City of Edmonton Solar Photovoltaic Program

Asset Management Guideline

Volume 5

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Prepared for

INTEGRATED INFRASTRUCTURE SERVICES
Facility Engineering Services –
Facility Planning & Design - Facility Infrastructure & Delivery

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INTENT OF USE

This guideline publication was developed for establishing guidelines for the City of Edmonton expectations for solar photovoltaic systems that are to be deployed on their facilities. The greatest care has been taken to confirm the accuracy of the information contained herein. The views expressed herein do not necessarily represent those of any individual contributor. Solar photovoltaic technologies continue to evolve, and deployment practices change and improve over time and it is advisable to regularly consult relevant technical standards, codes, and other publications on solar photovoltaic products and practices rather than relying on this publication exclusively.

Report Version History

- REV01 – September 25, 2020 – Released
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Acronyms & Abbreviations

AC – Alternating Current

AEP – Alberta Environment and Parks

AESO – Alberta Electricity System Operator

AHJ – Authorities Having Jurisdiction

Al – Aluminum (conductor)

A/M/E/S – Architectural / Mechanical / Electrical / Structural Consultants

ANSI – American National Standards Institute

APEGA - Association of Professional Engineers and Geoscientists of Alberta

ARCA - Alberta Roofing Contractors Association

AUC – Alberta Utilities Commission

CAPEX – Capital Expenditure

CEC - Canadian Electrical Code

CoE – City of Edmonton

CRCA - Canadian Roofing Contractors Association

CSA – Canadian Standards Association

Cu – Copper (conductor)

DC – Direct Current

DG – Distributed Generation

EMT – Electrical Metallic Tubing

EoR – Engineer-of-Record

EPC – Engineer Procure Construct

EPS – Electrical Power System

FRP - Fiber Reinforced Polymer

GFI – Ground Fault Interrupter

IEEE - Institute of Electrical and Electronics Engineers

IFC – Issued for Construction

IFR – Issued for Review

ILR – Inverter Load Ratio (a.k.a. DC:AC Ratio)

IR – Infra-red

kW – 1000 watts (unit of power)

kWh – Kilowatt Hour (unit of energy)

kWp – Peak Kilowatt Rating (see STC below)

LOTO – Lock-out Tag-Out

MPPT – Maximum Power Point Tracker

MSDS – Material Safety Data Sheet

MLPE – Module Level Power Electronics

MW – one million watts (unit of power)

MWh – one million-watt hours (or one thousand kWh)

NBC(AE) National Building Code – 2019 Alberta Edition

NBC – National Building Code

NFPA – National Fire Protection Association

NRCA - National Roofing Contractors Association

OHS – Occupational Health & Safety

OPEX – Operating Expenditure

O&M – Operations & Maintenance

PVC – Polyvinyl chloride

PV – Photovoltaic (Solar Electric)

PPA – Power Purchase Agreement

PPE – Personal Protective Equipment

SCADA –Supervisory Control and Data Acquisition

SLD – Single Line Drawings

STC – Standard Test Conditions: 1,000 Watts per square meter solar irradiance, 25 degrees C cell temperature, air mass equal to 1.5, and ASTM G173-03 standard spectrum; units in DC Watts

UL – Underwriters Laboratory

UV – Ultraviolet Light (high energy component of the solar spectrum)

WSP – Wires Service Provider

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1 Overview

The objective of this Asset management guideline is to create an overarching framework to support the development, deployment, and management of solar photovoltaic assets on City of Edmonton Facilities. The asset management project has been prepared based on solar PV industry best practices for the management of solar assets deployed in a net billing arrangement on City owned facilities.

1.1 Purpose & Scope

This document is intended to provide a guideline for use internally by City of Edmonton staff to establish the parameters and expectations around a comprehensive Solar Photovoltaic Asset Management Program. The contents of this guideline do not supersede any requirements of Authorities Having Jurisdiction (AHJ) but do provide, where possible, clarity for best practice expectations the City of Edmonton has for its projects. It is to be read in conjunction with the prior volumes (Vol1 – Vol4) of the City of Edmonton Solar Photovoltaic program.

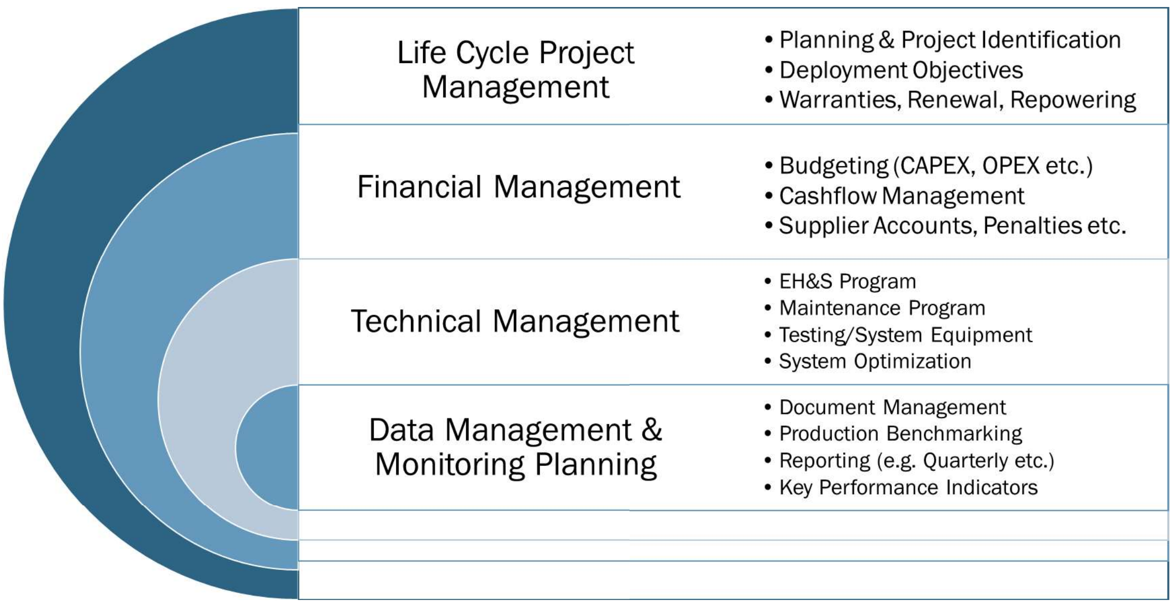

Figure 1 - Roles & Responsibilities Framework

1.2 Definitions

- Preventative Maintenance – activities undertaken to manage and maintain the solar photovoltaic system to ensure its long term safe, reliable and proper operation.
- Corrective Maintenance – repairs or reactive servicing necessitated by premature failure of components or devices.
- Key Performance Indicators (KPI) – metrics for evaluating the success of the operations & maintenance management program.

2 References

- *Solar Asset Management Best Practice Guidelines Version 1.0 – Solar Power Europe Asset Management – Best Practice Guidelines – Solar Power Europe*

3 Life Cycle Project Management

The intent for the Solar PV system deployment is to develop a standardized solution to minimize the greenhouse gas (GHG) generation rates caused by electricity consumption by offsetting electricity use within City of Edmonton owned facilities. This embedded generation methodology will require a level of integration between building systems, facilities maintenance, and energy management to ensure it is safely, reliably and effectively managed.

3.1 City of Edmonton Solar Photovoltaic Program Overview

The program envisions the life cycle of a solar photovoltaic project from initial site selection, design, construction, and ultimately the operation. This asset management program is crafted to tie those activities together into a comprehensive program that will be refined and informed by subsequent project deployments.

