Evaluation Ocean Thermal Energy Conversion Bahamas

Design Specifications Report

The Caribbean Community Climate Change Centre (CCCCC)

10 February 2023

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ABBREVIATIONS

CCCCC	Caribbean Community Climate Change Centre
EU	European Union
GCCA	Global Climate Change Alliance
IG	Imperial Gallon
IGPD	Imperial Gallon Per Day
OC-OTEC	Open Cycle OTEC
OTEC	Ocean Thermal Energy Conversion
PV	Photovoltaic
RO	Reverse Osmosis
WSC	Water and Sewerage Corporation

PREFACE

Witteveen+Bos has been commissioned by the Caribbean Community Climate Change Centre (CCCCC) to perform an OTEC feasibility study for the Bahamas.

The project aims to evaluate the feasibility of OTEC and its combination with SDC, solar thermal and/or solar PV to contribute to the decarbonization of the water supply in the Bahamas (Family Islands).

We complete four deliverables under this contract:
1 Inception Report - based on an inception meeting with local stakeholders and partners.
2 Assessment Report - bench-level assessment of the Water Resources of the Bahamas, regarding the inverted geothermal conditions from existing SWRO wells to support OTEC.
3 Energy Audit Report - energy efficiency audit of existing SWRO facilities and implications for OTEC pairing.
4 Conceptual Design Specifications for SWRO-OTEC pairing system.

This document is deliverable 4 - Design Specifications Report.

The Caribbean Community Climate Change Centre (CCCCC) has received financing from The European Union through the GCCA+ programme toward the cost of the project titled 'Enhancing Climate Resilience in CARIFORUM Countries' and intends to apply part of the proceeds towards a Consultancy for 'An evaluation of Ocean Thermal Energy Conversion'.

The Global Climate Change Alliance Plus (GCCA+) is a European Union flagship initiative which is helping the world's most vulnerable countries to address climate change.

OTEC is one of the emerging technologies that require research and scaling up effort. We are pleased to assist in the development of the technology in the Bahamas.

1

INTRODUCTION

The Bahamas is a potential area for implementing Ocean Thermal Energy Conversion (OTEC) as a renewable energy source. It has a tropical climate that enables high ocean temperature differences. OTEC requires 20°C temperature difference between warm surface water and cold deep ocean water.

Instead of utilizing ocean water as a source for OTEC, the idea was developed by the Beneficiary of this project to utilize saline groundwater. The groundwater is already utilized by SWRO plants in the Bahamas to produce fresh water. The current use of wells opens up an opportunity to investigate the possibility of implementing OTEC for SWRO plants.

Witteveen+Bos has been commissioned by the Caribbean Community Climate Change Centre (CCCCC) to perform a feasibility study of OTEC for the SWRO plants in the Family Islands. This report on the conceptual design of a SWRO-OTEC pairing system is the fourth out of four deliverables from this assignment. The main goal of the report is to design an OTEC installation at one pilot location and solar PV at two locations.

In this chapter, we elaborate on the background of this project, and the objective of the study.

1.1 Background

Report nr. 3, the Energy Audit Report, provides a cost assessment of OTEC and alternative renewable energy generation at three locations. Based on the assessment, it was recommended to pilot 30 kW OC-OTEC at Lower Bogue. We recommended implementing solar PV on the other two sites: Naval Base and Cockburn Town. In this report, we provide the design specifications for the installations at the three locations.

1.2 Goal of this work

This goal of this work was to conceptually design the OTEC and solar PV systems and to provide design specifications of the systems for three locations in the Family Islands.

1.3 Reading guide

This report is structured as follows. Chapter 2 provides the site information for the three locations. In Chapter 3, the design basis is described. Chapter 4 presents the conceptual design, followed by the design specification in Chapter 5.

2

SITE INFORMATION

In the previous report, the site of Lower Bogue has been selected for the pilot location of OTEC and the sites of Naval Base and Cockburn Town have been selected for the implementation of solar PV. In this chapter, we provide the information for each site.

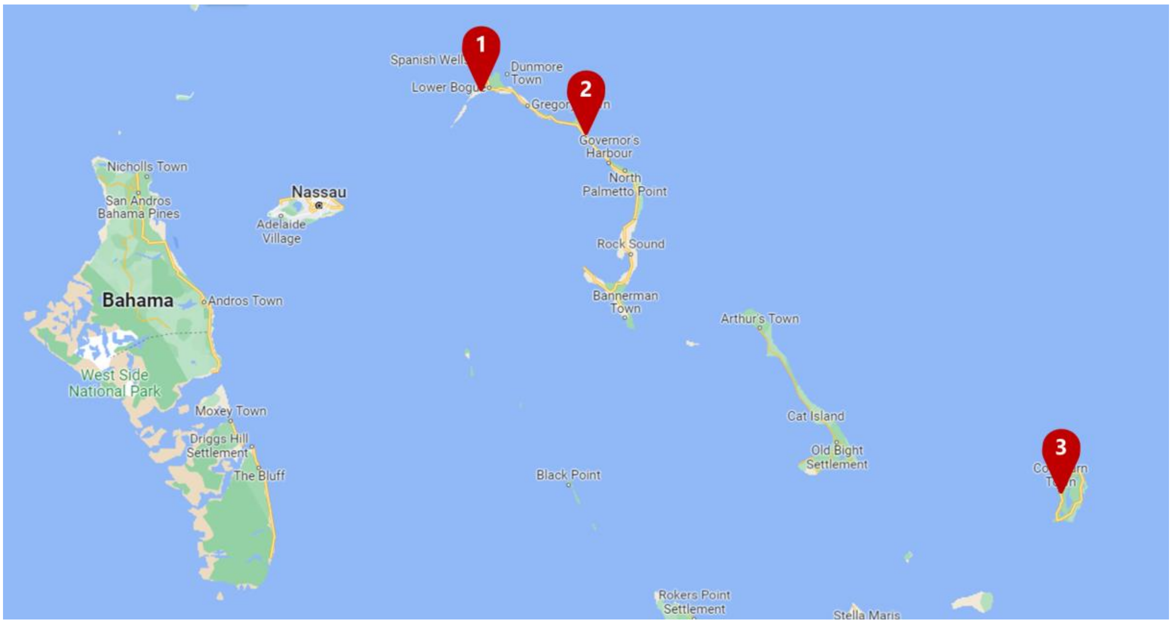
2.1 Location

The locations of the three sites are tabulated in Table 2.1.

Table 2.1 Site locations

Site	1	2	3
City/Town	Lower Bogue	Naval Base	Cockburn Town
Island	Eleuthera	Eleuthera	San Salvador
Country	Bahamas	Bahamas	Bahamas
Latitude	25.463901°	25.271333°	24.063465°
Longitude	-76.70415°	-76.314554°	-74.533702°
Altitude	10 m a.m.s.l.	18 m a.m.s.l	5 m a.m.s.l
Timezone	UTC -5	UTC -5	UTC -5

Figure 2.1 Locations of the three sites



2.2 Plot areas

The plot sizes of the three sites are tabulated in Table 2.2

Table 2.2 Plot size of each site

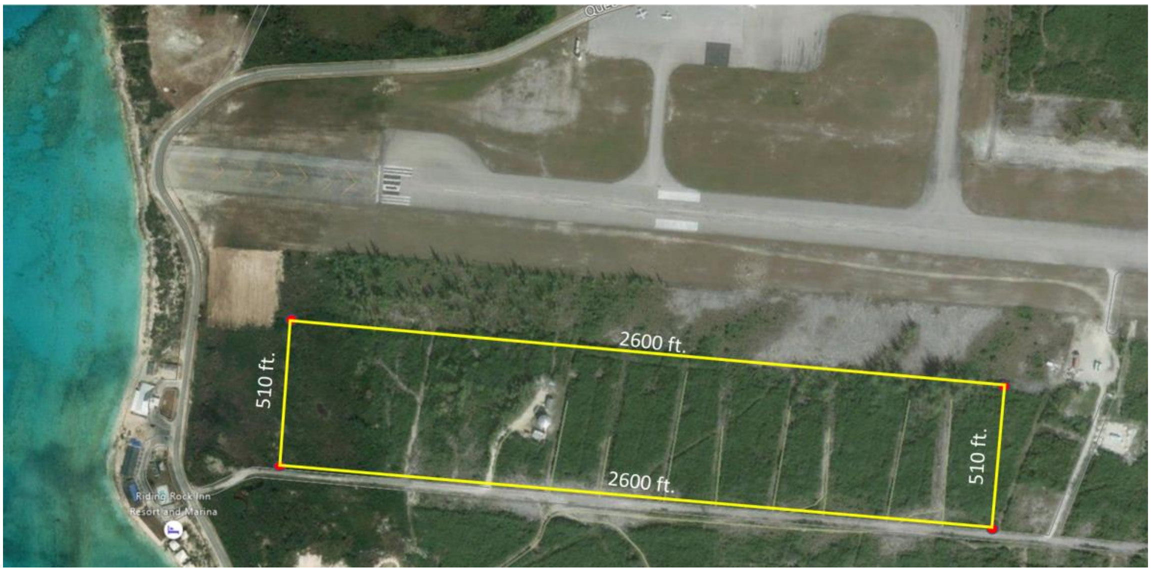
Site	1	2	3
City/Town	Lower Bogue	Naval Base	Cockburn Town
Area owned by WSC	1,012,500 ft^2 (94,142 m^2)	1,040,250 ft^2 (96860 m^2)	1,326,000 ft^2 (122,915 m^2)
Available area not covered by trees and buildings	1000 m^2	21000 m^2	850 m^2

Figure 2.2 to Figure 2.4 show the aerial view of the sites.

