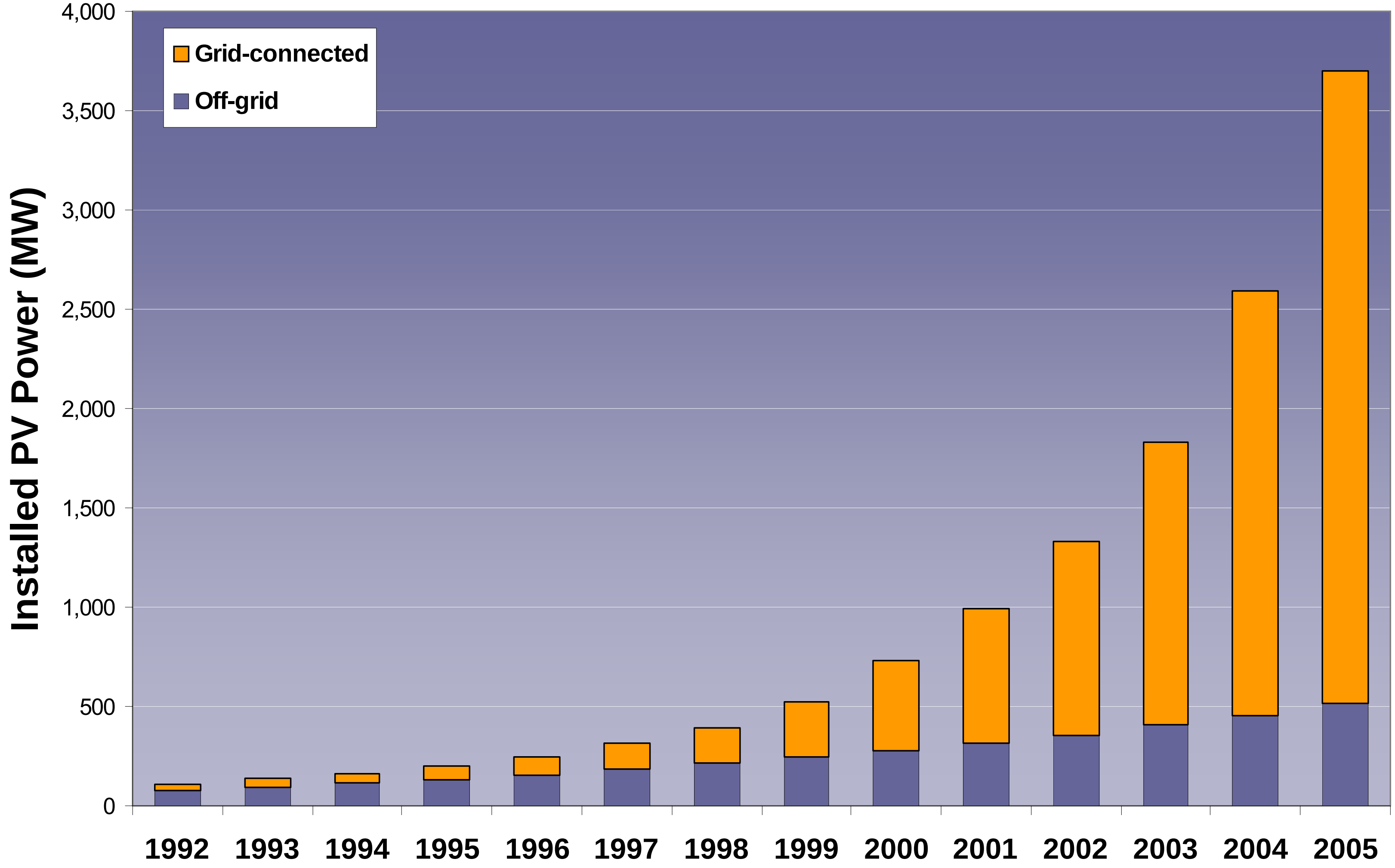
IEAust, August 2006

UNSW THE UNIVERSITY OF NEW SOUTH WALES } ENGINEERING

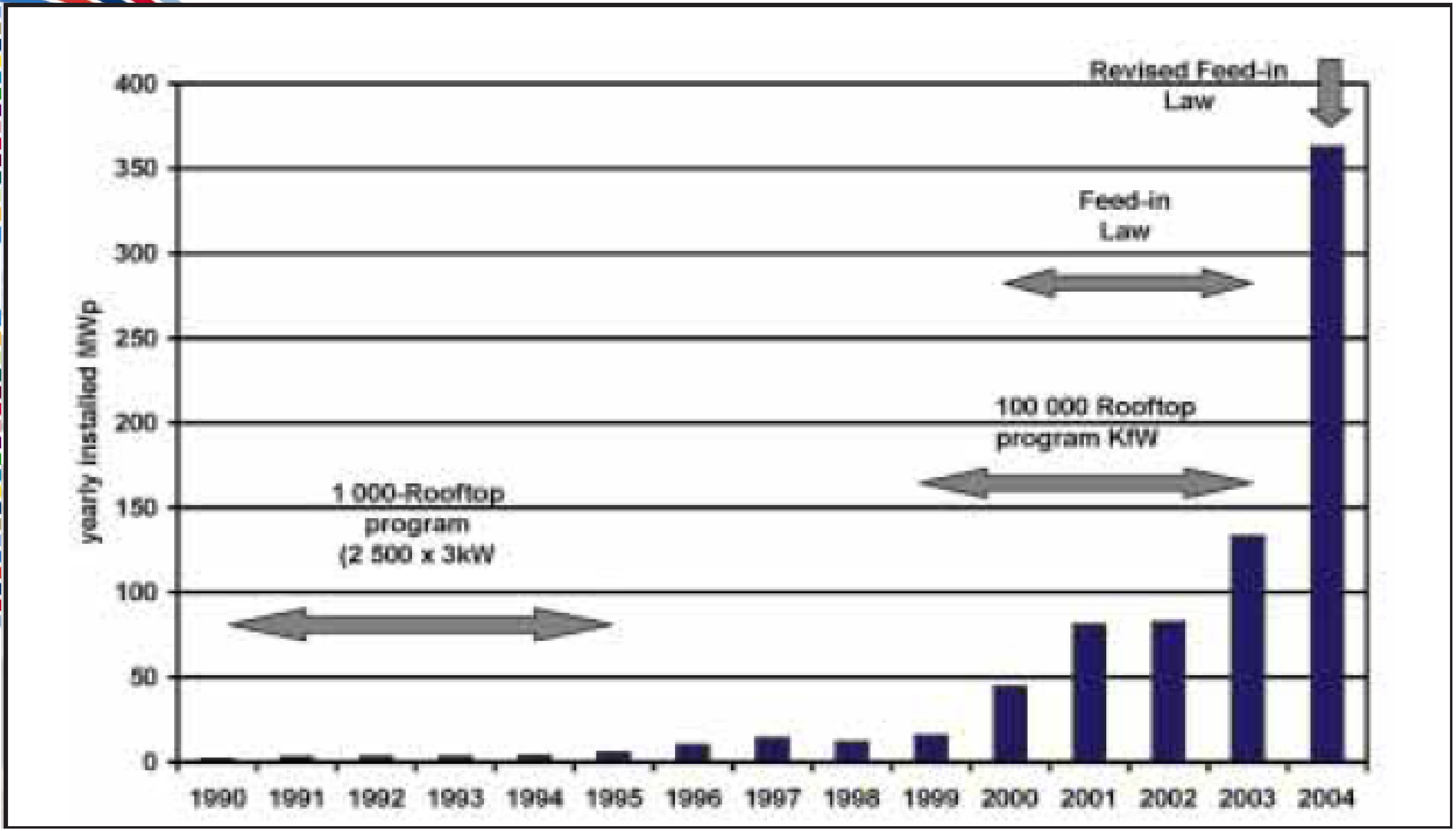
IEA PV Market 1992-2005

(IEA PVPS, 2006)

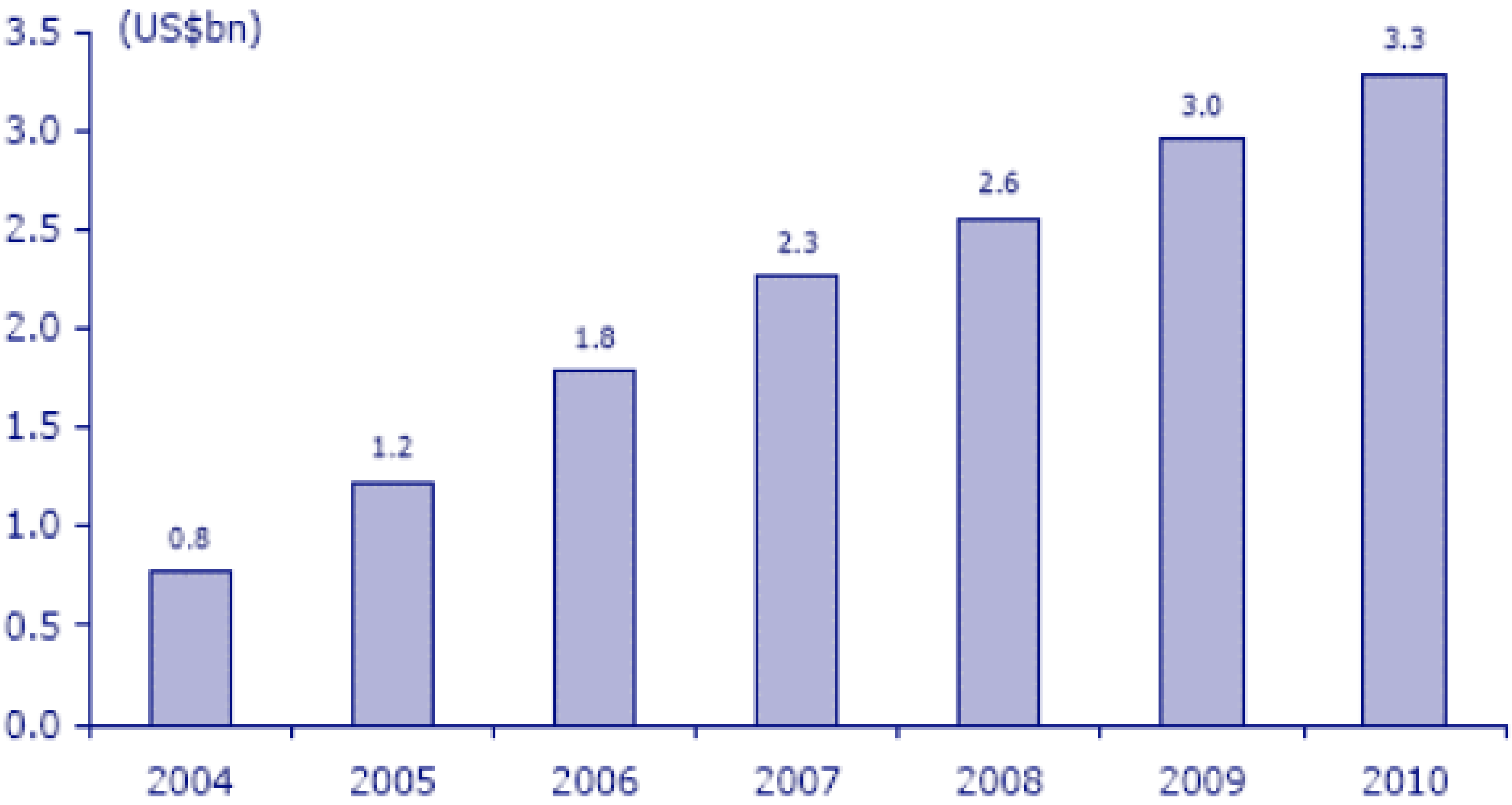
Figure 1 Cumulative installed grid-connected and off-grid PV power in the reporting countries – Years 1992-2005



German PV market growth
(EPIA, 2005a)



Projected World PV Market Value



Source: CLSA Asia-Pacific markets

Feed in Tariffs Germany from 2004

- Free surfaces (not roofs): 45.7 c€/kWh
- Roofs 30 to 100 kWp 54.6 c€/kWh
- Facades < 30 kWp: 62.4 c€/kW
- Facades > 100 kWp 59 c€/kWh
- Roofs < 30 kWp: 57.4 c€/kWh
- Roofs > 100 kWp: 54 c€/kWh
- Facades 30 to 100 kWp: 59.6 c€/kWh

PV in Germany by 2004

- Germany overtook Japan with the highest level of PV installations – 363 MWp
- Installed capacity in Germany reached 794 MWp
- Industry turnover €1.7 billion
- 20,000 people employed in the sector
- Average electricity bill increased by 0.16% (~ A$1.78 per annum)

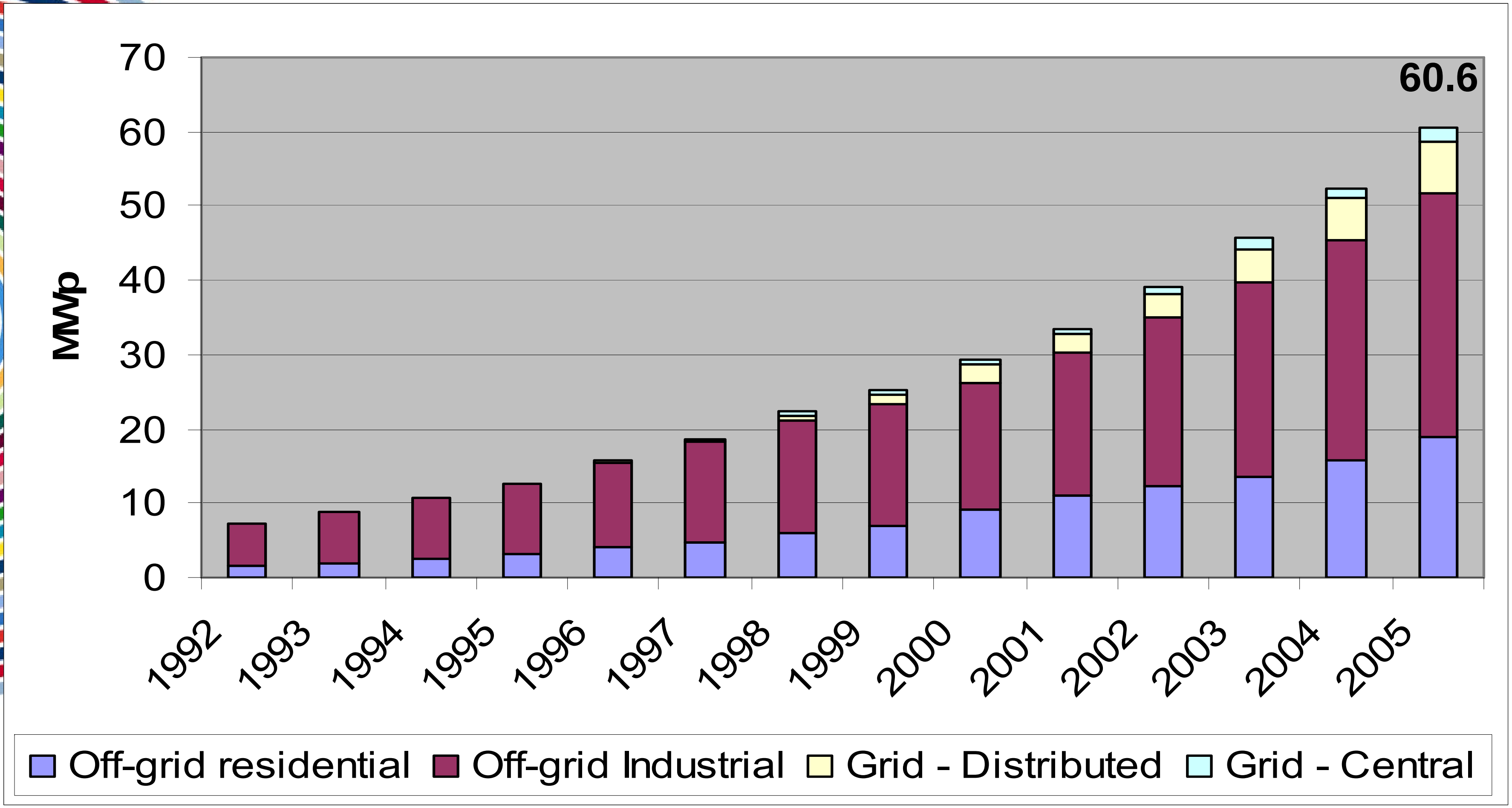
The Australian PV Market

IEAust, August 2006

UNSW THE UNIVERSITY OF NEW SOUTH WALES } ENGINEERING

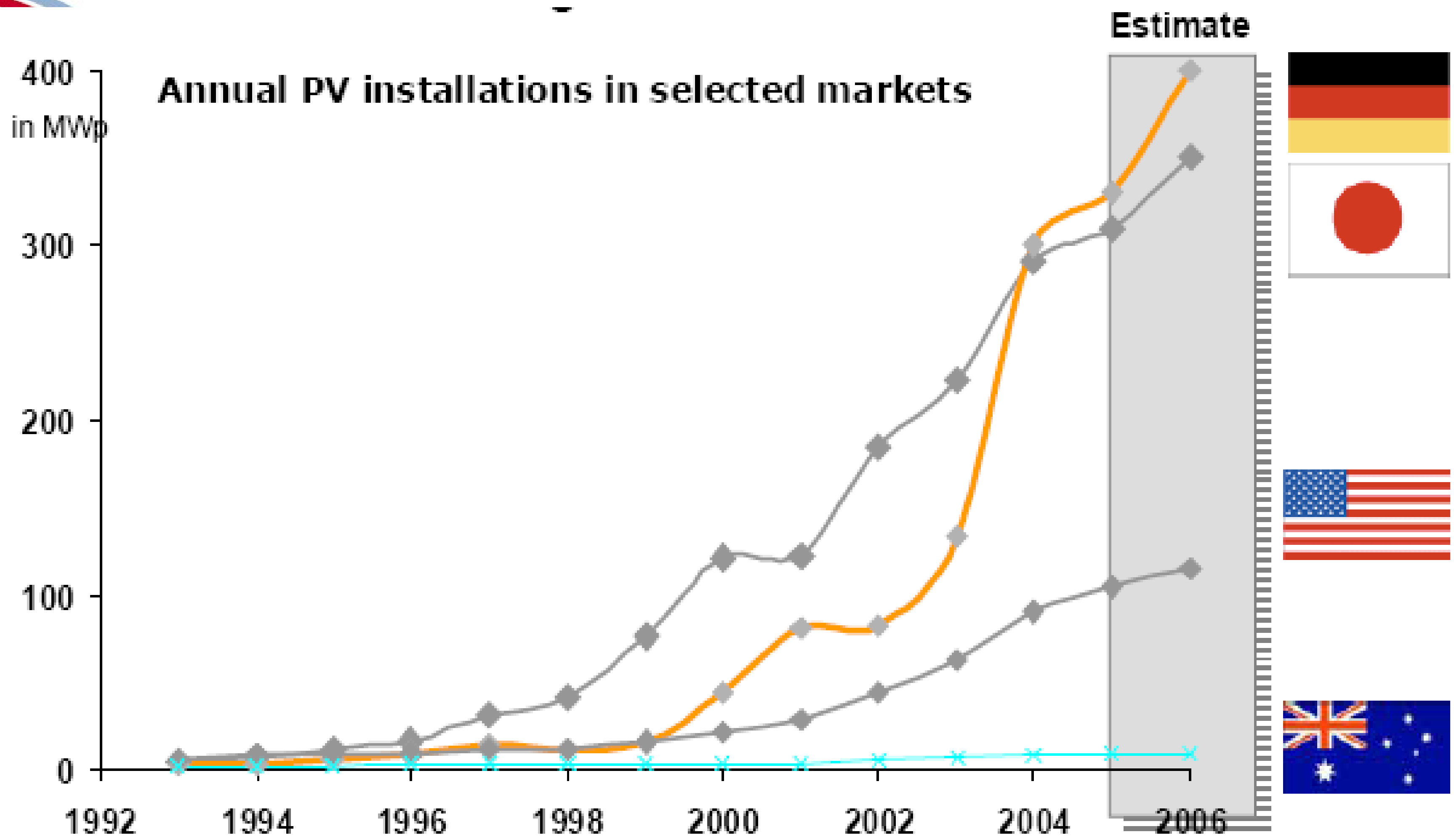
Cumulative PV Installations

(Australian PVPS Consortium, 2006)



UNSW THE UNIVERSITY OF NEW SOUTH WALES } ENGINEERING

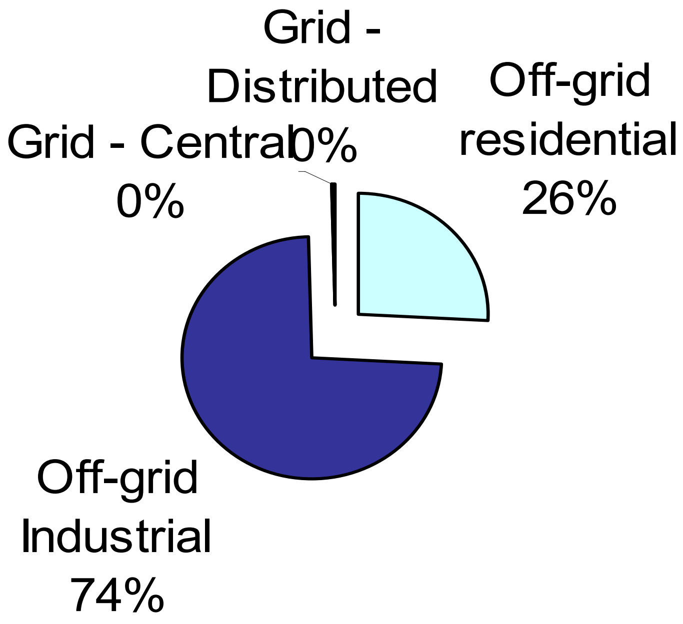
Australian and International PV Installation trends



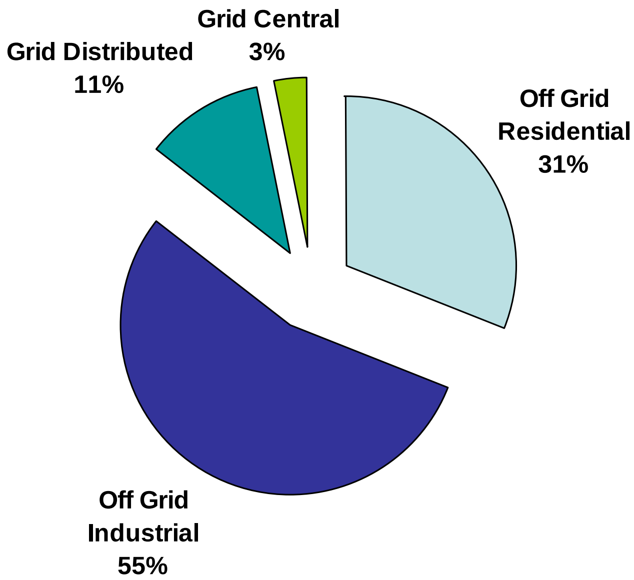
Source: Sarasin 2004

Cumulative Australian Installations 1995 and 2005

(Australian PVPS Consortium, 2006)



