



Photovoltaics in Australia Technology, Markets & Performance

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UNSW

IEAust, August 2006

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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?



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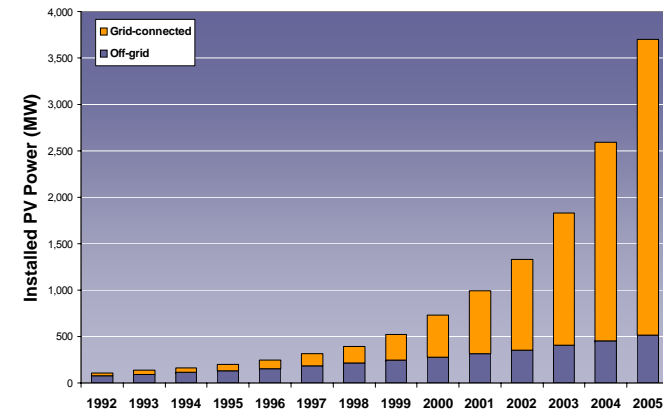
The World PV Market

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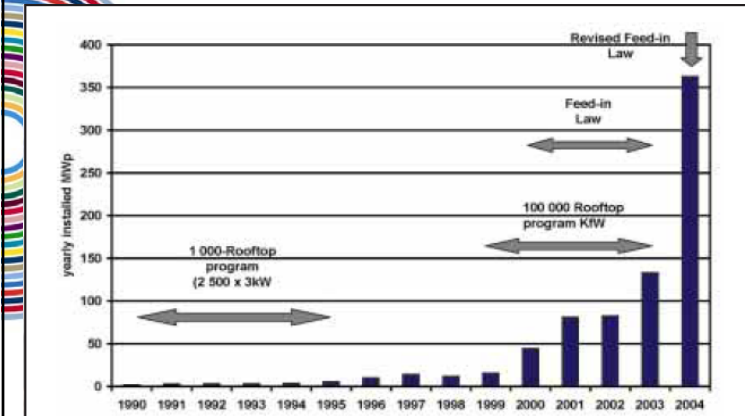
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IEA PV Market 1992-2005 (IEA PVPS, 2006)

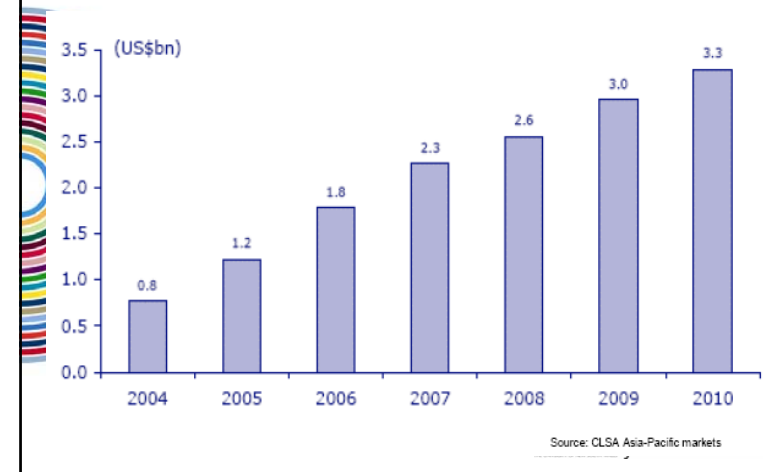
Figure 1 Cumulative installed grid-connected and off-grid PV power in the reporting countries – Years 1992-2005



German PV market growth (EPIA, 2005a)



Projected World PV Market Value



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€/kWh
- 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)



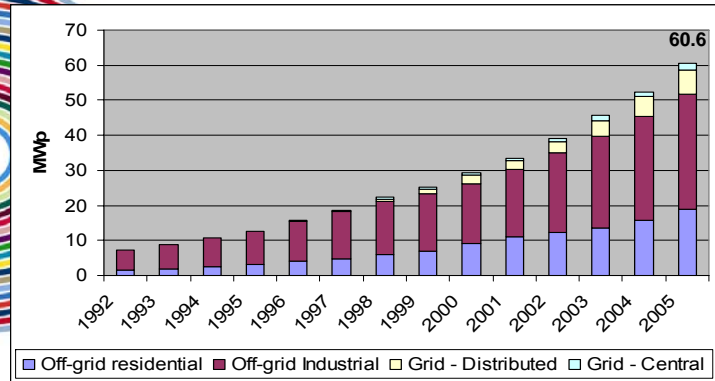
The Australian PV Market

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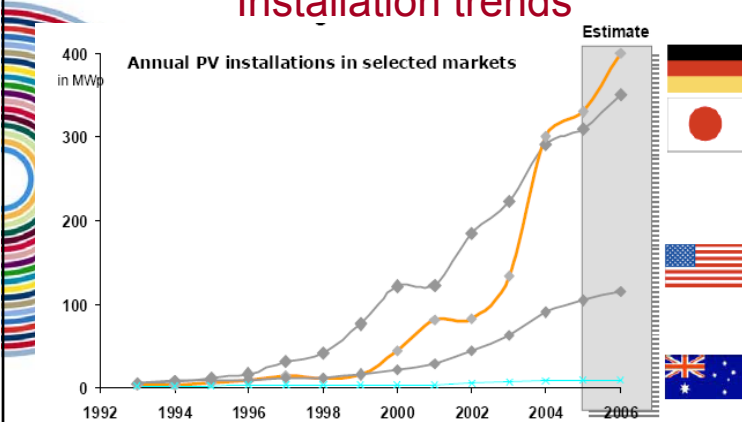
Cumulative PV Installations

(Australian PVPS Consortium, 2006)



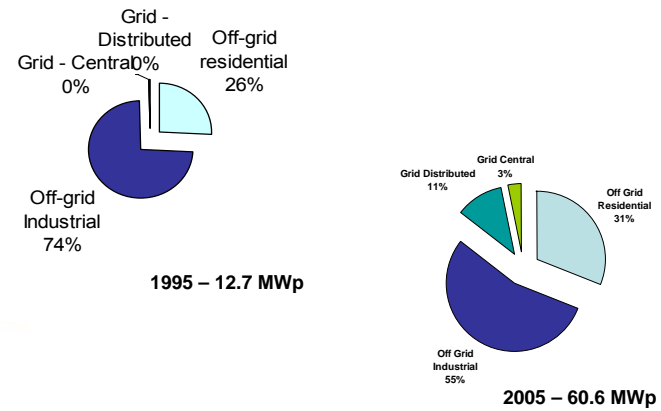
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Australian and International PV Installation trends



Cumulative Australian Installations 1995 and 2005

(Australian PVPS Consortium, 2006)



2005 PV Installations

(Australian PVPS Consortium, 2006)