Figure 2.2 Plot area at Lower Bogue

Figure 2.3 Plot area at Naval Base

Figure 2.4 Plot area at Cockburn Town



2.3 Weather

Located on the boundary of tropical and subtropical zones, the Bahamas has a semi-tropical or subtropical marine climate moderated by the Gulf Stream's warm waters. Mean daily temperatures range from 17°C to 32°C. The annual rainfall for the Bahamas ranges from about 865 mm to about 1470 mm. Inter-annual variability in climate is strongly influenced by the El Niño Southern Oscillation (ENSO). El Niño brings warmer and drier conditions between June and August.

The average temperature and windspeed at the three locations are shown in Figure 2.5 to Figure 2.7.

Figure 2.5 Temperature and wind speed profile at Lower Bogue (Meteoblue, 2022)

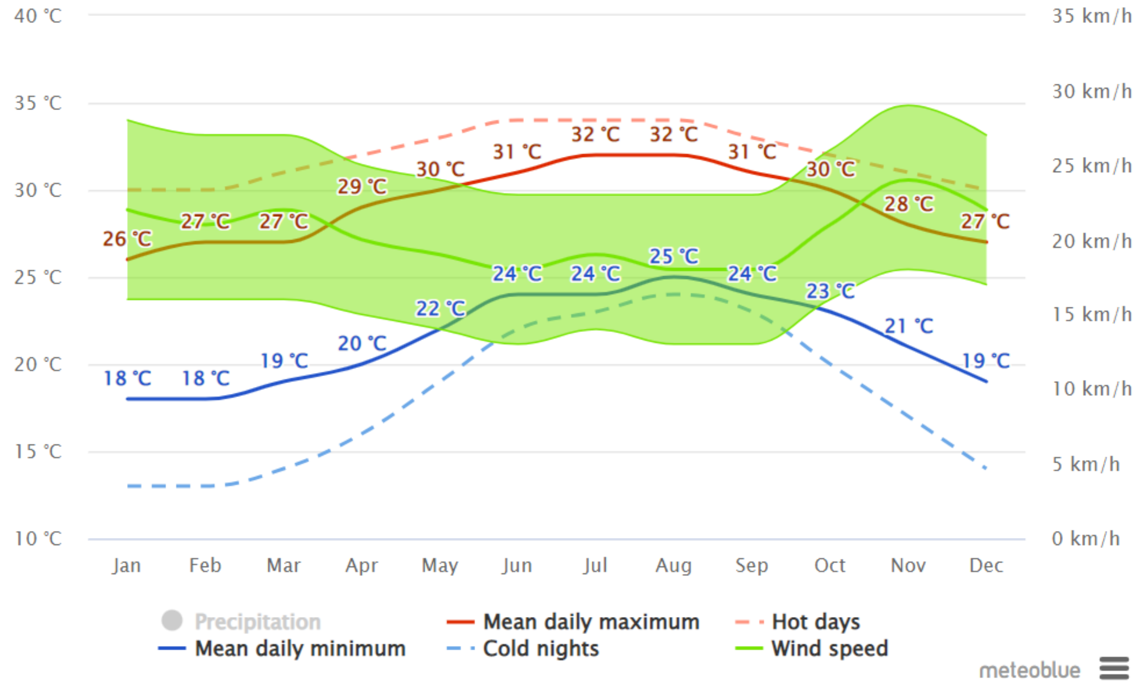


Figure 2.6 Temperature and wind speed profile at Naval Base (Meteoblue, 2022)

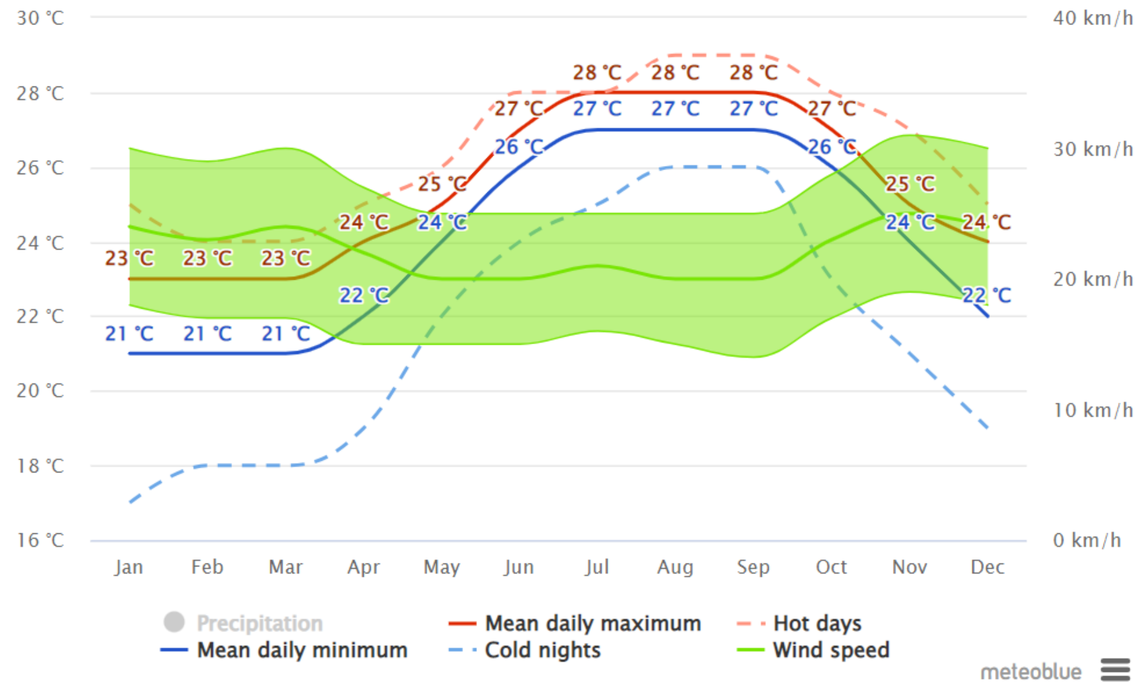
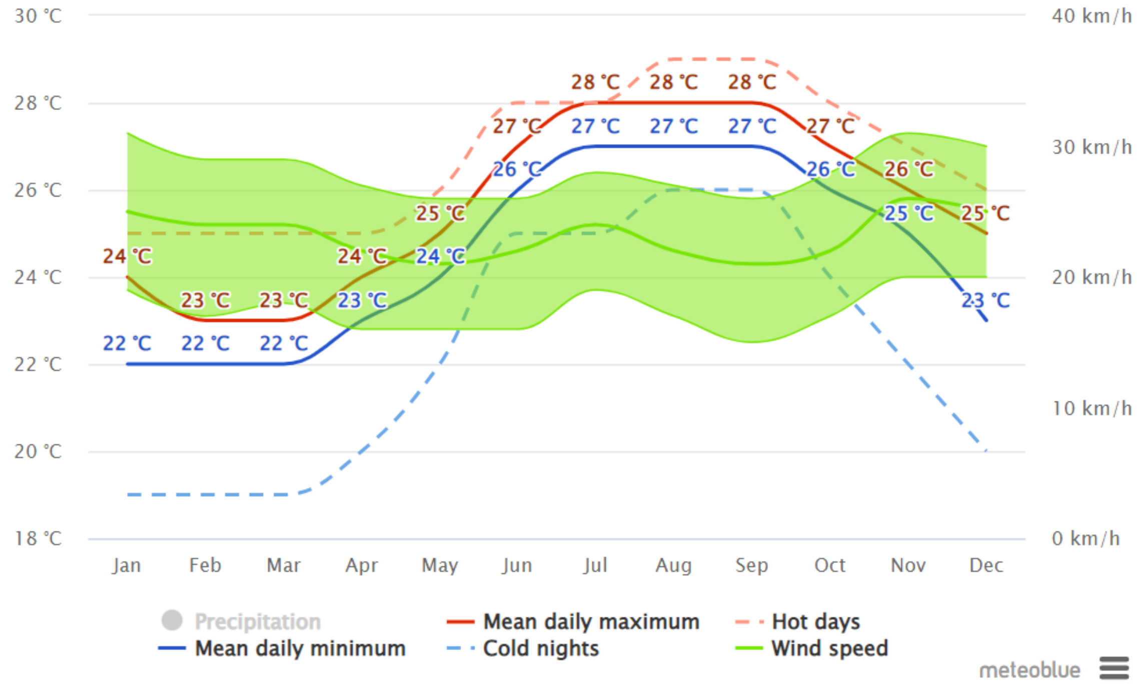


Figure 2.7 Temperature and wind speed profile at Cockburn Town (Meteoblue, 2022)



Hurricane
The Bahamas is also subject to hurricanes and tropical cyclones, especially during the August – November period. It is located in the heart of the Atlantic hurricane belt. Hurricane Dorian in 2019 was the strongest hurricane on record to strike the Bahamas, with one-minute maximum sustained winds of 185 mph (295 km/h). It caused $2.5 billion in damage and at least 74 deaths. Dorian in 2019 was one of four Category 5 hurricanes that hit the Bahamas. The others were the 1932 Bahamas hurricane, the 1933 Cuba–Brownsville hurricane, and Hurricane Andrew in 1992.