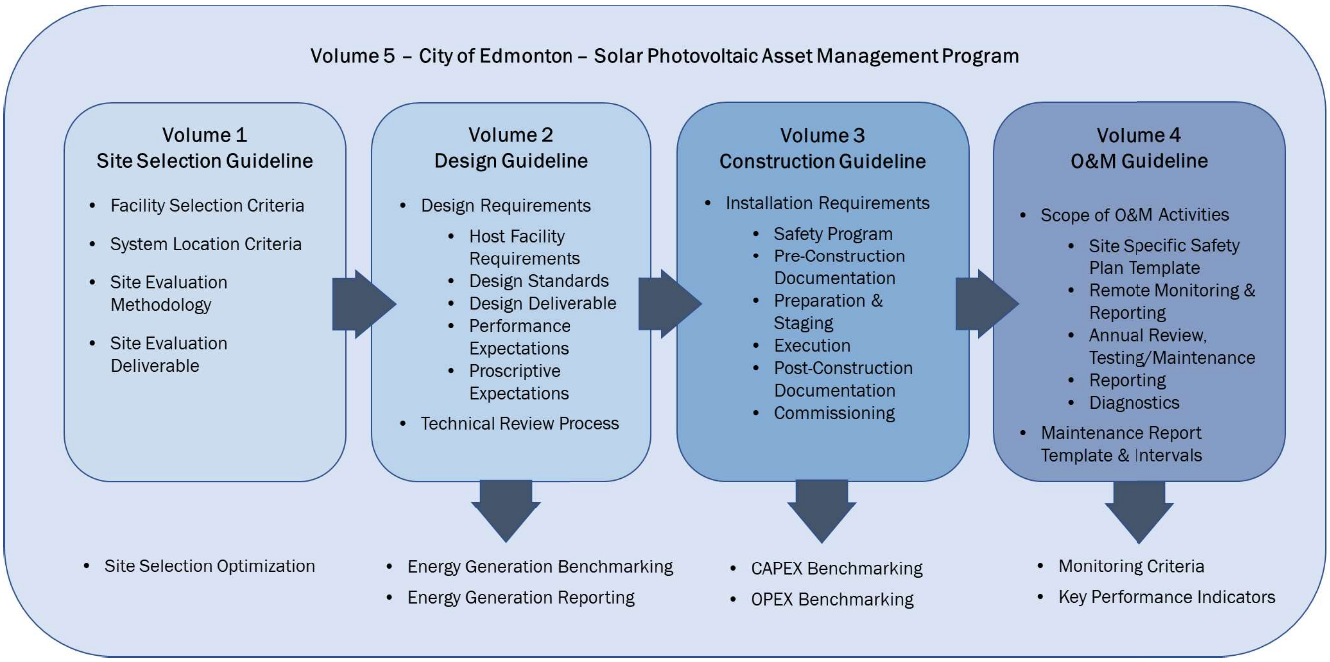

Figure 2 - Solar Photovoltaic Program Overview Diagram

3.2 Project Lifecycle

The intent of this program is to identify opportunities for deploying solar photovoltaic systems on City of Edmonton owned facilities – there are two expected pathways for this deployment:

- **Existing Facilities:** The largest opportunity for rapid deployment of solar photovoltaic systems as part of a Greenhouse gas mitigation strategy, is on the existing built infrastructure. This has been the focus of the site selection portion of the program, as well as a key emphasis in the design and construction guidelines.

- **New Facilities:** the more straightforward, but longer term deployment is on new facilities that are being constructed to be "solar-ready" meaning the structural, electrical, and mechanical infrastructure is in place to support the integration of a solar photovoltaic system.

In either of these cases the management of the asset is the same. The lessons learned at all stages of the project are to be incorporated into the program as whole to enable it to adapt to the changing market, both in terms of technological advancements as well as market trends.

3.3 Asset Management Team

The goal of the asset management team is to ensure each solar photovoltaic asset performs as expected. This means in terms of energy generation, cost expectations, long term durability and above all, safe operation of the assets:

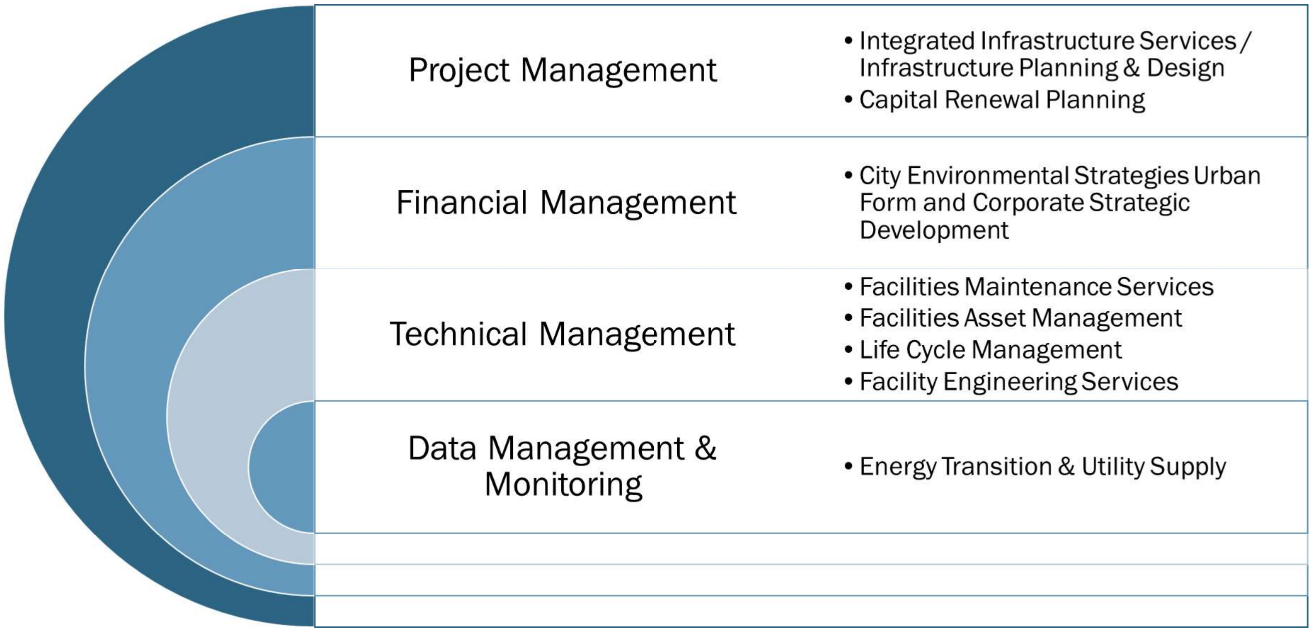

Figure 3 - Asset Management Team

Based on the integrated nature of the projects within the existing real estate asset base – it is expected that there will be a number of different individuals from different departments collaborating to ensure an effective program.

3.3.1 Roles

Based on this team there are several roles that will need to be fulfilled to ensure the asset management program is implemented as intended:

- **Project Management** – this will be a jointly held role with members from capital renewal (e.g. life cycle management) and will be focused on the implementation of projects.
- **Financial Oversight** – there is a role to ensure that the project operating costs are aligned with the established servicing budgets (both PM and CM roles).
- **Technical Oversight –** there will be a role for technical oversight of the projects, including FMS, Lifecycle Management, and Facility Engineering services – specifically for any assets that may not be operating as intended.
- **Data Management** – there will be a role (likely residing with FMS or Engineering) to ensure that data on the system is validated and established.
- **Monitoring & Benchmarking** – this role would land with Energy Transitions and Utility Supply to ensure that energy generation (which offsets consumption) is being tracked, identified, and compared to the original generation benchmarks established at the site selection and design stage.

At the outset it is anticipated that these roles would be fulfilled by staff from a variety of departments, however as the solar photovoltaic program grows, it will be necessary to consider dedicated staff to manage and maintain these projects.

The following RACI (**R**esponsible, **A**ccountable, **C**onsulted, **I**nformed) matrix has been added to illustrate these various stages of the program and the expected roles for each department.

	Infrastructure Planning and Design	Engineering Services	Facility Maintenance	Energy Management	Energy Transition	Economic and Environmental Sustainability	Life Cycle Management	Communications
Financial Reporting	R		I	I	I	A		
Accounting & Budget Management	R					C	C	
Preventative Maintenance	A	C	R				C	
Corrective Maintenance	C	I	R				I	
Testing Equipment	C	I	R					
Inventory Equipment	A	C	R				C	
Asset Optimization	I	C	R	A			C	
Document Management		R	A					
Operations Monitoring		C	R	I	I			
BAS Energy Metering Data	I	C	R	C	I		I	
Production Benchmarking	I		C	R	C	I	I	I
Calibrated Generation Estimates	I	R	A	I				

Figure 4 – Asset Management RACI Matrix

As noted within the matrix, multiple groups will be required at each stage of the program to ensure the proper responsibilities are assigned and information is shared throughout the process to inform future decisions.

3.3.2 Facility Maintenance Services Integration

Although the maintenance of these systems is unique, it is expected that the management of service calls both preventative and corrective will be managed by FMS. This will require a standardization and integration with the SAP dispatch system.

To help better illustrate the role FMS will play in the program, the following diagram (figure 5) has been included to outline the process flow of these corrective and preventative activities, along with the necessary collaboration between other departments.