<i>Sector</i>	<i>MWp installed</i>
Off Grid Residential	2.9
Off Grid Industrial	3.4
Grid – distributed	1.5
Diesel Grids	0.5
TOTAL	8.3

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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%

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BAU or Sunrise 350 in 2010

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

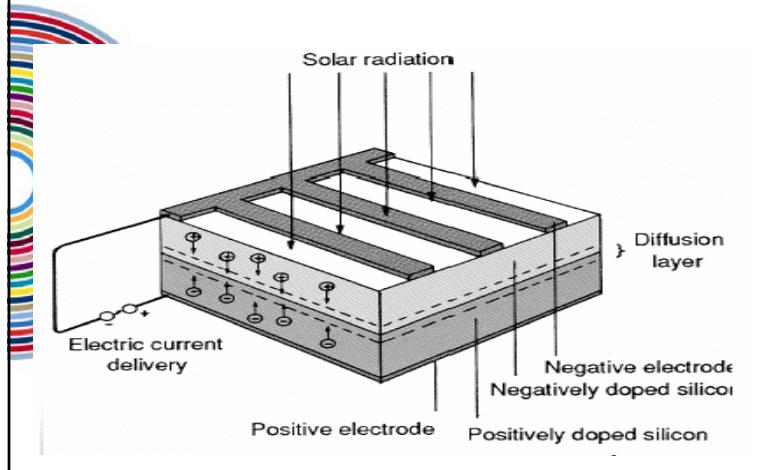
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PV Technologies

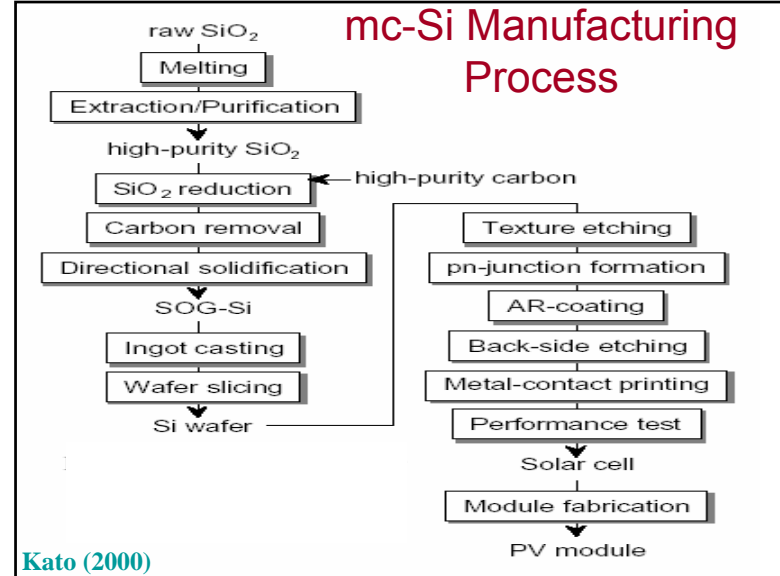
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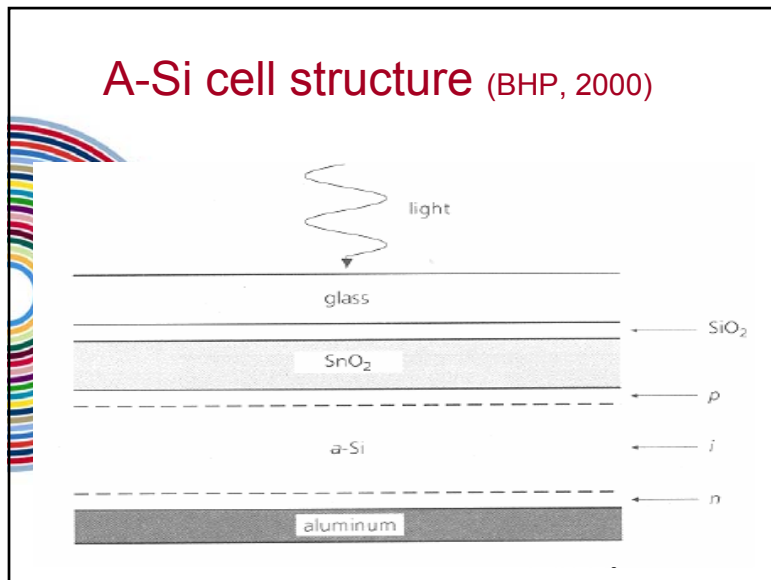
Mc-Si cell structure (BHP, 2000)



