PREPARED BY EES CONSULTING

WASHINGTON STATE

DEPARTMENT OF COMMERCE

Final Report

Green Roof and Rooftop Agrivoltaic Benefit-Cost Analysis

June 22, 2023

EES Consulting
a GDS Associates Company

PEAK SUSTAINABILITY

TABLE OF CONTENTS

1 Executive Summary

1.1 PURPOSE

The Washington state legislature appropriated $200,000 to the Washington Department of Commerce (Commerce) in its 2021-2023 Operating Budget to:

"…Conduct a cost-benefit analysis on the use of agrivoltaic and green roof systems on projected new buildings with a floor area of 10,000 square feet or larger to be developed over the next 20 years in communities of 50,000 or greater. The department shall consult with the department of ecology, private sector representatives, and an organization that has experience conducting cost-benefit analyses on green roofing. The cost-benefit analysis must include:

(i) The impact of widespread green and agrivoltaic roof installation on stormwater runoff and water treatment facilities in communities with a population of greater than 50,000;
(ii) Potential water quality and peak flow benefits of widespread green and agrivoltaic roof installation; (iii) Public health impacts;
(iv) Air quality impacts;
(v) Reductions in fossil fuel use for buildings with agrivoltaic systems;
(vi) Energy efficiency of buildings with agrivoltaic systems;
(vii) Job creation; and
(viii) Agrivoltaic installation and maintenance costs."[1]

A green roof is a layer of contained vegetation which sits over a waterproofing system, installed on top of a flat or slightly sloped roof. Agrivoltaics, for the purposes of this study, are the colocation of solar panels (photovoltaics) and green roof technology on commercial rooftops. All references to agrivoltaics, and colocation, throughout this report refer to rooftop applications only.

The objective of this work is to better understand the opportunity for green roof and rooftop agrivoltaic systems on new commercial buildings in densely-populated areas of Washington. The results of this analysis will support the development of policies and legislation to achieve increased green roof and rooftop agrivoltaic adoption in Washington cities.

1. The BCA must examine the costs and benefits associated with green roof and agrivoltaic systems on projected new buildings with a floor area of 10,000 square feet or greater.
2. The study will cover 3 urban areas in Washington with a population greater than 50,000 people.

1.1.1 Green Roof Types

Green (or eco-) roofs are a green infrastructure alternative to conventional roofs that reduce stormwater discharge and provide a wide range of additional environmental and aesthetic benefits. A green roof consists of a living layer of vegetation placed over a growing medium on top of a synthetic, waterproof membrane, the entire multi-layer system being supported by a building structural roof system. Living green roofs can significantly decrease stormwater runoff, save energy, improve water quality, absorb carbon dioxide, cool urban heat islands, and filter air pollutants. A vegetated roof can increase habitat for birds and insects and provide much needed greenspace for urban dwellers. Vegetated roof technologies can provide building owners with a proven return on investment, and create opportunities for significant social, economic and environmental benefits, particularly in urban areas. Green roofs are broadly divided into two types as follows:

[1] 2021-2023 Washington State Operating Budget, pg. 833

Extensive – Consists of low growing plants with 2-6 inches of soil. Irrigation after plant establishment may not be necessary in Western WA. These types of roofs have the best stormwater retention and require the least amount of maintenance, depending on the types of plants chosen. They can be placed on individual trays which spread out the load with easy access to the roof structure or membrane for easy replacement. Dormant species can return after a "brown out" in dry months.

Intensive – These roofs can be elaborate gardens with great plant diversity can include trees with the right quantity of soil and can be a "destination" for tenants or visitors to enjoy. While more visually attractive than extensive roofs, they need much more maintenance, irrigation and structural support.

1.2 OVERVIEW OF EXISTING PROGRAMS

A number of existing green roof infrastructure programs of varying levels of scope and maturity have been or are being implemented at the local and state level in the United States as well as abroad, particularly in Europe. Programs vary in their emphasis on building types, where the focus may be on residential, commercial, mixed-use and/or public office buildings. In general, western European countries have developed more advanced and robust programs for encouraging green roof alternatives for both new and existing building infrastructure. Many of these programs offer various incentive mechanisms that can make green infrastructure alternatives more attractive financially or more desirable from an end-user perspective.

1.3 SUMMARY OF BENEFITS AND COSTS

The project included an extensive review of benefits and associated costs of green roofs alone and in combination with solar cell energy production (photovoltaic). The combination of the two systems has been termed A*grivoltaic* for the purposes of this study. The benefits of these green roof and solar applications can be quantitative, where positive influences are expressed in terms of discreet units of measure, or can be qualitative, when benefits are tangible but not amenable to evaluation using discrete units of measurement.

1.3.1 Quantitative

The following potential quantitative benefits were evaluated in this study:

- Reduction in stormwater runoff volumes and associated management costs
- Impacts on building energy performance (HVAC)
- Leadership In Energy and Environmental Design (LEED) Credits
- Roof Installation and Operation & Maintenance (O&M) Costs
- Greenhouse Gas reduction or sequestration
- Avoided Costs (deferred capital expenses, social cost of carbon emissions, energy infrastructure)

1.3.2 Qualitative

The following potential qualitative benefits were evaluated in this study:

- Improvements in water and air quality
- Reduced surface temperatures and urban heat island effects
- Increased food production
- Biodiversity, ecosystem health and human quality of life considerations
- Highly impacted community effects

1.4 METHODOLOGY

The costs and benefits are quantified for several measure permutations that vary by climate zone, roof coverages, and building type. In total over 250 rooftop agrivoltaic measures were analyzed. The benefits and costs were used as input in the Northwest Power and Conservation Council (Power Council)'s ProCost model for evaluating energy efficiency savings and demand side resources such as behind-the-meter solar. The value assumptions such as the price of energy are updated with current market conditions, and each measure is analyzed based on the time-of-day energy savings or production occurs. The three cities selected for the measure analysis include Seattle, Yakima, and Spokane. Each of these cities has unique attributes in terms of population density, rainfall, climate, solar availability, and development. The benefit-cost analysis was prepared from a total resource cost or regional perspective.[2]

1.5 BENEFIT-COST ANALYSIS RESULTS

The benefit-cost analysis resulted in mixed cost-effectiveness levels. Because the analyses are prepared separately, their results can also be viewed separately. Mainly, solar PV was not cost-effective in any of the cases when a 15-year lifecycle is assumed. This result is not surprising from a wholesale energy perspective. Most rooftop solar installations are deemed cost effective when incentives are included and the energy produced is compared to retail utility rates which include costs that are considered transfers in this benefit cost analysis.

In some instances, green roofs alone were cost-effective. This is the case when stormwater benefits are quantified based on the analysis contained in this study. In this study, stormwater benefits are quantified only in Seattle and Spokane. Stormwater benefits in Yakima were not quantified but are believed to be minimal.[3] Table 1.1 summarizes the BCA results by combining all roof coverages for solar and green roof. Result details by roof coverage is provided in the main body of the report in Section 6.

TABLE 1.1: BENEFIT-COST RATIOS- GREEN ROOF PLUS SOLAR PV ALL COVERAGES

Building Type	Seattle	Spokane	Yakima
Assembly	0.82	0.50	0.41
Grocery	0.81	0.46	0.37
Hospital	0.91	0.72	0.65
Lodging	0.88	0.56	0.50
Mixed Commercial*	0.88	0.52	0.46
Multifamily High Rise (7+)	0.96	1.59	NA
Multifamily Low Rise (1-3)	0.92	0.56	0.51
Multifamily Mid Rise (4-6)	0.92	0.81	0.75
Office	0.88	0.51	0.45
Other	0.87	0.46	0.40
Residential Care	0.87	0.48	0.41
Retail / Service	0.88	0.52	0.46
School	0.86	0.46	0.40
Warehouse	0.86	0.47	0.40

[2] Consistent with the approach taken by the Northwest Power and Conservation Council in its evaluation of resources.