1995 – 12.7 MWp



2005 – 60.6 MWp

2005 PV Installations

(Australian PVPS Consortium, 2006)

Sector	***MWp installed***
Off Grid Residential	2.9
Off Grid Industrial	3.4
Grid – distributed	1.5
Diesel Grids	0.5
TOTAL	***8.3***

Australian PV Industry Roadmap
(BCSE, 2004)

- Business as Usual to 2010
  - Module imports 90%. No export
  - BOS imports 50%. Export 50%
- Sunrise 350
  - Module imports 25%. Export 50%
  - BOS imports 25%. Export 50%

UNSW } ENGINEERING
THE UNIVERSITY OF NEW SOUTH WALES

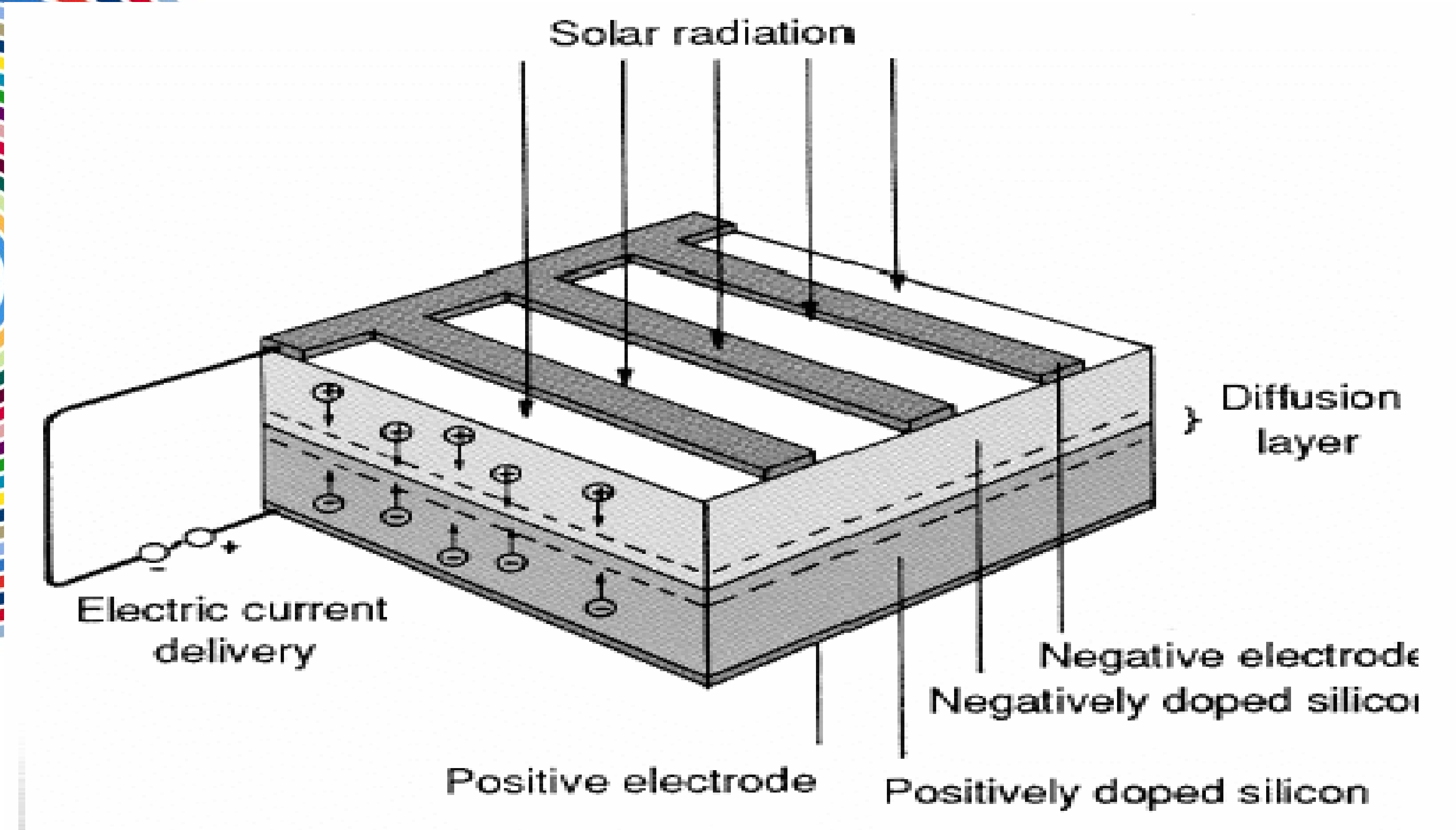
BAU or Sunrise 350 in 2010

	BAU	***Sunrise 350***
Annual Aus installed (MW)	16	127
Cumulative Aus Capacity (MW)	120	350
Module exports (MW)	20	445
Sales $m	80	1,180
Australian share of the global market (%)	<1	7
Jobs	310	5,300

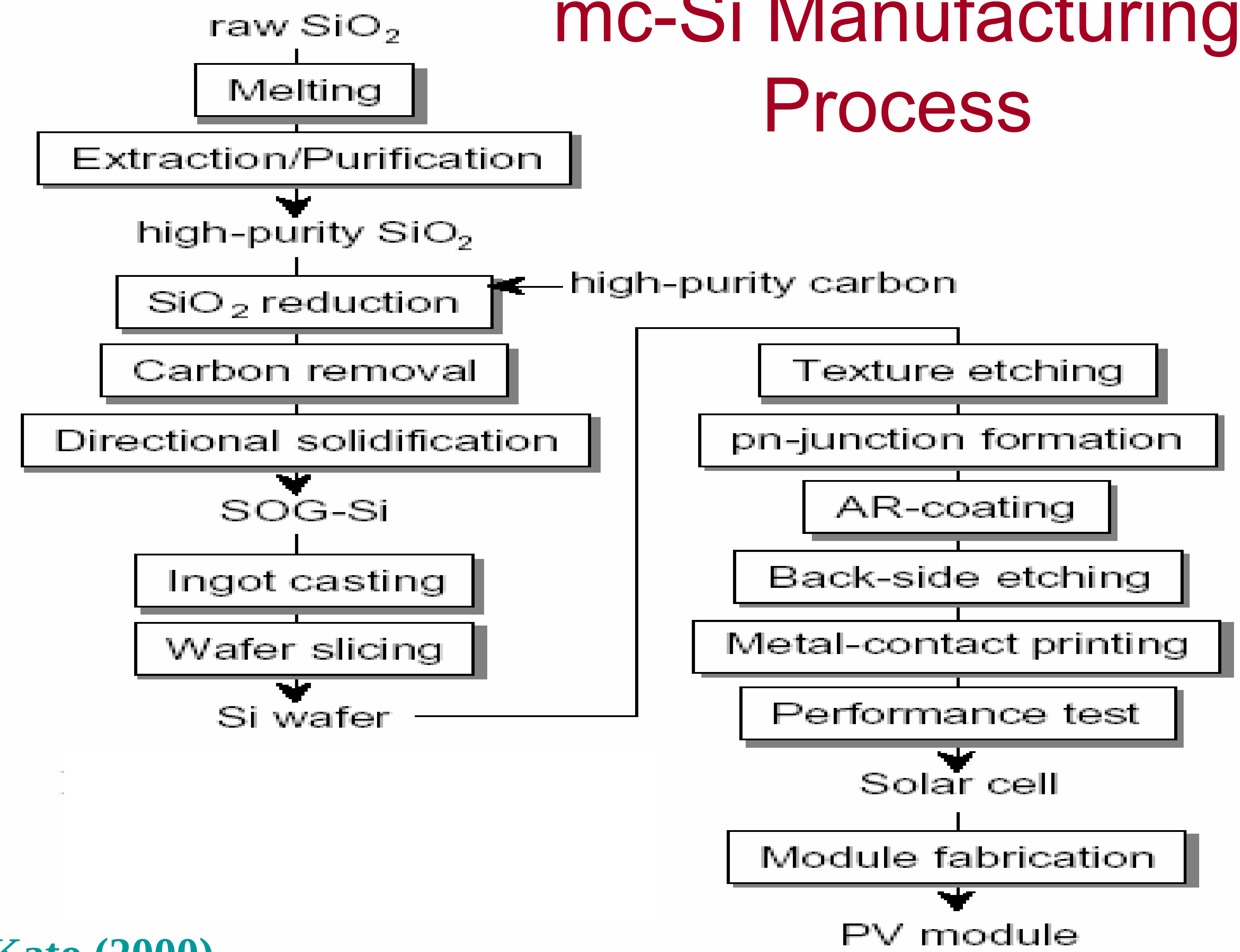
UNSW THE UNIVERSITY OF NEW SOUTH WALES } ENGINEERING

PV Technologies

Mc-Si cell structure (BHP, 2000)

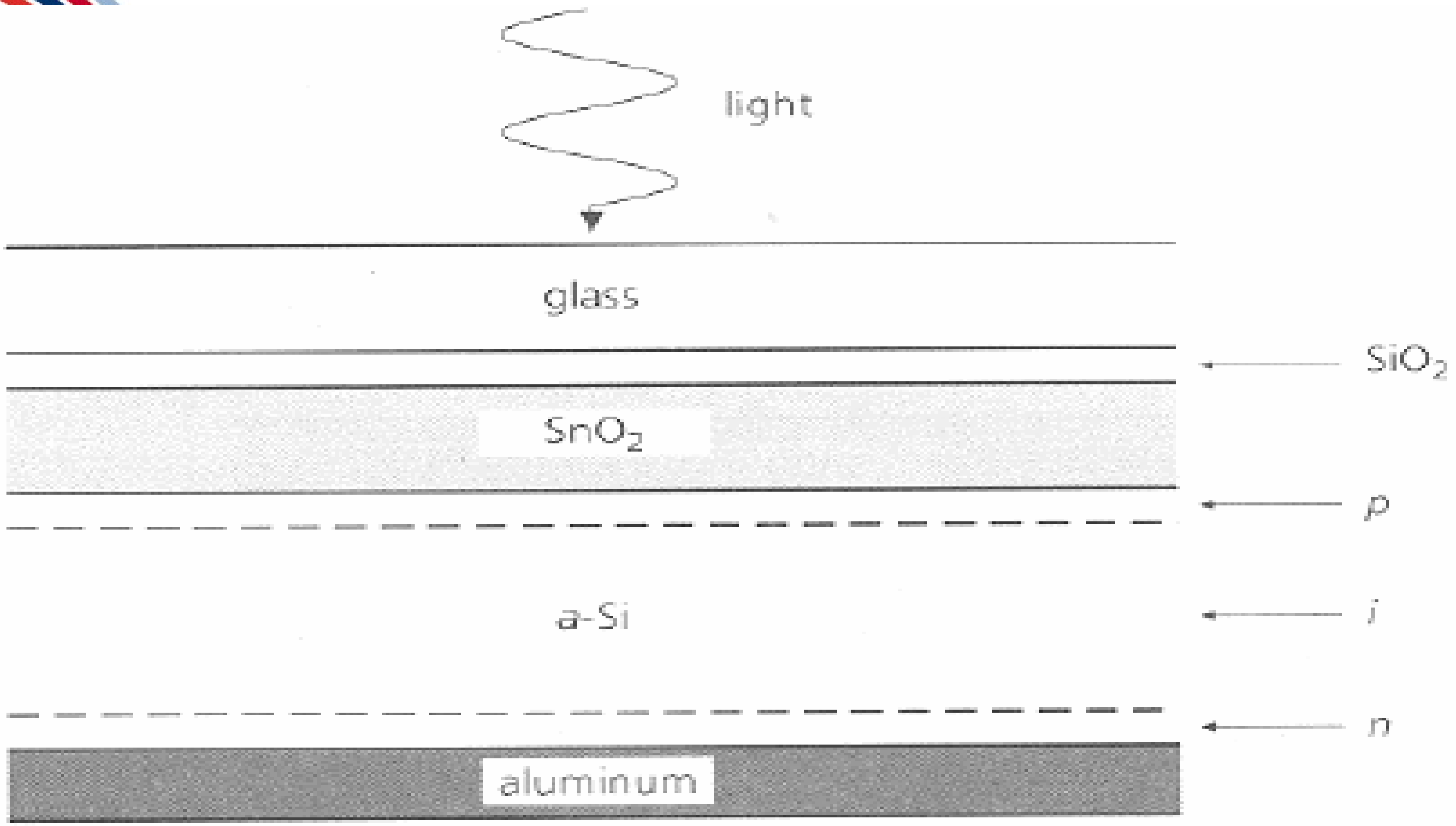


mc-Si Manufacturing Process

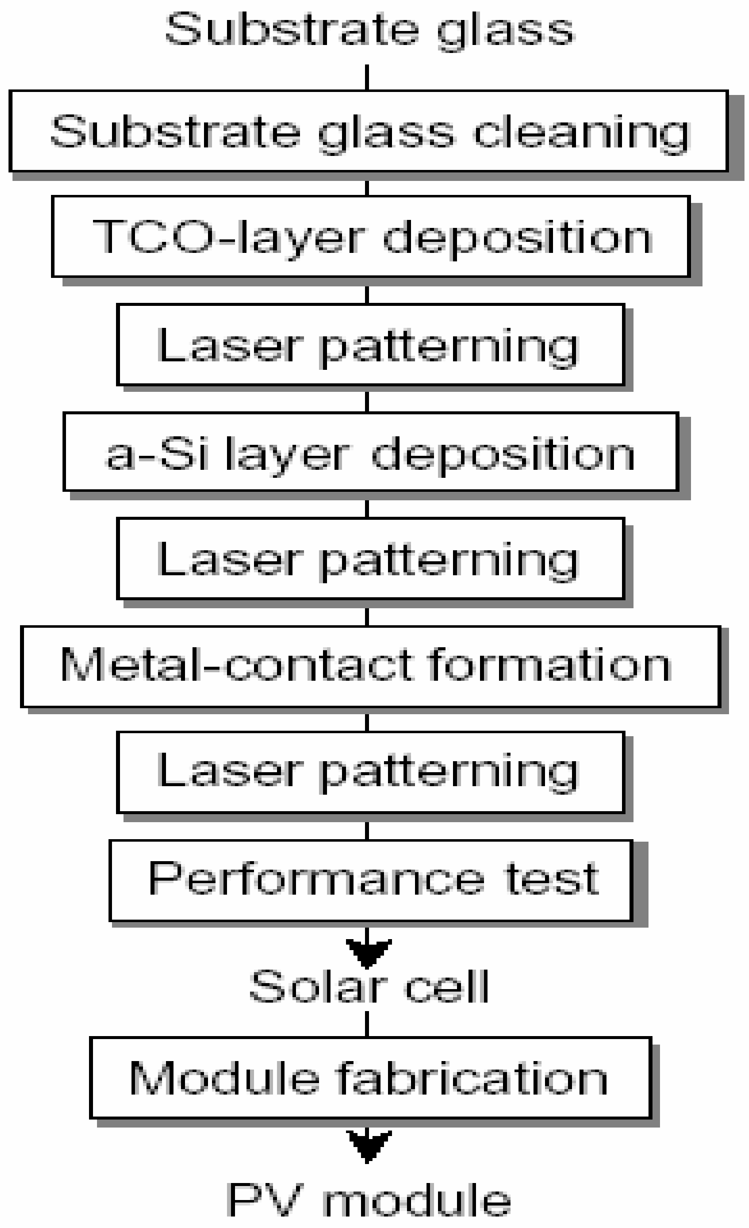


Kato (2000)

A-Si cell structure (BHP, 2000)

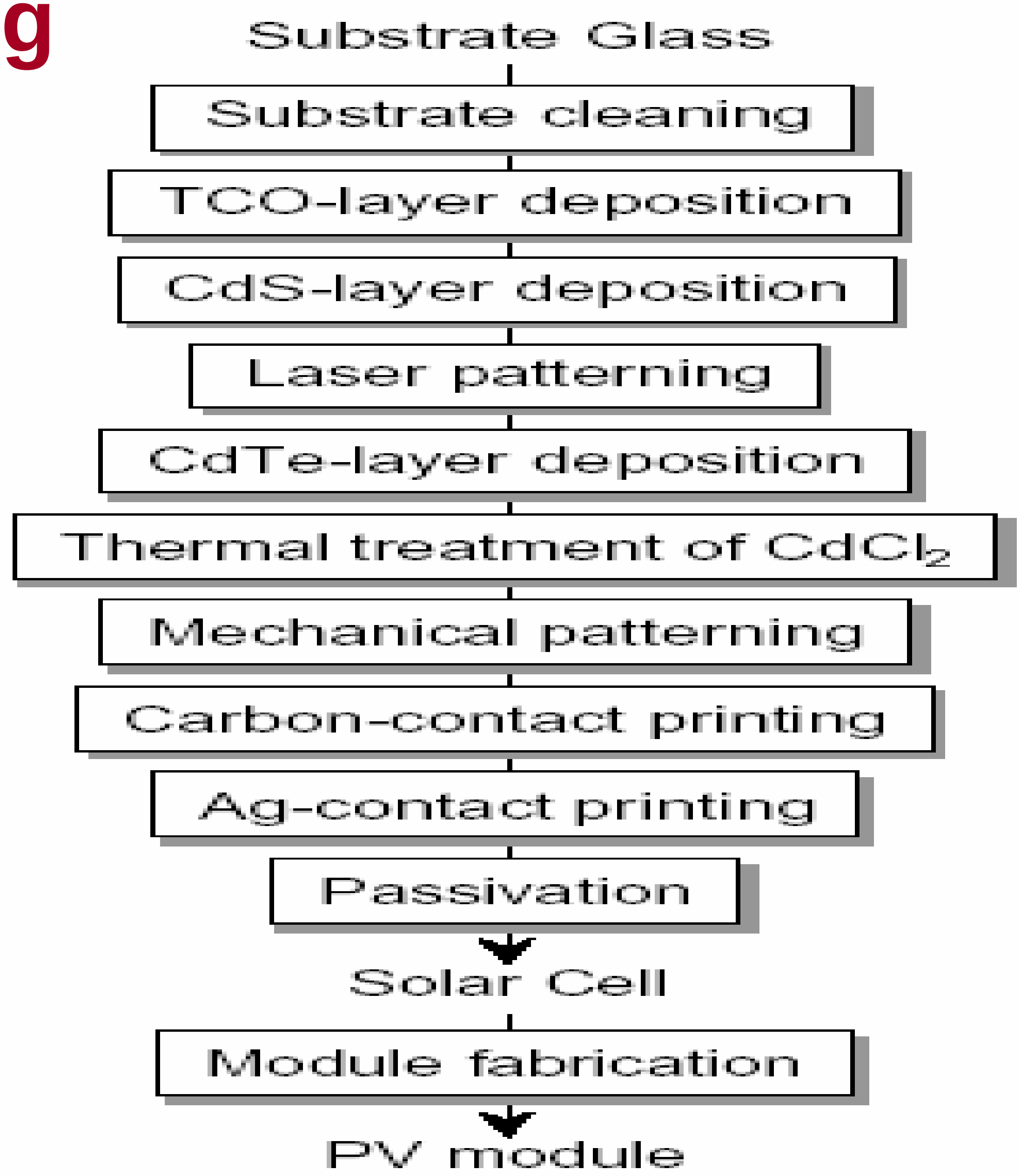


a-Si Manufacturing Process (Kato, 2000)



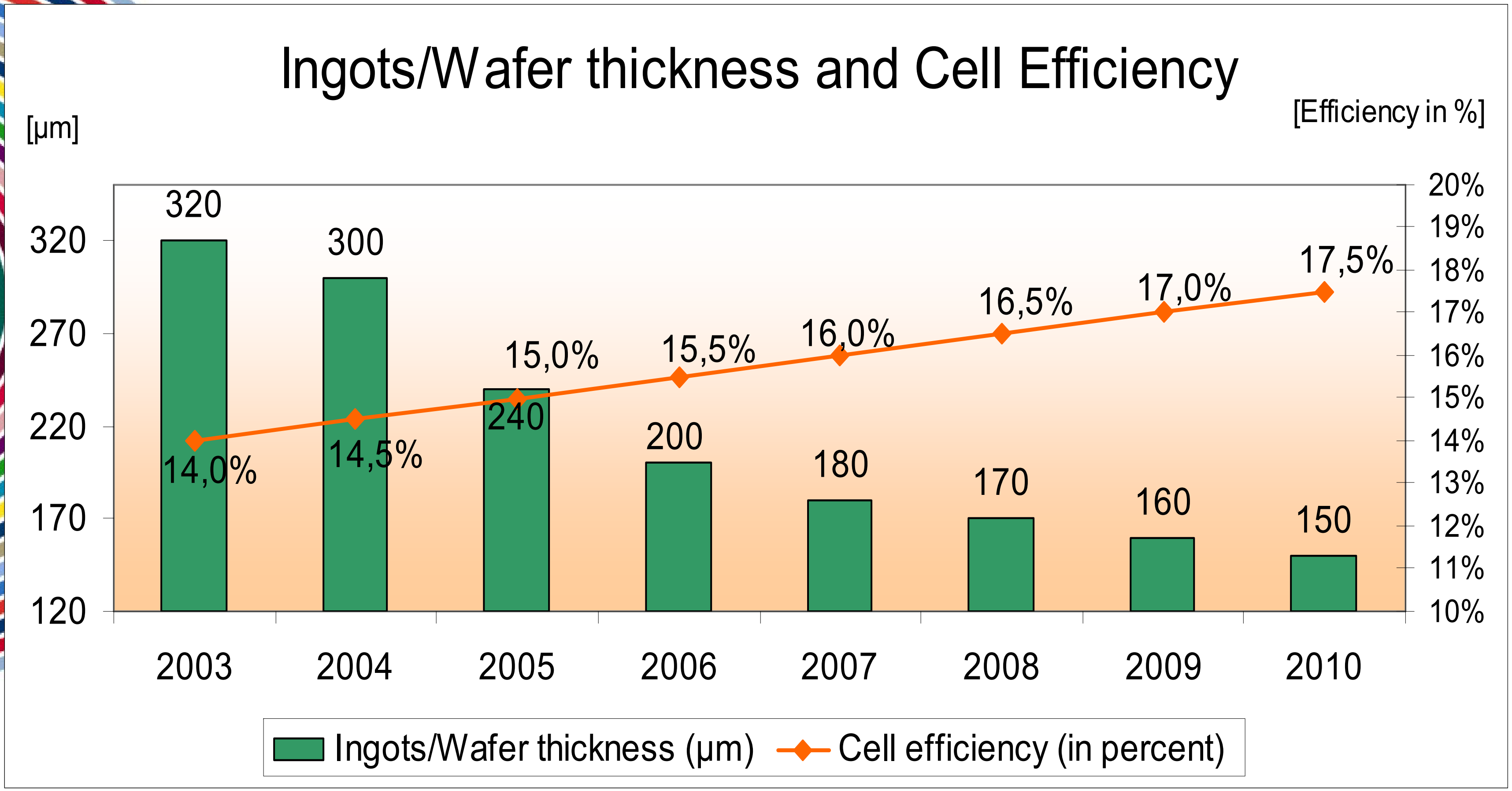
CdS/CdTe Manufacturing Process

(Kato, 2000)



