

# Re-deployable Hybrid Power Product Development Report



ARENA



Australian Government  
Australian Renewable  
Energy Agency

LAING O'ROURKE

**“A portable hybrid system, constructed off-site and easily transportable, could be a real game changer for off-grid locations in Australia and beyond”**

ARENA Chief Executive  
Ivor Frischknecht  
in The Australian, 2 April 2014



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## Aknowledgements

ARENA



Australian Government  
Australian Renewable  
Energy Agency

This project is supported by the Australian Government through the Australian Renewable Energy Agency (ARENA). ARENA was established by the Australian Government as an independent authority on 1 July 2012 to make renewable energy technologies more affordable and increase the amount of renewable energy used in Australia. ARENA is funded to 2022 to invest in renewable energy projects, support research and development activities, and increase industry and community knowledge about renewable energy. More information is available at [www.arena.gov.au](http://www.arena.gov.au)



Redispan  
DfMA™

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In addition to the parent company, two wholly-owned subsidiaries of Laing O'Rourke are involved with this project:

- Select Plant Hire owns and manages one of Australia's largest ranges of equipment with a current asset net book value of \$150 million. Select Plant Hire manages over 200 diesel generators across Australia with major current deployments including Ichthys Cryogenic Tanks (Northern Territory, 2MVA), Northern Water Treatment Plant (Queensland, 600kVA) and APLNG (Queensland, 1,150kVA).
- Redispan manufactures and markets Design for Manufacture and Assembly (DfMA) modules, chiefly conveyor systems for materials handling applications.

The chief contact point for this project is Laing O'Rourke's Clean Technology Leader Dr Will Rayward-Smith ([wraywardsmith@laingorourke.com.au](mailto:wraywardsmith@laingorourke.com.au))



The following parties were appointed by Laing O'Rourke and ARENA to deliver this project:

- SunPower for simulation of the solar farm and peer review of the solar module to ensure compliance with SunPower's product and power warranties;
- GreenSense for the remote monitoring of Select Plant Hire's existing diesel-only generators at APLNG, Queensland;
- Power Technology Engineered Solutions and Clean Technology Partners for the concept design and simulation of different hybrid integration strategies and technologies
- HOMER Energy for the provision of training on HOMER 2 (micro-grid design optimisation);
- Open Instruments for electroluminescence imaging of panels during the prototyping stage; and
- Coffey for geotechnical engineering of the ground restraint solution.

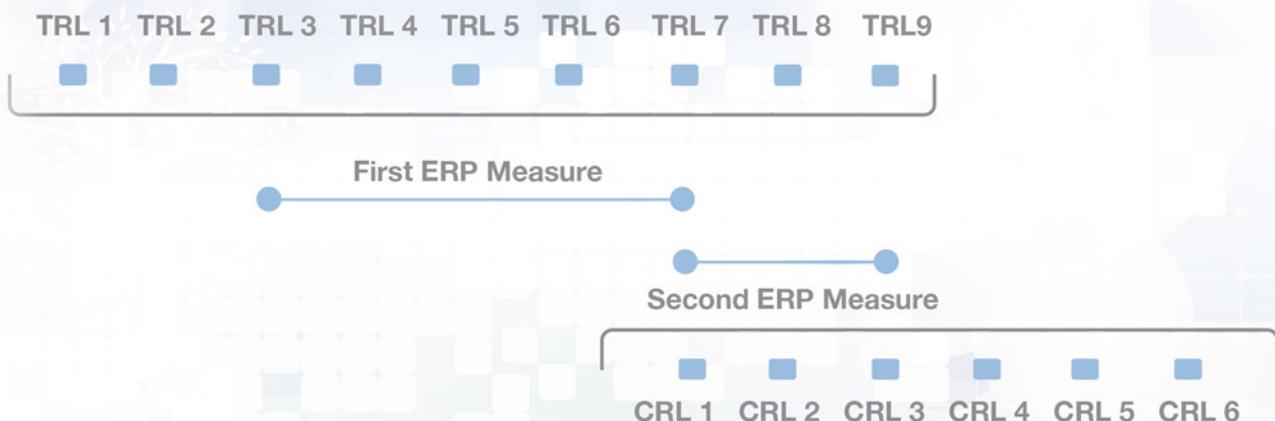
## History

In late 2013, Laing O'Rourke conceived the idea of a modular solar-diesel hybrid plant manufactured off-site and efficiently packed-down (installed) on-site. There are benefits in quality, programme, safety, cost and risk to be realised by all installations using this modular technology. Furthermore, the modular nature of the innovation enables the plant to be easily packed-up and re-deployed to a different site, thereby facilitating temporary installations.

Laing O'Rourke progressed the idea through concept design and early-stage feasibility to achieve Technology Readiness Level (TRL) 3 and, in early 2014, presented the concept to ARENA, seeking the support of the Australian Government, critical to enabling further product development.

On 6 March 2014, Laing O'Rourke and ARENA signed an equal-contribution Funding Agreement, in the form of an Emerging Renewables Program (ERP) Measure, to progress the technology to TRL 7 through detailed design and prototyping.

In June 2014, Laing O'Rourke presented the outcomes of the ERP Measure to ARENA, having also identified and planned the first commercial deployment of the technology. The success of the first Measure led to Laing O'Rourke and ARENA signing a second ERP Measure on 14 July 2014 to progress the technology to TRL 9 and Commercial Readiness Level (CRL) 3 through manufacture and first commercial deployment of a large-scale system.



## Purpose of this document

This document is produced at the end of the first ERP Measure to serve as an update to interested parties and the general public on the progress that has been achieved thus far. Such knowledge sharing will continue through into the second ERP Measure, with key deliverables of the second ERP Measure including:

- conference presentations;
- high-level technical specifications of the technology;
- contract type used for the first deployment and options for further deployments including retail, week-by-week hire and Power Purchase Agreements (PPAs);
- relevant Australian conditions, laws and regulations;
- product brochure with overview of logistics, pack-down, operation & maintenance and even tual pack-up;
- impact study of the first deployment on the local community;
- performance of the technology in operation; and
- video press release and site tours.

## Table of contents

<b>03</b>	<b>History</b>
<b>03</b>	<b>Purpose of this document</b>
<b>04</b>	<b>Table of abbreviations</b>
<b>05 1</b>	<b>Introduction</b>
<b>05 1.1</b>	The drivers
<b>06 1.2</b>	The market
<b>08 1.3</b>	The ambition
<b>08 2</b>	<b>The technological solution</b>
<b>08 2.1</b>	Mechanical design and the DfMA Solar Modules (DSMs)
<b>08 2.1.1</b>	Australian cyclonic and soil characteristics
<b>10 2.1.2</b>	Design evolution
<b>12 2.1.3</b>	Ground restraint
<b>13 2.1.4</b>	Digitally-engineered construction sequence
<b>15 2.1.5</b>	Prototyping
<b>17 2.2</b>	Electrical design and the Hybrid Integration Modules (HIMs)
<b>18 2.2.1</b>	Load profiles
<b>20 2.2.2</b>	Integration options
<b>21 3</b>	<b>The commercial wrap-up</b>
<b>22 4</b>	<b>The first commercial deployment</b>

## Table of abbreviations

<b>ARENA</b>	Australia Renewable Energy Agency
<b>BOS</b>	Balance of System
<b>CRL</b>	Commercial Readiness Level
<b>DfMA</b>	Design for Manufacture and Assembly
<b>DSM</b>	DfMA Solar Module
<b>ERP</b>	Emerging Renewables Program
<b>FDB</b>	Functional Design Brief
<b>HIM</b>	Hybrid Integration Module
<b>LCOE</b>	Levelised Cost of Energy
<b>PV</b>	Photovoltaic
<b>TRL</b>	Technology Readiness Level



# 1 Introduction

In this section we explain the drivers for a modular solar-diesel hybrid plant and discuss the market in Australia and abroad.

## 1.1 The drivers

The industry has seen a significant reduction in the Levelised Cost of Energy (LCOE) from solar photovoltaics (PV) over the past three decades. This reduction has chiefly been due to cost reductions in the solar panels, driven by both technological advances and mass manufacturing. As panel costs continue to decline, the civil, structural and installation costs become proportionately more important over time. In order to continue the downward trajectory in the LCOE from solar PV, innovations in these Balance of System (BOS) items must be conceived and developed.

The traditional approach to construction is to deliver large quantities of materials to the construction site, where large numbers of workers bring them together, often in inhospitable working conditions. A more innovative approach, adopted by Laing O'Rourke and challenging this traditional view, is to Design for Manufacture and Assembly – DfMA – where modules are fabricated off-site and efficiently assembled on-site. Benefits of DfMA include:

- significantly reduced construction programme and reduced risks on-site;
- increased quality and safety due to the majority of the work being carried out in a controlled factory environment; and
- the iterative optimisation of civil and structural elements is enabled.

Increasing the adoption of DfMA in the renewable industry represents an opportunity to drive down the costs of the BOS.

