Solar Boost Project

End of project report on the Kogan Creek Power Station Solar Boost Project

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Executive summary

The Kogan Creek A Power Station Solar Boost Project (the Solar Boost project) was a project to construct a solar thermal addition to the 750 megawatt coal-fired Kogan Creek Power Station near Chinchilla in south west Queensland.

The concept was for the solar thermal addition to 'boost' the generation output of a modern coal-fired power station by up to 44 megawatts in peak solar conditions. Solar thermal energy would be used to evaporate and superheat boiler feedwater to produce high quality steam. This steam would be fed into the power station's turbines to increase the power station's electricity generation output while burning the same amount of coal.

The project commenced construction in 2011 and was designed to use AREVA Solar's Compact Linear Fresnel Reflector (CLFR) technology. The project encountered significant delays during construction. After careful consideration of all possible options for the project, the responsible course of action was to discontinue the project. On 18 March 2016, CS Energy and ARENA announced that the Solar Boost project would not be completed due to technical and contractual difficulties and the resultant negative impact on the project's commercial prospects. The solar thermal addition could not be commercially deployed without substantial further financial investment and there was no prospect of ever getting a positive return on that investment.

This report provides valuable insights gained during the Solar Boost project that can be used to strengthen future renewable energy developments. CS Energy and ARENA are working together to ensure the project contributes to industry knowledge on solar thermal technology.

This report provides an overview of the Solar Boost project and knowledge gained through the design and construction stages.

In summary:

- Selection of the location for solar thermal addition is critical. A location's suitability is dependent on high solar insolation, reasonably flat land in close proximity to the power station, spare capacity in the power station, as well as a match between the power station's remaining asset life and the solar field's asset life.
- The version of CLFR technology to be deployed on the project was at an early stage of the solar thermal technology life cycle. Subsequent design improvements have the potential to reduce transportation costs, site assembly costs, operation and maintenance costs, and provide a safer, more controllable and more robust plant.
- The lack of maturity of the global, "least cost" supply chain for equipment and materials deployed by the technology provider severely impacted the project in the initial stages of construction, resulting in significant delays, coordination difficulties, and rework.
- Fabrication and construction quality issues that arose during the project raised concerns about the expected production and operation and maintenance costs assumed for the

solar thermal addition, negatively impacting the forecast commercial viability of the project.

- The project contributed to the knowledge and capability of local suppliers engaged to supply parts and services to the project, and provided local employment opportunities. More than 120 people worked on the first phase of the Solar Boost project’s construction.
- In 2009, when the project was conceived, the levelised cost of electricity from solar thermal generation was comparable to that of solar photovoltaic generation. However, over the intervening period, solar photovoltaic plants have significantly reduced their costs compared to solar thermal plants.
- The funding and project delivery model established for new technology projects must take into consideration the nature and requirements of the technology, the technology provider, construction costs and risks and project proponent’s funding capability, risk appetite and expertise. Models should consider facilitating solution-focused collaboration between the parties while meeting the project fundamentals of time, quality and budget.

Project overview

The Solar Boost project was an innovative project developed through collaboration between:

- the Kogan Creek Power Station owner, CS Energy Limited (though its subsidiary Kogan Creek Power Station Pty Ltd); and
- the technology provider and engineer, procure and construct (EPC) contractor, AREVA Solar KCP Pty Ltd.

The project was conceived in 2008, and CS Energy submitted a funding application to the Department of Resources, Energy and Tourism (DRET) in April 2009. All necessary project approvals to proceed were obtained in March 2011, including execution of a project funding deed between CS Energy and DRET. In July 2012, ARENA assumed DRET's rights and obligations under the funding deed.

Funding for the project included a $70 million contribution from CS Energy, and a contribution of $34.9 million from the Australian Government through its Renewable Energy Demonstration Programme. CS Energy received funding from its owner, the Queensland Government, via a contribution of $35.4 million to the company's Carbon Reduction Program which enabled funds to be directed to the project.

The Renewable Energy Demonstration Program objective was to accelerate the commercialisation and deployment of renewable technology in Australia, and demonstrate its application on a commercial scale.

Site work commenced in the middle of 2011. In early 2013, AREVA Solar stopped work on site. CS Energy and AREVA Solar then entered into extensive negotiations to identify a viable solution to the issues affecting the project's progress. In August 2014, AREVA Solar's parent entity, AREVA S.A., announced the group's intention to discontinue its concentrated solar power business.