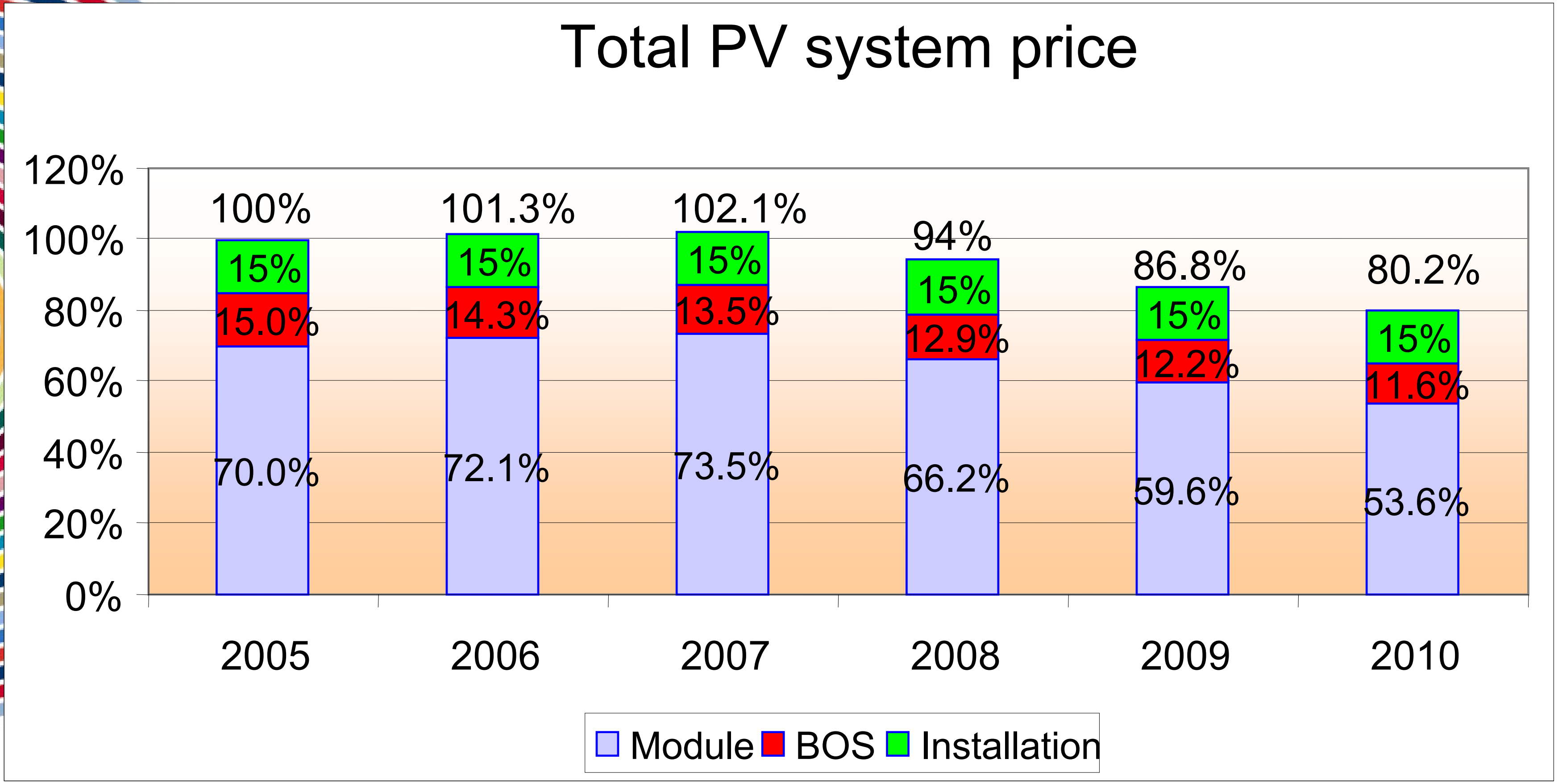
Production Projections

(EPIA, 2005b)



UNSW ENGINEERING
THE UNIVERSITY OF NEW SOUTH WALES

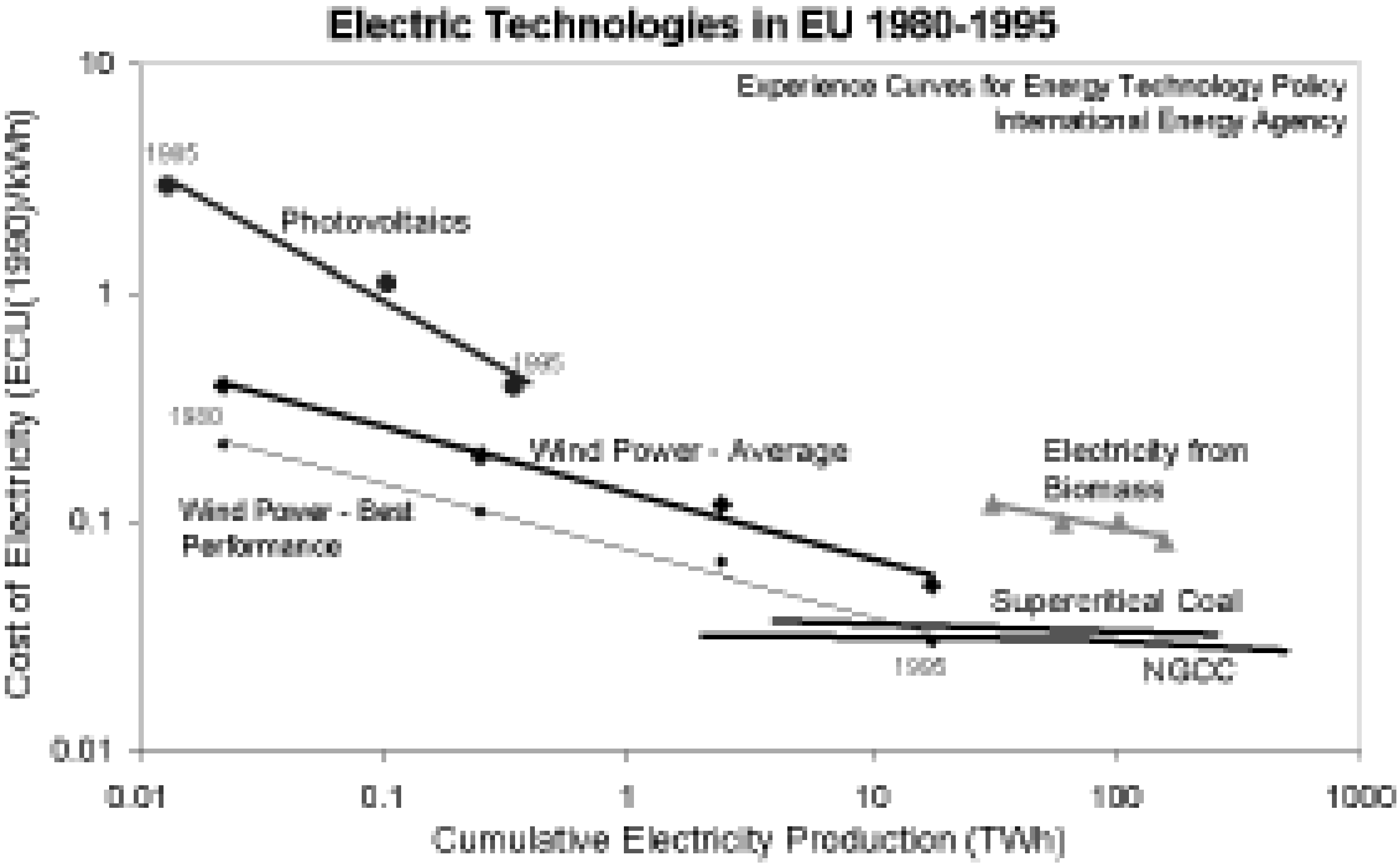
Price Projections (EPIA, 2005b)



All %-numbers after 2005 are in relation to the 100% stated in 2005

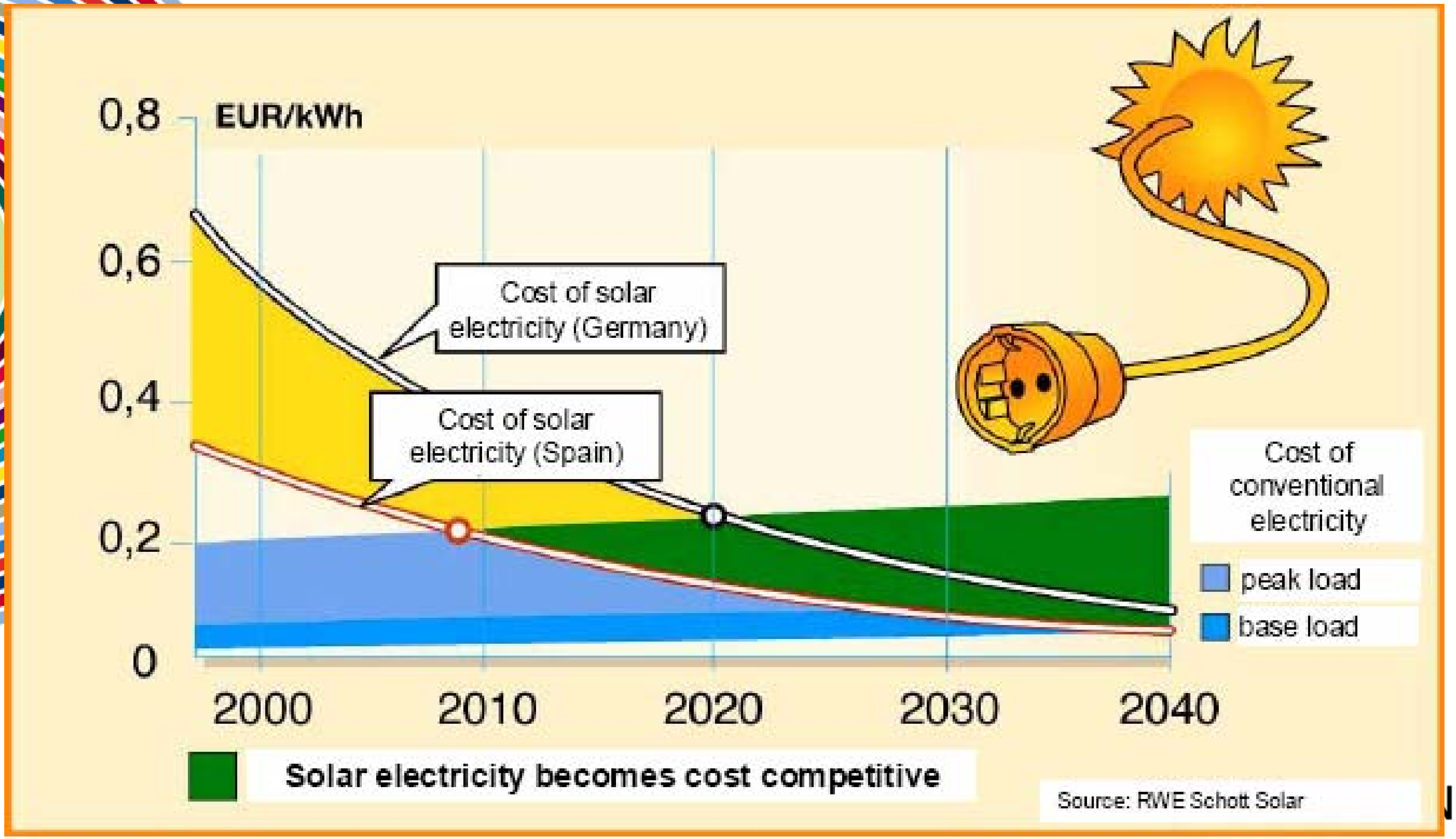
UNSW } ENGINEERING
THE UNIVERSITY OF NEW SOUTH WALES

Experience Curves for New Energy Technologies

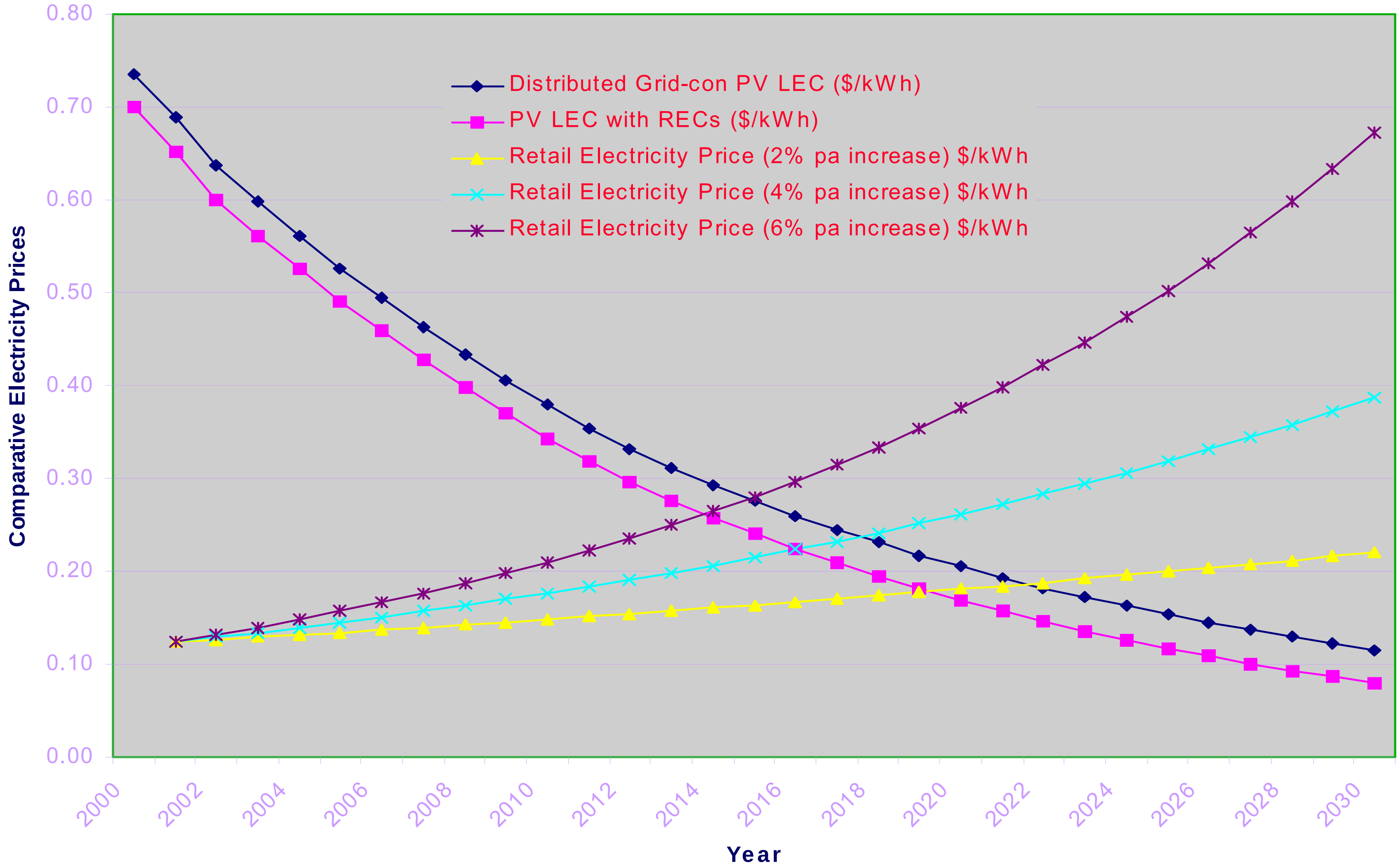


Source: IEA, 2000

European Projected Break-even points for PV



Australian PV and electricity price projections (BCSE, 2004)



Australian PV Research

IEAust, August 2006

UNSW THE UNIVERSITY OF NEW SOUTH WALES } ENGINEERING

University PV Research

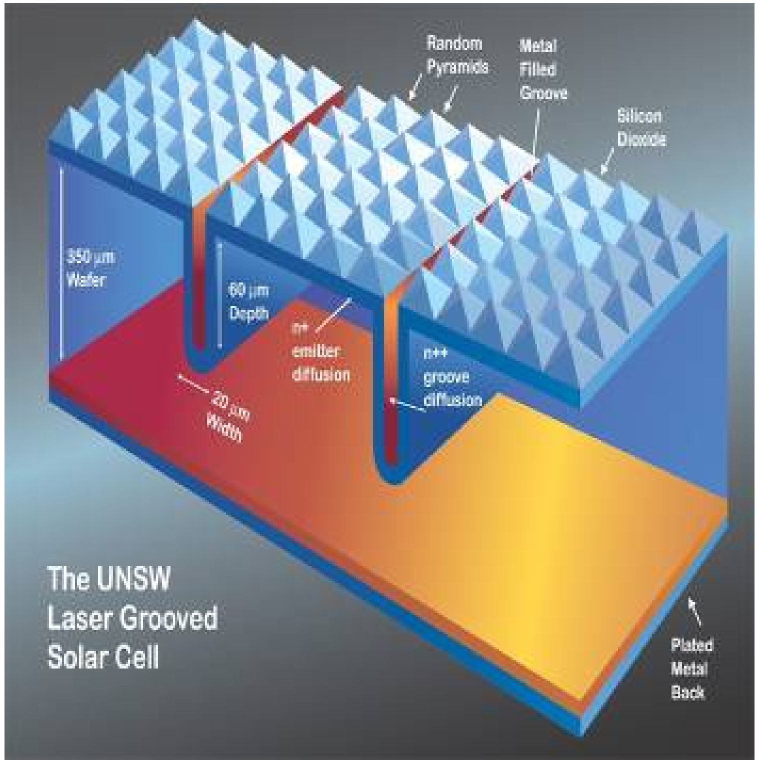
- UNSW:
  - Saturn – BP Solar
  - Thin film – CSG Solar
  - 3rd generation
- ANU:
  - Sliver (Origin)
  - Trough concentrators
  - CHAPS
  - Large scale solar thermal electric (Wizard)
- Murdoch, Sydney, QUT, Monash, Flinders……

ANU CHAPS

UNSW THE UNIVERSITY OF NEW SOUTH WALES } ENGINEERING

UNSW “first-generation” solar cell research (PV Centre, 2006)

- Streamlining manufacturing to reduce costs and improve energy conversion efficiencies
- Reducing manufacturing spread on multicrystalline wafer lines caused by variability in wafer quality
- Eliminating boron-oxygen defects
- Reducting silicon wafer thickness.
- “Buried-contact” solar cell improvements
  - increase efficiency, particularly for thin wafers
  - develop buried-contact sequences for substrates doped with phosphorus, rather than boron

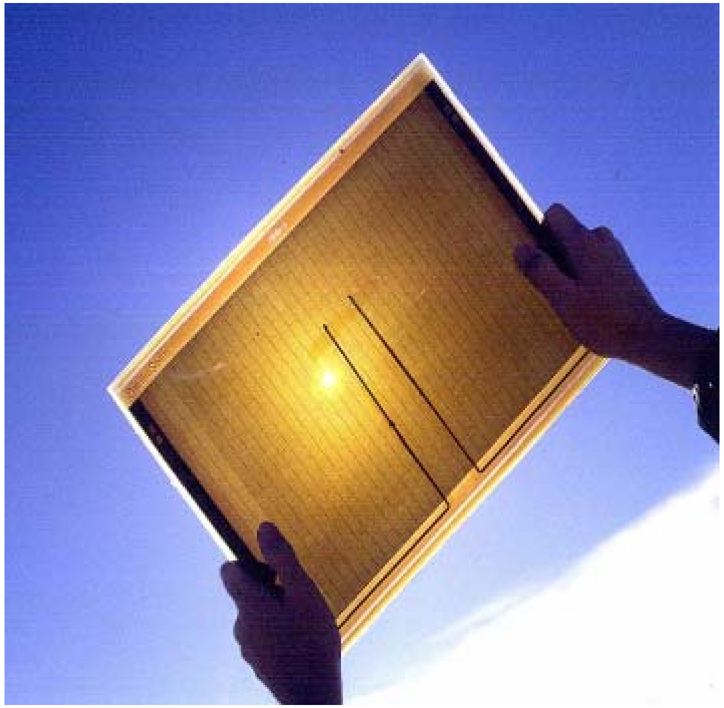


Buried Contact Cells Commercialisation by BP Solar Spain

UNSW THE UNIVERSITY OF NEW SOUTH WALES } ENGINEERING

UNSW "second-generation" solar cell research (PV Centre, 2006)

- Thin-film technology based on depositing thin layers of photoactive material onto supporting substrates or superstrates, usually glass
- Commercialisation by CSG Solar
- Also developing other methods of producing high-performance "silicon-on-glass" solar cells
  - improving quality of the silicon films
  - development of lower-cost evaporative deposition approaches

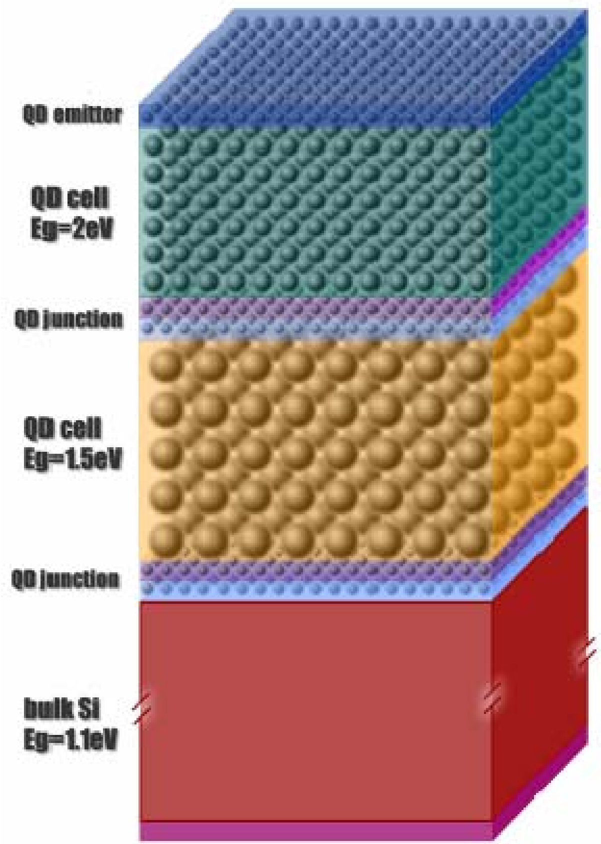


CSG Solar Module

UNSW THE UNIVERSITY OF NEW SOUTH WALES } ENGINEERING

UNSW “third-generation” solar cell research (PV Centre, 2006)