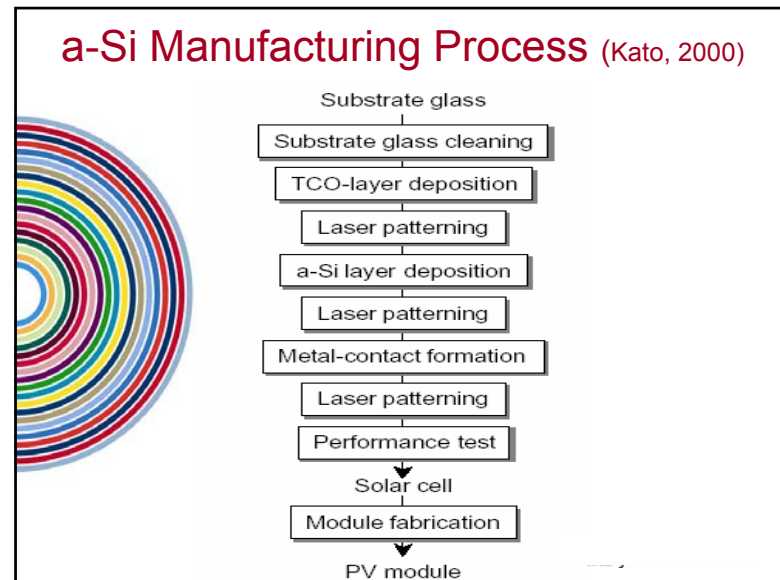
mc-Si Manufacturing Process

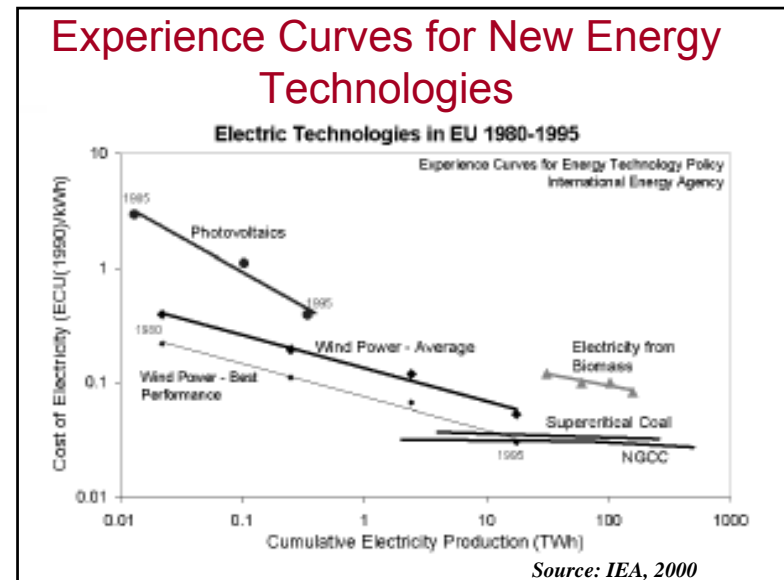
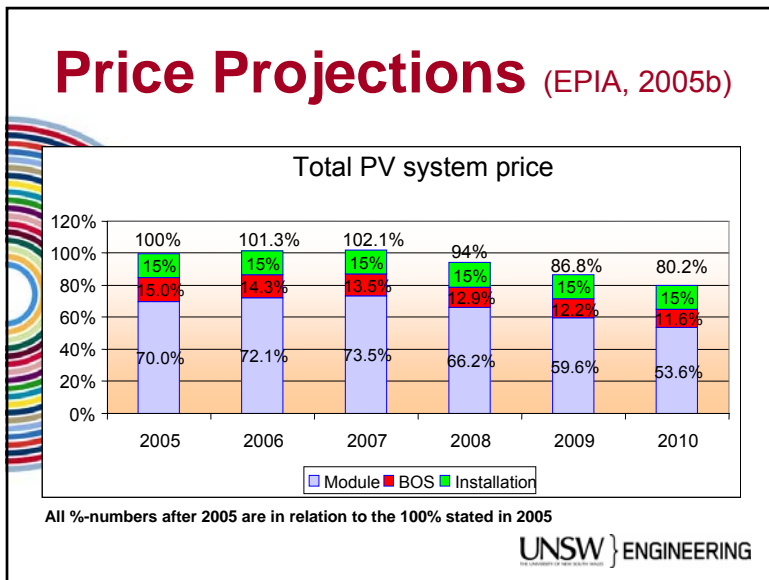
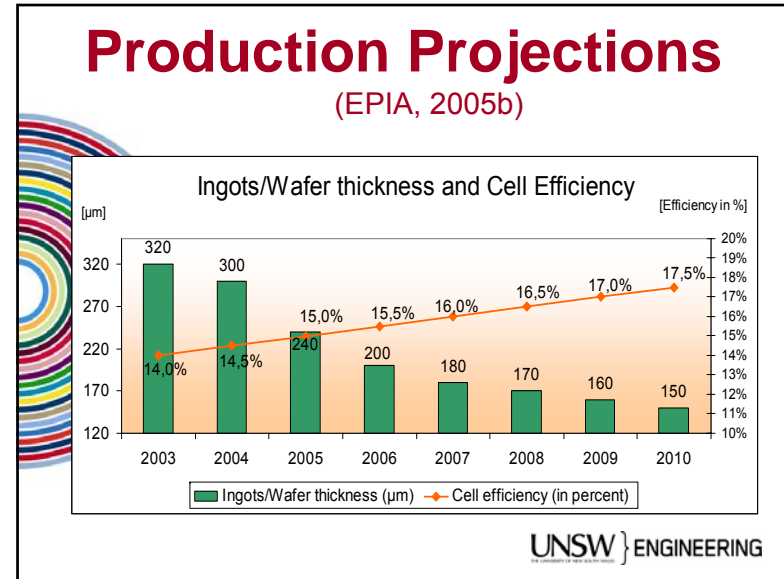
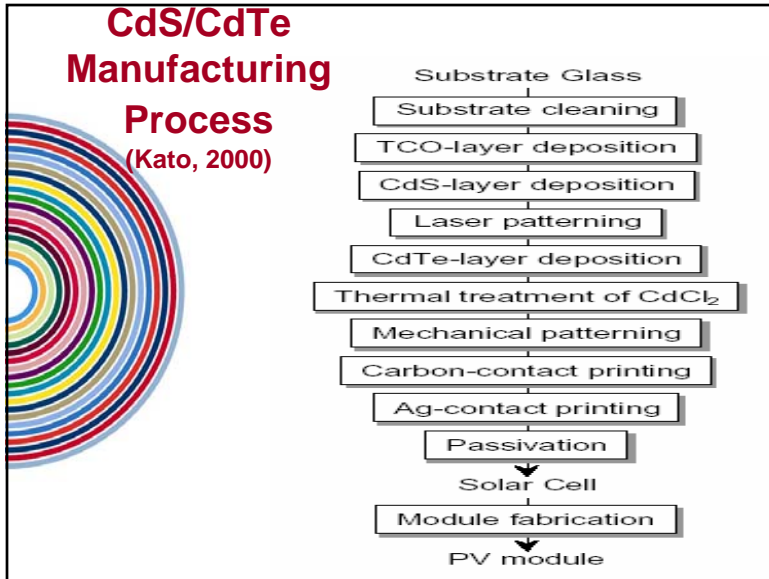


A-Si cell structure (BHP, 2000)

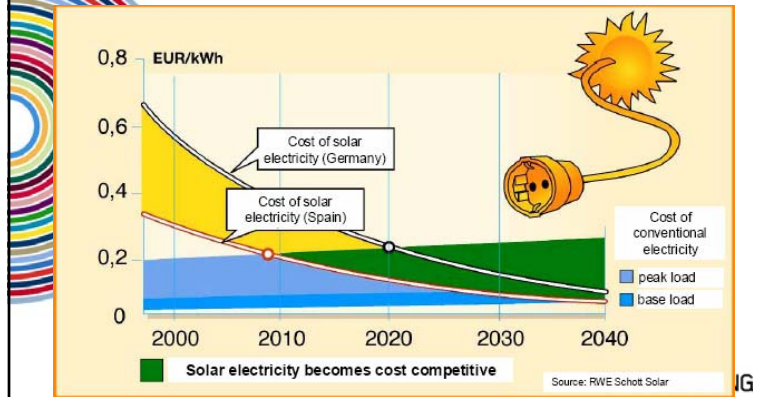


a-Si Manufacturing Process (Kato, 2000)

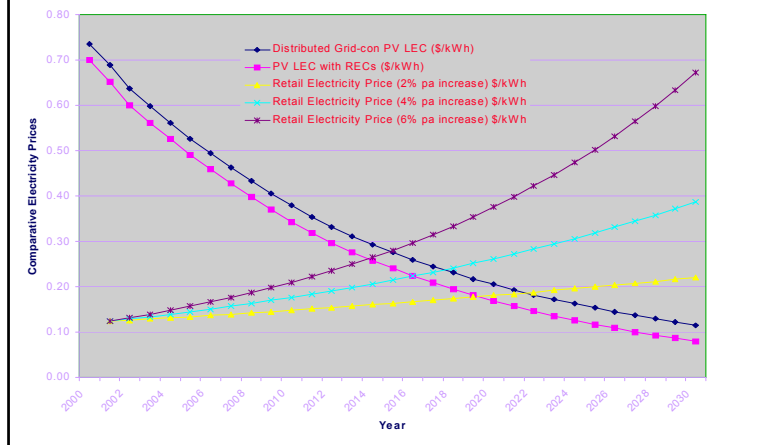




European Projected Break-even points for PV



Australian PV and electricity price projections (BCSE, 2004)



Australian PV Research

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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.....