2.4 Topography

The sites are generally at low elevations and have low inclinations. The topography of the sites is shown in Figure 2.8 to Figure 2.10.

Figure 2.8 Topography of Cockburn Town site

Figure 2.9 Topography of Naval Base site

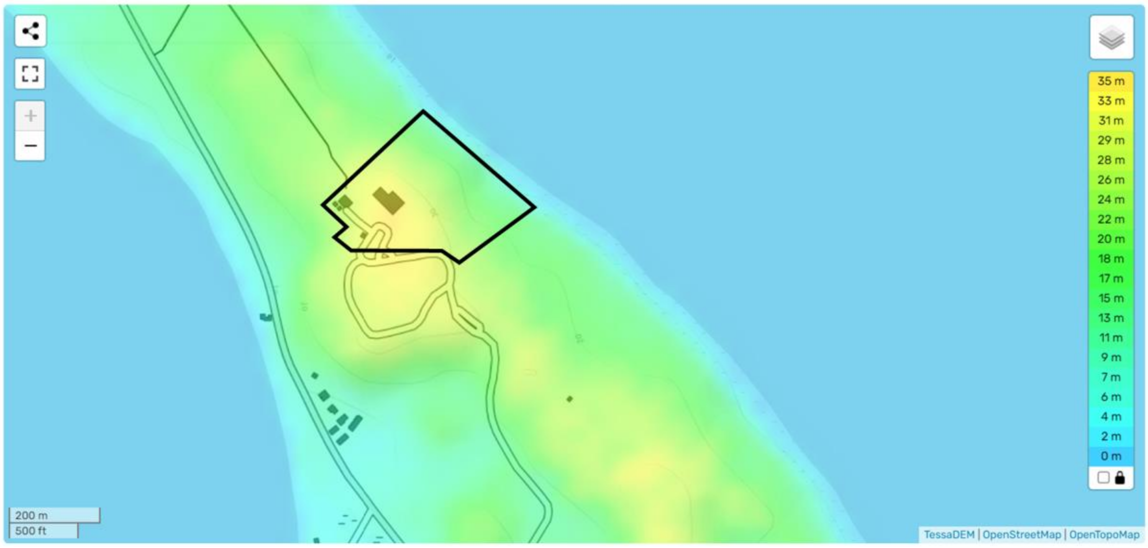


Figure 2.10 Topography of Lower Bogue site

2.5 Solar resources

The Bahamas has moderate solar irradiance. Table 2.3 presents the annual solar irradiance data for the two sites designed for the solar PV system.

Table 2.3 Annual solar irradiation data for 2 locations (Global Solar Atlas, 2022)

Site	Site 2: Naval Base	Site 3: Cockburn Town
Direct normal irradiation (kWh/m^2)	1995.8	1846.5
Global normal irradiation (kWh/m^2)	1988.1	1955.8
Diffuse horizontal irradiation (kWh/m^2)	685.2	756.4

As the Bahamas is located in the Northern hemisphere, the sun is relatively in the southern direction. The sun horizon and path for the two locations are shown in Figure 2.11 and Figure 2.12.

Figure 2.11 Solar horizon and path at Naval Base (Solargis, 2023)

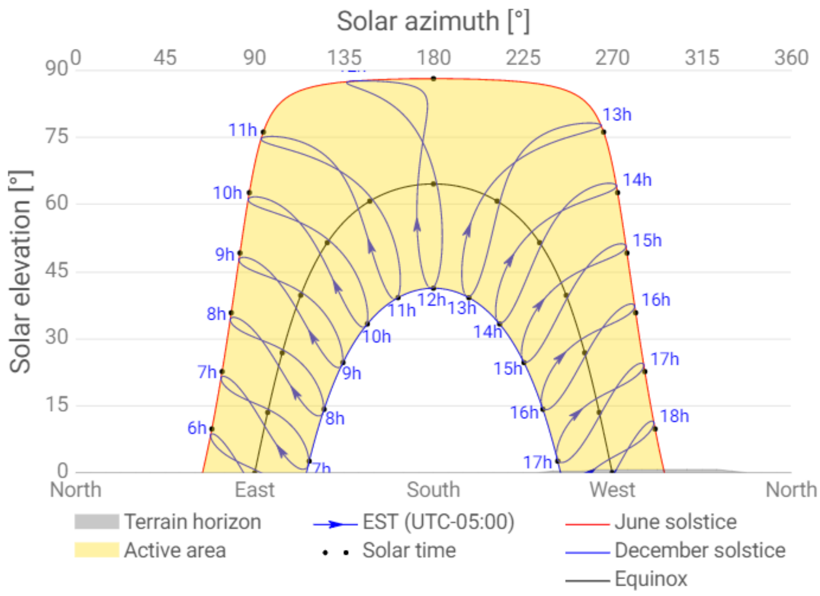
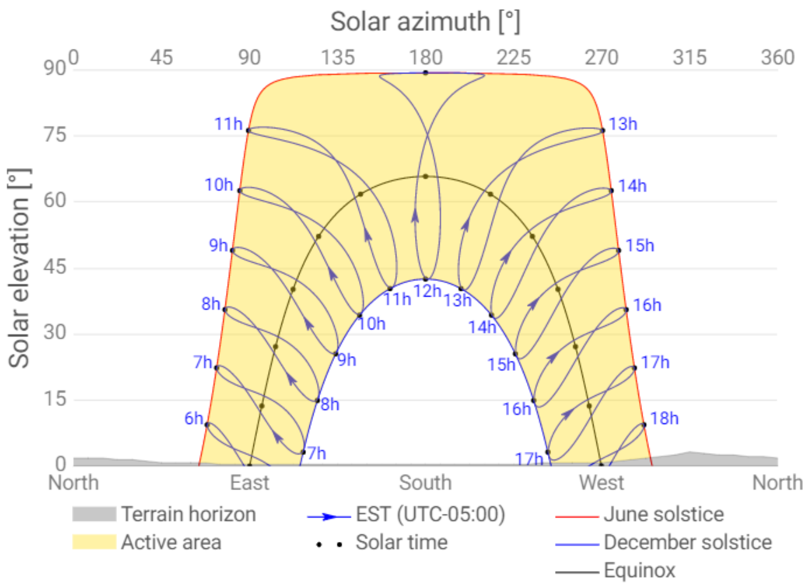


Figure 2.12 solar horizon and path at Cockburn Town (Solargis, 2023)



3

DESIGN BASIS

3.1 OC-OTEC at Lower Bogue

The OC-OTEC design at Lower Bogue are based on the followings:
1. 30-kW size is provisioned for the piloting stage.
2. OTEC is utilizing saline groundwater.
3. A separate new extraction well is designed for OTEC to make the drinking water extraction independent on the electricity supply from OTEC and to reach sufficient low or high temperatures. The well extracts water at a depth of 1,000 - 1,500 m.
4. The return water is injected into a new well at a depth where the groundwater temperature is equal to the water injected.

3.2 Solar field at Naval Base and Cockburn Town

The Solar PV design at two other locations is based on the followings:
1. The solar PV system shall meet 100 % electricity demand.
2. The installation must be located within the desalination plant area if possible, and no forest areas are to be utilized for renewable energy facilities.
3. Able to withstand 200 mph wind speed (Category 5 hurricane).

