DISTRIBUTED GENERATION OPTIONS

Lu Aye

International Technologies Centre (IDTC)
Department of Civil and Environmental Engineering
The University of Melbourne, Victoria 3010

lua@unimelb.edu.au

Outline

- Introduction: Distributed generation (DG)
- Cogeneration
- Microturbines (MT)
- Photovoltaics (PV)
- Gas Engines
- Greenhouse gas emissions benefits
- Conclusion

Distributed Generation (DG)

- DG is a any small-scale (< 10 MW_e) electrical power generation technology that provide electric power at or near the load site; it is either interconnected to the distribution system, directly to the costomer's facilities, or both (Borbely & Kreider 2001).
- Terms like distributed power, distributed energy, distributed energy resources, embedded generation, decentralized power, dispersed generation, and onsite generation can also be found in the literature. Although some of those terms may be used with a different meaning, typically they de facto refer to distributed generation (Wikipedia 2006).

Problems with electricity

- The rate of production must balance the rate with which it is consumed at all times.
- Demand for electricity does not remain constant and fluctuations in load occur:
  - at different times of the day,
  - on different times of the week,
  - in different months of the year.
- Sufficient 'generation capacity' must be constructed to meet demand at its highest point.

Average life cycle cost of electricity in Australia (Australian cents/kWh_e)

Energy source	c/kWh_e
Coal	2.8 – 3.5
Natural gas	3.8 – 6.5
Diesel	22 – 50
Biomass	5 – 15
Wind	5.5 – 10
Photovoltaic	40 – 80
(*Source*: Fung *et al*. 2002)	

Conventional generation
(Typical Australian data)

Type	Overall efficiency (%)	Net CO_2 (t/MWh)
Hydropower	40 - 70	0.00
Combined Cycle Gas Turbine	48	0.39
Thermal - Natural Gas	38	0.49
Thermal - Black Coal	35	0.93
Thermal - Brown Coal	29	1.23

(*Source*: ACA 1997)

Potential benefits of DG

- Less or no distribution losses (typical distribution losses 4 to 9%)
- Better power quality and consistent power supplies (i.e. no voltage dips, interruptions, transients, and network disturbances from other loads)
- Enable on-site waste heat recovery (i.e. cogeneration)
- Reduce grid demand during peak
- Can provide emergency power
- Can increase diversity of energy sources

DG technologies

- Internal combustion reciprocating engines (ICRE) and generators
- Small combustion turbine generators (including microturbines)
- Photovoltaic (PV) modules
- Fuel cells
- Solar thermal conversion
- Stirling engines
- Biomass conversion

Status of DG technologies

	IC Engine	Turbines	PVs	Fuel Cells
Capacity	50 kW – 5 MW	25 kW – 25 MW	1 kW – 1 MW	200 kW – 2 MW
Efficiency	25 – 45 %	29 – 42 %	6 – 19 %	40 – 57 %
Capital cost ($/kW)	200 – 350	450 – 1000	6000 – 10000	3750 – 5000
O&M cost* (¢/kWh)	1.00	0.50 – 0.65	0.10 – 0.40	0.17
Technology status	Commercial	Commercial in large sizes	Commercial	Commercial scale demos