[3] The City of Yakima's 2007 Annual Inflow and Infiltration Evaluation noted that leakage from irrigation is the primary driver of excess inflow/infiltration on the City's wastewater treatment plant. www.yakimawa.gov/services/wastewater-treatment-plant/files/2012/06/IandI2007.pdf

1.6 STUDY FINDINGS

The research and modeling revealed several key findings, some of which are specific to Washington State.

1. The primary benefit of green roofs is stormwater retention. Energy savings from the added R-value from green roof minimally impacted new building energy efficiency when the most recent Washington building codes are factored into the analysis.
2. Stormwater benefits in this study are dependent on the variable cost of stormwater treatment. Not all areas in Washington State face the same challenges in stormwater treatment. Yakima is an example from this study where the City's wastewater treatment facilities are impacted significantly through irrigation system leaks and less impacted by stormwater inflow and infiltration.
3. Increasing soil depths on green roofs in Spokane results in not needing irrigation systems due to consistent average monthly rainfall.
4. The primary quantified benefit of green roofs is the stormwater discharge reduction, and this benefit varies widely depending on the local stormwater infrastructure and precipitation. Studies that have shown positive cost/benefit results for green roofs have relied on quantifying softer benefits such as increased occupant productivity, comfort, or energy savings based on buildings that are not as efficient as required in Washington State.
5. In practice, rooftop agrivoltaic projects are not common. Most often when solar and green roofs are combined on the same roof, they exist separately leaving any, likely small, colocation benefits unrealized. Colocating closely together raises concerns from roofing contractors regarding how the photovoltaics will be anchored and the potential for puncturing of the green roof liner. The panels could also interfere with access to the green roofs for required regular maintenance.
6. Rooftop solar programs are well-defined in Washington State. The cost of the infrastructure is also well-known. Washington has already implemented several programs to promote increased adoption of rooftop solar including solar-ready buildings, sales tax rate exemptions, and grant monies for qualifying projects. Additionally, significant incentives are available at the Federal level from both the American Recovery and Reinvestment Act and the Inflation Reduction Act.
7. The colocation benefits of solar PV and green roofs related to energy production is not significant. The study identified qualitative colocation benefits for green roofs from solar PV shading; however, the data available was insufficient for quantifying those benefits.

From this study it can be concluded that rooftop agrivoltaics are not wholly cost-effective in the State of Washington. Regardless, the State may wish to promote rooftop agrivoltaics for economic or other reasons that are difficult to quantify based on the current literature. If the State were to move forward with a rooftop agrivoltaic program, the Project Team makes the following general recommendations:

1. Develop certification for O&M providers specific to green roof needs. Green roof maintenance should address erosion, roof drains, gravel stops, utilities, dead plants, fertilization, weeds, irrigation system, summer watering, mosquitos, and nuisance animals.
2. Green roofs should be given priority as a method to satisfy local stormwater management requirements in regions such as the Greater Puget Sound where stormwater runoff costs can be marginally impacted.
3. The value of stormwater reductions in terms of reduced long-term infrastructure costs can be passed onto developers in the form of tax reductions, utility fee reductions, or direct incentives. These programs are best suited for stormwater district administration which would include cities and counties.
4. Scoring for increased square footage, tax abatements, and stormwater credits can be based upon depth of soil media and green square footage.

5. If green roof mandates are considered, it is recommended to create multiple solutions for developers to meet the requirements. An example is the San Francisco model which lets builders choose between solar, green roof, or both.
6. Evaluate program spending or agrivoltaic potential based on specific parameters (mandate, incentive structure, grant funding level) for economic development impacts.
7. Carve out additional incentives for development incorporating rooftop agrivoltaics near highly impacted communities.

2 Study Overview and Methodology

Washington Department of Commerce (Commerce) retained the Project Team (EES Consulting, a GDS Associates Company and Peak Sustainability) to evaluate the costs and benefits of green roofs paired with solar photovoltaics.

Green rooftops paired with rooftop agrivoltaics have the potential to solve multiple challenges in areas with high population growth such as Washington State. Western Washington in particular has seen a significant growth in multifamily building investments. Urban planners must balance the trade-off between buildings and greenspace. At the same time, climate change is likely to increase winter rainfall in Western Washington and also lead to hotter, drier summers. Rooftop agrivoltaics could provide relief for some of these impacts.

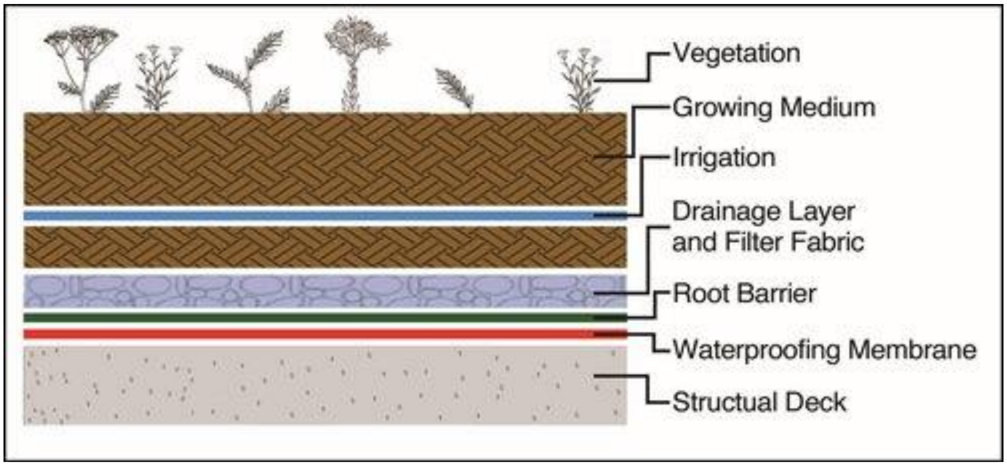
This study was developed using a variety of methods to develop assumptions and understand implementation barriers. Specifically, costs and benefits are estimated based on direct modeling, survey of industry experts and practitioners, and secondary research. Our team leveraged regional contacts and existing benefit-cost analysis construct to develop assumptions and results. This study also focused the literature review first on sources in the regions selected for this project. If no local studies were available, the study relies on the next best alternative including state level, adjacent or nearby states, United States, then international. Throughout the process, modeling decisions were vetted with Commerce staff and uncertainties discussed. The results of the study provide one of the first detailed analyses of the costs and benefits of rooftop agrivoltaic measures. The results are specific to Washington State for the purposes of providing recommendations for potential legislation or building codes amendments addressing green roof and rooftop agrivoltaic measures.

2.1 GREEN ROOF BACKGROUND

Green (or eco-) roofs are a green infrastructure alternative to conventional roofs that reduce stormwater discharge and provide a wide range of additional environmental and aesthetic benefits. A green roof consists of a living layer of vegetation placed over a growing medium on top of a synthetic, waterproof membrane, the entire multi-layer system being supported by a building structural roof system. Living green roofs can significantly decrease stormwater runoff, save energy, improve water quality, absorb carbon dioxide, cool urban heat islands, and filter air pollutants. A vegetated roof can increase habitat for birds and insects and provide much needed greenspace for urban dwellers. Vegetated roof technologies can provide building owners with a proven return on investment,[4] and create opportunities for significant social, economic and environmental benefits, particularly in urban areas. Green roofs are broadly divided into two types as follows:

FIGURE 2.1 GREEN ROOF CROSS SECTION

[4] Cushman & Wakefield. Green is Good: Sustainable Office Outperforms in Class A Urban Markets. August 2021.



