USC Solar Roof System

Group 4

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Abstract

Engineering project management skills were used to produce a thorough plan for installing solar panels on a roof at the University of Southern California (USC). The installation requirements stated the roof was 50,000 square feet, and the solar panel capacity must be 1,000 KW. This report utilized many techniques within project management to ensure all the requirements for the project were met. These techniques consisted of a scope statement, work breakdown structure, risk management, cost and budgeting, monitoring and control, scheduling, and a project closeout. Additionally, extensive research was conducted to ensure all assumptions made mimicked the reality of developing a plan to install solar panels.

1. Scope Statement

1.1. Problem Introduction

With the advent of global warming threatening the quality of life for both people and the environment with worsening air pollution and unsustainable temperature conditions, California has been one of the state leaders in proposing ambitious climate neutrality plans to achieve Net Carbon neutrality by 2045 set by Executive Order B-55-18[1,2]. Following suit to set an example for universities, the Presidential Working Group (PWG) on Sustainability at The University of Southern California initiated Assignment:Earth in 2022 to serve as a leader in aligning human economic development and life science across 4 critical pillars in research, education, operations, and community engagement to adopt energy sustainability solutions to align university-wide climate plan goals with the state of California's vision on carbon neutrality[3].

USC has taken an aggressive stance on achieving carbon net neutrality at the university level, with a target to achieve net neutrality for its campus facilities by the 2025 fiscal year. In particular, Assignment: Earth's operational goal 4.1.a measures carbon neutrality as defined by scope 1 and 2 emissions set by the International Greenhouse Gas Committee[11] . Since 2023, USC has achieved a 43% reduction in these kinds of emissions from an established 2014 Scope 1 and 2 baseline[6] . Thus, this project aims to introduce solar energy as a long-term renewable alternative for indirect electrical emissions generated by UCS facilities and offload the required purchase volume of carbon offsets.

1.2. Market and Business Case

Since the passing of AB 32 Global Warming Solutions Act in 2006, The cap and trade program developed by the California Air Resource Board created a free market around emission permits for GHG producers to increase incentives and pressures for companies to invest in greener technologies. This also subjects state entities such as the Los Angeles Department of Water and Power (LADWP) to mandatory GHG reporting and emission permits[10].

In 2022, California's Air Resource Board's scope management plan has only been more aggressive with creating state carbon reduction standards, spurring state agencies to seek both state and federal investments in energy alternatives. The recent legislation package codified calls for a reduction in California's anthropogenic GHG emissions to at least 85% below 1990 with AB 1279, carbon storage management with SB 905, and reducing emissions for carbon sequestration with AB 1757[1] . These measures are projected to generate 4 million new jobs and save Californian citizens over $200 billion by 2045 in healthcare costs due to pollution reduction[2] . However, challenges remain in making energy alternatives more affordable for residents and integrating system-wide consumption measures.

As a consequence, LADWP has aligned its own strategic vision in sustainability and affordability to achieve accelerated goals of 80% renewable energy by 2030[6]. One of the targets of conservation measures is smart grid technological integration with costs offset by solar energy under the LADWP Clean Energy Adder Program and $1 billion Smart Grid Program[9] . USC is a prominent stakeholder of LADWP supplied solar power, purchasing 30% of Springbok 3 Solar Farm capacity annually[8]. On its own, purchasing carbon offsets is not a sustainable long-term strategy as the price of carbon offsets is estimated to increase six-fold by 2035 and beyond; for the initial 2025 Net carbon neutrality goal, it is unavoidable for USC's strategy to contain a large contributing percentage of carbon offset purchasing[7] .

Thus, USC has developed a carbon management hierarchy to prioritize its portfolio of projects around carbon reduction and then emission elimination. According to the PWG operations committee, solar projects fall under USC's third priority goal to install solar on campus facilities[6] . Investing in Solar and renovation projects early allows USC to set a reduction target for carbon offset purchasing in light of the projected price increases. Though a higher initial investment, this solar project falls under the umbrella of cost-saving on-campus projects with high returns on investment in the long-run.

1.3. Scope Definition

This project aims to install a solar roof system on one of the USC campus buildings to reduce energy costs with a building capacity of 50,000 square feet and an energy capacity of 1000 KW in order to offset energy consumption costs for local residents and meet the clean energy goals of the Assignment:Earth initiative in offsetting greenhouse gas emissions. Completing this project will set USC further on track for its FY 2028 goal to achieve a platinum rating for the Sustainability Tracking , Assessment & Rating System (STARS) by contributing towards kWh usage metric for clean and renewable electricity[12] . This project would be the 3rd initiative in USC's portfolio of in-campus solar installations following the Galen Arena and Cardinal n' Gold housing complex.

1.4. Scope Management

The completion of this solar installation project aims to achieve the following deliverables across cost, schedule, and performance dimensions:

Project Deliverables	
Product	Deliver and install all required solar panels, inverters, mounting hardware on 50,000 square foot USC facility.
Cost	Stay within the expected budget
Schedule	Complete installation by the end of FY 2025 to meet Assignment: Earth net neutrality target of neutral carbon emissions
Performance	Produce a 1000 KW solar panel with a tolerance of +/- 5% power rating.

Acceptance Criteria	
Product	Shall meet stakeholder and local inspection and certification standards
Cost	Shall be kept to $4.3 million +/- 5% [2]

Schedule	Shall be completed within a maximum 2-year duration
Performance	Shall achieve at least 85% efficiency under verification & validation test for final installation

Business Objectives
• Contribute towards UCS's goal of achieving a platinum rating by 2028 for sustainability initiatives on the annual STARS report [4] • Contribute towards LAWDP's Energy Efficiency and Conservation Block Grant goals and attain rebates on clean energy consumption for USC

1.4.1. Scope Reporting

In order to meet the above acceptance criteria requirements, a work breakdown structure with assignment responsibilities has been developed for the project milestones proposed in the statement of work. Between each milestone, the verification and reviewing activities shall involve:

- Compliance reviews with local city permitting authorities
- Planning check tests for solar permitting guidelines with LADWP
- Design reviews for systems, integration, and assembly deliverables
- Safety compliance reviews with USC and LA authorities

1.4.2. Constraints

- Solar panels must accommodate a maximum of 50,000 sq. ft.
- Solar panel power capacity must within 1,000 KW +/- 5%
- Solar roof system installation must be in accordance with local and federal regulations
- Solar roof systems must meet all design requirements for customer acceptance
- Solar roof project should be completed within a $4.3 million +/- ~$200,000 budget
- Solar roof project should be complete within a maximum of 2 years

1.4.3. Assumptions

- Solar panel suppliers will be providing COTS parts with no long lead items
- Successfully obtain site construction permits ahead of project onset
- No issues with solar roof system installation into pre-existing structure or electrical grid system
- No natural disasters or global pandemics during build process
- No campus disruptions blocking access to site

1.5. Statement of Work (SOW)

Date Submitted:	01/01/2025
Project Name:	USC Solar Roof System
Description of Scope	
Summary:	Install a 1,000 KW solar panel system on a 50,000 square foot roof at USC.
Major Deliverables:	1. Solar Roof System with 1,000 kW generation capability 2. Documentation to City of Los Angeles and USC a. Requirements verification & validation documentation
Not covered in Scope:	1. Ongoing maintenance activities post- training and handover 2. Installation on other USC buildings
Milestones	
	Baselining Cost, Schedule, and Configuration Management
	Site Surveying and Analyses
	Design Requirement Definition
	Design Selection
	Engineering Development Testing
	System Assembly, Integration, and Installation
	Verification and Validation
	Training and Project Closeout
Resource Requirements	
	Labor (PM, Engineering, Legal, Technicians, Ops, Supply Chain, Quality, Safety, Subcontractors/Suppliers)
	Materials (Solar Panels, Steel, Electrical & Mechanical System components)

2. Work Breakdown Structure

2.1. WBS

The Work Breakdown Structure outlines all of the Solar Roof Project tasks and deliverables, otherwise known as work packages, that must be executed through to project completion:

1. Project Conception
    1.1. Project Baselining
        1.1.1. Baseline Schedule
        1.1.2. Baseline Cost
        1.1.3. Define KPIs & OKRs
        1.1.4. Manage stakeholder(s) need(s)
        1.1.5. Manage programmatic risk & assess feasibility
        1.1.6. Support throughout project lifecycle
    1.2. Resource Management
        1.2.1. Define staffing requirements
        1.2.2. Identify & manage supplier/subcontractor need(s)
        1.2.3. Interface w/Ops, QA, Safety, SMEs, etc.
        1.2.4. Support throughout project lifecycle
    1.3. Configuration Management
        1.3.1. Baseline documentation & reporting
        1.3.2. Support throughout project lifecycle
2. Site Assessment and Preparation
    2.1. Site Surveying
        2.1.1. Define location of panel installation
        2.1.2. Conduct shading analysis
        2.1.3. Conduct structural analysis
        2.1.4. Conduct electrical analysis
        2.1.5. Conduct technical risk analysis
    2.2. Site Readiness
        2.2.1. Obtain necessary permits & approvals
        2.2.2. Clear & prepare site
        2.2.3. Establish site safety parameters
    2.3. Design Requirements Definition
        2.3.1. Baseline product specifications from customer need(s)
        2.3.2. Develop product specifications from site surveying analyses
        2.3.3. Define installation approach & design requirements
3. Design and Engineering
    3.1. Computer-aided System Modeling
        3.1.1. Brainstorm system design options

3.1.2. Render preliminary system models & blueprints
3.2. Design Selection
3.2.1. Conduct tradeoff analysis to determine final system design
3.2.2. Prototype structural & electrical sub-systems
3.2.3. Perform Engineering Development Tests to ensure product meets requirements
4. Procurement and Installation
4.1. Components Receipt and Inspection
4.1.1. Test & inspect solar panels
4.1.2. Test & inspect inverters
4.1.3. Test & inspect mounting components
4.1.4. Test & inspect electrical components
4.2. System Integration and Installation
4.2.1. Assemble mechanical & electrical sub-systems
4.2.2. Test subsystem assembly to Acceptance requirements
4.2.3. Install solar panels & energy system
5. Verification and Validation
5.1. Commissioning and Testing
5.1.1. Pass initial installation & safety inspection
5.1.2. Test system start-up performance to requirements
5.1.3. Complete final certification & operations approval
6. Training and Project Closeout
6.1. Train preventative maintenance activities
6.2. Train routine inspection activities
6.3. Train emergency maintenance activities
6.4. Train system disassembly at End of Life
6.5. Conduct final programmatic review

2.2. Solar Roof Project Pre-Leveled Gantt Chart

Before leveling, the Solar Roof Project WBS spans a total project timeline of January 1, 2025 to January 13, 2026. The associated overall Gantt Chart and breakdown by WBS milestones and work packages can be seen below.

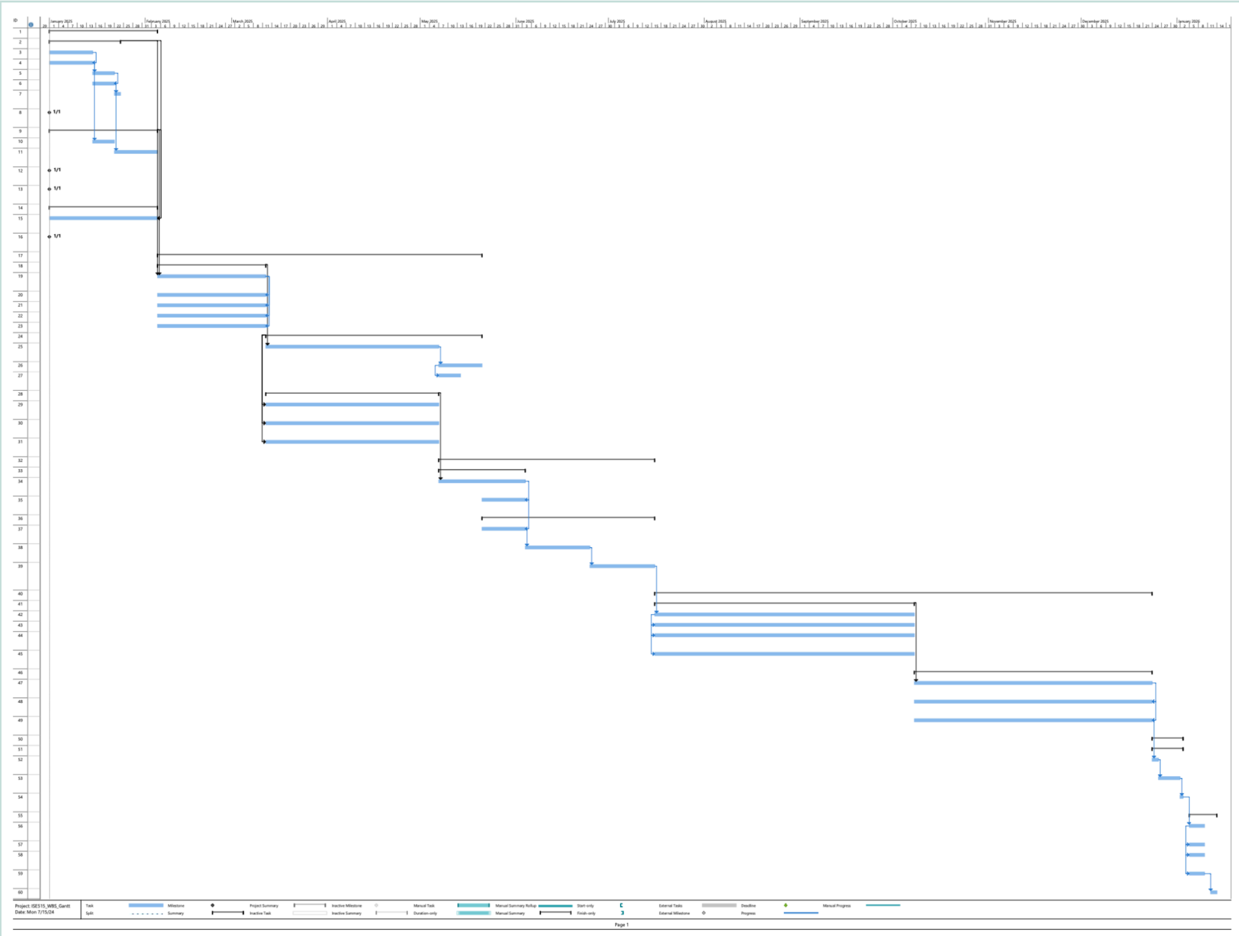
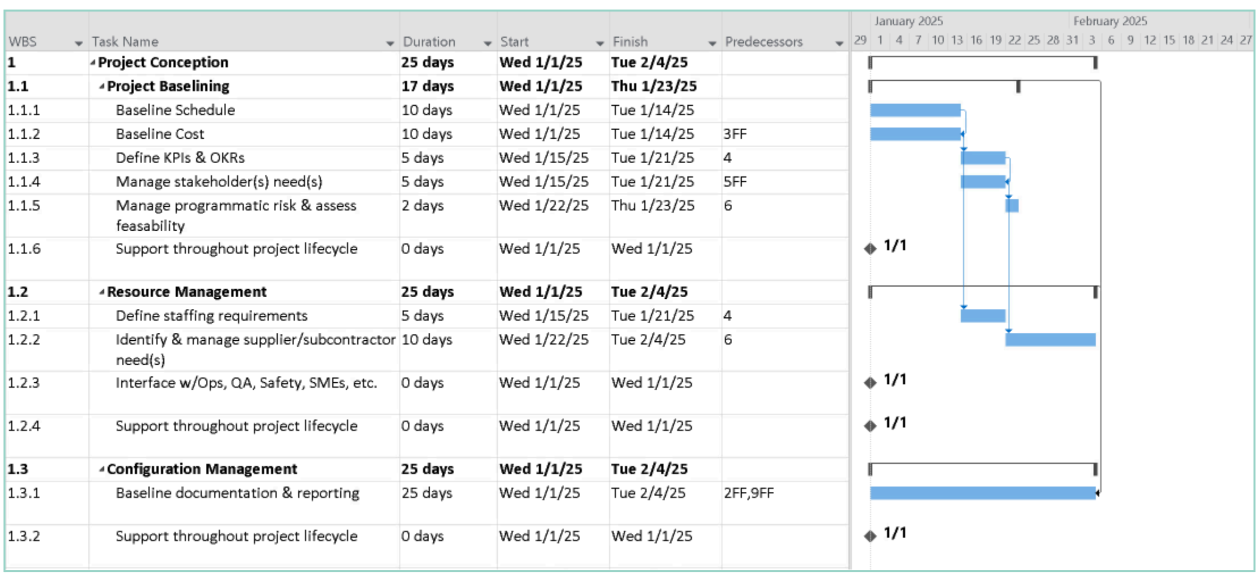


Figure 1: Pre-leveled Gantt from 1/1/25-1/13/26



WBS	Task Name	Duration	Start	Finish	Predecessors
1	**Project Conception**	**25 days**	**Wed 1/1/25**	**Tue 2/4/25**	
1.1	**Project Baselining**	**17 days**	**Wed 1/1/25**	**Thu 1/23/25**	
1.1.1	Baseline Schedule	10 days	Wed 1/1/25	Tue 1/14/25	
1.1.2	Baseline Cost	10 days	Wed 1/1/25	Tue 1/14/25	3FF
1.1.3	Define KPIs & OKRs	5 days	Wed 1/15/25	Tue 1/21/25	4
1.1.4	Manage stakeholder(s) need(s)	5 days	Wed 1/15/25	Tue 1/21/25	5FF
1.1.5	Manage programmatic risk & assess feasability	2 days	Wed 1/22/25	Thu 1/23/25	6
1.1.6	Support throughout project lifecycle	0 days	Wed 1/1/25	Wed 1/1/25	
1.2	**Resource Management**	**25 days**	**Wed 1/1/25**	**Tue 2/4/25**	
1.2.1	Define staffing requirements	5 days	Wed 1/15/25	Tue 1/21/25	4
1.2.2	Identify & manage supplier/subcontractor need(s)	10 days	Wed 1/22/25	Tue 2/4/25	6
1.2.3	Interface w/Ops, QA, Safety, SMEs, etc.	0 days	Wed 1/1/25	Wed 1/1/25	
1.2.4	Support throughout project lifecycle	0 days	Wed 1/1/25	Wed 1/1/25	
1.3	**Configuration Management**	**25 days**	**Wed 1/1/25**	**Tue 2/4/25**	
1.3.1	Baseline documentation & reporting	25 days	Wed 1/1/25	Tue 2/4/25	2FF,9FF
1.3.2	Support throughout project lifecycle	0 days	Wed 1/1/25	Wed 1/1/25	

Figure 2: 1. Project Conception

WBS	Task Name	Duration	Start	Finish	Predecessors
1	**Project Planning**	**25 days**	**Wed 1/1/25**	**Tue 2/4/25**	
2	**Site Assessment & Preparation**	**75 days**	**Wed 2/5/25**	**Tue 5/20/25**	
2.1	**Site Surveying**	**25 days**	**Wed 2/5/25**	**Tue 3/11/25**	
2.1.1	Define location of panel installation	25 days	Wed 2/5/25	Tue 3/11/25	2,9
2.1.2	Conduct shading analysis	25 days	Wed 2/5/25	Tue 3/11/25	19FF
2.1.3	Conduct structural analysis	25 days	Wed 2/5/25	Tue 3/11/25	19FF
2.1.4	Conduct electrical analysis	25 days	Wed 2/5/25	Tue 3/11/25	19FF
2.1.5	Conduct technical risk analysis	25 days	Wed 2/5/25	Tue 3/11/25	19FF
2.2	**Site Readiness**	**50 days**	**Wed 3/12/25**	**Tue 5/20/25**	
2.2.1	Obtain necessary permits & approvals	40 days	Wed 3/12/25	Tue 5/6/25	18
2.2.2	Clear & prepare site	10 days	Wed 5/7/25	Tue 5/20/25	25
2.2.3	Establish site safety parameters	5 days	Wed 5/7/25	Tue 5/13/25	26SS
2.3	**Design Requirements Definition**	**40 days**	**Wed 3/12/25**	**Tue 5/6/25**	
2.3.1	Baseline product specifications from customer need(s)	40 days	Wed 3/12/25	Tue 5/6/25	24SS
2.3.2	Develop product specifications from site surveying analyses	40 days	Wed 3/12/25	Tue 5/6/25	24SS
2.3.3	Define installation approach & Design requirements	40 days	Wed 3/12/25	Tue 5/6/25	24SS

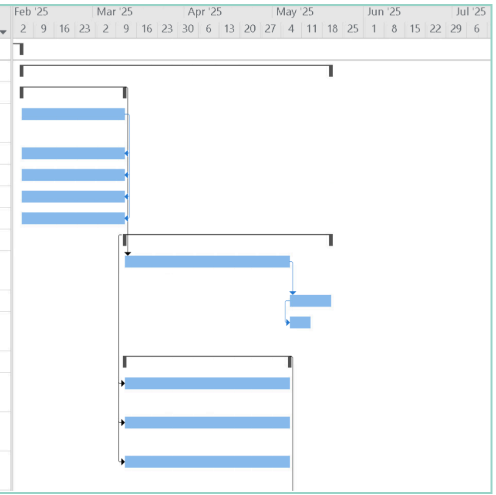


Figure 3: 2. Site Assessment & Preparation

WBS	Task Name	Duration	Start	Finish	Predecessors
1	**Project Planning**	**25 days**	**Wed 1/1/25**	**Tue 2/4/25**	
2	**Site Assessment & Preparation**	**75 days**	**Wed 2/5/25**	**Tue 5/20/25**	
3	**Design & Engineering**	**50 days**	**Wed 5/7/25**	**Tue 7/15/25**	
3.1	**Computer-aided System Modeling**	**20 days**	**Wed 5/7/25**	**Tue 6/3/25**	
3.1.1	Brainstorm system design options	20 days	Wed 5/7/25	Tue 6/3/25	28
3.1.2	Render preliminary system models & blueprints	10 days	Wed 5/21/25	Tue 6/3/25	34FF
3.2	**Design Selection**	**40 days**	**Wed 5/21/25**	**Tue 7/15/25**	
3.2.1	Conduct tradeoff analysis to determine final system design	10 days	Wed 5/21/25	Tue 6/3/25	35FF
3.2.2	Prototype Structural & Electrical sub-systems	15 days	Wed 6/4/25	Tue 6/24/25	37
3.2.3	Perform Engineering Development Tests to ensure product meets requirements	15 days	Wed 6/25/25	Tue 7/15/25	38

