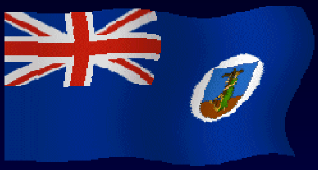


Geothermal and the Hydrogen Economy - a perspective from Montserrat

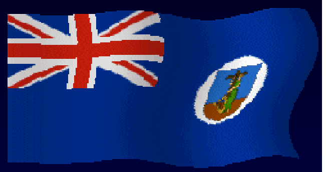
Thomas Yeung
Montserrat Utilities Ltd

28/29 September 2006

A presentation for the UNDESA/Govt of Iceland International Seminar on the Hydrogen Economy for Sustainable Development

Reykjavik, Iceland

Agenda



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- Guadeloupe – a case study?
- Summary and key messages

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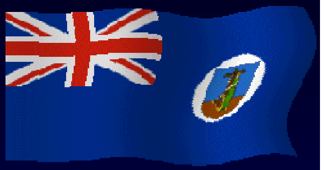

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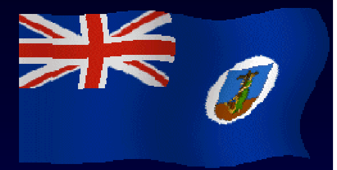
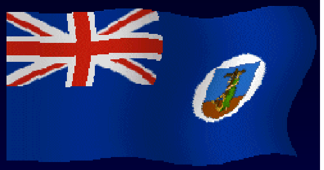
Montserrat is a small island in the Caribbean, and a British Overseas Territory

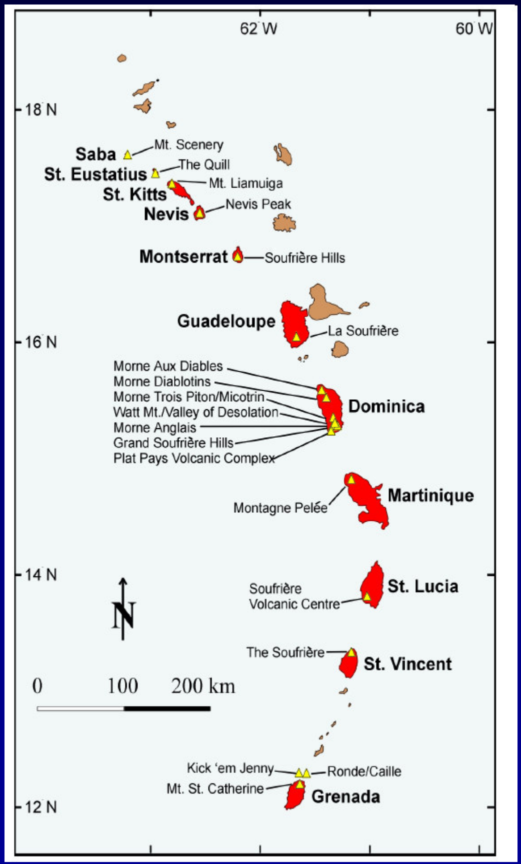


Map reproduced courtesy of www.maps.com

Geologically, it is located on the boundary between the Atlantic and Caribbean plates



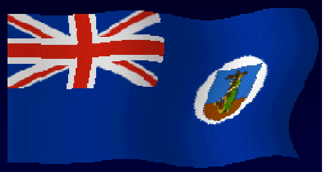
- Montserrat's volcano is only one of a chain of volcanoes along the boundary
- Most of these volcanoes are dormant or relatively quiet – but unfortunately <u>not</u> the one on Montserrat
- Since records started in 1635[1], the volcano has been active in 1897/98, 1933/37, and 1966/67 . . .



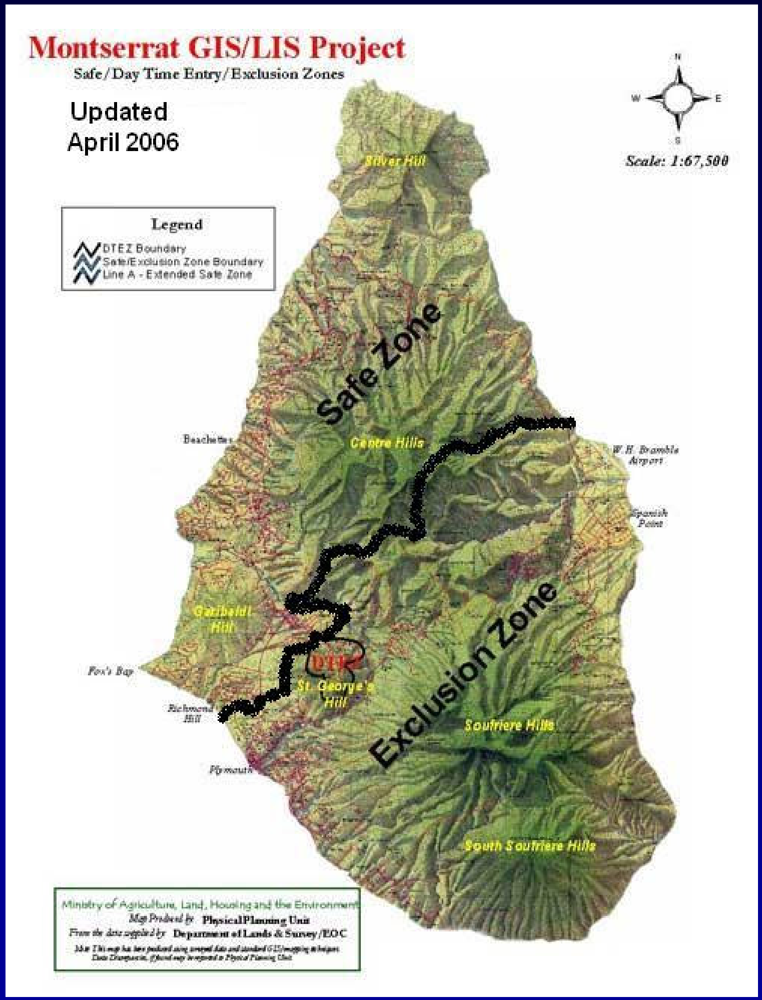
Map reproduced courtesy of ADEME (Guadeloupe) Mar06

1: Fergus (1994), Robson and Tomblin (1966); Wadge and Isaacs (1988); Perret (1939); Shepherd et al. (1971)
All dates taken from Roobol & Smith – www.caribbeanvolcanoes.com

In 1995, the volcano 'woke up' again, resulting in large-scale population migration

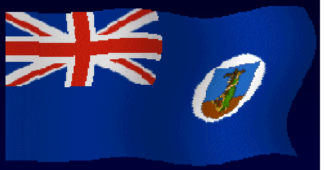


- Between 1995 and 1997, it covered the southern half of the island with several metres of ash and debris, making it uninhabitable – the 'Exclusion Zone'
- Two thirds of the people left the island – the remaining 4,800 are now based in the 'Safe Zone'
- All of the infrastructure has had to be rebuilt – roads, houses, schools, hospitals etc.