In 2015, in consultation with AREVA Solar and ARENA, CS Energy reviewed the original project and considered a number of alternative project completion options. During this period, CS Energy secured a licence to complete the project using AREVA Solar's intellectual property rights in the v1.3+ technology.

No viable alternative to the original project concept was identified. CS Energy was also unable to identify any viable project completion plan for the original project that overcame the commercial challenges. Additionally, CS Energy expected that AREVA's withdrawal from the concentrated solar power business would result in AREVA Solar's technical capability declining and being a further impediment to completing the project.

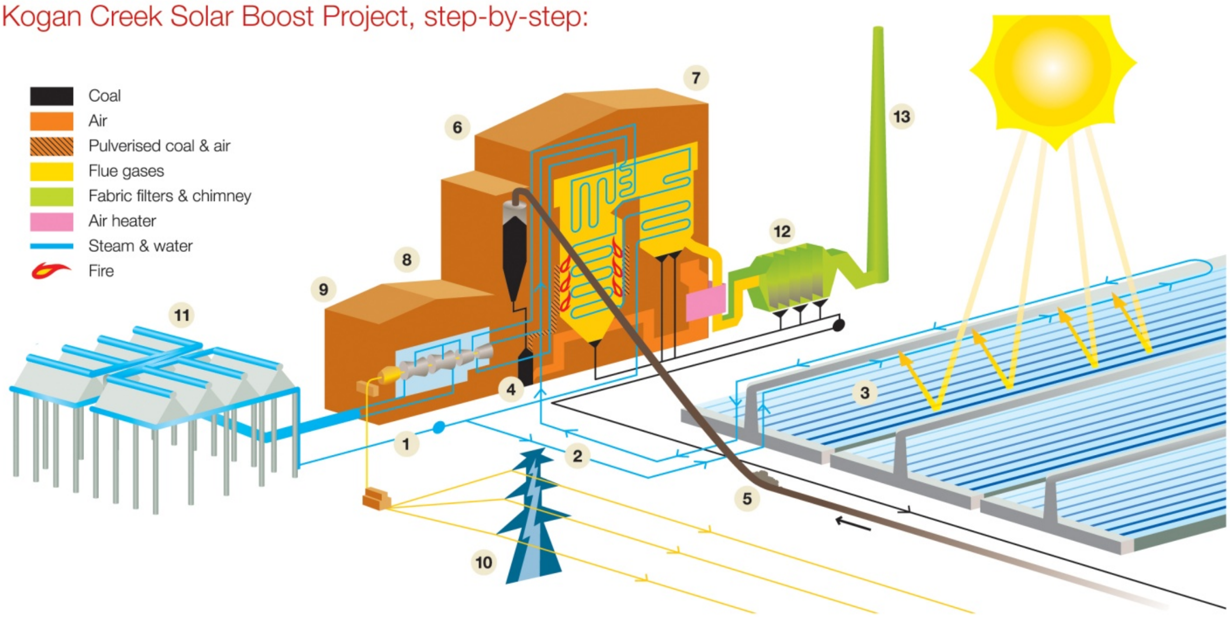
CS Energy announced on 18 March 2016 that the project would not be completed due to the technical and contractual difficulties encountered during construction and the resultant negative impact on the project's commercial prospects. It was determined that the solar thermal addition could not be commercially deployed without substantial further financial investment, and there was no prospect of achieving a positive return on that investment.

Project summary

The Solar Boost project was to provide, in peak solar conditions, a 44 megawatt solar thermal addition to the 750 megawatt Kogan Creek Power Station (equivalent to 44 gigawatt hours each year of electricity). The project was designed to use AREVA Solar’s CLFR technology to augment the power station’s system for heating the high temperature and high pressure steam used in the electricity generation process. The solar thermal technology was to be used to heat feedwater into superheated steam, supplementing the coal-fired boiler. The solar-heated steam would be used to generate extra electricity and increase the power station’s fuel efficiency.

The solar thermal addition would comprise a field of 14 solar steam generators covering a land area of 30 hectares adjacent to the power station. The diagram below provides an overview of how the project was designed to work.

Kogan Creek Solar Boost Project, step-by-step:



Solar energy will be used to boost the conventional coal-fired electricity generation process at Kogan Creek Power Station. The steps below outline how the two technologies will be combined.