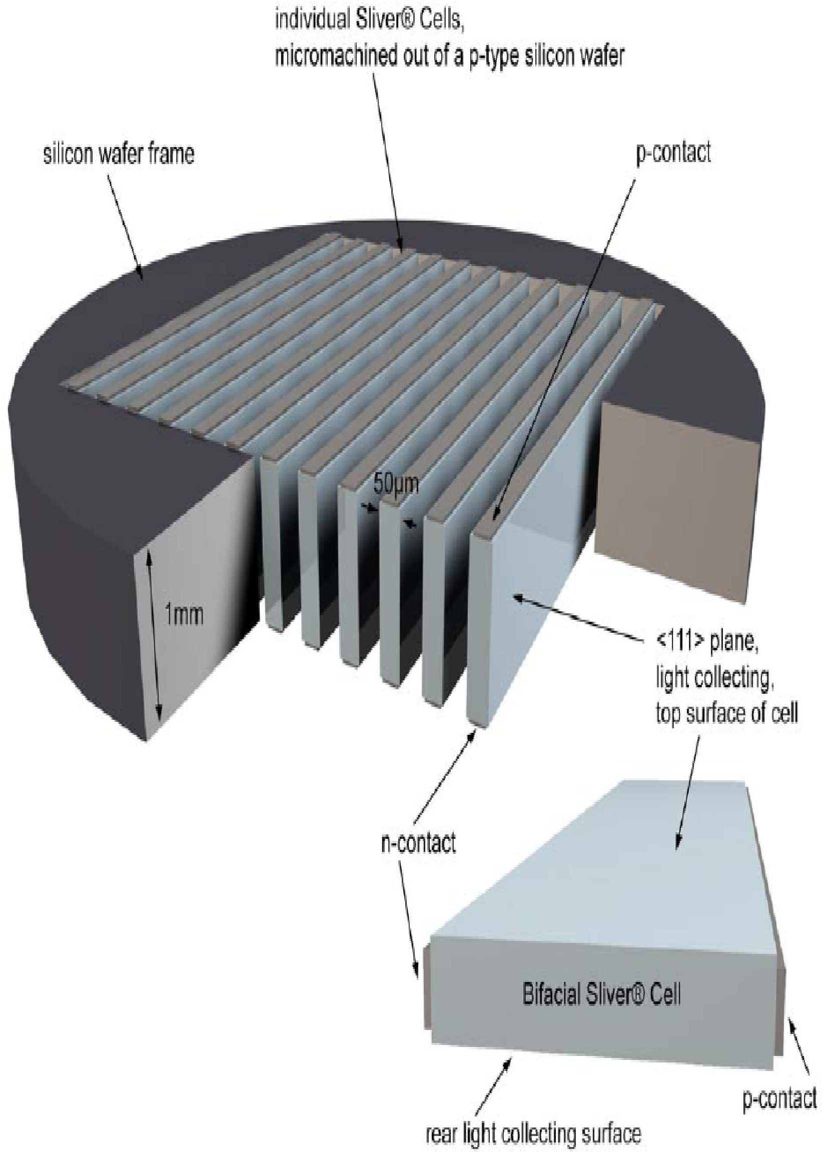
- High-efficiency and thin-film
- “All-silicon” tandem cells based on bandgap-engineering using nanostructures
- Uses mixed-phase semiconductor material based on partly-ordered silicon quantum-dots in an insulating amorphous matrix



UNSW THE UNIVERSITY OF NEW SOUTH WALES } ENGINEERING

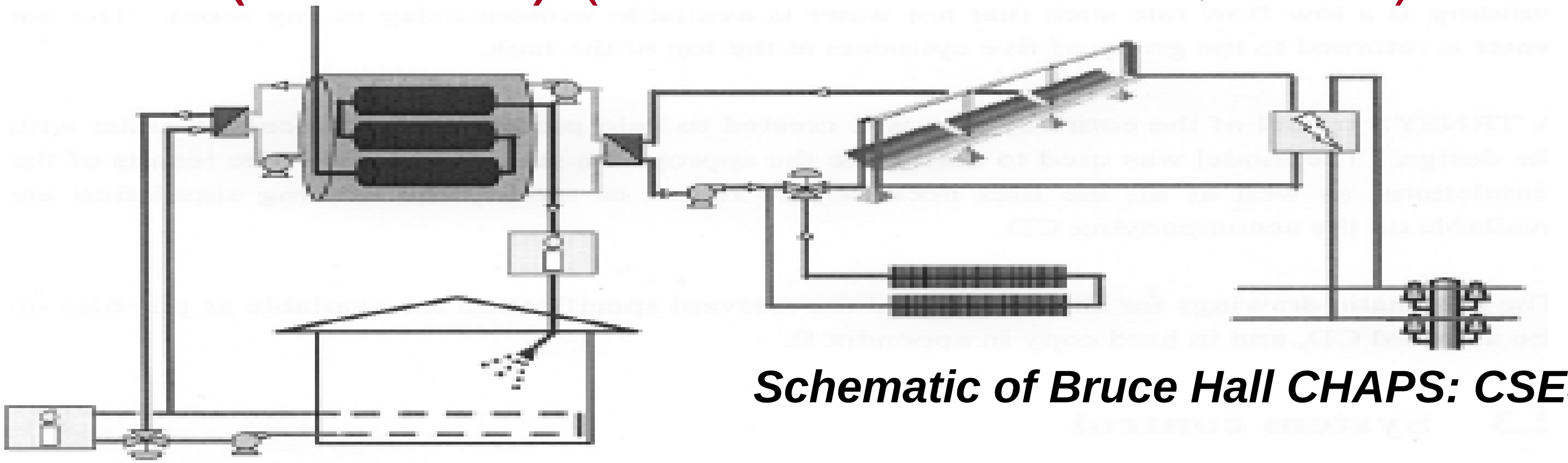
ANU Sliver Cells (Blakers et al, 2006)

- Commercialisation by Origin Energy.
- Si wafers (~1mm thick) micro-machined to create thousands of narrow grooves and thin silicon strips (“Slivers”).
- Each sliver is made into a bi-facial solar cell.
- Slivers cut out of wafer frame, laid flat, and electrically connected.
- Rotation of each Sliver through 90º generates large gain in active surface area compared with starting wafer.
- Laboratory efficiencies of 20%
- Large reductions in silicon and wafer throughput per MW → potential 75% module cost reduction



Combined Heat and Power System

(CHAPS) (Smeltink & Blakers, 2006)



Schematic of Bruce Hall CHAPS: CSES ANU

- 24 metre long, single axis reflective solar concentrating collectors
- Each collector has a microprocessor controlled tracking support structure
- Mirrors focus light onto high efficiency monocrystalline silicon solar cells suitable for mid-range concentration
- Heat is removed from the solar cells using a fluid, which flows through a passage in the cell housings
- The fluid then passes through a heat exchanger that transfers heat to hot water storage tanks
- Prototype systems have achieved combined electricity and heat production efficiencies over 60%

Industry PV Research

- BP Solar
  - Manufacturing processes
  - Products
- CSG Solar
  - New thin film cells
- Solar Systems
  - Concentrators
  - New cell types
- PV Solar Energy
  - Tiles
- Solar Sailor
  - Innovative applications

Dyesol - Dye sensitised cells (TiO2)

Most with some public funding as well

UNSW THE UNIVERSITY OF NEW SOUTH WALES } ENGINEERING

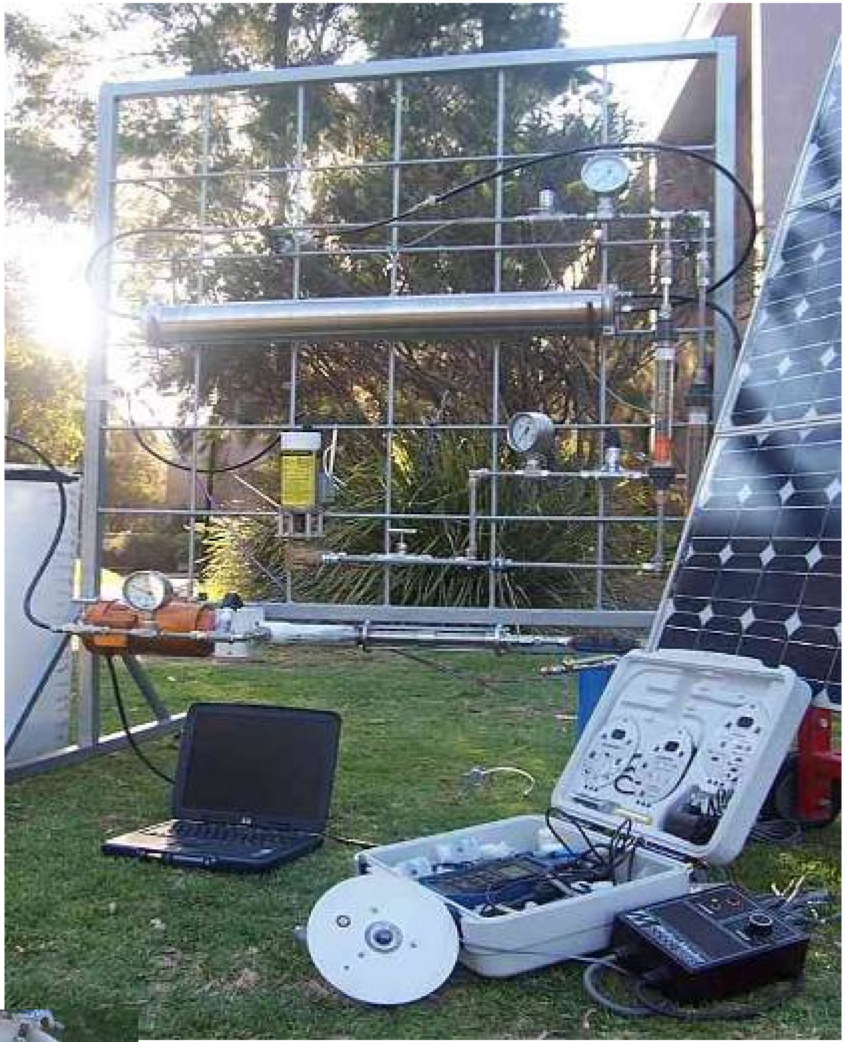
Australian PV Concentrator Technology

- In diesel mini grid to supply 6 communities
- Another 30 dishes (750kW) for 3 NT Power and Water Authority systems
- Suited to end of grid applications, hydrogen production, combined heat and power
- Each dish uses 112 curved mirrors which focus sunlight onto a central receiver to provide a 500 X concentrator effect.
- Dishes are cooled and independently track the sun

Solar Systems Pty Ltd:
220 kW PV Concentrator power plant at the Pitjantjara lands

ROSI R&D team

Testing of ROSI III at University of Wollongong (1000 L/day)



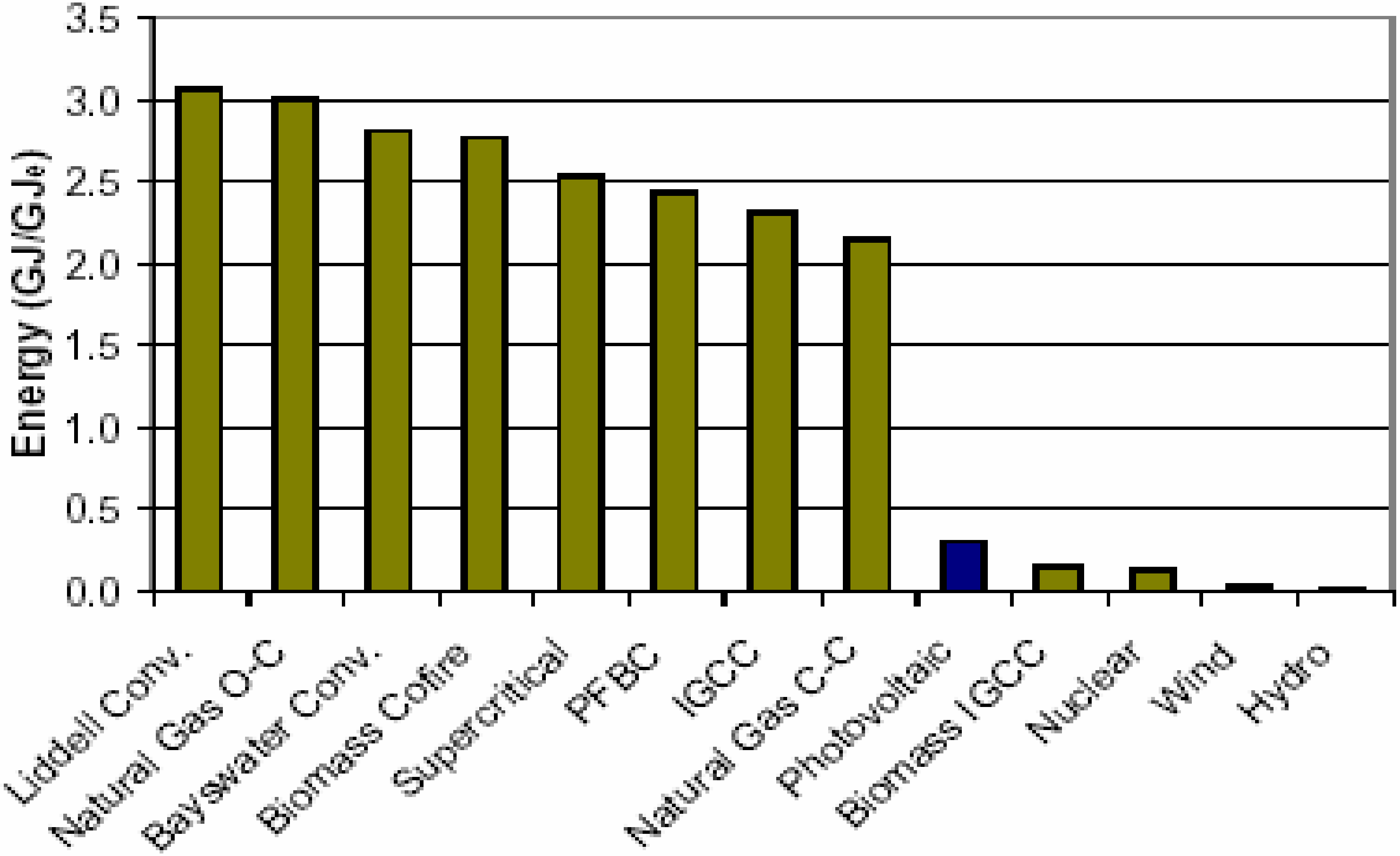
Ultrafiltration membranes remove pathogens, poisons, salt & other contaminants from brackish groundwater

Net Energy and Greenhouse Gas Impacts

IEAust, August 2006

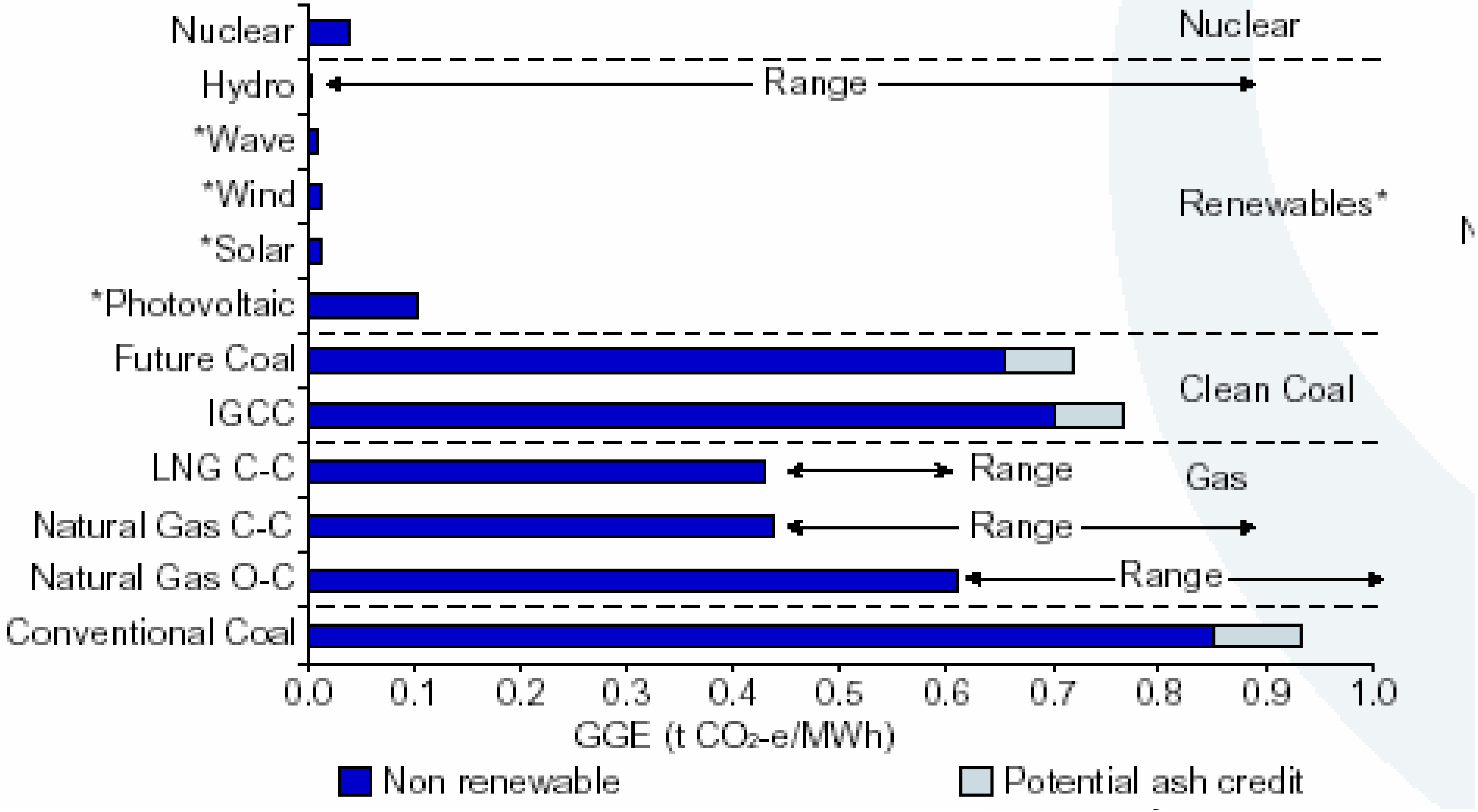
UNSW } ENGINEERING
THE UNIVERSITY OF NEW SOUTH WALES

Comparisons of Energy Input per GJ_e Produced (BHP, 2000)



NG

Life Cycle Ghg impacts of electricity generation (BHP, 2000)



Energy Payback Time - The Myth

- "PV does not pay back the energy used to create it!"
- May have reflected terrestrial PV 30 years ago
- Still commonly held belief and widely quoted but ***PV has more than paid back its energy requirements for the last three decades***