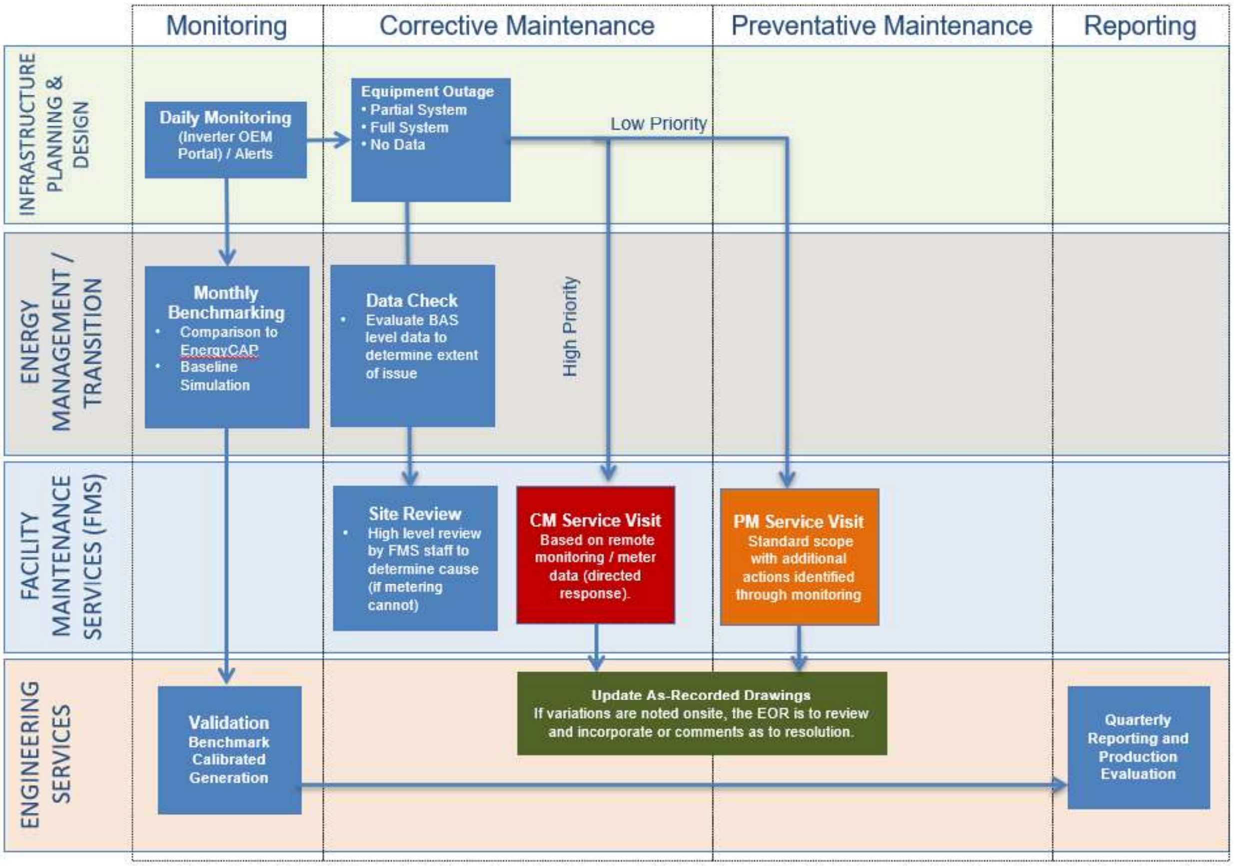

Figure 5 - Asset Monitoring & Response Process Flow

3.3.3 Host Facility Considerations

As there are operators onsite at some of the host facilities, it will be necessary to integrate them into the asset management program to ensure they understand their responsibilities, role, and limitations of that role in terms of oversight, interaction with, or activities around the solar photovoltaic system. They can be a strong advocate for the program onsite if they are properly engaged and trained about the site specific safety procedures that must be enforced. They can also be a valuable resource for validating system operation or status and avoid having to have an outside resource attend the sites.

It is understood that not all facilities have dedicated staff, and so in those cases where there is not a dedicated person onsite, the site access, requirements and orientation criteria must be well established so that City of Edmonton staff and contractors alike are clear on the expectations and site specific requirements.

3.3.4 Dedicated Staffing Approach

The level of time required to manage, and resources that can be committed, will be a function of the quantity and scale of projects. To support the identification of the team we anticipate the following roles and timing for these roles as follows:

PHASE 1 – Desktop Implementation [10 to 20 Projects]

Operations Coordinator – at this stage of the program an operations coordinator responsible for day-to-day monitoring of the inverter OEM portal, confirmation of system operation and initial first line response (e.g. review of alerts and data generated) will be required. This role would ideally be filled by a recent graduate from a technologist or technician program (or an Engineer-in-Training), familiar with solar photovoltaic systems and equipped to provide (at least initially) support with the Site Selection and screening activities required for the initial deployments. Initially this role would include inventory management and warranty tracking as part of the job description. This role would have no financial decision making or field requirement.

This would be the only dedicated position at this stage – and they would be reporting to the *Integrated Infrastructure Services / Infrastructure Planning and Design* group, however they would be required to liaise with all the departments involved in the solar photovoltaic program implementation.

PHASE 2 – Field Implementation [20 to 50 Projects]

In addition to the role outlined in the initial phase – we see the following positions required:

Service Manager – at this stage of the program a service manager with experience in the installation, maintenance, or management of solar photovoltaic assets would be required. This person's role would be to manage the contractors retained for preventative and corrective maintenance. They would also complete internal reviews of systems and issues (as identified by the Operations Coordinator) prior to mobilizing a service sub-contractor.

PHASE 3 – Full Implementation [50 to 100 Projects]

Operations Manager – at this stage of the program an operations manager assigned with financial responsibility for the maintenance, servicing, and budgeting for the projects would be necessary. This would be a management role overseeing dedicated staff involved in the solar photovoltaic program.

Monitoring Analyst – at a certain stage it will be necessary to differentiate the monitoring into a dedicated role to provide additional capacity to the operations coordinator for managing the increasing number of activities (e.g. warranty maintenance, replacement parts, inventory management etc.) and ensuring that sites alerts or issues are not overlooked.

Field Technician(s) – at a certain stage it will be reasonable to bring service technicians on staff to ensure that projects are being properly maintained, tracked, and serviced. It is reasonable to expect at the outset that in-house staff would be responsible for preventative maintenance, whereas corrective maintenance would still be contracted out (depending on the scale and scope of the project).

4 Financial Management

Ensuring fiscal viability of the projects is as important as ensuring the greenhouse gas reductions are achieved. The focus on the program is to ensure projects are adequately funded, designed and constructed to minimize operational costs, and enhance the safety for all involved.

4.1 Financial Reporting

This will be addressed through annual reporting, in conjunction with standard City budget cycles. Activities involved in the preceding period will be documented, tracked and included into these amounts.

4.2 Accounting & Budget Management

Presently the funding tranches are structured around a 10 year deployment cycle (from 2020 to 2030). Over this type of duration, it is expected that the budgeting metrics established at the outset will need to be refined as the program rolls out. This is the intent of project level feedback being provided to validate and calibrate the budgets.

4.2.1 CAPEX Budgeting

Over the last decade the solar photovoltaic industry has seen a dramatic reduction in system costs, on the order of 70 to 80% reduction from pre-2010 costs. The majority of these savings have been realized through cost reduction in equipment – however some reductions have also been realized based on economies of scale and industry experience.

Table 1 – Capital Expenditure (CAPEX) Benchmarking

Classification	Rooftop Lower $/W$_{DC}$ [150kW or Larger]	Rooftop Upper $/W$_{DC}$ [<150 kW]	Ground Mount Stand-Alone Solar [>250 kW]
Racking & Ballast (or foundations)	$0.20	$0.25	$0.45
Inverters & MLPE	$0.15	$0.20	$0.20
Solar PV Modules	$0.55	$0.60	$0.50
Wiring & BOS (switches, wiring etc..)	$0.35	$0.40	$0.45
Labour (Electrical, General, etc.)	$0.40	$0.45	$0.5
Engineering & Commissioning	$0.10	$0.20	$0.25
Permits & Approvals (Wires Owner.)	$0.10	$0.15	$0.20
Contingency	$0.10	$0.15	$0.20
Total CAPEX:	**$1.95**	**$2.40**	**$2.75**

4.2.2 OPEX Budgeting

The operational cost budgeting is on an annual basis which varies as the project ages. It is expected that preventative maintenance will stay relatively consistent and is manageable through competitive tenders. The corrective maintenance is expected to escalate as the system ages – but can be managed through timely and proactive preventative maintenance activities.