Map reproduced courtesy of the Montserrat Volcano Observatory (www.mvo.ms)

Currently, electricity is produced from four diesel units based at Brades Power Station

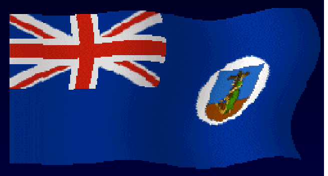


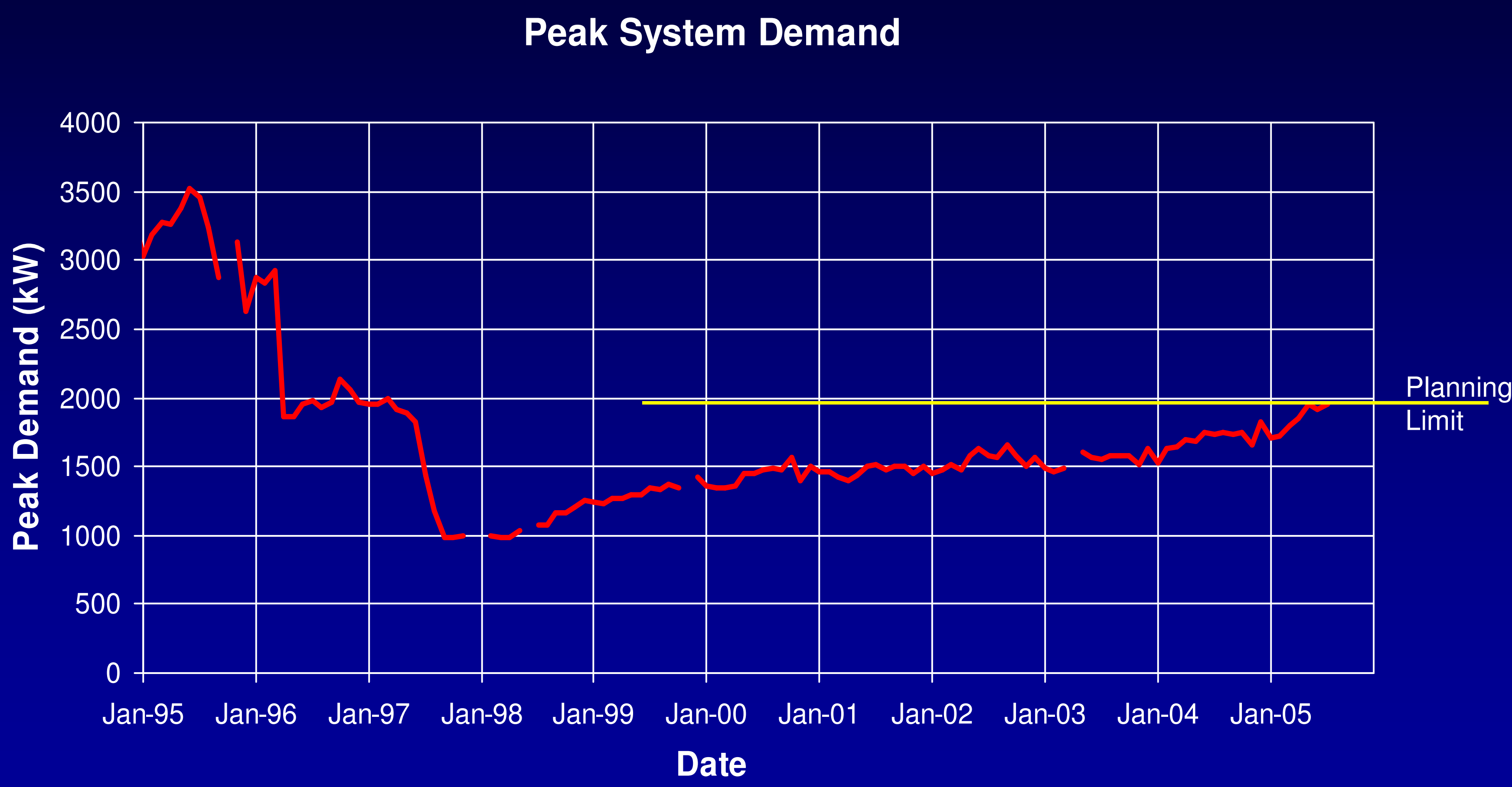
Location of Power Station:

- Plymouth (GTR) - closed in 1997
- Temporary station in Salem
- Moved to Brades in 1998 – 2000

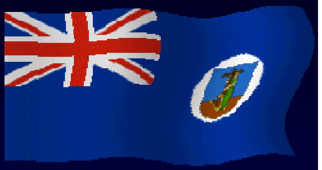
- All mechanical plant requires periodic shut-downs for maintenance – ‘scheduled outages’
- No mechanical plant is immune to failure – so there are occasional ‘unscheduled outages’
- ‘Best Practice’ generation planning is that sufficient capacity is available such that demand can be met even if the two largest units are unavailable

Peak system demand is increasing, and is rapidly approaching the planning limit





Two of the current units are approaching the end of their design life

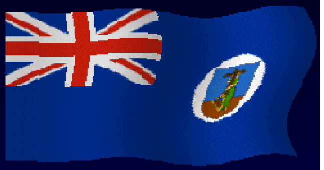


Unit No	1	2	2B	3	3B	4	4B
Installed	1996	1996	2000	1999	2004	2001	2003
Retired?		2000		2004		2003	
Max operating capacity	1000kW	-	900kW	-	1000kW	-	1250kW

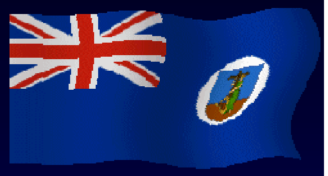
- Two units (units 1 & 2) were relocated from the Salem site
- Two further units were added, in 1999 and 2001
- All are ‘high speed’ (1800 rpm) units, which require more maintenance than low-speed stationary units like the ones installed at GTR [2]
- ‘This type of high speed generating set has a life of approximately 10 years provided the recommended maintenance is carried out’ [3]

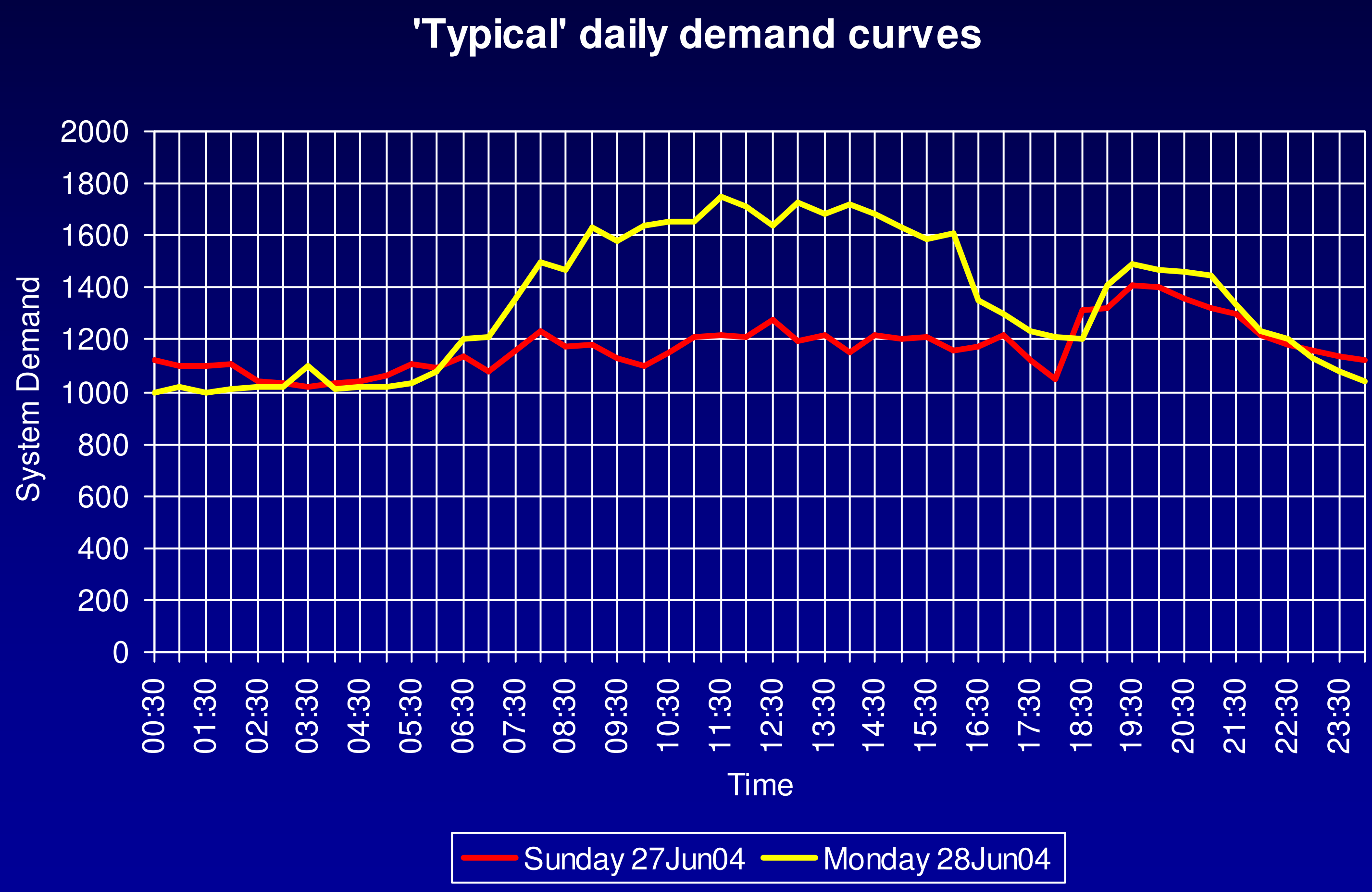
[2, 3] Mott McDonald Power System Study - 2004