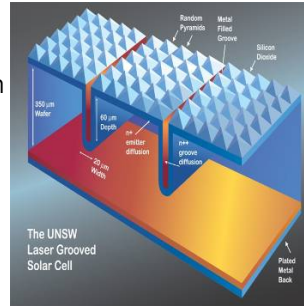


ANU CHAPS

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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
- Reducing 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

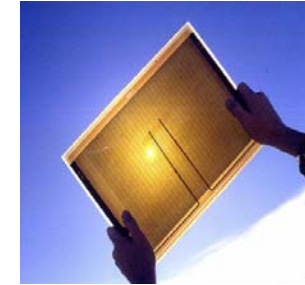


Buried Contact Cells Commercialisation by BP Solar Spain

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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

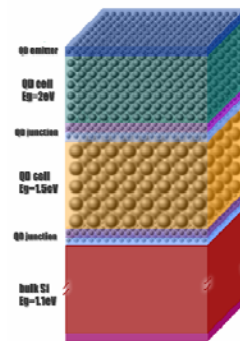


CSG Solar Module

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

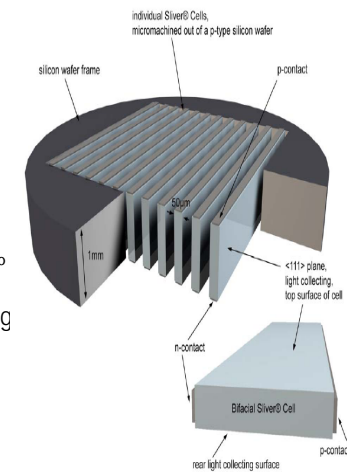
- High-efficiency and thin-film
- “All-silicon” tandem cells based on bandgap-engineering using nanostructures
- Uses mixed-phase semiconductor material based on partly-ordered silicon quantum-dots in an insulating amorphous matrix



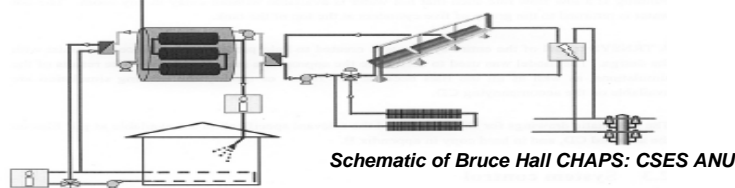
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ANU Sliver Cells (Blakers et al, 2006)

- 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 90° 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)



- 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

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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

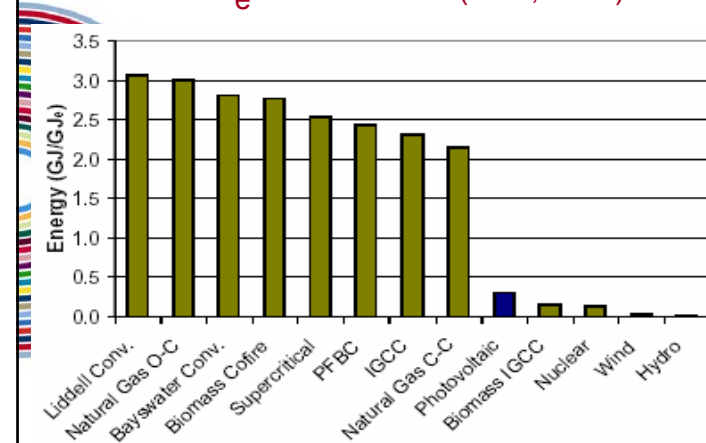


Net Energy and Greenhouse Gas Impacts

IEAust, August 2006

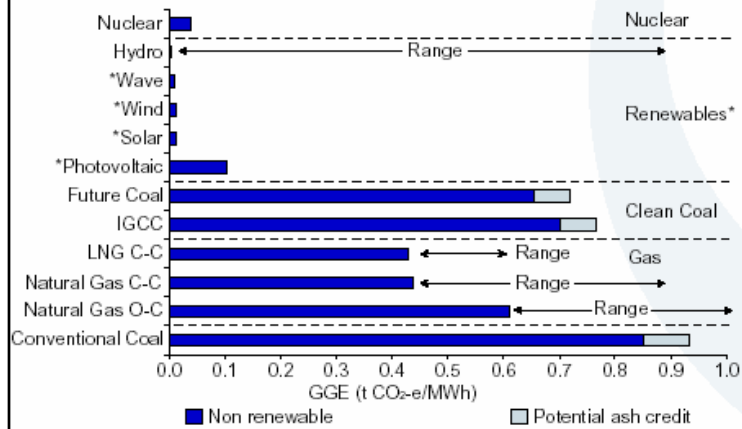
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Comparisons of Energy Input per GJ_e Produced (BHP, 2000)



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*

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Energy Payback Time - EPT

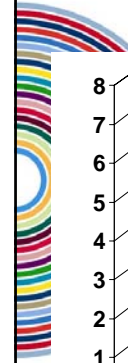


- The most commonly used parameter to quantify the life cycle performance of PV is EPT:
 - The time (in years) in which the primary energy input during the module life-cycle is compensated by electricity generated by the PV module
 - depends on cell technology, PV system application and irradiation