1. Cold water from the air-cooled condenser is piped to the boiler feedpump.
2. Water is diverted to the solar field.
3. The solar field converts the water to steam using large mirrored panels to reflect and concentrate sunlight on to elevated water pipes.
4. Steam from the solar field is further heated and used to power the intermediate pressure turbine to generate electricity.
5. Coal from the stockpile is fed to the power station.
6. Pulverised coal is blown and ignited in the boiler.
7. Water is heated in the boiler to produce steam.
8. Steam drives the turbine. The addition of the solar field increases the amount of steam available for the electricity generation process.
9. The turbine spins the generator. A powerful electromagnet is mounted on the generator shaft and when it rotates, produces electricity in the surrounding generator windings.
10. Electricity is transported to customers via high voltage transmission lines. At peak solar conditions, the solar field will enable Kogan Creek to generate an extra 44 megawatts of electricity.
11. Steam is condensed into water in the air-cooled condenser and then pumped back to the boiler feedwater pump for reuse.
12. A filter system cleans fly ash from the boiler exhaust gases before it is discharged up the chimney.
13. Ash is used in rehabilitation of the Kogan Mine site.

Expected societal benefits

The construction and operation of the solar thermal addition to the Kogan Creek Power Station was expected to demonstrate and support the subsequent commercial development and deployment of both hybrid and standalone solar thermal technology for use in electricity generation and industrial-scale heating applications.

In addition, the project was expected to create local employment and industry supply chain opportunities during its construction. It was envisaged that this would contribute to skills development in the region that could be applied to future solar thermal projects.

Timeline

DATE	EVENT
August 2008	Project inception – the first meeting between CS Energy and Ausra (later to become AREVA Solar).
15 April 2009	CS Energy submitted an application for grant funding for the project through the Commonwealth Government's Renewable Energy Demonstration Programme.
March 2011	Commonwealth Government funding deed signed between CS Energy and DRET for $35.4 million on a milestone basis. (The deed was subsequently transferred to ARENA.) CS Energy committed to the project by signing contracts with AREVA Solar to engineer, procure and construct (EPC) the solar field, and with Clyde Babcock Hitachi (Australia) Pty Ltd for the balance of plant work.
September 2011	Balance of plant interface work inside the boiler / turbine house was completed during a scheduled power station overhaul (on time/budget/quality).
6 July 2012	AVEVA Solar reached contract Milestone 4: Bulk earthworks completed.
January 2013	Mechanical erection sub contractor, Murphy Pipe and Civil, demobilise from site (mid-contract). AREVA Solar suspend site works.
May 2013	Original scheduled date for completion of AREVA Solar contract and commencement of project operation.
January 2014	Most project components fabricated and delivered to site, or to a nearby offsite storage yard. AREVA Solar suspended off site work. In 2016, post-execution of the settlement agreement, AREVA Solar completed delivery of all manufactured project components to site.
August 2014	AREVA announced its intent to exit from its global solar business.
18 March 2016	CS Energy announced the project would not be completed.

Project technology

The project used AREVA Solar's Solar Steam Generator "SSG" version v1.3+ technology. Fourteen SSGs were to be constructed. Each SSG was characterised by:

- 390 mirrored reflectors installed on one horizontal plane (arranged in a grid of 13 east-west by 30 north-south).
- Reflector dimensions of approximately 16 metres long and 2.2 metres wide.
- Overall SSG dimensions of approximately 500 metres north-south and 36 meters east-west.
- Reflectors in the north-south direction are "ganged" together in groups of six and driven by an electric motor and AREVA Solar custom drive reduction unit in the centre of the six reflectors. The number of reflectors in the north south-direction can be varied to suit site layout.
- One linear receiver located approximately 16 metres above the reflectors. The receiver is an insulated cavity with a glass bottom, which houses two independent sets of boiler tubes. Each independent set of boiler tubes has three economiser tubes on the outside that connect to a header at the northern end and return via an inner superheater tube.
- Valves and pipework for feedwater and steam arranged at one end.

Following execution of the EPC contract for the project, AREVA Solar entered into two solar field contracts using upgraded v2 technology for separate projects in Rajasthan in India and Arizona in the USA. CS Energy understands that the v2 plant at both these sites is operational.

CS Energy's understands that the v2 technology is characterised by increased size in most dimensions, including the reflectors, the reflector field, the receiver, and the receiver height above the field. The receiver has economiser tubes on the east and west, and one central, larger superheater tube. The design and operational concepts in v2 are refined compared to v1.3+; however they are not fundamentally different.

Lessons learned

This section of the report provides an overview of the key elements of the Solar Boost project, including the factors that contributed to the decision to not complete the project. This section also articulates the knowledge gained during the project for the benefit of future solar thermal technology projects.