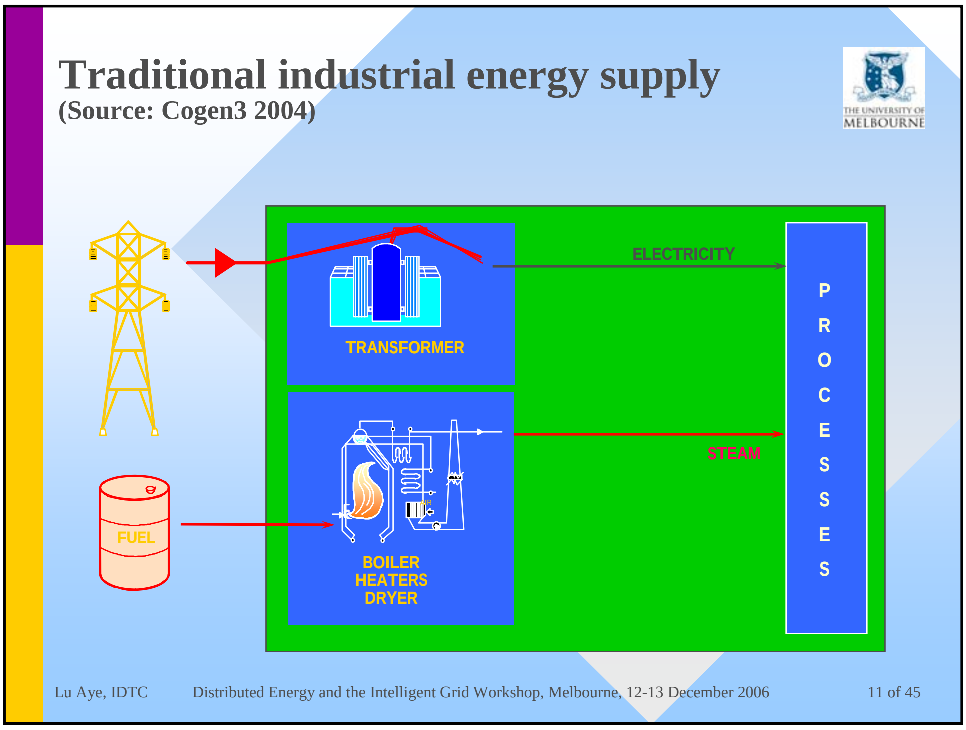
* O&M costs do not include fuel.
(*Source*: Adapted from Borbely & Kreider 2001)

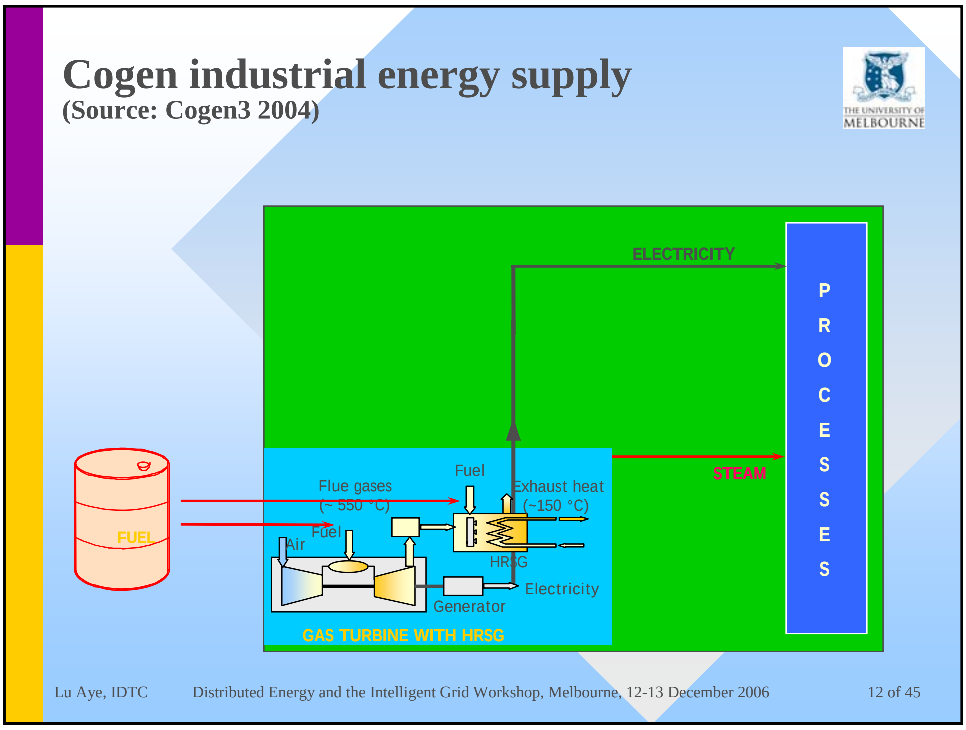
Lu Aye, IDTC Distributed Energy and the Intelligent Grid Workshop, Melbourne, 12-13 December 2006 9 of 45

Definition of "Cogeneration"

- Cogeneration is the sequential production of thermal and electric energy from a single fuel source.
- Heat is recovered that would normally be lost in the production of one form of energy.
- That heat is then used to generate the second form of energy.
- The overall fuel utilisation efficiency is typically 70-80% versus 30-40% for electric power plant.