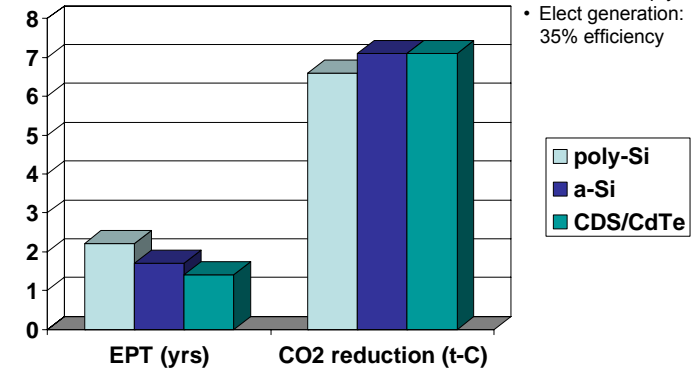
$$EPT = \frac{E_{input}}{E_{gen}}$$

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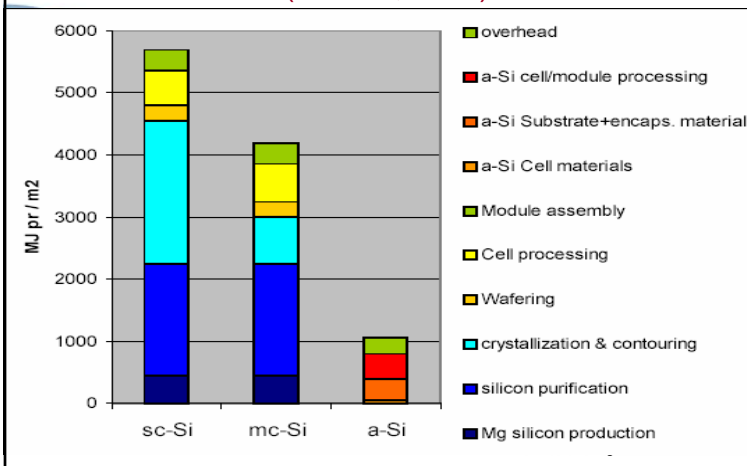
LCA (20 yr life) of 3kWp Japanese Rooftop PV (Kato, 2000)



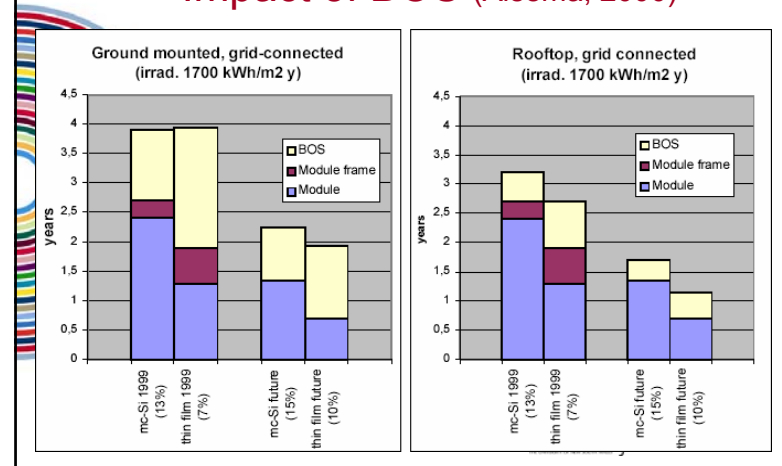
- 30 MW/yr plant
- 1160 kWh/Wp/yr
- Elect generation: 35% efficiency



Comparative energy requirements (Alsema, 2000)

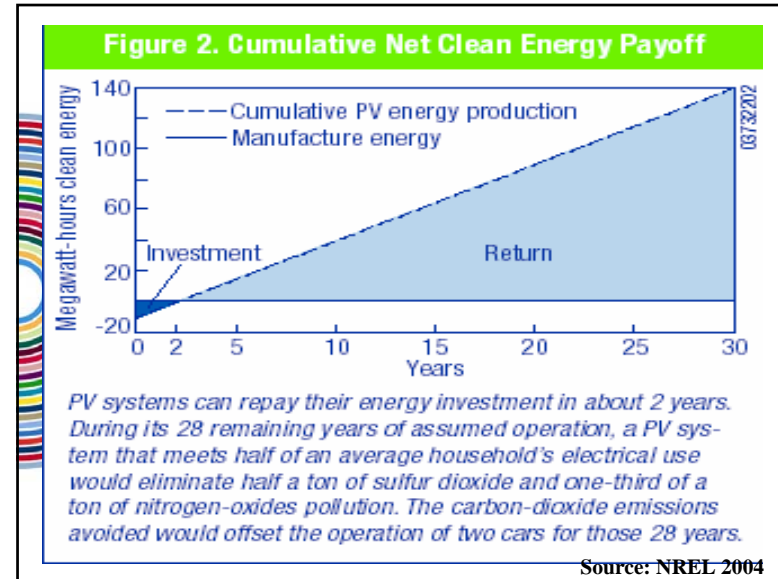


EPT - Future possibilities & Impact of BOS (Alsema, 2000)



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



The Energy Yield Ratio - EYR

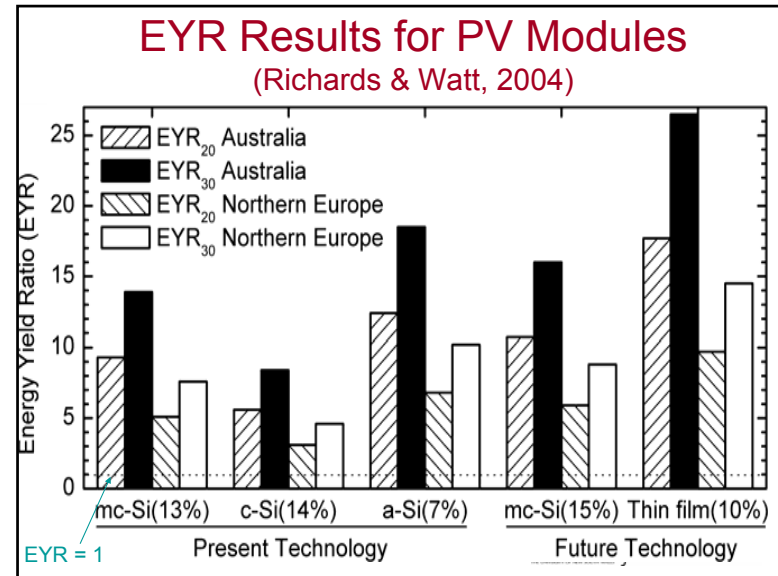


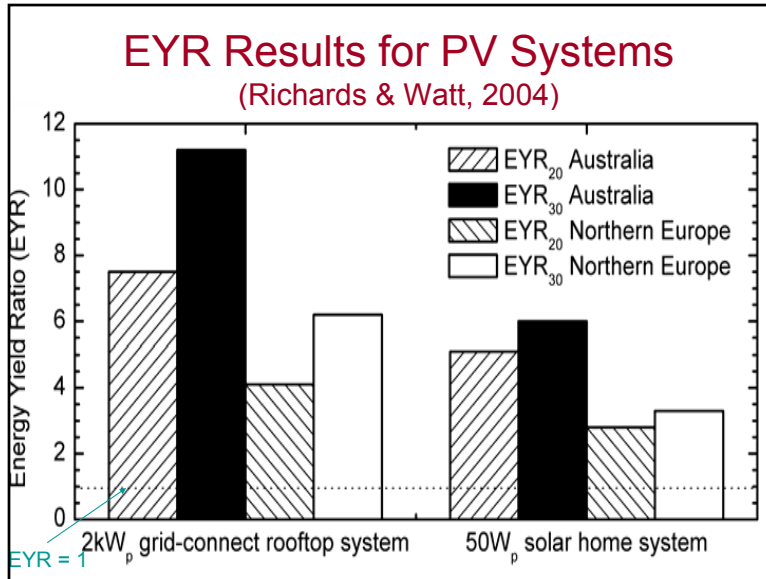
- Incorporates PV lifetime, L_{pv}
- EYR = "how many times the energy invested is returned or paid back by the system in its entire life"