In addition to DfMA benefiting permanent installations, such as power stations for remote communities, the approach ensures ease of pack-up and therefore enables re-deployment to a different site if required. In this way, new sub-sectors of the market may be served:

- Those demanding short deployments such as mines – in this case the customer may wish to:
  - i) own the asset and relocate;
  - ii) lease the asset for a short term from another owner; or
  - iii) purchase the energy from a power provider.
- Those demanding flexibility such as remote power providers – for example, a remote power provider may install a centralised power system with PV to power a community, only to find several years later that the community's demand decreases, perhaps through the uptake of rooftop solar within the community or through population movements. In this scenario, the remote power provider would benefit from relocating some of the solar PV to another load where it will be better utilised.

The incumbent technology for off-grid power is the diesel generator. Installing solar alongside a diesel generator represents an attractive proposition in that the output from the solar displaces diesel fuel and therefore solar output can achieve a sale price of >\$0.30/kWh – this is more than may be achieved by:

- installing solar on a residential/commercial rooftop and displacing retail electricity (~\$0.20/kWh); and
- installing solar on the grid and selling wholesale electricity (\$0.05-0.15/kWh).

Despite the high price that may be achieved for solar, the incumbent diesel generator continues to prevail and there is limited uptake of solar-diesel hybrids. The fundamental issue is that the diesel generator is a portable, modular, proven, off-the-shelf technology whereas traditional solar-diesel hybrid is perceived as a permanent, difficult to install, bespoke technology. In order for solar-diesel hybrid to become the modus operandi, it must become as modular, as proven and as 'off-the-shelf' as the trusted diesel generator.

## 1.2 The market

Together with ARENA, the Bureau of Resources and Energy Economics (BREE) provides a valuable source of information relating to the market for regional and remote electricity in Australia, identifying power sources for 94% of Australia's off-grid population in 2011-12 (see Beyond the NEM and the SWIS: 2011-2012 regional and remote electricity in Australia). In 2011-12, for off-grid electricity:

- demand (kWh) was 77% 'resources and energy' and 21% 'residential, commercial and community'; and
- supply (kWh) was 79% natural gas and 19% liquid fuels (predominantly diesel).

With regard to installed power capacity in Australia, our analysis, summarised in Figure 1, highlights that liquid fuels are the preferred source for low power applications off-grid (<8MW) and natural gas the preferred source for high power applications off-grid (>32MW).

### Cumulative installed capacity in off-grid Australia (MW)

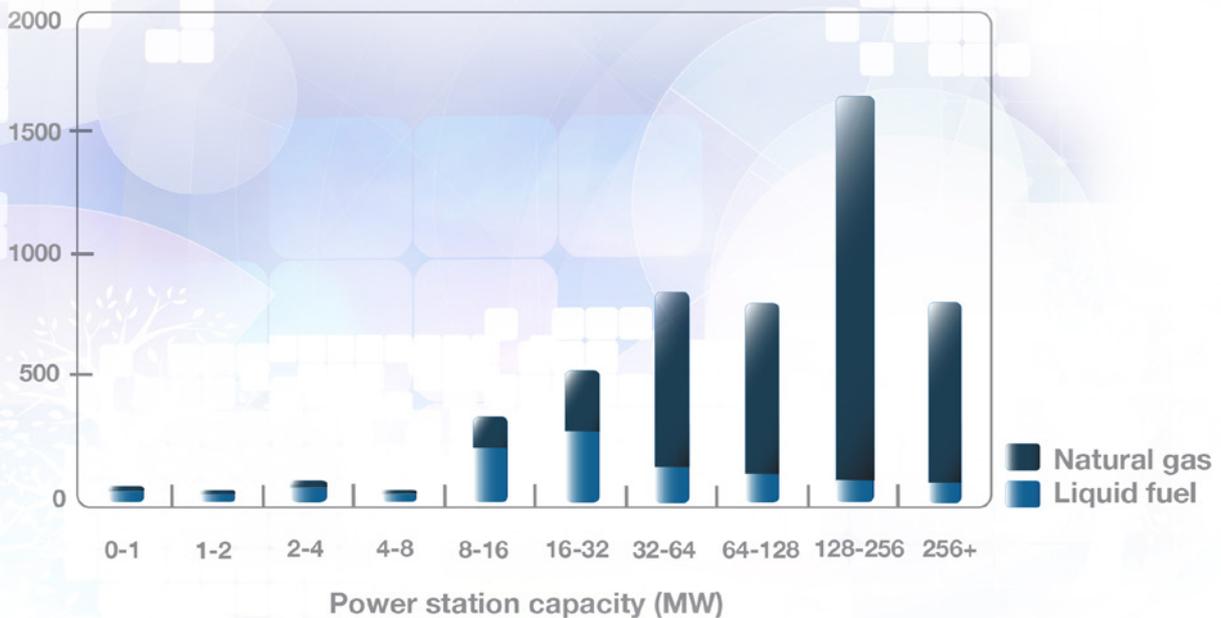


Figure 1  
Off-grid power stations in Australia, bucketed by nameplate power capacity

For the purpose of this report, we restrict our attention to the off-grid portion that is powered from liquid fuels. In 2011-12, 2,986GWh (gigawatt-hours) of electricity was generated from 27,254TJ (terajoules) of liquid fuel (predominantly diesel) via 1,187MW of generating capacity. Assuming that this is entirely diesel with an energy density of 38.6MJ/L, a cost of \$1.35/L (including delivery and with Federal Excise reclaimed) and a carbon intensity of 2.68kgCO<sub>2</sub>/L, we highlight the slaving of the off-grid market to diesel fuel, together with the economic and environmental implications:



We note that the scale of this diesel consumption for electricity generation is supported by the Australian Bureau of Statistics with 615,000,000L diesel consumed for electricity generation in 2001-02 (see ABS 4648.0.55.001).

If income from solar photovoltaics is simply diesel fuel displacement then the above figures highlight that:

- market saturation of low energy-penetration (10-20% of total kWh from solar) solar-diesel hybrids may divert approximately \$100-200m/year away from diesel fuel expense; and
- market saturation of high energy-penetration (>50% of total kWh from solar) solar-diesel hybrid may divert in excess of \$0.5bn/year away from diesel fuel expense.

High energy-penetration systems may not just displace diesel fuel but also diesel generating capacity, thereby diverting expense that would otherwise be spent on hiring/purchasing diesel generators. We may estimate the market's expense on hiring/purchasing diesel generators with the knowledge that 1,187MW of liquid fuel generating capacity is deployed in the off-grid market in Australia. We may calculate a lower bound by assuming that all generators are purchased and an upper bound by assuming that all generators are hired. Assuming an average purchase cost of \$250,000/MW and an average lifetime of 6 years, the lower bound is \$50m/year. Assuming an average hire rate (including operation and maintenance) of \$250,000/MW/year, the upper bound is \$300m/year. This highlights that it is chiefly the diesel fuel displacement rather than the diesel generating capacity displacement that represents the main opportunity for income diversion towards solar.

The market in Australia is by no means unique with regards to the pervasiveness of the diesel-only generator for electricity generation in remote areas. Globally, 40GW of new diesel generators are installed every year on top of a cumulative 500GW genset base, as shown in Figure 2.

