Replanting of King's Lynn CCGT - flexible operation and extended life

Author - Hassan Joudi and Ryan Broughton

Figure 1: Aerial view of King's Lynn Power Station, Norfolk, UK (pre-replant)

Abstract

The King's Lynn CCGT Replant project during 2017-19 included the replacement of a Siemens V94.3 gas turbine, with a new Siemens SGT5-4000F (version 7) gas turbine. With the original plant designed for baseload operation, the replant project objectives included improving the plant's output, flexibility, efficiency and reliability to enable two-shifting operation to better meet the changing demands of the UK electricity market, whilst also giving a further 15-20 years life extension and reducing the plant's environmental emissions. The capital investment required was significantly lower than an equivalent new build plant of the same capacity.

WSP, in collaboration with Centrica, and with the support of Siemens, carried out a feasibility assessment of the project. This involved comparing original design conditions versus potential upgraded performance and the intended future operating regime. Using a risk based, value engineering approach, modifications and refurbishment work were identified for the steam turbine, generator and Heat Recovery Steam Generator (HRSG). The result is a plant which has significantly shorter start-up (cold, warm, hot) and shutdown times and higher load ramp rates in a wider load range and which reuses existing infrastructure.

1 Plant overview

King's Lynn Power Station is a Combined Cycle Gas Turbine (CCGT) power plant located on Willows Business Park, Saddlebow, 3 miles south of King's Lynn, Norfolk UK. Construction of this power plant began in 1994 and the plant was completed and commenced commercial operation in 1997. The plant was originally owned by Eastern Electricity and then acquired by TXU Europe Group Plc (TXU). Centrica purchased the asset from TXU in 2001.

The original Gas Turbine (GT) was dual fuel capable, with natural gas from National Grid's National Transmission System used as the primary fuel source. Distillate oil stored on site was used as a secondary fuel source.
The plant comprised a single shaft power train using one 237 MW Siemens V94.3 GT, exhausting into a vertical gas flow, forced-circulation, triple pressure Heat Recovery Steam Generator (HRSG) designed by CMI SA (Belgium), supplied Cockerill Mechanical Industries (CMI) and

manufactured by International Combustion Limited (ICL). The powertrain also has one 123MW SST5-300 Steam Turbine (ST) with single flow axial exhaust that is coupled to the single common electrical generator via a self-synchronizing clutch. The electrical generator is a two-pole hydrogen cooled generator with a rating of 412.6 MVA at 21kV and 0.85 power factor running at 3,000 rpm. Power is exported via a 437.8MVA, 21/132kV generator transformer and an on-site 132kV substation which has six outgoing feeders to the 132kV electrical distribution system. The design output of the original power plant was 340MWe.

The plant used an Air Cooled Condenser (ACC) comprising a four by four cell configuration with motor driven axial-flow cooling air fans to condense the steam turbine exhaust via heat exchange tube bundles to condensate for return to the HRSG.

Designed primarily for base load operation, the plant ran for 15 years – initially at base load and later in a two-shifting regime - before rising fuel gas price and maintenance frequency constraints made the asset less competitive compared to new build higher efficiency CCGT plant. In April 2012 the plant was placed into a preservation status and remained under controlled preservation. During this period of preservation, asset owner Centrica initiated the replant development project, supported by WSP as Owner's Engineer providing technical advice, to explore the possibility of replanting the site with a new GT and making the plant fit for purpose in a flexible (rather than base load) operation regime.

2 Market trends and drivers

The first generation of CCGT power plants in the UK were commissioned in the early 1990s and with an expected life of 25 years (not including the possibility of life extension), many are therefore now coming towards the end of life.

With the increasing penetration of intermittent renewable generation, many first generation CCGT plants including King's Lynn Power Station were often forced to run in ways which were not anticipated when they were designed in order to remain competitive – namely cycling operation rather than baseload duty. Some of these first generation CCGT plants have been displaced from the market entirely by the higher efficiency and flexibility of newer plant, resulting in either early decommissioning or placing the plant into preservation until the future of the plant is decided.

Over the past decade the UK electricity mix has decarbonised rapidly as coal power stations close and are replaced by renewable power generation. Whilst energy storage capacity is growing, there remains a requirement for dispatchable generation plant that can operate with high flexibility, availability and reliability.