UNSW THE UNIVERSITY OF NEW SOUTH WALES } ENGINEERING

Energy Payback Time - EPT

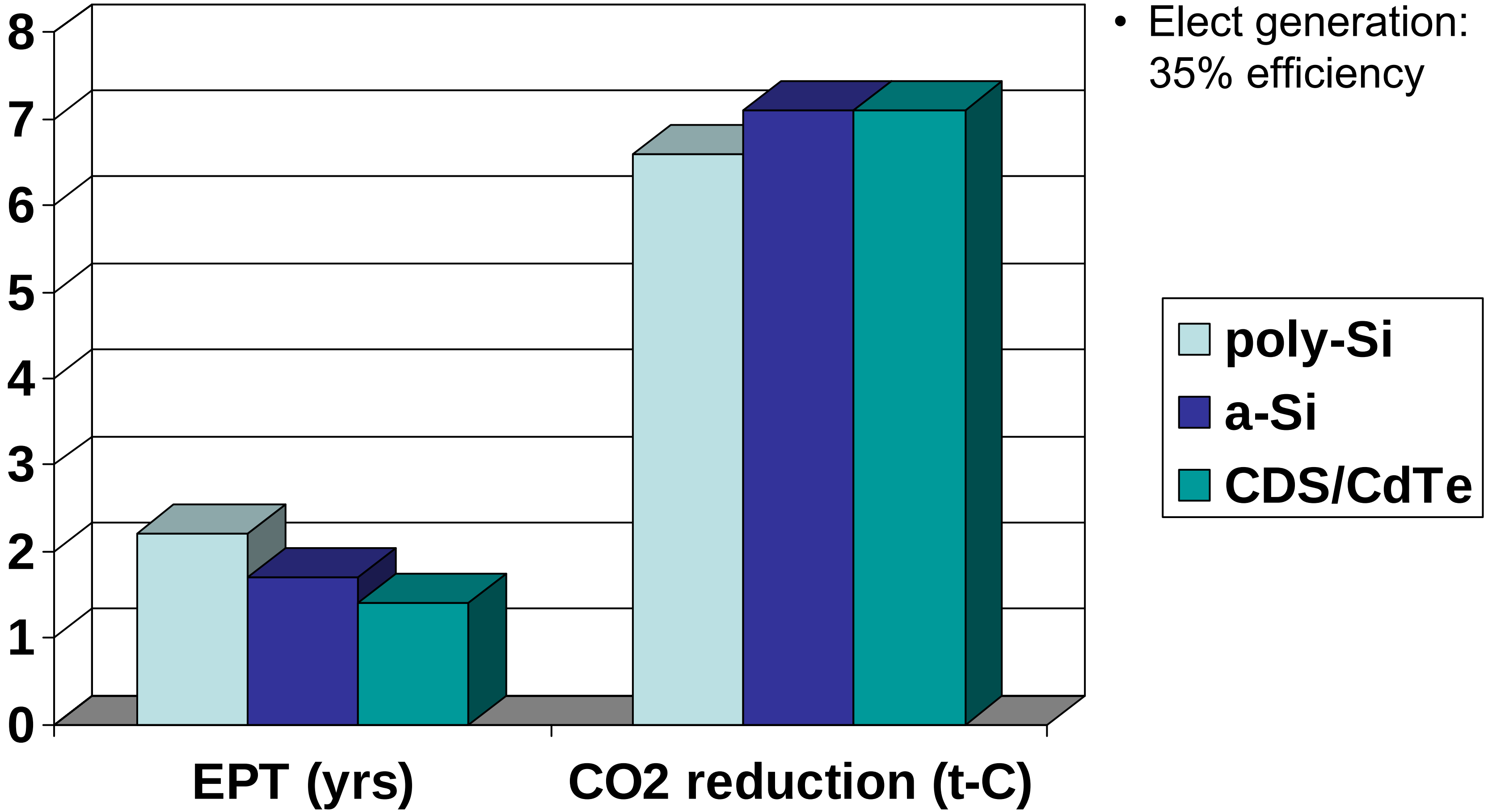
- The most commonly used parameter to quantify the life cycle performance of PV is EPT:
  - The time (in years) in which the primary energy input during the module life-cycle is compensated by electricity generated by the PV module
  - depends on cell technology, PV system application and irradiation

$$EPT = \frac{E_{input}}{E_{gen}}$$

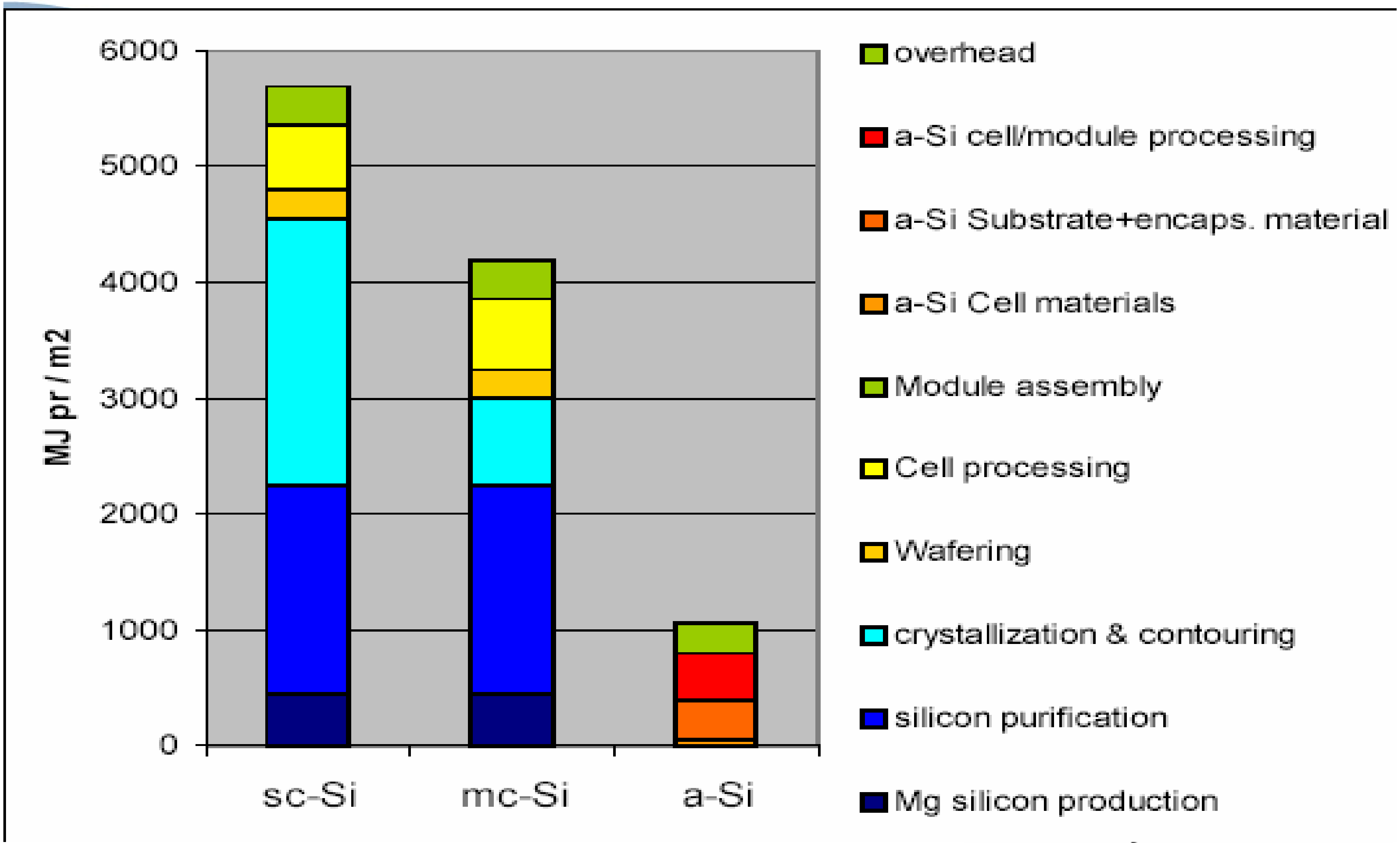
UNSW THE UNIVERSITY OF NEW SOUTH WALES } ENGINEERING

LCA (20 yr life) of 3kWp Japanese Rooftop PV (Kato, 2000)

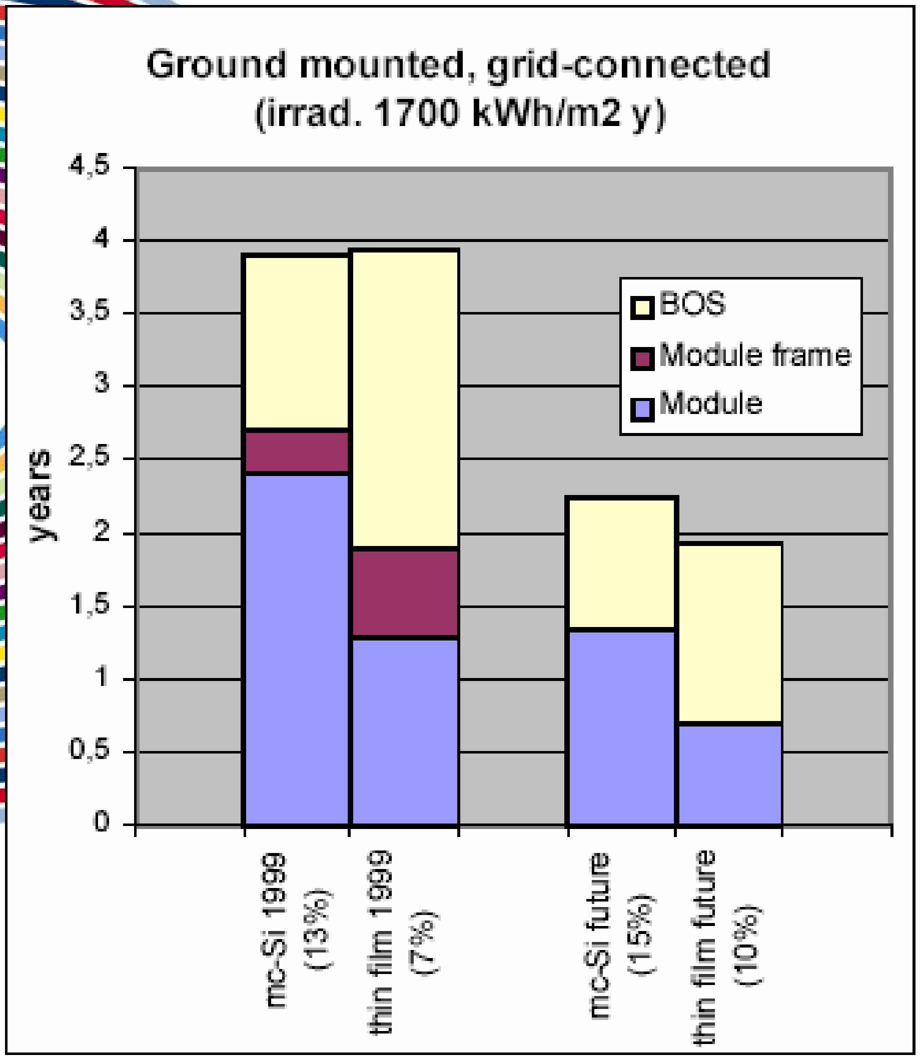
- 30 MW/yr plant
- 1160 kWh/Wp/yr
- Elect generation: 35% efficiency

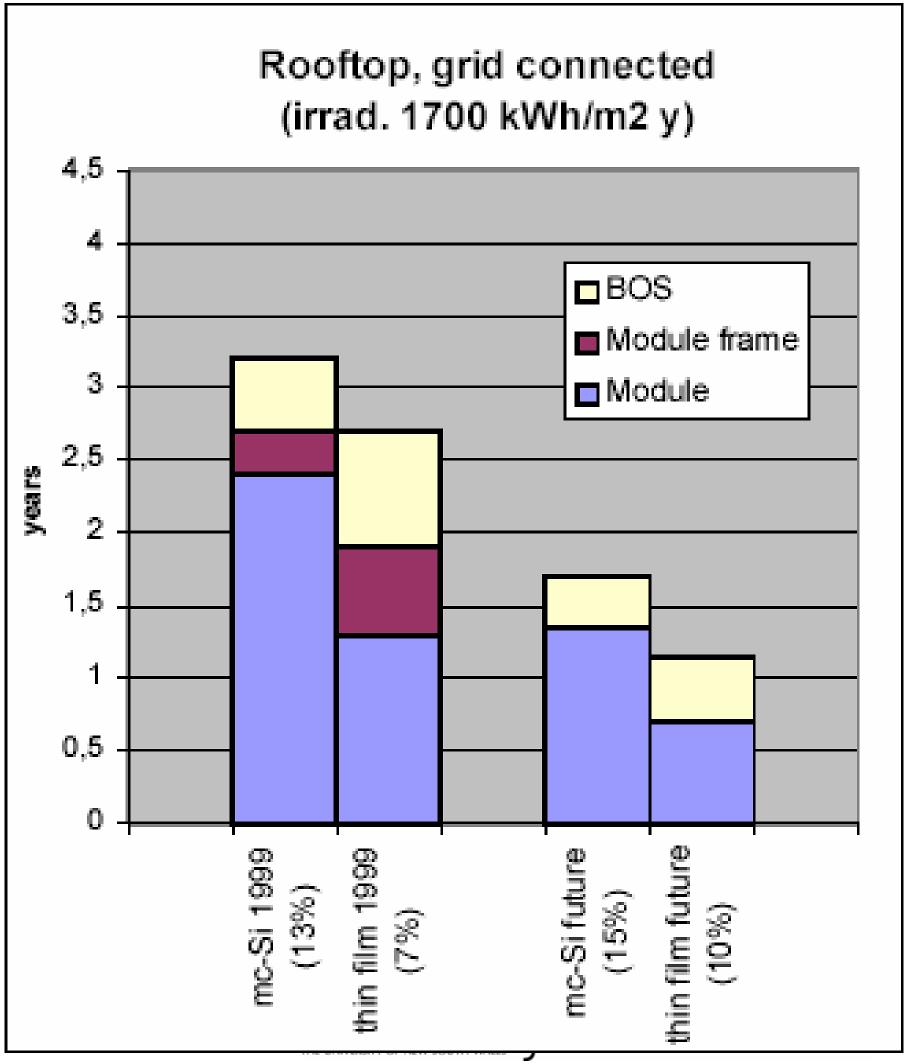


Comparative energy requirements
(Alsema, 2000)



EPT - Future possibilities & Impact of BOS (Alsema, 2000)

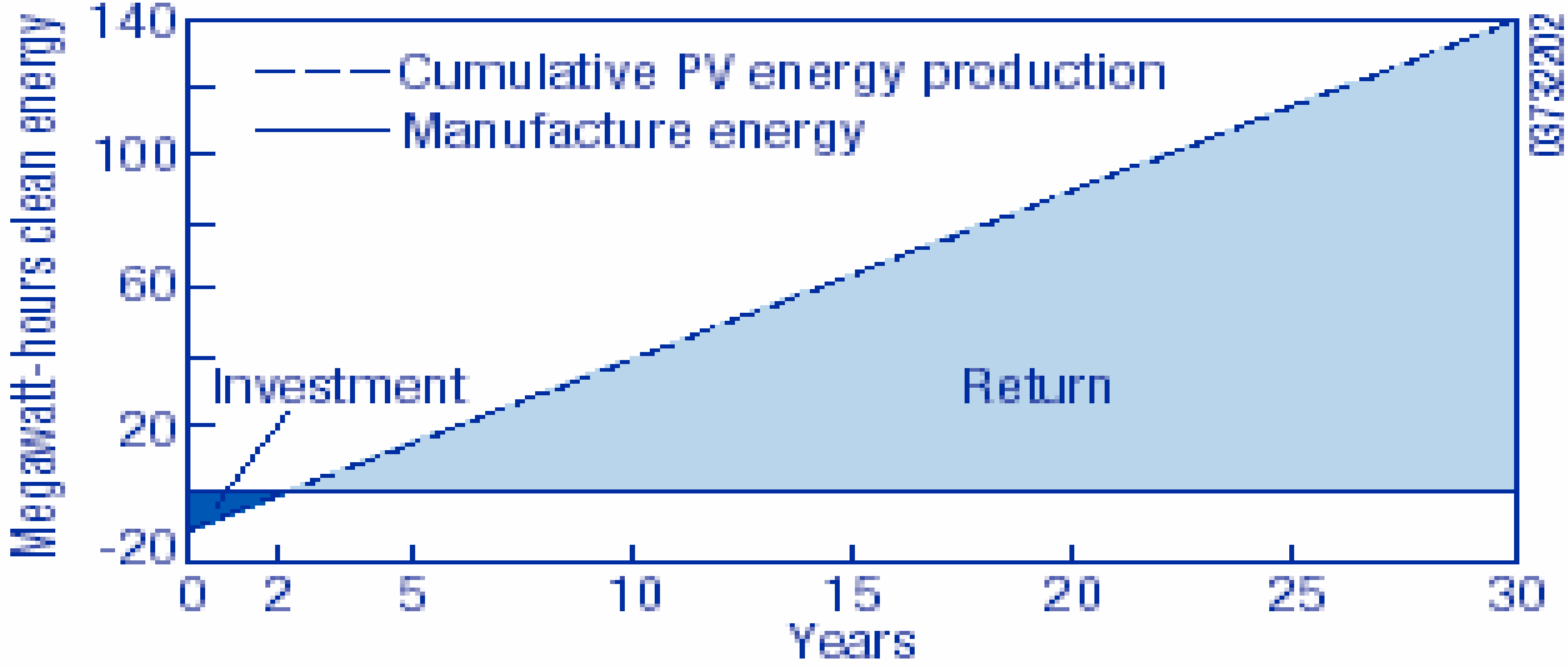




Problems with EPT

- Important quantity not included: ***PV lifetime!***
- Similar to economic pay-back, but does not account for energy generated after payback
- EPT implies that PV may not recover its embodied energy
- Hence value of PV misrepresented
  - a-Si PV modules may have better EPTs than mc-Si, but shorter life
  - EPT doesn't tell which PV panel generates more energy over its life
- No other energy system or product is characterised this way
  - important to use methodologies and terminology common to the energy sector
  - Life cycle analysis has standard methodologies which allow comparison between energy technologies

Figure 2. Cumulative Net Clean Energy Payoff



PV systems can repay their energy investment in about 2 years. During its 28 remaining years of assumed operation, a PV system that meets half of an average household's electrical use would eliminate half a ton of sulfur dioxide and one-third of a ton of nitrogen-oxides pollution. The carbon-dioxide emissions avoided would offset the operation of two cars for those 28 years.

Source: NREL 2004

The Energy Yield Ratio - EYR

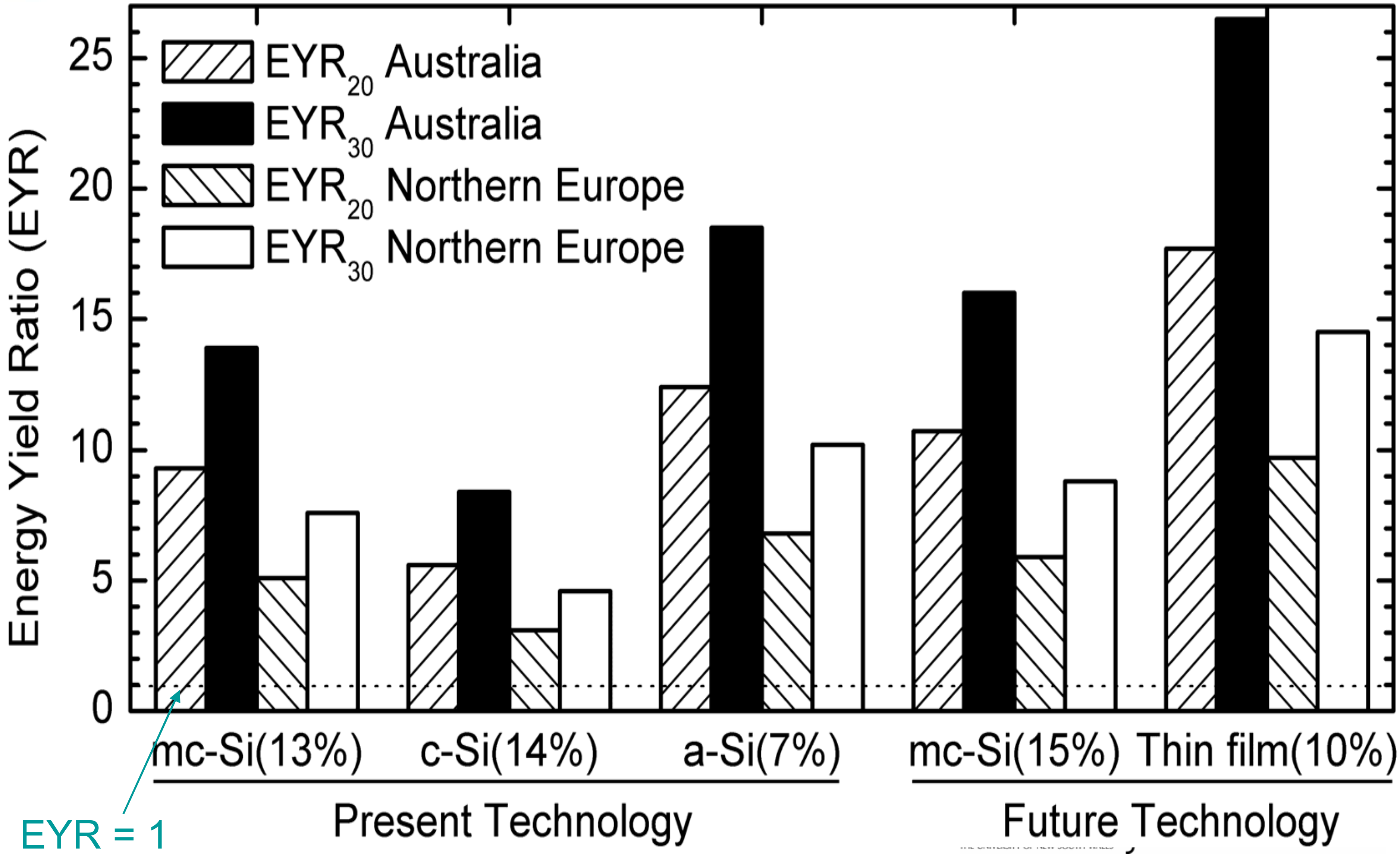
- Incorporates PV lifetime, L_{pv}
- EYR = "how many times the energy invested is returned or paid back by the system in its entire life"

$$EYR = \frac{E_{gen} \times L_{PV}}{E_{input}}$$

- EYR > 1 generates more energy over its lifetime than was required to fabricate it
- Unity is the break-even point so, above that, the higher the EYR the better

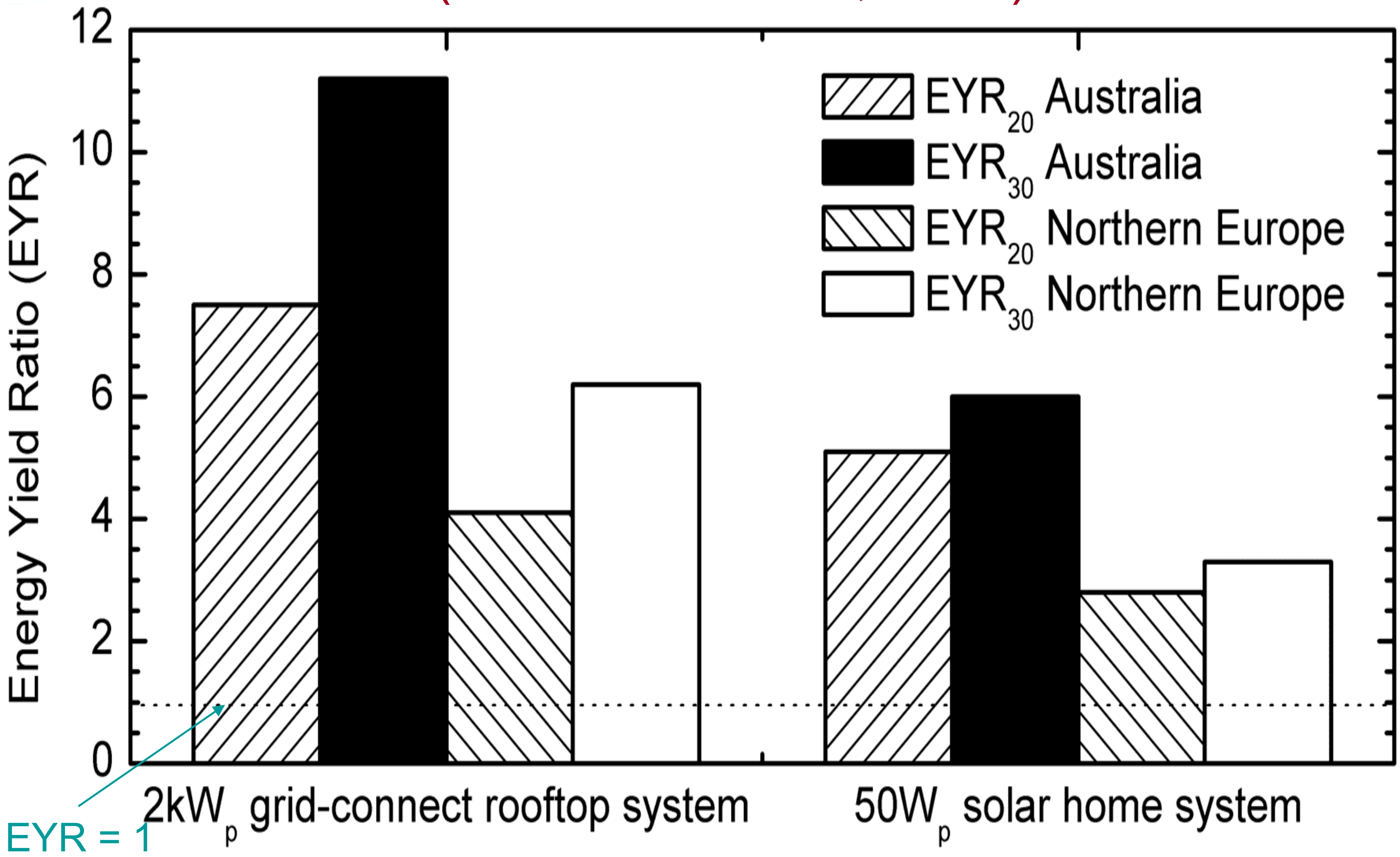
EYR Results for PV Modules

(Richards & Watt, 2004)