Lu Aye, IDTC Distributed Energy and the Intelligent Grid Workshop, Melbourne, 12-13 December 2006 10 of 45


Traditional industrial energy supply
(Source: Cogen3 2004)
THE UNIVERSITY OF MELBOURNE
TRANSFORMER
ELECTRICITY
FUEL
BOILER
HEATERS
DRYER
STEAM
PROCESSES
Lu Aye, IDTC
Distributed Energy and the Intelligent Grid Workshop, Melbourne, 12-13 December 2006
11 of 45


Cogen industrial energy supply
(Source: Cogen3 2004)
THE UNIVERSITY OF MELBOURNE
ELECTRICITY
FUEL
Flue gases
(~ 550 °C)
Fuel
Exhaust heat
(~150 °C)
Air
Fuel
HRSG
Electricity
Generator
GAS TURBINE WITH HRSG
STEAM
PROCESSES
Lu Aye, IDTC
Distributed Energy and the Intelligent Grid Workshop, Melbourne, 12-13 December 2006
12 of 45

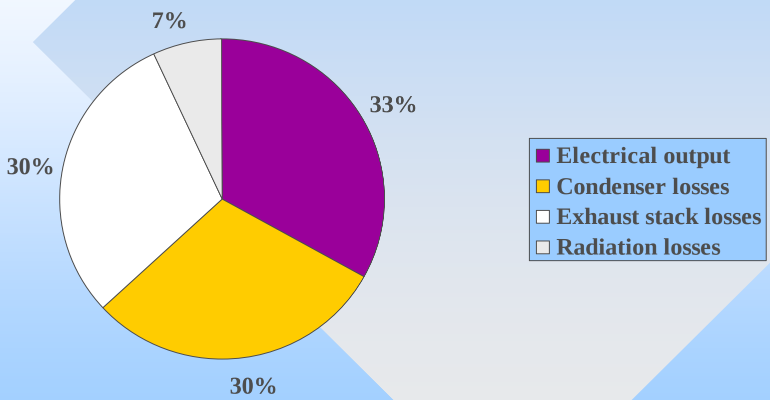
Components

- **Prime mover** produces mechanical energy through combustion.
- **Generator** converts the mechanical energy to electrical energy.
- **Waste heat recovery system** captures exhaust heat or engine coolant heat and converts that heat to a useful form.
- **Operating control systems** insure that the individual system components function together.

Types of prime mover

- Steam turbine systems
  - Consist of a boiler and turbine
  - Boiler can be fired by a variety of fuels (oil, natural gas, coal, wood, MSW, *etc*.)
- Combustion gas turbine systems
  - Made up of one or more gas turbines and a waste heat recovery unit
  - Fuelled by natural gas or light petroleum products
- Internal Combustion Engine systems
  - Utilise one or more reciprocating engines together with a waste heat recovery system
  - Fuelled by natural gas or distillate oils (petrol & diesel)

Energy balance of a typical power plant



Lu Aye, IDTC   Distributed Energy and the Intelligent Grid Workshop, Melbourne, 12-13 December 2006   15 of 45