Table 2 – Operating Expenditures (OPEX) Benchmarking

Classification	Rooftop Lower $/kW$_{DC}$ [150kW or Larger]	Rooftop Upper $/kW$_{DC}$ [<150 kW]	Ground Mount Stand-Alone Solar [>250 kW]
Preventative Maintenance	$12.5 / kW	$17.5 / kW	$15.0 / kW
Corrective Maintenance	$10 / kW	$12.5 / kW	$10 / kW
Contingency	10%	15%	10%
Total Cost of System	**~$25 / kW / year**	**~$35 / kW / year**	**~$27.5 / kW / year**

4.2.3 Major Maintenance Reserve Fund

The year over year operations and maintenance (aka OPEX) allowance does not address major project milestones where a significant capital expenditure is expected. Typically to manage these predictable repair or replacement timelines a reserve fund is established that can be contributed to on a year-over-year basis.

This type of replacement is typically related to inverters specifically, as their design service life (e.g. 10 to 15 years) is typically about 50% of what the solar PV modules (and associated balance of system) life expectancy is:

Table 3 - Inverter Failure Profile - Annual Failures

Year	Degradation Profile	Inverter Failure Rate
1	100.00%	2.5%
2	99.40%	2.5%
3	98.80%	1.9%
4	98.20%	1.9%
5	97.60%	1.9%
6	97.00%	1.9%
7	96.40%	1.9%
8	95.80%	1.9%
9	95.20%	1.9%
10	94.60%	1.9%
11	94.00%	4.0%
12	93.40%	4.0%
13	92.80%	4.0%
14	92.20%	4.0%
15	91.60%	4.0%
16	91.00%	16.0%
17	90.40%	16.0%
18	89.80%	16.0%
19	89.20%	16.0%
20	88.60%	16.0%

To establish a reasonable reserve fund, it is necessary to make some assumptions regarding anticipated failure rates on the inverters, which based on the City of Edmonton systems is the primary service component that will require major overhaul. An example worksheet of this is included (MMRA-Budget_COE) within the supporting forms for this document.

It was assumed that during the 10-year inverter warranty period (year 1 to 10) the costs associated with inverter replacements would relate to labour associated with switching out the inverters. All inverter costs during that period would be covered by the warranty. We have not accounted for any failures that may not be covered under warranty due to mitigating circumstances (e.g. initial installation, acts of god etc.).

The failure profile established with can be graphically represented as follows:

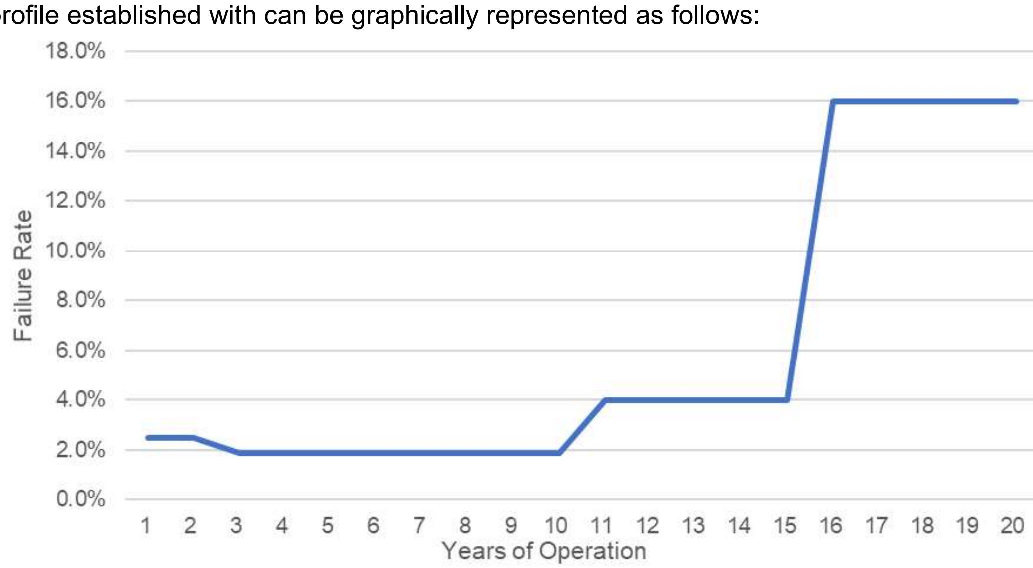

Figure 6 - Inverter Failure Profile

This profile does not reflect any significant "infant mortality" on inverters or components as it is assumed any of those would have been dealt with during the commissioning process and subsequently addressed.

Table 4 – Reserve Fund Metrics

Degradation Profile	Inverter Quantity (of Failures)	Corrective Maintenance (RM) Labour	CM Equipment Cost	MMRA Fund Requirements	MMRA Drawdown	MMRA Fund Cumulative
100.00%	21	$15,750	$0	[illegible]	$15,750	$124,731
99.40%	21	$16,026	$0	$142,940	[illegible]	$251,645
98.80%	16	$48,918	$0	$145,441	$48,918	$348,168
98.20%	16	$49,774	[illegible]	$147,986	$49,774	$446,380
97.60%	16	$50,645	$0	[illegible]	$50,645	$546,311
97.00%	16	$51,532	[illegible]	[illegible]	$51,532	$647,991
96.40%	16	$52,433	$0	$155,892	$52,433	$751,449
95.80%	16	[illegible]	$0	$158,620	$53,351	$856,719
95.20%	16	[illegible]	[illegible]	$161,396	$54,285	$963,831
94.60%	16	$55,235	$0	$164,221	$55,235	$1,072,817
94.00%	34	[illegible]	$85,000	$167,095	$159,935	$1,079,976
93.40%	34	[illegible]	$85,000	$170,019	$161,246	$1,088,749
92.80%	34	$77,581	$85,000	$172,994	$162,581	$1,099,162
92.20%	34	$78,938	$85,000	$176,022	$163,938	$1,111,246
91.60%	34	$80,320	$85,000	$179,102	$165,320	$1,125,028
91.00%	135	$81,725	$337,500	$182,236	$419,225	$888,038
90.40%	135	$83,156	$337,500	$185,425	$420,656	$652,808
89.80%	135	$84,611	$337,500	$188,670	$422,111	$419,368
89.20%	135	$86,091	$337,500	$191,972	$423,591	$187,748
88.60%	135	$87,598	$337,500	$195,332	$425,098	-$42,018

4.3 Cash flow Management

With an embedded microgeneration asset like these solar photovoltaic projects, there is no specific revenue generated (instead the benefit is an avoided energy cost from the amount of energy offset).

4.4 Supplier Account Management

There are several suppliers which will need to be managed to ensure the systems are properly maintained, these include:

- Service Providers – field maintenance contractors, module cleaning, aerial infra-red imaging etc.
- Consumable Items – fuses, filters, components, etc.

It may be necessary to ensure that there is some degree of evaluation for suppliers to ensure that they are equipped to provide the service in a timely and appropriate way. Caution should be exercised in using a lowest price where other metrics are not taken into consideration.

4.5 Equity-Debt Financing Management

The projects will be funded as a revolving fund, although these will be completely equity based projects, there should be a mechanism where projects "pay back" the avoided energy costs to facilitate the deployment of additional solar projects to enable the program to scale as envisioned by 2030.

4.6 Tax Preparation, Filing etc.

There are some specific tax implications associated with displaced energy use. The specifics of this should be reviewed with the City of Edmonton corporate accountants to ensure this is being properly managed.

4.7 Invoicing/billing and payments

It is expected that this will be managed through the existing City of Edmonton SAP system (and related infrastructure). The only item of note is that we recommend that all costs, payments, and funds are allocated to specific projects in order to validate the capital and operating budget benchmarks.

4.8 Insurance Management

There are a series of insurance aspects that need to be considered as the program is deployed:

- **Facility Infrastructure** – existing facility insurance policies will need to be amended to include for the solar photovoltaic system.
- **System Interruption Insurance** – it may be necessary for certain projects where the amount of generation is critical to the operation of the facility that insurance be considered to prevent system downtime or mitigate its impacts.
- **Service Specific Insurance** – as the City of Edmonton expands the amount of operations and maintenance work they are addressing in-house, it will be necessary to review the insurance requirements associated with equipment, vehicles, and tools.

5 Technical Management

The key expectations for the technical operation of the facilities has been addressed in the prior City of Edmonton Solar photovoltaic Program guidelines. It is important to note some asset management specific interactions that need to be managed:

5.1 Environment, Health & Safety

5.1.1 Risk Management

All activities onsite shall be subjected to annual risk management reviews. This includes facility operator interaction with the systems, service providers, and City of Edmonton facilities staff. Where practicable implement audits to determine if service staff are adhering to the solar program requirements and the City of Edmonton Safety requirements.

5.1.2 Labeling & Documentation

As detailed within the Design and Construction Guidelines, there is an expectation that all facilities are equipped with appropriate shock prevention, and arc flash labeling. This should be further supported by a Site Safety Data Sheet indicating site specific considerations.