In many cases the existing UK CCGT fleet has significant design life remaining, but with reduced operating hours asset owners are struggling to keep their plants running economically. One option available for owners of ageing CCGTs is a replant where the gas turbine(s) is replaced with a more flexible and efficient model and necessary modifications and refurbishments are made to other equipment in the plant. The objective is a refurbished power plant with higher flexibility, availability, reliability and efficiency to meet the changing demands of the electricity market, operating life extension and a reduction in environmental emissions.

Where project economics are favourable, replants offer an attractive investment for ageing CCGT asset owners at a level of capital investment significantly lower than an equivalent new build plant of the same capacity, as well as the deferral of decommissioning of the plant and its associated costs, and re-use of existing connection points for fuel gas import and electricity export. This opportunity was developed and executed at King's Lynn Power Station as outlined in this paper.

3 Replant project development

3.1 Preservation strategies and actions taken

In April 2012, after 15 years of commercial operation, due to challenging market conditions and inability of the GT to continue to operate flexibly to meet market demands, King's Lynn Power Station was placed in long term preservation.

The operation and maintenance team was reduced to a team of six personnel and a preservation strategy put in place with the following objectives:

- Minimising the degradation of non-operational plant
- Monitoring the plant condition regularly
- Ensuring the plant can be successfully returned to service in future

The following long-term preservation measures were adopted:

- The ST was preserved using dehumidified air circulation.
- The hydrogen-cooled generator was filled with dry air and maintained in a humidity-controlled condition. The slip ring brushes were removed to storage to prevent wear.
- The HRSG and steam systems were drained, dried and dehumidifiers connected in accordance with OEM recommendations for long term preservation. Corrosion coupons were placed and monitored regularly for humidity levels below recommended limits.
- The fuel gas supply system was isolated from grid supply (air-gapped) and filled with dry air.
- Auxiliary systems which contain non-aggressive fluids such as lubricating oils, were run on a routine basis to prevent system corrosion and ensure filtration.
- CCCW was left filled with demineralised water, corrosion inhibitor and anti-freeze.
- The water treatment plant was flushed, drained and ventilated.

- Balance of plant valves and pumps were operated based on preservation routines either by hand or via the Distributed Control System (DCS) to avoid seizure.
- Removal of plant items for smaller high-risk items such as pumps or motors and storage in clean dry conditions.
- Protection and monitoring of essential live systems which need to remain available but may be subject to freezing damage e.g. fire water systems, insulation and trace heating
- Compressed air systems were left in service as they were critical to the preservation of other systems.

These measures represented a deep level of preservation that remained in place for a significant period of time until the replant project construction works commenced in 2017. This meant a greater level of effort, time and risk was involved in returning the plant to service when re-commissioning was performed during 2018-2019 compared to a short-term preservation regime.

3.2 Concept outline and feasibility studies

During the preservation period from 2012 engineering studies were undertaken by Centrica to develop the replant opportunity at the site, supported by WSP as Owner's Engineer providing technical advice. A pre-feasibility study was first undertaken to determine the initial constraints and limitations of the plant to remain operational for an additional service life of 20 years.

The basis of the pre-feasibility study was to re-use as much of the existing power plant assets as possible, whilst replanting with a new GT to increase the plant's output, reliability, availability and efficiency. This would enable the asset to operate under a new intended cycling operating regime and allow it to participate competitively again in an electricity market that demands reliable cycling operation and aggressive start-up and shut-down profiles.

The feasibility studies assessed the maximum design capability of the existing major plant and equipment, as well as the constraints surrounding planning consent, fuel gas import and electrical power export. The effect of a new GT was then modelled using Thermoflow modelling software to establish the maximum possible performance whilst remaining within the design capability of the existing plant.

The studies confirmed that a replant was feasible and could progress to the next stage. Engagement with Siemens and other potential contract partners commenced during 2013-15 to carry out detailed verification checks and FEED studies. These studies were critical in establishing the suitability of each system for the new operating regime and identifying key components that would require refurbishment, modification or replacement. In addition, detailed performance modelling of individual items of the plant was undertaken to ensure appropriate performance improvements were defined and potential risks and issues with plant operation under the new intended operating regime were identified.

A value engineering approach to define the work scope was employed that focused engineering effort on components for which process conditions would be most affected by the new GT. The approach was further enforced by incorporating knowledge of the plant's history from operation and maintenance personnel. This enabled a focused work scope to be developed, whilst avoiding the need to redesign the whole plant entirely. It also provided the opportunity to engineer out plant items which had a difficult operation or maintenance history.

Where limited "As Built" documentation or historical operational records existed, condition assessment and inspections were carried out to assess the remnant life and condition of key components, in particular the HRSG and other pressure parts.