Extensive – Consists of low growing plants with 2-6 inches of soil. Irrigation after plant establishment may not be necessary in Western WA. These types of roofs have the best stormwater retention and require the least amount of maintenance, depending on the types of plants chosen. They can be placed on individual trays which spread out the load with easy access to the roof structure or membrane for easy replacement. Dormant species can return after a “brown out” in dry months.[5]

Intensive – These roofs can be elaborate gardens with great plant diversity and can include trees with the right quantity of soil and can be a “destination” for tenants or visitors to enjoy. While more visually attractive than extensive roofs, they need much more maintenance, irrigation and structural support.

2.1.1 Climate Considerations

The different climate zones have variations pertaining to the design, efficiency and maintenance of green roofs. Some of the literature recommend a deeper soil medium and roof pitch of 5-20 degrees for drier climates, where the roof pitch recommendation for Western Washington is flat. A more level roof maximizes stormwater retention. Depths of 2-3 inches support succulents, grasses and herbaceous plants when deeper soils substrate can allow for drought-tolerant perennials and grasses. A diverse assortment of plants is the key to surviving the arid summer and frigid temperatures of the winter months. The soil medium is the key factor in water retention.

2.2 WORK PLAN

The Project Team developed a work plan to specify the benefit-cost analysis framework. This work plan is provided below in this section.

2.2.1 Measure Specification

Rooftop agrivoltaic costs and benefits will vary by climate and solar zones across Washington State. The Project Team selected 3 metropolitan areas that represent the climate and solar resources across the state. Seattle, Spokane, and Yakima were selected based on representing Washington’s populous climate zones, precipitation, and solar zones. The table below compares the three selected areas. Heating zone one is a mild heating climate (winters are, on average, not cold). Heating Zone 2 experiences colder winter temperatures. Similarly, cooling zone 1 represents mild summer weather while cooling zones 2 and 3 experience hotter summer

[5] Paladino & Company, Inc., Green Roof Feasibility Review. February 2006. Available at: https://kingcounty.gov/~/media/depts/dnrp/solid-waste/green-building/documents/KC_Green_Roof_case-study.ashx?la=en

temperatures. Washington state is generally characterized by 2 solar zones with solar zone 1 having lower solar generation potential.

TABLE 2-1: STUDY AREAS

	Heating Zone	Cooling Zone	Annual Rainfall Inches	Solar Zone	Other Attributes
Wenatchee	1	3	8.4	3	
Yakima	1	3	8.0	3	Indian Reservation Represented
Spokane	2	2	16.5	3	Metropolitan Area Size
Seattle	1	1	37.1	1	Previous Green Roof Programs
Bellingham	1	1	36.1	1	

Note: Wenatchee and Bellingham were not initially selected for study based on lower construction rates for new commercial buildings

The table above shows that Yakima and Wenatchee have similar climate, rainfall, and solar potential. Yakima was selected based on its ability to represent an area where Native American populations exist. Measures developed for Yakima could also be applied to buildings in the Wenatchee area. Similarly, Seattle and Bellingham are similarly situated across the examined characteristics. Measures developed for Seattle could reasonably be applied to the Bellingham area.

Based on our initial research and subject matter expertise, the Project Team has specified measures according to the parameters in Table 2. The coverage percentage applies to 100% of roof space.

TABLE 2-2: MEASURE SPECIFICATIONS

Measure Option	Solar Panel	Multifamily Roof Area <25,000 SF		Commercial Roof Area 2,000 to 50,000 SF 65% Existing Buildings	Commercial Roof Area above 50,000 SF 35% Existing Buildings
		Green Roof Extensive	Green Roof Intensive	Green Roof Extensive	Green Roof Extensive
1	10%	50%		50%	
2	25%	70%		70%	
3	10%		30%		30%
4	25%		50%		50%
5	50%			70%	

Error! Reference source not found..2 illustrates how measure permutations might apply to different approaches t o green roof or rooftop agrivoltaics. In the example below, the coverage varies as well as the type of green roof: extensive or intensive. The measure permutations that are most likely to be feasible and cost-effective are prioritized in the modeling. Any exclusions are noted and explained in this report.[6]

[6] An exclusion may be where the measure is a "small saver," or a relatively costly measure with little expected benefit. An example might be green roof and agrivoltaic installations in unheated buildings.

FIGURE 2.2: MEASURE PERMUTATION EXAMPLES

01 50% Coverage Extensive
Agrivoltaic Green Roof on Office Building in Heating Zone 1, Cooling Zone 1, Solar Zone 3

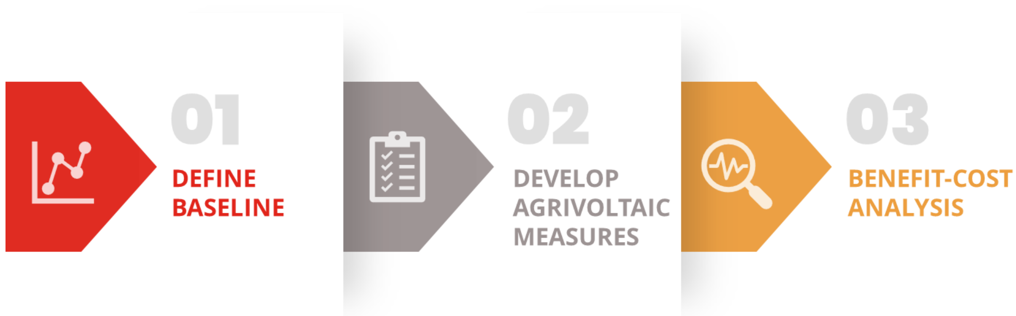
02 80% Coverage Extensive
Green Roof Agrivoltaic on Office Building in Heating Zone 1, Cooling Zone 1, Solar Zone 3

03 50% Coverage Intensive
Green Roof Agrivoltaic on Office Building in Heating Zone 1, Cooling Zone 1, Solar Zone 3

04 80% Coverage Intensive
Green Roof Agrivoltaic on Office Building in Heating Zone 1, Cooling Zone 1, Solar Zone 3

Each measure permutation will be compared to a baseline option. The baseline is the type of roof installation that would be used in absence of green roof or rooftop agrivoltaic options. Costs and benefits will be quantified for each measure permutation incrementally to the baseline.

FIGURE 2.3: BENEFIT COST ANALYSIS PROCESS



In the case where solar and green roofs are collocated, the solar panels considered in the modeling are specified as bifacial technology to allow for light to pass through to plantings below. The maximum coverage of solar panels is assumed at 50% based on initial research. There may be cases where solar and green roof vegetation do not overlap in design. The base analysis assesses designs where there is no overlap. Additional benefits are included in a separate analysis where varying degrees of overlap are modeled.

Green roof coverage varies by roof size and building use. While the scope of the study evaluates buildings over 10,000 square feet, most commercial building roof sizes will be above 25,000 square feet based on the 2019 Commercial Building Stock assessment supporting data (see Tables 3 and 4). Intensive coverage is reserved for special cases such as multifamily buildings in high-density areas. The Project Team discussed the following considerations for measure analysis:

1. A survey of current programs revealed the following:
    a. Coverage for solar and green roof compliance can be achieved by an either/or approach
    b. Minimum solar size was required by the program in some instances i.e. 4 MW
    c. Programs recognized that there is a minimum roof size to allow for sufficient economies of scale
2. Intensive green roofs are primarily installed in premium multifamily buildings to enhance real estate value.
3. For green roof applications, the program required green roof in cases where the roof pitch is flat or mostly flat
4. Consistent with our research, it is assumed that the maximum green roof coverage is 70% to allow for HVAC and other necessary rooftop equipment.
5. Solar can be installed on roof pitches up to 30%
6. Very large roof areas for certain building types may not produce significant cooling benefit if those buildings are located in lower density zones with vegetation surrounding the building.
7. Energy Use Intensity must be sufficient to produce energy savings and utilize on-site solar production. Tables 3 and 4 summarize the relevant energy use intensity (EUI) values by building type.

