GAS GENERATION – A CASE STUDY
THE STORY OF OUR LMS 100 SELECTION AND BUILD

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SurfAir Beach Hotel and Conference Centre,
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Today’s Presentation

• Who is Synergy
• The electricity market in WA
• Our load profile
• Our decision process
• Impact of renewables
• The technology options
• Our high efficiency GTs
• Performance to date
Who is Synergy

• Formed on 1 January 2014 by the merger of Verve Energy (generator) and the old Synergy (retailer) to form a “Gentailer”
• Wholly owned WA Government trading enterprise
• The largest provider of electricity to the South West Interconnected System (SWIS) – Approximately 55% of energy and 50% of capacity
Who is Synergy

• Approximately 900 employees
• 2600 MW of generating capacity
• 26 Gas / Oil / Coal units on 6 sites
  ➢ Directly Operated
  ➢ Contract Operated
• A “Portfolio” Generator
• 3 wind farms
• 1 Solar PV (as a joint venture)
• 4 plants output held as IPP power purchase agreements
The WA Market

- Regulated by the AEMO (took over from IMO - 2015)
- Based on bilateral trading – retail market only partially contestable – customers greater than 50MWhr / year
- Within Synergy – Ring fenced business units
  Wholesale Business Unit - Honest Broker
- Payment for generating capacity (keep the lights on)
- Real time load following traded in a Balancing Electricity Market (less than 10% of total energy)
- Synergy is not permitted to speculatively price balancing energy – default provider of balancing and load following services
- Synergy is default provider of spinning reserve
- Entire market structure currently under review as it is seen as “broken” and commercially unsustainable requiring large State government subsidy
The WA Market
The Real World

Summer

Winter

synergy
The WA Market – *Load Duration Curve*

- Approximately 9% of WA’s energy comes from renewables
- Balance of rest is 50/50 natural gas v/s coal
- Off take contracts distort ability to turn down some plants overnight
- Deteriorating system capacity factor – less than 55% and falling
- Load duration curve notably “shallower” than the NEM

*Source: IMO 2015 Statement of Opportunities*
Impact of Renewable Generation

• Estimated that there is now 450 MW of rooftop solar PV installed
  ➢ Around 8MW / month new applications (20% growth ! )
  ➢ 20% of households now have rooftop PV

• Over 450 MW wind – 200 MW has high overnight capacity factor

• Market permits wind to “free spill”

• 230 MW located in the “wind alley” - coastal area 200km north of Perth subject to winter storm fronts

• Frequency control is arduous
Fuel Diversity

• Coal is able to be stockpiled
  ➢ Provides buffer to supply and demand disconnects
  ➢ Historically able to be contracted over longer periods – price certainty
  ➢ Can be subject to quality variability impacting plant operation

• Gas fuel has two components
  ➢ Transport
    ➢ Capacity reserved for a fee with a pipeliner (DBP in our case) – take or pay
    ➢ A commodity charge is incurred when gas is physically shipped
    ➢ Strict operational parameters are in place – quantity balances, quality and overruns
  ➢ Supply
    ➢ Increasingly tight delivery regime – constant flow rates demanded by producers
    ➢ Recent step changes in long term prices
    ➢ Requires special purpose storage facilities
The Role for Coal

• Coal fired plant has limited fast response capability without auxiliary fuels
  ➢ Boilers have relatively long time constants
  ➢ Coal mills have small resident volumes of pf “ready to go”

• Can perform load following role with modern governing systems

• Has lowest short run marginal cost owing to primary fuel cost

• Collie basin units have high start up costs due to use of fuel oil

• Thermal cycling of thick walled components undesirable in terms of remnant life consumption

• Stations originally intended for high capacity factor, base load service
The Role for Gas

- Gas fired plant can come in three forms
  - Conventional thermal (Rankine Cycle)
  - Combined Cycle Gas Turbine (CCGT)
  - Open Cycle GT

- Gas fired thermal plant has much better fast response because of the absence of coal mills and hence fast heat release in the boiler
  - Relatively high capital cost
  - Modest efficiency – though acceptable incremental heat rates over usual load ranges
  - Not competitive against a modern CCGT plant
The Role for Gas

• CCGT plants
  ➢ Ultimate response limited by steam cycle
  ➢ Highly thermally efficient plants – generally between 46% and 55% (HHV Net) depending upon MW rating
  ➢ Careful design of HRSG is necessary for two shift operation – cold start up times typically 2 hours to full load as a minimum

• Open Cycle GT
  ➢ Historically relatively low efficiency (high heat rate)
  ➢ Fast start up
  ➢ Small foot print
  ➢ Modest capital cost
Our Decision

• Around 2007 it was clear the rules of the game were changing
• System ancillary services demands were becoming more onerous – impact of renewables
• The days of $2 / GJ gas were rapidly disappearing
• System capacity factor was deteriorating
• New market entrants were taking significant positions in the base load market
• Significant market and system analysis clearly showed new build increment was clearly a peaking requirement
Our Decision – So what to do?