Total monthly consumption has risen steadily since 2001



Consumption is greatest during working hours and there is a secondary evening peak





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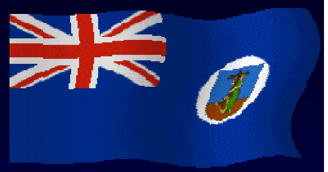

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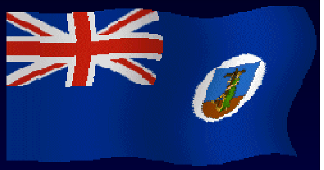
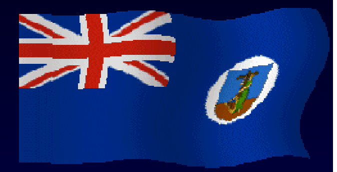
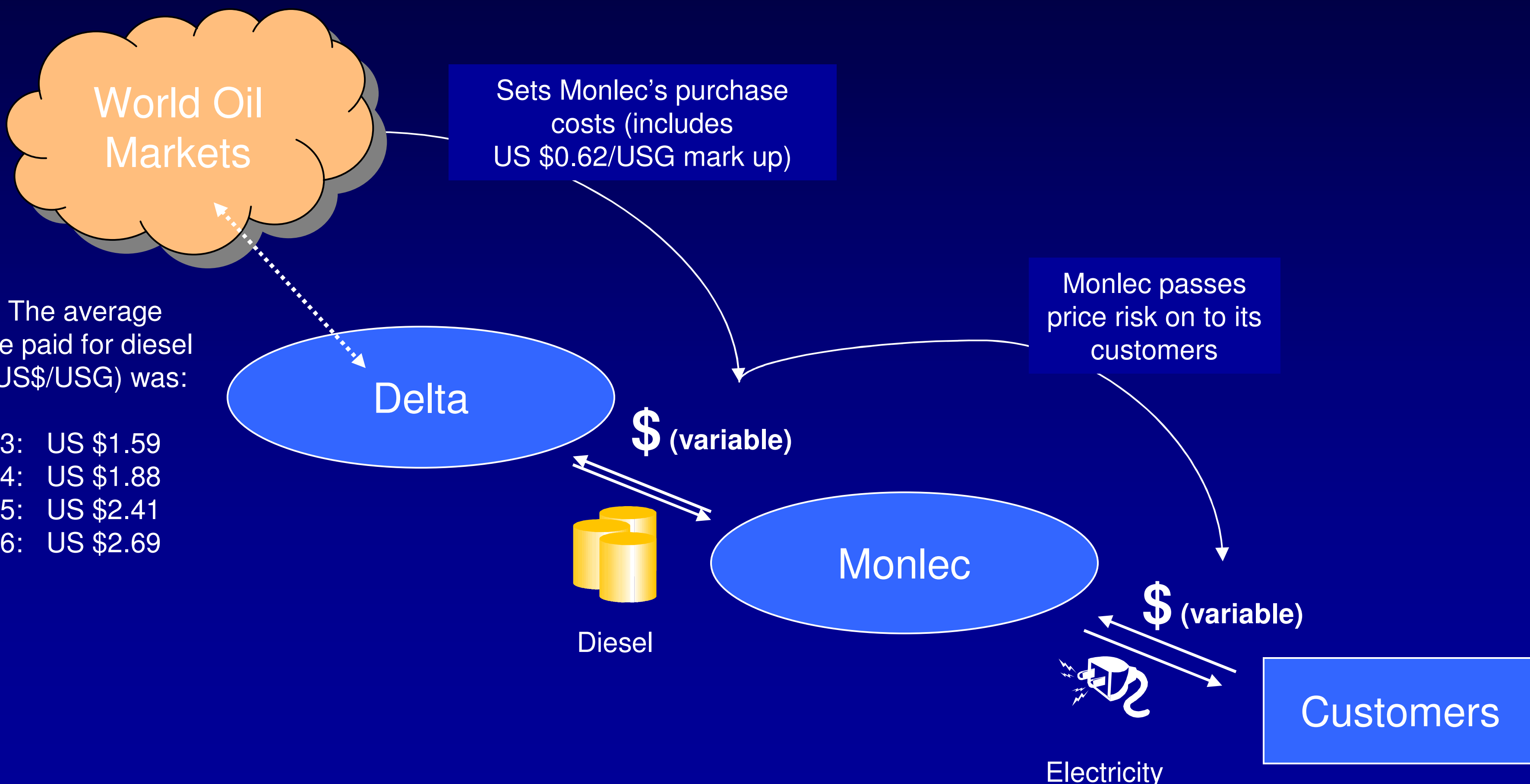
The price of electricity depends upon world oil prices, and is expected to remain high



- Customers pay a two-part tariff – a ‘Basic Price’, plus a ‘Fuel Surcharge’
- The Basic Price is intended to recover all operational costs (generation, transmission & distribution, administration and customer service) as well as provide revenue for further investment. It has remained at its current level since Feb 2001
- The Fuel Surcharge was introduced to protect Monlec from changes in the price of fuel – through it, the cost of diesel (excluding a very small amount already included in the Basic Price) is passed on to customers. It changes every month.
- There is no standing charge
- Current tariffs (Basic Price) (all US$):
  - Domestic – 18 ¢/kWh for first 75 units, 20 ¢/kWh thereafter
  - Commercial – 20 ¢/kWh
  - Industrial – 17 ¢/kWh

Currently, all diesel for generation is supplied by Delta on a ten-year contract signed in 2002