EYR Results for PV Systems

(Richards & Watt, 2004)



Australian PV Applications

IEAust, August 2006

UNSW } ENGINEERING
THE UNIVERSITY OF NEW SOUTH WALES

Photo: BP Solar

Case Study

NSW Department of Planning

Newington Solar Village

IEAust, August 2006

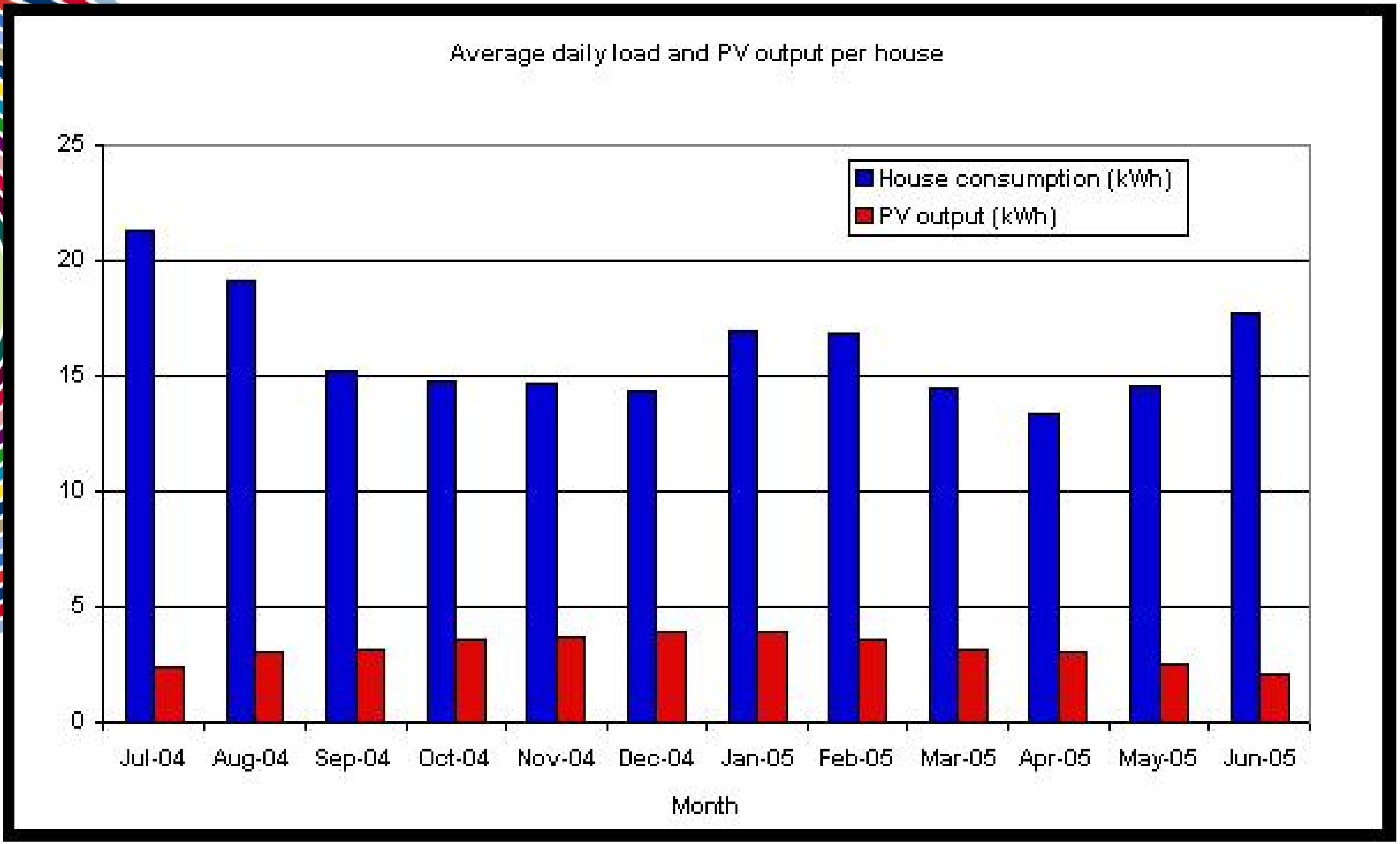
UNSW THE UNIVERSITY OF NEW SOUTH WALES ENGINEERING

Newington Solar Village

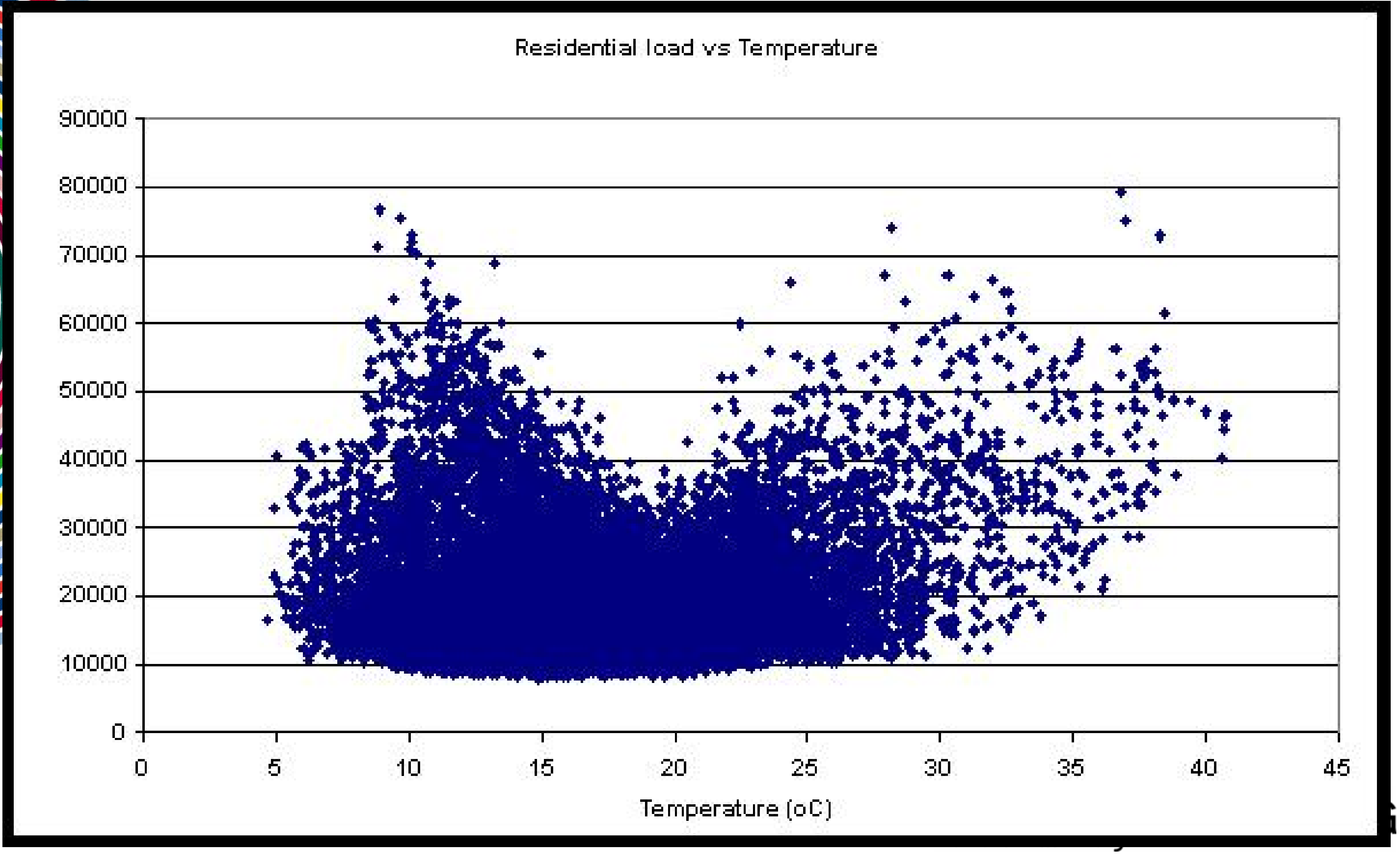
- 780 homes with 1000 Wp of PV and 199 houses with 500 Wp.
- Passive solar design, energy efficient appliances
  - Loads av 16 kWh/day cf 7.5 design
  - Load profile ‘peakier’ than for normal houses
- 30 homes monitored July 04-June 05
  - Av daily PV output per house 3.2 kWh (~20% of load)
  - 2 systems faulty -> 3.4 kWh/house, about 10% lower than expected (although 2005 may not be a typical year)
  - 0.65% of available capacity (accounting for faults but not accounting for temperature or tilt angle)
  - Average peak output 13 kW
  - Zone substation peak demand reduced by 30% of rated PV capacity

Household Load and PV Output

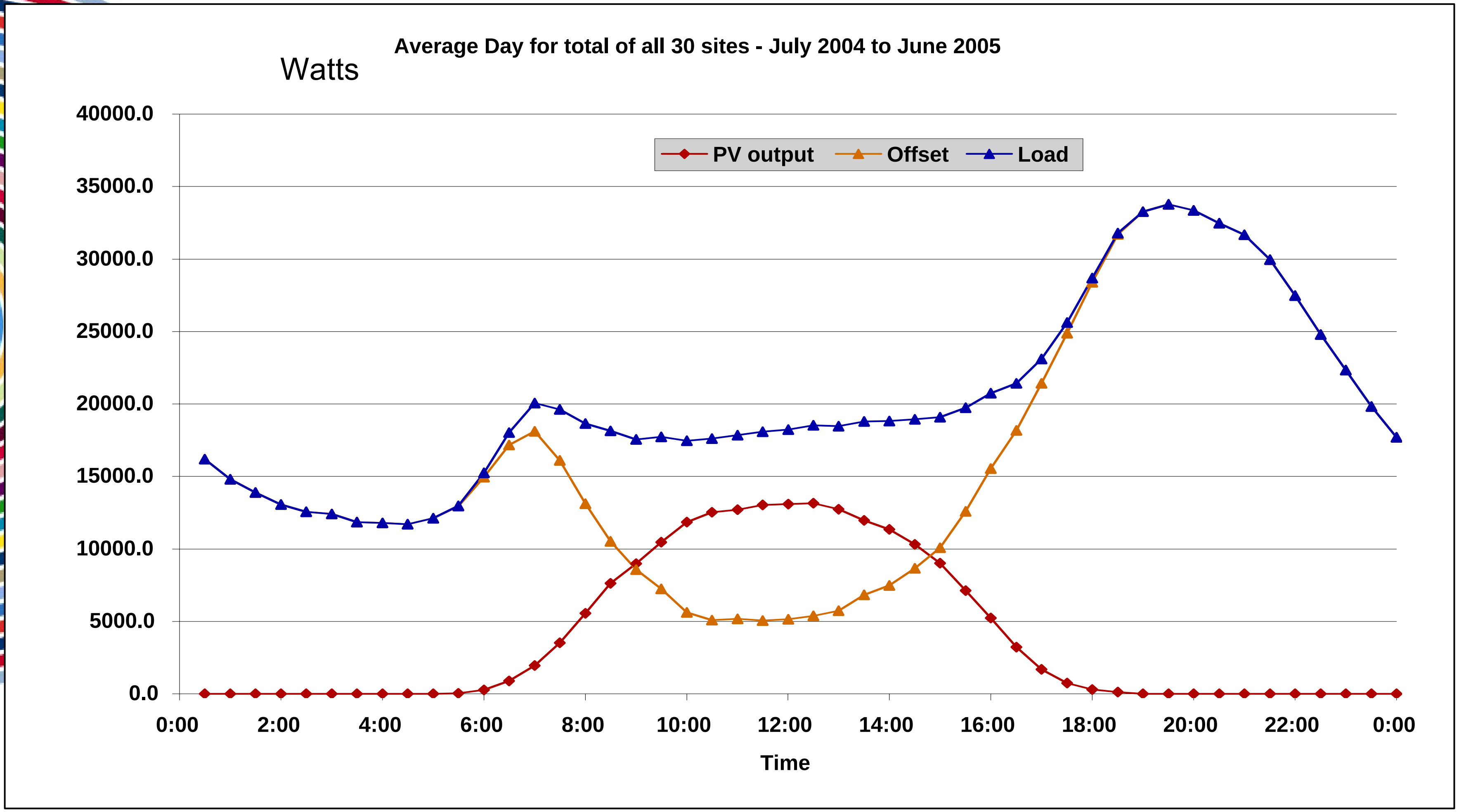
average over 30 houses
(NSW Dept of Planning, 2006, Newington study)



Relationship between electricity use and temperature, Newington

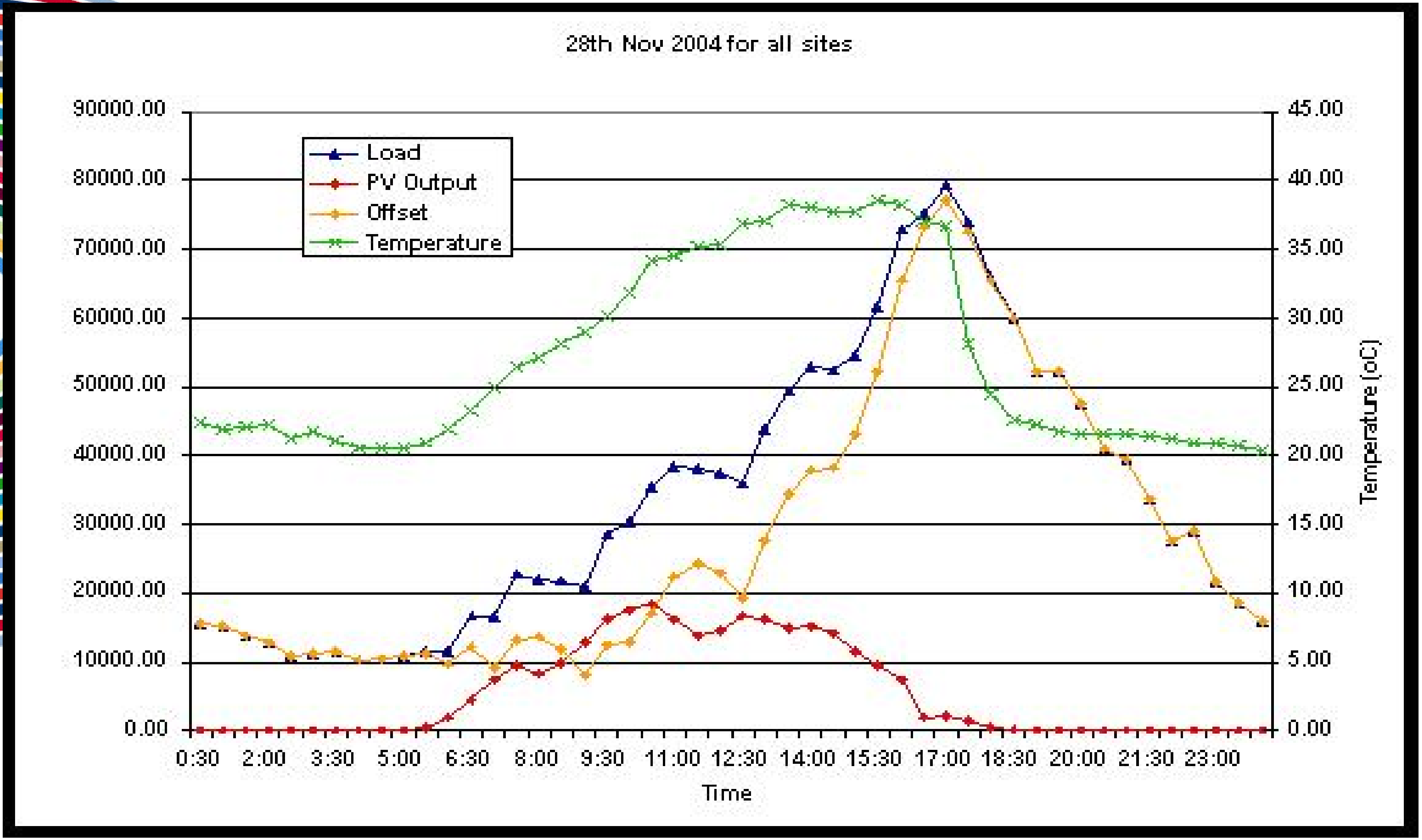


Annual Average Daily PV Output, Household Load and Offset, Newington

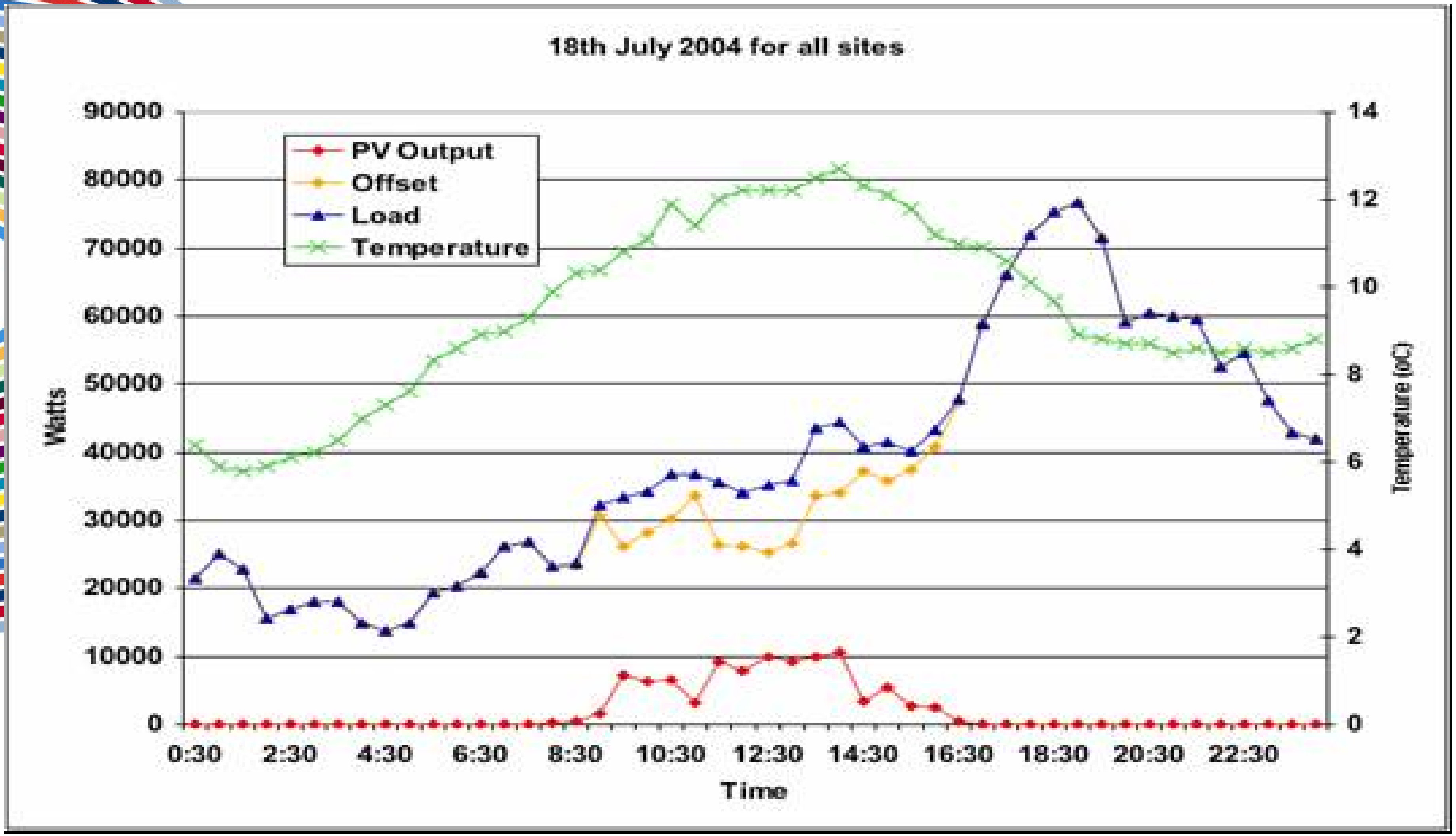


UNSW } ENGINEERING
THE UNIVERSITY OF NEW SOUTH WALES

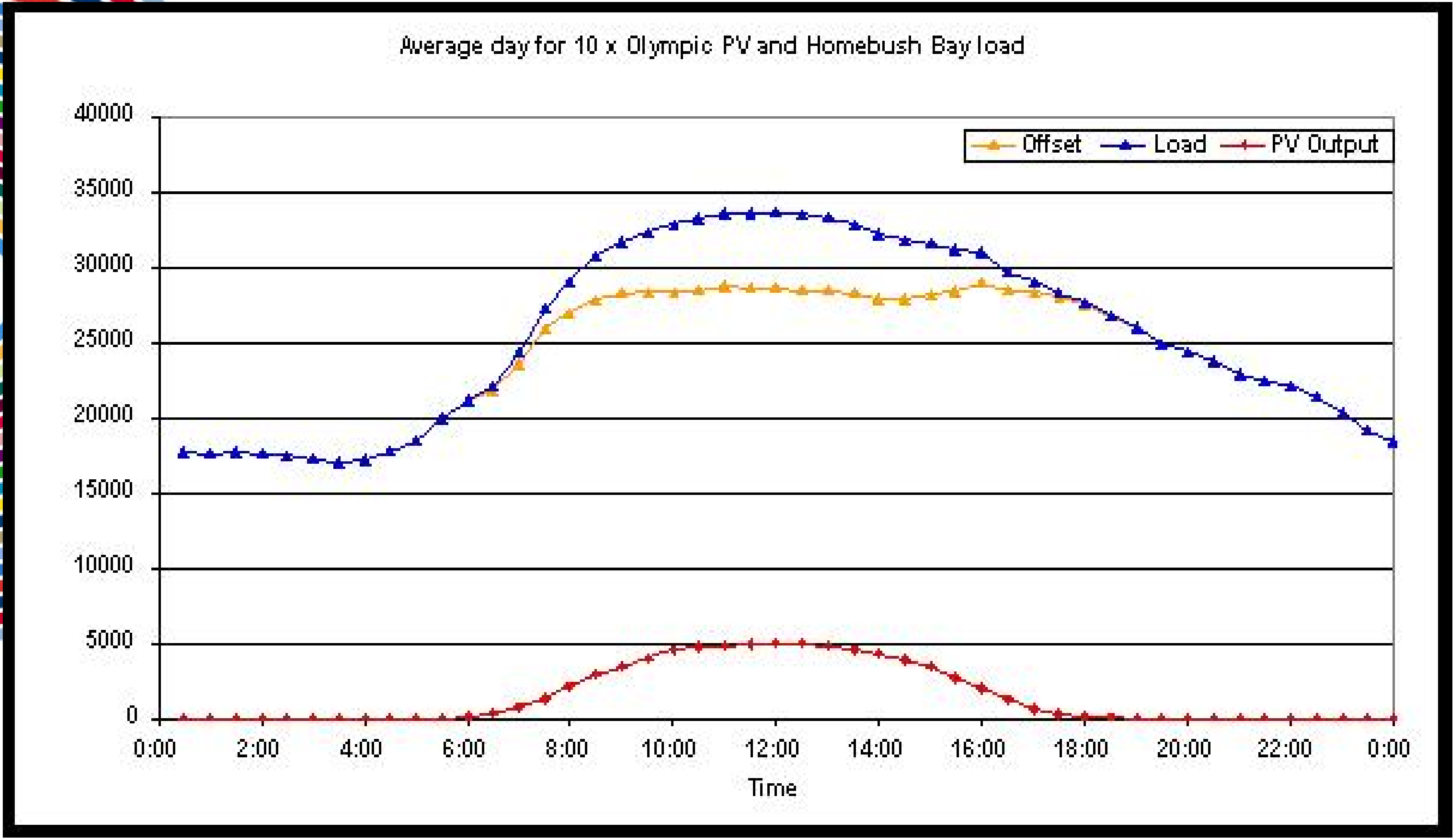
PV Output, Household Load and Temperature - Peak Summer Day, Newington