5.1.3 Safety Training

Specific training and orientation shall be mandated in all service provider agreements. This training shall be facilitated through the Facility Maintenance Services department and shall be provided to both unqualified and qualified personnel that may need to access the area within the limited approach boundary of the solar photovoltaic system.

5.1.4 Environmental Considerations

All products, cleaning agents, or solvents shall be tracked via the MSDS inventory as mandated by WHMIS. Disposal or off-flow of products and materials shall be considered and mitigated where possible. Where liquid filled transformers are used (e.g. larger-scale ground mount systems >500 kW) specific requirements around containment, management, and disposal of those fluids shall be incorporated into all service agreements.

5.1.5 Waste Management – Reuse, Recycling & Disposal

Disposal practices shall be enforced to reduce the impact on landfills at all stages of the project life cycle shall be considered. Provisions shall be made to ensure that packaging, and shipping materials are recycled where possible. Damaged electrical equipment (e.g. modules, inverters, optimizers etc.) shall be returned to the manufacturer or disposed of via an electronics recycler.

5.2 Maintenance Program

The maintenance program shall define the activities to be undertaken onsite, frequency of those activities, and reporting associated with those activities.

5.2.1 Annual Maintenance Plan

An annual maintenance plan shall be established and reviewed every three (3) to five (5) years depending on the timeline of the preventative maintenance agreements. This plan shall include specific activities to be undertaken to maintain the workmanship of the solar photovoltaic system. Refer to SCHEDULE 1 for a sample scope of work detailing annual:

- Preventative Maintenance
- Corrective Maintenance
- Reporting (Field Activities)
- Maintenance Records

5.3 Testing Equipment

Where testing equipment is being used on the sites (either owned by the City of Edmonton or supplied by a third party service provided). It is necessary to ensure the appropriate device is being used, its calibrations are up to date and it is in proper working order (Note: the O&M Guideline (Vol. 4) includes guidance on test equipment maintenance).

5.3.1 Equipment Inventory

All dedicated test equipment shall be included into the standard inventory. The inventory shall be setup to track calibrations to ensure that all equipment is tested and properly calibrated for the activities it will be used.

Table 5 – Equipment Inventory Example

Device	Model	Make	Ratings	Acquisition Date	Latest Calibration
IR Camera – Handheld	*FLIR*	*T540bx*	*Indirect*		
Digital Multi-Meter	*Fluke*	*376*	*600V/ 600A DC/AC*		
IV Curve Tracer	*Solmetric*	*PVA-1500*	*1500V*		
DC String Tester	*Seaward*	*PV 150*			
Insulation Resistance Tester	*Megger*	*INSERT*			
Power Quality Analyzer	*Fluke*	*435II*	*1000V Cat III, 600V Cat I / 6000A*		

5.3.2 Calibrations

All equipment shall be recalibrated on an annual basis by either the original equipment manufacturer or an approved third-party service provider. The calibration shall include adjustment, as well as feedback on the amount of drift the device has experienced over the prior cycle.

5.3.3 Certifications

Specialized equipment shall only be used by certified operators. Of specific note is Infra-red (IR) imaging equipment which should be managed as part of a larger quality assurance program. These certifications shall be managed centrally for both City of Edmonton staff, and service providers to ensure that field data collected is accurate, analyzed correctly, and that actions taken are merited.

5.4 Key Solar Photovoltaic Equipment

The asset management team will be tasked with managing key equipment including maintaining an appropriate inventory, tracking replacements (e.g. inverters, optimizers, modules etc.) and ensuring that proper records are maintained on active equipment in the field. There are a few key pieces of equipment that should be considered:

5.4.1 Inverter

The inverters across the City presently are almost exclusively string inverters equipped with module level power electronics (MLPE aka optimizers). These inverters range in size, but the system topology is consistent. Although sole sourcing is to be avoided, this degree of consistency provides standardization and permits total stock inventories of replacement parts, consumables, and spare optimizers and inverter units to be considered.

5.4.1.1 Serviceability

String inverters are a major part of the industry, and have been deployed since the early 2000’s. Many of these devices have evolved from field serviceable unit to more “black box” devices where insitu repair is not always possible (necessitating the removal of the device form the site).

5.4.1.2 Common Service Issues

The most common cause for service calls related to the equipment relates to Arc Fault Circuit Interrupt (AFCI) flags. These can occur whether or not an AFCI fault has occurred in the array. Causes for this relate to dangling wires, potentially loose, or improperly paired optimizers, or rapidly changing meteorological conditions (e.g. fast-moving clouds). There have been efforts made to enhance AFCI algorithms to reduce the occurrence of nuisance tripping.

5.4.1.3 Parts Availability

As subsequent models of string inverters are released, there is a time period (usually 3 to 5 years) where the current product can still easily be procured, and replacement parts secured. Depending on the manufacturer (and there has been significant attrition in the inverter industry) it can be difficult when approaching the 10 year mark to find parts or replacement units. To prevent issues around this we recommend procuring spare units to allow sites to operate relatively seamlessly until a major intervention is scheduled to occur (e.g. inverter replacement etc.)

5.4.1.4 Physical Exposure

In reviewing work relating to other portfolios, we have found that the string inverters physical enclosure, despite being rated for exterior exposure (e.g. NEMA 4X), have significantly degraded due to ongoing exposure to ultra-violet (UV) radiation and water ingress when covers/cases are not properly secured. We recommend that inverters are under covers, positioned under overhangs, or indoors (where adequate ventilation can be assured).

5.4.1.5 Spare Inventory

Given the number of inverters and optimizers deployed to date we recommend that spare units are kept on hand in a central location corresponding to the dispatch location for the O&M team. Given the delays in processing O&M requests experienced in 2019, we believe it would be reasonable to keep at least two (2) optimizer per site (prioritized by highest power output and cross compatibility) stored at a central location to be dispatched as needed. This should prevent the number of service calls, while permitting both CoE and non-CoE O&M staff to address inverter issues to minimize downtime.

5.4.1.6 Inverter Preventative Maintenance

The inverters should be reviewed no less than annually (preferably semi-annually) and torque checks on all screw terminal blocks (AC/DC) should be completed. IR Imaging should be undertaken during operation of the unit (i.e. as specified within Vol 4 O&M guideline), to permit the diagnosis of loose terminations. The inverter shroud and housing should be cleaned, and once every 3 years a visual review inside the inverter (where permitted by the manufacturer) should be undertaken to ensure there is no premature failure of components (e.g. capacitors, boards etc.).

5.4.2 Modules – Crystalline (Mono/Poly)

5.4.2.1 Common Service Issues

Typically, the mode of failure for modules relates to failure of blocking diodes, physical damage (e.g. cracking, or broken modules) and failure of electrical connections (most commonly at quick connector, but on occasion within the junction box). We recommend that O&M activities include a visual review of modules on an annual basis. We recommend this review include both visual and infrared imaging from an aerial imaging platform (e.g. fixed wing, or UAVS aka drone). Additionally, we recommend that open circuit voltage checks (Optimizer review or IV curve tracing) be undertaken on an annual basis to identify any module level issues.

5.4.2.2 Serviceability

The modules are typically not serviceable, they often include an encapsulated junction box and are not designed for replacement of parts. Any damaged equipment should be removed from operation and replaced with a module that matches the same physical dimensions and is correlated to the electrical configuration.

5.4.2.3 Parts Availability

Replacement modules in the 72-cell format are readily available from most Tier 1 Suppliers. It should be noted that module efficiencies continue to improve, and so when procuring replacement modules, they are almost always a higher wattage unit and will be derated when placed into operation on a string of lower wattage (i.e., current) modules. In systems equipped with module level electronics the impact can be mitigated. Replacement modules should always be evaluated to ensure compatibility between the optimizer and replacement modules (in terms of electrical specifications), Similarly the mechanical characteristics will need to be reviewed with the racking system specifications to ensure it will fit and be adequately secured.

5.4.2.4 Exposure

The modules are designed for harsh environments, most common point of failure relates to the quick connectors (e.g. MC4 like connector) which when exposed to moisture, or physical movement (i.e. if dangling down on the roof) can flex and cause arc faults, and if sustained, can result in a high resistance connection that eventually results in connector failure. The module leads (and associated home run cables) are susceptible to UV damage (despite the UV resistant rating), and over the life of the system it is important to prevent those conductors from being directly exposed to sunlight, hanging, or swaying. The other mode of failure occurs with sustained and unaddressed soiling which can cause the modules to run hotter and can lead to component failure.