8. In practice green roofs might include a mix of intensive and extensive plantings on one roof. This "mixed roof" scenario is highly specific to building type or use. The Project Team will define a minimum share of extensive or intensive plantings for each case. For example:
    a. Extensive – No more than 20% Intensive plantings
    b. Intensive – No greater than 80% extensive

Measure specification was further verified through conversations with professional installers and additional research.

2.2.2 Research Objectives

The objective of the research is to quantify costs and benefits of rooftop agrivoltaics and provide qualitative analysis where quantification is challenging, or data is not available. Data collection records will clearly define the sources as well as any quantitative limitations and objective assumptions used in the benefit-cost analysis.

2.2.3 Limitations on Proposed Research

Prior to starting the research, several potential limitations were identified.

1. Data for specific areas in WA state may not be available such as energy savings attributed directly to rooftop agrivoltaics or best practices for green roof installations in certain cities.
2. Data or analysis may not be available for certain rooftop agrivoltaic costs and benefits, including impacts on vulnerable communities.
3. Measure specification is based on best available data and distilled to a reasonable number of permutations. Due to the diversity in building construction and design, there may be some permutations where the costs and benefits are not well-represented by using average building attributes from the Commercial Building Stock Assessment.
4. The costs and benefits quantified will be specific to current market conditions, service, and values available at the time of the study.

These limitations and others were defined throughout the research and are presented in this report. Where data was limited, the Project Team relied on best available alternatives including studies from other regions and/or qualitative analysis.

2.3 DATA COLLECTION PLAN

The study will produce quantitative data in terms of $/SF of roof area. These data will include the costs and benefits detailed in Tables 2.7 and 2.8. Many of these parameters in Tables 2.7 and 2.8 will easily translate to $/sq-ft roof area. However, some items will need additional adjustments to produce the desired units. For example, HVAC savings for buildings with multiple stories will need to take into account the average number of stories.

Tables 2.3 and 2.4 summarize commercial building data for Washington buildings. Table 2.3 summarizes buildings data for 10,000 square feet or larger and Table 2.4 shows the same data for buildings with 50,000 square feet or larger. The energy use intensity (EUI) data applies to all buildings by type regardless of size.

TABLE 2.3: WASHINGTON BUILDINGS WITH AREA > 10,000 SF[1]

Building Type	Average of Site Floor Area	Building Count	Floors above Grade Average	Inferred Roof Size	Electric EUI kWh/SF	Natural Gas EUI Therms/SF
Assembly	36,333	24	2	19,378	7.93	0.44
Grocery	23,625	8	1	18,900	40.23	0.57
Hospital	207,115	26	3	64,107	32.34	1.35
Lodging	51,923	26	3	15,169	10.89	0.43
Mixed Commercial*	44,515	33	2	19,078	15.19	0.24
Office	58,308	13	3	22,970	11.84	0.16
Other	13,000	2	2	8,667	6.39	0.36
Residential Care	61,360	25	2	30,078	14.74	0.41
Retail / Service	78,842	19	1	59,920	9.59	0.29
School	73,000	23	1	49,382	7.39	0.22
Warehouse	71,838	37	2	47,464	3.72	0.14
Grand Total	**73,805**	**236**	**2**	**34,355**	**11.89**	**0.36**

*Mixed commercial applies to buildings with multiple commercial uses. The CBSA data did not include residential within Mixed Commercial definitions.

TABLE 2.4: WASHINGTON BUILDINGS WITH AREA >50,000 SF2

Building Type	Average of Site Floor Area	Building Count	Floors above Grade Average	Inferred Roof Size	Electric EUI kWh/SF	Natural Gas EUI Therms/SF
Assembly	130,333	3	4	32,508	7.93	0.44
Grocery	53,000	1	1	53,000	40.23	0.57
Hospital	248,200	20	4	62,050	32.34	1.35
Lodging	94,222	9	4	23,556	10.89	0.43
Mixed Commercial*	107,167	6	6	17,861	15.19	0.24
Office	119,400	5	3	39,800	11.84	0.16
Other	NA	NA	NA	NA	6.39	0.36
Residential Care	79,231	13	3	26,410	14.74	0.41
Retail / Service	549,500	2	2	274,750	9.59	0.29
School	107,273	11	2	53,637	7.39	0.22
Warehouse	143,364	11	2	71,500	3.72	0.14
Grand Total	**152,864**	**81**	**3**	**50,955**	**11.89**	**0.36**

*Mixed commercial applies to buildings with multiple commercial uses. The CBSA data did not include residential within Mixed Commercial definitions.

Multifamily building data from the most recent Residential Building Stock Assessment is provided in Tables 2.5 and 2.6. Due to the sample size, buildings from Oregon, Washington, Idaho, and Montana are included these tables.

TABLE 2.5: PACIFIC NORTHWEST MULTIFAMILY BUILDINGS[3]

Multifamily (stories)	Average Stories	Building Count	Average Floor Area SF	Electric EUI kWh/SF	Natural Gas EUI Therms/SF
Low Rise (1-3)	2.2	411	5,462	9.7	0.31
Mid-Rise (4-6)	4.4	12	9,481	8.1	0.29
High Rise (7+)	13	1	17,250	5.9	0.29
All	**2.3**	**424**		**9.5**	**0.3**

Of the 424 buildings in Table 2.5, 43 are greater than 10,000 square feet in floor area (see Table 2.6). The largest building surveyed is 3 stories and 46,720 SF. The smallest building in this subset is 2 stories and 10,075 SF.

TABLE 2-6: PACIFIC NORTHWEST MULTIFAMILY BUILDINGS WITH FLOOR AREA GREATER THAN 10,000 SF[4]

Multifamily (stories)	Average Stories	Building Count	Average Floor Area SF	Average Inferred Roof Area SF
Low Rise (1-3)	2.4	37	15,897	6,609
Mid-Rise (4-6)	4.8	5	14,501	3,021
High Rise (7+)	13	1	17,250	1,327
All	**2.9**	**43**	**15,766**	**5,380**

The above building types will be reviewed to develop measure data the options in Table 2.6 above. Some permutations by building type may be eliminated in this process to analyze technically feasible options that will likely be economic.

2.4 ANALYSIS PLAN

Tables 2.7 and 2.8 summarize the parameters and evaluation methodology proposed.

TABLE 2.7: BENEFIT PARAMETERS AND PROPOSED METHODOLOGY

Benefit	Methodology and Data Sources
Reduced Stormwater Mitigation	Reduced Stormwater quantities Roof slope impacts Measured through gallons/year/SF roof space Quantified using stormwater variable costs, deferred investments
Water Quality	Qualitative evaluation of increased stormwater purity
Reduced Surface Temperatures	Quantified according to LEED credit value (proxy) Qualitative components Impact on vulnerable communities
Reduced GHG	Energy savings and market greenhouse gas (GHG) content Consider CETA requirements Valued at WAC 194-40-100
GHG Sequestration	Carbon sequestration of green roofs Measure in lbs CO2e per year per SF Intensive and extensive green roof differences
Reduced Energy Use	Electricity savings, kWh/SF/yr by building type per DesignBuilder 3d model Natural Gas savings, MMBtu/SF/year Electric distribution and transmission benefits ($/kW-yr) Hourly HVAC savings shapes by building Sources: NWPCC, RTF, NEEA, other Building types (>50,000 sf): multifamily, commercial retail large, commercial office large, warehouse, hospital, school/university, grocery, Assembly, General Industrial
Solar PV + Battery Generation	Production curves solar and solar + battery options by solar zone Battery optimized for regional electric system peak
Electric Grid Resilience and Stability	Peak reduction with Battery storage $/kW
Colocation Benefits Solar	Increased efficiency (%) Solar resource production or lower O&M