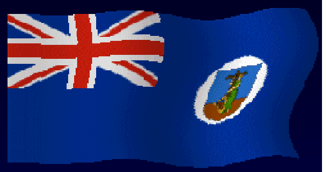


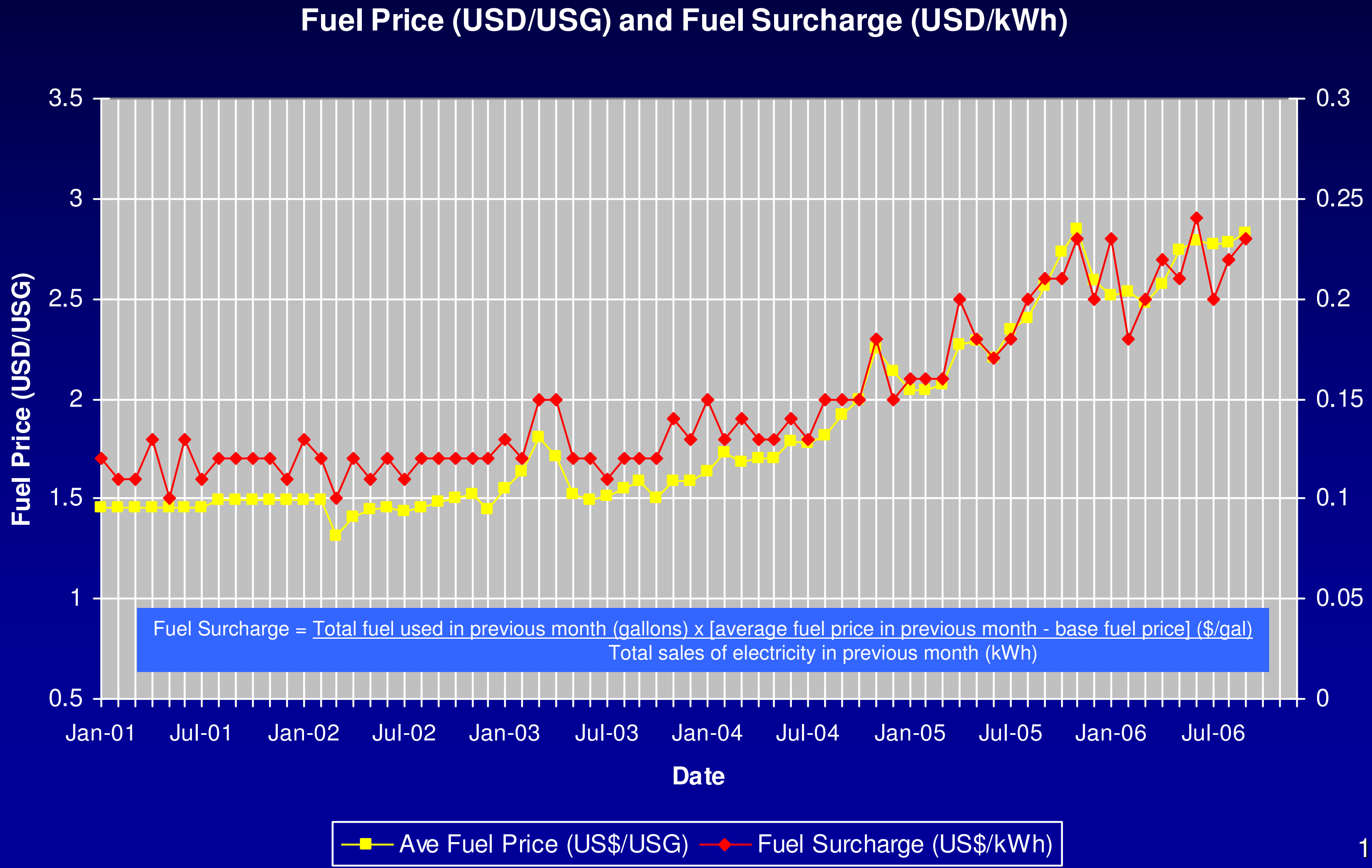


NB. The average price paid for diesel (in US$/USG) was:

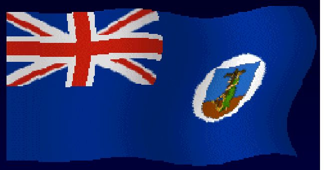
2003: US $1.59
2004: US $1.88
2005: US $2.41
2006: US $2.69

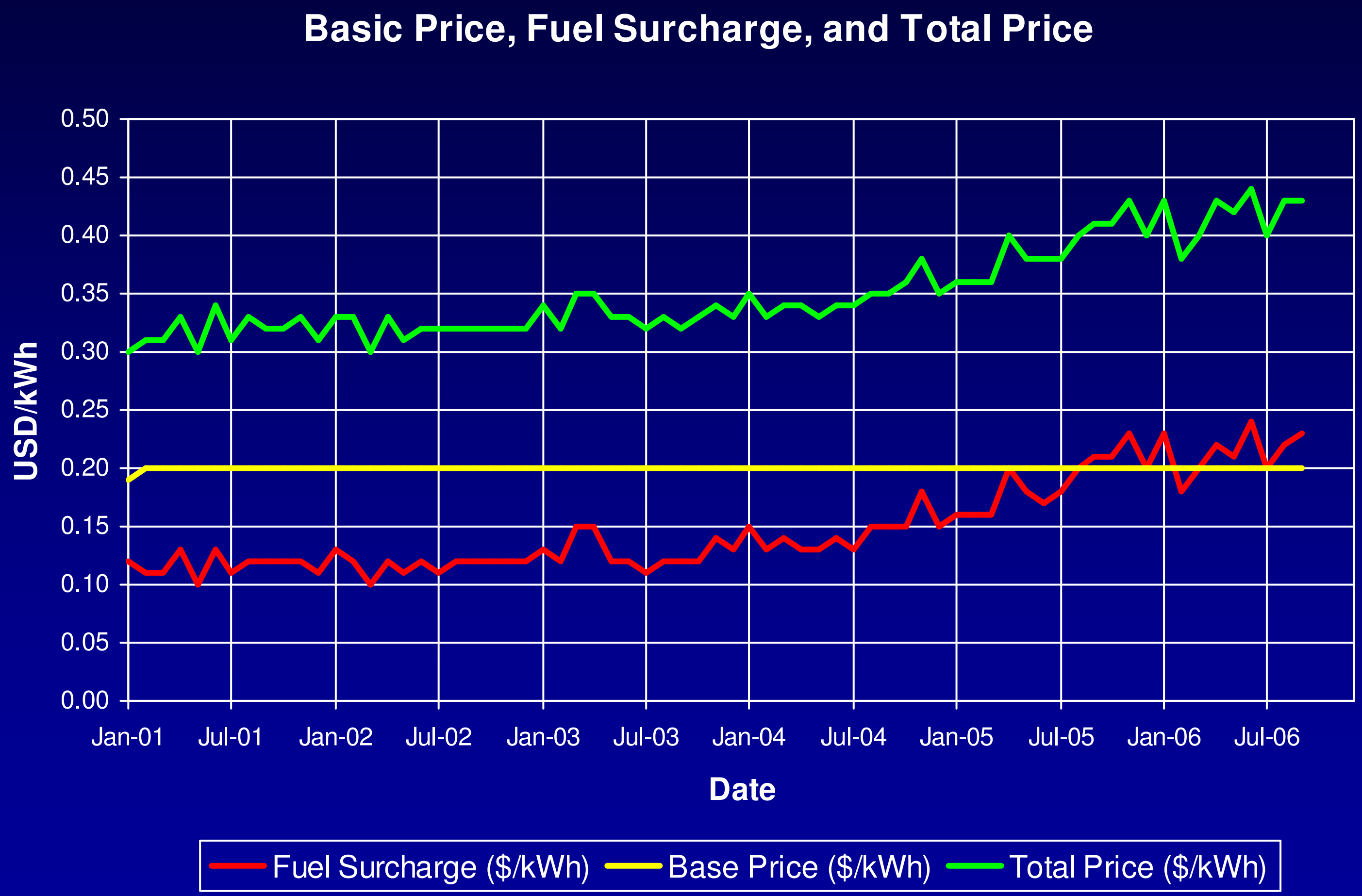
Each month, Monlec calculates the Fuel Surcharge based on its fuel purchase costs



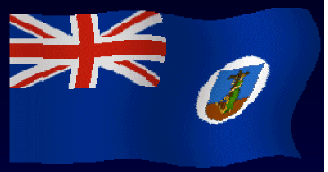


Total electricity price (Basic Price plus Fuel Surcharge) is high and is likely to remain so



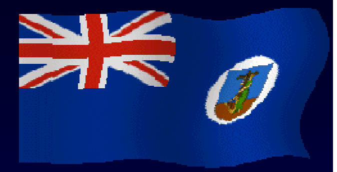


Montserrat's dependence on imported diesel, from a single supplier, leaves it exposed . . .