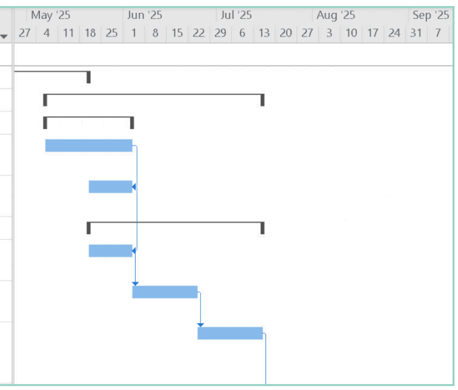


Figure 4: 3. Design & Engineering

WBS	Task Name	Duration	Start	Finish	Predecessors
1	**Project Planning**	**25 days**	**Wed 1/1/25**	**Tue 2/4/25**	
2	**Site Assessment & Preparation**	**75 days**	**Wed 2/5/25**	**Tue 5/20/25**	
3	**Design & Engineering**	**50 days**	**Wed 5/7/25**	**Tue 7/15/25**	
4	**Procurement & Installation**	**115 days**	**Wed 7/16/25**	**Tue 12/23/25**	
4.1	**Component(s) Receipt & Inspection**	**60 days**	**Wed 7/16/25**	**Tue 10/7/25**	
4.1.1	Test & inspect solar panels	60 days	Wed 7/16/25	Tue 10/7/25	39
4.1.2	Test & inspect inverters	60 days	Wed 7/16/25	Tue 10/7/25	42SS
4.1.3	Test & inspect mounting components	60 days	Wed 7/16/25	Tue 10/7/25	43SS
4.1.4	Test & inspect electrical components	60 days	Wed 7/16/25	Tue 10/7/25	44SS
4.2	**System Integration & Installation**	**55 days**	**Wed 10/8/25**	**Tue 12/23/25**	
4.2.1	Assemble Mechanical & Electrical sub-systems	55 days	Wed 10/8/25	Tue 12/23/25	41
4.2.2	Test subsystem assembly to Acceptance requirements	55 days	Wed 10/8/25	Tue 12/23/25	47FF
4.2.3	Install solar panels & energy system	55 days	Wed 10/8/25	Tue 12/23/25	48FF

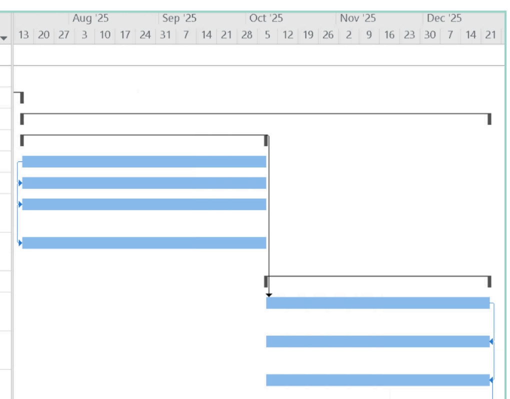
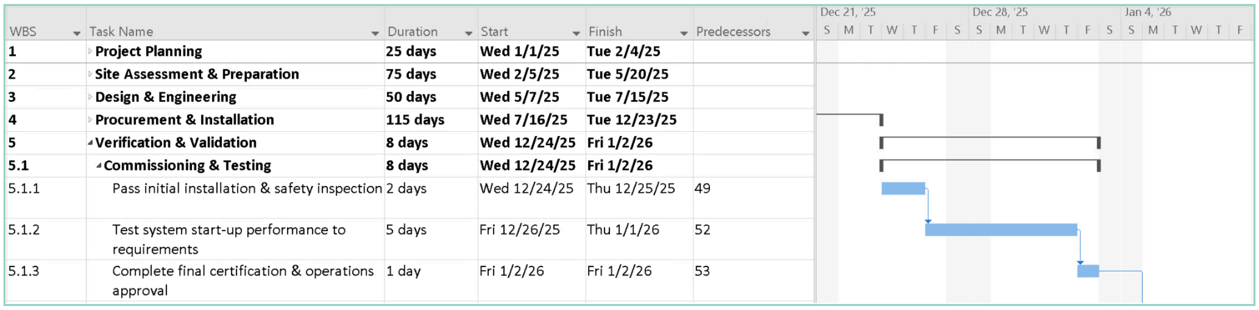
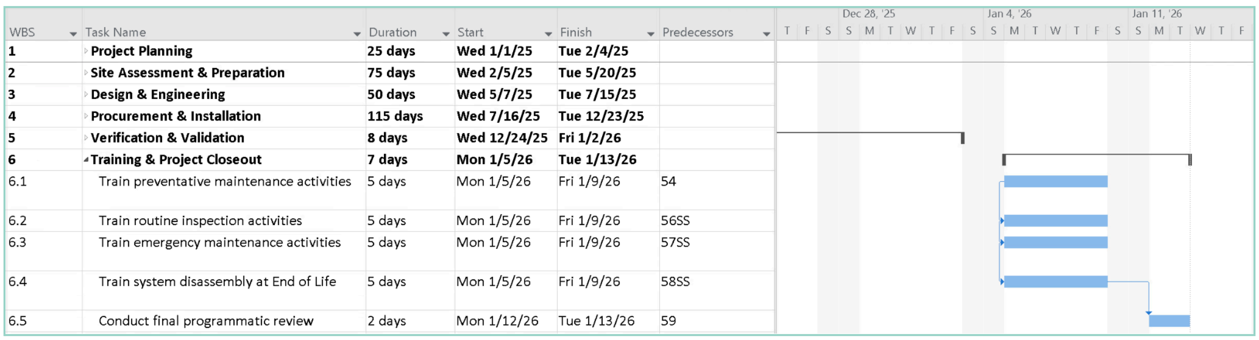


Figure 5: 4. Procurement & Installation



WBS	Task Name	Duration	Start	Finish	Predecessors
1	**Project Planning**	**25 days**	**Wed 1/1/25**	**Tue 2/4/25**	
2	**Site Assessment & Preparation**	**75 days**	**Wed 2/5/25**	**Tue 5/20/25**	
3	**Design & Engineering**	**50 days**	**Wed 5/7/25**	**Tue 7/15/25**	
4	**Procurement & Installation**	**115 days**	**Wed 7/16/25**	**Tue 12/23/25**	
5	**Verification & Validation**	**8 days**	**Wed 12/24/25**	**Fri 1/2/26**	
5.1	**Commissioning & Testing**	**8 days**	**Wed 12/24/25**	**Fri 1/2/26**	
5.1.1	Pass initial installation & safety inspection	2 days	Wed 12/24/25	Thu 12/25/25	49
5.1.2	Test system start-up performance to requirements	5 days	Fri 12/26/25	Thu 1/1/26	52
5.1.3	Complete final certification & operations approval	1 day	Fri 1/2/26	Fri 1/2/26	53

Figure 6: 5. Verification & Validation



WBS	Task Name	Duration	Start	Finish	Predecessors
1	**Project Planning**	**25 days**	**Wed 1/1/25**	**Tue 2/4/25**	
2	**Site Assessment & Preparation**	**75 days**	**Wed 2/5/25**	**Tue 5/20/25**	
3	**Design & Engineering**	**50 days**	**Wed 5/7/25**	**Tue 7/15/25**	
4	**Procurement & Installation**	**115 days**	**Wed 7/16/25**	**Tue 12/23/25**	
5	**Verification & Validation**	**8 days**	**Wed 12/24/25**	**Fri 1/2/26**	
6	**Training & Project Closeout**	**7 days**	**Mon 1/5/26**	**Tue 1/13/26**	
6.1	Train preventative maintenance activities	5 days	Mon 1/5/26	Fri 1/9/26	54
6.2	Train routine inspection activities	5 days	Mon 1/5/26	Fri 1/9/26	56SS
6.3	Train emergency maintenance activities	5 days	Mon 1/5/26	Fri 1/9/26	57SS
6.4	Train system disassembly at End of Life	5 days	Mon 1/5/26	Fri 1/9/26	58SS
6.5	Conduct final programmatic review	2 days	Mon 1/12/26	Tue 1/13/26	59

Figure 7: 6. Training & Project Closeout

2.3. Organizational Breakdown Structure (OBS)

The Organizational Breakdown Structure provides an overview of the program's department-level assignments to each project milestone and work package, as well as the labor hour costs (without overhead) associated with them.

Table 1: OBS

Departments	**1. Project Conception**			**2. Site Assessment & Preparation**			**3. Design & Engineering**		**4. Procurement & Installation**		**5. Verification & Validation**	**6. Training & Project Closeout**	
WBS Code	1.1	1.2	1.3	2.1	2.2	2.3	3.1	3.2	4.1	4.2	5.1	6.1-6.4	6.5
Work Package	Project Baselining	Resource Management	Configuration Management	Site Surveying	Site Readiness	Design Requirements Definition	Computer-aided System Modeling	Design Selection	Component(s) Receipt & Inspection	System Integration & Installation	Commissioning & Testing	Training Activities	Conduct Final Programmatic Review
Programmatics	$10,447.10	$7,416.00	$5,115.00			$17,102.56		$1,023.00					
Logistics	$8,913.24	$3,597.87	$11,072.00		$17,715.20								
Engineering	$6,274.64	$1,086.13	$8,146.00	$118,569.96		$91,959.30	$21,550.56	$34,379.78	$119,438.40	$55,649.26	$3,060.48	$24,084.40	$716.00
Site Management	$1,075.40	$393.07		$5,833.14	$4,312.40	$3,126.40		$1,149.98	$55,756.80	$48,206.40	$1,626.24		

The department-level breakdowns to the individual staffing level are defined below and expanded upon in Section 2.4. Responsibility Assignment Matrix:

- **Programmatics**
  - Project Management Team: Project Manager, Project Coordinator, Project Analyst
  - Business Team: Business Manager, Financial Analyst, Business Analyst
- **Logistics**
  - Supply Chain Manager
  - Planning Team: Project Planner, Scheduler, Logistics
  - Legal Team: Corporate Lawyer, Contract Manager, Compliance Officer
- **Engineering**
  - Engineering Manager
  - Design: Lead DE, Architect, Structural Engineer, CAD Designer, Autocad Drafters
  - Mechanical: ME Manager, Lead ME, Thermal ME, CAD ME
  - Electrical: EE Manager, Lead EE, Electrical Engineers, Systems Engineers
  - Product: Lead Product Engineer, Process Engineer, Quality Engineer
- **Site Management**
  - Safety Officer
  - Technicians: Electrical Technicians, Mechanical Technicians
  - Construction Team: Construction & Site Managers, Supervisor, Laborers, Equipment Ops

2.4. Responsibility Assignment Matrix (RAM)

The following linear responsibility chart was developed to acknowledge a clear linkage among all lead project personnel:

- **Abbreviations:**
  - **BT:** Business Team
  - **CT:** Construction Team
  - **DE:** Design Engineers
  - **EE:** Electrical Engineer Manager
  - **EM:** Engineering Manager
  - **TECH:** Technicians
  - **LT:** Legal Team
  - **MEM:** Mechanical Engineering Manager
  - **P:** Planner
  - **PE:** Production Engineerings
  - **PM:** Project Manager
  - **SO:** Safety Officer
  - **SCM:** Supply Chain Manager

R: Responsible	**S:** Support
N: Notification	**A:** Approval

Table 2: Project Conception RAM

1. Project Conception		Lead Project Personnel												
Output	Task & Code	BT	CT	DE	EE	EM	TECH	LT	MEM	P	PE	PM	SO	SCM
1.1 Project Baselining	1.1.1 Baseline Schedule		S	S	N	S	N		N	R	S	A	N	N
	1.1.2 Baseline Cost	S										N		R
	1.1.3 Define KPIs & OKRs	R				S						S		S
	1.1.4 Manage stakeholder(s) need(s)	R				S						S		
	1.1.5 Manage programmatic risk & assess feasibility	S				S						R	S	S
	1.1.6 Support throughout project lifecycle	S				S				N		R		S
1.2 Resource Management	1.2.1 Define staffing requirements	N	S			S				N		R		S
	1.2.2 Identify & manage supplier/ subcontractor need(s)	S				N				N		R		S
	1.2.3 Interface with Operations, QA, Safety,SMEs, & other functional support groups			S	S	R			S		S	N	S	S
	1.2.4 Support throughout project lifecycle	S				S					N	R		S
1.3 Configuration Management	1.3.1 Baseline documentation & reporting	S				S		R			N			N
	1.3.2 Support throughout project lifecycle	S				S		R		S				

Table 3: Site Assessment & Preparation RAM

2. Site Assessment & Preparation		Lead Project Personnel												
Output	Task & Code	BT	CT	DE	EE	EM	TECH	LT	MEM	P	PE	PM	SO	SCM
2.1 Site Surveying	2.1.1 Define location of panel installation		S	S	S	S			R			N	N	
	2.1.2 Conduct shading analysis			S	S	S			R				N	
	2.1.3 Conduct structural analysis			S		S			R				N	
	2.1.4 Conduct electrical analysis			S	R	S							N	
	2.1.5 Conduct technical risk analysis			S	S	R			S				S	
2.2 Site Readiness	2.2.1 Obtain necessary permits & approvals							R				N		
	2.2.2 Clear & prepare site		R			N				N				
	2.2.3 Establish site safety parameters		N									N	R	
2.3 Design Requirements Definition	2.3.1 Baseline product specifications from customer need(s)	S		S	S	S			S		S	R		
	2.3.2 Develop product specifications from site surveying analyses			S	S	R			S		S			
	2.3.3 Define installation approach & Design requirements		N	S	S	S			S		R		S	

Table 4: Design & Engineering RAM

3. Design & Engineering		Lead Project Personnel												
Output	Task & Code	BT	CT	DE	EE	EM	TECH	LT	MEM	P	PE	PM	SO	SCM
3.1 Computer-aided System Modeling	3.1.1 Brainstorm system design options			R	S	S			S					
	3.1.2 Render preliminary system models & blueprints			R	N	N			N		N			
3.2 Design Selection	3.2.1 Conduct tradeoff analysis to determine final system design	S		S	S	R			S			A		
	3.2.2 Prototype structural & electrical sub-systems				S	N	S		S		R			
	3.2.3 Perform engineering development tests to ensure product meets requirements			S	R	N			S		S			

Table 5: Procurement & Installation RAM

4. Procurement & Installation		Lead Project Personnel												
Output	Task & Code	BT	CT	DE	EE	EM	TECH	LT	MEM	P	PE	PM	SO	SCM
4.1 Component(s) Receipt & Inspection	4.1.1 Test & inspect solar panels				S		R		S		N			
	4.1.2 Test & inspect inverters				S		R				N			
	4.1.3 Test & inspect mounting components						R		S		N			
	4.1.4 Test & inspect electrical components				S		R				N			
4.2 System Integration & Installation	4.2.1 Assemble Mechanical & Electrical sub-systems		S			N	R				S	N		
	4.2.2 Test subsystem assembly to Acceptance requirements				S		R		S		S			
	4.2.3 Install solar panels & energy system per section 2.3.3		R		S	N	S		S		S	N		

Table 6: Verification & Validation RAM

5. Verification & Validation		Lead Project Personnel												
Output	Task & Code	BT	CT	DE	EE	EM	TECH	LT	MEM	P	PE	PM	SO	SCM
5.1 Commissioning & Testing	5.1.1 Pass initial installation & safety inspection				A	A	R		A		A		A	
	5.1.2 Test system start-up performance to requirements				S	N	R					N		
	5.1.3 Complete final certification & operations approval				A	R			A		A	N	A	

Table 7: Training & Project Closeout RAM

6. Training & Project Closeout		Lead Project Personnel												
Output	Task & Code	BT	CT	DE	EE	EM	TECH	LT	MEM	P	PE	PM	SO	SCM
6.1 Train preventive maintenance activities					R				R		S			
6.2 Train routine inspection activities					R				R		S			
6.3 Train emergency maintenance activities					R				R		S			
6.4 Train system disassembly at End of Life					R				R		S			
6.5 Conduct final programmatic review												R		

3. Risk Management

3.1. Risk Categorization

The risk breakdown structure associated with this solar project was categorized as a hierarchy by their initial exposure scope beginning from internal originating risks within the control of the project and external risks that project owners cannot control. This risk breakdown structure (RBS) diagram is based on the following level 3 risk category descriptions:

Table 8: Risk Categories

Category	Description
Environmental	Risks originating from natural causes include earthquakes, hail, floods, and other uncontrollable disasters.
Safety	Risks related to hazardous conditions for workers and the general public
Regulatory and Compliance	Risks associated with permitting and compliance, solar ordinance changes, federal and state funding, political, and security risks
Technical	Risks relating to solar panel installation, design failures, performance setbacks, and grid issues.
Organizational	Risks relating to budgeting, role changes, stakeholder management, and resource management for solar PV materials and processes

3.1.1. Risk Breakdown Structure

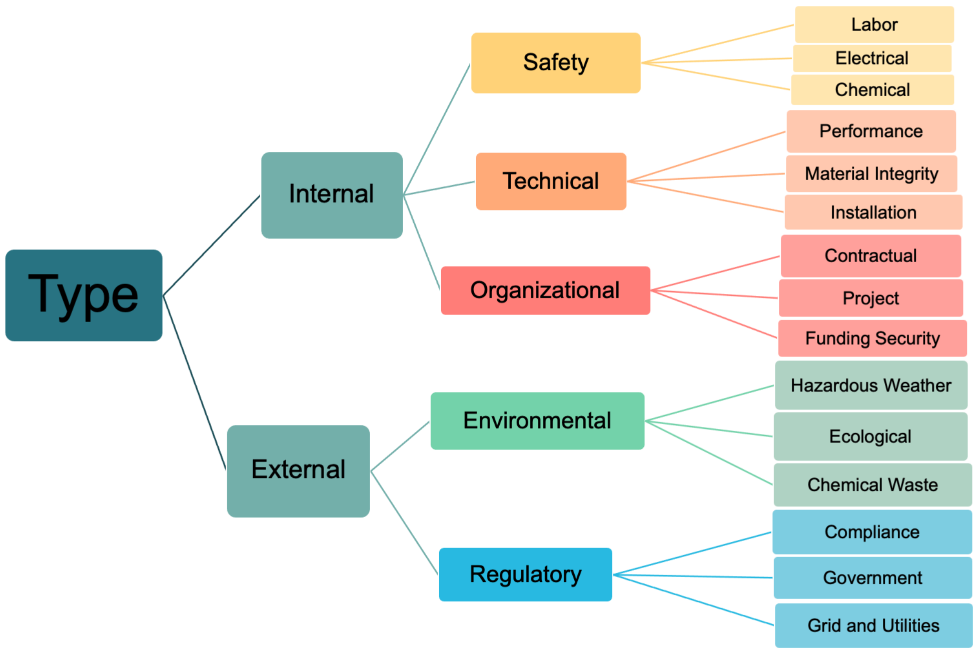


Figure 8: Risk Breakdown Structure

Our 3 level hierarchy allows us to codify individual risks by categorically similar events, and identify the scope of exposure along different project dimensions to best develop mitigation protocols.

3.1.2. Risk Definitions and Codes

Each risk group is further divided into the specific scenarios that comprise the respective category:

Table 9: Environmental Risks

Category	Risk Group	Risk Code	Description	Impact Classification
Environmental	Chemical Waste	E.CW.4	Lead and Cadmium environmental leaching [5]	Likely risk with significant impact on liability from environmental damage
Environmental	Ecological	E.E.1	Attraction bed for aquatic-seeking insect species[6]	Unlikely risk with inconsequential impact on panel integrity
Environmental	Ecological	E.E.2	Avian mortality due to "lake-like" appearance	Likely risk with minimal impact on liability from

			of panels as source of water body[19]	environmental damage and panel integrity
Environmental	Ecological	E.E.3	Impede visibility for aviation air crafts and surrounds skyscrapers[4]	Rare risk with moderate impact on liability from endangerment
Environmental	Ecological	E.E.4	Panels shading highly reflective surfaces [2]	Rare risk with minimal impact on panel performance
Environmental	Ecological	E.E.5	Potential eye sore for solar panel equipment to USC campus	Rare risk with minimal impact on project redesign
Environmental	Ecological	E.E.6	Increased negative human health conditions with PMAS coating exposure[20]	Unlikely risk with minimal impact on liability from worker endangerment
Environmental	Hazardous Weather	E.HW.1	Minor Earthquakes comprising structural integrity of mounting systems and roof	Probable risk with moderate impact on roof mounting integrity and re-installation
Environmental	Hazardous Weather	E.HW.2	Harmful reproduction habits and food web relations effects of polarized light pollution for polarotactic insect populations (Mayflies (Ephemeroptera), stoneflies (Trichoptera), dolichopodid dipterans, and tabanid flies (Tabanidae))[5]	Likely risk with inconsequential impact on project design considerations
Environmental	Hazardous Weather	E.HW.3	heat wave damage to solar panel surfaces	Probable risk with minimal impact on panel design and performance check planning
Environmental	Hazardous Weather	E.HW.4	Particle deposition on solar panels due to air	Rare risk with moderate impact on panel design and

			pollution decreasing electrical output[12]	performance check planning
Environmental	Hazardous Weather	E.HW.5	Hazardous weather damage expediting EOL of solar panel, leading to increased e-waste due to lack of PV recycling adoption[14]	Probably risk with minimal impact on panel design
Environmental	Hazardous Weather	E.HW.6	Mounting system damage from wind uplift between roof and panels [8]	Probable risk with moderate impact on panel mounting requirements

Table 10: Organizational Risks

Category	Risk Group	Risk Code	Description	Impact Classification
Organizational	Contractual	O.C.1	Change of management during contractor engagement	Rare risk with moderate impact on project schedule
Organizational	Contractual	O.C.2	Insolvency of a contractual party during panel installation	Rare risk with moderate impact on project cost and schedule
Organizational	Funding Security	O.F.1	Budget re-prioritization of allocated project funds [7]	Rare risk with significant impact on project cost

Table 11: Regulatory Risks

Category	Risk Group	Risk Code	Description	Impact Classification
Regulatory	Government	R.G.1	California policy changes on rebates for excess energy production	Unlikely risk with moderate impact on project cost
Regulatory	Government	R.G.2	Change in government stakeholder budget allocations	Rare risk with significant impact on project cost
Regulatory	Government	R.G.3	Governmental administrative changes affecting permitting and compliance expediency	Likely risk with moderate impact on project schedule
Regulatory	Government	R.G.4	Political Instability in regions where contractors operate causes sourcing delays	Likely risk with significant impact on project installation and cost
Regulatory	Grid and Utilities	R.GU.1	Exceeding the penetration limit of distributed generation with solar panels caused reverse power flow [2]	Likely risk with moderate impact on project cost and efficiency
Regulatory	Grid and Utilities	R.GU.2	Change in government incentives for rebates and grants from utility producers	Likely risk with significant impact to project cost

Table 12: Safety Risks

Category	Risk Group	Risk Code	Description	Impact Classification
Safety	Electrical	S.E.1	Flammable conditions due to thermal runaway of panels from combustible roofs [10]	Rare risk with severe consequences on project execution
Safety	Electrical	S.E.2	Live cable wiring increases risk of electrical shock [12]	Unlikely risk with significant impact on project liability and schedule
Safety	Labor	S.L.1	Increased trip/fall hazard for workers	Unlikely risk with significant impact on project liability and schedule
Safety	Labor	S.L.2	Restricted access to roof for emergency responders and workers	Unlikely risk with moderate impact on project design

Table 13: Technical Risks

Category	Risk Group	Risk Code	Description	Impact Classification
Technical	Installation	T.I.1	Incorrect cable placement and panel angles	Unlikely risk with moderate impact on panel installation
Technical	Installation	T.I.2	Use of out of out-of-specification parts for installation	Likely risk with moderate impact on panel installation
Technical	Installation	T.I.3	Minor weather events cause work delays in installation	Probable risk with minimal impact on project schedule
Technical	Material Integrity	T.MI.1	Gravity load imposed by solar panels on buildings	Rare risk with severe impact on panel installation
Technical	Performance	T.P.1	High Urban heat index (UHI) in the city leads to performance reduction of panels due to air convection	Probable risk with moderate impact on panel design

			between surface and air [17]	
Technical	Performance	T.P.2	Increased cooling system load in buildings due to trapped heat from rooftop panels [15]	Likely risk with moderate impact on panel design
Technical	Performance	T.P.3	Thermal runaway generally caused by instantaneous hot spots from foliage and debris, and surrounding building shade [10]	Likely risk with minimal impact on panel design
Technical	Performance	T.P.4	Insurgence of power plant use outside of peak sunlight hours driving energy costs too high [7]	Likely risk with inconsequential impact on battery design

3.2. Risk Analysis Definitions

In defining the initial risks associated with the project, the below definitions serve as an initial qualitative scale in justifying both the likelihood of each risk and the consequential impact. We assume for each scale the baseline measure of the project cost, schedule, performance, and product deliverables along each project phase as the parameter conditions for each scale.