Benefit	Methodology and Data Sources
Colocation Benefits Green Roof	Increased food or plant production Greenhouse Gas sequestration Other efficiencies
Food Production	Separate qualitative analysis
Roof Service Life	Useful life of liner based on literature review and/or manufacturer or installer warranty
LEED Credit	Potential for LEED credit
Noise Reduction	Qualitative Analysis based on literature research
Increased Comfort	Qualitative Analysis based on literature research
Increased Aesthetic	Qualitative Analysis based on literature research
Economic Development	Input-Output modeling Contractor survey input for job creation O&M jobs Labor wages available from RTF

TABLE 2.8: COST PARAMETERS AND PROPOSED METHODOLOGY

Cost	Methodology and Data Sources
Green Roof Construction	Useful life, capital, engineering, & installation source from literature and local survey of contractors Defined as incremental to baseline roof costs
Green Roof O&M	Incremental to Baseline O&M Define replacement period.
Solar PV + Storage	Sizing Construction O&M Useful Life Data sourced from various sources
Program Administration	Typically 20% of capital cost (NWPCC) Depends on Program design/mandate Other considerations?

2.5 COLLABORATION

The following table summarizes the entities that were contacted by the Project Team to ensure a comprehensive analysis. The Project Team developed a list of 23 questions for installers about installation costs, O&M, best practices, and potential barriers (see Appendix A). Green roof installers and partners were contacted and asked to participate in a 20-30 minute telephone interview using thequestionnaire template.

TABLE 2.9: COLLABORATION PLAN

Entity	Objective
Northwest Power and Conservation Council/Regional Technical Forum	Discussed work that may have been completed already or in support of rooftop agrivoltaic measure evaluation
Energy Trust of Oregon	Discussed work that may have been completed already or in support of rooftop agrivoltaic measure evaluation
Green Roof Installers **Landscape companies** **(26 initial contacts)**	Sourced from green roof professionals map and recommendations from industry professionals to collect cost and anecdotal data 1. Costs, O&M 2. Best practices 3. Barriers 4. Colocation of solar benefits/drawbacks
Architects of Washington State **Structural Engineering Firm/s**	Obtain range of cost estimates for green roof/solar support for coverage options in Table 2.2
Seattle City Light (Utility)	Green Roof Program outcome, insights, coordination of efforts Example sites
Puget Sound Energy (Utility)	Green roof/solar program participation/findings
USGBC certification for LEED	Identify LEED benefits

3 Existing Programs

The Project team developed a matrix of various mandatory and voluntary programs related to green roof or solar, or both. This section of the report summarizes the key findings. Most programs are focused on either green roof or rooftop solar. Few programs are designed to integrate both green roof and solar PV; however, these programs are described in more detail followed by solar only or green roof only summaries.

3.1 GREEN ROOF AND COMBINED SOLAR PROGRAMS

3.1.1 San Francisco Better Roofs Ordinance

Notably, San Francisco's Better Roofs Ordinance combines green roof and solar technology for new building construction. The Better Roofs Ordinance went into effect January 1st, 2017, and allows "living roofs" to meet the requirements of a state law that mandates a portion of roofs be "solar ready."

There are requirements for new building construction to facilitate the development of renewable energy facilities and living roofs. These standards require that 15% of the roof space on most new construction is solar. These requirements can also be met by providing 30% of the roof space as a living roof (i.e. green or vegetated roof), or installing a combination of both solar and living roof. This option will allow a project sponsor to replace the required solar with living roof at a ratio of 2 square feet of living roof for every 1 square foot of solar. Better Roofs requirements apply to all projects proposing new construction that meet all of the following below:

- Non-residential with a gross floor area of 2,000 square feet or more, or residential of any size;
- Has 10 or fewer occupied floors; and
- Applies for a site permit or building permit on or after January 1, 2017.
- Commercial with 2,000 SF or more, any residential. Between 15-30% of roof space incorporate solar, living roof, or both.

In total, 30% of roof space must be either solar, living roof, or a combination of both with any combination of the following technologies, such that the performance requirements for each installed technology are met:

- PV, with a minimum 10 W DC per sq. ft. or roof area allocated to PV
- Solar Water Heat (SWH), with minimum 100 kBtu/SF of roof area allocated to SWH
- For buildings over 5,000 SF and subject to the SF Stormwater Management Ordinance (SMO), living roof, such that 2 sq. ft. of living roof is installed to satisfy 1 sq. ft of minimum solar zone area

The program includes stormwater management and non-potable water ordinances within the Better Roofs ordinance. Roof area is defined as all outside coverings of the building envelope. Planting emphasis on biodiversity

3.1.2 New York City Administrative Code and Building Code

Another example of a city ordinance that applies to new buildings or new roofs on existing buildings. The requirements for sustainable roofs were effective in 2019. The sustainable roofing zone must be either 100% solar, 100% green roof, or a combination.

The ordinance allows for exceptions and design considerations regarding roof slope and solar PV capacity. Specifically, on a high-slope roof (roof slope > 2:12), a solar photovoltaic system shall be provided. Where the solar photovoltaic system cannot meet or exceed a capacity of 4kW, the roof is exempt.[7] Additionally, there are several areas excluded from the sustainable roofing zone, including NYC Fire Code compliance areas, areas with rooftop structures, areas occupied by stormwater management practices, building setbacks, recreational spaces, pitched roofs, and areas where site conditions, as determined by the Department, are unfavorable to either solar or green roof systems.

Tax credits are available to offset the cost of green roof installation based on soil depth. These tax credits apply to roof areas ranging from 3,500 to 20,000 square feet.

3.1.3 City of Chicago Green Roofs; Solar Express Permit Program

The City of Chicago's Express Permit Program applies to new or retrofit buildings with minimum area defined by specific formula for either green roof or solar. To be eligible, the applicable roof area must be 50% or 2,000 square feet. The City has implemented a user-friendly online portal to help administer the program.

3.1.4 Summary Green Roof and Combined Solar Programs

All three programs offer structure for an either/or approach to rooftop solar or green roof (or blue roof). This flexibility allows for wider compliance opportunities where building characteristics vary widely. All mandated programs allow for exceptions for small scale technical feasibility. The drafters of these ordinances seemed to recognize that economies of scale were an important consideration to the cost-effectiveness of the building upgrades.

TABLE 3.1: GREEN ROOF AND COMBINED SOLAR PROGRAMS SUMMARY

City	Program Description	Incentive	Notes
San Francisco	Green roof or solar PV to meet Building Code requirement for Solar Ready buildings	Alternative to solar Ready, green roofs or combination can meet building code requirement	Various program requirements including roof size, PV size and 30% coverage
New York City	Sustainable Roof 100% solar PV, green roof, or combination	Mandate, as a separate program, tax credits are available to offset the cost of green roof installation based on soil depth	Exceptions for roof slope and solar PV capacity
Chicago	Express Permit Program for solar PV or green roof	Shorter permitting process	Coverage of 50% or at least 2,000 SF

3.2 GREEN ROOF ONLY PROGRAMS

The City of Seattle has a stormwater facility credit program (SFCP) that offers incentives to property owners for installing systems that mitigate the amount and quality of stormwater released into the city's stormwater system. Besides incentives, reduced fees can be a motivation for developers. Fees for new development often include a cost for the new impervious area of the project. Green roofs are considered pervious and can reduce or eliminate this fee. In addition, the DOE Stormwater Manual for both sides of the state requires "Flow Control" to reduce the impact of the additional impervious (impermeable) surface created by new construction or redevelopment. The intent is to "control" the release rates for 2-, 10- and 100-year storms to protect downstream waterways and habitat from increased erosions by mimicking natural conditions. The water is detained in a pond

[7] Exempt from both green roof and solar.

or structure (like a concrete vault) which reduce the amount of land area available for that development and can have an extraordinary cost (in the case of an underground vault).