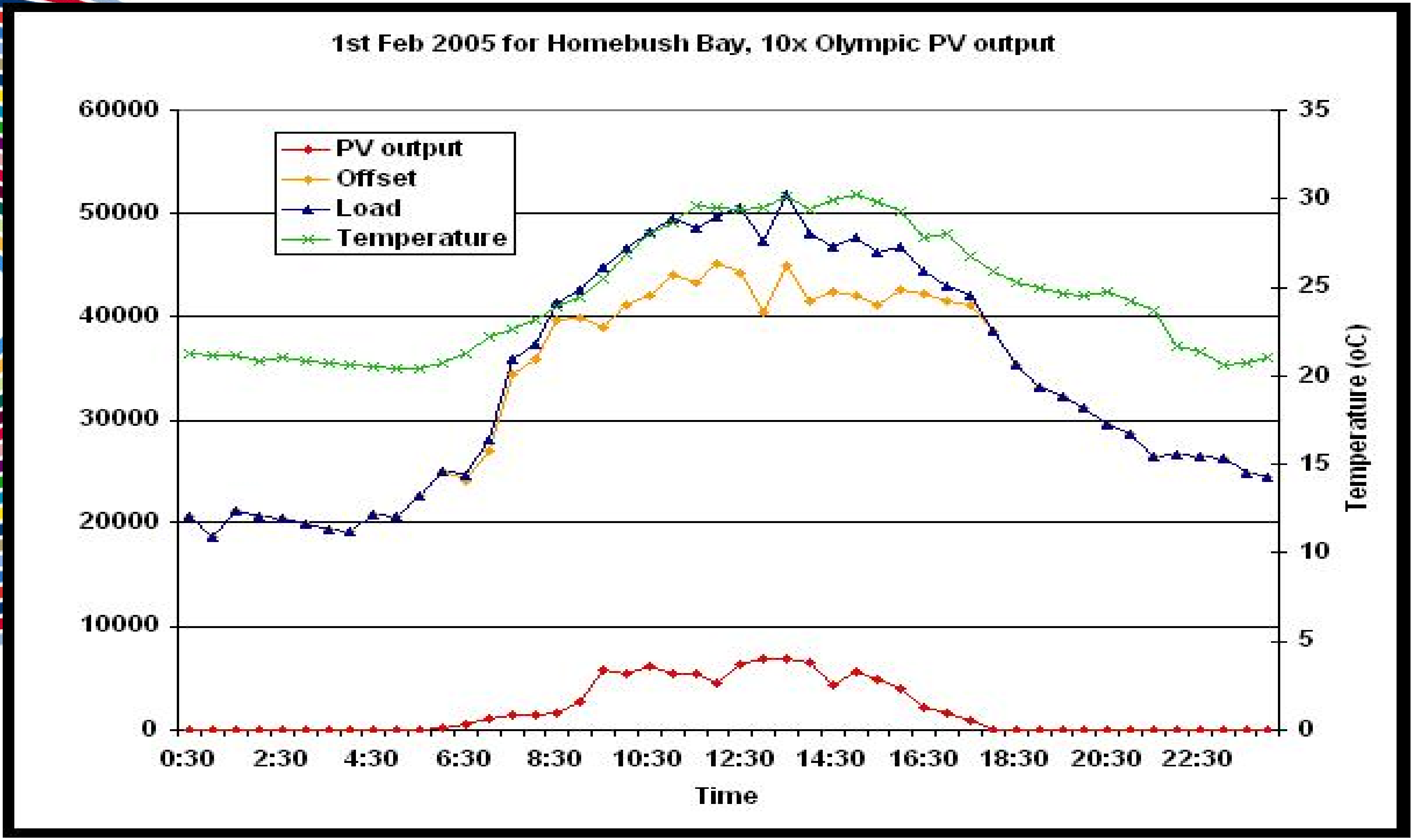
PV Output, Household Load and Temperature - Peak Winter Day, Newington



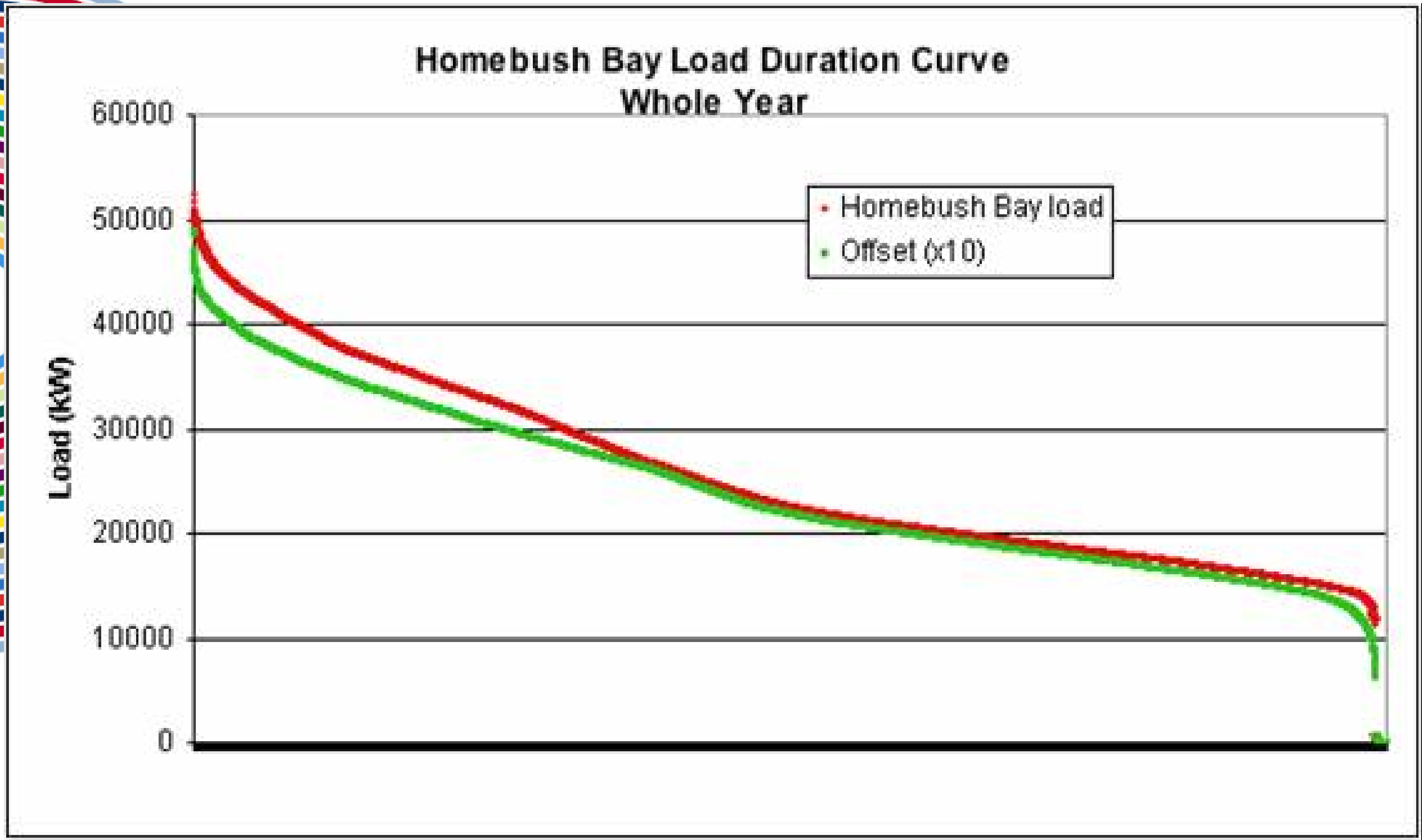
Annual Average PV Output (X10) and Homebush Bay Substation Load



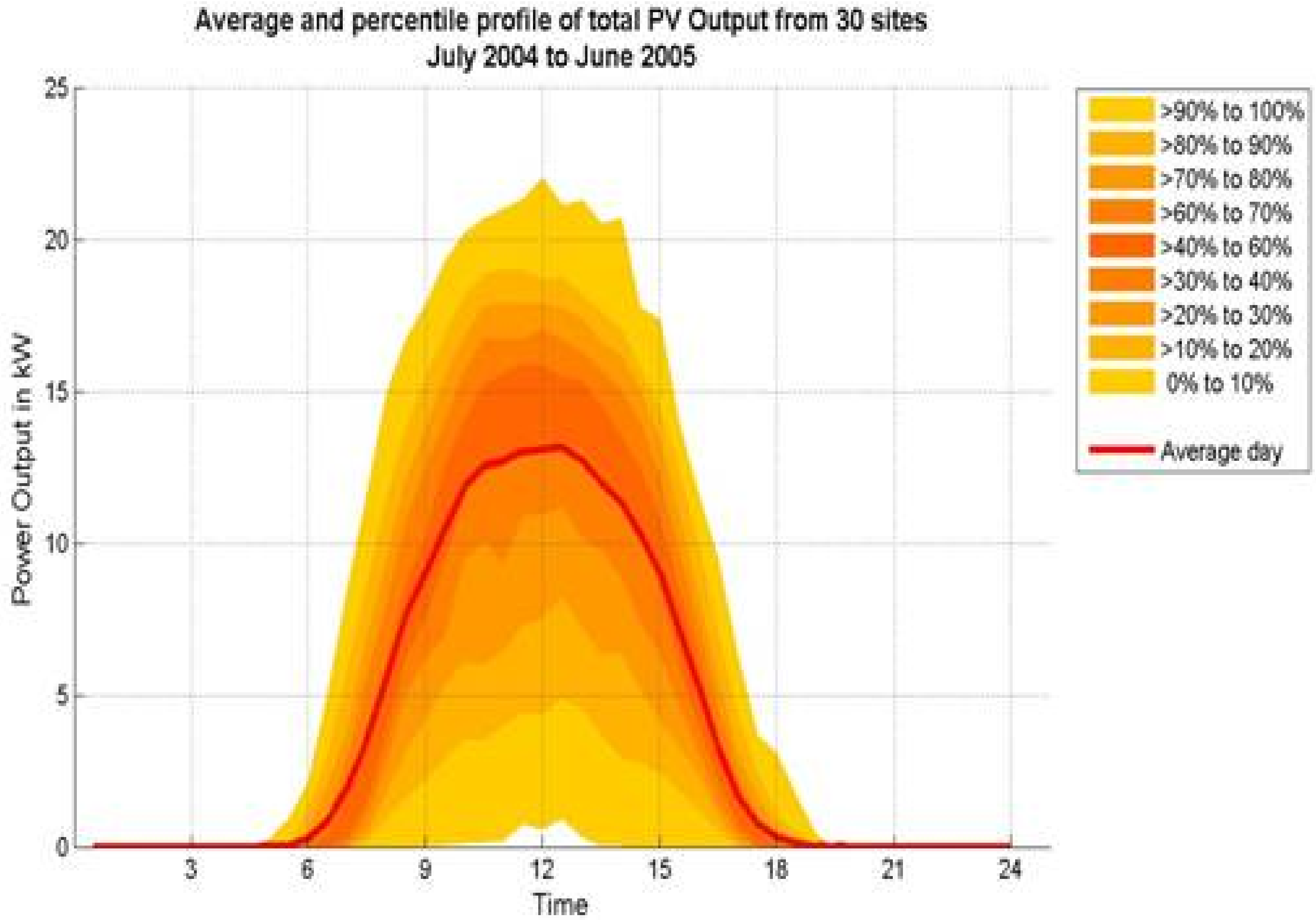
PV Output, Homebush Bay Substation Load and Temperature - Peak Load Summer Day



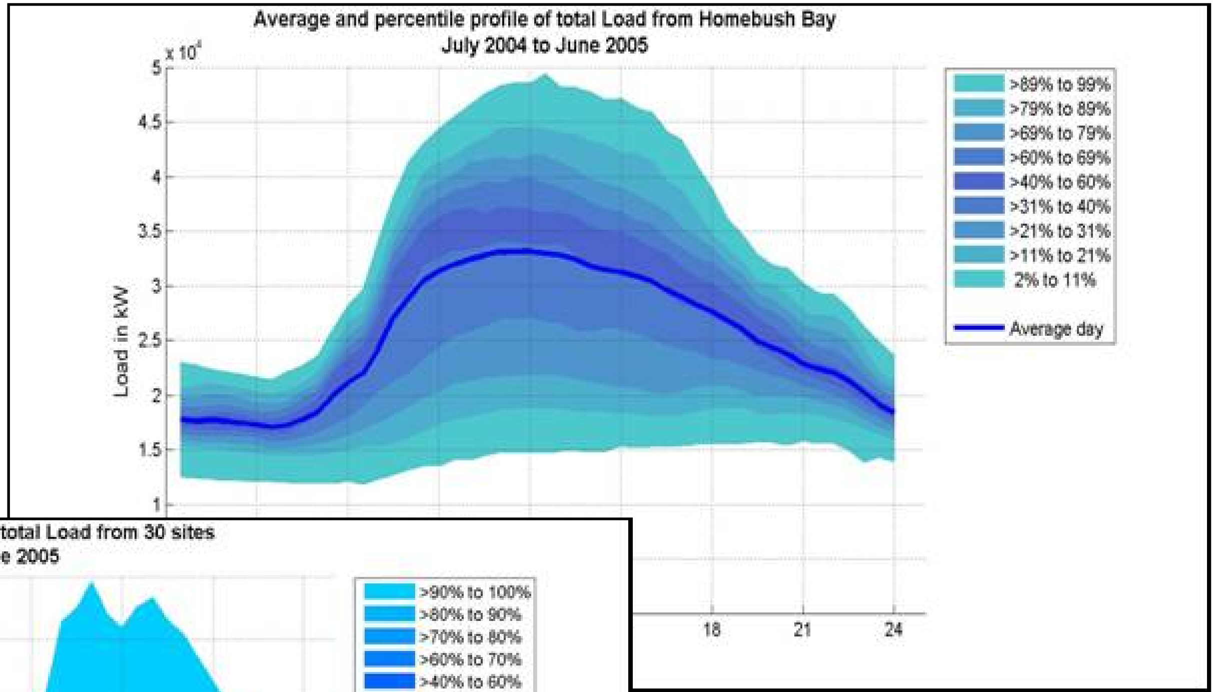
Load Duration Curve Homebush Bay with impact of 10X current PV Output

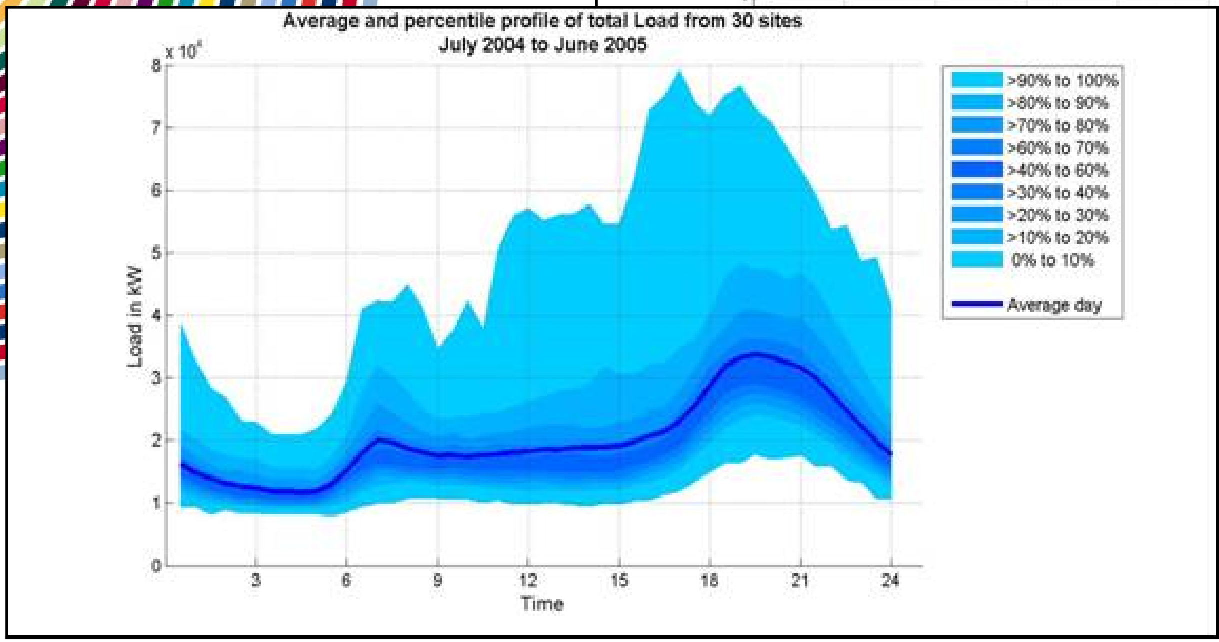


PV output varies



But so does load….





Case Study

NSW Department of Planning

Kogarah Town Square

Photo: Energy Australia

Kogarah Town Square
(NSW Dept of Planning, 2005, Kogarah Study)

- 160 kWp (2800m^2) BiPV commissioned 2003
  - a-Si roof tiles
  - Glass-glass modules
- Most at 20° pitch, some 10°
- Most at 53° W of N, some 100°, 190°, 280°
- 58 inverters (1.2 and 2.5 kW rating)
- Combined residential / commercial but predominantly commercial load
- Connected to Carlton zone substation

Summer PV Performance, Kogarah

- Average daily output 473 kWh (3 kWh/kWp)
- 74% of rated capacity if temperature, shading & orientation considered
- Peak site demand reduced by 35% of available PV capacity
  - Demand often high through afternoon
  - Zone substation demand reduced by 24% of available capacity
- 40% of inverters failed within 1 year of installation
  - Under-rated internal connection, readily fixed on discovery
- PV value – 7c/kWh if spot price paid cf 4.41 c/kWh @ average prices and 11 c/kWh if net metered

Water Pumping & Purification

- Developed by Perth based Solco
- Reverse osmosis unit which can be powered by a single PV module
- High quality drinking water to WHO standards
- Completely automatic
- Can be combined with a PV water pump & Sun Tracer® tracker
- Designed for easy maintenance

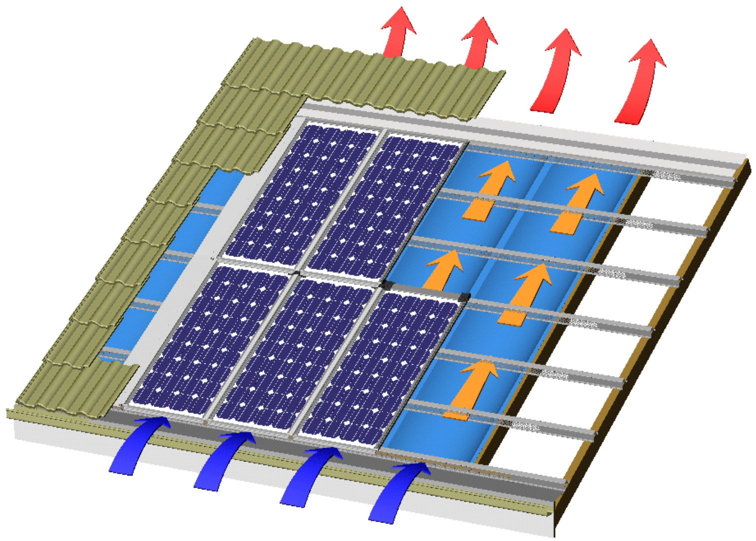
Solco's Solarflow

UNSW THE UNIVERSITY OF NEW SOUTH WALES } ENGINEERING

Building Products

- tile acts as weatherproof roof
- good thermal performance
- PV AirFlow™ ventilation or heat extraction system
- improves c-Si PV performance in hot conditions
- air flows behind PV into roof cavity, for external venting in summer, internal venting in winter
- winter indoor temperatures in a Sydney home using a 1.5 kWp system raised by 4 degrees C