Table 14: Risk Definition

Likelihood Scale		**Consequence Scale**	
Likelihood	**Description**	**Consequence**	**Description**
Rare	Most certainly will never occur at all under baseline project conditions	**Inconsequential**	The risk has a negligible effect on moving between project gates, schedule, reliability, and performance processes

Unlikely	Typically won't occur under baseline project conditions	**Minimal**	The risk has minimal effect on moving between project gates, schedule, reliability, and performance processes
Probable	May occur at least once under normal project baseline conditions	**Moderate**	The risk creates moderate setbacks on moving between project gates, schedule, reliability, or performance processes
Likely	Expected to occur a few times under normal project baseline conditions	**Significant**	The risk creates significant barriers to moving between project gates, schedule, reliability, or performance processes
Most Certain	Frequent occurrence under normal project baseline conditions	**Severe**	The risk has major ramifications on halting project gates, schedule, reliability, or performance processes

3.3. Qualitative Risk Analysis

From the above definitions, a qualitative analysis was performed to take into account the project parameter assumptions for each risk on which the consequence and likelihood scales are based to determine the magnitude of the effect on the project's success.

3.3.1. Likelihood and Consequence Association

For each risk item, the associations are as follows in table 15:

Table 15: Risk Item Summary

Risk Code	Likelihood	Consequences
E.CW.1	Likely	Significant
E.E.1	Unlikely	Inconsequential
E.E.2	Likely	Minimal
E.E.3	Rare	Moderate
E.E.4	Rare	Minimal

E.E.5	Rare	Minimal
E.E.6	Unlikely	Minimal
E.HW.1	Probable	Moderate
E.HW.2	Likely	Inconsequential
E.HW.3	Probable	Minimal
E.HW.4	Rare	Moderate
E.HW.5	Probable	Minimal
E.HW.6	Probable	Moderate
O.C.1	Rare	Moderate
O.C.2	Rare	Moderate
O.F.1	Rare	Significant
R.G.1	Unlikely	Moderate
R.G.2	Rare	Significant
R.G.3	Likely	Moderate
R.G.4	Likely	Significant
R.GU.1	Likely	Moderate
R.GU.2	Likely	Minimal
S.E.1	Rare	Severe
S.E.2	Unlikely	Significant
S.L.1	Unlikely	Significant
S.L.2	Unlikely	Moderate
T.I.1	Unlikely	Moderate
T.I.2	Likely	Moderate
T.I.3	Probable	Minimal
T.MI.1	Rare	Severe
T.P.1	Probable	Moderate
T.P.2	Likely	Moderate
T.P.3	Likely	Minimal
T.P.4	Likely	Inconsequential

3.3.2. Qualitative Likelihood and Consequence Matrix

		Consequence				
		Inconsequential	Minimal	Moderate	Significant	Severe
Likelihood	Rare		E.E.4, E.E.5	E.E.3, E.HW.4, O.C.1, O.C.2	O.F.1, R.G.1	T.MI.1, T.I.1
	Unlikely	E.E.1	E.E.6	R.G.1,S.L.2, T.I.1	S.E.2, S.L.1	
	Probable		E.HW.5, T.I.3, E.HW.3	E.HW.1, E.HW.6, T.P.1,		
	Likely	E.HW.2,T.P.4	E.E.2, LR.GU.2, T.P.3	R.G.3, R.G.4, T.I.2, T.P.2	E.CW.1, R.G.4,	
	Most Certain					
Legend	Low Risk	Moderate Risk	High Risk	Very High Risk		

Figure 9: Likelihood and Consequence Matrix

From the initial qualitative analysis, the **prioritized** class includes those risks correlated in the following dimensions:

High Risk:

- **Moderate/Probable:** R.G.3, R.G.4, T.I.2, T.P.2
- **Moderately/Likely:** R.G.3, R.G.4, T.I.2, T.P.2
- **Unlikely/Significant:** S.E.2, S.L.1

Very High Risk:

- **Likely/Significant:** E.CW.1, R.G.4

3.4. Qualitative Risk Analysis Factors

3.4.1. Risk Prioritization

Using the above relational matrix for the likelihood and consequences definitions, we have assigned to each risk its correlation between the consequence impact and likelihood of failure. Some considerations that factored into the classification for each risk include:

- Time Scale of risk effect
- Time Scale of Project
- Recurrence frequency of risk
- Feasibility of mitigation strategy
- Overarching effect of risks to other risk groups
- Stake of liability with risk occurrence

3.5. Risk Scope Management

As a secondary measure of risk analysis, the dimensions of project phase were considered to note the most loaded phases in the development cycle. Since this is a commercial solar project for a private campus community, the projected timeline to completion of a year and $4.5 million budget in comparison to utility solar projects has a much tighter turnaround time and risk impacts that are smaller in scale. Therefore, many of the well-researched environmental, regulatory, and technical performance risks in the scope of consideration for solar panel technologies take into consideration the required mitigation scope and appropriate ownership of the risk.

3.5.1. Project Phase Load

The project phase load is defined as:

$$\frac{Risks\ belonging\ to\ Project\ Phase}{Total\ Project\ Risk\ Load}$$

Where each risk may be associated with multiple project phases, and the total project load sums all risks associated with each phase.

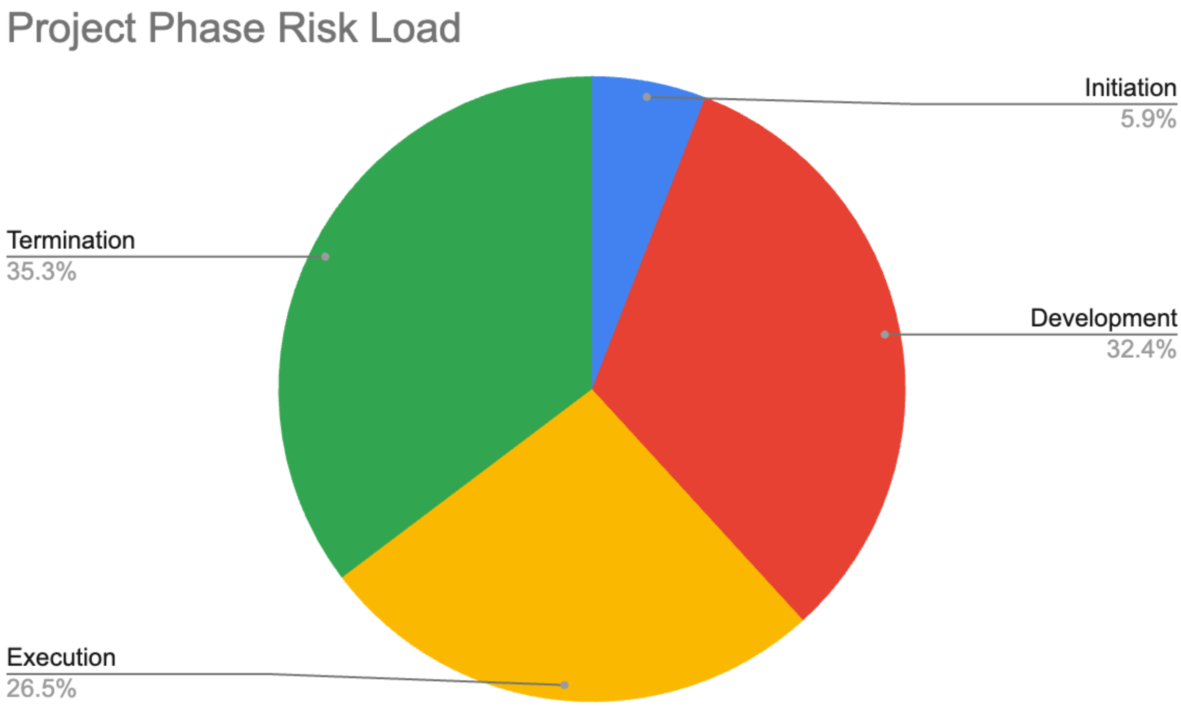


Figure 10: Project Risk Load Pie Chart

3.5.2. Risk Project Phase Analysis

Based on our previous delineation of scope in Section 1.3, we noted that operational and monitoring processes are out of scope for an installation-focused solar project. The distribution of the phase load demonstrates the need for the **development** of contingency, monitoring, and maintenance protocols coupled with **termination** disclosure for stakeholders for **operational** risks beyond the scope of the installation project. Thus, our focus is to provide the proper disclosure, preliminary analysis, and maintenance suggestions for assumed risks beyond the lifetime of project ownership under the installation company.

Most notably, the 3 risk categories are related in the following ways:

1. **Environmental Risks**
   a. The environmental risks identified in this proposal arise from well-documented historical evidence about ecological impacts that generalize to most solar projects in urban areas for Southern California and as present throughout the lifetime of the solar panels. Thus, these risks will require *preliminary impact analysis and design considerations* at the least.

2. **Technical Risks**
    a. Performance-type technical risks in particular require disclosure to stakeholders in the type of monitoring needed post-closeout of the installation project. Thus, these risks will require *monitoring and maintenance checks.*
3. **Regulatory Risks**
    a. Risks posed from governments and federal agencies are highly irregular but are less likely to impact a year-long solar installation. Stakeholders assume most risks at termination or development with *disclosure and acknowledgment.*

3.6. Risk Mitigation Strategy

With each risk that's identified, an associated mitigation strategy must be developed to minimize impact to the program.

3.6.1. Qualitative Analysis

To prioritize which risk factors to address first, the project management team would focus on the constructed qualitative likelihood and consequence matrix (3.3.1). This matrix helps identify the most severe to inconsequential risk in the USC Solar Roof System project. There are four risk categorization mitigation strategies that help label the risk such as acceptable, minimizing, shared, and transferable. By utilizing these methods, the risks can be processed to identify which risk to address first in the project.

Environmental:

Below are risk codes for environmental risks along with their respective mitigation approach and category.

Table 16: Environmental Risk Mitigation

Risk Code	Mitigation Approach	Mitigation Category
E.CW.1	Ensure the solar panel material and coating is water-tight for the entire panel EOL or require ongoing leakage maintenance checks. Source lead-free solders for PV panels.	Minimize
E.E.1	Have routine inspections and cleaning of solar panels	Accept
E.E.2	Have physical deterrents to prevent birds from getting near the solar panels. Bird statues or roof spikes	Minimize
E.E.3	Ensure high quality photovoltaic (PV) cells are used in the solar panels with smaller reflection coefficients	Minimize

Risk Code	Mitigation Approach	Mitigation Category
E.E.4	Perform thermal analysis	Accept
E.E.5	Design storage for wire harnessing and routing out of sight from populated areas on campus	Accept
E.E.6	Ensure adequate coating requirements are provided to suppliers	Transfer
E.HW.1	Ensure the solar panels are mounted in a way that does not comprise the structural integrity of the building. Have integrity check plans for transfer phase for future project owners	Minimize
E.HW.2	Apply anti reflective coating on the solar panels to reduce polarized light pollution	Accept
E.HW.3	Perform thermal analysis and provide liquid cooling on panels to optimize design	Minimize
E.HW.4	Train maintenance teams on routine inspections and cleaning of solar panels	Transfer
E.HW.5	Use/design solar panels designed to withstand hazardous weather damage	Accept
E.HW.6	Use multiple, strong anchors to attach solar panels to the roof.	Minimize

Organizational:

Below are risk codes for organizational risks along with their respective mitigation approach and category.

Table 17: Organizational Risk Mitigation

Risk Code	Mitigation Approach	Mitigation Category
O.C.1	Have a contract that states the management team is going to see the entirety of the project or a clause stating the new manager needs to complete it.	Share
O.C.2	Include clauses in contracts, avoid single contractors, and consult with the legal team.	Minimize

O.F.1	Identify potential risk to meet budget standards such as prioritizing critical activities, regular monitoring, and cost benefit analysis.	Minimize

Regulatory:

Below are risk codes for regulatory risks along with their respective mitigation approach and category.

Table 18: Regulatory Risk Mitigation

Risk Code	Mitigation Approach	Mitigation Category
R.G.1	Stakeholders should understand rebate risks going into project onset	Transfer
R.G.2	Having a signed contract from each stakeholder and making sure there is enough money before starting the project and providing binding requirements	Shared
R.G.3	File for permits as soon as possible to prevent delays and try not to file in a transition time for governmental administration	Minimize
R.G.4	Establish contingency plans with multiple suppliers	Minimize
R.GU.1	Design in back-up flow battery systems	Minimize
R.GU.2	Provide binding contracts at project onset	Transfer

Safety:

Below are risk codes for safety risks along with their respective mitigation approach and category.

Table 19: Safety Risk Mitigation

Risk Code	Mitigation Approach	Mitigation Category
S.E.1	Perform thermal and structural analyses to ensure adequate air flow along cooling systems	Minimize
S.E.2	Wearing correct PPE and using proper tools and equipment in handling the wire, as well as training	Minimize

S.L.1	Ensure all employees are trained and have the correct PPE for the job. Also, have proper signage indicating cautious areas	Minimize
S.L.2	Strategically placing solar panels that leave a pathway to allow first responders access to the roof	Minimize

Technical:

Below are risk codes for technical risks along with their respective mitigation approach and category.

Table 20: Technical Risk Mitigation

Risk Code	Mitigation Approach	Mitigation Category
T.I.1	Perform checks on cable placement and panel angels to ensure proper installation	Minimize
T.I.2	Perform testing and inspection to ensure quality parts, return to vendor if they are not in compliance	Minimize
T.I.3	Implement flexible scheduling, monitoring weather forecasts, plan protective measures, provide sufficient training, and suspend all lift activities to ensure minimal project disruption.	Minimize
T.MI.1	Ensure the building code is structurally sound to withstand weight of solar panels	Share
T.P.1	Perform thermal/electrical analysis to optimize panel placement and provide liquid cooling systems	Minimize
T.P.2	Install solar panels that have a dedicated cooling system with a fan. HVAC system strain is typically unexpected	Minimize
T.P.3	Analyses to ensure that solar modules are placed in a spot where it can withstand instantaneous heat	Minimize
T.P.4	Work with utility companies to seek battery storage solutions	Accept

3.6.2. Quantitative Analysis

In addition to conducting a qualitative risk analysis, quantitative risk analyses are equally as important. Risk is comprised of the probability of the event occurring and the consequences of the event. In a quantitative risk assessment, probabilities are assigned to both of these factors. These two factors are named probability of failure and consequence of failure. The probability of failure is made up of 3 sections: Maturity, Complexity, and Dependency. Maturity defines how much development is needed for the product to be operational. Complexity describes how complex the design of the solar panel system will be. Lastly, the dependency is a measure of how the development of the solar panel system will impact the project in terms of timeline, cost, and implementation. The consequences of failure are made up of 4 parts: Cost, Schedule, Reliability, and Performance. A scale with an associated probability is assigned to each component of the probability of failure and the consequence of failure. These assigned probabilities are used to calculate the overall risk factor for the project.

Table 21: Probability of Failure

Probability of Failure (Pf)			
Score	Maturity	Complexity	Dependency
Low (0.1)	Existing solar panel system ready to implement (COTS)	Simple design	No impact on the project. The project is not dependent on the solar panel implementation
Minor (0.3)	Minor modifications to readily available solar panel system	A minor increase in the complexity of the design	Due to the maturity/complexity of the project, there is a minor impact on the schedule, cost, or implementation of the solar panels.
Moderate (0.5)	Major modifications to readily available solar panel system	Moderate increase in complexity of design	Moderate project impact (schedule, cost, or implementation) due to maturity/complexity level
Significant (0.7)	A significant change from readily available solar panels development of new subsystems required	Significant increase in complexity of design	Significant impact on the project timeline, cost, or other factors due to the development of new subsystems.

Major (0.9)	Ground-up/brand-new solar panel system	Extremely complex design	Major impact on the project due to ground-up development of solar panel system

Table 22: Consequence of Failure

Consequence of Failure (Cf)				
Score	Cost	Schedule	Reliability	Performance
Low (0.1)	Budget not exceeded	Less than 1-week delay in schedule	Minimal (non-noticeable) reliability impact	Performance requirements are met redesign is not required
Minor (0.3)	Budget exceeds target by 1- 6%	2-3 weeks delay in schedule	A small decline in reliability impact	A small decline in performance no redesign is required all performance requirements are met
Moderate (0.5)	Budget exceeds target by 6-10%	4-5 weeks delay in schedule (critical path impacted)	Some reduction in reliability (noticeable)	Degradation of performance occurs. Performance requirements are met but without proper margins.
Significant (0.7)	Budget exceeds target by 10-15%	6-7 weeks delay in schedule (critical path must be delayed)	Significant reliability decline	Significant decline in performance. Redesign is required and some performance requirements are not met.
Major (0.9)	Budget exceeds target by more than 15%	More than 7 weeks delay in schedule (client is impacted by schedule delay)	Solar panels do not meet reliability goals	No performance requirements are met. A complete redesign is required.

The following probabilities were selected for this project based on collaboration with the team:

Table 23: Project Probability Selection

Pm (maturity)	0.3
Pc (complexity)	0.3
Pd (dependency)	0.5
Cc (cost)	0.3
Cs (schedule)	0.5
Cr (reliability)	0.2
Cp (performance)	0.2

As a group we decided on a Pm value of 0.3 because we plan to only develop the mounting system for the solar panels. The other systems will be used as is. The Pc values is 0.3 because the design of mounting/electrical will be more complex than the baseline components. The Pd value is selected as 0.5. This value is based on the maturity/complexity of the project. It is expected some project impact could occur.

The Cc value is chosen as 0.3. This value was chosen because we expected the budget to be within 1-6% of the target budget. The Cs value is assigned a value of 0.5. This is because we want to include a cushion in the timeline of 4-5 weeks of delay. The Cr and Cp were determined to be 0.2. This is because this project will be using parts that are standardized with documented reliability and performance. These components include solar panels, inverters, and mounting hardware all of which have established performance/ reliability standards.

$$Pf = \frac{Pm + Pc + Pd}{3} \qquad 0.367 = \frac{0.3+0.3+0.5}{3}$$

$$Cf = \frac{Cc+Cs+Cr+Cp}{4} \qquad 0.3 = \frac{0.3+0.5+0.2+0.2}{4}$$

$$RF = Pf + Cf - (Pf * Cf) \qquad RF = 0.367 + 0.3 - (0.367 * 0.3) = 0.557$$

Using the above equations, **the Probability of Failure is 0.367, Consequence of Failure is 0.3 and the calculated risk factor is 0.557**. According to the rule of thumb for risk factors, this is considered a **medium risk** for the project, since the RF is between 0.3 and 0.7.

4. Cost Estimation & Budgeting

4.1. Cost Overview

Table 24: Project Cost Overview

Category	Cost	Description
Labor Total	$735,949.06	Cost of all hours worked (68 team members)
Materials and Equipment Total	$4,536,191	Cost of all materials needed (including permits)
Permits	$99,466.08	Cost of Los Angeles County permits
Facilities Total	$12,839.43	Cost of equipment needed for lab testing
Subcontract Total	$0	No subcontractors used
Grand Total	$5,384,445.22	Total Project Cost
15% Markup	$6,192,112.01	Markup for the installation
USC Price w/ Tax Credit	$4,334,478.40	Price USC will pay after 30% CA tax credit
Profit	$807,666.78	Company profit

Types of Cost:

The types of cost associated with this project are labor, materials and equipment, permits, and facilities. There are no subcontractors that are hired in this project, as all labor is hired through the company, as such, the subcontractor total is 0.