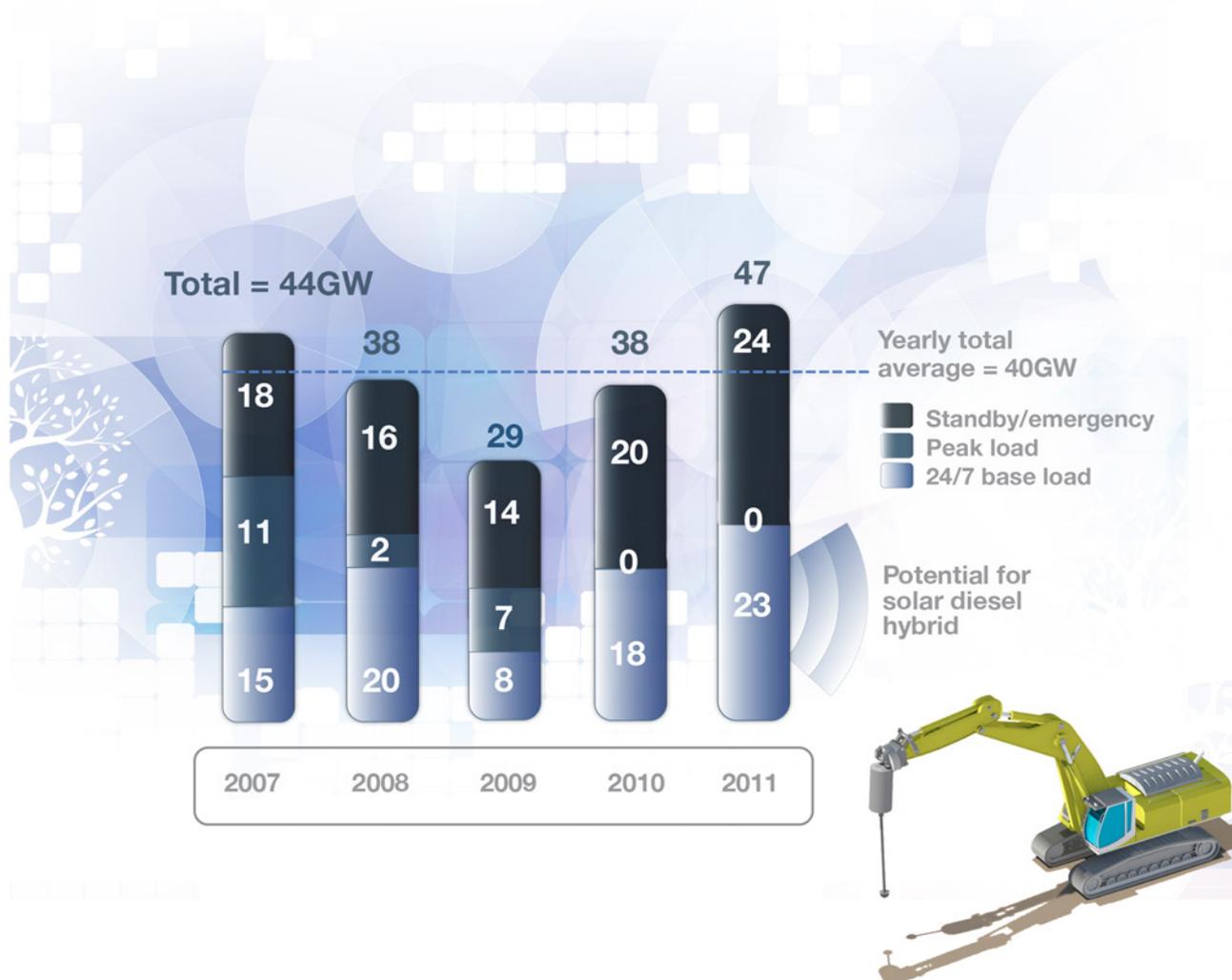


Figure 2  
Global new installations of diesel generators by year of install  
(Data source: 35th-37th Power Generation Order Survey)

## 1.3 The ambition

Innovation may be partitioned into sustained innovation, where incremental improvements over time occur on technologies, and disruptive innovation, where a new technology shifts the market entirely in a new direction. The ambition is to deliver a disruptive innovation to the market in the form of a modular solar-diesel hybrid plant that will fundamentally alter the trajectory of the off-grid, fringe-of-grid and grid-constrained markets – away from inefficient, expensive, polluting diesel-only generators towards modular, reliable, easy to install, commoditised solar-diesel hybrid plants. Reducing diesel consumption also reduces exposure to the volatility of diesel prices.

Significant interest has already been received by both ARENA and Laing O'Rourke in this initiative, including:

- potential customers – defence, energy retailers, remote construction operations, overseas electrification projects, mining operations; and
- public – articles in RenewEconomy, The Courier Mail, The Australian, Ferret, Climate Spectator, PV Magazine.

## 2 The technological solution

In order for the technological solution to be an attractive proposition to the market and be capable of marginalising diesel-only generators, it must:

- be a kit of parts that are easily selected and configured to meet the user's demand, with minimal engineering and design time and associated cost required for this optimisation process;
- be simple and inexpensive to deploy;
- be temporary such that the user is not required to have a long-term commitment on their books; and
- minimise the total cost of energy that the plant provides over its long lifetime in order to maximise the return for the plant owner.

The solution consists of DfMA Solar Modules (DSMs) and Hybrid Integration Modules (HIMs), and we will now provide an overview of these modules.

### 2.1 Mechanical design and the DfMA Solar Modules (DSMs)

In this section we analyse the cyclone and ground conditions in Australia to be designed for. We then present how the design of the solar module and associated ground restraint evolved over the course of this Measure, concluding with the digitally engineered construction sequence and the prototyping.

#### 2.1.1 Australian cyclonic and soil characteristics

Being 3,860km from its most northerly point to its most southerly point in Tasmania and 4,000km wide, from east to west, Australia exhibits a wide range in weather and ground conditions. At the time of publication of this report, Australian Standard AS1170.2:2011 is the latest version of the Australian loading code for wind, providing the geographical distribution and the wind load conditions of the cyclone regions of Australia categorised, with increasing severity, A, B, C and D. Geoscience Australia's Surface Geology of Australia digital dataset, compiled at 1:1 million scale, is a seamless national coverage of outcrop and surficial geology. This digital dataset is freely available under Creative Commons and shows the wide range of ground conditions to design for, ranging from sand to intrusive rock. In Figure 3, these sets of data are brought together to illustrate regional trends and to highlight the most common conditions to design for.



Zone	Cyclone region	Soil material
1	B, C&D	Sand plains
2	A1 & A4	Sedimentary rocks/intrusive rocks (granites)
3	A4	Mainly metamorphic rocks
4	A4, B & C	Floodplain alluvium and sand plains
5	A4, B & C	Volcanic and metamorphic rocks
6	A4	Colluvium and/or residual deposits, boulder, gravel and sand
7	B & C	Floodplain alluvium, gravel, sand, silt and clay/sand plains
8	A4	Metamorphic rocks
9	B & C	Floodplain alluvium, gravel, sand, silt and clay/ colluvium and/or residual deposits, boulder
10	A4, B & C	Floodplain alluvium, gravel, sand, silt and clay
11	A4	Sedimentary metamorphic rocks
12	A4	Mainly sand plains
13	A4	Sedimentary metamorphic Rocks
14	A4	Sand plains
15	A1	Sedimentary metamorphic rocks
16	A1 & A4	Floodplain alluvium, gravel, sand, silt and clay/sand plains
17	A4	Sedimentary metamorphic rocks
18	A4	Floodplain alluvium, gravel, sand, silt and clay
19	A4	Metamorphic rocks/intrusive rock
20	B & C	Colluvium and/or residual deposits, boulder, gravel and sand
21	A4, B & C	Metamorphic rocks/intrusive rock
22	B	Metamorphic rocks/intrusive rock
23	A2 & A3	Metamorphic rocks/intrusive rock
24	A3	Metamorphic rocks/intrusive rock

Figure 3  
Map of Australia partitioned by soil conditions and cyclone ratings.

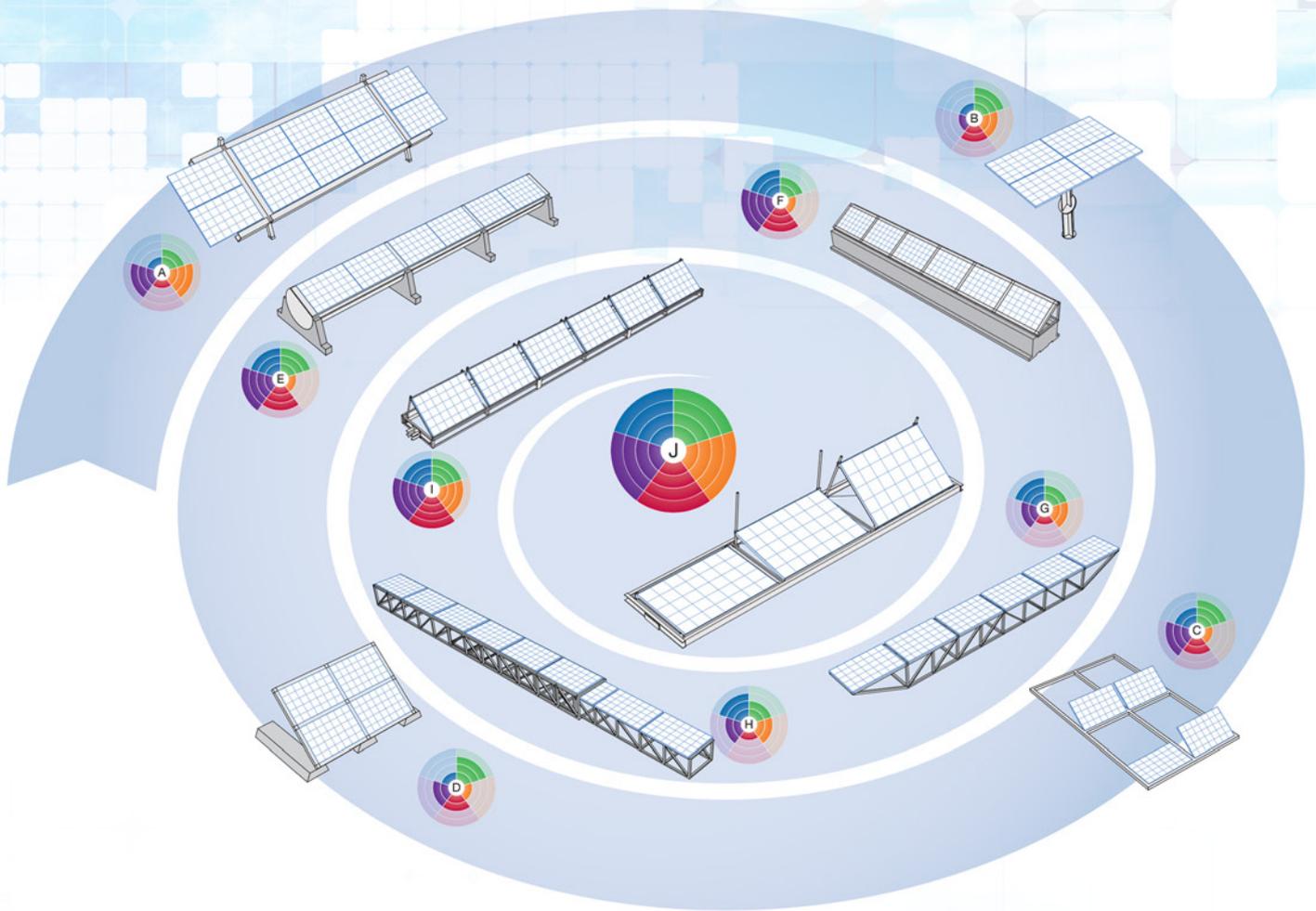
## 2.1.2 Design evolution

A DSM is a readily deployable structure that **i)** contains and supports photovoltaic panels, **ii)** is easily handled, **iii)** is efficiently transported and **iv)** is safe to use.