4

CONCEPT DESIGN

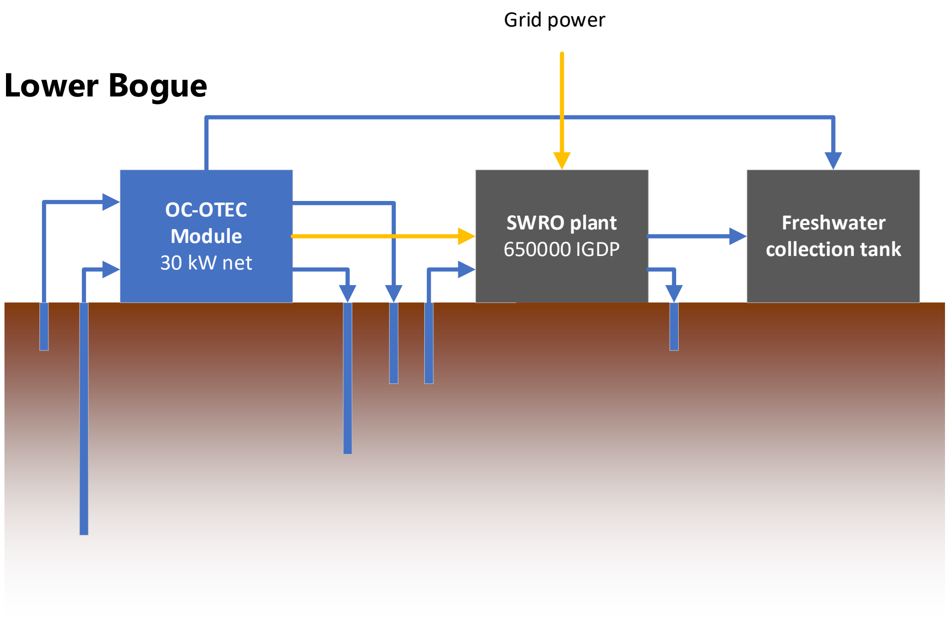
This chapter presents the conceptual design of the OTEC at Lower Bogue and solar PV at Naval Base and Cockburn Town.

4.1 OTEC Pilot at Lower Bogue

The OTEC pilot at Lower Bogue is designed as an Open Cycle (OC) type at 30 kW-net design power. This is equivalent to 6 % of the power demand. This OTEC plant also produces desalinated water. The desalinated must first be re-mineralized and chlorinated before being supplied to the collection tank. The water generation capacity, 70 m^3/day, is equal to 2.3% of the current SWRO plant capacity.

Figure 4.1 shows a schematic of the OTEC pilot system designed for Lower Bogue.

Figure 4.1 Schematic of OTEC pilot system at Lower Bogue



Process description

The process flow diagram of the OTEC plant is shown in Appendix III.

Warm groundwater (approx. 27 °C) is pumped by pump P-101 from a shallow well to a low-pressure flash evaporator V-101 through a valve. Due to low pressure below the saturation point, the water is flash evaporated. A small part of the water is evaporated into steam. The steam drives turbine T-201 to generate electricity by generator G-201.

The steam from the turbine is condensed by the cold groundwater from deep underground on condenser E-301. After use, the cold water is still cold enough to be utilized for cooling purposes. For this pilot, this option is not considered.

The steam that is condensed from E-301 is demineralized water. It is further processed by re-mineralization and chlorination and sent to the existing potable water storage tank. Since the water generated from this pilot is only 2.3 % of the current capacity, the existing re-mineralization and chlorination should be able to handle this extra water.

Equipment list

The main equipment needed for the installation is listed in Table 4.1.

Table 4.1 Equipment list

Tag #	Components	Specifications
P-101	Submersible pump warm water	- Power rating: 1.3 kW - Capacity 540 m^3/h
P-102	Submersible pump cold water	- Power rating: 1.8 kW - Capacity: 536 m^3/h
P-301	Injection pump cold water	- Power rating: 1.8 kW - Capacity: 290 m^3/h
P-302	Injection pump warm water	- Power rating: 1.3 kW - Capacity: 290 m^3/h
V-101	Flash evaporator	- Pressure: 3 kPa(abs), - approx. dia: 2 m - approx. height: 4 m
T-201 & G-201	Turbogenerator	- power rating: 36 kW - steam flow: 28 m^3/s - pressure: 2 kPa steam
E-301	Condenser	- 482 m^2 exchange area - Pressure: 2 kPa
P-303	Vacuum pump	- Target pressure 3 kPa(abs), - Non-condensable gas rate: 28 m^3/s

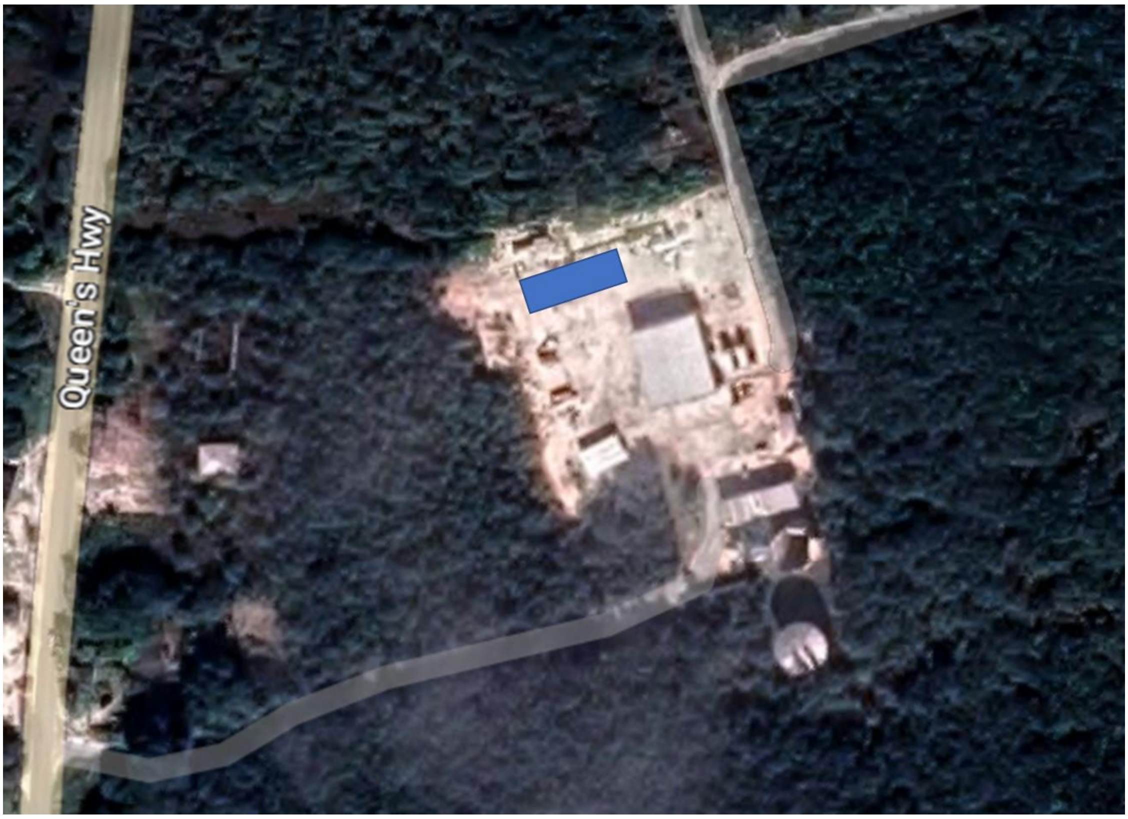
Table 4.2 Wells specification

Components	Lower Bogue
Cold water extraction well	1 x 14 in, 1000 m depth
Cold water injection	1 x 12 in, 500 m depth
Warm water extraction well	1 x 12 in, 50 m depth
Warm water injection	1 x 14 in, 100 m depth

4.1.1 Plot plan

The installations require approximately 300 m^2 area. Figure 4.2 shows the plot area.

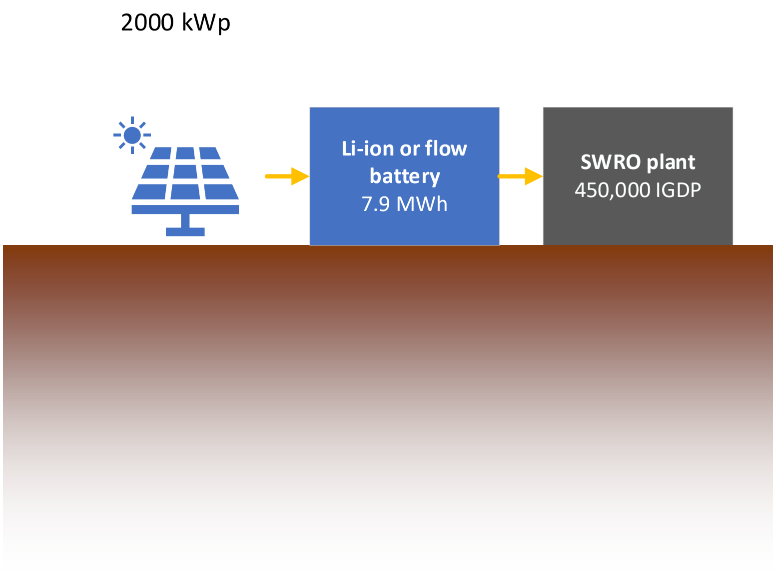
Figure 4.2 Plot area 30 kW OC-OTEC



4.2 2000 kWp Solar PV at Naval Base

A 2000 kWp solar PV with a 9.7 MWh battery has been designed to supply 100% power demand of SWRO at Naval Base. The design is based on the energy profile on the site shown in chapter 4.2.1. A battery system is provided to overcome the variability of power generation. Figure 4.3 shows a schematic of the solar PV system, including a battery facility for the Naval Base location. Appendix II provides the single-line diagram of the solar PV system.