5.4.2.5 Spare Inventory

Given the changes in module frame sizes and formats that we have seen across all the major manufacturers. and reduction in overall frame rigidity/style – we recommend procuring enough inventory to satisfy 1.5% effective stock in inventory. These stock modules if possible, should be an equivalent class of modules. This should be enough to satisfy module replacement, and string repair over the duration of the contract (e.g. due to failed diodes, cracked modules/cells or other issues short of major damage to a full system).

5.4.2.6 Preventative Maintenance

The PM activities for modules should focus primarily on maintaining proper wire management, preventing sagging wires that could put excess stress on junction boxes (i.e. as a result of ice buildup) and ensuring that racking systems are uniform and there is no unexpected mechanical strain put on the modules. Annual or bi-annual cleaning of the modules should be an integral part of any maintenance program as noted in the Module Cleaning section within SCHEDULE 1.

5.4.3 Racking

It is expected that racking equipment will vary significantly across the project base. As a result, it will be necessary to maintain an inventory of spare clamps, clips and consumable components.

5.4.3.1 Common Service Issues

Most common with racking systems is fasteners becoming loose due to temperature variations, or increased wind loading (particularly on the upper edge of the array). The bonding system is also susceptible to damage through aging and should be tested at intervals, and re-established if it is found lacking. We recommend that visual reviews are completed on an annual basis. As systems age the ability to remove and reinstall fasteners degrades, and so spare parts are essential.

5.4.3.2 Serviceability

The racking system should be reviewed and torques checked on an annual or bi-annual basis to ensure that equipment is not shifting. Aerial based review of larger monolithic or elevated arrays can be used to avoid the risks of having staff in areas exposed to working at heights restrictions.

5.4.3.3 Parts Availability

Specific manufacturers change product lines from time-to-time, however for third-party manufactured bonding clamps (e.g. FATH PV as an example) one set of clamps could be used in multiple systems.

5.4.3.4 Exposure

The racking is exposed to the elements, but in this case all components are aluminum, and utilize stainless steel fasteners so there is no concern relating to galvanic corrosion damaging the racking and leading to premature failure.

5.4.3.5 Spare Inventory

It is not recommended that rails be kept in stock, instead we recommend keeping spare clamps equivalent to support the modules in stock (i.e. 2x total number of modules) as it is common to experience a 50% failure rate on clamps when they have been installed for greater than 5 years. Galling occurs between the stainless steel hardware and aluminum clamp body, and then they need to be removed to facilitate a module replacement.

5.5 Asset Optimization

Monitoring and benchmarking activities should be utilized to empower asset managers to ensure that the systems are meeting (or exceeding) the expected performance. This requires issues relating to variance in performance from the benchmark model to be investigated and resolved effectively:

5.5.1 Root Cause Analysis (RCA)

A Root Cause Analysis investigation should be undertaken for a number of reasons including:

- **Major Equipment Fault** – in the event of a major equipment fault (e.g. catastrophic loss of an inverter, sub array, or module string) to determine the cause and identify corrective action. This can prevent repeated failures of a component for similar causes (either on the same site or on similar systems).

- **System Underperformance** – in the event a system has shown consistent underperformance (as compared to the baseline model) despite no sign of equipment failure/downtime, further investigation into to the site specific nature (e.g. local shading, damaged string) should be undertaken.

5.5.2 Repowering & Replacement

With the ongoing development of the PV industry and subsequent technology, it is recommended that at major system milestones (e.g. at 5 year intervals) the solar team should review ongoing opportunities to enhance the overall performance of each photovoltaic system. With the various components within a PV system, the following should be considered for repowering and replacement as systems begin to age:

- **PV Modules** – as noted within section 5.4.2.3 module efficiencies continue to improve within the industry and opportunities for higher overall system performance (increase in DC kW) can be realized.
- **Inverters** – as the core piece of the system it is critical to understand the impact of inverter replacement on the technical configuration of the array. This is something that could drive design and construction decisions in terms of ensuring the project is ready for future refurbishment.

Prior to considering a repowering opportunity or equipment replacement, careful consideration of the technical challenges (e.g. code iteration, existing equipment ratings etc.) should be reviewed. There also should be a business case around the performance benefit compared to costs to determine when major equipment should be replaced.

6 Data Management & Monitoring

At each stage of the project development there is critical information that must be incorporated into the asset management program to ensure that this can be effectively tracked.

- Site Selection: Initial energy projections, system size, and configuration.
- Design: project drawings, base-building modifications, and project requirements
- Construction: as-built drawings, shop drawings, spare parts, commissioning results,
- Operations: system performance, monitoring results, operational validation reports
- Maintenance: servicing and repair logs, updates to record documents.

Each of these stages requires specific approval milestones, and sign-offs as needed.

6.1 Documentation Management

All documentation is centralized managed by the Facility Engineering Services Group. This includes record documents and drawings. Major revisions to these documents (associated with major repair or replacement) would be tracked as separate projects and archived accordingly.

6.1.1 Design Generation Estimates

Generation estimates for each project shall be tracked, from the site selection stage, through detailed design (validated by the Engineer-of-Record responsible for the design) and an updated version provided with the final as-built drawings (as detailed within the *CoE Solar PV Program Volume 2 – Design Guideline*).

6.1.1.1 Basis of Modeling

Modeling at all stages shall be consistent with the basis of modeling established within the *CoE Solar PV Program Volume 2 Design Guideline*. Project specific information shall be updated accordingly, and any variations from the basis of modeling shall be tracked to ensure consistency for a given project.

6.1.1.2 Software (e.g. PVSyst)

We recommend that a bankable software package be used, one that has been validated by third-party engineering firms to be representative. A specific list of acceptable solar photovoltaic simulation software has been included within the Site Selection guideline. Amendments to this list shall be at the discretion of the Facility Engineering Services group.

6.1.1.3 Flash Test Data (for PV modules)

The final as-built simulation shall include site specific flash test data provided by the manufacturers. This data is typically provided complete with bench testing results (e.g. flash test at a simulated 1000 W/m^2 at 25 ^{o}C) and serial numbers. This information shall be archived for future warranty reference, or performance evaluations. Because of the common practice of module manufacturers positively biasing module ratings (i.e. +5% / -0% tolerances) the actual flash test values will typically be higher than the nominal ratings.

6.1.1.4 Target Generation Criteria

System generation targets shall be established at a portfolio level. These targets shall be customized per site during the site selection stage. At the design and construction milestones, the simulations shall be compared back to the original target with an explanation of variances. It is recommended that projects of similar orientation and configuration are used to validate these targets. As the quantity of systems increases establishing metrics at a portfolio level will be easier to achieve.

6.1.1.5 Commissioning Data (for Benchmarking)

All commissioning data and year-over-year operations and maintenance data shall be archived and referenced to trend long-term performance issues. This data should be evaluated on an annual basis as the subsequent year’s information is included.

6.1.2 Third Party Reviews

As outlined in the design and construction guidelines (Vol 2 & 3), various reviews (Owner, Tenant) are required, however from time to time it may be necessary to include an additional third party engineer to review the design, construction practices, or operations of the facility. Additional stages of review in addition to already established practices outlined within the section 2.2 of Vol 1 - Consultant Manual could include:

6.1.2.1 Construction Due Diligence

Where there are concerns about construction practices, approaches, or methodologies, and these are not resolved directly by the engineer-of-record (which can be a challenge under some procurement models). It will be necessary to engage the services of an experienced professional to review the sites. Like the design review the constructor should be informed of the activities and it is recommended this review occurs prior to the submission for substantial completion.

6.1.2.2 Installers Warranty Period Review

Prior to the conclusion of the agreed upon warranty period, it is prudent to complete a review of the system to determine if all the deficiency list items (identified at the construction stage) have been addressed. As well as identify any potential issues with the installation which only occur after it has been in operation (e.g. weathertightness of enclosures are demonstrated, and wire management, etc.). This review should be completed with the installer so that items can be reviewed in conjunction with other close-out activities.

6.2 Production Benchmarking and Reporting

Beyond the daily and weekly monitoring undertaken by the operations team, it will be necessary to benchmark system performance to ensure that the systems are delivering what is expected. If variations are experienced from the benchmark numbers

6.2.1 BAS Energy Metering Data

Energy data including peak output (kW), and energy generated (kWhr) will be tracked by the existing City of Edmonton sub-metering system. This data will be captured and reconciled against the production data for long-term benchmarking. This will be used as a supplement to OEM Inverter Monitoring data for the operations team when they need to verify if the system is operating during OEM portal outages. The methodology used to validate energy consumption (e.g. EnergyCAP) shall also incorporate the solar generation data from this BAS meter to ensure proper reconciliation.