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

- 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

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Australian PV Applications

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Case Study

NSW Department of Planning
Newington Solar Village

Photo: BP Solar

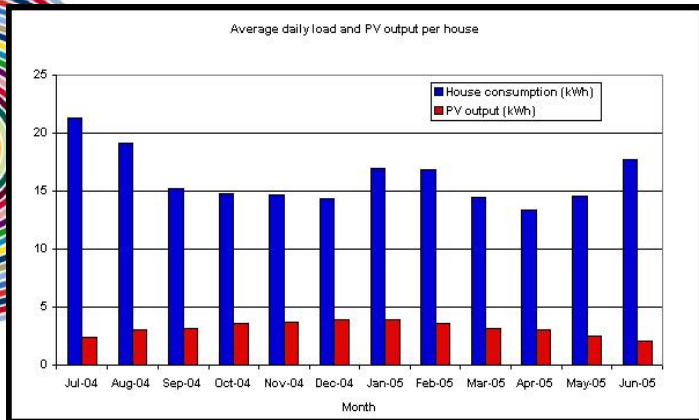
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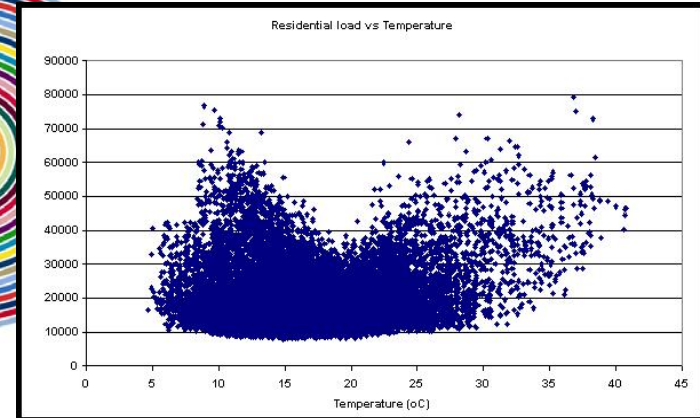
Newington Solar Village

- 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

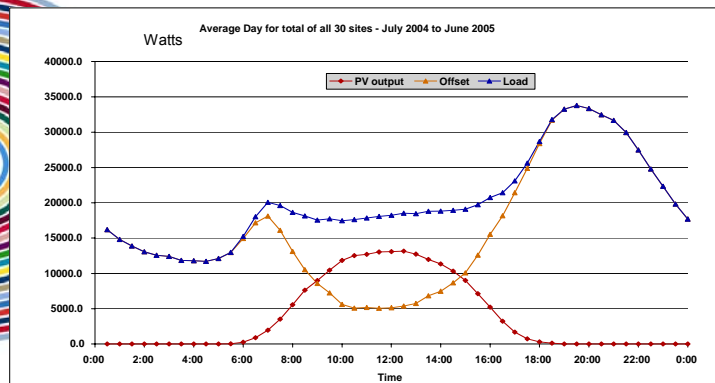
Household Load and PV Output average over 30 houses (NSW Dept of Planning, 2006, Newington study)



Relationship between electricity use and temperature, Newington

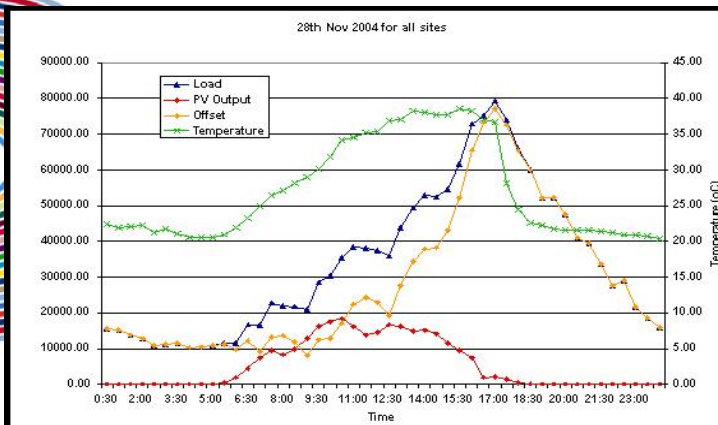


Annual Average Daily PV Output, Household Load and Offset, Newington

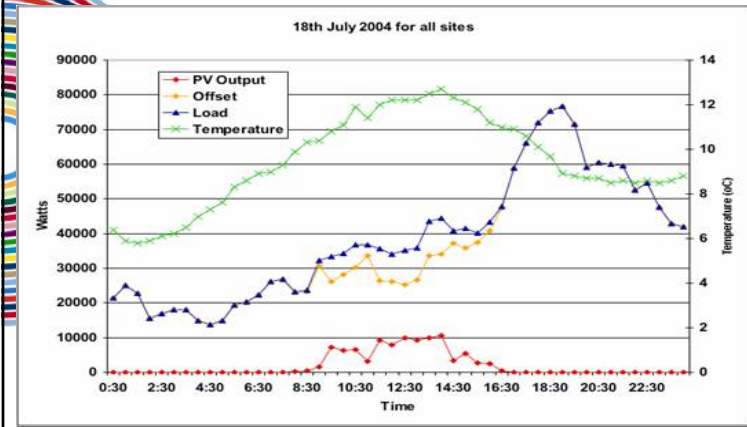


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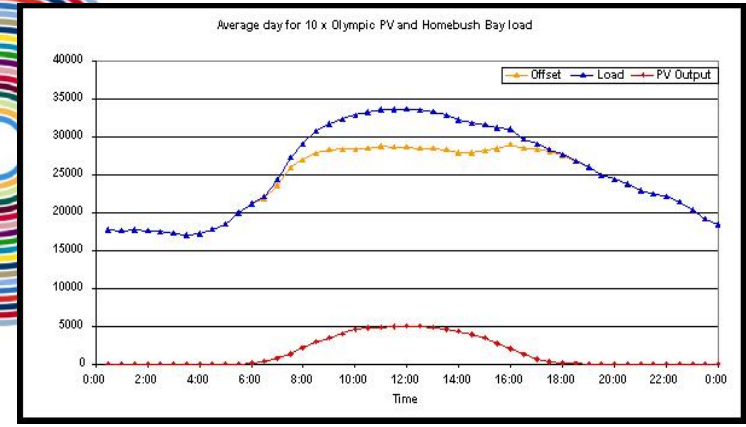
PV Output, Household Load and Temperature - Peak Summer Day, Newington