Figure 4.3 Schematic of Solar PV system at Naval Base



The overview of the design metrics is shown in Table 4.3.

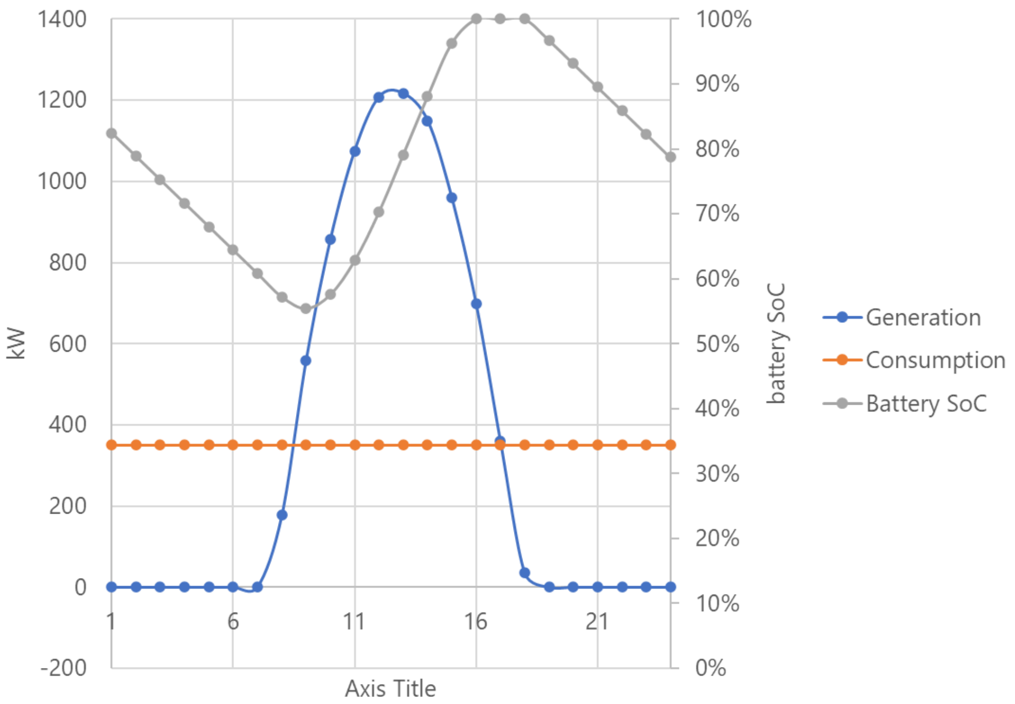
Table 4.3 Solar PV system metrics

Parameters	Value
Module DC Nameplate	2.17 MW
Inverter AC Nameplate	1.76 MW
Load ratio	1.24
Annual Production	3.462 GWh
Performance Ratio	80.10%
kWh/kWp	1,593.80

4.2.1 Energy profile

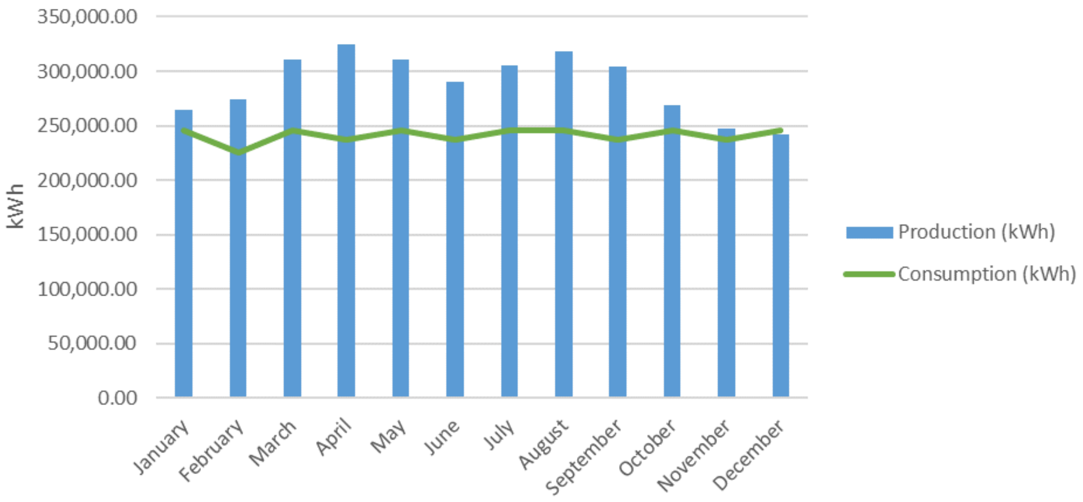
Figure 4.4 shows the hourly profile of energy generation by solar PV, energy consumption by the SWRO plant, and the battery State of Charge (SoC) conditions. During a normal day, about 50% battery capacity is used. The other half is available for times of bad weather, such as long cloudy- or rainy days.

Figure 4.4 Energy generation, energy consumption and battery State of Charge (SoC) profile on a sample day



For each month, the energy generated by solar PV is sufficient to meet the whole demand of the plant. The simulated monthly profile is presented in Figure 4.5.

Figure 4.5 Expected monthly profile of energy production and consumption at Naval Base



4.2.2 Components list

The main components required for a solar PV installation battery storage facility are listed in Figure 4.5.

Table 4.4 Main components for a solar PV installation, including battery

Component	Specification	Count
inverters	24 kW inverter	73 (1.76 MW)
strings	10 AWG (Copper)	365 (17,149.2 m)
modules	345 W solar module	6,296 (2.17 MW)
battery	9.7 MWh, 500 kW	1 package

4.2.3 Plot plan

The solar PV is to be on the clear area within the WSC boundary, as shown in Figure 4.5. Table 4.5 provides an overview of the area and racking system.

Figure 4.6 Plot plan solar PV at Naval Base

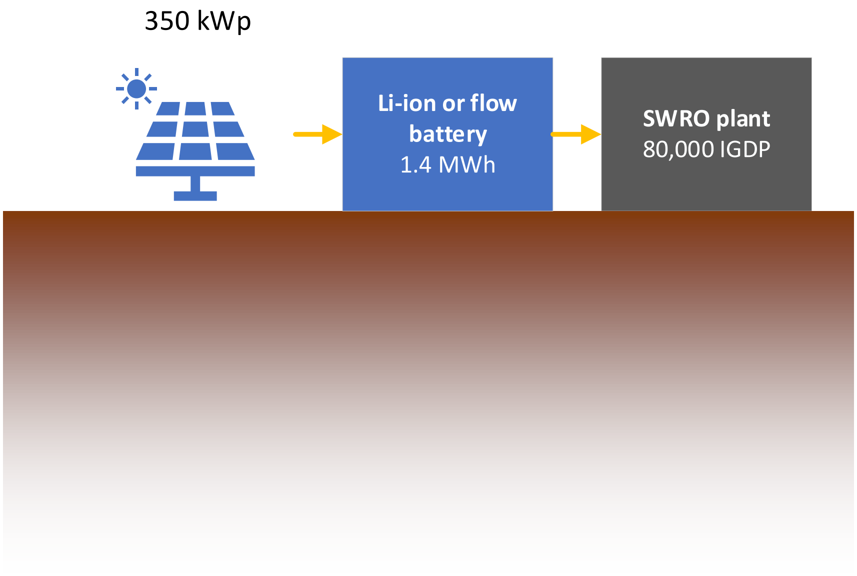
Table 4.5 Racking system and area

Parameters	Value
Racking	
Orientation	Landscape (Horizontal)
Tilt	23°
Azimuth	180 °C
Intrarow spacing	2.4 m
Frame size	4x1
Frames	1,547
Modules	6,296
Area	
Footprint	19,775.0 m^2
Ground coverage ratio (GCR)	0.63

4.3 350 kWp Solar PV at Cockburn Town

350 kWp Solar PV with a 1.4 MWh battery has been designed to supply 100% power demand of SWRO at Cockburn Town based on the energy profile shown in Chapter 4.3.1. Appendix II provides the single-line diagram of the solar system.

Figure 4.7 Schematic of Solar PV system at Naval Base



The design overview is shown in Table 4.6.