CS Energy's involvement with the Solar Boost project has enabled the company to form a view on the deployment of this solar thermal technology. In particular, the technical elements of the technology applied to the project, an assessment of the technical viability of the technology, design issues and constructability.

CS Energy's perspective on the v1.3+ solar thermal technology and project execution is outlined in the sections below. They are categorised as follows:

1) Location;
2) Technical;
3) Design;
4) Supply chain;
5) Operation and maintenance;
6) Contract and Funding Model; and
7) Commercial viability.

Location

The decision on whether an existing power station is suitable for solar hybrid addition is complex, with considerations including:

- access to reasonably flat land very close to the power station;
- high solar insolation;
- spare capacity in the power station turbine to "swallow" extra solar steam;
- environmental factors; and
- a match between a power station's remaining asset life and the solar field's asset life (to minimise the risk of a stranded asset).

These factors were considered and found to be favourable with respect to the location of the Solar Boost project adjacent to the Kogan Creek Power Station. The completed work on the project confirmed that the original selection of the Kogan Creek Power Station was valid, although there were integration issues that remain unproven and could only be validated by completion and operation of the solar project.

Technical

CS Energy reviewed the AREVA Solar v1.3+ technology and viewed an operating AREVA Solar plant with v1.3+ technology at Kimberlina in California, USA prior to signing the EPC contract. CS Energy's view was that the design and construction was technically suitable for a successful Kogan project. During the design and construction phase of the project, CS Energy conducted a design review and did not identify any fundamental design flaws in the v1.3+ technology, though many minor issues and multiple potential improvements were subsequently identified. This view of the technical viability is reinforced by the operation of the v2 technology at other sites.

However, the Kogan project experienced one significant technical issue. During construction, CS Energy formed the strong view that the boiler tubing supplied for the project was unsuitable for the site conditions. This became apparent when the majority of the economiser boiler tubes rapidly rusted both pre and post-installation. These economiser boiler tubes were "Solonyx" coated tubes, which was a coating developed by AREVA Solar. AREVA Solar discontinued production of this coating shortly after completion of the tube production run for the project, and subsequently used a commercially available coating produced by a third party supplier. The superheater tubes, which used conventional nickel plating, were not affected by the site conditions.

At the time of project approval, a full risk assessment was conducted to identify and mitigate risks associated with integration of the solar field with the Kogan Creek Power Station. However, a significant technical issue, relevant to the integration of the solar thermal addition materialised post that risk assessment, being the impact on the Kogan steam turbine from a sudden reduction in solar steam flow caused by rapidly moving clouds. The emergence of this issue heightened CS Energy's concerns regarding the risks associated with integrating the solar boost addition with the power station.

Design

The v1.3+ design was at an early stage of solar thermal technology life cycle. Improvements in design could reduce transportation costs, site assembly costs, operation and maintenance costs, and provide a safer, more controllable and more robust plant.

A number of technical issues and opportunities for improvement were identified. These include:

1) The supplied design had the boiler tubes in two separate halves – effectively two separate boilers per receiver; with common boiler external piping and valves, rather than a single superheater tube. This "two half" design resulted in control challenges to balance the flow and temperature in each "half" and maintain stable steam flows from each "half" without choking the flow in one half with resultant over temperatures caused by the low flow. AREVA Solar's v2 design has addressed this issue.
2) The temperature measurement system within the boiler was complicated and a potential failure point and the location restricted access for repairs. Physical temperature measurements were unreliable in the solar steam generator's receiver due to the tube

expansion and a relatively small receiver cavity. Opportunities to improve measurement availability and to reduce the cost of repairs to measurement equipment include:

- the provision of dual head Resistance Temperature Devices (RTDs);
- mounting RTDs in a thermowell for easier maintenance;
- design for failure in cabling that preserves the RTD itself at the sacrifice of the cable, which is easier to replace; and
- alternative, prospective methods of control which may reduce capital and operation and maintenance costs, and improve control include measuring tube expansion as proxy for RTDs and modelling the temperatures rather than direct RTD measurement.

3) The amount of interconnecting cabling and cable tray could be reduced by using available hollow steel beams where possible. The need for buried cabling could be reduced by using overhead structures where available.
4) The access to the receivers for maintenance could be more cost effective with improved design. Additionally, design improvements could reduce the need to access the receiver. For example, more robust and reliable RTDs and a design that allows cleaning of the receiver glass from one end of the receiver, rather than requiring access along the entire receiver.
5) A reduction in health and safety hazards could be achieved by adopting a safety in design approach. For example, reducing sharp metal edges and reducing pinch points on reflector drives.
6) Ribbed boiler tubes might allow improved control and reduced costs as a smaller diameter tube would have higher fluid velocity with reduced process dead time and delays that make control difficult.