- What happens if fuel prices continue to rise?
  - Price paid to Delta would rise
  - Fuel Surcharge would rise to recover this cost
  - Customers' bills would rise as a result
- What happens if supply is disrupted? (e.g. landing or storage facilities destroyed by hurricane, industrial action at Delta or the port, etc.)
  - Monlec has only a limited fuel storage capacity
  - Alternative arrangements will be made for alternative supplies, but these may be insufficient to meet demand or may take time to set in place
  - Monlec may be forced to reduce electricity production – rolling black outs and loss of supply is possible

Increasing international focus on Climate Change is both a threat and an opportunity



- The United Nations Framework Convention on Climate Change[1] (UNFCCC) was signed in 1992 by the UK
- This was followed by the Kyoto protocol[2] in 1997, committing signatories to reductions in greenhouse gas emissions. The UK was one of these, and Montserrat will be covered under that agreement
- Many countries are actively looking for ways to reduce CO2 emissions, and there are now international markets in 'carbon credits' – tradable, verifiable reductions in CO2 that result from changes in energy use or production.
- As a small island, Montserrat produces little CO2 itself – but it has the potential (through geothermal) to support other countries in their efforts – and to be recompensed accordingly

1: http://unfccc.int/essential_background/convention/items/2627.php
2: http://unfccc.int/essential_background/kyoto_protocol/items/2830.php

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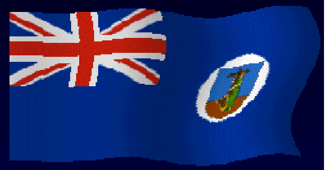

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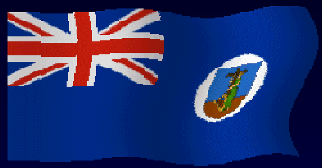
Potentially, there are many ways of generating electricity other than burning diesel . . .



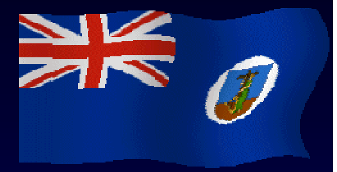
Wind

Solar PV

Hydro

Geothermal

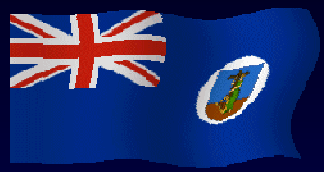
Wind energy is well proven around the world, and can be cost effective



- Over 13,000 MW is already installed world wide[1]
- Installed capacity has doubled every three years since 1990[2]
- Each doubling has been accompanied by a 15% reduction in the price of wind turbines (US$/kW) – but smaller machines are proportionately more expensive
  - Current (Sept 2004) capital costs for small machines (less than 200kW) range from 1100 US$/kW for a 120kW machine, to 1500 US$/kW for a 50kW machine.
  - Operating costs range from 25US$/kW pa for 250kW machines to around $13US$/kW pa for a 1.5 MW machine
  - Overall generation costs depend on wind speed, cost of capital, and economic life of the turbines – European experience in small turbines suggests 8 US¢/kWh at 7.5m/s[3]

1 World Energy Council website: www.worldenergy.org
2 David Milborrow, WREN International Seminar, 2004
3 Gipe, P. 'Wind Power' published by James & James Ltd. 2004

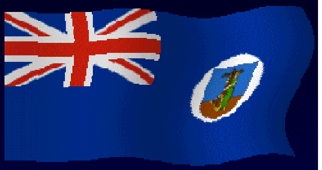
Montserrat has direct experience of building, installing, and operating wind turbines



- May 1982 – Wind Resource Assessment completed
- Nov 1986 – BEI are appointed to advise on wind projects
- May 1987 – 80kW ESI wind turbine installed at St Georges Hill East
- Dec 1987 – 27 manufacturers invited to tender
- Jun 1989 – Second turbine installed – a 100kW Vestas V20
- Sep 1989 – Both turbines destroyed by Hurricane Hugo
- Jun 1991 – Two new 100kW Vestas machines commissioned

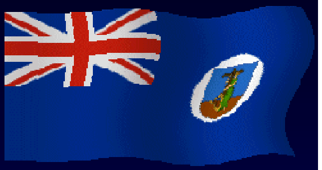
- The turbines were shut down after major volcanic activity in 1997, and have not operated since. They are currently in a state of disrepair and may not be recoverable

Large-scale hydro schemes are not feasible on Montserrat



- There are two forms of hydro generation: storage-based (dams and reservoirs) and run-of-river based
- The amount of energy available depends upon the vertical distance the water can fall (the ‘’head’) and the volume of water available
- Network-scale hydro generation (1MW and above) would require the movement or storage of large quantities of water, and this would almost certainly have major environmental implications
- Small hydro (less than 1MW) generation can and has been used in the past on Montserrat to meet specific local needs
  - for example, at Waterworks local electricity requirements were met from a small hydro generator

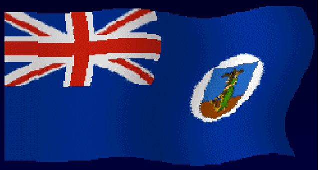
Solar water heating makes economic sense - and PV is useful in some situations



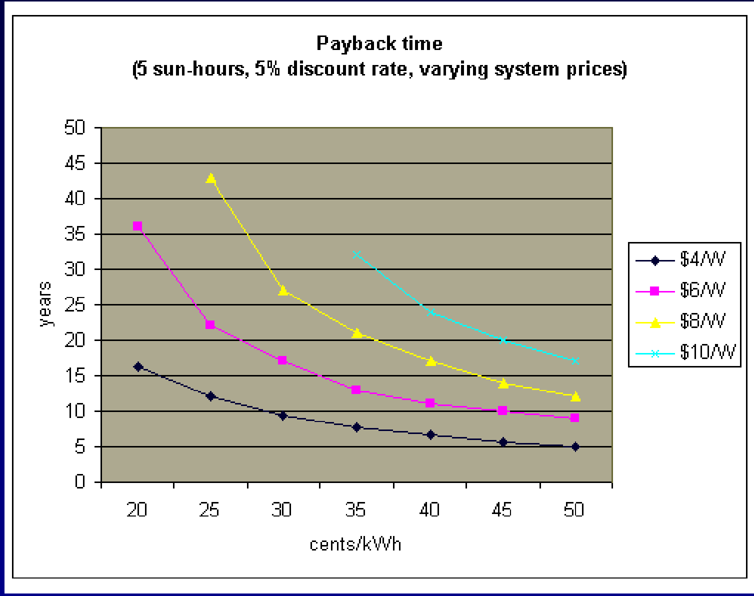
- Solar energy can be captured in two ways – solar thermal (where the sun's energy is used directly for hot water, etc.) and solar photo-voltaic (where the sun's energy is converted into electricity and stored in a battery)
- Solar thermal (for water heating) generally saves money and energy – if correctly sized and oriented, domestic-scale solar water heaters can provide all the hot water for a household with no requirement for electricity
- On a network scale, solar PV is still expensive to buy – capital costs for just the cells themselves are around 5000 US$/kW [1] but maintenance costs are very low and fuel costs nothing. This compares with an installed capital cost of around 1000 US$/kW for conventional plant [2]
- PV is most useful as distributed generation (for remote communities) and for applications such as radio repeaters, signage etc.

1: http://www.solarbuzz.com/Consumer/Payback.htm
2: http://www.cat.com/cda/layout?m=37480&x=7&location=drop

Some individuals may choose to use PV in their home – but for non-economic reasons

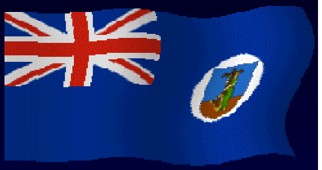


- A solar PV system comprises solar panels, batteries, an inverter, and a controller
- A domestic system would cost approx USD $16000 (based on a 2kW peak system) to buy and install
- In a sunny country such as Montserrat, where electricity costs around 40 US¢/kWh, the payback period would be approximately 15 years
- If an individual chooses to invest in solar, they should not be prevented from doing so



(All figures in US dollars)

Geothermal is a real possibility on several islands in the Caribbean region



- Geo-Caraibes (sponsored by OAS and GEF), are working with St Lucia, Dominica, St Kitts & Nevis [1]
  - Legislative frameworks
  - Resource analyses
  - Other enablers (but NOT drilling)
- Other islands believed to have potential include St Vincent, Grenada, Saba, Martinique and Statia [2]
- Guadeloupe already has geothermal plant in operation, and is currently expanding production
- Montserrat?? We'll see . . . .