At the outset of the product development, a detailed Functional Design Brief (FDB) was written for the DSM outlining mandatory, optional and desired requirements under different criteria including manufacture, transport, assembly, safety and value for money. This FDB was used throughout the design evolution to assess different design ideas and to select, at each stage of design (concept, basic, preliminary and detailed), the top performing design. A sample of the designs considered is shown in Figure 4, illustrating how the design evolved and achieved a solution that is elegant and optimal with regard to the key criteria of the FDB. A brief description of each design option is provided below.

### Option Description

- A** A ten panel DSM consisting of six stationary panels and four peripheral panels. The peripheral panels fold in for stowing and transportation. The DSM legs are telescopic and compact.
- B** A four panel DSM of vertical configuration. Tilting the panels is done using an inclined swivel.
- C** An analogous configuration of a roof mounted system, this four panel DSM would be easy to fabricate and would create a large grid of DSMs with each unit joined to the next.
- D** A four panel unit that utilises concrete sleepers as ballast. The metal frame supporting the panels would need to be strong enough to support the mass of the sleepers in order to enable a modular unit.
- E** A six panel unit made from either high-density polyethylene or steel duct and filled with water as ballast.
- F** Alternate configuration of option E with a rectangular design rather than a cylindrical design.
- G** A six panel unit consisting of a four panel truss and two peripheral panels.
- H** A twelve panel telescopic unit, consisting of a six panel truss inside another six panel truss.
- I** A cut-down truss with six panels. This sits directly on the ground and attempts to utilise small hot rolled sections.
- J** A three panel unit that can resist localised torsion better than design option I. It fits within the logistical envelope and is compact when stacked. Multiples of this option can be bolted together to reduce the quantity of ground restraints required. The panel sub-frames can be removed if required to enable quick change over of a damaged panel. The use of light hot rolled sections has been maximised combined with 90-degree cuts in material resulting in the ability to use crop shears to cut material to size quickly during fabrication.



### Assessment Criteria

-  Manufacture
-  Transport
-  Assembly
-  Safety
-  Value for money

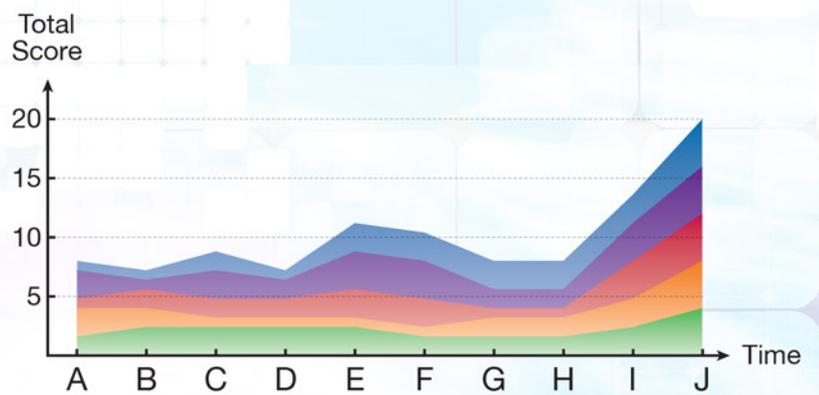


Figure 4 The design evolution of the DfMA Solar Module (DSM), showing how each design was assessed against manufacture, transport, assembly, safety and value for money.

The chosen, and patent pending, design for the DSM is configured as a large cassette-type chassis 100mm in height, within it housing three 327W photovoltaic panels installed in landscape orientation each within a supporting sub-frame. Each sub-frame is inclined and elevated manually and held in location by two telescopic struts. These telescopic struts use pinned connections to remove the need for tools during pack-down (i.e. installation on site) and pack-up (i.e. removal from site), and to eliminate the risk of fasteners loosening when subject to vibration (e.g. during transport). When not in use, such as during transport, the struts and sub-frame stow within the chassis envelope and may be locked in this stowed position with pins. The DSM has been designed to cyclone region D conditions.

As the DSM may be re-deployed multiple times, PV panel fatigue has been carefully considered:

- The first mitigating strategy was to use robust panels. SunPower's panels have a solid copper foundation that increases their resistance to stresses significantly. (A further benefit of SunPower's panels is their high efficiency, reducing the number of DSMs required)
- The second mitigating strategy was to onboard SunPower during the design development of the DSM. SunPower was appointed as a consultant during the design development. SunPower peer-reviewed the design as it evolved to ensure that the panels' product and power warranties are not voided. The first result of this has been a design with sub-frames which hold the panels. The sub-frames are not subject to any other load than their own mass. The DSM outer chassis is the structure that supports both the sub-frames and other DSMs when stacked. The second result of SunPower's peer-review has been the isolation of the panel from the sub-frame through the introduction of a rubber strip between the panel and the sub-frame. This reduces any induced shock loadings.

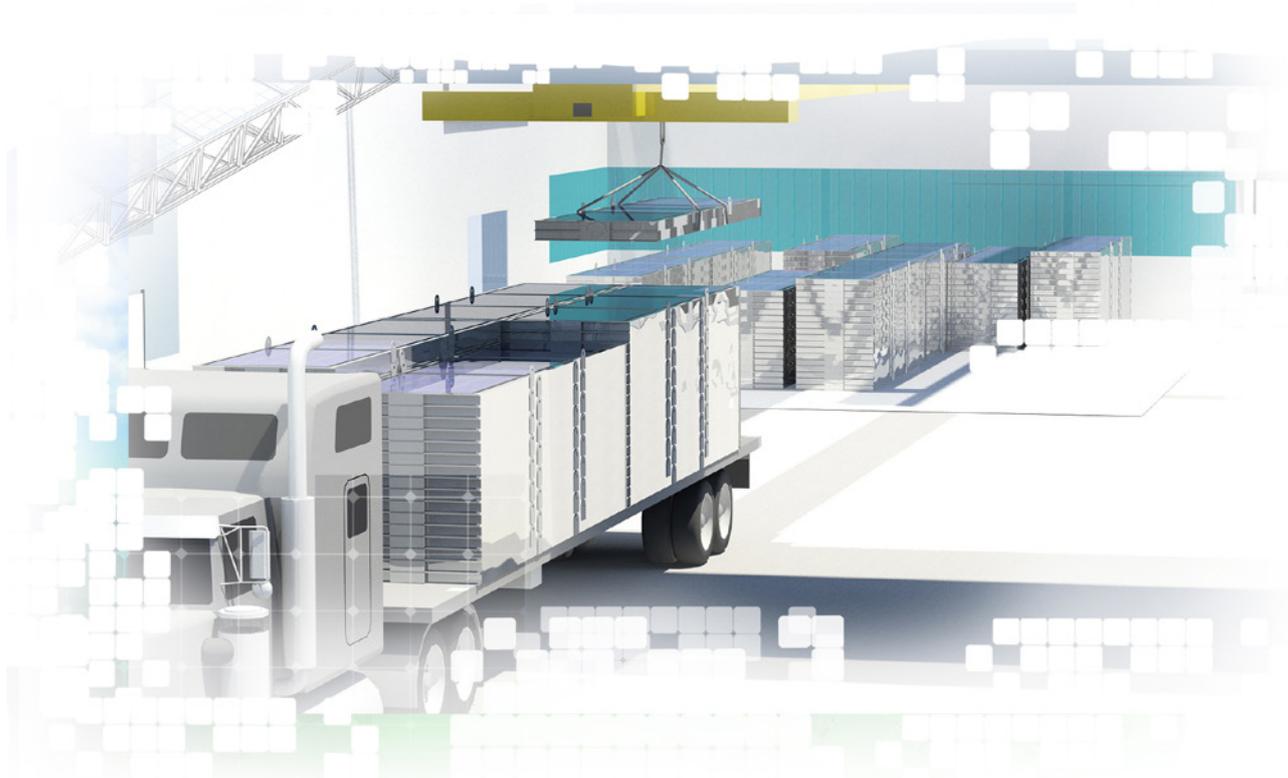
### 2.1.3 Ground restraint

A wide range of ground restraint options were considered, analysed and assessed against transport, reusability, minimal installation, applicability to different ground strengths (using Australian Standard AS1170-1993: very soft clay, soft-firm clay, stiff-very stiff clay, hard clay-weak rock, rock, loose sand, medium dense sand, dense sand, gravels) and applicability to different site reactivity classes (using Australian Standard AS 2870-2011: little, slight, moderate, high, very high and extreme movement from moisture change). These options included concrete-pad footings, soil/water-fill footings, paving ballast, percussion-driven piles, screw-piles and rock anchors.