6.2.2 Calibrated Generation Estimates

The generation estimates based on historical data will need to be calibrated to actual irradiance experienced onsite. This can be done using onsite reference cells, compared to actual generation. Each inverter OEM platform has different export formats – however it is expected that this process can be automated to streamline the evaluation. The specific approach will be at the discretion of the Solar Operations team, an example of this is included (*CoE Solar PV Monitoring Summary Sheet*) within the supporting forms for this document.

6.2.3 Alert Thresholds (for performance)

Annual irradiance year-to-year can vary by as much as 10% on average, and month-to-month by as much as 25%. Attention should be paid for alerting to specific issues to ensure that it is calibrated data that is used. System wide issues that trend greater than 5% from the comparison shall be prioritized for further investigation (either by the operations team or a more specific root cause analysis).

6.3 Reporting Expectations

A fundamental mandate for this program is to reduce GHG gas consumption. As a result, the energy generation shall be tracked and correlated to marginal GHG offsets for reporting through the Tableau platform. In addition to that ongoing reporting, there is a need to track historical records to support future maintenance or refurbishment activities.

6.3.1 Maintenance Records Review

One of the challenges of trending long-term issues is when the operations team is expected to track year-over-year changes. They are typically focused on real-time issues and resolution of issues. For these reasons it is critical that the asset management team have a comprehensive way to track issues, resolution, and multi-year investigations. The Asset Management team should be considered the “Client” for all operations related reporting, and creating a dynamic between the two groups is helpful in ensuring issues are tracked, addressed, and resolved in a timely manner.

6.3.2 Deferred Maintenance Tracking

Issues that are identified but are not budgeted in a given fiscal year need to be logged, possibility of further degradation monitored, and scheduled (based on the best available information collected onsite). Trying to anticipate when an issue will accelerate to a point of failure is challenging. However, the time of year should be considered, ability to service, and opportunities to shift routine non-essential issues to off-peak times (from a solar generation perspective to minimize the impact of downtime).

6.3.3 Incident Response Owner Obligations

It is essential that there is proper oversight, not just at the desk, but also in the field to responses. Seemingly small issues (e.g. communications drops off) that do not self-resolve within a day or two could actually be obscuring a larger issue (e.g. inverter failure damages communications network leaving a portion of the system exposed, or potentially compromised). This is why the ability to interrogate the system through multiple platforms (e.g. BAS metering, vs. Inverter OEM platform) is valuable in determining the health of the system before dispatching field personnel. As outlined within the O&M Guideline, the specific level of response needs to be established based on the potential risk to the system, the host facility, and building occupants.

Table 6 – Incident Response Levels

Classification	Nature of Issue	Response Required
Emergency	Safety, Fire, etc.	Emergency service call (after hours or weekends) and potentially first responders.
Urgent	System Outage (>150 kW) or full communications outage	1 to 2 business day turnaround
Medium	System Outage (<150 kW) full or partial system outage	2 to 5 business day turnaround
Low	Little to No Safety or Production Impact	Next scheduled maintenance

The specific approach and classification will need to be tailored to the context of the site. A site that is showing recurring faults of a specific type (i.e. arc fault trips) may require more investigation to get to the root cause.

6.4 Quarterly Asset Management Reporting

Based on sample input data provided by your operations and maintenance (O&M) contractor, we will prepare a template for use by your O&M contractors to standardize on the type, style, and framework for reporting. This template will be developed in concept (full functionality would be at the discretion of the O&M contractor and their backend system for reporting):

- **Executive Summary –** should identify any trends, patterns, or unsolved technical problems with respect to the operation, performance, availability, maintenance, or servicing of the projects that merit further investigation.
- **Activity Summary** – indication of the maintenance performed during the preceding month (both directly by the O&M contractor, but also by any designated sub-contractors.
- **Spare Parts Inventory** – indicating the spare parts used during the preceding month, and stock remaining on any project specific allocated inventory. Including what consumable parts are stored onsite, and what parts the contractor is expected to stock in their service vans.
- **Major Equipment Inventory** – indicating the spare equipment (e.g. PV Modules, inverters etc.) used during the preceding month, and stock remaining on any project specific allocated inventory.
- **Technical Issue Log** – indicates technical issues identified in the previous month, along with any outstanding issues (including duration of the issue and anticipate date of resolution) and planned remedies.
- **Warranty Log** – this will indicate if any warranty claims were made, the nature of the claims, and impact on overall system. This section will also indicate years remaining on key equipment warranties (e.g., modules, inverters, racking etc.).
- **Outage Log** – indicates the outages that occurred in the preceding month, including duration, cause, and whether they were scheduled or unscheduled. This log will identify the amount of time and cause for the outages. Including downtime due to maintenance, manufacturer's responsibility, the Owner/utility responsibility or other conditions.
- **Site Generation Summary** – indication of the preceding month's Expected Production and Actual Production based on the onsite monitoring equipment (e.g. inverter level data) including weather metrics (e.g. irradiance).
- **Inverter Comparison** – this breakdown will list inverters and the respective generation relative to each other.

- **Health & Safety Log** – will indicate health and safety issues encountered within the preceding month.
- **Equipment Calibrations -** lists any equipment that has been calibrated in the preceding month. Data shall include device type, manufacturer, model number, serial number (if applicable), calibration date and any relevant notes provided with the calibration report.
- **Links to Digital Archive of** - real-time and archived system performance data. Such performance data shall include detailed measurements of individual inverters (hourly or more frequent average measurements) and aggregated information at the subsystem level and shall also include all available weather measurements.
- **Service Report & Photo Record –** reference will be made to any documentation/photos based on the prior month's activities, including preventative maintenance, reactive maintenance, or emergency call-outs. The monthly report template will include reference/links to separate site reports.

6.5 Key Performance Indicators

There are a series of metrics that can be used to determine both the health of the system, as well as the effectiveness of the operations & maintenance program.

6.5.1 Performance Ratio

The performance ratio represents the end-to-end efficiency of the system – from solar irradiance (or insolation) in and power (or energy) out. The power (kW) portion of this equation compared to onsite irradiance is something that can be tracked on a day-to-day basis and should be a key focus of the operations monitoring team. The energy (kWhr) component compared to insolation (W/m^2) during the same time is something that should be benchmarked by the solar asset management team.

6.5.2 System Availability

Records should be tracked for system availability. Outages whether scheduled or unscheduled shall be logged, and where possible lost generation should be estimated (either based on similar inverters operating, or irradiance onsite based on standard performance ratios). This is important so to ensure that benchmarking (whether quarterly or annual) considers any system (or component) downtime and it is not mistaken for a generalized under performance issue.

6.5.3 Response Time

The dispatch and ticket tracking should include metrics associated with identification of an issue, dispatch request, and resolution to evaluate the performance of differing field service teams, and to inform the optimization of the monitoring and corrective maintenance program. It is expected that this is a function that can be implemented through the SAP platform.

6.5.4 Quality Management

This last item is more challenging to quantify, however it includes review of sub-contractor, or field staff activities to ensure that all issues are addressed appropriately. There are often times when staff with the best of intentions, under the pressure of time and in the heat of the moment may make short-term decisions which can impact the safety, reliability or durability of the system in the long term. This can apply to all stages of an asset deployment (e.g. design, construction, or operations).

7 Conclusion

The City of Edmonton Solar Photovoltaic Program is all encompassing and is supported by a holistic view of the solar photovoltaic asset through all the stages of its development and deployment. The asset management component is the framework that holds this program together, and it is something which will continue to evolve as the number of projects increases, and the role that City of Edmonton staff take on directly evolves.

That said, the program and this asset management guideline are focused on establishing a path to illustrate how solar photovoltaic systems deployed on city facilities can meet the high technical standards established by the City of Edmonton. The end goal is to achieve the mandate for solar photovoltaic assets that are safe, reliable, and ultimately deliver on the Greenhouse Gas (GHG) reduction targets.

As the solar photovoltaic industry continues to evolve, it will be necessary to continue to adjust this program, and its constituent guidelines to address those changes. However, the expectation is that the experience captured within these documents, and furthered through actively deploying projects will provide the City of Edmonton with a best in class municipal solar photovoltaic asset management program which will set the standard by which other programs are measured against.

SCHEDULE 1 - Annual Maintenance Program

Semi-Annual Review and Maintenance

The first visit should be completed within 6-months after commencement of the O&M, and then at 12-month intervals thereafter. Depending on the size of the system all of these activities could be carried out over the course of a single day with approximately 2 hours of system down-time during off-peak hours. If areas of concern or deficiencies are identified during the review and cannot be corrected immediately, a comprehensive site report that documents the issue and suggested corrective action (as applicable) should be generated. This report will then be used to guide the necessary repairs for future visits.