The studies resulted in a recommended replant scope of work that included the replacement of the original Siemens V94.3 GT with a new Siemens SGT5-4000F(7) GT with a slightly derated output to remain with the electrical export limits. In addition, several upgrade scopes of work to ensure other plant areas could accommodate the increased power and heat output were also developed and these are outlined in Section 4 below.

Technical specifications for the new or modified plant and equipment were prepared and a review of performance guarantees provided by OEMs conducted, in particular Siemens for the GT and John Cockerill (formerly CMI) for the HRSG, to ensure consistency of approach across the full combined cycle plant.

3.3 Benefits of the replant

The replant opportunity offered the following benefits for King's Lynn Power Station:

- Improved plant performance, including higher output, efficiency, flexibility, availability and reliability, enabling a competitive advantage in the electricity market and providing the opportunity for additional revenue streams from ancillary services.
- Life extension of the existing asset, thereby improving the utilisation of a functional plant with useful remaining life and avoiding the requirement for purchasing new plant.
- Deferral of decommissioning of the asset and its associated costs, as well as ensuring the extension of job opportunities in the local area and avoiding the need to redeploy or lose staff with extensive plant knowledge and experience.
- Re-use of existing brownfield site, thereby mostly avoiding the permitting process for a new site including planning applications and consultations.
- Reduced upfront capital investment compared to a new build of the same capacity, with the majority of the costs being in the supply and installation of the new GT.
- Better environmental performance of the newer GT thanks to lower NOx and CO emissions in compliance with latest environmental legislation.

- Increasing maintenance outage interval for newer GT with latest technology, thereby reducing ongoing maintenance costs.
- Opportunity to renegotiate service agreements with OEMs alongside negotiation of EPC contract.

4 Modifications and refurbishments work scopes

The sections below outline the main modification and refurbishment scopes of work developed for each major plant area at King's Lynn Power Station as a result of the introduction of the new gas turbine. In addition, the project also saw the planned major overhaul of the ST and generator. Emergent engineering issues were also identified during the construction phase that had to be incorporated into unplanned scopes of work.

4.1 Gas Turbine

Following a detailed engineering study of the plant's "As Built" documentation and historical operations records, as well as a review of GT options available in the market, the original Siemens V94.3 silo combustor GT was recommended to be replaced by a new derated Siemens SGT5-4000F (version 7) annular combustor GT. A factory slot was swiftly obtained, and a build timescale of 12 months was achieved. The new GT was transported by sea to King's Lynn port.

As part of the supply and installation of the new GT, the following modifications were carried out:

Figure 2: Removal of Siemens V94.3A gas turbine

Figure 3: Gas turbine silo combustor ready for scrap or resale

Figure 4: New SGT5-4000F in Siemens' Berlin assembly works

Figure 5: New GT being installed on concrete foundation pads

Figure 6: GT Combustion chambers in turbine hall

- Support foundations – foundation upstands modified to match supports of new GT
- Air intake duct – new duct section and silencer installed
- Drive shaft to generator – new drive shaft installed
- Exhaust system – diffuser and expansion joint replaced and new sound protection enclosure and HRSG expansion joint installed (interface point with the HRSG scope of work)
- Fuel gas supply skid – new gas valve skid installed
- Hydraulic Clearance Optimisation (HCO) – in line with latest technology developments a HCO system was installed to close turbine seals during full load operation alongside new hydraulic and lubrication oil skids
- Auxiliary systems – integration of GT auxiliary systems including mobile compressor wash, natural gas, lube oil, jacking oil, hydraulic oil, turning gear and compressed air systems
- Gas detection/fire protection systems – replaced with new
- Control system – Plant Control System (PCS) for GT integrated into new DCS for the overall plant
- Blade air cooler – redundant blade air cooler unit disconnected from Low Pressure (LP) steam supply and decommissioned.

Parts of the redundant GT unit including blades, vanes, combustion tiles and inner casings, as well as DCS components were disassembled and sold in the second-hand market.

4.2 Heat Recovery Steam Generator (HRSG)

An HRSG uprate study was performed by WSP to understand the expected impact of the new GT exhaust heat output on the HRSG process conditions, and what refurbishment and modification work scopes would be required as a result. In addition, condition assessment studies found the overall HRSG to be in good condition and the majority of components suitable for continued operation at the new process conditions, except for the High Pressure (HP) superheater and Intermediate Pressure (IP) reheater modules that did not have sufficient design temperatures to accommodate the hotter GT exhaust gases and steam temperatures expected post-replant. An assessment of some thick-walled components was also carried out to ensure the HRSG was fit-for-purpose for cyclic operation.