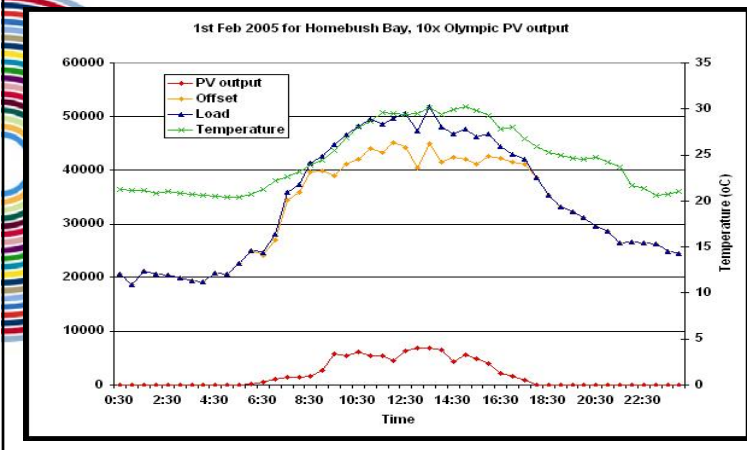
PV Output, Household Load and Temperature - Peak Winter Day, Newington



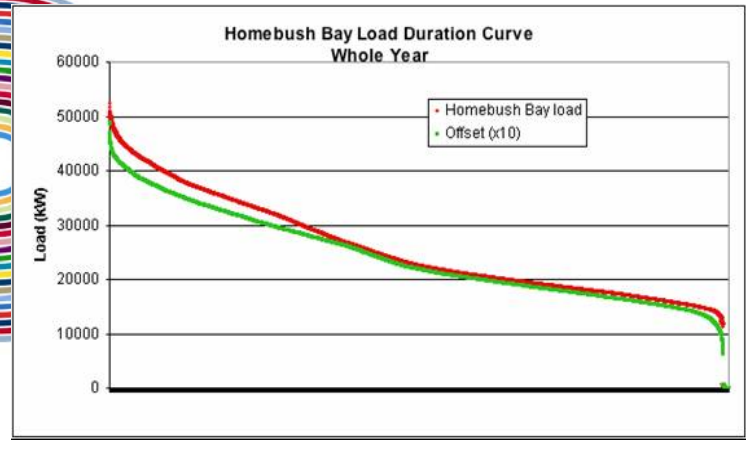
Annual Average PV Output (X10) and Homebush Bay Substation Load

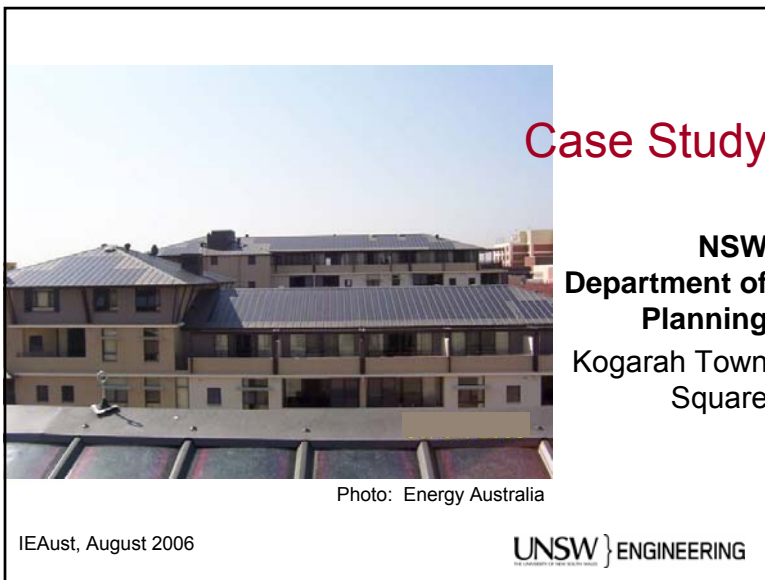
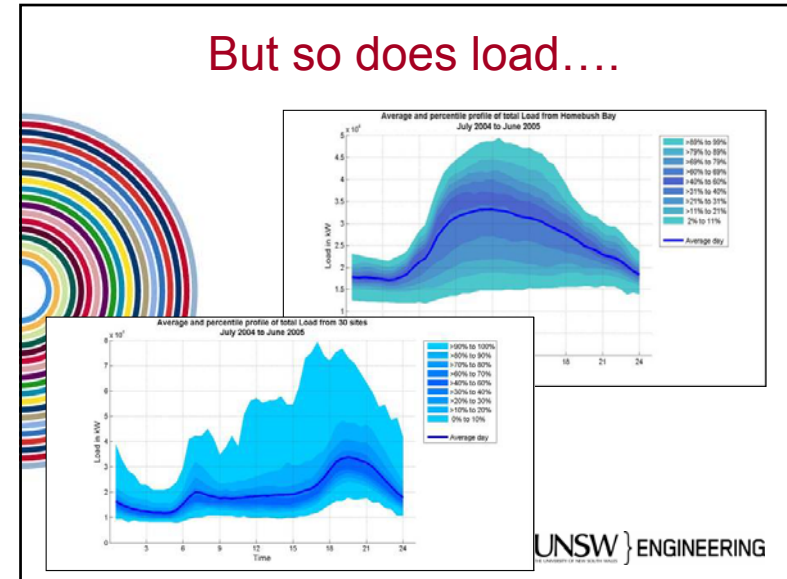
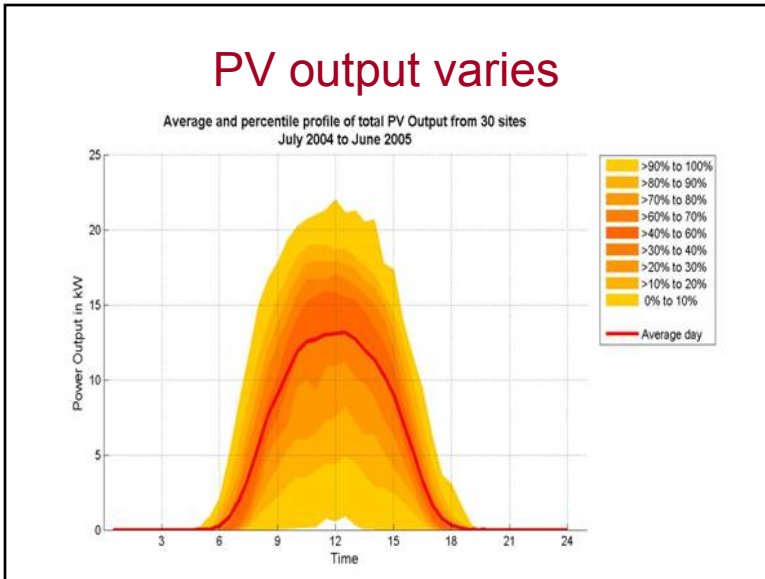