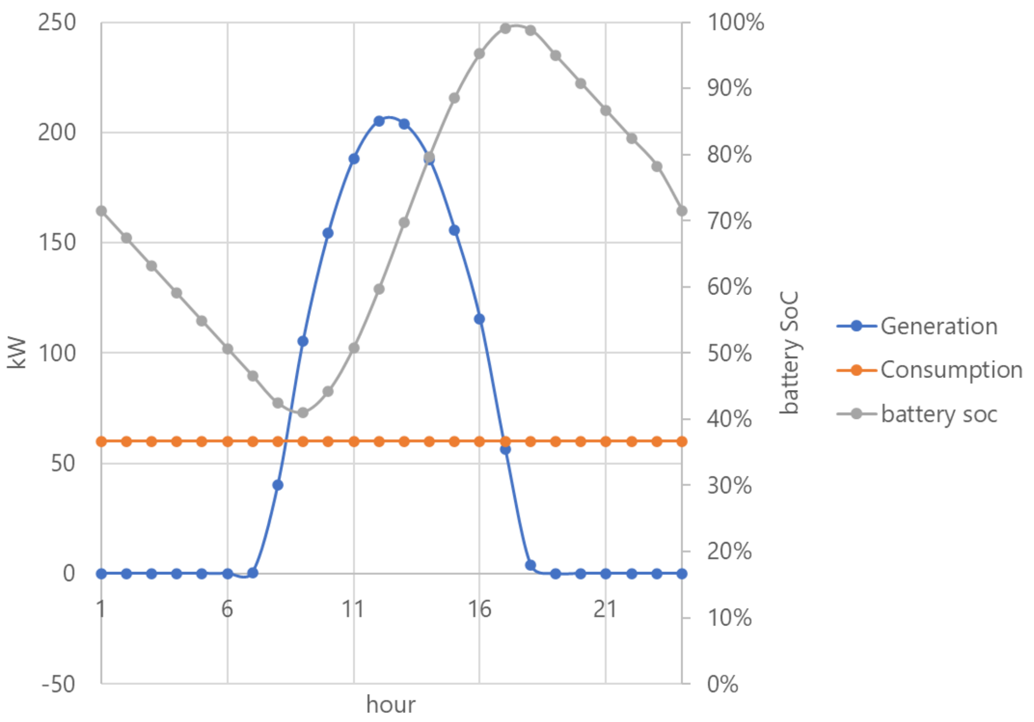
Table 4.6 Solar PV design metrics

Parameters	Value
Module DC Nameplate	479.0 kW
Inverter AC Nameplate	385.0 kW
Load ratio	Load Ratio: 1.24
Annual Production	697.7 MWh
Performance Ratio	74.70%
kWh/kWp	1,456.50

4.3.1 Energy profile

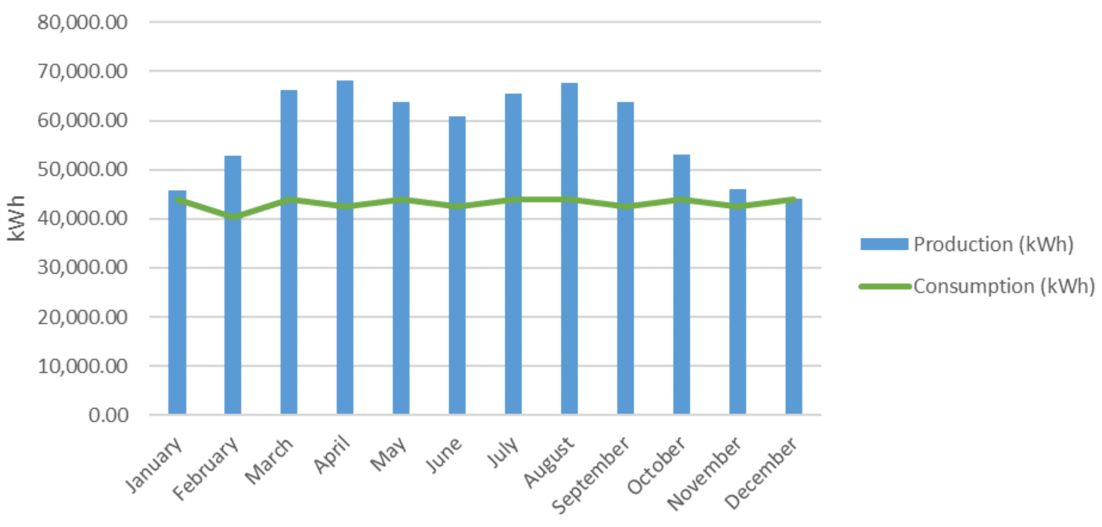
Figure 4.4 shows the hourly profile of energy generation by solar PV, energy consumption by the SWRO plant, and the battery State of Charge (SoC) conditions. During a normal day, about 60 % of the battery is utilized. The other 40 % is available for times of bad weather, such as long cloudy- or rainy days.

Figure 4.8 Energy generation, energy consumption and battery State of Charge (SoC) profile on a sample day



The energy generated by solar PV is sufficient to meet the whole demand of the SWRO plant. Figure 4.8. shows the monthly generation and demand profile.

Figure 4.9 Monthly profile of energy production and consumption



4.3.2 Equipment list

The components for the solar field, including the battery facility at Cockburn Town are listed in Figure 4.5.

Table 4.7 Main components

Component	Specifications	Count
inverters	24 kW	16 (385.0 kW)
strings	10 AWG (Copper)	80 (3,817.3 m)
modules	345 W solar module	1,497 (479.0 kW)
battery	1.4 MWh, 80 kW	1 package

4.3.3 Plot plan

The solar PV is to be located close to the airport runway, as shown in Figure 4.5. The proposed area is not within the WSC area, since the WSC area is almost completely covered by trees. WSC can cooperate with the airport operator to install solar PV on a larger scale to also supply to the airport.

Figure 4.10 Location solar PV

The PV module configurations and the racking system is tabulated in Table 4.8.

Table 4.8 Racking system and area

Racking	
Orientation	Landscape (Horizontal)
Tilt	22°
Azimuth	180 °C
Intrarow spacing	0.6 m
Frame size	3x1
Frames	499

Modules	1497
Area	
Footprint	4,210.9 m^2
Ground coverage ratio (GCR)	0.70
Design requirement	
Wind speed	180 mph

5

DESIGN SPECIFICATIONS

In Chapter 5.1 the design specifications for the OTEC pilot at Lower Bogue are provided. The design specifications for the solar PV, including battery at Naval Base and Cockburn Town are provided in 5.2 and 5.3, respectively.

5.1 Lower Bogue (OTEC pilot)

Table 5.1 shows the design specifications for the 30 kW OTEC pilot for the Lower Bogue location.

Table 5.1 Design specifications 30 kW OC-OTEC

Parameters	**Value**
gross power	< 39 kW
net power	30 kW
max footprint	300 m^2
type	Open Cycle
annual production	250 MWh
availability	> 95%
water generation	24,000 m^3/year
freshwater requirement	see Table 5.2
Wells	
cold water intake well	290 m^3/h, 1000 - 2000 m
cold water injection well	290 m^3/h, 100m (if warm) - 500 m (if cold)
warm water intake well	540 m^3/h, 50 - 100 m
warm water injection well	540 m^3/h, 150 m

Table 5.3 shows the requirements for tap water. The desalinated water generated from the open cycle OTEC plant must be processed to conform to these requirements.

Table 5.2 Tap water quality requirements

Parameter	Value
Physical Analysis	
Appearance	Clear
Odor	Not offensive
pH	6.5 - 8.5
Temperature	25 °C is desirable
Apparent Color Unit	15
True Color Unit	15
Turbidity	0.5
Chemical Analysis	
Total Chlorine	1.5
Free Chlorine	1.0
Alkalinity	50 mg/L
Conductivity	> 1500 µS
Total Hardness	100 mg/L as CaCO3
LSI	0 - 1

5.2 Naval base

Table 5.3 Design specification 2000 kWp ground-mounted solar PV

Parameters	Value
Electrical	
Module DC Nameplate	2.17 MW
Inverter AC Nameplate	1.76 MW
Load ratio	1.24
Annual Production	3.462 GWh
Performance Ratio	80.10%
kWh/kWp	1,593.80
Racking	
Orientation	Landscape (Horizontal)
Tilt	23°
Azimuth	180 °C
Intrarow spacing	2.4 m
Frame size	4x1
Frames	1,547
Modules	6,296
Area	
Footprint	19,775.0 m^2
Ground coverage ratio (GCR)	0.63

Parameters	Value
Design requirement	
Wind speed	180 mph

Table 5.4 Design specification 9.7 MWh battery

Parameters	Value
max charge power	500 kW
discharge power	350 kW
capacity	9.7 MWh
max area	180 m^2

5.3 Cockburn Town

Table 5.5 Design specification 450 kWp ground-mounted solar PV

Parameters	Value
Electrical	
Module DC Nameplate	479.0 kW
Inverter AC Nameplate	385.0 kW
Load ratio	Load Ratio: 1.24
Annual Production	697.7 MWh
Performance Ratio	74.70%
kWh/kWp	1,456.50
Racking	
Orientation	Landscape (Horizontal)
Tilt	22°
Azimuth	180 °C
Intrarow spacing	0.6 m
Frame size	3x1
Frames	499
Modules	1497
Area	
Footprint	4,210.9 m^2
Ground coverage ratio (GCR)	0.70
Design requirement	
Wind speed	180 mph

Table 5.6 Design specification 1.4 MWh battery

Parameters	Value
max charge power	85 kW
discharge power	60 kW
capacity	1.4 MWh
max footprint	60 m^2

6

REFERENCES

Meteoblue. (2022, February 3). *Simulated historical climate & weather data*. Retrieved from Meteoblue: https://www.meteoblue.com/en/weather/historyclimate/climatemodelled/