Site Condition Visual Review

As part of this task a qualitative review of the site, assessing aspects that may impact future system performance, operation and maintenance activities, and security. During this review focus will be on:

- Shading (e.g. soiling)
- Site security (e.g. fencing)
- Safety
- Monitoring system meteorological sensors
- Vandalism
- Trash and debris

AC and DC Visual Review

As part of this task our focus a qualitative review of the workmanship of the installation with respect to performance, durability, reliability and safety for the AC and DC portions of the system. As part of this review, completion of the following inspection tasks should be undertaken:

- Visual review of connections and terminations of conductors, as well as assembly of fasteners, fittings and joints
- Inspect conduit and cables for general condition, signs of heat, cracks, secure attachment
- Review of the wire management to ensure that conductors are properly supported and protected
- Visual inspection of racking system, including "spot checks" of racking-to-frame connections and module-to-racking connections
- A comprehensive review of the grounding/bonding
- A review of installed modules, and DC conductors
- A review of all inverters, all AC equipment (including fuses, disconnects, transformers, etc.), and the AC conductors to verify that they conform with the final drawings and supporting documents
- A review of labeling for presence and legibility

Housekeeping and Repairs

As part of this task, housekeeping activities on the equipment and inverters, including replacement of filters (if applicable) or cleaning of inlet screens, and cleaning of enclosures should be completed. Pest control services by removing nests, insects, and rodents from equipment and the through the roof top array should be performed during this phase.

Repairs that can be made at the time of the site visit will be carried out with materials on hand in the spare parts inventory. This includes items such as tightening bolted connections, corrections to wire management, and replacement of string fuses. Deficiencies that require extensive repairs (e.g. re-wiring, replacement of electrical equipment, etc.) or that require special equipment (e.g. lift to facilitate a module replacement) will be documented in a site review report for further action.

In an effort ensure that your string inverters are running optimally, we will also upload the latest firmware available from the manufacturers at the time of this visit.

Summary of Services and Deliverables:

Service	Schedule	Deliverable
Semi-Annual Review and Maintenance	First visit should be carried out within 6-months after commencement of the O&M contract and then at 12-month intervals thereafter	One day onsite is anticipated; work carried out will be recorded in O&M record log
Site Review Report	Only if deficiencies are identified and are unresolved following Semi-Annual Review and Maintenance	PDF report sent to you by email and uploaded to a shared Google Drive folder

Annual Site Review, Testing, and Maintenance

In addition to the standard visual review and maintenances activities provided in the semi-annual task, the annual site review and maintenance visit includes infrared thermal imaging. This allows us to focus on aspects of the system "health" that cannot be evaluated using the monitoring systems and a visual review.

Like the semi-annual review, it is our intent, given the size of the system that these activities will be carried out over the course of a single day. To obtain the best infrared thermal imaging results, this visit will be carried out between the months of May through September to ensure that suitable weather conditions and irradiance exist for testing.

Site Condition Visual Review

(See above for description)

AC and DC Visual Review

(See above for description)

Housekeeping and Repairs

(See above for description)

Infrared Survey of System

Infrared imaging is a powerful tool used to identify numerous safety, performance, and longevity issues. Using this non-destructive technique, assessment of the integrity of electrical components and connections in the AC equipment listed below should be undertaken:

- PV Modules
- Inverters
- AC Combiner Panel
- Isolation Transformer
- DG System Disconnects

Images will be studied onsite for patterns of infrared radiation which could suggest potential problems. If a problem is found, the surveyor will switch to quantitative techniques to further assess the severity of the problem and determine the corrective action required. Any problems identified will be thoroughly documented in a site review report which can be used be a certified electrician to carry out the necessary repairs.

Notes:

1. *All images will be analyzed by a Level 1 or Level 2 certified thermographer*
2. *Infrared imaging activities will be carried out when the sky is clear, the wind speed is low, the system is operational, and all modules are clear of snow cover. All images will be acquired at peak conditions, after the system has been operating for an adequate length of time, when there is adequate irradiance (i.e. ≥ 500 W/m^2), and with adequate electrical load (i.e. ≥ 60%) on the equipment.*

Infrared Ariel Imaging

Qualifications

All aerial drone imaging shall be conducted by an Advanced RPAS Pilot with current qualifications as established by Transport Canada. All flights shall be preceded by an approved flight plan. Approvals shall be required by the City of Edmonton facility operators and the relevant aerodrome control authorities (e.g. airport control tower).

Imaging Criteria

Infrared imaging activities shall be scheduled for a day when the sky is clear, the wind speed is low, the system is operational, and all modules are clear of snow cover. All images will be acquired when there is adequate irradiance (i.e. > 500 W/m2) and the system is operating at least 60% output.

At peak conditions, and after the system has been operating for an adequate length of time (no less than an hour), a certified RPAS Pilot shall carry out an infrared aerial thermography survey of the entire Solar PV Array. The height of the flight shall ensure no less than one pixel per cell and shall provide resolution capable of analysis on each individual PV module in the system.

Analysis Criteria

All images acquired will be calibrated for wind speed, ambient temperature, reflected temperature, humidity, and emissivity. The electrical load (i.e. current) and irradiance will be measured through the Inverter OEM monitoring system for the duration of the flight to capture the conditions present for each image of the aerial survey.

Review of Monitoring System Sensors

During the annual site review readings will be compared and collected by the meteorological sensors and calibrated by hand-held field testing devices. If a deviation exists, the manufacturer should be contacted to rectify the problem.

Module Cleaning

Module cleaning should be completed on low slope arrays (e.g. 5^0 or less) on an annual basis to ensure that ongoing accumulation of dust and sediment on the modules does not undermine system performance.

Cleaning should be undertaken by a qualified sub-contractor utilizing non-conductive (e.g. carbon fibre) poles, using clean water (provided by the contractor). All implements used to wash the modules shall be microfibre brushes or scrubbers (NOTE: squeegees are not permitted as they can damage the surface of the modules). The sub-contractor shall ensure that roof drains and associated pathways for water shed during the washing process are clear and free.

For flush mounted arrays, the cleaning sub-contractor shall use a mobile rotary brush with water delivered to the rotary end to ensure that sediment is fully removed from the modules.

For steeper slope systems cleaning frequency could be adjusted to bi-annual as the level of sedimentation and soiling will be notably less.

Summary of Services and Deliverables:

Service	Schedule	Deliverable
Annual Review, Testing and Maintenance	First visit will be carried out within 6-months after commencement of the O&M contract and then at 12-month intervals thereafter	One day onsite is anticipated; work carried out will be recorded in O&M record log
Site Review Report	Issued following Annual Review, Testing and Maintenance (only if deficiencies are identified)	PDF report sent to you by email and uploaded to a shared Google Drive folder
Infrared Images	Issued following annual testing	Provided in "raw" format we use to analyze them (e.g. Microsoft excel spreadsheets and jpeg files), not in an extensive reporting format

Maintenance Reporting

Site Visit Reports

If deficiencies are identified during the annual review, a formal site visit report will be generated and issued (note: if no deficiencies are identified, a site report will not be issued). This report will provide item-by-item commentary on each deficiency and clearly describes the action that is required to address them. If required, photos and an annotated roof plan will be included to provide further context to the issues identified.

As is described in the sections above, the annual review and maintenance visit includes testing activities. The results of these tests will be reviewed by qualified staff and uploaded to Google Drive for future reference. Please note that the results will be provided in "raw" format we use to analyze them (e.g. Google Sheets and jpeg files), not in an extensive reporting format.

O&M Record Log

An O&M record log will be generated for each site to track observations, work that was performed, and any actions that are required for future visits. The date and personnel responsible for each entry will also be recorded for future reference. Each time a visit is made, or work is performed, an entry will be added to the O&M record log.

A hardcopy of the O&M log will be kept onsite in a weatherproof enclosure central to the AC equipment, in a location that is easily accessible by you and our team. The enclosure will also include a set of the as-built drawings, inverter manuals, monitoring system documentation, O&M team contact information and emergency shut-down procedures.

The O&M record log will also be made available on the shared Google Drive folder

Shared Google Drive Folder

An easily accessible Google Drive folder will be shared to provide 24-hour, 365-day, access to the documentation generated and collected during O&M activities. This includes:

- Monthly generation reports

- Annual generation reports
- Site review reports
- Photos acquired during review and maintenance activities
- I-V curve tracing results (Microsoft excel format)
- Infrared images
- O&M record log
- Equipment literature
- Contact information for our O&M team