Building integrated PV Solar Tile™



PV Solar Energy

UNSW THE UNIVERSITY OF NEW SOUTH WALES } ENGINEERING

Commercial Buildings

normal or uninterruptible power supply

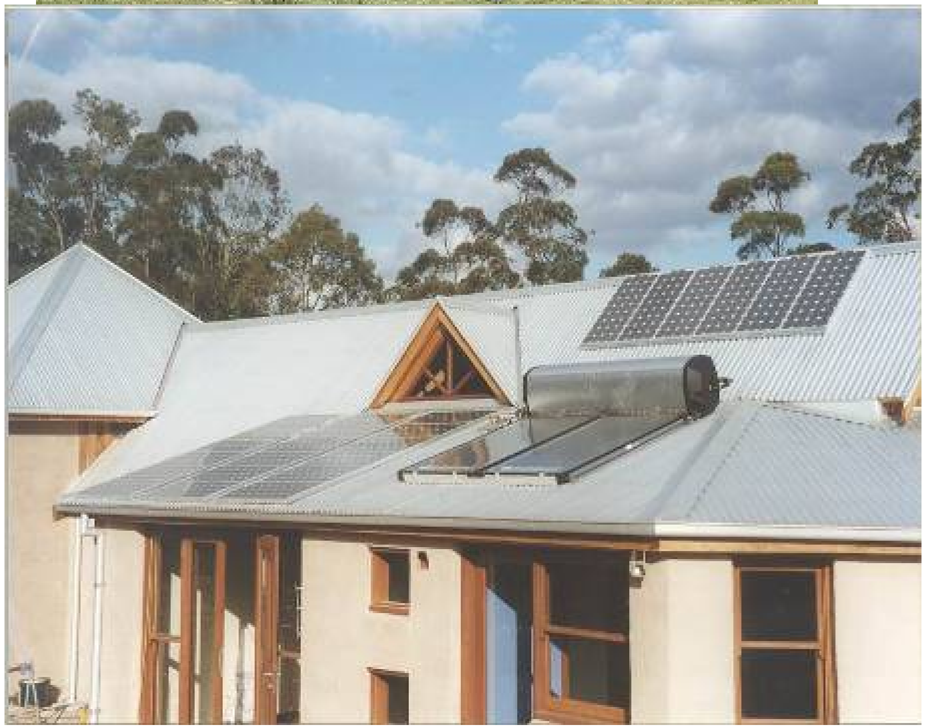
Edward St Brisbane

Melbourne Uni Private (Photo: STI)

Shell Harbour Services Club

Residential PV systems

- standard kits for rapid installation on tiled or metal roofs
- grid interactive or stand-alone inverters
- Weather station, monitoring or display devices available



Central Power Plants

- Largest Australian central PV system
- 400 kWp grid connected
- A-Si and mc-Si arrays
- 5 X 50 kW inverters and 36 X 4 kW inverters
- provides 500,000 kWh of electricity each year for Pure Energy customers

Singleton – Energy Australia

Innovative uses: Solar Sailor

Photo: Solar Sailor

- Hybrid Marine Propulsion all electric drive PV powered, wind assisted catamaran with high efficiency low noise diesel or LPG generator
- in high demand for harbour cruises in Sydney
- seamless transition between battery and generator
- High efficiency BP Solar PV cells in non-glass, rugged, lightweight Flexicell™ module
- technology now used in a wide range of vessel types and sizes
- researching fuel cell and hydrogen applications

Government Support for PV

IEAust, August 2006

UNSW THE UNIVERSITY OF NEW SOUTH WALES } ENGINEERING

Australian Government Support for PV

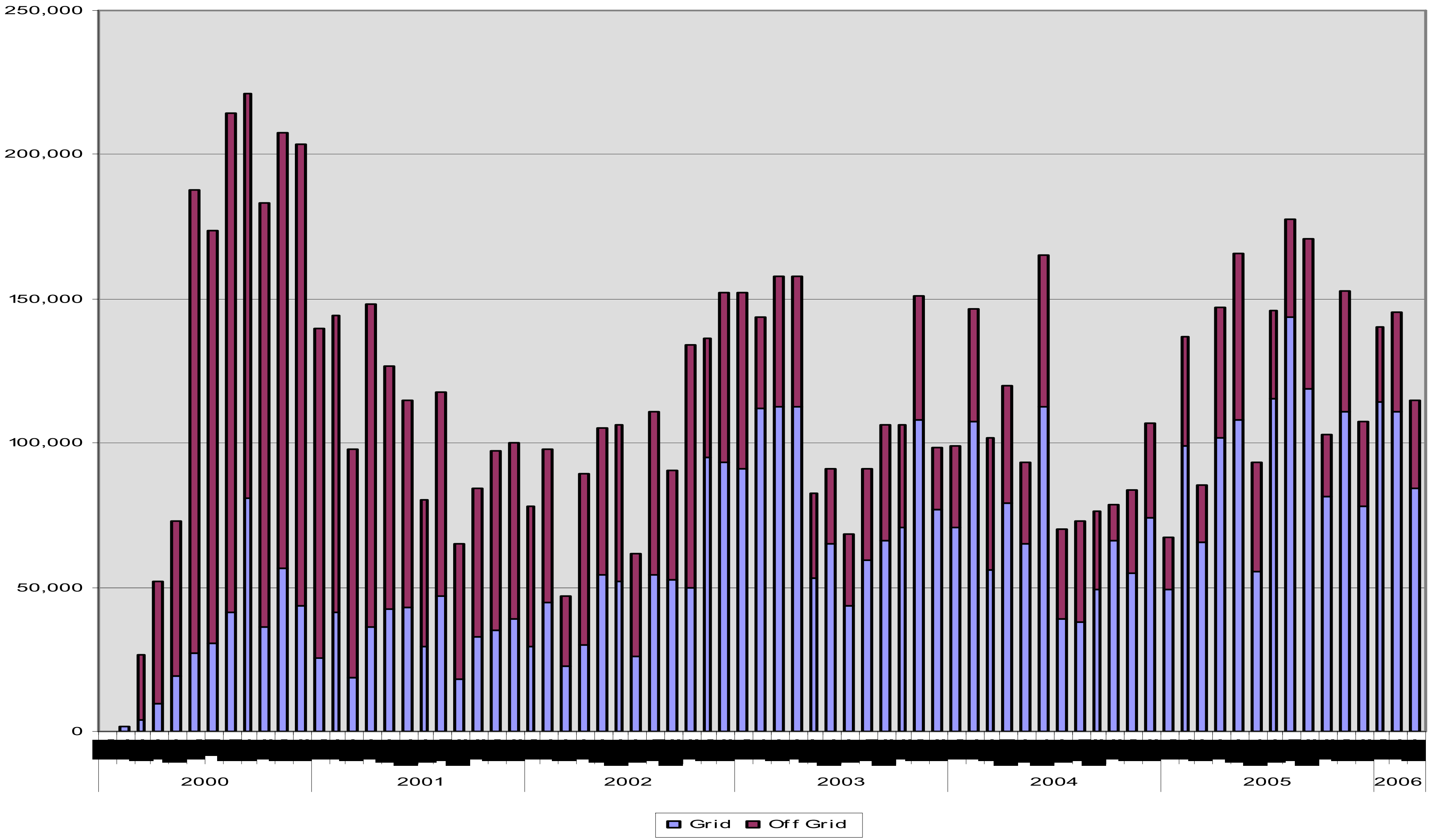
- PV Rebate Program
  - May end 2007 - will grid market be sustained?
- Renewable Remote Power Generation Program
  - Trend to larger systems -> wind, concentrators?
  - Restrictions on water pumping
  - Money remaining only in WA and NT
  - Implications of removal of diesel fuel excise
- Mandatory Renewable Energy Target
  - Increase in deeming period for PV & size of deemed systems
  - Demand tapering off from 2005
- Solar Cities
  - Short term grid sales -> longer term impact?
- Renewable energy R&D funding
  - Industry priorities need to be defined
  - Opportunities for product & systems development

PVRP

Australian Government
Department of the Environment and Heritage
Australian Greenhouse Office

Watts Installed by Month
to March 2006

8.65MW to date



Solar Cities trials

- $75M over 5 years to demonstrate high penetration uptake of solar technologies, energy efficiency, smart metering
- aimed at improving the market for distributed generation and demand side energy solutions
- Tenders called 2005 – must include monitoring and associated tariffs, marketing and financing strategies
- Eleven consortia short-listed from 23 applicants.
- Final decision imminent about the location of Australia’s 4 Solar Cities.

Where to from here?

Technical Issues for Australian PV Systems

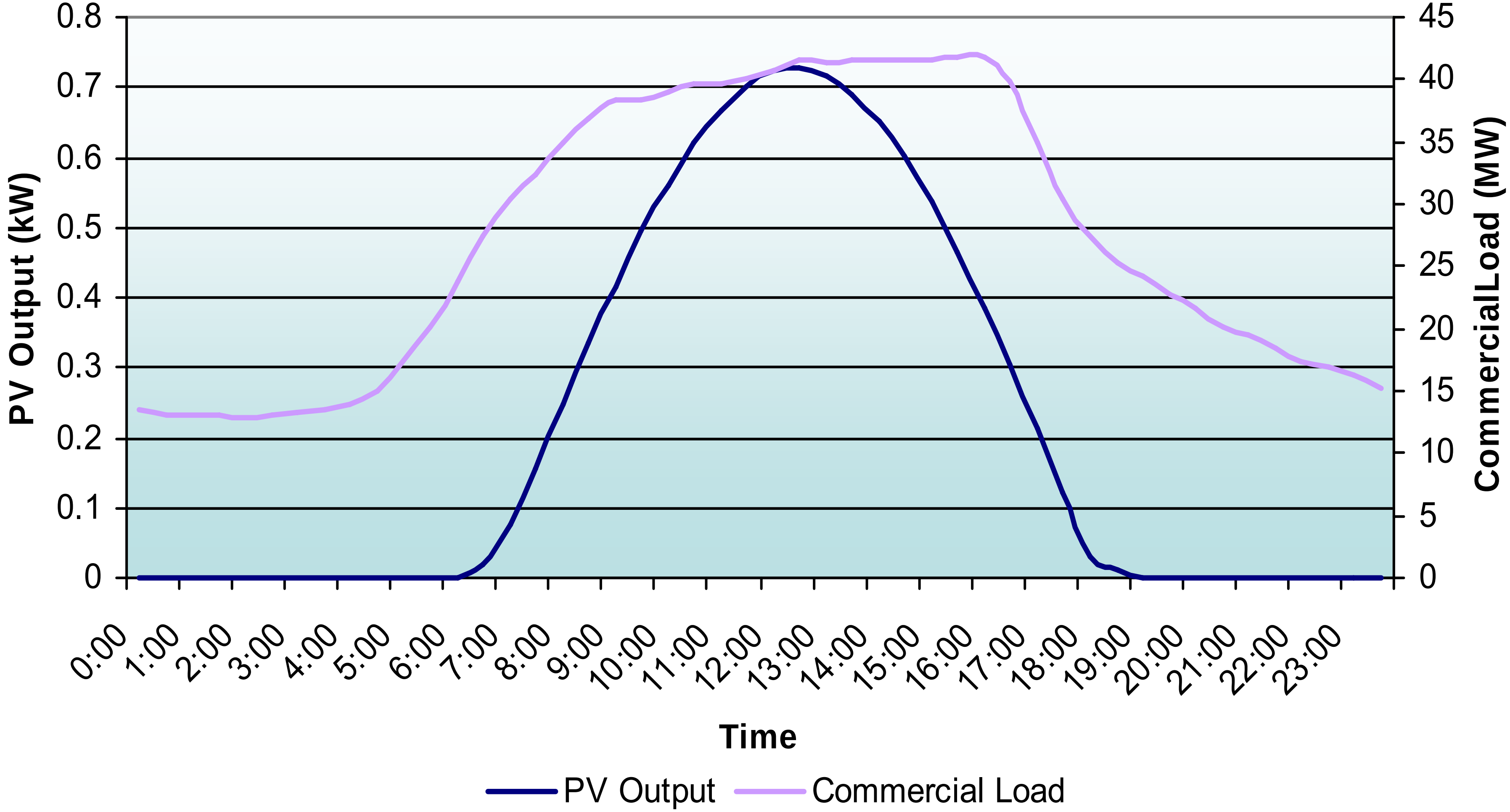
- Temperature
  - Ratings should be at 45 deg or higher
- Siting
  - Orientation, shading, tilt angle need consideration
- Maintenance
  - Information needed
  - Responsibility needs to be specified
- Inverters
  - Configuration and numbers
  - Rating – temperature, PV output, siting
- Link to energy use and efficiency
  - End user knowledge and interest essential

Market Issues for PV in Australia

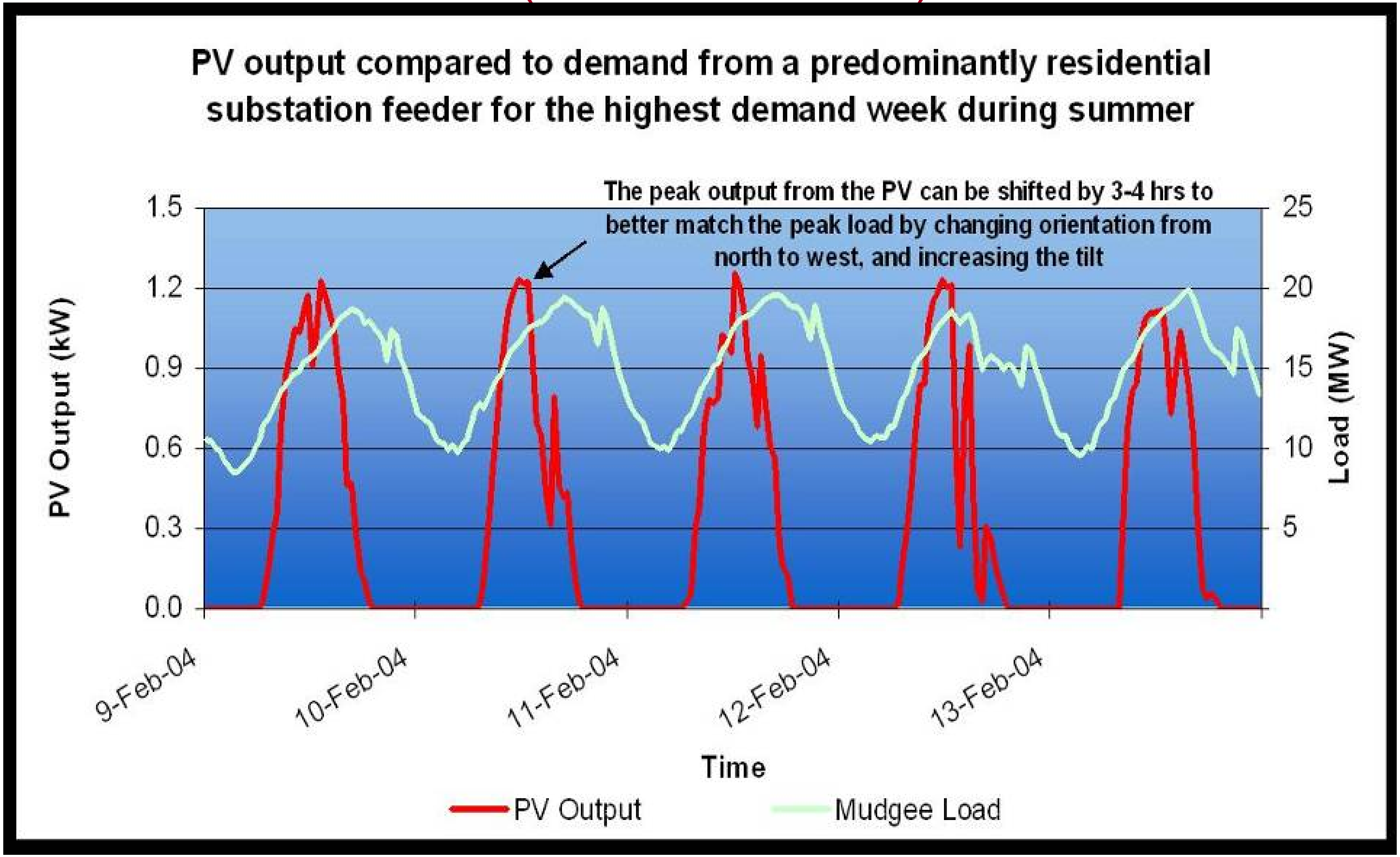
- Large increase in international PV demand
- Critical silicon shortage
  - 2 years to resolution
  - Difficult to access wafers / modules for small market
  - Pressures on price
- What is Australia's place in the new PV market?
  - PV / BOS Manufacture
  - Systems
  - New technology
  - Expertise
  - How can we maintain a role?
- How can we grow the Australian market?
  - Selection of sites based on substation profiles
  - Products linked to controllable loads / air conditioning
  - Use MRET for larger systems
  - Feed-in-tariffs?

PV Output & Commercial Load

(Watt et al, 2004)

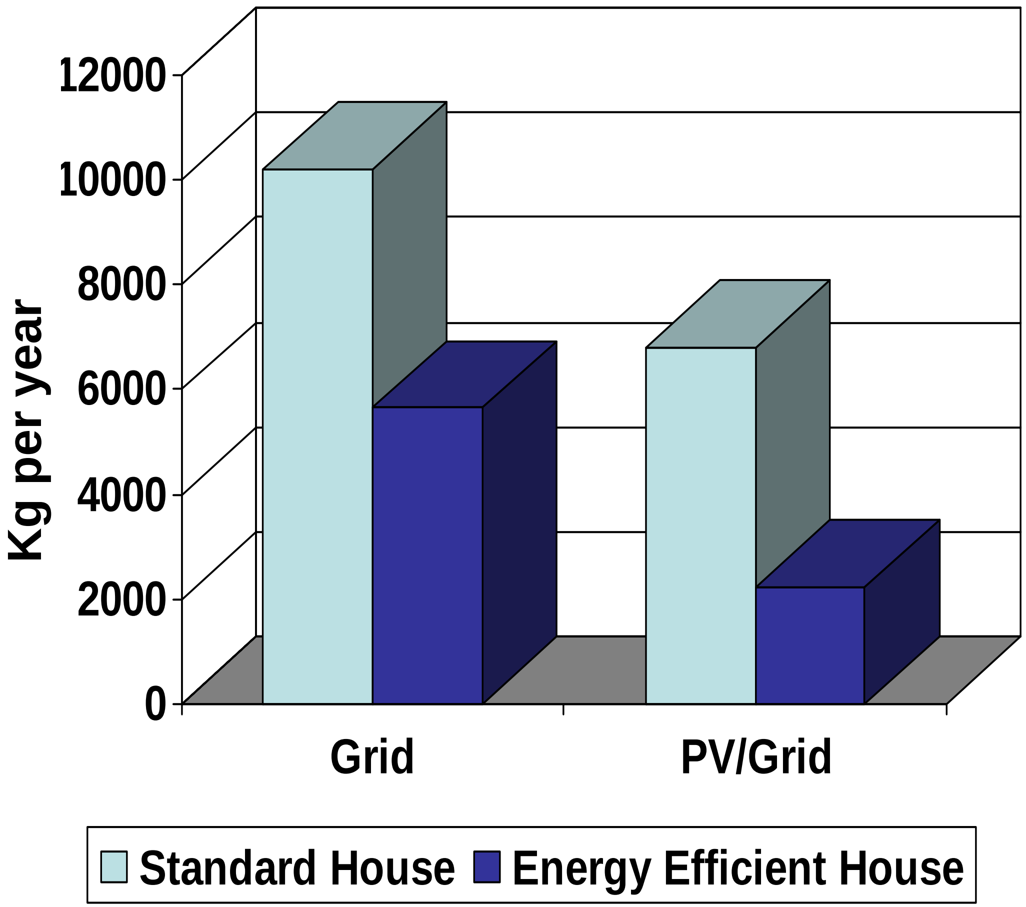


PV Output & Residential Load
(Watt et al, 2004)



CO_2 Emission Reduction Options

(Watt et al, 1998)



UNSW THE UNIVERSITY OF NEW SOUTH WALES } ENGINEERING

Other trends

(Australian PVPS Consortium, 2006)

- Increasing imports
  - <10% to ~ 60% over a decade
- Reduced % of local BOS components
- Government support:
  - 40% of total market
  - PVRP 63% of grid market
  - RRPGP & PVRP 35% of off-grid market
- > 80% of cells exported
- > 4.5MWp of modules / systems exported (including imported modules)

What PV Strategies should Australia adopt?

- R&D
  - Device research to reduce costs
  - Systems research for new products
  - Product and end-user focus to increase uptake
- Industry policies
  - Targeted policies to encourage renewables industries and prevent loss of Australian technologies overseas (demonstration, manufacturing establishment, market development)
- Electricity policies
  - Change in focus from totally supply side to examining demand side and distributed resource potential
  - Change restructuring focus from wholesale to retail markets, including tariff reform
  - Active promotion of renewables and efficient energy use
  - Target markets (commercial load substations, diesel grids)
  - A carbon signal!

References

- Alsema E.A., 2000, ***Energy Pay-Back Time and CO2 emissions of PV Systems***. Progress in Photovoltaics, 8(1), 17-25.
- Australian PVPS Consortium, 2006, ***Photovoltaics in Australia 2005***, by Muriel Watt.
- BHP, 2000, Electricity from Photovoltaics, Case Study B9-1.
- Blakers, A., Weber, K., Everett, V., Franklin E. and Deenapanray, S., 2006, "Sliver Cells – a Complete Photovoltaic Solution", presented at the ***4th World Conference on PV Energy Conversion***, Waikoloa, Hawaii, 8-10 May, 2006.
- Business Council for Sustainable Development (BCSE), 2004, ***The Australian Photovoltaic Industry Roadmap***.
- European PV Industry Association (EPIA), 2005a, Position Paper on Feed-in-Tariffs for PV Solar Electricity.
- EPIA, 2005b, Workshop on Capacity and Market Potential for Grid Connected Systems by 2010, Frankfurt, Dec, 2005.
- International Energy Agency (IEA) 2000***, Experience Curves for Energy Technology Policy,*** OECD/IEA, Paris.
- IEA PV Power Systems Programme, 2006, International Survey Report 2005, www.iea-pvps.org.
- Kato, K., 2000, "Energy Resource Saving and Reduction in GHG Emissions by PV Technology – values in the present and added value in the future, ***IEA PVPS Task I Workshop***, Glasgow.
- NREL, 2004, ***PV FAQs: What is the energy payback for PV?,*** US Department of Energy, DOE/GO-102004-2040.
- NSW Dept of Planning, 2005, ***Kogarah Town Square Photovoltaic Power System Demand Management Analysis,*** Report by Energy Australia.
- NSW Dept of Planning, 2006, ***Newington Village - An analysis of photovoltaic output, residential load and PV's ability to reduce peak demand***, Report by Watt, Passey, Barker & Rivier, CEEM.
- Richards B.S., Watt M.E., 2004, ***Permanently Dispelling a Myth of Photovoltaics via the Adoption of a New Net Energy Indicator***, Progress in Photovoltaics.
- Smeltink, J.F.H. and Blakers, A.W., 2006, "40kW PV Thermal Roof Mounted Concentrator System", presented at the ***4th World Conference on PV Energy Conversion***, Waikoloa, Hawaii, 8-10 May, 2006.
- Watt M.E., Johnson A.J., Ellis M., Outhred H.R..,1998, ***Life-cycle Air Emissions from PV Power Systems***, Progress in Photovoltaics, 6, 127-136.
- Watt, M. et al, 2004, "Analyses of Photovoltaic System Output, Temperature, Electricity Loads and National Electricity Market Prices – Summer 2003-04", ***Solar 04,*** Perth December 2004.
- UNSW Centre of Excellence for Advanced Silicon Photovoltaics and Photonics, 2006, Annual Report.