Challenges with Cost:

For challenges related to cost, it can be difficult to determine how much overhead some labor may charge based on the situation and technical difficulties. General delays also result in workers having no work and needing overhead that they can charge to. This difficulty in determining these costs are attempted to be covered in our estimations for overhead. Scheduling hours for supporting teams can also be difficult as specific teams can offer support hours than others for certain work packages. As there is no uniform and reliable way to do this, we evenly split the hours worked by all supporting teams relative to the responsible team/individual. This way, we ensured consistency within our RAM and teams. Additionally, scheduling delays such combined with overlapping schedules can cause cost issues.

<u>Cost Estimation Justification</u>:

To estimate cost, the number of workers were first estimated, which was approximately 68. From there, the workers were broken down into their specific functions and the average salary was obtained for each job. The salaries were averaged for each team and the expected number of hours each team would put into the project were estimated from the WBS and RAM. Additional overhead hours were added based on what the possible need would be for each team (i.e. construction received 200 overhead hours as there could be delays and other issues, engineering received 50 hours per team). The total required hours were multiplied by the average hourly salary rates and combined which gave an estimated labor cost of $735,949.06.

Material costs were also accounted for and broken up into categories: Solar Panels & Fixed Mounts, Solar Irradiance Meters & Thermal Cameras, Personal Protective Equipment (PPE), Tooling, and Electrical Components. Software and Construction Equipment Rentals sum up the project's overall Equipment costs, with LA City Permits and Facilities acting as their own stand-alone categories.

4.2. Materials Cost

The tables below are a summary of the material costs associated with this project:

Table 25: Solar Panels + Fixed Mounts

ITEM	QUANTITY	COST	W/ TAX	TOTAL
Solar Panels	4000	$825	$835.31	$3,341,250
Fixed Mounts	4000	$20	$20.25	$81,000
			Total	$3,422,250

The average solar panel is expected to cost around $3.30 per Watt [39]and the average solar panel generates 250-400W of electricity [40]. Assuming the worst case scenario, we will use 250W solar panels, a total of 4,000 panels are needed to reach the 1MW requirement. The total cost of solar panels is then determined by multiplying the total number of panels by the cost per Watt and how much wattage each panel produces. Fixed mounts are needed to mount the solar panels onto the roof of the USC building as we do not plan on masking small adjustments to the solar panels once mounted. The same number of mounts are needed as solar panels and each costs around $20 [39], bringing the grand total to approximately $3,422,250 for both solar panels and fixed mounts. This estimation is based on the worst case scenario and allows our company to ensure enough funds are granted to secure the right amount of solar panels to meet the 1MW requirement. In the scenario our solar panels generate more electricity, we would be able to make a larger profit.

Table 26: Solar Irradiance Meters + Thermal Cameras

ITEM	QUANTITY	COST	W/ TAX	TOTAL
Fluke IRR2-BT Solar Irradiance Meter Pro	1	$494	$545	$545
Fluke MB1-IRR Panel Mounting Bracket For Irradiance Meters	1	$89.99	$99.21	$99
Fluke TiS75+ Thermal Imaging Camera	1	$6,271.95	$6,914.82	$6,915
SMFT-1000 Solar Tools Kit: Fluke Multifunction PV Tester and Performance Analyzer, I-V Curve Tracer	1	$5,500	$6,063.74	$6,064
Fluke 376 FC True-RMS Clamp Meter with iFlex	1	$660	$727.64	$728
Fluke 117 Electrician's Multimeter with Non-Contact Voltage	1	$289.99	$319.71	$320
			Total	$14,670

Harnessing solar irradiance is a pivotal process in the project; therefore, these materials help determine the optimal location to place the solar panels on USC's building rooftop. In addition, the items are needed to help measure irradiance, temperature, inclination, direction of the solar arrays, and energy production estimations from the solar power systems. Also, these materials can help troubleshoot problems that could arise during installation. The final cost to acquire these objects is $14,670.

Table 27: Personal Protective Equipment

ITEM	QUANTITY	COST	W/ TAX	TOTAL
Hard Hat	28	$11.47	$12.65	$354.08
Safety Glasses (6 Pack)	28	$25.97	$28.63	$143.16
Class 2 High Visibility Vests w/ Pockets	28	$21.97	$24.22	$678.21
Gloves (Electric Shock Resistant)	25	$19.99	$22.04	$550.97
Steel Toed Boots	25	$125.00	$137.81	$3,445.31
Fall Protection Tension Cable	16	$26.97	$29.73	$475.75
Fall Protection Harness	16	$49.98	$55.10	$881.65
Hearing Protection	25	$21.97	$24.22	$605.55
Electric Shock Sleeves	25	$19.97	$22.02	$550.42
			Total	$7,685.11

PPE such as hard hats, safety glasses, safety harnesses, and electric shock resistant gloves were taken into account to protect the construction team along with additional personnel who may need it. The proper PPE installing solar panels on a roof was followed according to OSHA standards [47].

Table 28: Tooling

ITEM	QUANTITY	COST	W/ TAX	TOTAL
Utility Belt	16	38.90	42.89	686.20
Tool Box	16	54.98	60.62	969.85
4 Piece Pliers Set/6 Piece Screwdrivers Set/2 Piece Utility Knife/ Measuring Tape	16	119.00	131.20	2,099.16
24 in./48 in. Compact Box Level Set	5	105.00	115.76	578.81
Self-Leveling Cross-Line Laser Level	5	79.97	88.17	440.83
Stud Finder	5	19.97	22.02	110.08
Electric Drill	16	79.00	87.10	1,393.56
Screwdriver Drill Bit Kit	16	20.97	23.12	369.91
Titanium Twist Drill Bit Set	16	37.97	41.86	669.79
Wrench Set w/ Storage Kit	16	59.97	66.12	1,057.87
Hammer	16	7.97	8.79	140.59
Allen Wrench Set	16	22.30	24.59	393.37
Hex Cap Screws	12,780	$1.02	$1.12	$15,844.85
100 Solar Siphon clips for Solar Frame	40	$129	$142	$6,272
Asymmetrical Clamp Kit M8*25	2130	$0.50	$0.55	$1,294.51
100 Pack PV Panel Wire Clips	10	$29.90	$32.96	$363.44
Conduit Bender	16	42	46.305	816.8202
Caulk Gun	16	$44	$49	$776
Wire Stripper	16	$39	$43	$688
Hack Saw	16	$5.82	$6.42	$102.66
Fuse Puller	16	$8.99	$9.91	$158.58
Tape Measure	16	$10	$11	$176
Angle Finder	16	$29	$32	$512
Jigsaw	16	$4.50	$4.96	$79.38
Right Angle Drill	16	$151	$166	$2,664
			Total:	$24,591.64

Tools required to install solar panels were determined and calculated for each laborer to have their own set to increase efficiency and ensure the project is completed on time. Other electrical tools needed and machinery to outfit the solar panels were estimated per laborer in order to increase efficiency and guarantee and on time completion of the project.

Table 29: Electrical Components

ITEM	QUANTITY	COST	W/ TAX	TOTAL
500 ft 10 AWG PV Wire	20	$250	$276	$5,513
Renogy Solar Panel- to-charge Controller adapter	284	$5.99	$6.60	$1,875.53
Cable Wire Connect Charge Controller to Battery	2	$29.99	$33.06	$66.13
Battery Inverter Cables for 3/8 in Lugs	$2	$42	$46	$92.61
Solar Optimizers	4000	$76.11	$83.91	$335,645.10
DC Circuit Breaker (MCCB)	2	$3,300	$3,638	$7,277
MC4 Parallel Connector	98	$24.45	$26.96	$2,641.70
Pre-wired Compact Solar Combiner Box with Fuse	34	$349	$385	$13,082
Solar Panel Monitoring System	1	$290	$320	$320
On-site Power Meter	1	$271.19	$298.99	$298.99
500 kWh Lithium Ion Battery	1	$172,500	$190,181	$190,181
Junction Box	4000	$27	$30	$119,070
SmartSolar MPPT RS 450/200-Tr Charge Controller	2	$2,432.15	$2,681.45	$5,362.89
Pin cable lug for 4-6mm² cable, yellow, 1pc	4000	$1.50	$1.65	$6,615.00
ADVANCED ENERGY AE_500TX-480 500KW INVERTER. Comes with MPPT controller.	2	119,210.14	131429.1794	$262,858.35
Solar Arc Protector	284	$38.00	$41.895	$11,898.18
			TOTAL	$962,797

The solar panel subsystems consist of 14 panels (36V each) connected in series, producing a total voltage of 504V and generating 3500W per string. Each string operates at approximately 6.9A on the inverter, of which there are 2 500 kWh inverters. Considering a maximum current rating of 1600A and applying an 85% load limit, the system supports up to 197 solar panel subsystems . The final design includes 14 panels in series in 197 rows. With 1242 panels remaining, the solar panels are divided evenly between the 2 inverters, resulting in 142 solar systems on each side, each side drawing 979A. Thus, the costs for the electrical components were configured based on the 2 inverters and their specifications.

Table 30: Software

ITEM	QUANTITY	COST	W/ TAX	TOTAL
Microsoft 365 Business Basic	37	$78.00	$78.00	$1,952.25
Autodesk Civil 3D	1	$1,400.00	$1,400.00	$1,400.00
Solidworks 3DExperience Works	1	$15,500.00	$15,500.00	$15,500.00
Solidworks	5	$2,820.00	$2,820.00	$14,100.00
Solidworks Electrical	2	$1,000.00	$1,000.00	$2,000.00
ABAQUS (FEA & Thermal Software)	2	$6,750.00	$6,750.00	$13,500.00
			Total	$48,452.25

Software is needed for any business to function, and part of that includes basic office softwares such as Microsoft Excel, Word, Powerpoint, and Teams which is included in the MS 365 Business Basic package which is charged on a per month / per user basis. Software subscriptions to these programs are all like this, so quantity here represents the number of licenses needed and the cost associated with each license. There is no tax on software licenses in the state of California, and all software accounted for here is assuming the maximum time someone will be on the project and using a month to month subscription model instead of an annual renewal.

Table 31: Construction Equipment Rentals

ITEM	QUANTITY	COST	W/ TAX	TOTAL
Large Crane	2 Months	$15,000	$16,425	$32,850.00
Fencing	900	$1.85	$2.03	$3,646.35
Cones (6 Pack)	15	$315.52	$345.49	$5,182.42
			Total	$41,678.77

Construction equipment is needed to assist in the installation of solar panels onto the roof of the building. A large crane is needed to lift solar panels into place over the span of around 2 months. Renting a crane is needed for this because it is not practical to buy a crane for this project. Fencing is needed to wall off the site from non authorized persons. ~900 ft of fencing is needed for around 2 months which results in a cost of $3,646.35 for 2 months. The cost of fencing is based on a per linear ft / per month length. Cones are also necessary to help wall off areas of the site, costing around $5,000 for 90 cones in order to cordon off the building to ensure safety of campus members.

Table 32: LA City Permits

ITEM	QUANTITY	COST	W/ TAX	TOTAL
Electrical Plan check	1	$1,169.03	N/A	$1,169.03
Building Permit	1	$98,189.14	N/A	$98,189.14
Electrical Permit	1	$107.91	N/A	$107.91
			Total	$99,466.08

Permits are needed to allow the company to begin construction. An electrical plan check for the wiring of the entire solar array system is needed along with an electrical permit to build said system. As this is a modification of an already existing building, a building permit is required to build this structure on top of the building. The total cost from the Los Angeles City Government permit calculator produced a total of almost $100,000 for all 3 permits.

Table 33: Facilities

ITEM	QUANTITY	COST	W/ TAX	TOTAL
Multimeters	10	$9.99	$11.01	$110.14
Oscilloscopes	3	$475.33	$524.05	$1,572.15
UV meters	5	$249.99	$275.61	$1,378.07
Soldering tools kit	5	$24.99	$27.55	$137.76
Insulation resistance testers	5	$164.99	$181.90	$909.51
Solar Simulator	1	$3,800	$4,190	$4,190
Reference Solar Cell	1	$4,120	$4,542	$4,542
			Total	$12,839.43

The cost breakdown section of lab equipment focused on equipment needed for testing and supporting electrical equipment. The total cost for all materials is $12,839.43. This price takes into consideration employees who will use lab equipment such as EE techs, ME techs, EE engineers, and system engineers. This lab is mainly focused on electrical testing. Lab equipment is expected to be shared between users. Expected equipment needed for testing includes insulation resistance tester (to measure resistance due to insulation of), solar simulator which is a light source which is representative of the light source that the solar panels will see once installed. Lastly, the budget includes a reference solar cell which is used as a calibration device to baseline irradiance measurements of the solar panel.

4.3. Cost Analysis

The project has a total cost of $5,384,445.22. The budget comes from various categories such as labor hours, materials and equipment, permits, and facilities. When estimating the budgets for each respective category, we decided to overestimate most items and hours to ensure there is a budget for labor hours, equipment, solar panels, facility testing tools, and more; the only category that was not overestimated was permits. This way, the company is guaranteed to make profit, but has additional room for various expenses as needed.

An additional 15% markup is made on the grand total to guarantee profits, bringing the total price to $6,192,112.01. The state of California issues a 30% federal tax credit for solar roof projects, saving USC $1,857,633.60 and bringing the total cost for USC to $4,334,478.40. The approximate profit for the company is $807,666.78, however, this number has a high likelihood of increasing as overhead hours and other overhead estimates remain untouched. In the event our costs begin to exceed the budgeted costs, having a plan in place is pivotal to maintaining a successful project and staying within budget.

Contingency Plan:

This budget has taken into account a profit margin that would be preferable. There is also a built in 10% buffer in the budget that allows the project to pay for expedites, overtime for workers, and extra material costs should those arise. However, if the costs begin to run more into that buffer than what should be deemed acceptable, around 20% of that 10% buffer, the project manager is to follow the plan outlined below:

1. Determine if the overspending is an equipment/material or labor issue.
2. If the overspending issue is equipment/material related, follow the following plan:
    - 2.1. Every additional equipment request from the construction, ops, etc team, must be forwarded to the lead of each department and then forwarded to the project manager.
    - 2.2. The project manager must evaluate if this material/equipment is necessary for completion of the project
    - 2.3. The project manager is to inform each team if their equipment/material request has been approved or denied
3. If material/equipment issues are impossible to spend less on and/or labor is the major cost overrun, follow the following plan:
    - 3.1. Review labor hours being charged in each department.
    - 3.2. For the departments that are overrunning on hours being charged, talk to each department leader and determine who could be moved to another project within the company

3.3. After this determination, inform the employee(s) they are being moved to another project due to cost reasons. Do not fire them.

3.4. Monitor labor hours in each department for the next month and reconvene every month to see who could be moved without affecting the schedule of the project.

Should this continue and the entire budget buffer will be used up, the project manager is to inform leadership of the decrease in profits and present leadership with how much of the project is left to complete and how much profits will be lost.

Cost Breakdowns

Table 34: Material Cost Breakdown

Item	Cost	Description
Solar Panels + Mounts	$3,422,250	Cost of 4,000 solar panels and fixed mounts
Site Surveying Equipment	$14,670	Thermal and solar equipment to assess the best location and angle to orient the solar panels
Personal Protective Equipment	$7,685.11	Equipment needed for personnel who will be working on the active construction site
Tooling	$38,658.01	All tooling: wrenches, hammers, screws, washers, welding torches, angle grinders, etc.
Electrical Components	$962,797	Inverters, wiring, and connectors needed for a monitoring system
Software	$48,452.25	All software needed for the team to complete the required work
Construction Rentals	$41,678.77	Cranes, fencing, and cones needed to lift the solar panels and cordon off the building
Facilities (Lab)	$12,839.43	Electrical component needed to test the solar panels
Permits	$99,466.08	LA city building and construction permits

Table 35: Labor Cost Breakdown

Labor w/ overhead	$735,949.06	Labor costs with extra budgeted hours to be used as needed
Labor w/o overhead	$688,797.11	Anticipated labor costs to be used
Total overhead cost	$47,151.95	Additional value of overhead hours
Project hours	13,167.6	Total hours expected to be spent
Overhead hours	1,292	Extra hours budgeted and included in the price

From the table above, there are 2 labor costs: $735,949.06 and $688,797.11 (labor costs with overhead hours and labor costs without overhead hours). Considering the fact that most projects often fall behind schedule with additional hours worked, it was decided to add additional overhead hours for each team.The WBS already overestimated the number of days needed to perform each work package; however, having additional overhead hours in the budget grants an additional safety net that guarantees the company will maximize profits and has funds ready in the event additional hours are needed. The analysis conducted however utilizes labor hours without overhead as this was the accurate estimate for work to be done and the necessary duration. The labor hours with overhead costs is simply the number to be proposed to USC when proposing the bid for the project.

4.4. Cost Budgeting

__Table 36:__ **Days Worked for Task Completion** - *this table depicts the required days required to complete each task from the WBS and which teams are needed. The required days were decided based on data from the WBS; the team responsible was allocated the full quantity of days as assigned per the WBS. The supporting teams had their days assigned based on an even split of the responsible team on the basis that each team is evenly supporting the responsible team. In the event that more days are needed for work to be completed, we assigned additional overhead hours to be used to fulfill the labor costs needed.*

Code	BT	CT	DET	EET	EM	T	LT	MET	P	PET	PMT	SO	SCM
1.1.1		2.5	2.5		2.5				10	2.5			
1.1.2	10												10
1.1.3	5				1.25	1.25					1.25		1.25
1.1.4	5				2.5						2.5		
1.1.5	0.5				0.5						2	0.5	0.5
1.1.6	0				0						0		0
1.2.1		1.67			1.67						5		1.67
1.2.2	5										10		5
1.2.3			0	0	0			0		0		0	0
1.2.4	0				0						0		0
1.3.1	12.5				12.5		25						
1.3.2	0				0		0		0				

2.1.1		6.25	6.25	6.25	6.25			25					
2.1.2			8.25	8.25	8.25			25					
2.1.3			12.5		12.5			25					
2.1.4			8.25	25	8.25	8.25							
2.1.5			6.25	6.25	25			6.25				6.25	
2.2.1							40						
2.2.2		10											
2.2.3												5	
2.3.1	6.8		6.8	6.8	6.8			6.8		6.8	40		
2.3.2			10	10	40			10		10			
2.3.3			8	8	8			8		40		8	
Code	**BT**	**CT**	**DET**	**EET**	**EM**	**T**	**LT**	**MET**	**P**	**PET**	**PMT**	**SO**	**SCM**
3.1.1			20	6.6	6.6			6.6					
3.1.2			10										
3.2.1	2.5		2.5	2.5	10			2.5					
3.2.2				5		5		5		15			
3.2.3			5	15				5		5			
4.1.1				30		60		30					
4.1.2				60		60							
4.1.3						60		60					
4.1.4				60		60							
4.2.1		27.5				55				27.5			
4.2.2				18.15		55		18.15		18.15			
4.2.3		55		13.75		13.75		13.75		13.75			
5.1.1						2							

5.1.2				5		5							
5.1.3					1								
6.1				5				5		10			
6.2				5				5		10			
6.3				5				5		10			
6.4				5				5		10			
6.5												2	

LEGEND

BT = Business Team
CT = Construction Team
DET = Design Engineering Team
EET = Electrical Engineering Team
EM = Engineering Manager
T = Technicians
LT = Legal Team

MET = Mechanical Engineering Team
PT = Planner
PET = Product Engineering Team
PMT = Project Management Team
SO = Safety Officer
SCM = Supply Chain Manager

<u>Table 37:</u> Costs Associated for Task Completion - *this table depicts the required costs to complete each task from the WBS. The costs were determined by determining the hourly rate for each team, or individual, (depicted in Table 38). To get the hours needed, the days worked from Table 36 were multiplied by eight to get the total work hours needed per team. This value was multiplied by the hourly rate to get the cost needed per team and per work package.*

Code	BT	CT	DET	EET	EM	T	LT	MET	P	PET	PMT	SO	SCM
RATE	$51.15	$29.48	$44.21	$60.22	$81.46	$29.04	$55.36	$65.52	$32.15	$49.58	$44.75	$48.85	$67.46
1.1.1		589.60	884.20		1,629.20				2,572.00	991.60			
1.1.2	4,092.00												5,396.80
1.1.3	2,046.00				814.60	290.40					447.50		674.60
1.1.4	2,046.00				1,629.20						895.00		
1.1.5	204.60				325.84						716.00	195.40	269.84
1.1.6													
1.2.1		393.07			1,086.13						1,790.00		899.47
1.2.2	2,046.00										3,580.00		2,698.40
1.2.3													
1.2.4													
1.3.1	5,115.00				8,146.00		11,072.00						
1.3.2													
2.1.1		1,474.00	2,210.50	3,011.00	4,073.00			13,104.00					
2.1.2			2,917.86	3,974.52	5,376.36.			13,104.00					
2.1.3			4,421.00		8,146.00			13,104.00					
2.1.4			2,917.86	12,044.00	5,376.36	1,916.64							
2.1.5			2,210.50	3,011.00	16,292.00			3,276.00				2,442.50	
2.2.1							17,715.20						
2.2.2		2,358.40											
2.2.3												1,954.00	

Code	BT	CT	DET	EET	EM	T	LT	MET	P	PET	PMT	SO	SCM
RATE	$51.15	$29.48	$44.21	$60.22	$81.46	$29.04	$55.36	$65.52	$32.15	$49.58	$44.75	$48.85	$67.46
2.3.1	2,728.56		2,405.02	3,275.97	4,341.42			3,564.29		2,697.15	14,320.00		
2.3.2			3,536.80	4,817.60	26,067.20			5,241.60		3,966.40			
2.3.3			2,829.44	3,854.08	5,213.44			4,193.28		15,865.60		3126.40	
3.1.1			7,073.60	3,179.62	4,301.09			3,459.36					
3.1.2			3,536.80										
3.2.1	1,023.00		884.20	1,204.40	6,516.80			1,310.40					
3.2.2				2,384.71		1,1149.98		2,594.59		5,949.60			
3.2.3			1,750.72	7,226.40				2,594.59		1,963.370			
4.1.1				14,452.80		13,939.20		15,724.80					
4.1.2				28,905.60		13,939.20							
4.1.3						13,939.20		31,449.60					
4.1.4				28,905.60		13,939.20							
4.2.1		6,485.60				12,777.60				10,907.60			
4.2.2				8,743.94.		12,777.60		9,513.50		7,199.02			
4.2.3		12,971.20		6,624.20		3,194.40		7,207.20		5,453.80			
5.1.1						464.64							
5.1.2				2,408.80		1,161.60							
5.1.3					651.68								
6.1				2,408.80				2,620.80		991.60			
6.2				2,408.80				2,620.80		991.60			
6.3				2,408.80				2,620.80		991.60			
6.4				2,408.80				2,620.80		991.60			
6.5											716.00		