The engineering study concluded that screw-piles are the most practical, economical and safe restraint solution for the DSM. The construction of a screw-pile consists of a flanged top, a pipe shaft and a cast steel helix at the base. A screw-pile is able to be installed in all soil types except for rock, where rock bolts may be used. Screw-piles are installed using an excavator together with an off-the-shelf, low-cost drilling attachment. The use of excavators eliminates costly and time-consuming heavy manual effort to install and remove the screws. The flanged top allows the screw-pile to be readily removed from the ground using the reverse method of installation and provides a good point of connection for the DSM. Alternate methods of restraint succumb to one or several of the following characteristics:

- manual installation with power tools that involves heavy lifting, physical exertion, continuous exposure to vibration and heat stress;
- multiple units required in place of a single screw-pile (or rock bolt);
- does not resist load combinations as well as a screw-pile;
- requires additional civil works or is laborious in manufacture or use;
- is not as compact in transport as a screw-pile (or rock bolt);
- is not recoverable or is recoverable at significantly more cost; and
- is more expensive to purchase per unit.

DSMs are assembled on-site in rows and joined end to end. There is sufficient space between adjacent DSMs for a screw-pile to be located there. In low cyclonic regions a screw-pile may be required between only every third or even every fourth DSM, whilst in high cyclonic conditions screw-piles may be required between every second DSM or every DSM. Varying the number of screw-piles, together with varying the helical diameter and pipe-shaft length of the screw-pile addresses the range of different site conditions. A simple design tool has been developed whereby the ground and cyclone characteristics provide a preliminary design for the number, helical diameter and length of screw-piles. For the majority of scenarios, screw-piles of length 2.4m between every second DSM are sufficient.



**Figure 5**  
The DSMs are transferred from storage onto the back of a semi-trailer.

### 2.1.4 Digitally-engineered construction sequence

An engineering study and preliminary design of logistics about the DSM concluded that an excavator with tracks is the optimal selection of machine to handle and transport DSMs on site. Excavators can slew and turn on the spot providing good manoeuvrability in small areas and eliminate hazards such as the need for the operator to travel in reverse. Excavators are designed to transport loads safely and do not require the use of outriggers. However the blade of an excavator is quickly deployable for additional stability if required.

For road transport, four stacks of eighteen DSMs, equivalent to 67kWp of PV, can safely fit onto a standard semi-trailer. Two DSMs side by side longitudinally on a truck make for a load that is not hindered by road restrictions and thoroughfare curfews. The DSM incorporates lifting lugs that may also perform the additional function of stacking locators when in transport and storage, preventing the DSMs from sliding laterally. For safety, the DSMs will not be stored in stacks higher than 1.6m so that people amongst stored DSMs are visible.

Figures 5, 6, 7 and 8 show the construction sequence and illustrate the “build twice – once virtually” approach to construction, that detects clashes digitally rather than on-site, minimises risks and programme and therefore reduces costs significantly.



Figure 6  
The semi-trailer travels from the storage depot to the site for deployment.



Figure 7  
Excavators are used to install the screw-piles and place the DSMs.

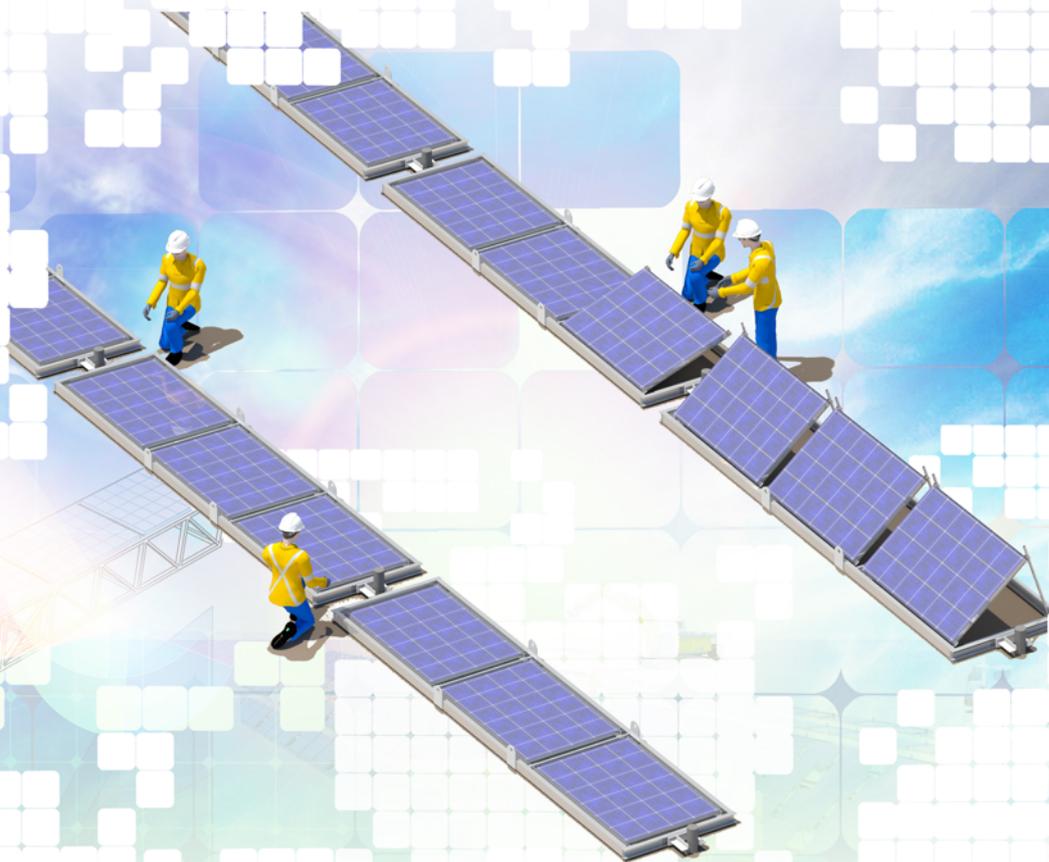


Figure 8  
The connections are tightened and the panels simply inclined.

### 2.1.5 Prototyping

Four DSMs have been prototyped by Redispan in Newcastle, New South Wales, in order to validate the performance of the DSM, their ease of off-site manufacture and efficiency in on-site assembly (Figure 9). Electro-luminescence imaging of the PV panels was performed before and after trialling to check that no micro-cracks came about from the manufacturing process, lifting, transport or pack-down of the DSM (Figure 10).



Figure 9  
One of the four prototype DSMs fabricated by Redispan, showing two panels inclined and one panel stowed.

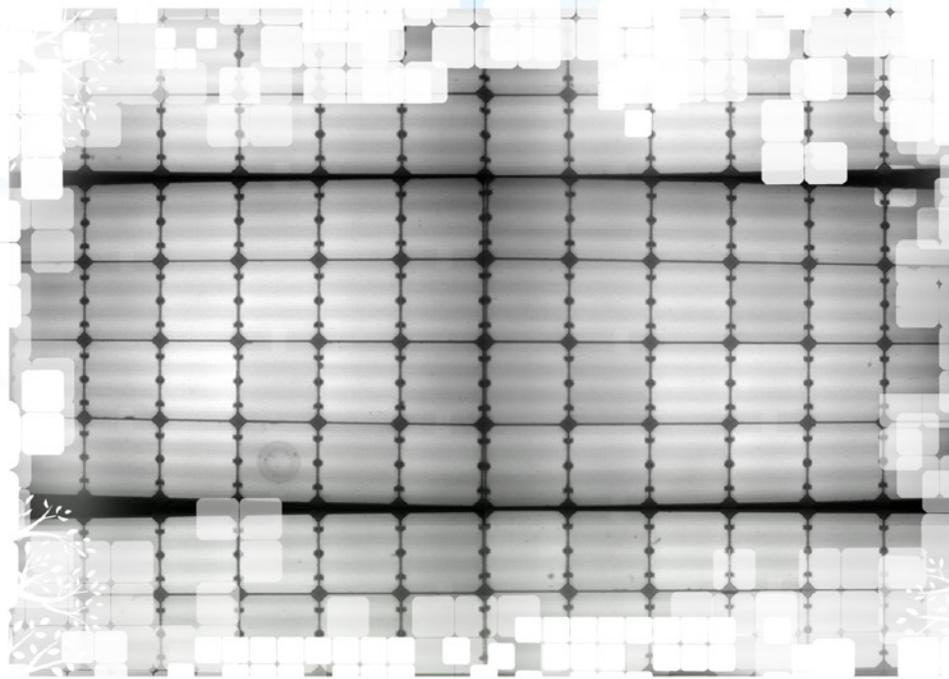


Figure 10  
Electroluminescence imaging of the panels.

A trial screw-pile installation and removal cycle was repeated three times, with installation taking 150 seconds and removal taking 90 seconds (Figure 11). The helical thread of the screw-pile was checked after three cycles and no damage was found (Figure 12).



Figure 11  
A screw-pile trial installation performed by an excavator with a drilling attachment on the end of the arm.



Figure 12

The helical thread after three install and removal cycles showing no damage sustained.