The modification and refurbishment work scope developed included:

- Replacement of HP superheater and IP reheater modules and adjacent pipework. The modules were designed by the OEM John Codkerill (formerly CMI) and fabricated in South Korea before shipment by sea to King's Lynn port. A specialist sub-contractor was used to cut away the underside casing of the vertical gas path HRSG and remove the original superheater and reheater modules by controlled lowering from their hung position to grade using hydraulic jacks and sliding out of the HRSG building on Teflon sliding tracks. The new modules were slid in, lifted and fixed into position in a reverse operation and the golden weld joints with inlet/outlet pipework performed before the casing underside and insulation was re-installed. A tandem crane lift through the GT exhaust duct was considered but ruled out due to space constraints.
- The HRSG casing was modified to accommodate the increased length of the HP superheater and IP reheater modules. The casing's support bracing and insulation was also modified to improve flexibility and reduce heat loss.
- High priority valves, including HP, IP and LP main isolation valves and steam attemperators that were originally designed for base-load operation, and would not be suitable for the cycling operation post-replant, were either refurbished or replaced with new valves that were designed for the expected duty. Control and drain valves to manage HRSG drum swelling on start-up, drum level control, steam attemperation and bypass systems are all also key sub-systems for flexible operation that were modified or replaced.
- Forged tees and elbows that were unsuitable for cycling operation were uncovered whilst de-lagging pipework at the start of the construction phase, and the decision made to replace them with new thinner walled components suitable for cycling operation.

Figure 7: Old HRSG modules in laydown area following removal

Figure 8: New HRSG modules ready for lifting into place

- To enable ongoing condition assessment of the plant, additional thermocouples on the HRSG headers and pipework were installed to enable monitoring of temperature ramp rates for assessment of fatigue and creep life.
- The original plant did not have HRSG header inspection ports, so the opportunity was taken to install these to improve maintainability by enabling borescope inspection of headers during maintenance outages without the need to enter confined space inside the casing in future.

4.3 Steam turbine and steam/water cycle

Engineering studies found that the SST5-300 Steam Turbine (ST) was in good condition for a machine of its age and had the capability to continue operation for at least a further 20 years. The ST underwent its' planned major overhaul by the OEM, as well as replacement of last row blading with the latest design and new seals throughout to improve efficiency.

In addition, modification to the overall steam/water cycle systems to improve overall combined cycle plant flexibility included:

- To improve start up times and reduce thermal stress on the ST, Siemens installed electric heating blankets combined with the ST insulation. These blankets are designed to maintain ST rotor and casing temperatures following a shutdown and significantly reduce or remove ST temperature warming times during the following start.
- Refurbishment of feedwater, circulation and other pumps within the steam/water cycle as well as modifications to them where required
- Upgrades to steam attemperator systems to provide additional cooling capacity including modifications to pipework, attemperator lances and feedwater valves.
- Decommissioning of the original plant's diesel-fired auxiliary boiler with a new electric auxiliary boiler. The new electric auxiliary boiler supplies start up steam to the steam turbine and is now connected directly to the HRSG HP pressure part to supply sparging steam to keep thick walled components warm during shutdown (see point below). The electric auxiliary boiler also required a new low voltage transformer for power supply.
- Sparging steam – an OEM integrated plant design philosophy was introduced for keeping the steam/water cycle major components (including HP drum, HP superheater headers and parts of the HP main steam line) hot during periods of shut down in order to

shorten start-up times and reduce the number of cold starts, thus minimising thermal stresses on the relevant plant components. This is achieved by supplying the HP pressure parts with sparging steam from the electric auxiliary boiler, closing the HRSG weather dampers to retain heat inside the casing, and closing the main steam isolation valves.

- New operational concept FACY (FAst CYcling) – an OEM integrated plant control concept to increase flexibility by shortening the start-up and shutdown times, removing hold points and allowing simultaneous ramping of the GT and ST during start-up.
- New control sequences were also introduced to reduce shutdown times and fuel gas consumption. In contrast to a normal shut down procedure, where the GT is de-loaded to Inlet Guide Vane (IGV) minimum position and kept at this load while the ST is shut down, the ST shutdown is initiated in parallel to the GT de-loading based on a maximum allowable gradient.