Potential heat recovery

- 100 % of Condenser/cooling losses
- 40% of Exhaust stack losses

$$E_{in} = E_{out}$$

$$Q = E_{electricity} + E_{condenser} + E_{exhaust} + E_{radiation}$$

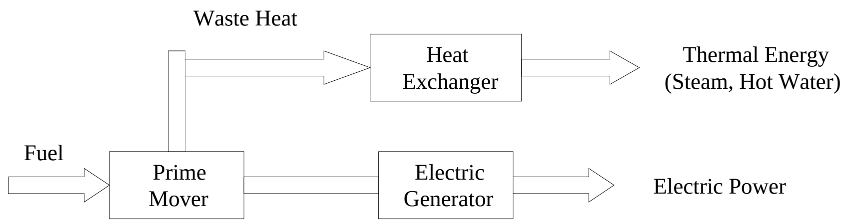
$$E_{electricity} = 0.33Q,\ E_{condenser} = 0.3Q,\ E_{exhaust} = 0.3Q$$

$$E_{available} = E_{condenser} + 0.4E_{exhaust} = 0.42Q$$

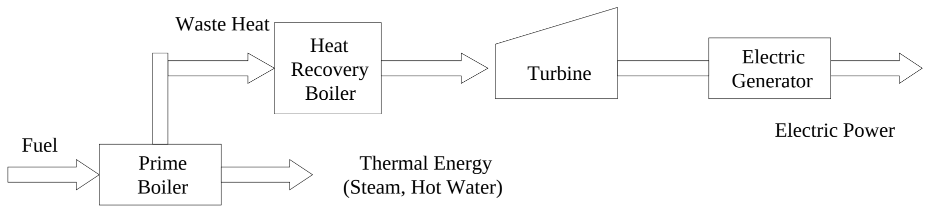
$$E_{available} = 1.273E_{electricity}$$

Lu Aye, IDTC   Distributed Energy and the Intelligent Grid Workshop, Melbourne, 12-13 December 2006   16 of 45

Topping cycle (Brayton & Rankine)



Bottoming cycle



Combined cycle

- Rankine cycle on the "topping" portion and Brayton cycle on the "bottoming" portion of the combination.
- Ideal mix of power delivered from Brayton and Rankine portions: 70 % and 30 %.
- There are many variations and options available.

Combined cycle variations

- Gas turbine exhaust is used to produce low pressure steam (200 kPa) for steam turbine with no additional fuel burnt.
- Gas turbine exhaust is used directly for a boiler (1.5-18 MPa).
- Gas turbine exhaust is fired in the duct with additional fuel for a steam turbine (6-9 MPa).

Cogeneration technologies
(*Source*: Cogen3 2004)

Steam turbines

Gas turbines

Combined cycles

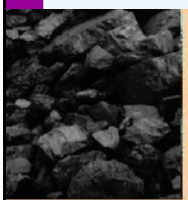
Engines (N. gas, Diesel)

Microturbines

Fuel cells

Stirling engines

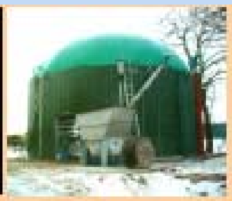
Cogeneration fuels
(*Source*: Cogen3 2004)



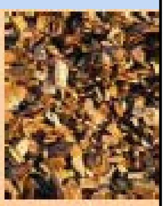
Coal

Oil

Natural Gas



Biogas



Biomass

- **Cogeneration can be done from a variety of fuels – also Municipal Solid Waste (MSW)**
- **Installations may be designed to accept more than one fuel**

Prime mover selection criteria

- Hours of operation
  - Continuous: steam turbine (ST) & gas turbine (GT)
  - Intermittent: reciprocating engines (RE)
- Maintenance requirements
  - RE: highest maintenance requirement; GT: require less frequent maintenance; ST: require less maintenance than gas turbines
- Fuel requirements
  - RE: fix fuel quality required, GT: fuel may be switched, ST: limited only by the fuel for their steam source
- Capacity limits
  - RE: 40 kW-3 MW, GT: 0.5-30 MW, ST: >1 MW

Typical energy production (%)

Output	RE Gas	RE Diesel	GT <2 MW	GT with after burner	CC G&ST	ST
Electricity	28	32	22	18	40	12
960 kPa Steam	18	21	50	66	37	0
200 kPa Steam	0	0	0	0	0	68
82°C Hot water	33	27	0	0	0	0
Waste	21	20	28	16	23	20