• Traditionally open cycle GTs were used – we already owned 16, between 20 and 120 MW rating

• All were based on Heavy Duty industrial “Frame” turbines

• Class E firing temperatures
Our Decision – *So what to do?*

- **Industrial Gas Turbines**
  - Intended as base load machines – either electricity production or mechanical drive
  - Their part load heat rates are poor – constant compressor speed and hence mechanical load limited only by inlet air throttle
  - They suffer significant high ambient temperature de-rating
  - Are manufactured using thick walled castings – thermal cycling causes cracking and distortion
  - Starting penalties are material – the concept of EOH

- We had lots of experience of the consequences

![Frame 9 Diffuser Barrel Cracking](image1.png)

![First Stage Nozzle

Starts: 593; Hours 6,000 since last inspection

Refurbished nozzle](image2.png)
Technology Options

• **More of the same?**
  - Yes ….but could we do better

• **Reciprocating Engines?**
  - Multiple units – space problem
  - Low inertia – network issues
  - Part load heat rate an issue for spinning reserve

• **Aero Derivative GTs?**
  - Mostly sub 50 MW unit size – space problem
  - Low inertia
Technology Options

• There was however a unique machine arriving in the market place

- Very high energy density - MW / m²
- Nominally 100 MW – big enough to be useful
- Acceptable inertia (though not great still)
- Good fit for Synergy’s portfolio operation
- High open cycle efficiency
- Rapid start up (cold to full load in 11 minutes)
- Excellent part load efficiency – load following ancilliary service cost driver
- Superior hot weather performance
- Good load following performance
- No starts penalty as such (but a cycle penalty)
But ..,

• **Could we justify the price premium?**
  - Increasingly expensive gas made heat rate a key driver
  - Given the likely severe service, prospect of reduced maintenance costs were attractive

• **Did we have the appetite for leading edge technology?**
  - Lots of case studies where leading edge becomes “bleeding” edge
  - Could we insure it (prototypical status)?
So what did we do?

• Kwinana Power Station stage B was decommissioned in January 2009.

• 2 x 120MW gas / oil fired thermal units (early 1970’s)

• Demolition of stage B began in June 2009 and was completed in April 2010.
So what did we do? (Big kids fun! )
So what did we do?

• Contracts were awarded to GE for 2 x LMS100 units in July 2009 and to United Group Infrastructure Pty Ltd for the power station EPCM in September 2009

• Ours would be unique – the first in the world to use sea water cooling for the plant (significant because of the intercooler)

• Site works began in April 2010

• Brownfield project with interfaces
So what did we do?

- Commercial operation September 2012
Some Numbers

• First intercooled gas turbine for power generation
• High gross efficiency: 43% - LHV @ ISO conditions
• Gross output (no evap cooler in service): 104.5 MW
• <12-minutes start from cold to full load
• Superior hot-day performance – low derate
• Rapid load following and cycling capabilities - 800kW/s
• Low emissions, 25ppm NOx
• Dual fuel capability (natural gas and diesel)
• No direct EOH penalties
• Low turndown ratio – 25% emissions limit (wet NOx control used deliberately)
Some Numbers

So where does an LMS 100 sit amongst other machines?

Source: GE Promotional Material
Some Numbers

Part load efficiency

Temperature de-rating

Source: GE Promotional Material
Some Details – The GT

• 3-shaft aero-derivative hybrid with intercooler

• Low pressure 6 stage compressor - LPC - (VIGV) driven by intermediate pressure 2 stg power turbine - IPT (5000 rpm nominal)

• High pressure 14 stg compressor - HPC - (VIGVs and VSVs) driven by high pressure 2 stg turbine - HPT (9000 rpm nominal)

• Power turbine (5 stg) and generator (3000rpm when synch) – no gearbox, aerodynamic couple to IP turbine exhaust (determines inertial constant)

• LPC heavy duty frame pedigree – MS6001FA

• HPC, HPT and associated IPT pure aero – LM6000/CF6A

• Single annular combustor

• Exhaust temperature 400 deg C - not good for CCGT application
Some Details
The configuration and its origins

CF6-80C2
High Pressure Compressor (HPC)

CF6-80E
High Pressure Turbine (HPT)

Frame derivative
Power Turbine Shaft

Frame derivative
Exhaust Diffuser

Aero derivative
Power Turbine (LPT)

Aero derivative
Intermediate Pressure Turbine (IPT)

Supercore

MS6001FA
Low Pressure Compressor (LPC)

Intercooler System

Source: GE Promotional Material
Some Details – The Intercooler

- Enables compression ratio of 41:1 (Frame GT typically <19:1)
- Compressed air from the LPC cooled then delivered to HPC
- Intercooling reduces specific volume and temperature, which enables a larger mass flow, but greater heat input during combustion – offset by lower compressive power requirements
- Effective control of air temperature over varying ambient, especially with sea water cooling, minimises temperature de-rating
- Condensate production in intercooler of up to 180l/min
- Variable Bleed Valve control to manage compressor stall
Some Details