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EET = Electrical Engineering Team
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T = Technicians
LT = Legal Team
MET = Mechanical Engineering Team
PT = Planner
PET = Product Engineering Team
PMT = Project Management Team
SO = Safety Officer
SCM = Supply Chain Manager

<u>Table 38:</u> Labor Costs - *this table outlines the costs associated with the installation of the USC Solar Roof System. It breaks down the teams into individual roles, specifying the number of personnel required for each role. The median salary for each role in Los Angeles was determined and then multiplied by the number of people needed. These values were summed and averaged to calculate the average team salary, which was then used to determine the hourly rate. Work hours were estimated from the Work Breakdown Structure (WBS), and additional overhead hours were included to account for any extra work required beyond the allocated time. Overhead hours were assigned based on estimation of additional work hours needed per team. The hourly rate was then multiplied by the total hours to calculate the labor cost.*

POSITION	# ON TEAM	MEDIAN SALARY	MEDIAN x # ON TEAM	COMBINED AVERAGE SALARY	HOURLY RATE	APPROX WORK HOURS	ESTIMATED OVERHEAD HOURS	TOTAL
	BUSINESS TEAM							
BUSINESS MANAGER	1	$158,094	$158,094	$106,389.63	$51.15	377.33	20	$20,323.60
FINANCIAL ANALYST	2	$74,226	$148,452					
BUSINESS ANALYST	1	$119,012.50	$119,013					
	CONSTRUCTION TEAM							
CONSTRUCTION TEAM MANAGER	1	$169,435	$169,435	$61,310.04	$29.48	823.33	200	$30,163.76
CONSTRUCTION SUPERVISOR	1	$89,075	$89,075					
SITE MANAGER	1	$145,877	$145,877					
LABORERS	16	$40,623	$649,968					
EQUIPMENT OPERATORS	4	$88,944	$355,776					
	DESIGN ENGINEERING TEAM							
LEAD DESIGN ENGINEER	1	$157,043	$157,043	$91,960.00	$44.21	850.67	150	$44,241.01
ARCHITECT	1	$75,128	$75,128					
STRUCTURAL ENGINEERS	1	$82,040	$82,040					
CAD DESIGN	1	$73,087	$73,087					
AUTOCAD DRAFTERS	1	$72,502	$72,502					

POSITION	# ON TEAM	MEDIAN SALARY	MEDIAN x # ON TEAM	COMBINED AVERAGE SALARY	HOURLY RATE	APPROX WORK HOURS	ESTIMATED OVERHEAD HOURS	TOTAL
ELECTRICAL ENGINEERING TEAM								
ELECTRICAL ENGINEERING MANAGER	1	$178,439	$178,439	$125,263.40	$60.22	2,454.00	200	$159,831.28
LEAD ELECTRICAL ENGINEER	1	$182,000	$182,000					
ELECTRICAL ENGINEERS	2	$89,287	$178,574					
SYSTEMS ENGINEER	1	$87,304	$87,304					
TECHNICIANS								
ELECTRICAL TECHS	4	$63,225	$252,900	$60,404.50	$29.04	3,082.67	100	$92,426.63
MECHANICAL TECHS	4	$57,584	$230,336					
LEGAL TEAM								
CORPORATE LAWYER	1	$122,193	$122,193	$115,154.33	$55.36	520.00	32	$30,560.19
CONTRACT MANAGER	1	$151,370	$151,370					
COMPLIANCE OFFICER	1	$71,900	$71,900					
MECHANICAL ENGINEERING TEAM								
MECHANICAL ENGINEERING MANAGER	1	$176,666	$176,666	$136,277	$65.52	2,137.33	200	$153,137
LEAD MECHANICAL ENGINEER	1	$192,000	$192,000					
THERMAL MECHANICAL ENGINEER	1	$89,488	$89,488					
CAD MECHANICAL ENGINEER	1	$86,954	$86,954					

POSITION	# ON TEAM	MEDIAN SALARY	MEDIAN x # ON TEAM	COMBINED AVERAGE SALARY	HOURLY RATE	APPROX WORK HOURS	ESTIMATED OVERHEAD HOURS	TOTAL
PLANNING TEAM								
PROJECT PLANNER	1	$76,800	$76,800	$66,878.67	$32.15	80.00	24	$3,343.93
SCHEDULER	1	$70,829	$70,829					
LOGISTICS	1	$53,007	$53,007					
PRODUCT TEAM								
LEAD PRODUCT ENGINEER	1	$123,784	$123,784	$103,136	$50	1,430.00	150	$78,344
PROCESS ENGINEER	2	$85,692	$171,384					
QUALITY ENGINEER	1	$117,377	$117,377					
PROJECT MANAGEMENT TEAM								
PROJECT MANAGER	1	$82,631	$82,631	$93,077.80	$44.75	502.00	60	$25,148.91
PROJECT COORDINATOR	2	$71,237	$142,474					
PROJECT ANALYST	2	$120,142	$240,284					
SAFETY OFFICER								
SAFETY OFFICER	1	$101,599	$101,599	$101,599	$48.85	158.00	16	$8,499
ENGINEERING MANAGER								
ENGINEERING MANAGER	2	$169,435	$388,870	$169,435	$81.46	1229.33	120	$109,916
SUPPLY CHAIN MANAGER								
SUPPLY CHAIN MANAGER	1	$140,317	$140,317	$140,317	$67.46	147.33	40	$12,638

<u>Table 39:</u> Costs Associated per WBS Work Package - *this table details the associated costs for each WBS work package and deliverable. This table does not account for overhead hours and is the minimum labor cost budget needed assuming the project goes according to plan.*

ESTIMATED WBS COST BY WORK PACKAGE (W/O OVERHEAD)				
DELIVERABLE CODE	**WORK PACKAGE**	**WORK PACKAGE TITLE**	**HOURS NEEDED**	**COST**
1	1.1	PROJECT BASELINING	512	$26,710.38
	1.2	RESOURCE MANAGEMENT	240	$12,493.07
	1.3	CONFIGURATION MANAGEMENT	400	$24,333.00
		TOTAL	**1152**	**$63,536.45**
2	2.1	SITE SURVEYING	2000	$124,403.10
	2.2	SITE READINESS	120	$22,027.60
	2.3	DESIGN REQUIREMENTS DEFINITION	1920	$112,188.26
		TOTAL	**4040**	**$258,618.96**
3	3.1	COMPUTER-AIDED SYSTEM MODELING	400	$21,550.56
	3.2	DESIGN SELECTION	640	$36,552.76
		TOTAL	**1040**	**$58,103.32**
4	4.1	COMPONENT(S) RECEIPT AND INSPECTION	3840	$175,190.20
	4.2	SYSTEM INTEGRATION & INSTALLATION	2640	$103,855.66
		TOTAL	**6480**	**$279,050.86**
5	5.1	COMMISSION & TESTING	104	$4,686.72
		TOTAL	**104**	**$4,686.72**
6	6.1-6.4	TRAINING ACTIVITIES	640	$24,084.40
	6.5	FINAL PROGRAM REVIEW	16	$716.00
		TOTAL	**656**	**$24,800.80**
		CUMULATIVE TOTAL COST		**$688,797.11**

Breakdown of Cost by WBS Deliverables:

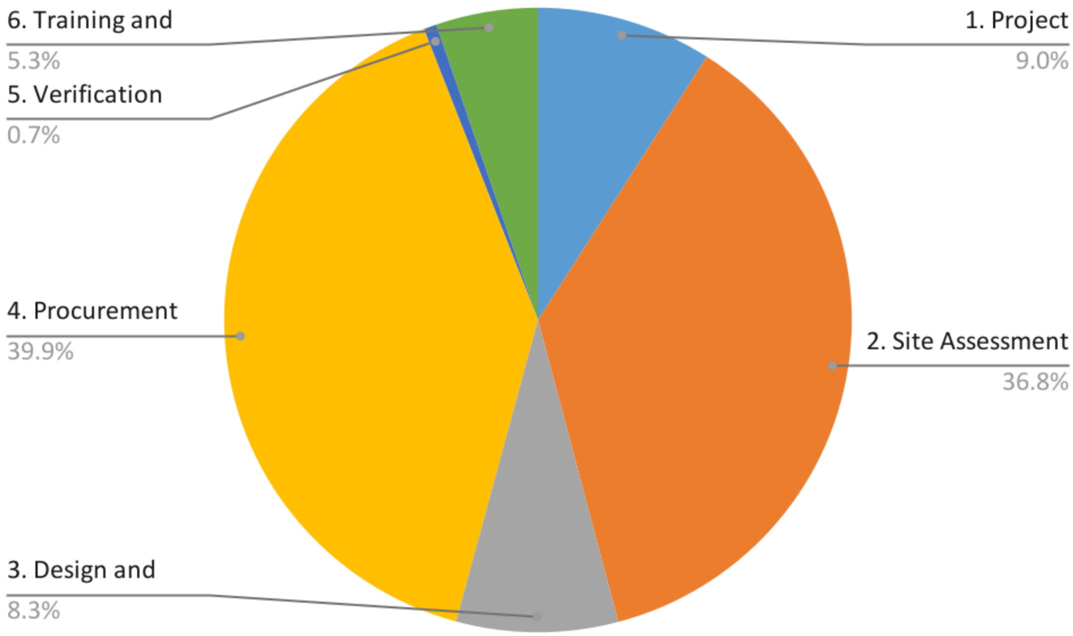


Figure 11: Breakdown of Costs by Deliverable

1. Project Conception
2. Site Assessment & Preparation
3. Design & Engineering
4. Procurement & Installation
5. Verification & Validation
6. Training & Project Closeout

Breakdown of Cost by Department:

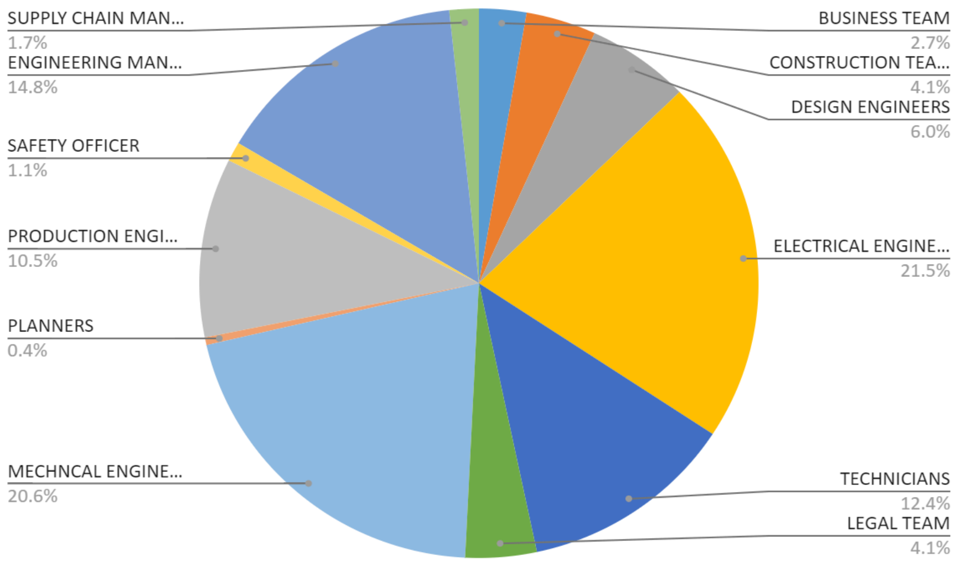


Figure 12: Breakdown of Cost by Department

Breakdown of Total Costs:

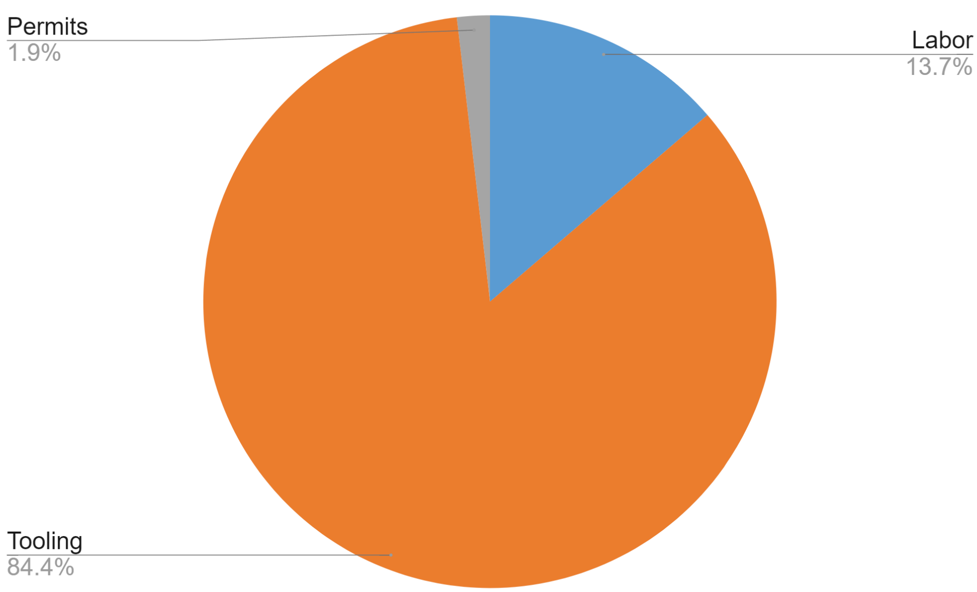


Figure 13: Breakdown of Project Costs

*Facilities included within tooling due to the small comparable budget

5. Scheduling & Resource Management

5.1. Staffing, Standard Rates, & Resource Allocation

With the completion of cost estimating and budgeting, we can begin to define our staff and their associated standard rates, or salaries per hour, in the Solar Roof Project's Microsoft Project file (MSP) as can be seen below:

ⓘ	Resource Name	Type	Material	Initials	Group	Max.	Std. Rate	Ovt. Rate	Cost/Use	Accrue	Base
	Business Team	Work		BT	Team	400%	$51.15/hr	$0.00/hr	$0.00	Prorated	Standard
	Business Manager	Work			Individual	100%	$76.01/hr	$0.00/hr	$0.00	Prorated	Standard
	Financial Analyst	Work			Individual	200%	$35.69/hr	$0.00/hr	$0.00	Prorated	Standard
	Business Analyst	Work			Individual	100%	$57.22/hr	$0.00/hr	$0.00	Prorated	Standard
	Construction Team	Work		CT	Team	2,300%	$29.48/hr	$0.00/hr	$0.00	Prorated	Standard
	Construction Team Manager	Work			Individual	100%	$81.46/hr	$0.00/hr	$0.00	Prorated	Standard
	Construction Supervisor	Work			Individual	100%	$42.82/hr	$0.00/hr	$0.00	Prorated	Standard
	Site Manager	Work			Individual	100%	$70.13/hr	$0.00/hr	$0.00	Prorated	Standard
	Laborers	Work			Individual	1,600%	$19.53/hr	$0.00/hr	$0.00	Prorated	Standard
	Equipment Operators	Work			Individual	400%	$42.76/hr	$0.00/hr	$0.00	Prorated	Standard
	Design Engineering Team	Work		DET	Team	500%	$44.21/hr	$0.00/hr	$0.00	Prorated	Standard
	Lead Design Engineer	Work			Individual	100%	$75.50/hr	$0.00/hr	$0.00	Prorated	Standard
	Architect	Work			Individual	100%	$36.12/hr	$0.00/hr	$0.00	Prorated	Standard
	Structural Engineer	Work			Individual	100%	$39.44/hr	$0.00/hr	$0.00	Prorated	Standard
	CAD Designer	Work			Individual	100%	$35.14/hr	$0.00/hr	$0.00	Prorated	Standard
	AutoCAD Drafter	Work			Individual	100%	$34.86/hr	$0.00/hr	$0.00	Prorated	Standard
	Electrical Engineering Team	Work		EET	Team	500%	$60.22/hr	$0.00/hr	$0.00	Prorated	Standard
	Electrical Engineering Manager	Work			Individual	100%	$85.79/hr	$0.00/hr	$0.00	Prorated	Standard
	Lead Electrical Engineer	Work			Individual	100%	$87.50/hr	$0.00/hr	$0.00	Prorated	Standard
	Electrical Engineers	Work			Individual	200%	$42.93/hr	$0.00/hr	$0.00	Prorated	Standard
	System Engineer	Work			Individual	100%	$41.97/hr	$0.00/hr	$0.00	Prorated	Standard
	Engineering Manager	**Work**		**EM**	**Individual**	**100%**	**$81.46/hr**	**$0.00/hr**	**$0.00**	**Prorated**	**Standard**
	Technicians	Work		T	Team	800%	$29.04/hr	$0.00/hr	$0.00	Prorated	Standard
	Electrical Technicians	Work			Individual	400%	$30.40/hr	$0.00/hr	$0.00	Prorated	Standard

Figure 14: Staffing as Defined in MSP

Resource Name	Type	Material	Initials	Group	Max.	Std. Rate	Ovt. Rate	Cost/Use	Accrue	Base
Electrical Technicians	Work			Individual	400%	$30.40/hr	$0.00/hr	$0.00	Prorated	Standard
Mechanical Technicians	Work			Individual	400%	$27.68/hr	$0.00/hr	$0.00	Prorated	Standard
Legal Team	Work		LT	Team	300%	$55.36/hr	$0.00/hr	$0.00	Prorated	Standard
Corporate Lawyer	Work			Individual	100%	$58.75/hr	$0.00/hr	$0.00	Prorated	Standard
Contract Manager	Work			Individual	100%	$72.77/hr	$0.00/hr	$0.00	Prorated	Standard
Compliance Officer	Work			Individual	100%	$34.57/hr	$0.00/hr	$0.00	Prorated	Standard
Mechanical Engineering Team	Work		MET	Team	400%	$65.52/hr	$0.00/hr	$0.00	Prorated	Standard
Mechanical Engineering Manager	Work			Individual	100%	$84.94/hr	$0.00/hr	$0.00	Prorated	Standard
Lead Mechanical Engineer	Work			Individual	100%	$92.31/hr	$0.00/hr	$0.00	Prorated	Standard
Thermal Engineer	Work			Individual	100%	$43.02/hr	$0.00/hr	$0.00	Prorated	Standard
CAD Mechanical Engineer	Work			Individual	100%	$41.80/hr	$0.00/hr	$0.00	Prorated	Standard
Planners	Work		P	Team	300%	$32.15/hr	$0.00/hr	$0.00	Prorated	Standard
Project Planner	Work			Individual	100%	$36.92/hr	$0.00/hr	$0.00	Prorated	Standard
Scheduler	Work			Individual	100%	$34.05/hr	$0.00/hr	$0.00	Prorated	Standard
Logistics	Work			Individual	100%	$25.48/hr	$0.00/hr	$0.00	Prorated	Standard
Product Engineering Team	Work		PET	Team	400%	$49.58/hr	$0.00/hr	$0.00	Prorated	Standard
Lead Product Engineer	Work			Individual	100%	$59.51/hr	$0.00/hr	$0.00	Prorated	Standard
Process Engineers	Work			Individual	200%	$41.20/hr	$0.00/hr	$0.00	Prorated	Standard
Quality Engineer	Work			Individual	100%	$56.43/hr	$0.00/hr	$0.00	Prorated	Standard
Project Management Team	Work		PMT	Team	500%	$44.75/hr	$0.00/hr	$0.00	Prorated	Standard
Project Manager	Work			Individual	100%	$39.73/hr	$0.00/hr	$0.00	Prorated	Standard
Project Coordinators	Work			Individual	200%	$34.25/hr	$0.00/hr	$0.00	Prorated	Standard
Project Analysts	Work		P	Individual	200%	$57.76/hr	$0.00/hr	$0.00	Prorated	Standard
Safety Officer	Work		SO	Individual	100%	$48.85/hr	$0.00/hr	$0.00	Prorated	Standard
Supply Chain Manager	Work		SCM	Individual	100%	$67.46/hr	$0.00/hr	$0.00	Prorated	Standard

Figure 15: Staffing Continued

The Solar Roof Project Team's overall headcount is 68 team members. The "Max" column percentages were assigned based on the number of individuals on each team. This was done to get an accurate representation of the amount of labor hours that were charged per work week. For example, the Business Team has four allocated members. If each of these team members works a total of 8 hours/day, then the team overall has a total of 32 allotted working hours per day. In MSP, this is reflected by changing the Business Team's resource "Max" allocation from 100% to 400%.