Environmental advantages & disadvantages

- Better fuel utilisation efficiency: 70-80% versus 30-40% for conventional electric power plant
- Need to look at from fuel life cycle point of view
- Depend on the nature of the fuel used
  - Impacts on global air pollutants
  - Impacts on local air pollutants

Microturbines

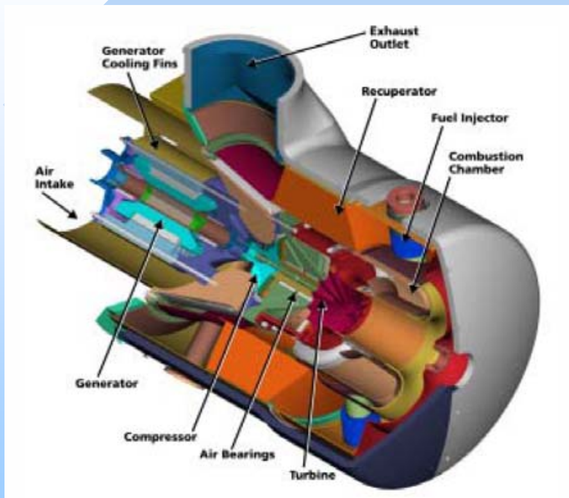
- One of the best short-term DG options
  - because of their simplicity and
  - because no major technological breakthroughs are required for their deployment.
- Capacity: 25 – 500 kWe power output
- Single-stage compressor and single-stage turbine
- Pressure ratio: 3 – 4 (Conventional: 13 – 15)
- Rotor: short drive shaft with generator on one end with a bearing in the middle

Discussion

- Roles of cogeneration

Capestone microturbine

(*Source*: Gillette 2006)

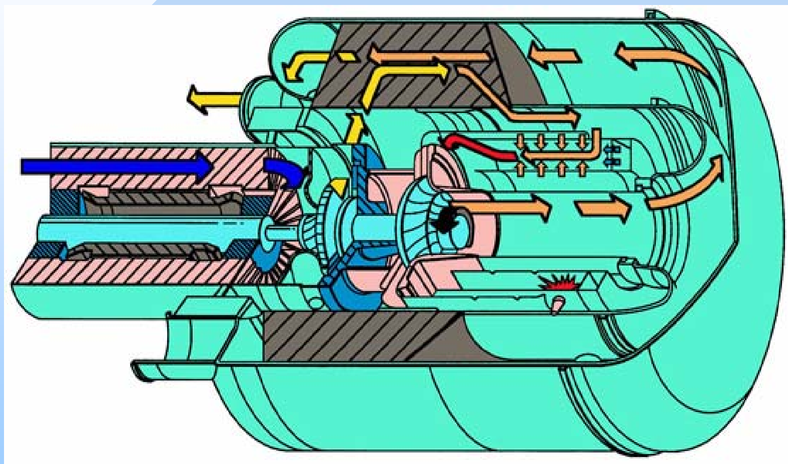


Example microturbine specifications

Manufacturer	N krev/min	Power kW_e	Efficiency %(LHV basis)	Recuperated
Capstone	30	96	28	Yes
Honeywell	75	75	30	Yes
Elliott	116	45	17	No
(*Source*: Rodgers *et al*. 2001)				

Recuperated microturbine

(Source: http://www.grc.nasa.gov/WWW/RT2002/5000/5960weaver.html)



MT overview

Fuel	Natural gas, hydrogen, propane, diesel
Efficiency	15 % (unrecuperated) 20 – 30% (recuperated) up to 85 % (with heat recovery)
Cost ($/kW)	700 – 1100 (+ 75 – 350 with heat recovery)
O & M costs (¢/kWh)	0.5 – 1.6
NO_x	< 9 – 50 ppm
Other features	Cogen (50 – 80°C water)
Commercial status	Small volume production, commercial prototypes now
(*Source*: CEC 2006)	

PV background

- Photovoltaics generate electricity without no moving parts from the renewable source of sunlight.
- Can be installed on or at the building.
- PV modules are well proven with an expected service life of at least 30 years.
- It is a modular technology, viable and cost effective option in many stand alone applications.