Opportunities for design improvements also exist in the trade-off between the supply cost for solar thermal plant equipment and on-site labour erection cost. The v1.3+ technology design was at an early life cycle stage and not fully optimised, resulting in items such as the mirror drives being an AREVA Solar designed solution with significant on site erection labour. This issue could be addressed by purchasing the mirror drives from an experienced actuator drive supplier with a depth of experience in similar applications and lower site erection costs.

Improved design that takes into account transportation and quicker site assembly could result in reductions to transport-related costs, which are a key factor for projects, particularly those in regional or remote locations. For example, there is a trade-off between fabricating the reflectors on or close to the solar field site, with the size unconstrained by transport considerations, and the reflectors being partially pre-made in a central factory with simple final assembly on site. If the latter option is required due to on-site fabrication costs (labour, etc), then the reflector size must be optimised for transport and designed for simple final assembly on site. Similarly, design changes could facilitate better stacking of equipment for transport in order to facilitate cheaper transport costs and reduced costs for unloading the materials at site.

Supply chain

Kogan Creek was AREVA Solar's first commercial project and the work package decisions and supply chain concept resulted in delays, coordination difficulties and rework that might have been avoided with a different model. This section discusses those decisions.

AREVA Solar devised a procurement model that included a worldwide supply chain, least cost procurement, shipping from suppliers to site by an AREVA group appointed logistics company and just in time delivery to the construction site. The plant was split into the SSG component ("product"), which was a standard design, and the balance of plant, which was customised for Kogan Creek. The construction was originally intended to be awarded to a single design and construction company, however was ultimately split into civil, mechanical and electrical construction companies. The civil and mechanical designs were also separately awarded, whilst the electrical design was undertaken by the electrical construction company. An advanced, robotic manufacturing facility was set up nearby at Dalby to fabricate the approximately 5,500 mirrored reflectors required for the project.

One of the expected benefits of the Solar Boost project was its potential to contribute to the knowledge and capability of local suppliers. CS Energy and AREVA Solar achieved this by sub-contracting local suppliers to supply parts and services to the project. All equipment for the 14 SSGs was manufactured and delivered, leading to significant local work opportunities. Local suppliers from the Darling Downs region were successfully engaged in this program. Local suppliers were also engaged to re-work faulty equipment that arrived from overseas suppliers. These suppliers provided good quality components with a quick turnaround and were effectively monitored by the local AREVA Solar project team. The project also provided local employment opportunities during construction. More than 120 people worked on the first phase of the Solar Boost project's construction, however, the completed project would not have resulted in any permanent jobs.

However, project delays and difficulties arose from the immaturity of the supply chain. Design changes delayed fabrication, while fabrication in many geographically diverse factories resulted in difficulty in monitoring quality, leading to rework either overseas or in Australia and further delays. These issues consumed project management time at the expense of other project management tasks. One local fabricator went into administration, requiring an alternative local supplier to be selected and to ramp up production. This had the potential to delay the project if all other project activities were running to schedule, however concurrent issues with greater delays resulted in the administration issue not actually delaying the project.

A mitigating measure implemented late in the project was to move from the "just in time" delivery model to a model where equipment was delivered early, with significant quantity of equipment held on site in advance of the construction schedule. This was intended to avoid off-site issues impacting the expensive on site erection task and should have been effective. However, AREVA Solar did not resume site construction so the effectiveness of the change was not tested.

The project team considered that economies of scale and improvements in quality could be achieved with larger manufacturing volumes.

In addition, AREVA Solar's separation of the design and construction work packages, and the split of the construction package into civil, mechanical and electrical contracts created work coordination inefficiencies and Federal Safety Commission compliance issues. A larger AREVA Solar management workforce was required to coordinate these packages, reducing any expected economic gains from splitting the work packages.

Operation and maintenance

CS Energy engaged AREVA Solar on the basis that the delivered project would set new standards for a low maintenance, low operating cost project. The operating regime appeared to be progressing to target and most plant equipment was selected for trouble free operation. However, some quality issues resulted in an increase in maintenance costs and the semi automatic mirror cleaning remained unresolved. These are discussed below in the context of reflector cleaning, plant automatic operation and other maintenance items.