4.4 Generator

A generator uprate study identified two options for modifications to the electrical power train to accommodate the increased GT power output of 435MVA at derated operation, including:

- Purchasing a new generator to match the new GT power output, therefore making the existing step-up transformer (437.8MVA) the main restriction in MW output
- Modifying the existing SGEN5-2000H generator which is rated to 412.6MVA via a rotor rewind and hydrogen pressure increase to achieve an increased generator output capacity.

The study indicated that the existing stator winding, bushings, rotor winding, sliprings, hydrogen coolers, stator casing and seal oil pumps were suitable for operation at the uprated generator output of 435MVA. Therefore, the preferred solution was a modification and refurbishment of the existing generator, as follows:

- Rewind of the generator rotor
- Increase in hydrogen cooling gas pressure and replacement of any components in the hydrogen gas system that are not designed for the higher pressure
- Reconfiguration of instrumentation, alarm equipment and controls associated with the hydrogen gas and seal oil systems
- Installation of alternative IGVs under rotor retaining rings to improve gas flow
- Installation of flux probe for online monitoring of rotor condition
- Replacement of static excitation transformer due to increased rotor current.

4.5 Air Cooled Condenser (ACC)

The increased GT power output means an increased ST exhaust mass flow rate for the ACC, thus increasing the required cooling capacity. In addition, plant operators reported historical issues with ST high backpressure alarms and trips when operating at high ambient temperatures, especially in windy conditions, indicating the original ACC may have been under-sized. Several options were considered, including an additional street of four cells, one additional cell to each of the existing four streets, introduction of a spray water system, upgrading the fans or installing a parallel dry/wet cooling system.

The preferred solution was to add an additional street with four cells – thereby increasing the total number of

Figure 9: Structural frame for new fifth street

Figure 10: ACC steam duct pipework modification


Figure 11: Air-gap in fuel gas supply pipeline during preservation


Figure 12: New water recirculation skid for fuel gas preheater

cells from 16 to 20 – as well as increasing fan speeds and optimising blade angles, in order to reduce the ST back pressure at the design point. The scope of work included:

- A new fifth street with four cells to be constructed to the north end of the existing ACC structure
- All fan motors serviced, gearboxes replaced, fan angles optimised, and speed controls calibrated
- A new control scheme applied to assist in optimisation

4.6 Fuel supply system

An uprate study was performed to review options for increasing the operating pressure of the fuel gas supply pipeline from the original 28barg operating pressure, to the required 35barg to meet the required inlet supply pressure of the new GT.

The fuel gas pipeline has a design pressure of 37barg and following a structured design revalidation process, the existing line was refurbished to ensure it is fit-for-purpose for the new operating conditions, including:

- Refurbishment or replacement of large bore and small-bore valves and valve actuators
- Installing an additional vent line for compliance with BS ISO 21789:2009 Gas Turbine Applications - Safety
- Installing a new water recirculation system for the water/fuel gas preheater, for optimising fuel gas inlet temperature to the new GT during start-up
- Updating of ATEX hazardous area zoning
- Reconnecting and recommissioning the entire pipeline from the National Grid Above Ground Installation (AGI)

4.7 Distributed Control System (DCS)

The main function of the DCS is to control, monitor and protect the plant. With the increasing flexibility requirements of the new plant placing new demands on the DCS, and the increasing age of the plant giving rise to potential future obsolescence issues, the original Siemens TXP DCS hardware was replaced by the latest DCS system hardware Siemens T3000.

The new DCS allowed multiple areas of plant such as the water treatment plant, to be controlled from the DCS for the first time and made it possible to provide enhanced flexibility and control of the plant via the new operational concept.

5 Conclusion

Current electricity market conditions and the increasing need for flexible and dispatchable capacity to support intermittent renewable generation poses challenges for ageing CCGT power plants which were originally designed for baseload operation and now need to operate more flexibly. A gas turbine replant presents an opportunity for ageing CCGT asset owners to improve plant flexibility and competitiveness in the market, alongside a 15-20 year life extension and reduced environmental emissions.