After the staff were defined, they were allocated to WBS work packages based on RAM assignments. "Responsible" staff were allocated at 100%, while "supporting" staff work hours were averaged evenly across the number of supporting teams, relative to the "Responsible" team, as an estimate. Once this was completed, it became clear that the Engineering Manager was being over-allocated:

Task Mode	WBS	Task Name	Duration	Start	Finish	Predecessors	Resource Names
	1	**Project Conception**	**25 days**	**Wed 1/1/25**	**Tue 2/4/25**		
	1.1	**Project Baselining**	**17 days**	**Wed 1/1/25**	**Thu 1/23/25**		
	1.1.1	Baseline Schedule	10 days	Wed 1/1/25	Tue 1/14/25		Construction Team[25%],Design Engineering Team[25%],Engineering Manager[25%],Planners,Product Engineering Team[25%]
	1.1.2	Baseline Cost	10 days	Wed 1/1/25	Tue 1/14/25	3FF	Supply Chain Manager,Business Team
	1.1.3	Define KPIs & OKRs	5 days	Wed 1/15/25	Tue 1/21/25	4	Engineering Manager[25%],Supply Chain Manager[25%],Technicians[25%],Business Analyst,Project Management Team[25%]
	1.1.4	Manage stakeholder(s) need(s)	5 days	Wed 1/15/25	Tue 1/21/25	5FF	Business Manager,Engineering Manager[50%],Project Management Team[50%]
	1.1.5	Manage programmatic risk & assess feasability	2 days	Wed 1/22/25	Thu 1/23/25	6	Engineering Manager[25%],Safety Officer[25%],Supply Chain Manager[25%],Project Management Team,Business Team[25%]
	1.1.6	Support throughout project lifecycle	0 days	Wed 1/1/25	Wed 1/1/25		Engineering Manager,Supply Chain Manager,Project Management Team,Business Team
	1.2	**Resource Management**	**25 days**	**Wed 1/1/25**	**Tue 2/4/25**		
	1.2.1	Define staffing requirements	5 days	Wed 1/15/25	Tue 1/21/25	4	Construction Team[33%],Engineering Manager[33%],Supply Chain Manager[33%],Project Management Team
	1.2.2	Identify & manage supplier/subcontractor need(s)	10 days	Wed 1/22/25	Tue 2/4/25	6	Project Management Team,Supply Chain Manager[50%],Business Team[50%]
	1.2.3	Interface w/Ops, QA, Safety, SMEs, etc.	0 days	Wed 1/1/25	Wed 1/1/25		Design Engineering Team,Electrical Engineering Manager,Engineering Manager,Mechanical Engineering Manager, Product Engineering Team,Safety Officer,Supply Chain Manager
	1.2.4	Support throughout project lifecycle	0 days	Wed 1/1/25	Wed 1/1/25		Business Team,Engineering Manager,Project Management Team,Supply Chain Manager
	1.3	**Configuration Management**	**25 days**	**Wed 1/1/25**	**Tue 2/4/25**		
	1.3.1	Baseline documentation & reporting	25 days	Wed 1/1/25	Tue 2/4/25	2FF,9FF	Engineering Manager[50%],Legal Team,Business Team[50%]
	1.3.2	Support throughout project lifecycle	0 days	Wed 1/1/25	Wed 1/1/25		Business Team,Engineering Manager,Legal Team,Planners
	2	**Site Assessment & Preparation**	**75 days**	**Wed 2/5/25**	**Tue 5/20/25**		
	2.1	**Site Surveying**	**25 days**	**Wed 2/5/25**	**Tue 3/11/25**		
	2.1.1	Define location of panel installation	25 days	Wed 2/5/25	Tue 3/11/25	2,9	Construction Team[25%],Design Engineering Team[25%],Engineering Manager[25%],Electrical Engineering Team[25%], Mechanical Engineering Team
	2.1.2	Conduct shading analysis	25 days	Wed 2/5/25	Tue 3/11/25	19FF	Design Engineering Team[33%],Electrical Engineering Team[33%],Engineering Manager[33%],Mechanical Engineering Team
	2.1.3	Conduct structural analysis	25 days	Wed 2/5/25	Tue 3/11/25	19FF	Design Engineering Team[50%],Engineering Manager[50%],Mechanical Engineering Team
	2.1.4	Conduct electrical analysis	25 days	Wed 2/5/25	Tue 3/11/25	19FF	Design Engineering Team[33%],Electrical Engineering Team,Engineering Manager[33%],Technicians[33%]
	2.1.5	Conduct technical risk analysis	25 days	Wed 2/5/25	Tue 3/11/25	19FF	Design Engineering Team[25%],Engineering Manager,Safety Officer[25%],Electrical Engineering Team[25%],Mechanical Engineering Team
	2.2	**Site Readiness**	**50 days**	**Wed 3/12/25**	**Tue 5/20/25**		
	2.2.1	Obtain necessary permits & approvals	40 days	Wed 3/12/25	Tue 5/6/25	18	Legal Team
	2.2.2	Clear & prepare site	10 days	Wed 5/7/25	Tue 5/20/25	25	Construction Team
	2.2.3	Establish site safety parameters	5 days	Wed 5/7/25	Tue 5/13/25	26SS	Safety Officer
	2.3	**Design Requirements Definition**	**40 days**	**Wed 3/12/25**	**Tue 5/6/25**		
	2.3.1	Baseline product specifications from	40 days	Wed 3/12/25	Tue 5/6/25	24SS	Design Engineering Team[17%],Engineering Manager[17%],Product Engineering Team[17%],Project Management Team,

Figure 16: Resource Allocation to WBS 1

Task Mode	WBS	Task Name	Duration	Start	Finish	Predecessors	Resource Names
	2.3	**Design Requirements Definition**	**40 days**	**Wed 3/12/25**	**Tue 5/6/25**		
	2.3.1	Baseline product specifications from customer need(s)	40 days	Wed 3/12/25	Tue 5/6/25	24SS	Design Engineering Team[17%],Engineering Manager[17%],Product Engineering Team[17%],Project Management Team, Business Team[17%],Electrical Engineering Team[17%],Mechanical Engineering Team[17%]
	2.3.2	Develop product specifications from site surveying analyses	40 days	Wed 3/12/25	Tue 5/6/25	24SS	Design Engineering Team[25%],Engineering Manager,Product Engineering Team[25%],Electrical Engineering Team[25%], Mechanical Engineering Team[25%]
	2.3.3	Define installation approach & Design requirements	40 days	Wed 3/12/25	Tue 5/6/25	24SS	Design Engineering Team[20%],Engineering Manager[20%],Product Engineering Team,Safety Officer[20%], Electrical Engineering Team[20%],Mechanical Engineering Team[20%]
	3	**Design & Engineering**	**50 days**	**Wed 5/7/25**	**Tue 7/15/25**		
	3.1	**Computer-aided System Modeling**	**20 days**	**Wed 5/7/25**	**Tue 6/3/25**		
	3.1.1	Brainstorm system design options	20 days	Wed 5/7/25	Tue 6/3/25	28	Design Engineering Team,Electrical Engineering Team[33%],Engineering Manager[33%],Mechanical Engineering Team[33%]
	3.1.2	Render preliminary system models & blueprints	10 days	Wed 5/21/25	Tue 6/3/25	34FF	Design Engineering Team
	3.2	**Design Selection**	**40 days**	**Wed 5/21/25**	**Tue 7/15/25**		
	3.2.1	Conduct tradeoff analysis to determine final system design	10 days	Wed 5/21/25	Tue 6/3/25	35FF	Design Engineering Team[25%],Electrical Engineering Team[25%],Engineering Manager,Mechanical Engineering Team[25%], Business Team[25%]
	3.2.2	Prototype Structural & Electrical sub-systems	15 days	Wed 6/4/25	Tue 6/24/25	37	Electrical Engineering Team[33%],Mechanical Engineering Team[33%],Product Engineering Team,Technicians[33%]
	3.2.3	Perform Engineering Development Tests to ensure product meets requirements	15 days	Wed 6/25/25	Tue 7/15/25	38	Design Engineering Team[33%],Electrical Engineering Team,Mechanical Engineering Team[33%],Product Engineering Team[33%]
	4	**Procurement & Installation**	**115 days**	**Wed 7/16/25**	**Tue 12/23/25**		
	4.1	**Component(s) Receipt & Inspection**	**60 days**	**Wed 7/16/25**	**Tue 10/7/25**		
	4.1.1	Test & inspect solar panels	60 days	Wed 7/16/25	Tue 10/7/25	39	Electrical Engineering Team[50%],Mechanical Engineering Team[50%],Technicians
	4.1.2	Test & inspect inverters	60 days	Wed 7/16/25	Tue 10/7/25	42SS	Electrical Engineering Team,Technicians
	4.1.3	Test & inspect mounting components	60 days	Wed 7/16/25	Tue 10/7/25	43SS	Mechanical Engineering Team,Technicians
	4.1.4	Test & inspect electrical components	60 days	Wed 7/16/25	Tue 10/7/25	44SS	Electrical Engineering Team,Technicians
	4.2	**System Integration & Installation**	**55 days**	**Wed 10/8/25**	**Tue 12/23/25**		
	4.2.1	Assemble Mechanical & Electrical sub-systems	55 days	Wed 10/8/25	Tue 12/23/25	41	Construction Team[50%],Product Engineering Team[50%],Technicians
	4.2.2	Test subsystem assembly to Acceptance requirements	55 days	Wed 10/8/25	Tue 12/23/25	47FF	Electrical Engineering Team[33%],Mechanical Engineering Team[33%],Product Engineering Team[33%],Technicians
	4.2.3	Install solar panels & energy system	55 days	Wed 10/8/25	Tue 12/23/25	48FF	Construction Team,Electrical Engineering Team[25%],Mechanical Engineering Team[25%],Product Engineering Team[25%], Technicians[25%]
	5	**Verification & Validation**	**8 days**	**Wed 12/24/25**	**Fri 1/2/26**		
	5.1	**Commissioning & Testing**	**8 days**	**Wed 12/24/25**	**Fri 1/2/26**		
	5.1.1	Pass initial installation & safety inspection	2 days	Wed 12/24/25	Thu 12/25/25	49	Technicians

Figure 17: Resource Allocation to WBS 2

Task Mode	WBS	Task Name	Duration	Start	Finish	Predecessors	Resource Names
	4.2.3	Install solar panels & energy system	55 days	Wed 10/8/25	Tue 12/23/25	48FF	Construction Team,Electrical Engineering Team[25%],Mechanical Engineering Team[25%],Product Engineering Team[25%], Technicians[25%]
	5	**Verification & Validation**	**8 days**	**Wed 12/24/25**	**Fri 1/2/26**		
	5.1	**Commissioning & Testing**	**8 days**	**Wed 12/24/25**	**Fri 1/2/26**		
	5.1.1	Pass initial installation & safety inspection	2 days	Wed 12/24/25	Thu 12/25/25	49	Technicians
	5.1.2	Test system start-up performance to requirements	5 days	Fri 12/26/25	Thu 1/1/26	52	Electrical Engineering Team,Technicians
	5.1.3	Complete final certification & operations approval	1 day	Fri 1/2/26	Fri 1/2/26	53	Engineering Manager
	6	**Training & Project Closeout**	**7 days**	**Mon 1/5/26**	**Tue 1/13/26**		
	6.1	Train preventative maintenance activities	5 days	Mon 1/5/26	Fri 1/9/26	54	Electrical Engineering Team,Mechanical Engineering Team,Product Engineering Team[50%]
	6.2	Train routine inspection activities	5 days	Mon 1/5/26	Fri 1/9/26	56SS	Electrical Engineering Team,Mechanical Engineering Team,Product Engineering Team[50%]
	6.3	Train emergency maintenance activities	5 days	Mon 1/5/26	Fri 1/9/26	57SS	Electrical Engineering Team,Mechanical Engineering Team,Product Engineering Team[50%]
	6.4	Train system disassembly at End of Life	5 days	Mon 1/5/26	Fri 1/9/26	58SS	Electrical Engineering Team,Mechanical Engineering Team,Product Engineering Team[50%]
	6.5	Conduct final programmatic review	2 days	Mon 1/12/26	Tue 1/13/26	59	Project Management Team

Figure 18: Resource Allocation to WBS 3

Resource Name	Work	Details		Qtr 1, 2025			Qtr 2, 2025			Qtr 3, 2025			Qtr 4, 2025			Qtr 1, 2026
			Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan
CAD Designer	0 hrs	Work														
AutoCAD Drafter	0 hrs	Work														
Electrical Engineering Team	2,452 hrs	Work			263.52h	171.92h	109.12h	83.36h	80.88h	328h	420h	440h	183.52h	92.8h	110.88h	168h
Electrical Engineering Manager	0 hrs	Work		0h												
Lead Electrical Engineer	0 hrs	Work														
Electrical Engineers	0 hrs	Work														
System Engineer	0 hrs	Work														
Engineering Manager	**1,228.4 hrs**	Work		159.2h	355.04h	288.4h	241.12h	155.36h	21.28h							8h
Baseline Schedule	*20 hrs*	Work		20h												
Define KPIs & OKRs	*10 hrs*	Work		10h												
Manage stakeholder(s) need(s)	*20 hrs*	Work		20h												
Manage programmatic risk & assess feasability	*4 hrs*	Work		4h												
Support throughout project lifecycle	*0 hrs*	Work		0h												
Define staffing requirements	*13.2 hrs*	Work		13.2h												
Interface w/Ops, QA, Safety, SMEs, etc.	*0 hrs*	Work		0h												
Support throughout project lifecycle	*0 hrs*	Work		0h												
Baseline documentation & reporting	*100 hrs*	Work		92h	8h											
Support throughout project lifecycle	*0 hrs*	Work		0h												
Define location of panel installation	*50 hrs*	Work			36h	14h										
Conduct shading analysis	*66 hrs*	Work			47.52h	18.48h										
Conduct structural analysis	*100 hrs*	Work			72h	28h										
Conduct electrical analysis	*66 hrs*	Work			47.52h	18.48h										
Conduct technical risk analysis	*200 hrs*	Work			144h	56h										
Baseline product specifications from customer need(s)	*54.4 hrs*	Work				19.04h	29.92h	5.44h								
Develop product specifications from site surveying analyses	*320 hrs*	Work				112h	176h	32h								
Define installation approach & Design requirements	*64 hrs*	Work				22.4h	35.2h	6.4h								
Brainstorm system design options	*52.8 hrs*	Work						47.52h	5.28h							
Conduct tradeoff analysis to determine final system design	*80 hrs*	Work						64h	16h							
Complete final certification & operations approval	*8 hrs*	Work														8h

Figure 19: Engineering Manager Resource Allocation Breakdown Pre-leveling

Before leveling the project Gantt chart, the Engineering Manager was over-allocated at 1,228.4 hours throughout the entire project timeline. Adding a second Engineering Manager had no impact on the total cost of labor, since the total number of work hours allotted to assigned tasks remained the same. The two Engineering Managers would simply split the total number of work hours and associated load between the two of them. Labor costs were determined by an hourly work basis, so a second engineering manager has no impact on the total cost.

5.2. Leveled Gantt Chart

In order to de-conflict the over-allocation of the Engineering Manager, a preliminary attempt at leveling was done with only one Engineering Manager still allocated. In this case, the project finish date was pushed from 1/13/26 to 6/30/26, which is about a 50% increase in the overall project's time table. Two conflicting work packages also still remained (3.1.1 & 3.2.1) due to predecessor assignments: design requirements definition and rendering preliminary system models & blueprints, respectively:

Task Mode	WBS	Task Name	Duration	Start	Finish	Predecessors	Resource Names
	1	**Project Conception**	**130 days**	**Wed 1/1/25**	**Tue 7/1/25**		
	2	**Site Assessment & Preparation**	**180 days**	**Wed 2/12/25**	**Tue 10/21/25**		
	3	**Design & Engineering**	**50 days**	**Wed 10/22/25**	**Tue 12/30/25**		
	3.1	**Computer-aided System Modeling**	**20 days**	**Wed 10/22/25**	**Tue 11/18/25**		
	3.1.1	Brainstorm system design options	20 days	Wed 10/22/25	Tue 11/18/25	28	Design Engineering Team,Electrical Engineering Team[33%],Engineering Manager[33%],Mechanical Engineering Team[33%]
	3.1.2	Render preliminary system models & blueprints	10 days	Wed 11/5/25	Tue 11/18/25	34FF	Design Engineering Team
	3.2	**Design Selection**	**40 days**	**Wed 11/5/25**	**Tue 12/30/25**		
	3.2.1	Conduct tradeoff analysis to determine final system design	10 days	Wed 11/5/25	Tue 11/18/25	35FF	Design Engineering Team[25%],Electrical Engineering Team[25%],Engineering Manager,Mechanical Engineering Team[25%], Business Team[25%]
	3.2.2	Prototype Structural & Electrical sub-systems	15 days	Wed 11/19/25	Tue 12/9/25	37	Electrical Engineering Team[33%],Mechanical Engineering Team[33%],Product Engineering Team,Technicians[33%]
	3.2.3	Perform Engineering Development Tests to ensure product meets requirements	15 days	Wed 12/10/25	Tue 12/30/25	38	Design Engineering Team[33%],Electrical Engineering Team,Mechanical Engineering Team[33%],Product Engineering Team[33%]
	4	**Procurement & Installation**	**115 days**	**Wed 12/31/25**	**Tue 6/9/26**		
	5	**Verification & Validation**	**8 days**	**Wed 6/10/26**	**Fri 6/19/26**		
	6	**Training & Project Closeout**	**7 days**	**Mon 6/22/26**	**Tue 6/30/26**		

Figure 20: Preliminary Attempt at Leveling with 1 Engineering Manager Allocated

After the preliminary attempt at leveling, it became apparent that the optimal solution to ensure an on-time project schedule and minimize overtime was to add a second Engineering Manager to split the total work hours across the full duration of the project. Instead, this solution pushed the project deadline by only 35 days, with a February 17, 2026 finish date, and resulted in a fully leveled Gantt chart:

Task Mode	WBS	Task Name	Duration	Start	Finish
	1	**Project Conception**	**25 days**	**Wed 1/1/25**	**Tue 2/4/25**
	1.1	**Project Baselining**	**17 days**	**Wed 1/1/25**	**Thu 1/23/25**
	1.2	**Resource Management**	**25 days**	**Wed 1/1/25**	**Tue 2/4/25**
	1.3	**Configuration Management**	**25 days**	**Wed 1/1/25**	**Tue 2/4/25**
	2	**Site Assessment & Preparation**	**100 days**	**Wed 2/5/25**	**Tue 6/24/25**
	2.1	**Site Surveying**	**50 days**	**Wed 2/5/25**	**Tue 4/15/25**
	2.2	**Site Readiness**	**50 days**	**Wed 4/16/25**	**Tue 6/24/25**
	2.3	**Design Requirements Definition**	**40 days**	**Wed 4/16/25**	**Tue 6/10/25**
	3	**Design & Engineering**	**50 days**	**Wed 6/11/25**	**Tue 8/19/25**
	3.1	**Computer-aided System Modeling**	**20 days**	**Wed 6/11/25**	**Tue 7/8/25**
	3.1.1	Brainstorm system design options	20 days	Wed 6/11/25	Tue 7/8/25
	3.1.2	Render preliminary system models & blueprints	10 days	Wed 6/25/25	Tue 7/8/25
	3.2	**Design Selection**	**40 days**	**Wed 6/25/25**	**Tue 8/19/25**
	3.2.1	Conduct tradeoff analysis to determine final system design	10 days	Wed 6/25/25	Tue 7/8/25
	3.2.2	Prototype Structural & Electrical sub-systems	15 days	Wed 7/9/25	Tue 7/29/25
	3.2.3	Perform Engineering Development Tests to ensure product meets requirements	15 days	Wed 7/30/25	Tue 8/19/25
	4	**Procurement & Installation**	**115 days**	**Wed 8/20/25**	**Tue 1/27/26**
	4.1	**Component(s) Receipt & Inspection**	**60 days**	**Wed 8/20/25**	**Tue 11/11/25**
	4.2	**System Integration & Installation**	**55 days**	**Wed 11/12/25**	**Tue 1/27/26**
	5	**Verification & Validation**	**8 days**	**Wed 1/28/26**	**Fri 2/6/26**
	5.1	**Commissioning & Testing**	**8 days**	**Wed 1/28/26**	**Fri 2/6/26**
	6	**Training & Project Closeout**	**7 days**	**Mon 2/9/26**	**Tue 2/17/26**