## 2.2 Electrical design and the Hybrid Integration Modules (HIMs)

A Design for Manufacture and Assembly (DfMA) approach has also been applied to the remaining electrical plant in order to ensure ease of pack-down and, if required, pack-up and re-configurability from one deployment to the next:

- The Delivery Centre HIM integrates the three main elements of the hybrid system: the diesel generators, the solar farm and any energy storage. The Delivery Centre HIM houses a main switchboard and the integrating control system. The main switchboard accepts inputs from each of the elements of the power system, while the control system schedules the generators and any energy storage, and curtails the solar farm, when required (e.g. to maintain minimum loading of diesel generators).
- The Energy Storage HIM may be used when a higher level of energy-penetration is deemed to be commercially attractive. The Energy Storage HIM contains inverters, transformer and accommodates a range of battery sizes depending on the demand requirements of that particular deployment.
- All HIMs are pre-wired with external connections to allow fast, easy, plug-and-play connection during pack-down and pack-up.
- The solar farm consists of multiple sub-arrays. Each sub-array has an inverter and a number of DSMs. The number of sub-arrays may be easily adjusted depending on the load profile to be served.
- Across the entire electrical plant, all cabling is preformed/pre-terminated to allow fast connection, while input sockets are pre-wired into all enclosures to ensure IP ratings are maintained. The plug and socket arrangement of all cables allows the use of extension cables to accommodate a variety of site layouts.

## 2.2.1 Load profiles

Laing O'Rourke has multiple remote construction jobs across Australia and employs remote monitoring to inform its understanding of load profiles and fuel consumption/efficiency. Figure 13 shows the averaged load profile for a 450-person accommodation village in Queensland, where the average daily demand is 6,500kWh/day with a fuel consumption of 2,200L/day. The minimum load occurs in the night, 161kW at 2am, and the peak occurs in the early evening, 601kW at 6pm, when workers have returned from the construction site and are typically either showering or having dinner.

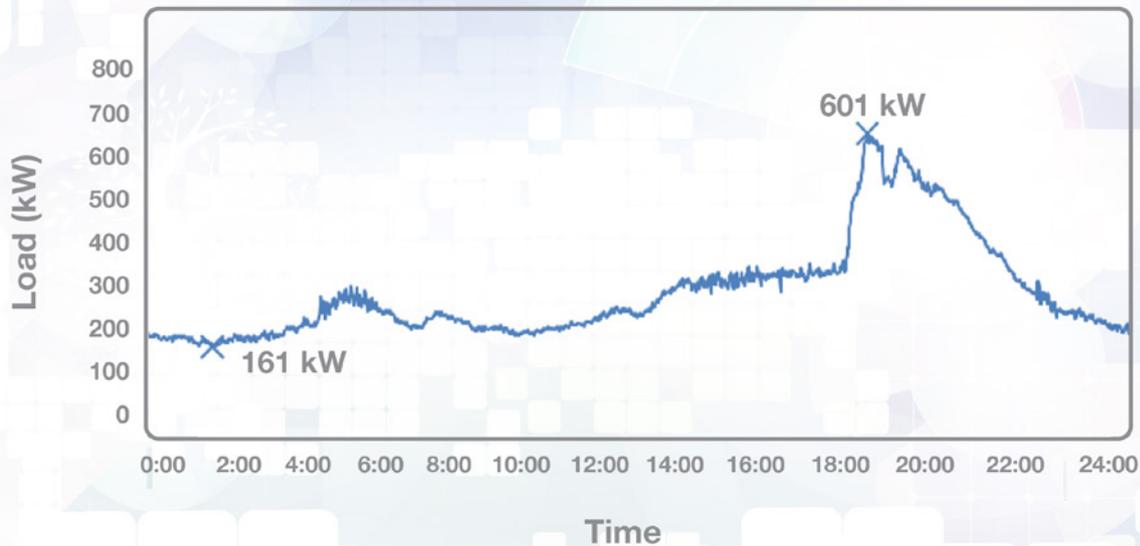


Figure 13  
The average load profile for a 450-person accommodation village, with labels showing the maximum and minimum.

Laing O'Rourke has minute by minute data on generator efficiency and these data points, for a 400kW diesel generator, are collated in Figure 14, highlighting the inefficiency associated with operating generators at low loads. It is worth noting that operating generators at low loads also leads to unwanted glazing and wet stacking effects.

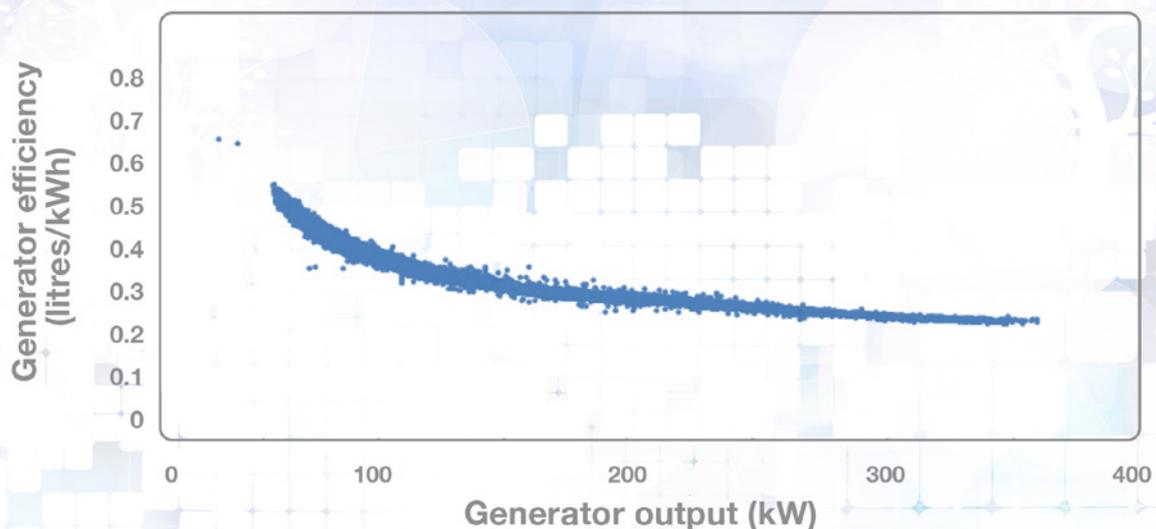


Figure 14  
Fuel efficiency of a 400kW diesel generator, sampled at minute intervals.

In scenarios where there are multiple generators and there is an overarching control strategy for partitioning the load, it is economically important to optimise this strategy. This may be illustrated by considering a sub-optimal control strategy compared to an optimal strategy: in Figure 15, the load was partitioned equally across three generators, resulting in low loading and a high diesel consumption rate of 0.403L/kWh; in Figure 16, the optimised control strategy was implemented resulting in a diesel consumption rate of 0.320L/kWh (note that, in this scenario, generators swap over at midnight as the chief generator in order to avoid a single generator being overworked).

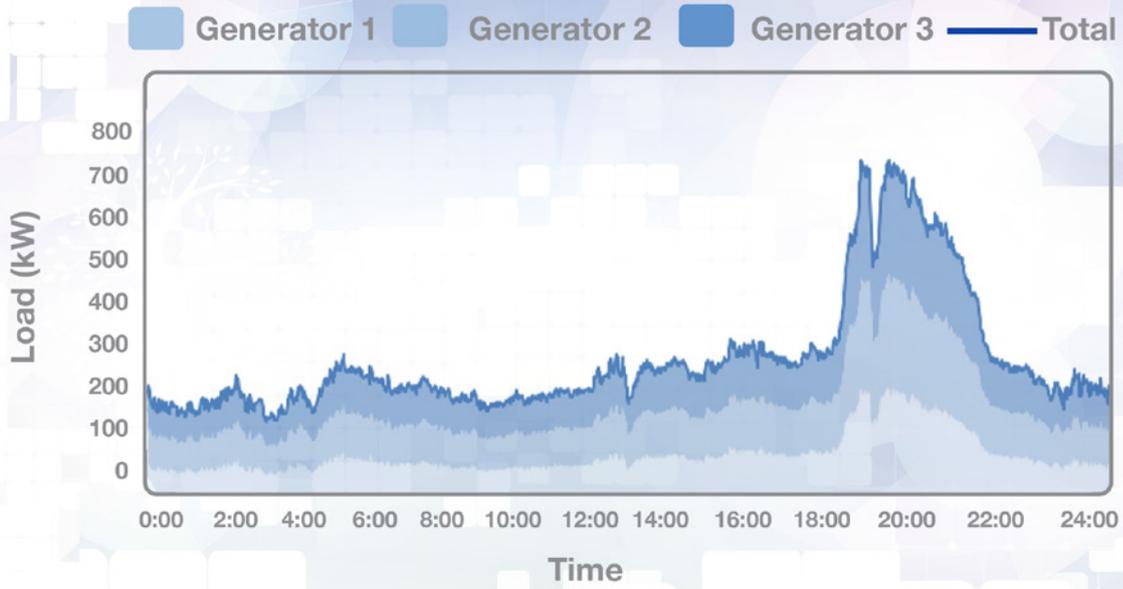


Figure 15  
The load sharing of three generators resulting from a sub-optimal control strategy, where the load is equally partitioned