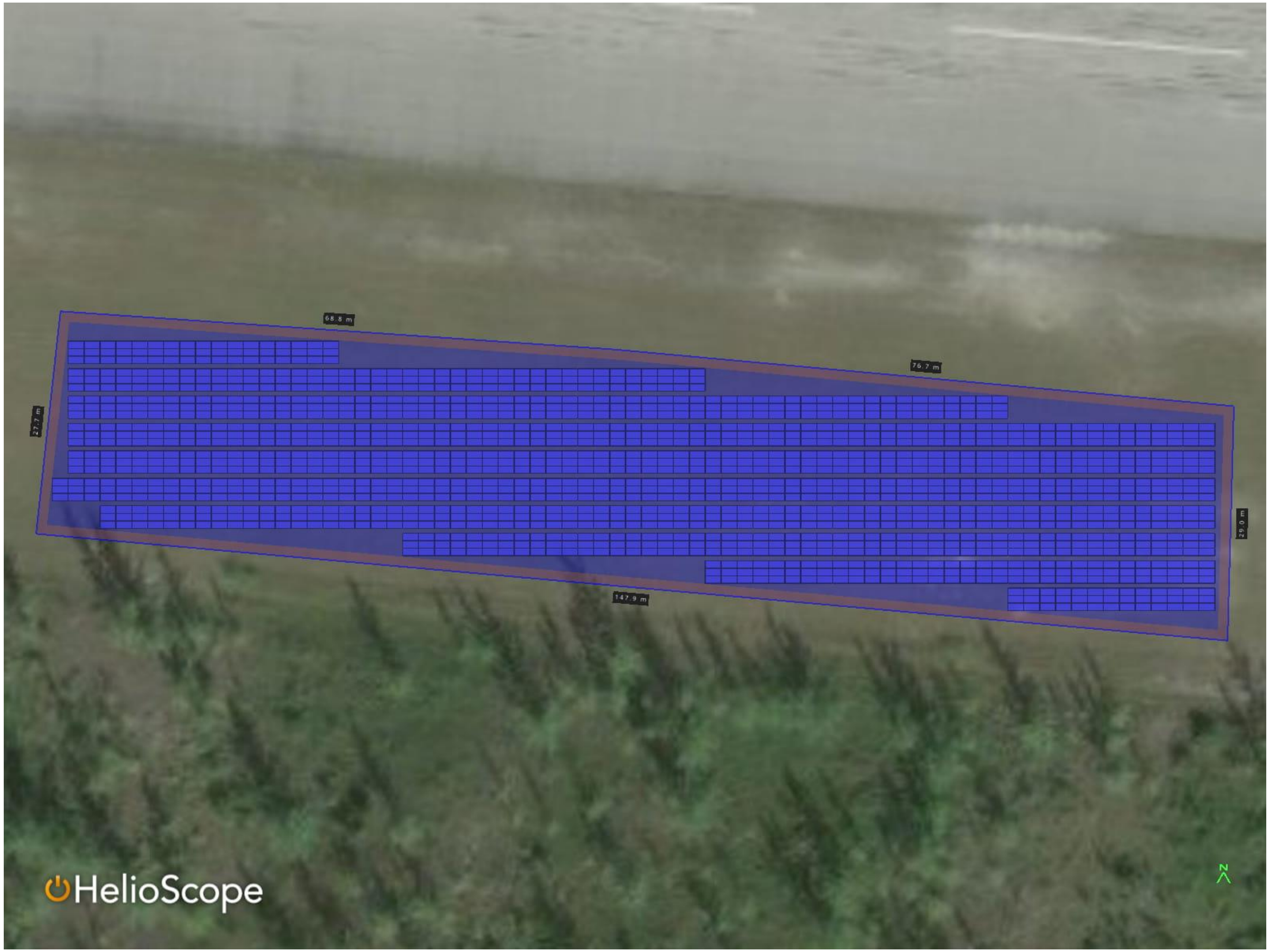
Solargis. (2023). *Global Solar Atlas.* Retrieved January 9, 2023, from https://globalsolaratlas.info/map

Appendices

APPENDIX: DETAILED SOLAR PV LAYOUT

Figure I.1 Detailed layout of solar PV at Naval Base

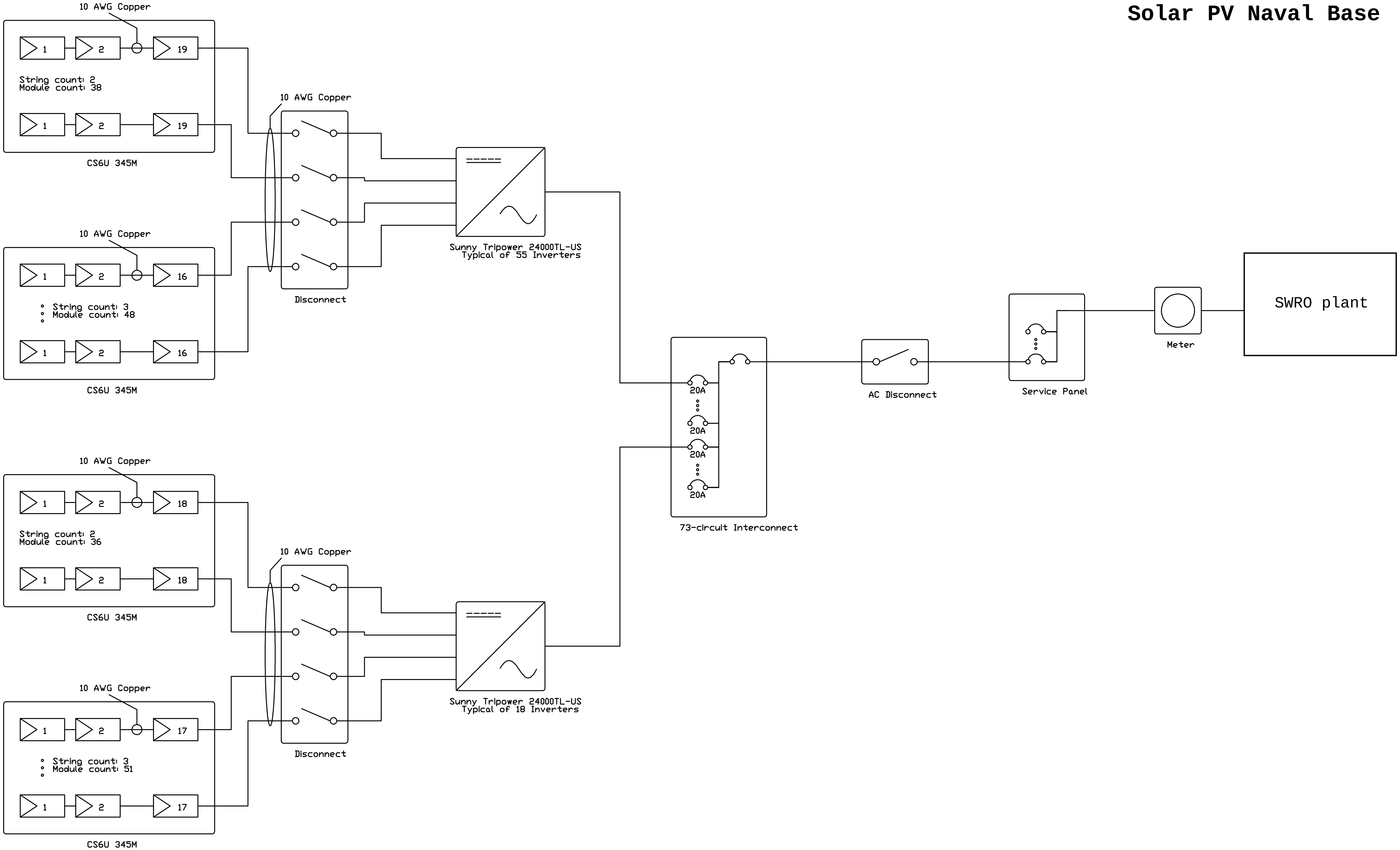
Figure I.2 Detailed layout of solar PV at Cockburn Town