1: http://www.oas.org/main/main.asp?sLang=E&sLink=http://www.oas.org/dsd
2: 'Geothermal Small Power Opportunities in the Leeward Islands' – Huttrer, 1999

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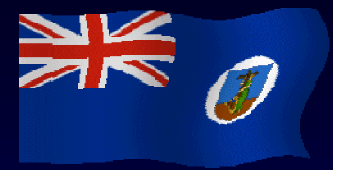

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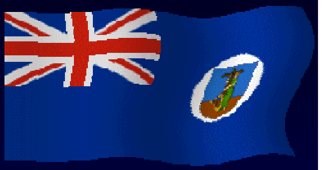
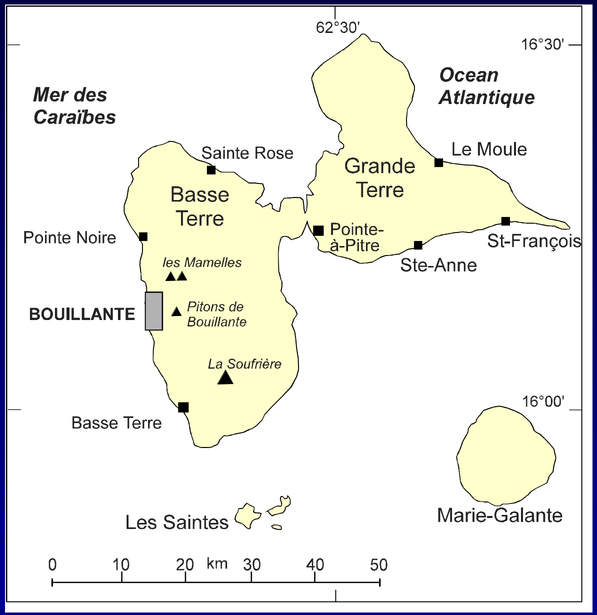
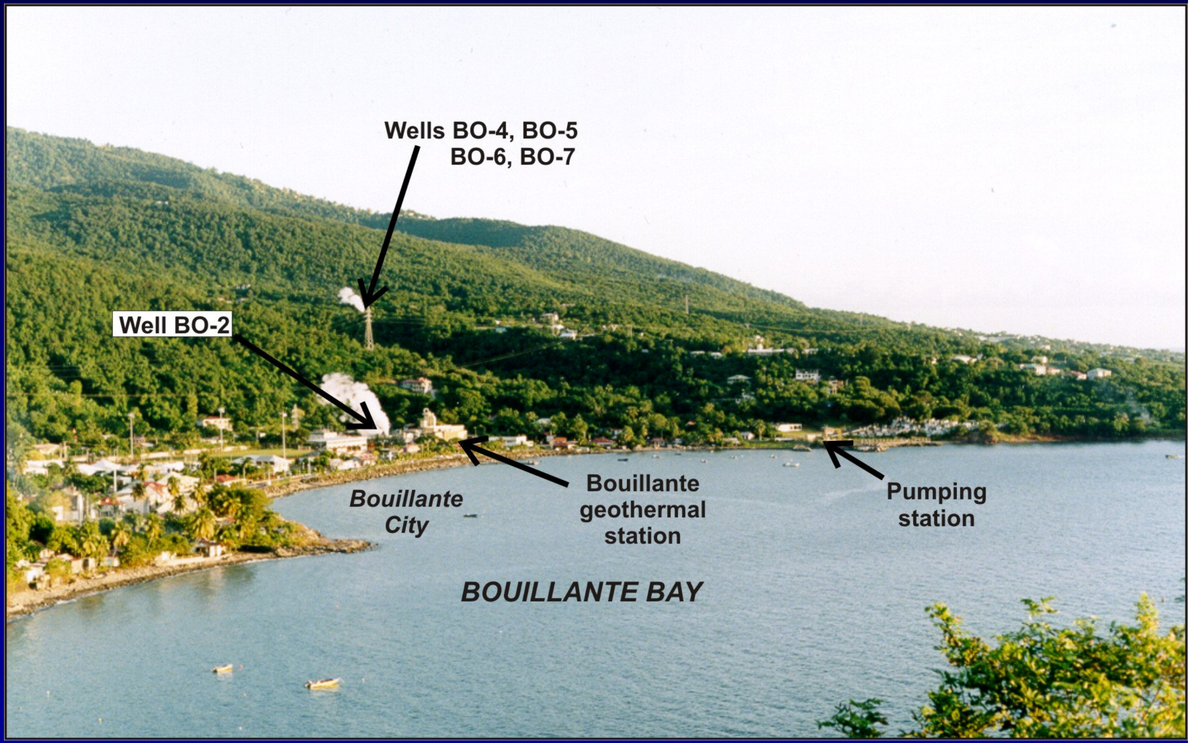
Experience from Guadeloupe – the only operational geothermal plant in the Caribbean