Reflector cleaning: A significant, outstanding maintenance issue was the cleaning system for the reflectors. Reflector cleaning is customised for each facility, as each facility is unique from a labour cost, labour skill, revenue and soiling (dust) perspective. AREVA Solar had not developed a cost effective cleaning system suitable for the Solar Boost plant, however, had identified a number of prospective semi-automated robotic solutions. The manual cleaning of reflectors using squeegees and demineralised water was a viable, albeit higher cost, interim solution.

Plant automatic operation: CS Energy had specified that operation of the Solar Boost plant was to be fully automatic, as AREVA Solar had demonstrated good progress towards achieving automation at their Kimberlina plant in the USA. Consequently, operator staffing at the plant was expected to be minimal, leveraging off the existing Kogan Creek Power Station workforce, with no increase in the number of full time positions at the power station. While the project did not reach the operation and maintenance stage, preparation for this was well advanced with CS Energy witnessing the testing of the plant control systems. CS Energy expected that automatic operation of the plant would be achieved.

Other Maintenance: Fabrication and construction quality issues arose during the project. Some plant components did not comply with design requirements. For example, some components were supplied unpainted, welds on imported equipment were not to Australian or international standards, and corrosion issues emerged due to inappropriate material selection. In addition, the internal road construction for the project did not comply with the design. The result of these quality issues was a forecast increase in maintenance costs had the project been commissioned.

The emerging operation and maintenance issues had an impact on the commercial viability of the project, with CS Energy having a residual concern that new emergent issues would further negatively impact the net cash flow from the project.

Project delivery contract and funding model

The structure of the project delivery model (incorporating both contract and funding mechanisms) established for new technology projects must take into consideration a number of issues including the:

- nature and requirements of the technology;
- the capability and experience of the technology provider;
- capability and experience of the constructor;
- construction costs and risks; and
- project proponent's funding capability, risk appetite and expertise.

Models should facilitate solution-focused collaboration between the parties while meeting the project fundamentals of time, quality and budget with a well-specified scope of works. It is also important to determine the appropriate risk allocation that will be shared between the parties (which will also influence cost).

Commercial viability

In 2009, when the project was conceived, the levelised cost of electricity from solar thermal generation was comparable to solar photovoltaic. However, over the intervening period, solar photovoltaic plants have significantly reduced their costs compared to solar thermal plants.

Large scale solar thermals plants are still being constructed with the assistance of grants and subsidies. However, they now include thermal storage to shift their generation to more desirable peak periods, where the competing technology is solar photovoltaic with battery storage.

More specific to the Solar Boost project's commercial viability were the aforementioned technical and contractual issues. Once these issues arose, it became clear that the project could not be commercially deployed without substantial further financial investment – and no prospect of ever getting a positive return on that investment.

Conclusion

The Solar Boost project was a project to construct a solar thermal addition to the 750 megawatt coal-fired Kogan Creek Power Station. The concept was for the solar thermal addition to ‘boost’ the generation output of the power station by up to 44 megawatts in peak solar conditions.

In March 2016, CS Energy and ARENA announced that the project would not be completed due to technical and contractual difficulties and the resultant negative impact on the project’s commercial prospects. The solar thermal addition could not be commercially deployed without substantial further financial investment – and there was no prospect of ever getting a positive return on that investment.

Given the difficulties experienced, it remains questionable as to whether the project’s actual performance would have met that originally conceptualised had the project been completed.

The key insights gained through the project can be summarised as:

- Selection of the location for solar thermal addition is critical.
- The project contributed to the knowledge and capability of local suppliers engaged to supply parts and services to the project; and provided local employment opportunities.
- The version of CLFR technology to be used on the project was at an early stage of the solar thermal technology life cycle. Design improvements have the potential to reduce costs and provide a safer, more controllable and more robust plant.
- The lack of maturity of the global, “least cost” supply chain for equipment and materials deployed by the technology provider severely impacted the project.
- Fabrication and construction quality issues that arose during the project raised concerns about the operation and maintenance costs, further eroding the commercial viability of the project.
- Solar photovoltaic plants have significantly reduced their costs compared to solar thermal plants in the period since the project was conceived. Large scale solar thermals plants are still being constructed with the assistance of grants and subsidies, however they now include thermal storage capability.

The combination of factors that resulted in the Solar Boost project not being completed was unique to the project. These factors are, however, not uncommon in the deployment and commercialisation of new technology.