King's Lynn Power Station is one of the first plants in the UK to undergo this transformation and re-enter the market following a significant period of preservation. Asset owner Centrica initiated the project, supported by WSP as Owner's Engineer


Figure 13: Cable racks for new communication and power cables

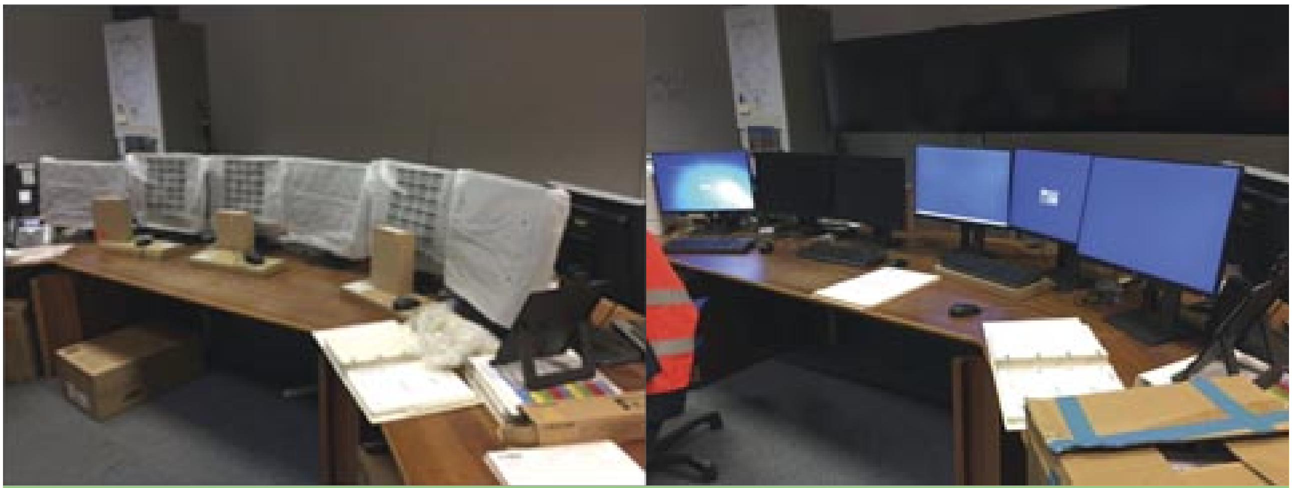

Figure 14: New LCD screens in CCR replaing original CRT screens

providing technical advice, resulting in the replanting of the original Siemens V94.3 gas turbine with two silo-combustors, with a new derated Siemens SGT5-4000F model with an annular combustor.

The replant also saw the major overhaul of the steam turbine and generator, as well as the replacement of HP superheater and IP reheater modules in the HRSG, the construction of an additional ACC street for additional cooling capacity, installation of a new DCS and several other upgrades and improvements. Replant project development took place 2013-2016, with construction commencing in 2017 and re-commissioning of the plant and return to commercial operation successfully achieved in 2019 with an uprated output of 382MW.

Following commercial operation an agreement was reached for RWE to buy King's Lynn Power Station from Centrica.

Throughout the replant project development phase, a staged process for defining the scope of work was followed to ensure that maximum performance benefit was extracted from the new gas turbine whilst remaining within the capability of the existing plant. A bespoke multi-EPC contracting strategy was adopted which required close co-ordination and monitoring of design and construction activities by the Owner's Engineer. Particular attention was paid to the management of interfaces between contractors and between old and new plant. Finally, close co-ordination between the asset owner and the OEM during the re-commissioning phase was essential to ensure successful return to service of existing plant operating alongside newly commissioned plant.

Candidate CCGT power plants currently under preservation or approaching the end-of-life offer opportunities for replants as a form of life extension and deferral of decommissioning. For other plants originally fuelled by coal or heavy-oil but with significant remnant life in the steam/water cycle and Balance of Plant, fuel-switching to natural gas-fired CCGT offers a valuable way to utilise existing assets. The nature of each replant will be site-specific and highly depends on the level of design margin built into the original plant, as well as its maintenance history, current condition and remnant life of key components.

Careful planning and a value engineering approach can result in an optimised replant scope of work, and where project economics are favourable, enables asset owners to offer flexible power generation capacity to the market from their existing portfolio, at significantly lower capital investment levels than a new build project of a similar capacity. ■

Acknowledgements

Authors would like to acknowledge their colleagues for their support and valued input, in particular, from Centrica, Adam Kennard and James Eyton, and from WSP, Katherine Jackson and Andrei Bettinson.

The authors

Ryan Broughton is a Principal Engineer with WSP working in the development and delivery of power projects, particularly replants, combined heat and power and decarbonisation. He has a keen interest in the planning, technical and regulatory changes that will affect the energy market over the next decade.

Hassan Joudi is a Senior Engineer with WSP with experience of working on both the client and consultant sides of power generation projects. He has worked across multiple phases of project delivery, including tender evaluation, construction management, independent certification, management of change control and asset integrity.