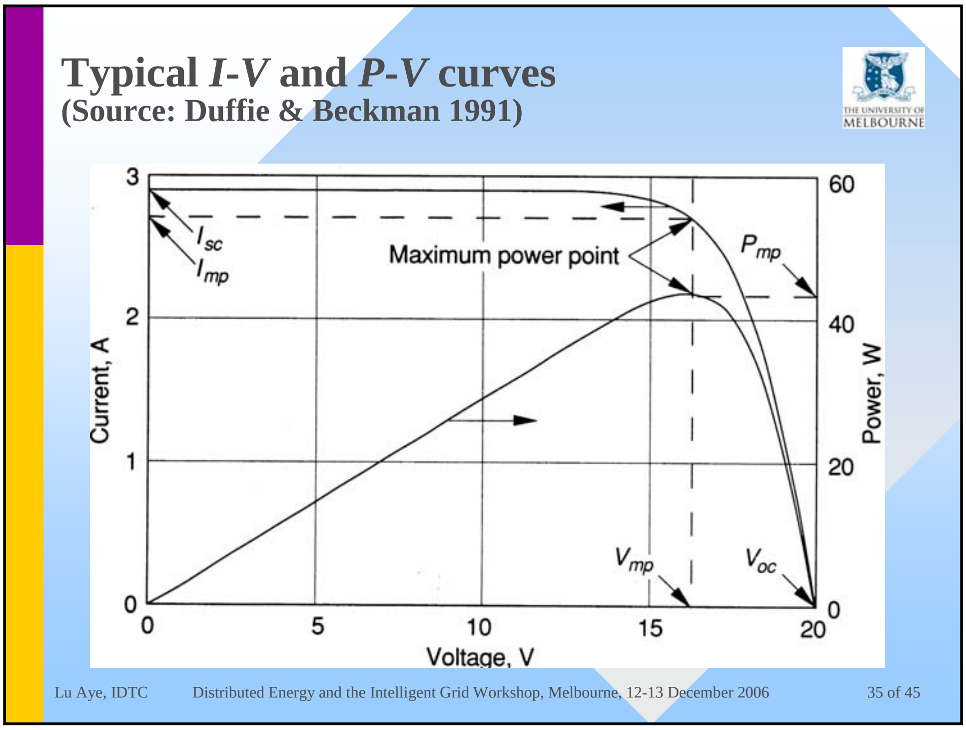
Typical cell, module & array

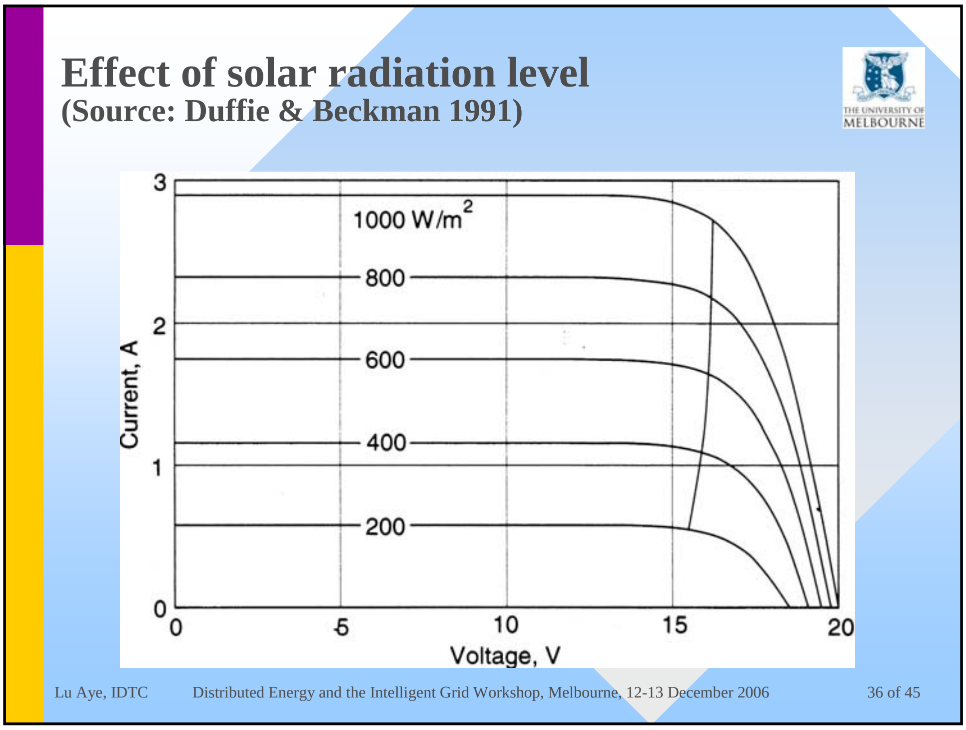
- A typical crystalline silicon solar cell is 100 cm^2 and produces about 1.75 peak watts (Wp) at 0.5V & 3.5A under full sun at standard test conditions (STC: AM 1.5, 1 kW/m^2 and 25ºC cell temperature).
- Modules are typically available in ratings from less than 50 Wp to greater than 250 Wp.
- Crystalline silicon modules deliver approximately 100-120 W/m^2 at STC.
- Amorphous silicon (a-Si) thin-film modules deliver 40-50 W/m^2 at STC.