The Supercore
Some Details – The Balance of Plant (BOP)

• Air inlet filter with pulse air and evaporative cooler
• Stack height 60m
• Gas compressor – screw oil injected – 1.2 MW 6.9MPa
• NOx water system – 25000 l/hr
• Liquid fuel (diesel) system – 40000 kg/hr
• Secondary cooling water systems
• Waste water systems
• Compressed air 38 Sm3/min – control, sealing, cooling
• Fire protection
• Hypochlorite dosing
• Generator step up transformer – 11.5 / 132kV 135MVA
• Unit transformer – 11.5 / 3.3kV 7MVA
• Electrical protection and DC systems
• Stack emissions monitoring system
• Control – BOP + Turbine control all GE Mark VIe
Performance – *How have we been using them?*

- Typical daily load profile
- Plant capacity factor approximately 50% higher than financial model prediction
Performance – *What about the rest of the portfolio?*

Before LMS 100

After LMS 100
Performance – Our Numbers

Gross efficiency, LHV, evap cooler off

Temperature de-rating
Performance – *Show me the money!*

- Based on actual operating gross efficiency since 2012;
  - Frame 9 average: 24%
  - LMS100 average: 35.2% (lots of part load operation)
- Monthly fuel saving around 190 TJ equivalent
  (*Based on calculated fuel burn if LMS100s had not been in service*)
### Performance – So where are we at?

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<th><strong>KWGT2</strong></th>
<th><strong>KWGT3</strong></th>
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<tr>
<td></td>
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<td>Commissioning to June 2014</td>
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<tr>
<td></td>
<td>10843 fired hours</td>
<td>10662 fired hours</td>
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GT 2 had 2 supercore exchanges in FY 14, GT 3, for various fleet issues. Whilst the basics of the machine are well known to industry – the sum of the parts is revealing issues.
Performance – *So where are we at?*

- Reliability is good (always has been) – when running they rarely have trips (low FOF).
- When they are available to run, they are very reliable.
- Planned outage factor is unacceptable – engine change outs take time and are far too frequent ($$$$$$) – it is getting better however.
- They are (and probably always will be) more expensive than a Frame GT to maintain.
Performance – Supercore Issues

• High Pressure Turbine – life started out <8000 hrs (almost an engine change per year !) – have got it up to 12,000 hrs……not to the claimed 25,000 yet !

• Combustor cracking – risk to HPT – getting better

• Intermediate Pressure Turbine - Stage 2 shroud wear

• High Pressure Compressor Stage 1 Mid span damper wear initially <10,000hrs life – hopefully sorted

• Anti ice hose failures

• Booster vane carriers wearing
Performance – *So has it all been easy?*

• HPC first stage blading mid span platform accelerated wear

• GE have been proactive - combination of vibration and leaching due to compressing damp air - redesign complete and deployed in 2014 so far so good
Performance – *So has it all been easy?*

- HPT first stage blading – Too much NOx water ??

May 2014 borescope found combustor required changing. Some stress of HPT noted but assessed acceptable by OEM

Kwinana Unit 2; borescope inspection October 2014
Total operating hours: 6759 since HPT replacement August 2013
Performance – *So has it all been easy?*

- VBV actuator failure – wearing itself to death!

- Most likely a result of our severe service……..however control system never lets the damper “settle” – GE reviewed control strategy to dampen activity
Performance – *So has it all been easy?*

- HPT blading barrier coating degradation – some temperatures higher than anticipated. New coating deployed. Seems improved.
- Fuel transfer gas / diesel on load problematic still.
- NOx water mapping - better.
- Power turbine shaft cooling fan failures – poor QA.
- CEMS performance and accuracy – annoyance value.
- VSV lever arm failure – our arduous duty?
- LP compressor stall issues (haven’t damaged a unit yet however).
Performance – Unit Issues

- Gas booster compressor stator vane failure
- Intercooler seal failures
- NOx water pump failures
- Control System “Block” software upgrades…still
- Bimetallic corrosion issues in intercooler – now fixed
Lessons learned

- The LMS100 is much more complex than conventional aero derivative gas turbines…and it was a prototype as we now know
- Design and construction risk is considerably higher owing to extensive balance of plant
- Contracting strategy is critical – fair apportionment of risk
- Significant efficiency improvement compared to Frame 9, but less so compared to simpler aero derivative gas turbines.
- Hot weather performance is vastly superior and better than envisaged
- Requires a rethink of maintenance support arrangements – necessary skill sets are different – they are not set and forget machines
- Essential to get your people on the ground early to manage IP transfer
So would we do it again?

On balance **Yes** (we are masochists!) –

- Simply the fuel savings are enormous and flexibility of the units suit our needs well

- There have been issues associated with our early uptake – OEM support for significant issues has been good though manufacturers work at a different pace to operators!

- QA issues in construction were annoying

- Contracting model would need to be different – fair apportionment of risk
Questions Please?