PV Output, Homebush Bay Substation Load and Temperature - Peak Load Summer Day



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





- ### Kogarah Town Square
- (NSW Dept of Planning, 2005, Kogarah Study)
- 160 kWp (2800m²) 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
- UNSW } ENGINEERING**

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

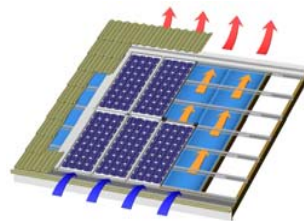


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Building Products

- 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

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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



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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

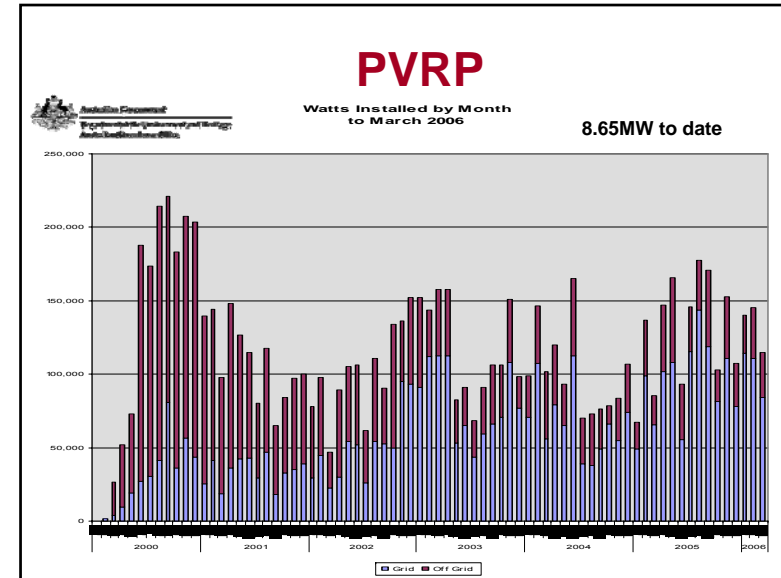
Government Support for PV

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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



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?

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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

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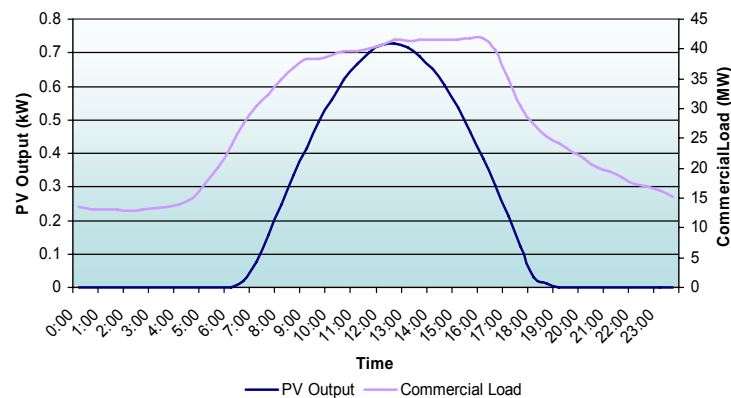
Market Issues for PV in Australia



- 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?

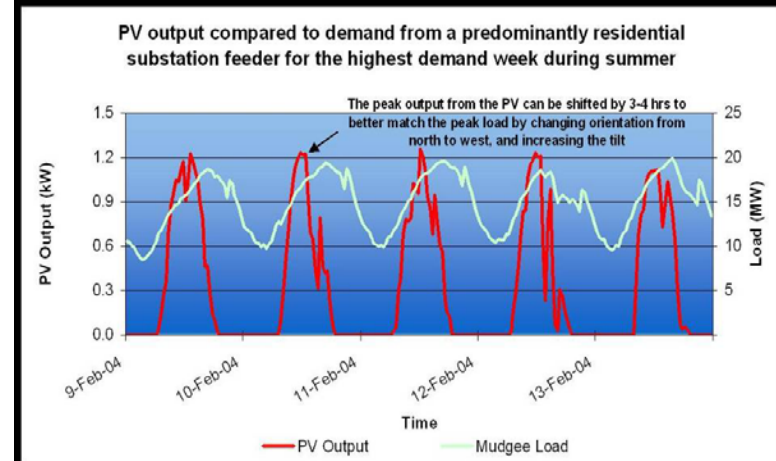
PV Output & Commercial Load

(Watt et al, 2004)



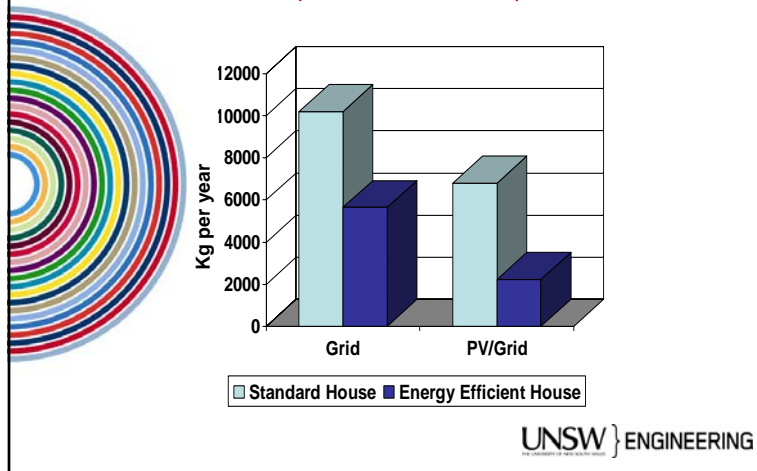
PV Output & Residential Load

(Watt et al, 2004)



CO₂ Emission Reduction Options

(Watt et al, 1998)



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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
 - RRRPG & PVRP 35% of off-grid market
- > 80% of cells exported
- > 4.5MWp of modules / systems exported (including imported modules)

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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!

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