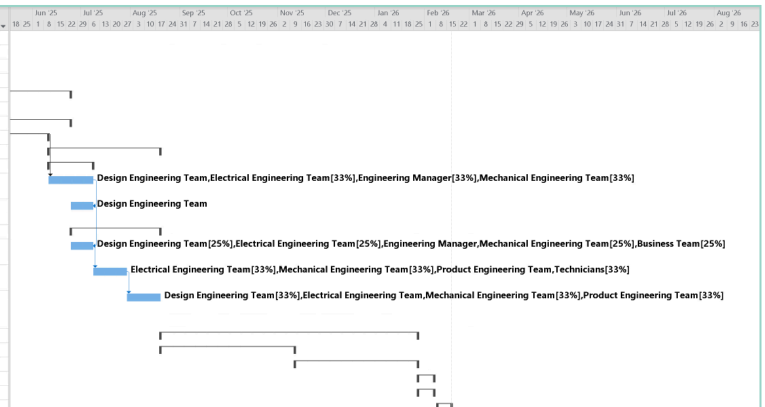


Figure 21: Final Attempt at Leveling with 2 Engineering Managers Allocated

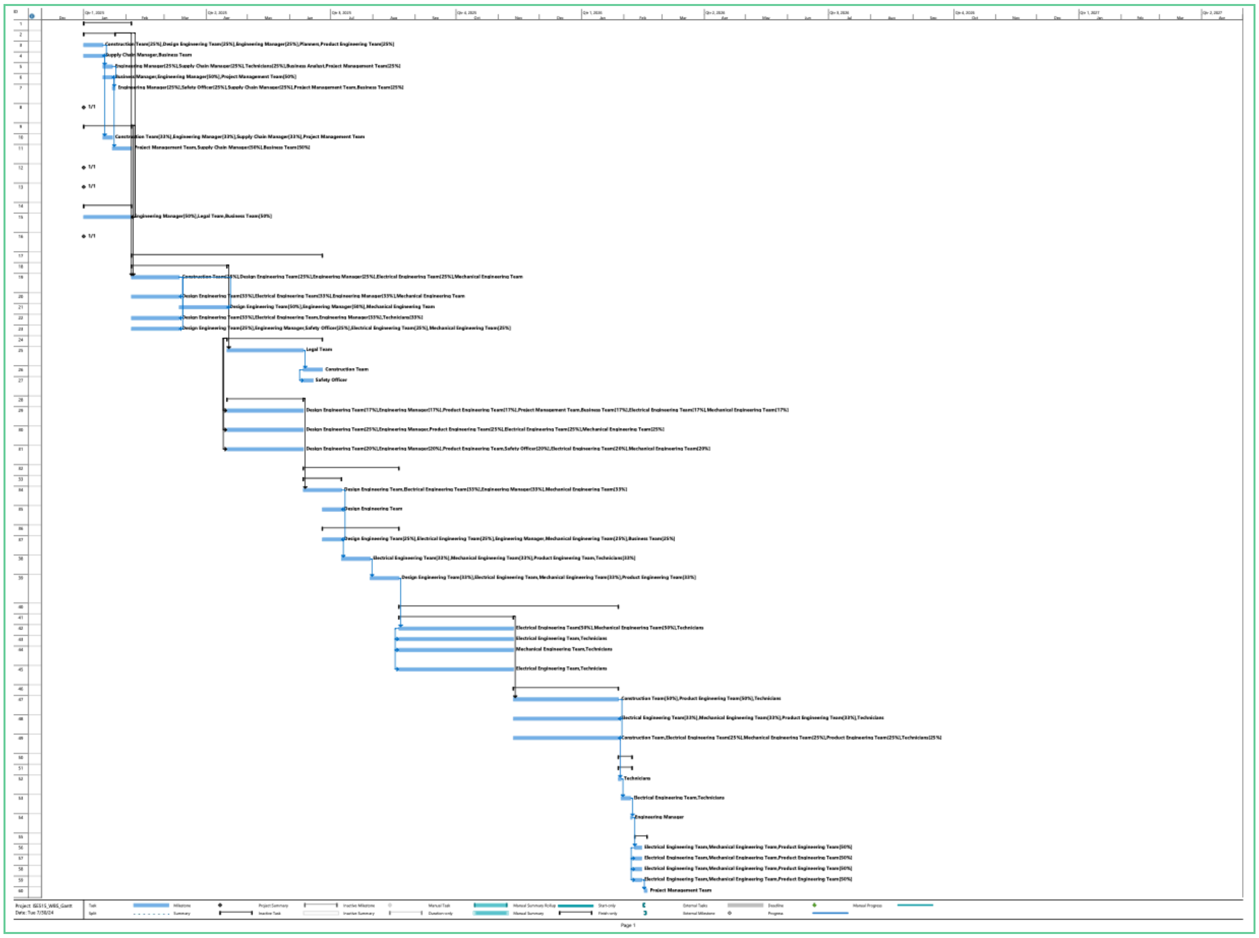
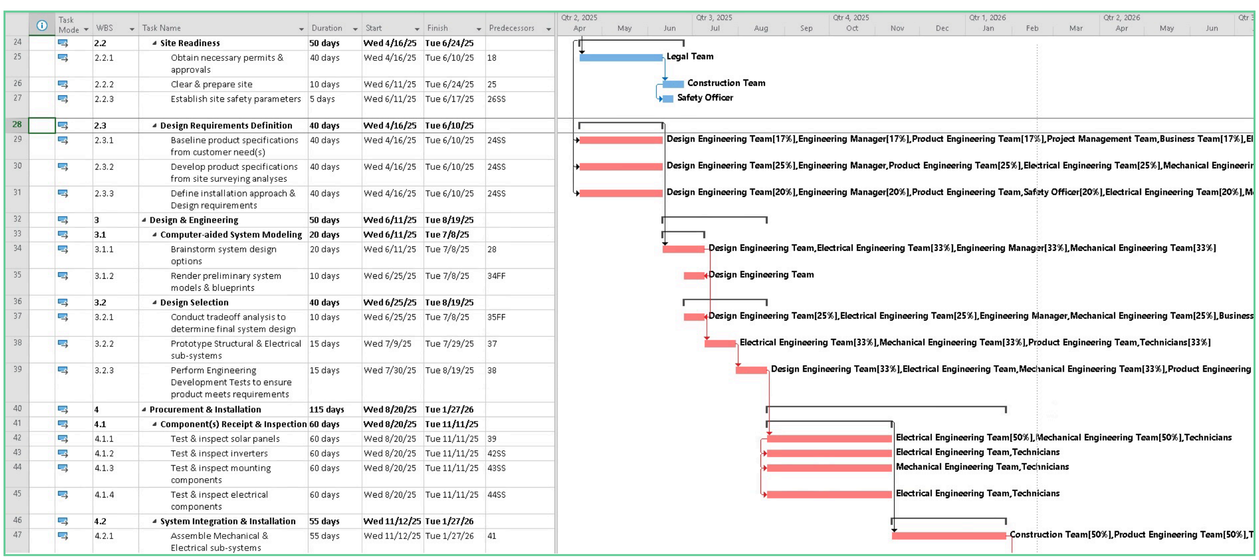


Figure 22: Fully Leveled Overall Gantt Chart with 2/17/26 Finish Date



ID	WBS	Task Name	Duration	Start	Finish	Predecessors
24	2.2	**Site Readiness**	**50 days**	**Wed 4/16/25**	**Tue 6/24/25**	
25	2.2.1	Obtain necessary permits & approvals	40 days	Wed 4/16/25	Tue 6/10/25	18
26	2.2.2	Clear & prepare site	10 days	Wed 6/11/25	Tue 6/24/25	25
27	2.2.3	Establish site safety parameters	5 days	Wed 6/11/25	Tue 6/17/25	26SS
28	2.3	**Design Requirements Definition**	**40 days**	**Wed 4/16/25**	**Tue 6/10/25**	
29	2.3.1	Baseline product specifications from customer need(s)	40 days	Wed 4/16/25	Tue 6/10/25	24SS
30	2.3.2	Develop product specifications from site surveying analyses	40 days	Wed 4/16/25	Tue 6/10/25	24SS
31	2.3.3	Define installation approach & Design requirements	40 days	Wed 4/16/25	Tue 6/10/25	24SS
32	3	**Design & Engineering**	**50 days**	**Wed 6/11/25**	**Tue 8/19/25**	
33	3.1	**Computer-aided System Modeling**	**20 days**	**Wed 6/11/25**	**Tue 7/8/25**	
34	3.1.1	Brainstorm system design options	20 days	Wed 6/11/25	Tue 7/8/25	28
35	3.1.2	Render preliminary system models & blueprints	10 days	Wed 6/25/25	Tue 7/8/25	34FF
36	3.2	**Design Selection**	**40 days**	**Wed 6/25/25**	**Tue 8/19/25**	
37	3.2.1	Conduct tradeoff analysis to determine final system design	10 days	Wed 6/25/25	Tue 7/8/25	35FF
38	3.2.2	Prototype Structural & Electrical sub-systems	15 days	Wed 7/9/25	Tue 7/29/25	37
39	3.2.3	Perform Engineering Development Tests to ensure product meets requirements	15 days	Wed 7/30/25	Tue 8/19/25	38
40	4	**Procurement & Installation**	**115 days**	**Wed 8/20/25**	**Tue 1/27/26**	
41	4.1	**Component(s) Receipt & Inspection**	**60 days**	**Wed 8/20/25**	**Tue 11/11/25**	
42	4.1.1	Test & inspect solar panels	60 days	Wed 8/20/25	Tue 11/11/25	39
43	4.1.2	Test & inspect inverters	60 days	Wed 8/20/25	Tue 11/11/25	42SS
44	4.1.3	Test & inspect mounting components	60 days	Wed 8/20/25	Tue 11/11/25	43SS
45	4.1.4	Test & inspect electrical components	60 days	Wed 8/20/25	Tue 11/11/25	44SS
46	4.2	**System Integration & Installation**	**55 days**	**Wed 11/12/25**	**Tue 1/27/26**	
47	4.2.1	Assemble Mechanical & Electrical sub-systems	55 days	Wed 11/12/25	Tue 1/27/26	41

Figure 23: Critical Path on Leveled Gantt

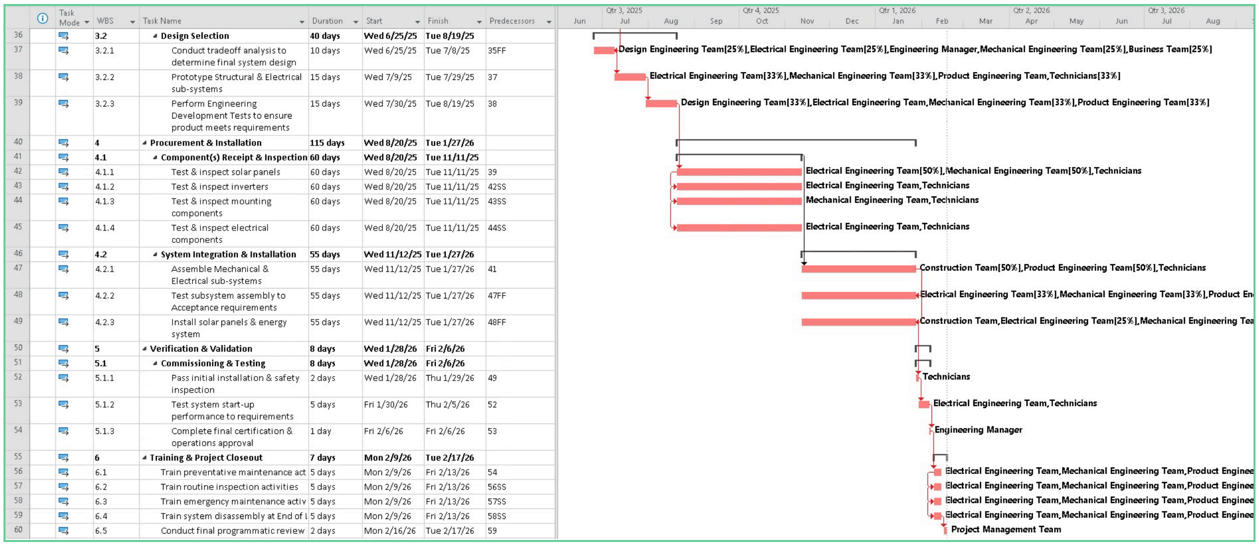


Figure 24: Critical Path on Leveled Gantt continued

5.3. Crashing Analysis

Based on our Earned Value analysis conducted on August 1st, we noted that our project was 100 % complete for both milestones 1 and 2, but only 30% complete for milestone 3. August 1st was the anticipated completion date for the work packages for milestone 3. However, 70% of milestone 3 tasks remain. In our crashing analysis, we adjusted the normal times for activities 3.1 and 3.2 based on the actual completion times of 53% and 13% respectively of the original planned time respectively. The original critical path length from milestone 1 to 3 was **165 days**. At the current Earned Value analysis, we are lagging behind schedule by **35 days** as the current completion time to date is **130 days.** Therefore, to make up for the time lag in completion for milestone 3, we performed a crashing analysis at the current project state on August 1st estimate the total cost of the project **with an additional 35 days** to be on the scheduled completion time.Crashing Costs are only accounting for labor at 1.5 times the normal hourly rate on the work package level.

Table 40: Milestones and Associated Crashing

Activity	Predecessor	Normal Time	Crash Time	Avail Crash time	Normal Cost	Normal Cost / Day	Total Crash Cost	Crash Cost / Day	Order
A Project Baseline		17	11.9	5.1	$26,710	$1,571	$12,020	$2,357	
B	A	8	5.6	2.4	$12,493	$1,562	$5,622	$2,342	

Resource Management									
C Configuration Management	A, B	25	17.5	7.5	$24,333	$973	$10,950	$1,460	
D Site Surveying	B	50	35	15	$124,403	$2,488	$55,981	$3,732	
E Site Readiness	D	50	35	15	$22,028	$441	$9,912	$661	
F Design Requirements Definition	E	40	28	12	$122,188	$3,055	$54,985	$4,582	
G Computer Aided System Modeling	F	9.4	6.58	2.82	$21,551	$2,293	$9,698	$3,439	3
H Design Selection	G	3.48	2.436	1.044	$36,553	$10,504	$16,449	$15,756	6
I Component(s) Receipt and Inspection	E, H	60	42	18	$175,195	$2,920	$78,838	$4,380	4
J System Integration and Installation	I	55	38.5	16.5	$103,856	$1,888	$46,735	$2,832	2
K Verification and Validation	J	8	5.6	2.4	$4,687	$586	$2,109	$879	1
L Training and Project Closeout	K	7	4.9	2.1	$24,801	$3,543	$11,160	$5,314	5
	Totals:	332.88	233	99.86	$698,797	$31,823	$314,459	$47,734	

Based on the above activities, a network diagram was constructed to visualize the process as shown in Figure 25.

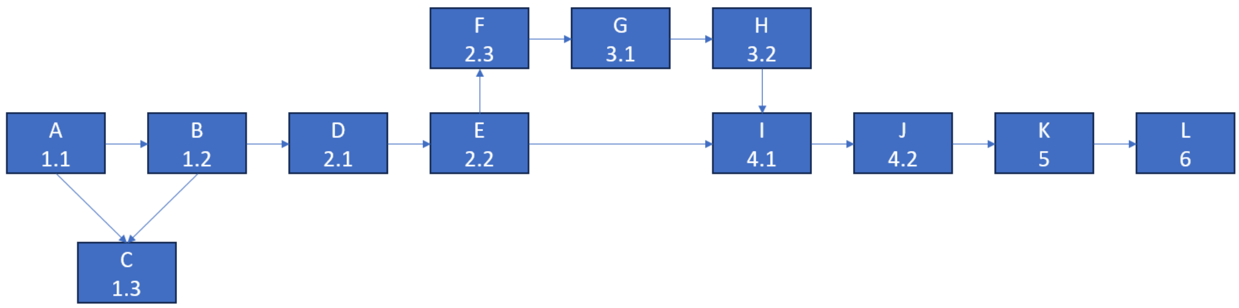


Figure 25: Project Network Diagram

The costs associated with crashing for each day are laid out in Table 41 describing how the total project cost changes with how much crashing is done.

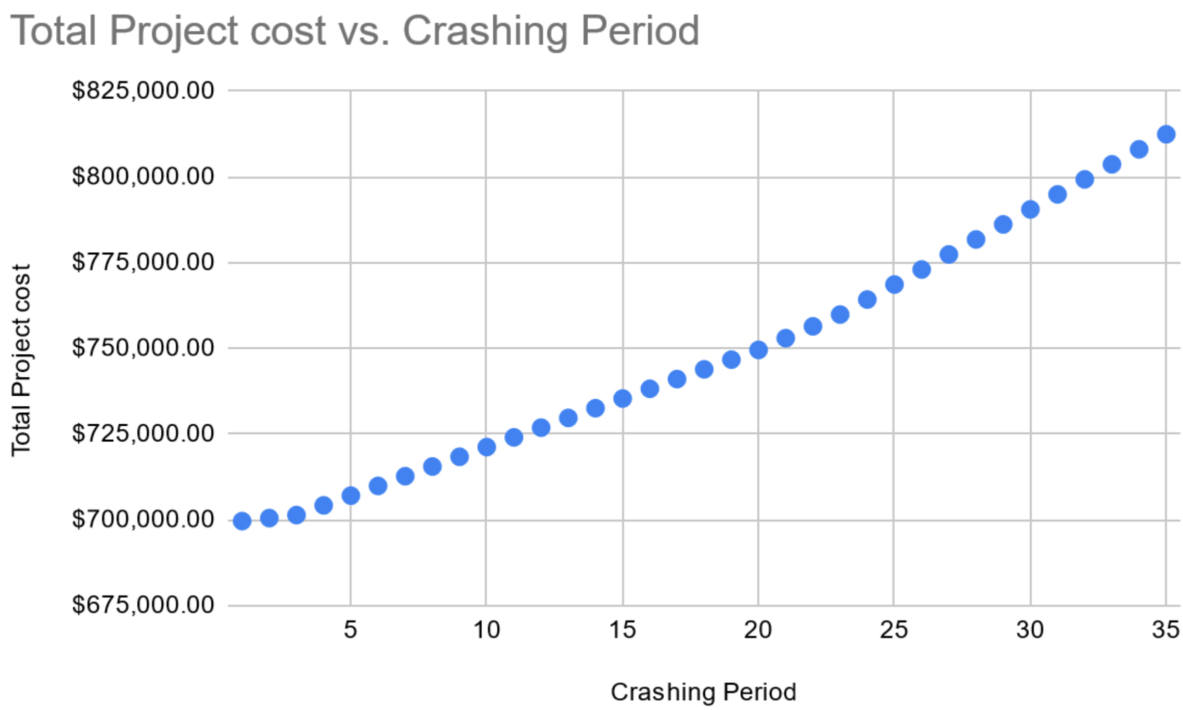
Table 41: Cost of Crashing

Crashing Period	Activity Crashed	Cost of Crashing / Day	Total Cost of Crashing	Adjusted Critical Path Duration (GHIJKL)	Total Project Cost
1	K	$879	$879	143	$699,676
2	K	$879	$1,758	142	$700,555
3	K	$879	$2,636	141	$701,433
4	J	$2,832	$5,469	140	$704,266
5	J	$2,832	$8,301	139	$707,266
6	J	$2,832	$11,134	138	$709,931
7	J	$2,832	$13,966	137	$712,763
8	J	$2,832	$16,798	136	$715,596
9	J	$2,832	$19,631	135	$718,428
10	J	$2,832	$22,463	134	$721,260
11	J	$2,832	$25,295	133	$724,093
12	J	$2,832	$28,128	132	$726,925

13	J	$2,832	$30,961	131	$729,758
14	J	$2,832	$33,793	130	$732,590
15	J	$2,832	$36,625	129	$735,423
16	J	$2,832	$39,458	128	$738,423
17	J	$2,832	$42,290	127	$741,087
18	J	$2,832	$45,123	126	$743,920
19	J	$2,832	$47,955	125	$746,752
20	J	$2,832	$50,788	124	$749,585
21	G	$3,439	$54,226	123	$753,024
22	G	$3,439	$57,665	122	$756,462
23	G	$3,439	$61,104	121	$759,901
24	I	$4,380	$65,484	120	$764,281
25	I	$4,380	$69,864	119	$768,661
26	I	$4,380	$74,244	118	$773,041
27	I	$4,380	$78,624	117	$777,420
28	I	$4,380	$83,004	116	$781,801
29	I	$4,380	$87,384	115	$786,181
30	I	$4,380	$91,763	114	$790,561
31	I	$4,380	$96,143	113	$794,940
32	I	$4,380	$100,523	112	$799,320
33	I	$4,380	$104,903	111	$803,700
34	I	$4,380	$109,283	110	$808,080
35	I	$4,380	$113,663	109	$812,460

Graphing the results of the crashing analysis results in the following graph shown in Figure 26.

Figure 26: Crashing Analysis Cost and Duration

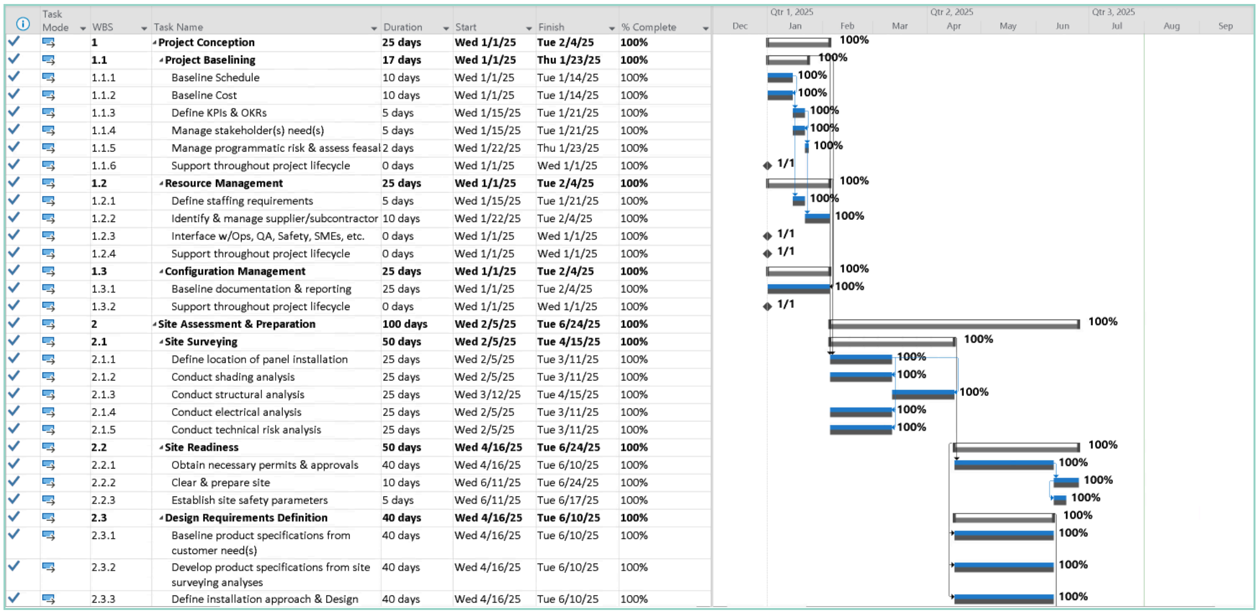


Based on this crashing analysis, this project can be sped up by 35 days for approximately $113,663 to keep this project on schedule. This can be expanded by continuing to crash activities I, J, K, and L should this project continue to be over schedule.