II

APPENDIX: SINGLE LINE DIAGRAM SOLAR PV

Solar PV Naval Base

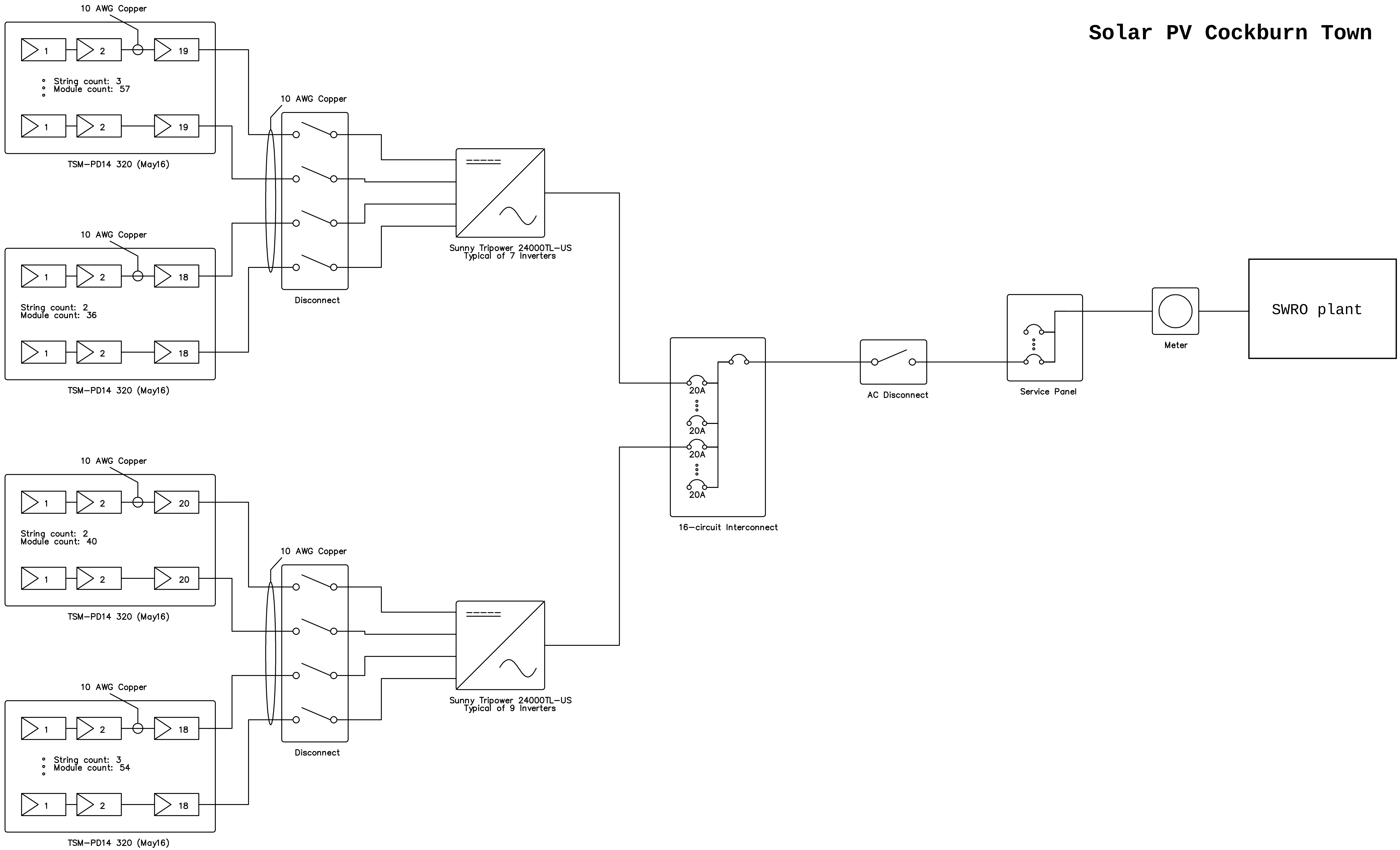


Module Specifications	
6296x Canadian Solar CS6U 345M	
STC Rating	345 W
Vmp	38.1 V
Imp	9.06 A
Voc	46.4 V
Isc	9.56 A

Inverter Specifications	
73x SMA Sunny Tripower 24000TL-US	
Max AC Power Rating	24.06 kW
Max Input Voltage	1,000 V

Wire Schedule		
Tier	Wire	Length
String	365x 10 AWG	17149m

Solar PV Cockburn Town



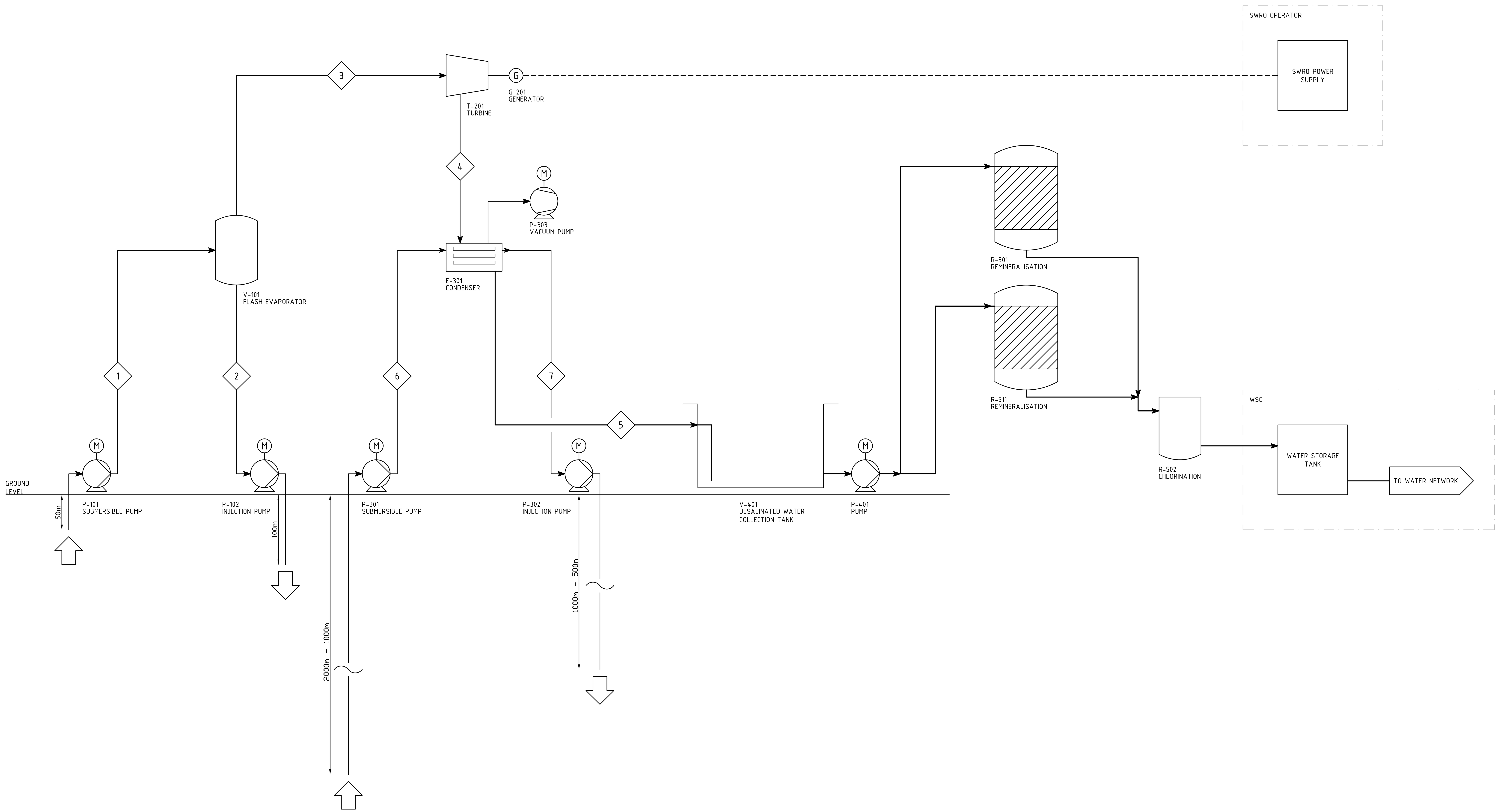
Module Specifications	
1497x Trina Solar TSM–PD14 320 (May16)	
STC Rating	320 W
Vmp	37.1 V
Imp	8.63 A
Voc	45.8 V
Isc	9.1 A

Inverter Specifications	
16x SMA Sunny Tripower 24000TL–US	
Max AC Power Rating	24.06 kW
Max Input Voltage	1,000 V

Wire Schedule		
Tier	Wire	Length
String	80x 10 AWG	3817m

III

APPENDIX: PROCESS FLOW DIAGRAM 30 KW OC-OTEC AT LOWER BOGUE



	1	2	3	4	5	6	7
Stream	Seawater	Seawater	Steam	Steam	Condensate	Cold water	Cold water
Mass flow (kg/h)	534,200	532,170	2,030	2,030	2,030	296,400	296,400
Volumetric flow (m3/h)	540	536	188,300	187,800	290	290	290
Temperature (°C)	27	23.4	23.4	13,0	10,0	7	10
Pressure (kPa) (abs)	101	3	2	1	1	101	100

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Rev.	Drawn by	Date	Description
A			
B			
C			

DOCUMENT IN PROGRESS 02 07-02-2023

Client
CARIBBEAN COMMUNITY CLIMATE CHANGE CENTRE
Project
EVALUTATION OCEAN THERMAL ENERGY CONVERSION (OTEC) CONCEPTUAL DESIGN
Description
30 kW OPEN CYCLE OTEC
PROCESS FLOW DIAGRAM

Status: Document in progress
Date
Drawn: J. Tjon-A-San
Checked: R. Salam
Approved: R. van der Velde

Format	Scale	Project code	Drawing number	Sheet
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Plot date: 2/7/2023 11:06

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