Efficiency records

Classification	Theo (%)	Cell (%)	Module (%)
Si (crystalline) UNSW PERL (3/99)	29	24.7 ± 0.5	22.7 ± 0.6
Si (multicrystalline) UNSW/Eurosolare (2/98)	27	19.8 ± 0.5	15.3 ± 0.4
CdTe NREL, on glass (9/01)	31	16.5 ± 0.5	10.7 ± 0.5

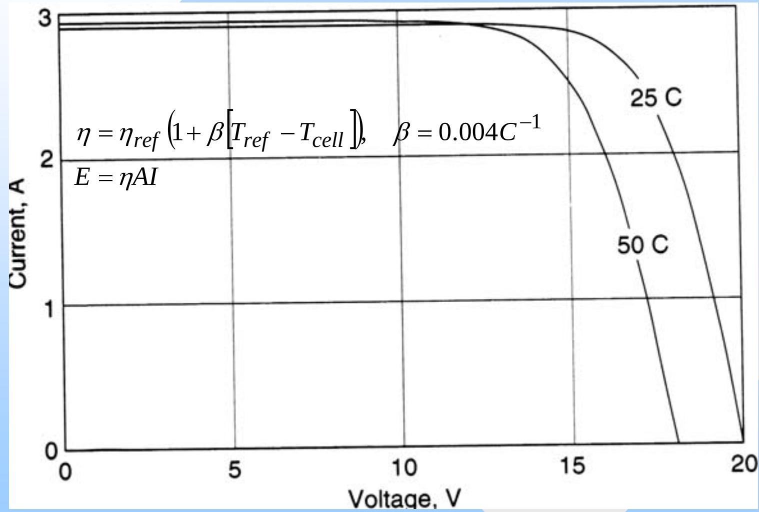
Source: Green *et al*. 2003, Prog. Photovolt: Res. Appl. 11:347-52


Typical I-V and P-V curves
(Source: Duffie & Beckman 1991)
THE UNIVERSITY OF MELBOURNE
3
2
1
0
Current, A
0
5
10
15
20
Voltage, V
60
40
20
0
Power, W
I_{sc}
I_{mp}
Maximum power point
P_{mp}
V_{mp}
V_{oc}
Lu Aye, IDTC
Distributed Energy and the Intelligent Grid Workshop, Melbourne, 12-13 December 2006
35 of 45


Effect of solar radiation level
(Source: Duffie & Beckman 1991)
THE UNIVERSITY OF MELBOURNE
3
2
1
0
Current, A
1000 W/m^2
800
600
400
200
0
5
10
15
20
Voltage, V
Lu Aye, IDTC
Distributed Energy and the Intelligent Grid Workshop, Melbourne, 12-13 December 2006
36 of 45

Effect of temperature

(*Source*: Duffie & Beckman 1991)