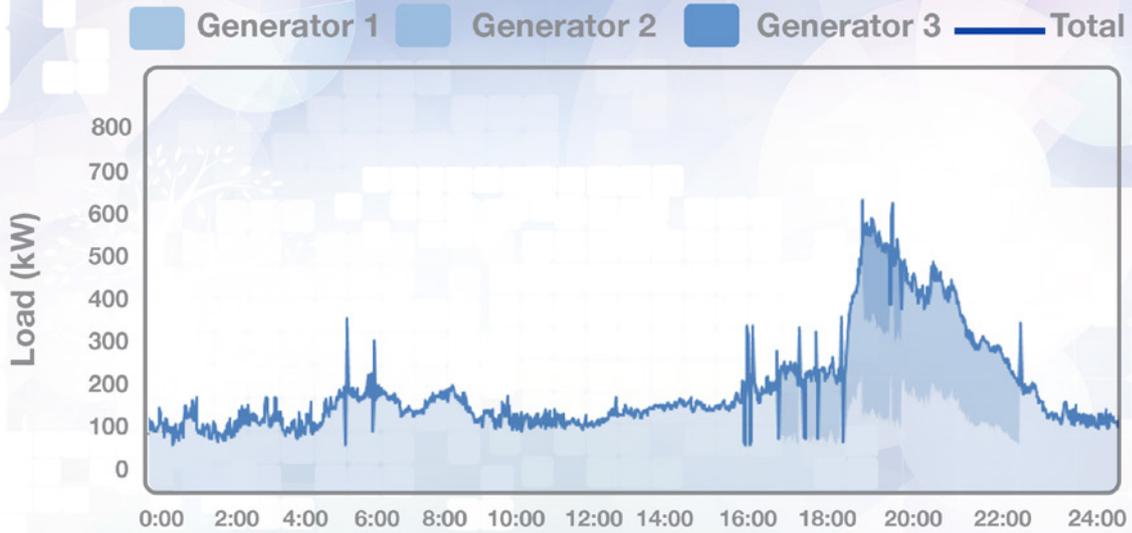


Figure 16  
The load sharing of three generators resulting from an optimised control strategy.

## 2.2.2 Integration options

A HOMER simulation was undertaken to understand the Levelised Cost of Energy (LCOE) of different system configurations. HOMER is a leading micro-grid power flow and total cost modelling software package that allows the user to simulate a range of flexible (e.g. generator sets and batteries) and variable (e.g. solar PV) generators to service a given load profile. For the analysis undertaken, the actual load profile from a Laing O'Rourke accommodation village in Queensland was used. HOMER considers lifetime costs of the system – capital, operating and maintenance, fuel, replacement and salvage – to calculate LCOE for each configuration. The tool runs through high numbers of defined system configurations and calculates LCOE results and parameter sensitivities in order to hone in on the optimum solution. An assumption was made that the plant would be redeployed 6 times over 20 years and this was reflected within the

HOMER model. The reference case was a diesel-only system. Three distinct hybrid systems were considered, with the following main conclusions against each system:

- Solar-diesel systems achieve a lower LCOE than the reference case but only for low penetration levels of solar. At high solar penetrations, too much solar energy is produced and, as there is no means of storage, this excess solar is wasted.
- Solar-diesel-flywheel systems were found to be prohibitively expensive as the flywheel acts as a parasitic load during the daytime and also has a high operation and maintenance cost, with a typical fly wheel requiring a bearing change every 4 years.
- Solar-diesel-battery systems have a higher LCOE than the reference case for low solar penetrations, due to there being insufficient solar energy produced to utilise, and therefore pay for, the battery. At higher solar penetrations, the LCOE becomes less than the reference case and, in fact, less than the LCOE achieved with a solar-diesel system.

Laing O'Rourke undertook a review of various battery technologies and determined that lithium-ion represents the most suitable technology for the required fast injection and absorption of power, due to its fast, linear, symmetric charge/discharge behaviour. The smaller footprint as compared to other battery technologies is a further benefit, both in terms of logistics and land requirements on-site. Within the HOMER analysis, two lithium-ion chemistries were considered: lithium titanate and lithium manganese oxide.

When there is insufficient operating reserve from the diesel generators, solar PV may be curtailed in order to force an additional generator to come online. Such curtailment of PV may be avoided by opening a communication channel between the PV controller and the diesel generator controller.

A diesel generator typically has a minimum loading requirement, below which its operation is both inefficient and potentially damaging to the generator. Solar PV may be curtailed in order to protect the generator from operating below its minimum loading. Such curtailment of PV may be avoided by controlling dispatchable loads, such as hot water tanks. Switching on hot water tanks serves to increase the demand from the solar-diesel hybrid plant. In this way, loads are shifted from evening or night time to the day time, and curtailment of solar PV is minimised.

When determining the size and number of diesel generators at each mini-grid, two approaches may be employed:

- Cascading is an approach adopted by Power and Water Corporation (see their ARENA-supported Solar-Diesel Mini-Grid Handbook) that uses multiple generators sets of different sizes. Such configurations typically have just one generator in operation at any one time – the generator with optimal fuel efficiency at that particular load. One consequence is that the fleet's number of engine run hours is minimised, thereby reducing the operation and maintenance costs and delaying capital expenditure on engine replacement. However, if a smaller generator fails then a large generator may be required to operate at low load.
- Equal-sizing is an approach where multiple engines of one size are utilised. Such configurations typically have multiple generators in operation at any one time and a scheduling algorithm is implemented to share run hours across the fleet. This approach is commonly used by the plant hire industry due to the benefits of common operation and maintenance processes and common parts. Unlike cascading, all generators have the same fuel efficiency curve and there is therefore no opportunity to minimise fuel efficiency through the selection of an optimal generator at that particular load. In this way, equal-sizing typically results in higher fuel consumption than cascading.

Laing O'Rourke's approach to diesel generator sizing is a marriage of these two strategies, deploying multiple equal-sized generators together with 1-2 smaller generators (typically from the same manufacturer to maximise common parts and common operation and maintenance processes), thereby realising the benefits of both a cascading and equal-sizing approach.

With the results of the HOMER model, it is possible for us to conduct an energy and carbon payback calculation for the DSM frame. For a solar-diesel system and using the World Steel Association Life Cycle Assessment Methodology (2011, ISBN 978-2-930069-66-1) values for the energy intensity and carbon intensity of hot-dip galvanised steel, 27.5MJ/kg-steel and 1.3kgCO<sub>2</sub>/kg-steel respectively, the energy and carbon payback periods for the DSM frame was calculated to be just 5 months and 8 months respectively.

### 3 The commercial wrap-up

Commercially, there are two actors for us to consider – the owner and the user.

Under certain scenarios, Laing O'Rourke foresees the owner and the user to be the same entity:

- entities that have secured multiple successive sites to power;
- entities, such as mining companies, that have secured one temporary site to power but expect to later recover a high percentage of the asset cost by either securing a further site to power or selling the asset to another owner; and
- entities, such as remote communities, that have one permanent site to power but the high ease of install, operation and maintenance of the modular solar-diesel hybrid is commercially attractive and may utilise and up-skill local labour.

Under these scenarios, Laing O'Rourke would act as a product retailer of its manufactured modular solar-diesel hybrid plants.



Figure 17  
Laing O'Rourke's Woleebee Accommodation Village.

Alternatively, the user and owner are different entities and there are two main commercial relationships that may operate:

1. lease arrangement, whereby the user pays the owner a weekly rate according to the nameplate power rating of the system (\$/kW/week) – this is the typical commercial arrangement used for the hire of diesel generators; and
2. retailer arrangement, whereby the user pays the owner a rate per unit of energy provided from the system (\$/kWh) – this is the commercial arrangement commonly used in remote micro-grids.

Under these scenarios, the asset owners are most likely to be either electricity retailers or equipment hire companies (such as Laing O’Rourke’s Select Plant Hire, Figure 17). Users will include businesses and communities who are off-grid and also those who are fringe-of-grid/grid-constrained.

## 4 The first commercial deployment

With the first ERP Measure successfully completing the product development of the modular solar-diesel hybrid, ARENA awarded Laing O’Rourke a second ERP Measure to enable the first modular solar diesel hybrid plant to be manufactured and commercially deployed.

The first deployment is at the Combabula APLNG 350-person accommodation village in Queensland and is expected to have a deployment duration of 12 months, after which the plant will be re-deployed to a different site. The second ERP Measure serves to advance the technology to Technology Readiness Level (TRL) 9 and its Commercial Readiness Level (CRL) to CRL 3. The chief focus of this second ERP Measure is to demonstrate to the market the modular nature and ease of pack-down and pack-up, and therefore a solar-diesel system was selected rather than a solar-diesel-battery system. The modular solar-diesel hybrid plant at Combabula has been modelled and digitally rendered (Figure 18).



Figure 18  
Rendered image of the modular solar farm at Combabula.

Item	Value
<b>CONFIGURATION</b>	134kWp of solar PV; no Energy Storage HIM
<b>LOGISTICS</b>	134kWp of solar PV fits onto 2 trucks
<b>SOLAR USED</b>	180MWh/year
<b>DIESEL SAVING</b>	50,000L/year
<b>CO<sub>2</sub> SAVING</b>	130T/year

It is expected that for every kWh of solar generated electricity, 0.91 kWh of diesel generated electricity is to be avoided – it is not a 1:1 matching due to predicted curtailment of solar PV to maintain minimum loading requirements of diesel generators.