6. Monitoring & Control

6.1. Milestone Analysis

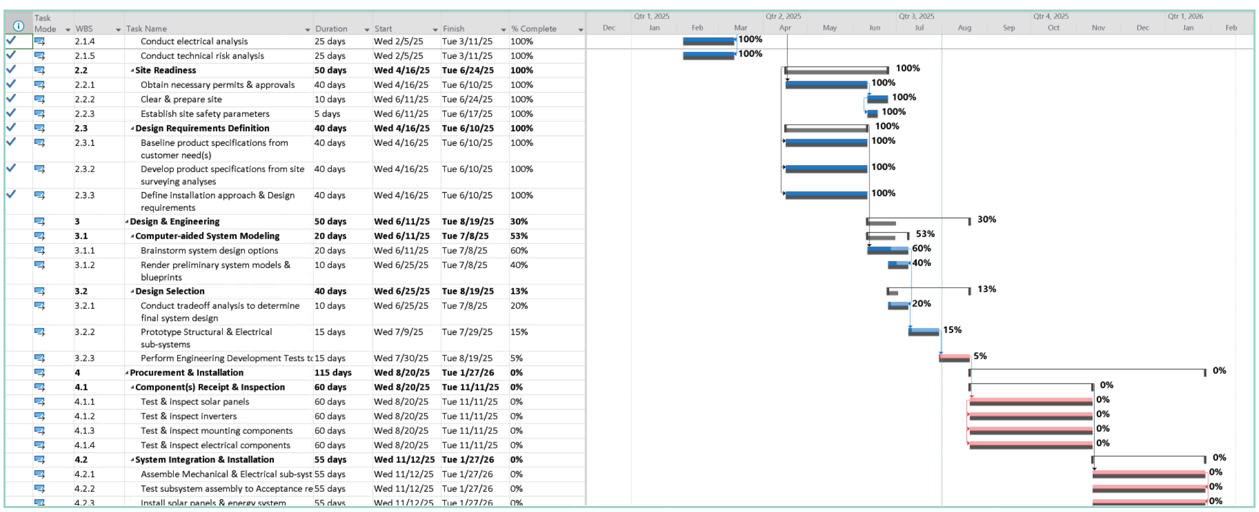
The tracked performance to plan and progress of the Solar Roof project was evaluated at 8/1/2025, with Milestone 1: Project Conception and Milestone 2: Site Assessment & Preparation completed:



Task Mode	WBS	Task Name	Duration	Start	Finish	% Complete
	1	**Project Conception**	**25 days**	**Wed 1/1/25**	**Tue 2/4/25**	**100%**
	1.1	**Project Baselining**	**17 days**	**Wed 1/1/25**	**Thu 1/23/25**	**100%**
	1.1.1	Baseline Schedule	10 days	Wed 1/1/25	Tue 1/14/25	100%
	1.1.2	Baseline Cost	10 days	Wed 1/1/25	Tue 1/14/25	100%
	1.1.3	Define KPIs & OKRs	5 days	Wed 1/15/25	Tue 1/21/25	100%
	1.1.4	Manage stakeholder(s) need(s)	5 days	Wed 1/15/25	Tue 1/21/25	100%
	1.1.5	Manage programmatic risk & assess feasal	2 days	Wed 1/22/25	Thu 1/23/25	100%
	1.1.6	Support throughout project lifecycle	0 days	Wed 1/1/25	Wed 1/1/25	100%
	1.2	**Resource Management**	**25 days**	**Wed 1/1/25**	**Tue 2/4/25**	**100%**
	1.2.1	Define staffing requirements	5 days	Wed 1/15/25	Tue 1/21/25	100%
	1.2.2	Identify & manage supplier/subcontractor	10 days	Wed 1/22/25	Tue 2/4/25	100%
	1.2.3	Interface w/Ops, QA, Safety, SMEs, etc.	0 days	Wed 1/1/25	Wed 1/1/25	100%
	1.2.4	Support throughout project lifecycle	0 days	Wed 1/1/25	Wed 1/1/25	100%
	1.3	**Configuration Management**	**25 days**	**Wed 1/1/25**	**Tue 2/4/25**	**100%**
	1.3.1	Baseline documentation & reporting	25 days	Wed 1/1/25	Tue 2/4/25	100%
	1.3.2	Support throughout project lifecycle	0 days	Wed 1/1/25	Wed 1/1/25	100%
	2	**Site Assessment & Preparation**	**100 days**	**Wed 2/5/25**	**Tue 6/24/25**	**100%**
	2.1	**Site Surveying**	**50 days**	**Wed 2/5/25**	**Tue 4/15/25**	**100%**
	2.1.1	Define location of panel installation	25 days	Wed 2/5/25	Tue 3/11/25	100%
	2.1.2	Conduct shading analysis	25 days	Wed 2/5/25	Tue 3/11/25	100%
	2.1.3	Conduct structural analysis	25 days	Wed 3/12/25	Tue 4/15/25	100%
	2.1.4	Conduct electrical analysis	25 days	Wed 2/5/25	Tue 3/11/25	100%
	2.1.5	Conduct technical risk analysis	25 days	Wed 2/5/25	Tue 3/11/25	100%
	2.2	**Site Readiness**	**50 days**	**Wed 4/16/25**	**Tue 6/24/25**	**100%**
	2.2.1	Obtain necessary permits & approvals	40 days	Wed 4/16/25	Tue 6/10/25	100%
	2.2.2	Clear & prepare site	10 days	Wed 6/11/25	Tue 6/24/25	100%
	2.2.3	Establish site safety parameters	5 days	Wed 6/11/25	Tue 6/17/25	100%
	2.3	**Design Requirements Definition**	**40 days**	**Wed 4/16/25**	**Tue 6/10/25**	**100%**
	2.3.1	Baseline product specifications from customer need(s)	40 days	Wed 4/16/25	Tue 6/10/25	100%
	2.3.2	Develop product specifications from site surveying analyses	40 days	Wed 4/16/25	Tue 6/10/25	100%
	2.3.3	Define installation approach & Design	40 days	Wed 4/16/25	Tue 6/10/25	100%

Figure 27: Milestone Analysis on Project Conception and Site Assessment & Preparation

However, Milestone 3: Design and Engineering, was analyzed at only 30% completion. The tracked progress on the subsequent individual work packages can be seen in the figure below:



Task Mode	WBS	Task Name	Duration	Start	Finish	% Complete
	2.1.4	Conduct electrical analysis	25 days	Wed 2/5/25	Tue 3/11/25	100%
	2.1.5	Conduct technical risk analysis	25 days	Wed 2/5/25	Tue 3/11/25	100%
	2.2	**Site Readiness**	**50 days**	**Wed 4/16/25**	**Tue 6/24/25**	**100%**
	2.2.1	Obtain necessary permits & approvals	40 days	Wed 4/16/25	Tue 6/10/25	100%
	2.2.2	Clear & prepare site	10 days	Wed 6/11/25	Tue 6/24/25	100%
	2.2.3	Establish site safety parameters	5 days	Wed 6/11/25	Tue 6/17/25	100%
	2.3	**Design Requirements Definition**	**40 days**	**Wed 4/16/25**	**Tue 6/10/25**	**100%**
	2.3.1	Baseline product specifications from customer need(s)	40 days	Wed 4/16/25	Tue 6/10/25	100%
	2.3.2	Develop product specifications from site surveying analyses	40 days	Wed 4/16/25	Tue 6/10/25	100%
	2.3.3	Define installation approach & Design requirements	40 days	Wed 4/16/25	Tue 6/10/25	100%
	3	**Design & Engineering**	**50 days**	**Wed 6/11/25**	**Tue 8/19/25**	**30%**
	3.1	**Computer-aided System Modeling**	**20 days**	**Wed 6/11/25**	**Tue 7/8/25**	**53%**
	3.1.1	Brainstorm system design options	20 days	Wed 6/11/25	Tue 7/8/25	60%
	3.1.2	Render preliminary system models & blueprints	10 days	Wed 6/25/25	Tue 7/8/25	40%
	3.2	**Design Selection**	**40 days**	**Wed 6/25/25**	**Tue 8/19/25**	**13%**
	3.2.1	Conduct tradeoff analysis to determine final system design	10 days	Wed 6/25/25	Tue 7/8/25	20%
	3.2.2	Prototype Structural & Electrical sub-systems	15 days	Wed 7/9/25	Tue 7/29/25	15%
	3.2.3	Perform Engineering Development Tests tc	15 days	Wed 7/30/25	Tue 8/19/25	5%
	4	**Procurement & Installation**	**115 days**	**Wed 8/20/25**	**Tue 1/27/26**	**0%**
	4.1	**Component(s) Receipt & Inspection**	**60 days**	**Wed 8/20/25**	**Tue 11/11/25**	**0%**
	4.1.1	Test & inspect solar panels	60 days	Wed 8/20/25	Tue 11/11/25	0%
	4.1.2	Test & inspect inverters	60 days	Wed 8/20/25	Tue 11/11/25	0%
	4.1.3	Test & inspect mounting components	60 days	Wed 8/20/25	Tue 11/11/25	0%
	4.1.4	Test & inspect electrical components	60 days	Wed 8/20/25	Tue 11/11/25	0%
	4.2	**System Integration & Installation**	**55 days**	**Wed 11/12/25**	**Tue 1/27/26**	**0%**
	4.2.1	Assemble Mechanical & Electrical sub-syst	55 days	Wed 11/12/25	Tue 1/27/26	0%
	4.2.2	Test subsystem assembly to Acceptance re	55 days	Wed 11/12/25	Tue 1/27/26	0%
	4.2.3	Install solar panels & energy system	55 days	Wed 11/12/25	Tue 1/27/26	0%

Figure 28: Milestone Analysis on Design and Engineering at only 30% Completion

6.2. Earned Value Analysis

After completing a milestone analysis and assigning percentage completes, baselining the schedule, and evaluating on a date of 8/1/25, an Earned Value Analysis of the project's progress so far can be conducted. In the below figure, Earned Value (EV) Over Time, it can be seen that the project's BCWS (planned value) and BCWP (earned value) are nearly one-to-one until Milestone 3 time-frame, where the planned value surpasses the earned value. However, right around June to August 2025, we can see that the ACWP (actual cost) spent ends up significantly higher than both the BCWS and BCWP. Because the ACWP is higher than the BCWP, the project is running over-budget, and with the BCWS being higher than the BCWP, we are also slightly behind schedule at this point in time.

Figure 29: EV Over Time

The associated plots for both the schedule variance and schedule and cost performance indices can be seen in the figures below. In Figure 30, we can see that the SV is trending positively, right around the July-August timeframe, which is when we fall slightly behind schedule on Milestone 3. In Figure 31, we can see that the CPI trends on-cost at the beginning of the project, but slowly degrades over time, as our actual costs begin to deviate from our planned, baseline values.

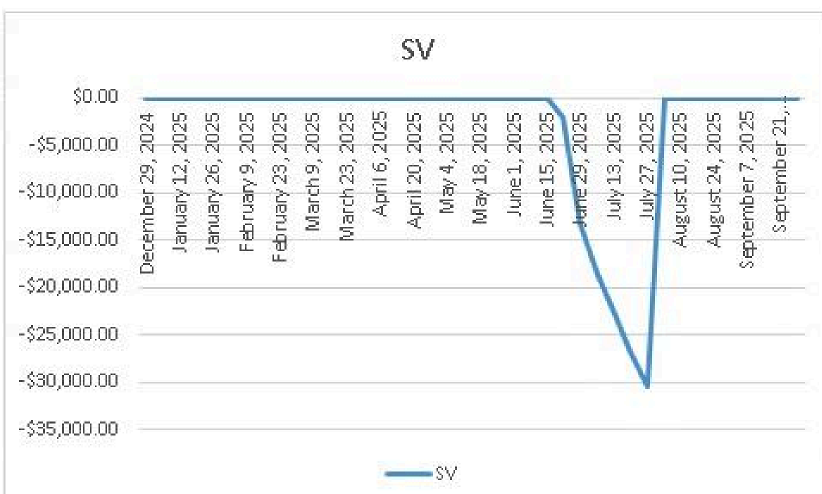


Figure 30: Variance Over Time

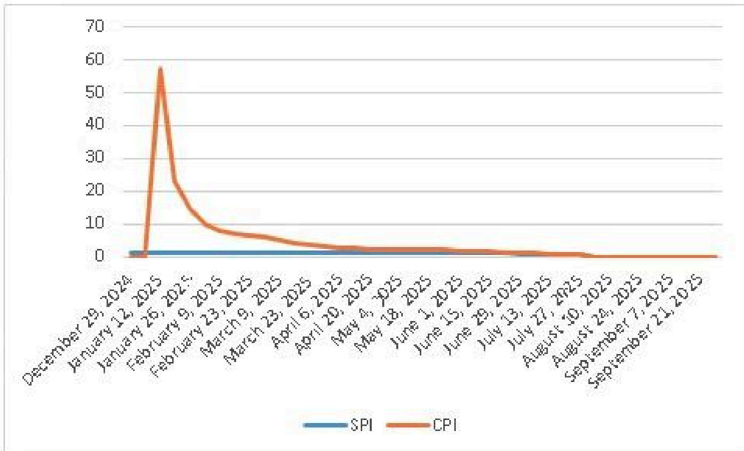


Figure 31: Indices Over Time

6.3. S-Curve Analysis

The main technique to control the solar panel project is the EVM analysis in section 6.2. An additional project monitoring technique that we decided to apply to this project is the S-curve analysis. This monitoring technique helps us track spending of the project over the duration of the project. In order to generate this S-Curve we took the following steps. First, we broke down spending as the deliverable level (work package). Next, we totaled the baseline spending per month (see table below). Then, we added the actual costs of the project based on the microsoft project file (MSP) (see table below). We manually assigned actual costs to each deliverable in the MSP file. Finally, we graphed the actual cost of the project to the baseline cost of the project.

Table 42: S-Curve Analysis: Cost Breakdown per Month of All Deliverables

	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb
1.1.1	$6,666													
1.1.2	$9,488													
1.1.3	$4,273													
1.1.4	$4,570													
1.1.5	$1,711													
1.1.6	$0.00													
1.2.1	$4,144													
1.2.2	$4,162	$4,162												

1.2.3	$0.00													
1.2.4	$0.00													
1.3.1	$12,166	$12,166												
1.3.2	$0.00													
2.1.1		$11,936	$11,936											
2.1.2		$12,686	$12,686											
2.1.3			$12,835	$12,835										
2.1.4		$11,127	$11,127											
2.1.5		$13,616	$13,616											
2.2.1				$5,905	$5,905	$5,905								
2.2.2						$2,358								
2.2.3						$1,954								
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**
2.3.1				$11,158	$11,158	$11,158								
2.3.2				$14,543	$14,543	$14,543								
2.3.3				$11,694	$11,694	$11,694								
3.1.1						$9,006	$9,006							
3.1.2						$1,768	$1,768							
3.2.1						$5,469	$5,469							
3.2.2							$12,078							
3.2.3							$6,767	$6,767						
4.1.1								$11,029	$11,029	$11,029	$11,029			
4.1.2								$10,711	$10,711	$10,711	$10,711			
4.1.3								$11,347	$11,347	$11,347	$11,347			
4.1.4								$10,711	$10,711	$10,711	$10,711			

4.2.1											$10,056	$10,056	$10,056	
4.2.2											$12,744	$12,744	$12,744	
4.2.3											$11,816	$11,816	$11,816	
5.1.1														
5.1.2													$464	
5.1.3													$1,785	$1,785
6.1														$6,021
6.2														$6,021
6.3														$6,021
6.4														$6,021
6.5														$716
Total:	$47,183	$65,694	$62,201	$56,136	$43,301	$63,858	$35,091	$50,566	$43,798	$43,798	$78,417	$34,618	$36,868	$18,000
Cum. Total:	$47,183	$112878	$175,080	$231,216	$274,517	$338,376	$373,467	$424,033	$467,832	$511,631	$590,048	$624,667	$661,535	$679,535
Actual Cost:	$66,700	$155,950	$237,950	$309,200	$361,700	$434,192	$450,684	$451,184	$451,184	$451,184	$451,184	$451,184	$451,184	$451,184

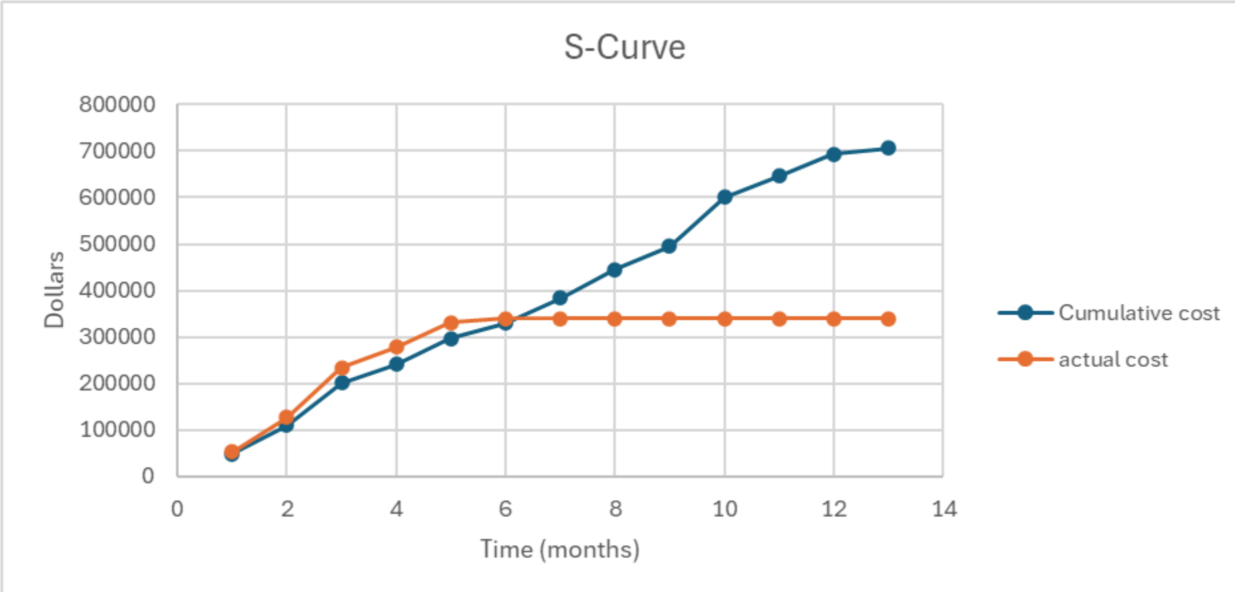


Figure 32: S-Curve Cumulative and Actual Cost

According to the MSP file, our design and engineering phase of the project is delayed which impacts the percent completion of the tasks. That as well as project budget overruns in the project conception and site assessment/preparation phase cause deviations in project spending from the baseline cost. This graph tracks the project up to 6 months. The orange line shows the actual costs of the project for the first 6 months. The blue line represents the projected spending of the project to completion. The gap between the blue and orange line shows overspending or the cost variance at this point. The cost variance is positive showing the project is currently running over budget. See the table below for cost variance of the project for the first 6 months.

Table 42: Cost Variance for First 6 Months

Total:	$47,183.88	$65,694.75	$62,201.55	$56,136.65	$43,301.15	$63,858.23
Cumulative Total:	$47,183.88	$112,878.63	$175,080.18	$231,216.83	$274,517.99	$338,376.22
Actual Cost:	$66,700.00	$155,950.00	$237,950.00	$309,200.00	$361,700.00	$434,192.48
Cost variance per month	$19,516.12	$43,071.37	$62,869.82	$77,983.17	$87,182.01	$95,816.26

7. Project Closeout

7.1. Termination Procedure

The termination procedure was completed shortly after the installation was finished. This project was categorized as Build, Operate, Transfer (BOT), meaning ownership of the project was shared among contractors and stakeholders throughout the whole duration.

7.2. Close-out Documents

A checklist was created to ensure all the required tasks were completed in order to hand over the project to USC. These tasks were implemented to facilitate a smooth transition.

Table 43: Project Close Out Review

Project Close Out Review	Yes	No	Comments/Reference
Required Reviews			
Have all personnel been trained in maintenance, inspection, and disassembly?	✓		
Has the final programmatic review been conducted?	✓		
Has the project met all the stakeholders' needs and wants?	✓		
Have all the necessary permits been uploaded to the USC database?	✓		Report #2024
Have all tasks from the project review been completed?	✓		
Have all key personnel reviewed the project?	✓		Project Sign Off Document
Have all lessons learned been documented and submitted to the database?	✓		Report #2025
Has the project closeout report been prepared?	✓		
Have all key deliverables been met?	✓		
Has the project collected and billed for all invoices	✓		
Project Cost & Resources			
Has the project met its target cost?	✓		

Have all allocated resources been released into and out of the project according to the schedule?	✓		
Have all evaluations of planned versus actual resource usage been completed and relevant department metrics been updated?	✓		
Engineering Reviews			
Have all design change requests been executed?	✓		
Have all engineering designs been tested/inspected and recorded in a database?	✓		Report #2026
Have lessons learned been recorded in the database?	✓		Report #2027
Solar Panel Procurement Review			
Have the necessary components in the solar panel been inspected and approved?	✓		
Customer Feedback			
Has USC provided feedback on project performance and completion?	✓		

After the Project Close Out Review was complete, personnel responsible in each department reviewed the termination procedure and provided their approval by signing off.

Table 44: Project Sign off Document

Project Sign off Document		
Responsible Department	Attendee	Approval Signature
Business	Biz Nest	Biz Nest
Construction	Construt Shun	Construt Shun
Design Engineering	Dee Sign	Dee Sign
Electrical Engineering	Cal Electric	Cal Electric
Engineering	Engine Ear	Engine Ear

Mechanical Engineering	Mick Canical	Mick Canical
Production Engineering	Product Shun	Product Shun
Legal	Lee Gal	Lee Gal
Project	Pra Duct	Pra Duct
Safety Officer	Safe Tee	Safe Tee
Supply Chain	Sup Ply	Sup Ply
USC Representative	Tommy Trojan	Tommy Trojan

7.3. Lessons Learned

The project management team identified several factors to help improve future project endeavors. Before coming up with a project strategy it is important to do research to get a solid understanding of the project's requirements and develop the best strategy to complete the project. One factor the team identified was when adding another engineer, the cost and budget changed by adding more cost towards the overall project budget. Another factor identified was when crashing the project, the team was crashing at the milestone level; therefore, to resolve this issue thorough analysis had to be done to crash at the task level. A third issue identified was that the project management team calculated the wrong actual cost in the EVM which produced an incorrect S-Curve. To fix this problem, the team had to manually update the actual cost in the MSP file to develop accurate analysis of the S-Curve. All these factors were noted and resolved by doing root cause analysis to determine the error.

Documentation was done in a structured manner to help keep track of project timelines, project problems, task completions, meeting minutes, and specific details about the project. This helped assess the flow of project management processes. In addition, all presented information was cited to give the reader further resources for accurate information. Utilizing an excellent documentation tactic helped the team produce effective reports, and demonstrate the knowledge learned through the project in detailed presentations.

The project was assessed periodically to identify areas that needed correcting. Neglecting these factors can impact the project's completion. The lessons learned from working on this project will help avoid future mistakes, optimize project executions, and ensure continuous project improvements.

8. Conclusion

This report described every detail needed to complete the installation of a solar panel roof system and proactively implementing project management principles to estimate all necessary requirements of executing on the installation. The techniques and tools used included project scope definitions and conducting a business case analysis, cost and estimation of materials and labor, a project work breakdown structure and the associated department accounts for each work package, as monitoring and control measures such as crashing analysis, risk assessment mitigation strategies, and earned value analysis. With such measures in place, the project schedule costs, permitting requirements, and expected benefits shall be set forth accurately and in detail to the stakeholders responsible for signing off for approval on this solar panel installation at USC.

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Note, our citations are numbered accordingly to restart at each respective section

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