Lu Aye, IDTC Distributed Energy and the Intelligent Grid Workshop, Melbourne, 12-13 December 2006 37 of 45

Life cycle emission factors (g/kWh)

Energy Source	SO_x	NO_x	CO_2	Energy input (kWh/W installed)
Coal	3.400	1.800	322.8	12
Oil	1.700	0.880	258.5	18
Natural Gas	0.001	0.900	178.0	6
Nuclear	0.030	0.003	7.8	4
Photovoltaic	0.020	0.007	5.3	2

(*Source*: NREL 2001)

Lu Aye, IDTC Distributed Energy and the Intelligent Grid Workshop, Melbourne, 12-13 December 2006 38 of 45

Gas engines overview

Methane content (%)	30 – 90 Landfill to natural gas
Efficiency (%)	37 – 40
CO (mg/Nm^3)	25 – 45
NMHC (mg/Nm^3)	37 – 58
NO_x (mg/Nm^3)	250 – 500
(*Source*: Hüchtebrock, B 2003)	

Status of DG technologies

	IC Engine	Turbines	PVs	Fuel Cells
Capacity	50 kW – 5 MW	25 kW – 25 MW	1 kW – 1 MW	200 kW – 2 MW
Efficiency	25 – 45 %	29 – 42 %	6 – 19 %	40 – 57 %
Capital cost ($/kW)	200 – 350	450 – 1000	6000 – 10000	3750 – 5000
O&M cost* (¢/kWh)	1.00	0.50 – 0.65	0.10 – 0.40	0.17
Technology status	Commercial	Commercial in large sizes	Commercial	Commercial scale demos

* O&M costs do not include fuel.
(*Source*: Adapted from Borbely & Kreider 2001)

Discussion

- Roles of DG technologies
  - Gas engines
  - Microturbines
  - PV

Conclusion

- MT: fuel, ambient condition, load
- PV: solar radiation, cell temperature
- GE: fuel, load

References

ACA 1997, *Profiting from Cogeneration*, Australian Cogeneration Association.

Borbely, A-M & Kreider, JF 2001, 'Distributed generation: An introduction', in Distributed Generation The Power Paradigm for the New Millennium, Eds A-M Borbely & JF Kreider, CRC Press.

CEC 2006, *California Energy Resource Guide*, California Energy Comission

Cogen 3 2004, EC-ASEAN COGEN Programme Phase 3 Workshop, AIT, Bangkok, 13 January.

Duffie JA & Beckman WA 1991, *Solar Engineering of Thermal Processes*, 2nd Ed, John Wiley & Sons, Inc.

Fung, PYH; Kirschbaum, MUF; Raison, RJ & Stucley, C 2002, 'The potential for bioenergy production from Australian forests, its contribution to national greenhouse targets and recent developments in conversion processes' *Biomass and Bioenergy*, 22 (4) 223-236.

Gillette 2006, 'CHP case studies – Saving money and increasing security' http://www.capstoneturbine.com/_docs/WCEMC04.pdf.

Hüchtebrock, B 2003, Stationary gas engine development trends, CHAPNET Workshop, Brussels, 16. September 2003.

NREL 2001, *Solar Electric Power – The U.S. Photovoltaic Industry Roadmap*, National Renewable Energy Laboratory

Rodgers, C; Watts, J; Thoren, D; Nichols, K & Brent, R 2001 'Microturbines', in Distributed Generation The Power Paradigm for the New Millennium, Eds A-M Borbely & JF Kreider, CRC Press.

Wikipedia 2006, http://en.wikipedia.org/wiki/Distributed_generation.

Acknowledgements

I wish to thank:

- Dr Martin Cope and Dr Tom Beer, CSIRO Energy Transformed Flagship for inviting me to give this talk
- Ms Fiorella Chiodo, IDTC for providing administrative assistance

Thank you!

For more information contact:

Lu Aye
International Technologies Centre (IDTC)
Department of Civil & Environmental Engineering
The University of Melbourne
Vic 3010

lua@unimelb.edu.au