The table below summarizes attributes of green roof only programs. Most programs for green roofs are focused on the stormwater benefits. Consequently, incentives often include credit on municipal stormwater billing. The first 3 examples are from Washington State in the areas selected for specific study.

TABLE 3.2: GREEN ROOF PROGRAMS SUMMARY

City	Program Description	Incentive	Notes
Seattle	Multiple ordinances and programs for stormwater management	Stormwater bill credit	Special height requirements can be adjusted to allow for green roof vegetation
	Seattle Green Factor	Mandatory	Requirements for new buildings vary per their zoning. A score must be achieved through various methods, one of which are green roofs.
Yakima	City encourages green roof practices for low impact growth	None Found	
Spokane	Encourages green roofs to meet stormwater requirements	None Found	
Philedephia	Green Roof on new or retrofit buildings	Tax Credit	Up to 50% of the cost of green foor installation
Devens, MA	Industrial Performance Standards. Projects that require air quality permit are required to have a vegetated roof that covers at least 40% of roof area	mandatory	
Portland	In certain zones, developments with rooftop gardens receive bonus floor area.	For each square foot of rooftop garden area, a bonus of one square foot of additional floor area is earned.	The rooftop garden must cover 50% of the roof area and at least 30% of the garden area must contain plants. The property owner must execute a covenant with the City ensuring continuation and maintenance of the rooftop garden by the property owner.
Denver	Building Ordinance requires coverage minimums for green roof: New buildings: 60% Retrofit: 18%	$999 fine or one year in prison per violation. Each violation accrues over 24 hours.	Requirement does not apply to residential buildings less than 4 stories or 50 feet in height, or greenhouses

City	Program Description	Incentive	Notes
	Vegetation shall be 80% of green roof area	Coverage requirement varies by roof area size	and their related structures.
Austin	Credit for open space in downtown area	Incentive is based on area developed	The percent of vegetated roof cover is calculated as a portion of total roof area excluding mechanical equipment, photovoltaic panels, swimming pools, and skylights.
Nashville	Sewer rebate per square foot for green roof coverage of 50% or more	$10/square foot rebate per month until full amount is applied or 60 months	Private property owners only. Limit of $500,000 annually
Washington D.C.	Multiple: Stormwater Retention Clean Rivers Incentive River Smart Rewards River Smart Rooftops	Stormwater Retention credits Discount up to 20% for green roof installation Up to 55% discount based on volume of stormwater reduction Reduced water bill of $15/SF	

3.3 ROOFTOP SOLAR PROGRAMS

Rooftop solar programs types are summarized in Table 3.3 by general type of program.

TABLE 3.3: ROOFTOP SOLAR PV PROGRAMS SUMMARY

Program Type	Program Description	Incentive	Notes
Feed-in-Tariff	Fixed payment for solar PV output from utility company.	$/kWh production	Incentive varies by utility. Typically for in front of the meter applications
Net Energy Metering (rooftop solar PV)	Net billing reduces energy bills to consumers	Incentive level depends on State rules but can range from full retail rate to avoided power costs. True-up period may apply.	WA State NEM policy caps have been met for most utilities Renewable energy credits owned by utility.
Expedited Building Permits	For new or retrofit building permits meeting certain requirements for energy efficiency or solar PV, the permitting process is streamlined.	Shorter permitting process	
Building Codes	California building code requires all new	Mandatory Program	

Program Type	Program Description	Incentive	Notes
	residential buildings to be solar ready		
Solar Loan Programs PACE	Long-term, low-interest loans for solar PV installation costs	Incentive varies by program	
Sales Tax Exemption	Solar PV equipment and installation is exempt from state sales tax		
Property Tax Exemption	Solar energy systems not held for resale are exempt from state, local, and county property taxes.		Struck down in Missouri Court in 2022 as unconstitutional (State)
Renewable Energy Credit Tariff	Utility pays solar PV owner for renewable energy credits for a period of 15 years	Fixed price $/kWh	Program in Connecticut has been discontinued
Federal Tax Credit	Applies regardless of system size	30% of project cost	Original installations only

3.4 INTERNATIONAL PROGRAMS

Programs from other countries are summarized in the table below. The most successful programs internationally have promoted significant education and engagement. Cities with the highest green roof penetration have provided support at multiple levels (regional, local, federal) for many years.

TABLE 3.4: INTERNATIONAL PROGRAMS SUMMARY

Country	Program Description
Germany	Germany was the first country to develop national green roof standards in the 1970s. More than 80 German cities offer green roof incentive programs and over 15% of all roofs in Germany are green roofs.
Denmark	In Copenhagen, all new roofs of less than 30 degree pitch are required to be green roofs. No financial incentives are available; however, there are no detailed requirements for size or habitat developed.
Toronto, Canada	Mandatory green roof law in 2009. Mandatory green roofs on industrial buildings since 2012.
Sydney	Defines green roof as 30% or greater coverage and can include renewable facilities. Primarily educational programs including training and technical guidelines
England	GRO Green Roof Code based on German model but consists primarily of intangible incentives such as training and technical guidelines.

3.5 SUMMARY

Many of the jurisdictions surveyed included multiple programs. Where mandates exist, there were also incentive programs to reduce implementation costs. Flexibility in mandates help buildings with differing characteristics meet the requirement efficiently. Copenhagen was the exception in that no incentives are offered; however, the lack of specific requirements inferrs project design flexibility and the potential for cost containment.

4 Regional Study Coordination

The Research Plan identified several contacts to coordinate study efforts. The efforts and results of this collaboration are summarized in this section of the Report.

Northwest Power and Conservation Council/Regional Technical Forum (RTF)

The Power Council and RTF maintain the methodologies and multiple publicly available data sources used by regional planners for estimating the potential for energy efficiency and demand savings. The RTF continually evaluates new and existing energy and demand-saving measures including updating costs and savings information in response to building code changes or planning environment. As a first step, the Project Team reviewed existing and proposed measure files developed by the RTF and did not find any green roof related work. The Project Team then reached out to Power Council Staff via email to ask about current or previous work on green roof measures. Council Staff reported that there has been no history of green roof measures under evaluation. Council staff also reached out to the Northwest Energy Efficiency Alliance (NEEA) and confirmed that NEEA has also not undertaken research or projects related to green roofs.

Energy Trust of Oregon

The Energy Trust of Oregon administers various energy savings programs for Oregon investor-owned utilities. Energy Trust frequently evaluates programs and new energy saving measures. The Project Team reached out to the Energy Trust via phone to discuss any previous work that relates to green roofs. Energy Trust staff reported that it has not looked into green roofs as energy savings measures. Energy Trust does offer renewable energy programs to customers in its service area including community solar, residential solar plus battery, and income-qualified solar.

Puget Sound Energy (PSE)

PSE is an investor-owned utility serving 1.2 million electric and 900,000 natural gas customers in Western Washington. The Project Team contacted PSE to discuss the utility's plans regarding potential green roof programs. PSE staff reported that PSE was in the very beginning phases of evaluating tree plantings near buildings to reduce summer cooling costs. PSE also reported that it was unaware of any analysis of combined solar and green roofs within its service area, PSE has not been made aware of new commercial construction with green roofs through its energy efficiency programs, and PSE's understanding is that kWh savings is limited with regard to cooling loads in the Pacific Northwest. The Project Team asked PSE staff about the types of information the utility may find useful from this study. PSE noted that having savings and $/square foot for green roofs would be useful to them.