Laing O'Rourke is committed, with ARENA, to share knowledge with the broader industry resulting from the second ERP Measure in the form of:

- conference presentations;
- high-level technical specifications of the technology;
- contract type used for the first deployment and options for further deployments including retail, week-by-week hire and Power Purchase Agreements (PPAs);
- relevant Australian conditions, laws and regulations;
- product brochure with overview of logistics, pack-down, operation & maintenance and eventual pack-up;
- impact study of the first deployment on the local community;
- performance of the technology in operation; and
- video press release and site tours.

The market reception of modular solar-diesel hybrid plants has been highly positive and Laing O'Rourke looks forward to rolling out the product across Australia, serving the needs of the market, lowering the cost of remote power and reducing carbon emissions. For any enquiries, please contact Dr Will Rayward-Smith ([wraywardsmith@laingorourke.com.au](mailto:wraywardsmith@laingorourke.com.au)).

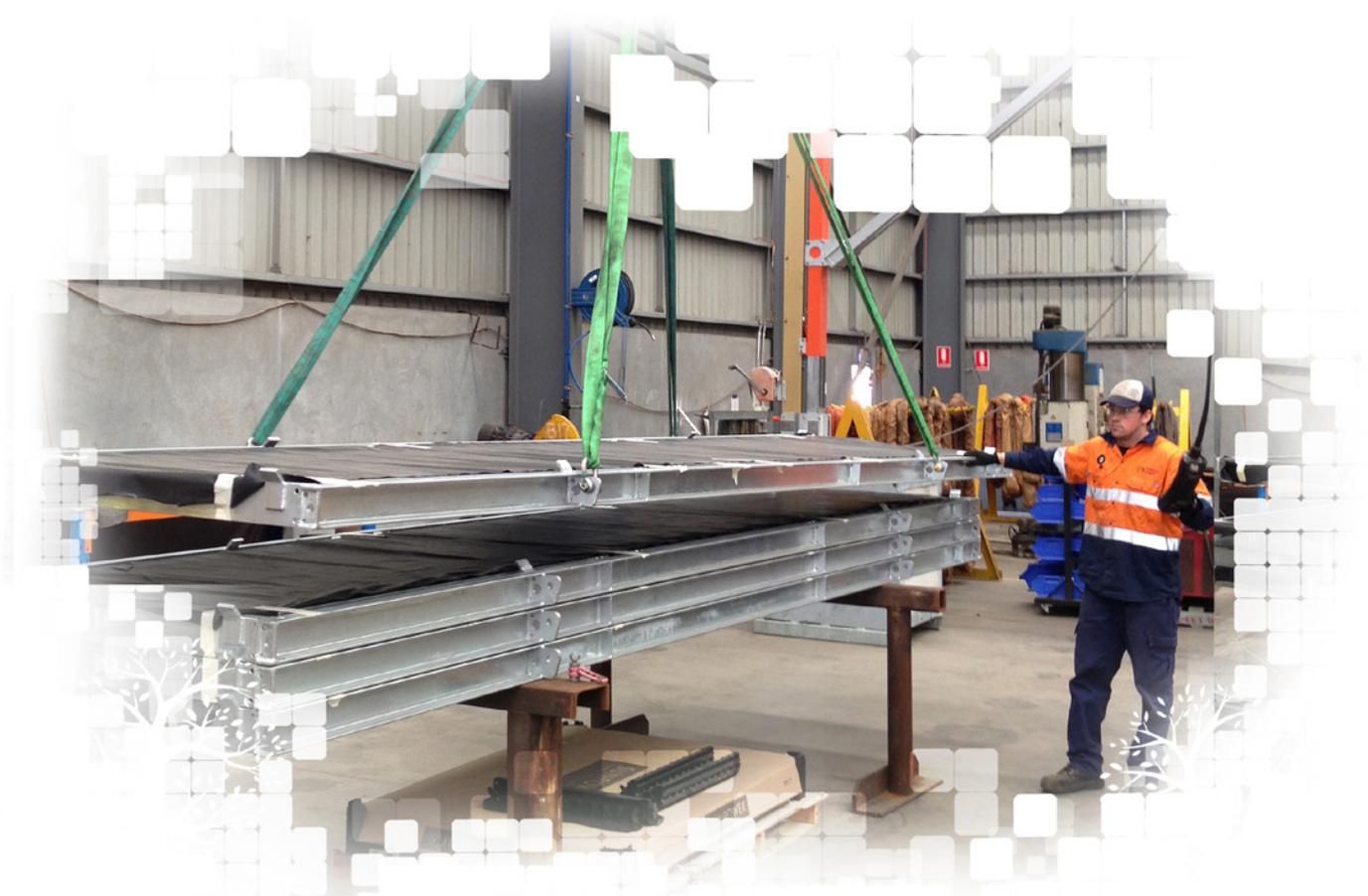


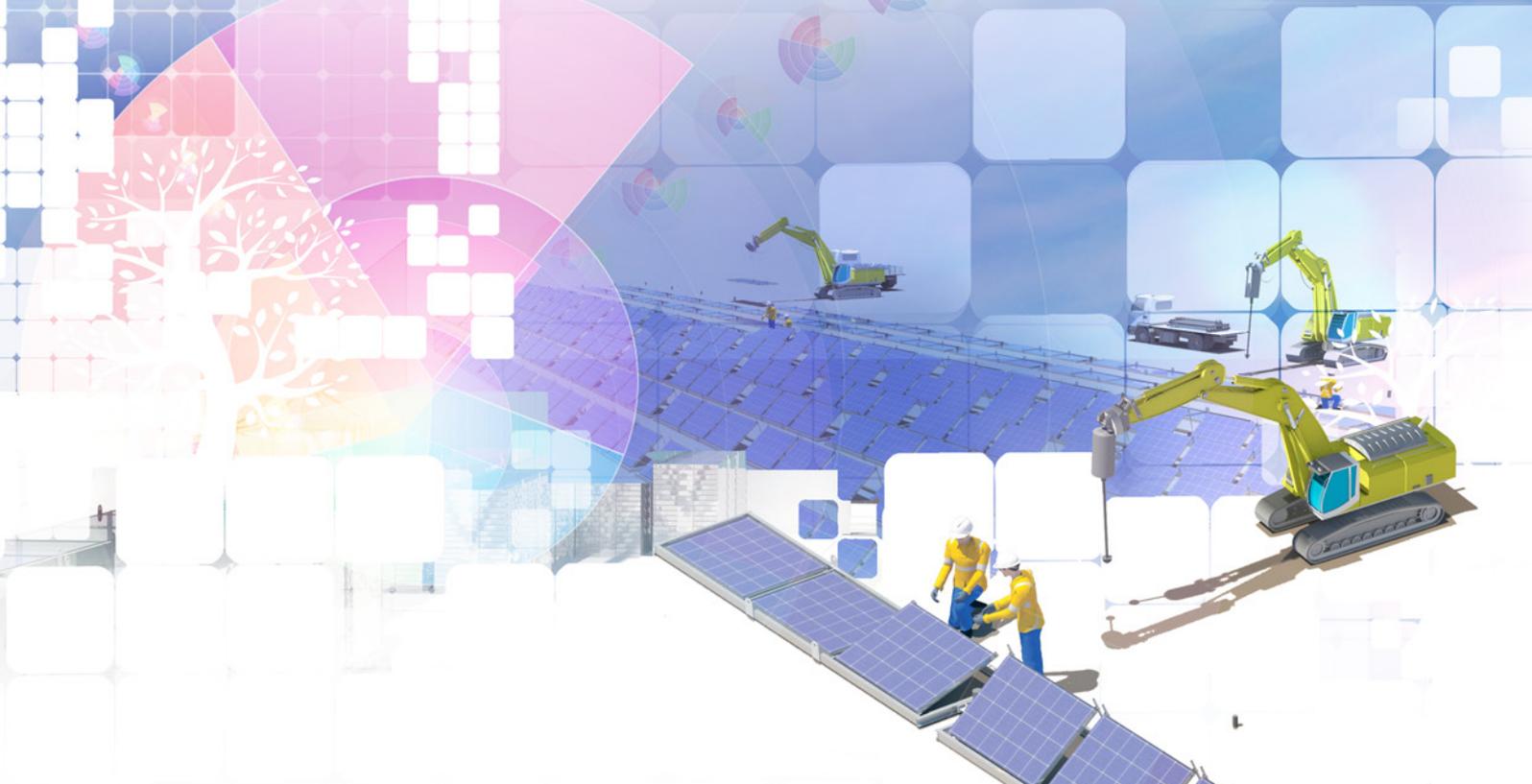
Figure 19  
Lifting one DSM off a stack of three DSMs at Redispan.



From left to right: Will Rayward-Smith, Michael Read, Michael West



From left to right: Andrew Henderson, Will Rayward-Smith, Michael Read, Rexine Jones, Paul Ward, Michael West



“The speed at which this game-changing solution has progressed from the drawing board to the field is a testament to the clever Australian design and its potential to bring more renewable energy to off-grid Australia”

ARENA Chief Executive  
Ivor Frischknecht  
in The Courier Mail,  
13 August 2014

## Laing O’Rourke project team

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