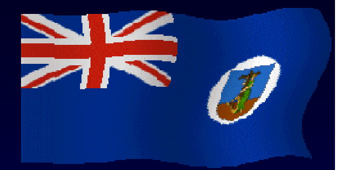


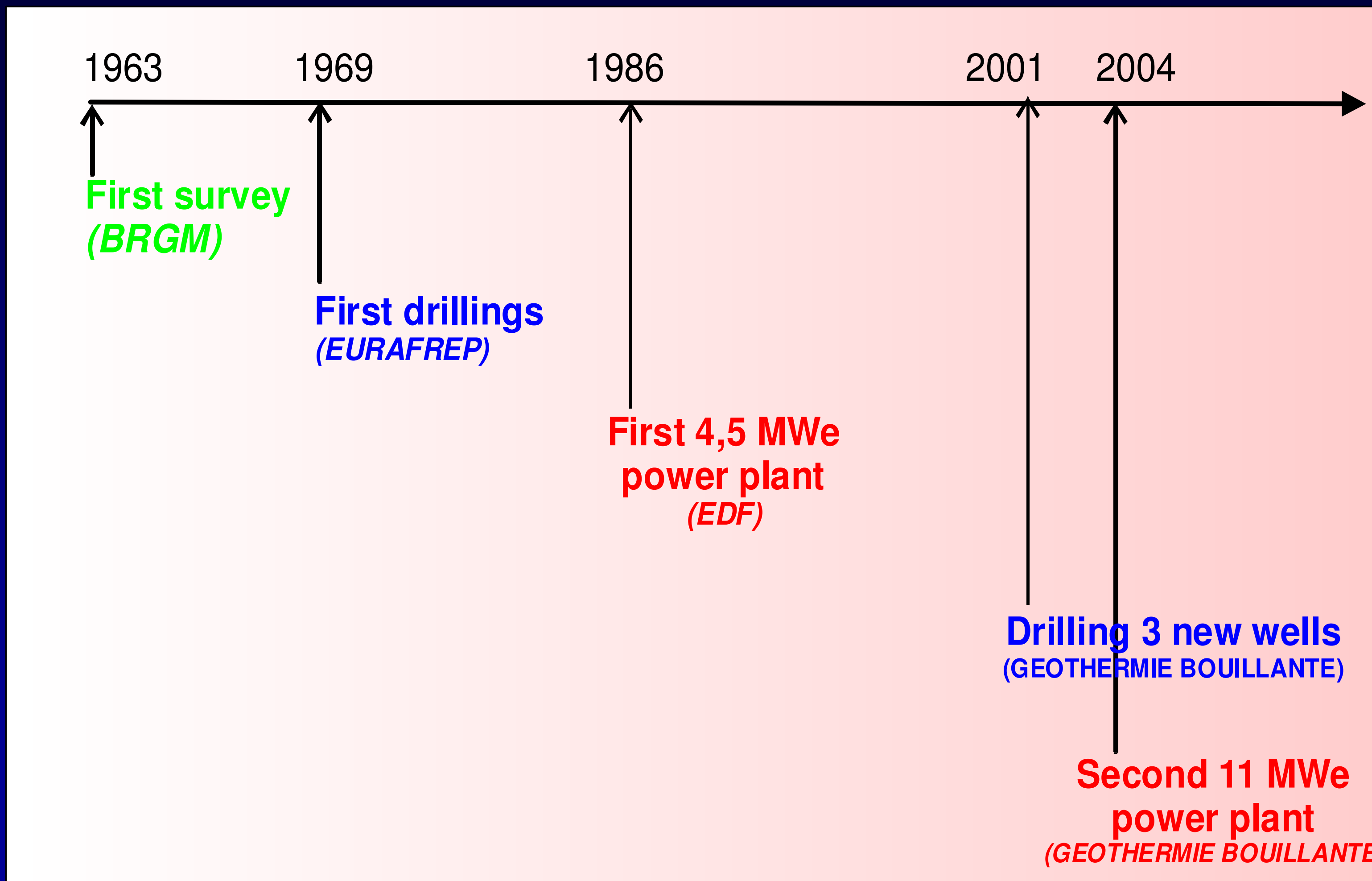


Key challenges include:
Urban area
Steep topography
Sea proximity

All Guadeloupe slides courtesy of Jules Cairo, Geothermie Bouillante SA

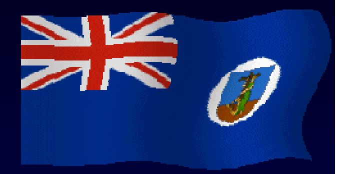
Development timeline





All Guadeloupe slides courtesy of Jules Cairo, Geothermie Bouillante SA

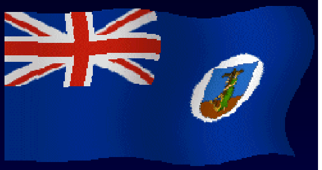
Drilling results at Bouillante

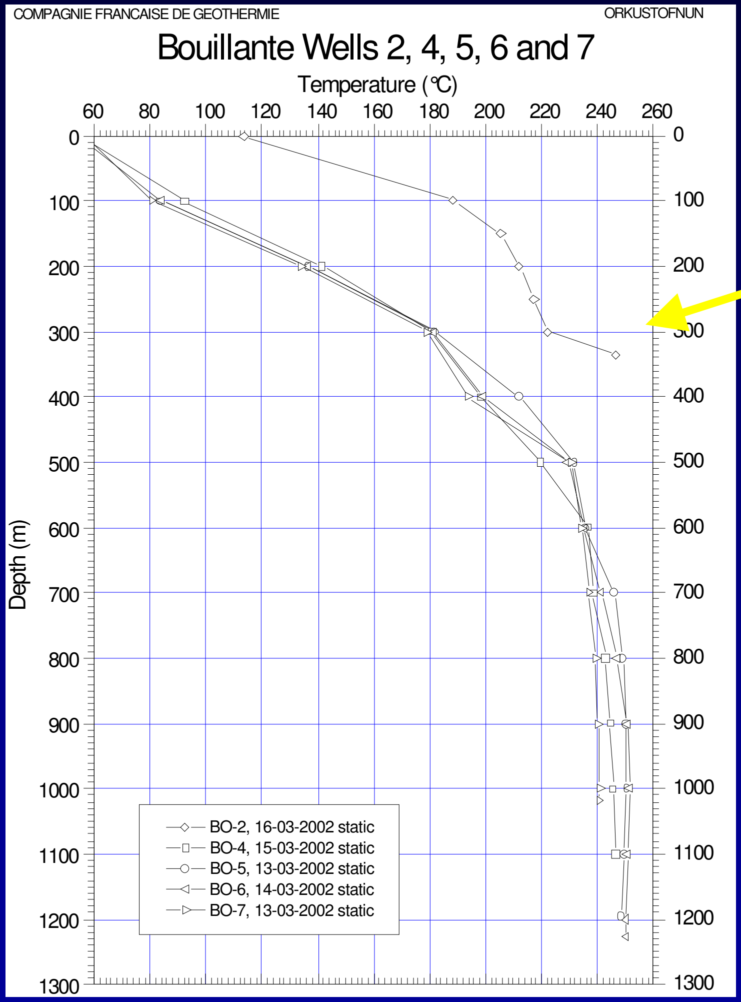


Well	Year	Trajectory	Total length (m)	Bottom hole temp (℃)	Result
BO – 1	1969	Vertical	850	(225)	No HP production
BO – 2	1970	Vertical	350	245-250	Producer
BO – 3	1970	Vertical	850	(245)	No HP production
BO – 4	1974 – 77	Vertical	2 500	250	Low producer *(Stimulation needed)*
BO – 5	2001	Deviated	1 197	250	Good producer
BO – 6	2001	Deviated	1 248	250	Good producer
BO – 7	2001	Deviated	1 400	240	No HP production

All Guadeloupe slides courtesy of Jules Cairo, Geothermie Bouillante SA

Temperature profiles for the Bouillante wells





240°C at shallow level (well BO-2)

Reservoir temperature around 250°C

All Guadeloupe slides courtesy of Jules Cairo, Geothermie Bouillante SA

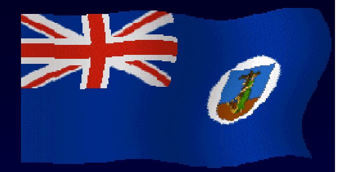
Aerial view of the geothermal plant located within the city

Bouillante 1:
4.7MW

Bouillante 2:
11MW

All Guadeloupe slides courtesy of Jules Cairo, Geothermie Bouillante SA

Commercial and operational performance

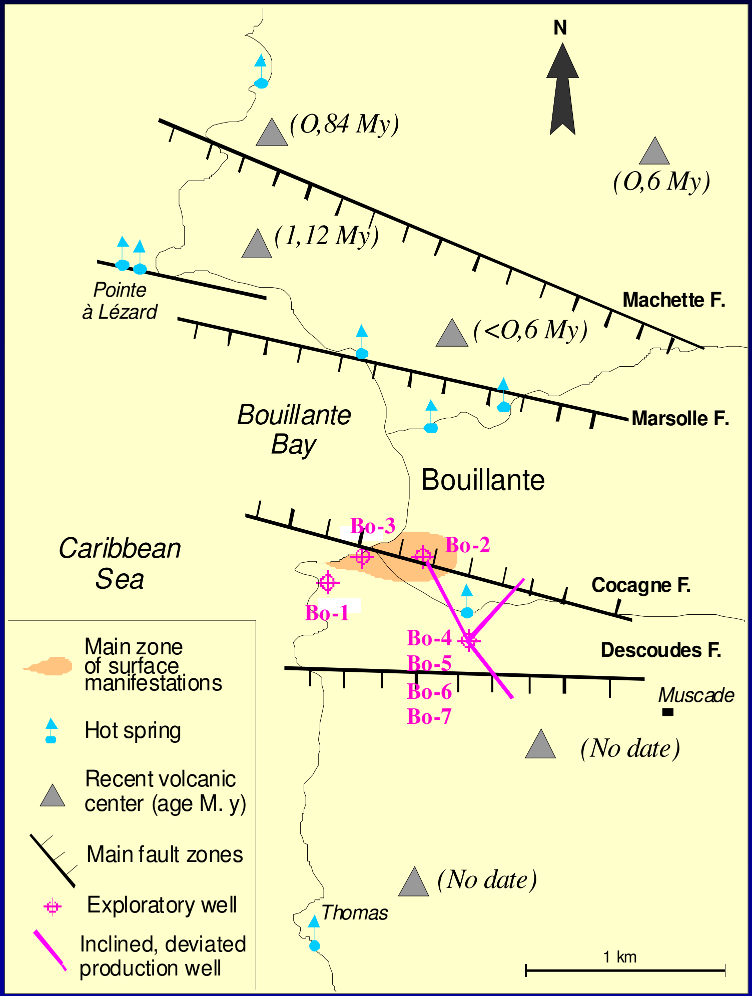


- Bouillante 1 – in operation since 1986
  - Nominal Power capacity : 4.7 MW
- Poor availability (less than 50%) from 1986 to 1994 due to problems with control gear
- Back on line in 1996 after overhaul, new control gear, and stimulation of BO- 4
- Bouillante 2 – in operation since 2004
  - Nominal Power capacity : 11 MW
- Total Annual Production: 30 GWh (Bouillante 1) and 72 GWh (Bouillante 2) – approx 9% of all the electricity consumed in Guadeloupe
- Availability factor : 90%
- Currently sells approx 100 GWh pa to EDF for approx 10 US c/kWh