Seattle City Light

SCL provides electric service to the City of Seattle including large industrial areas such as the Port of Seattle. Due to building codes within the City, many of the green roof examples in Washington State can be found in Seattle. The Project Team reached out to SCL multiple times, and, at the time of this draft report, have not received feedback.

Architects of Washington State

Architects of Washington State shared the driving forces for designing and building green roof projects. It is often the case that a green roof is an exciting design idea but rarely gets built due to costs and fears around maintenance from other trades in the building industry. The most practical application of green roofs for developers are those that allow occupiable space and where solar panels can be incorporated as a shade structure for the building occupants.

4.1 GREEN ROOF INSTALLERS

The Project Team contacted a total of 26 service providers believed to be engaged in Green Roof (GR) installations in the State of Washington. The pool of service providers that were contacted, and the interview questions, are included in this report as Appendix A.

A priority was placed on obtaining the following information from each of the service providers:

- Confirming that each company installs green roofs and the extent to which green roofs make up total business for each company
- Geographical service area and type(s) of installations (i.e. new, retrofits, etc.)
- Building types (commercial, multi-unit residential, etc.)
- Average costs of green roof installation and of required operation and maintenance (O&M)
- Known/common incentives for building owners
- Impediments/challenges/lessons learned associated with green roofs
- Role of/involvement with architects or engineers

An e-mail was sent to each company with the survey questions. The Project Team then followed up with telephone contact. A total of 8 parties ultimately responded and provided information. A communications record is included as Appendix B. Responses to individual questions were significantly variable. Key findings from the survey are provided below.

1. The limited amount of cost data gathered from this survey shows considerable variability and should be viewed with caution; it was not feasible to standardize the criteria for cost information in the context of the interviews.
2. Respondents opined that green roof incentives will increase the amount of green roof construction with the caveat that the process to obtain the incentives is a simple process.
3. Respondents stated that policies encouraging green roofs need to be strong, but also need to motivate users to not look for loopholes and workarounds.
4. Green roofs are currently implemented for occupiable space because it’s viewed by developers as potentially bringing in more money or increasing asset value.
5. Developers are not interested in green roofs for sustainability because of the high overhead and maintenance concerns around green roofs, including leaks.
6. Maintenance is the “make it or break it” to green roofs. Maintenance and installation companies need to be properly trained, and probably certified.
7. Respondents reported their observations that the conventional roofing industry is not interested in learning new green roof technologies and is generally skeptical of the entire concept.
8. Motivated building owners often lack the resources for green roof installations and are unwilling to commit to the ongoing overhead associated with long term upkeep and maintenance.
9. There are mixed perspectives about combining green roofs and solar panels. Unless plant production is a driving factor, green roof installers are skeptical of colocation.
10. The plant height to cool solar panels are thought to require an intensive green roof which is more expensive and requires more structural support; it is not viewed as cost effective.
11. There is a desire from architects to design these buildings, but the architects observe a general reluctance from the installers and contractors to get involved with implementation.

5 Costs and Benefits

The overall approach to collecting and summarizing benefits information focused preferentially on more recent reports (i.e. last 10 years) specific to the Pacific Northwest, and supplementing that as needed (and when available) with information originating from broader geographical area – namely, other areas in the U.S. Since so much green roof (GR) work has been done in other countries (primarily western Europe and Australia), select international information is also included in support of filling data gaps and identifying general trends.

Generally, most of the information reviewed is from academic research, with additional information provided by various levels of government and sourced primarily from case studies, trade associations and service providers.

Multiple information sources have cautioned that many of the stated benefits of green roofs are highly dependent on a variety of site-specific variables including those intrinsic to the green roof itself (i.e. design specifications, life cycle) and extrinsic variables like climate, green roof operation and maintenance (O&M). Consequently, it is difficult (and risky) to identify universal beneficial outcomes from all green roof installations; the research summarized in this report focuses on generally reported trends and overall findings, and includes qualifiers influencing resultant benefits, where these are identified.

5.1 STORMWATER QUALITY

A very large body of information on the benefits of green roofs related to stormwater (SW) quality has been generated over the last 20 years.[8] Studies have evaluated different plant bed media and plant species. Many of these studies have focused on plant nutrients and to a lesser extent, trace metals – both groups being prominent in urban stormwater runoff. Depending on the airshed, rainwater is relatively pure in most cases; constituents are limited to solids (dissolved or in suspension and possibly metallic components). Rainwater may also have an acidic component.

The quality of SW runoff from a green roof can be considered both from a pollutant concentration and a total pollutant amount (mass loading) standpoint. Green roofs are known to have the capacity to retain a significant portion of precipitation, to slow the release of retained precipitation, and to release precipitation back into the atmosphere through plant evapo-transpiration. Looking at SW quality in terms of mass loading, the mechanisms described above can reduce the total quantity of SW that would otherwise be discharged, resulting in an overall decrease in polluting constituents.

Looking strictly at water quality (WQ) however, reviewed information presents a "mixed bag." Green roofs can be either a sink or a source of water pollutants, depending on whether plants and the growing substrate take up or release constituents as water passes through.

The primary reported[9] determining factors influencing SW quality are as follows:

[8] Akther et. al., "A Review of Green Roof Applications for Managing Urban Stormwater in Different Climatic Zones", *Sustainability* 2018, *10*(8), 2864

[9] Gnecco et. al. "The Role of Green Roofs as a Source/Sink of Pollutants in Storm Water Outflows", Water Resources Management Vol 27, pgs. 4715–4730 (2013)

- Climate, seasonal and hydrologic variables (seasonal and rainfall influences)
- Factors effecting constituent update or release from green roof growing beds
  - Bed depth (intensive/extensive) and substrate (i.e. mineral and organic content)
  - Vegetation type and health
  - Fertilizer or other applications (nutrient and pH profile)
- Age of the green roof and maintenance practices

In the context of SW discharges from green roofs, the primary WQ constituents of concern, particularly in developed watersheds, are nutrients (phosphorus (P) and nitrogen (N) compounds). The contributions from green roofs of other constituents impacting stormwater discharges to an urban watershed (i.e. zinc, copper, petroleum compounds) is typically assumed to be minimal.[10]

Research papers reviewed indicate that green roofs can be a source or a sink of P and N; for example, concentrations of these nutrients were generally found to be higher in new green roof installations and to decrease over time, as plant uptake stabilizes, and the growing medium ecosystem matures.[11] However, site-specific factors and short-term variations, typically caused by poor green roof management techniques, can result in significant release of chemical constituents from a green roof. For example, excessive use of fertilizers, particularly during wet seasons, can release concentrated "slugs" of nutrients to the local watershed. Given that, a scenario involving a number of these poorly maintained green roofs discharging excessive nutrients to nearby surface waters (i.e. a nearby pond or recreational lake) could contribute to eutrophication problems. This underscores the importance of continued care and maintenance of green roofs throughout the duration of their useful life.

The information reviewed generally concludes that healthy, well-maintained green roofs either benefit SW quality or have a net neutral effect on the quality of discharged SW over the long term, the overall benefit of green roofs to SW quality is generally positive, primarily due to stormwater retention and moderation of flow volumes over time, and to a lesser extent, to the filtering and natural attenuation of water-borne constituents by plants and the growing substrate. Stormwater quality impacts can vary significantly across specific green roof sites and over time periods at any specific site, however, the overall impact to the runoff WQ within a given watershed, however, may be minimal.

5.2 IMPROVED AIR QUALITY (AQ) AND REDUCED GREENHOUSE GAS (GHG) EMISSIONS

Vegetation can improve air quality in the local environment. Larger shrubs and trees can intercept air borne solid particles (such as dust, diesel soot particles, etc.) directly onto their foliage. Rainwater picks up airborne contaminants directly as it falls through the atmosphere, and deposits it on plant surfaces. Plants can directly trap aerosol particulates potentially containing contaminants. By these mechanisms, contaminants are transferred from the atmosphere and deposited within or on the plants or are transported down into the growing medium (substrate).