All Guadeloupe slides courtesy of Jules Cairo, Geothermie Bouillante SA

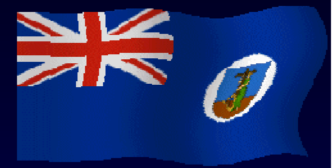
Next steps – a new facility in Bouillante bay

- Following the commercial success of the Bouillante 1 and 2, Geothermie Bouillante is planning to build annother facility further along the coast
- This new facility could be as much as 30MW



All Guadeloupe slides courtesy of Jules Cairo, Geothermie Bouillante SA

Electricity costs from geothermal projects can be low – ranging from 2.5 to 10.5 US¢/kWh



- Sizes range from 100kW to 100MW depending upon resource characteristics and local demand
- The main cost factors are:
  - temperature and volume, and chemical composition of the geothermal fluids
  - number and depth of well(s) required
  - environmental compliance costs (including disposal of large amounts of geothermal fluids if using a flash system)
  - capital costs, project costs, financing costs

Unit Cost of Power (US¢/kWh)			
	High Quality Resource	Medium Quality Resource	Low Quality Resource
Small plant (<5MW)	5.0 - 7.0	5.5 – 8.5	6.0 – 10.5
Medium plant (5 – 30MW)	4.0 - 6.0	4.5 – 7.0	Normally not suitable
Large plant (>30MW)	2.5 – 5.0	4.0 – 6.0	Normally not suitable

Source: www.worldbank.org/html/fpd/energy/geothermal/

Direct capital costs (per kW) decrease with size – economies of scale drive larger projects

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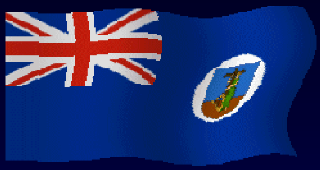
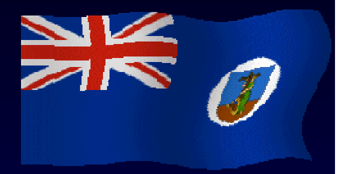


Direct Capital Costs (US$/kW installed capacity)		
Plant Size	**High Quality Resource**	**Medium Quality Resource**
Small size (<5MW)	Exploration: 400 – 800 Steamfield: 100 – 200 Power Plant: 1100 – 13 00 **Total: 1600 - 2300**	Exploration: 400 - 1000 Steamfield: 300 - 600 Power Plant: 1100 – 1400 **Total: 1800 - 3000**
Medium size (5 – 30MW)	Exploration: 250 - 400 Steamfield: 200 – 500 Power Plant: 850 – 12 00 **Total: 1300 - 2100**	Exploration: 250 - 600 Steamfield: 400 - 700 Power Plant: 950 1200 **Total: 1600 - 2500**
Large size (>30MW)	Exploration: 100 - 200 Steamfield: 300 - 450 Power Plant: 750 - 1100 **Total: 1150 - 1750**	Exploration: 100 - 400 Steamfield: 400 - 700 Power Plant: 850 - 1100 **Total: 1350 - 2200**

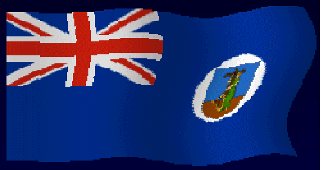
Source: www.worldbank.org/html/fpd/energy/geothermal/

To 'dispose' of this energy, Montserrat can either export electricity to Antigua . . .



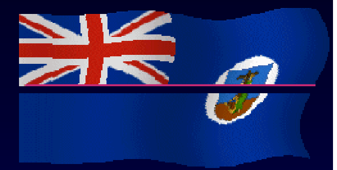
- Initial discussions with APUA suggest that they would be willing to buy 40MW of electricity from Montserrat under a long term PPA
  - if it was available soon (they are short of capacity now)
  - if it was reliable and secure
  - if it was cheaper than they could generate themselves
- In order to transport the electricity to Antigua, we would have to build an undersea link between the islands
  - The distance is not impossible – much wider and deeper waterways have been crossed before (Bass Straits, English Channel etc.)
  - Weather and other factors are no worse than other crossings

. . . encourage energy intensive businesses to set up in Montserrat . . .



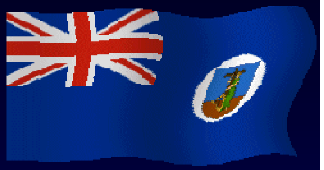
- Concrete manufacturing
- Aluminium smelting
- Paper manufacturing

. . . or convert the electricity into another form and export

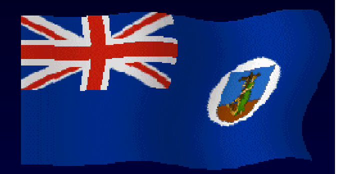


- Ethanol
  - Source Bagasse from local (Caricom) sources
  - Ferment, and then distil the ethanol
  - Sell the ethanol into the European market as a fuel additive
- Hydrogen
  - Electrolyse water to generate ‘clean’, green hydrogen?
  - Export as compressed gas, or stored as a metal hydride

Geothermal Economics



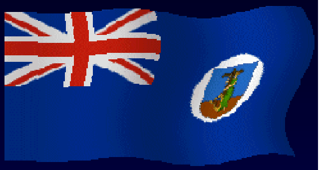
Proving the resource is the most risky part of the venture. An indicative budget might be:



- Pre-drilling analysis $300,000
  - based upon a proposal received from Dr Simon Young of GEOSY (and former MVO director)
- Drilling costs $1,000,000
  - based on five slimline exploration wells up to 1000m deep. Estimate from Prof Paul Younger based on drilling experience in Iceland, Central America, and the USA – includes allowance for Montserrat-specific mobilisation costs
- Contingency (15%) $200,000
  - because things never run to plan!

- So for US $1.5m, the resource is well characterised, proven, and bankable

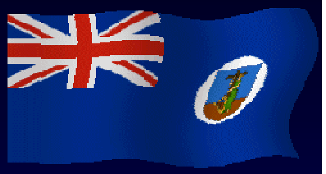
The capital cost of the generation plant will depend upon its size and technology



- The industry-standard Costing Model (Sanyal, 2005) is based upon actual cost data from thousands of projects world-wide – includes production borehole drilling and generating plant construction
  - Unit Production Cost = $2538/kW or $12.7m for a 5MW plant
- Prof Paul Younger offers the following estimate:
  - Drilling of two production-scale boreholes similar to those in Guadeloupe $3.5 million
  - Generation plant (assumed flashed steam, atmospheric exhaust, wellhead turbine rated at 5MW – quotes ranged from $5.75m to $8.72m[1] depending on options selected. Budget estimate (conservative) $8.0 million
  - Engineering Design & Contract Supervision $0.5 million
  - Contingency (10%) $1.2 million
  - TOTAL COST $13.2m for a 5MW plant
- For comparison, Ormat quoted $1700/kW plus for binary plant

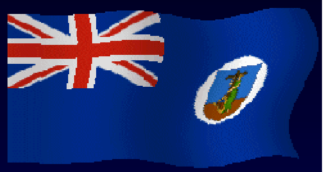
1: Quotes from: Mitsubishi Heavy Industries and Fuji Electric Systems Ltd

Agenda



- Introduction to Montserrat
  - Geography and geology
  - Existing generation plant
  - Production and demand
- Why do we need to change?
  - Costs and prices
  - Security of supply
  - Climate change – a threat and an opportunity?
- Role of renewables
- Guadeloupe – a case study?
- Summary and key messages

Key messages to take home



- Montserrat appears to have enormous geothermal potential, far in excess of local electricity requirements
- But the quality and scale of the resource will not be known for sure until test wells are drilled
- Exploration and drilling is financially risky - there is no guarantee of finding a commercially exploitable resource
- If a suitable resource is found, then geothermal projects can provide large amounts of clean energy at very low cost
- Access to cheap energy can be used to drive Montserrat's development and secure its long-term future

- How best to develop and exploit Montserrat's geothermal potential is an important political and social decision