[10] Okita, et. al., "Effect of Green Roof Age on Runoff Water Quality in Portland, Oregon", Journal of Green Building (2018) 13 (2): 42–54

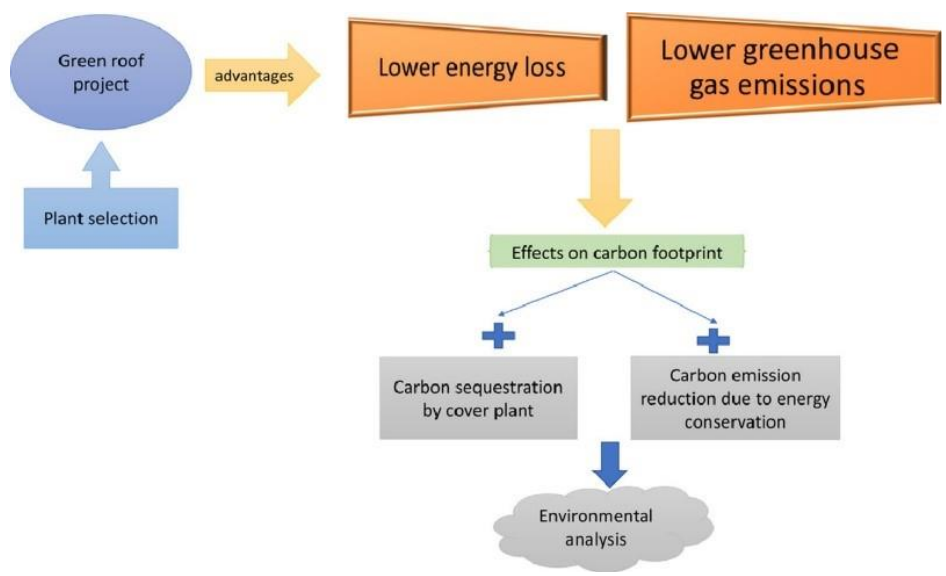
[11] Lim, "What happens to nitrogen and phosphorus nutrient contributions from green roofs as they age? A review", Environmental Advances, Vol. 12, July 2023, 100366

In addition to direct air pollution removal mechanisms, plants improve air quality by converting carbon dioxide (CO2) into oxygen through photosynthesis. CO2 is a major greenhouse gas (GHG) emission, so plants play a major role in countering global warming. Green roofs can contribute to reducing GHG emissions as plants take up CO2 and sequester carbon within plant growth through photosynthesis. Green roofs could be credited as a carbon sink in a cap-and-trade system, which provides a mandatory cap on carbon emissions.

Green roofs indirectly reduce GHG emissions through their contribution to cooling and insulating a building's heat envelope. Insulation provided by green roofs can reduce the amount of energy needed to moderate building temperatures, since roofs are the site of the greatest heat loss in the winter and the hottest temperatures in the summer. The specific amount of energy saved depends on a variety of site and setting -specific factors. The temperature moderating effects of green roofs can reduce demand for electrical power generation needed for building heating and cooling, thereby potentially decreasing the amount of CO2 and other pollutants being released into the air. For example, research published by the National Research Council of Canada found that an extensive green roof reduced the daily energy demand for air conditioning in the summer by over 75%.[12] (Liu, 2003)

Numerous studies over the past 20 years reveal that green roofs directly sequester substantial amounts of carbon in plants and soils through photosynthesis, countering the effects of global warming by reducing GHGs.[13] The two mechanisms – direct carbon sequestration and reduction in building power demands – are represented graphically in the figure below.

FIGURE 5.1: GREEN ROOF CARBON FOOTPRINT IMPACTS[14] (SEYEDABADI, 2021)



[12] Liu et. al., "Thermal Performance of Green Roofs Through Field Evaluation", In Proceedings: The First North American Green Roof Infrastructure Conference, Chicago, IL, 2003 (pgs. 1-10)

[13] Shafique, et. al., "An overview of Carbon Sequestration of Green Roofs in Urban Areas", Urban Forestry & Urban Greening, Vol. 47, January 2020, 126515

[14] Source: Seyedabadi et. al., "Plant Selection for Green Roofs and Their Impact on Carbon Sequestration and the Building Carbon Footprint" Environmental Challenges, Vol. 4, August 2021, 100119

As an example of the research conducted in this area, a 2021 study[15] modeling buildings with green roofs found that popular sedums resulted in sequestration of 0.029 to 0.424 lbs of CO_2 per square foot per year. For perspective, a 2009 report on green roofs in Seattle WA estimated the total square footage at 359,375.[16] Using the lower carbon sequestration factor (0.029) from above, this amount of green roof area would correspond to 5.2 tons of sequestered CO_2. Using the same lower factor, a national survey in 2018 estimated the total square footage of green roof in the US to be 3,112,818,[17] corresponding to 45 tons of sequestered CO_2.

Using the carbon sequestration metric from the building simulation study, and the social cost of carbon, each square foot of extensive green roof has a carbon sequestration value of approximately $0.01 per year ($2023). Intensive green roofs store more CO_2 resulting in an average value of $0.018/square foot per year using the carbon sequestration values estimated in a 2017 study in Mexico City.[18]

Building development density impacts surface temperatures in many cities around the world where urban properties experience markedly warmer temperatures compared with the surrounding countryside. These areas are called "urban heat islands" (UHI). The effect occurs because most urban surfaces are typically buildings, roads and sidewalks that tend to absorb heat from the sun. Rooftops typically make up 5 to 35 percent of the urban landscape.[19] In addition, urban areas have much less "green canopy" provided by trees and other plants to provide cooling through evapotranspiration, when heat energy is dissipated as water evaporates and transpires from vegetation. In addition, light absorbed by vegetation would otherwise be converted into heat energy.

The U.S. Environmental Protection Agency (EPA) reports that over 90% of the rooftops in the United States are dark in color. Since dark surfaces reflect very little sunlight, they absorb all the incoming heat. As a result, city roof surfaces can reach temperatures of 150°-190°F (66°-88°C) during the summer.[20] At these elevated temperatures, cooling interior building spaces requires much more electricity. Urban air pollution, especially photochemical smog is intensified by the heat island effect. Consequently, heat island effects increase heat-related illness and mortality, in addition to increasing building energy consumption and related GHG generation.

Green roofs help reduce the urban heat island effect by replacing black heat-absorbing surfaces with vegetation that can significantly reduce local temperatures in cities during the hottest times of the year, through the natural functions of plants, during the diurnal dew point and evaporation cycle, plants on vertical and horizontal surfaces are able to cool cities during hot summer months and reduce the UHI effect. One study found that green roof temperatures are within ambient air temperatures whereas conventional roofing temperatures are 7 degrees Celsius higher than ambient temperatures.[21]

---

[15] See id.

[16] McIntosh, "Green Roofs in Seattle - A Survey of Vegetated Roofs and Rooftop Garden", prepared for the City of Seattle, Dept of Planning & Development and the University of Washington Green Futures Lab, August 2010

[17] Green Roofs for Healthy Cities, "2018 Annual Green Roof Industry Survey Executive Summary", (www.greenroofs.org), October 2019

[18] Collazo-Ortega, Margarita, Ulises Rosas and Jeronimo Reyes-Santiago. Towards Providing Solutions to the Air Quality Crisis in the Mexico City Metropolitan Area: Carbon Sequestration by Succulent Species in Green Roofs. March 2017. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5400495/#:~:text=The%20species%20displayed%20their%20typical,meters%20in%20the%20short%20term.

[19] U.S. Environmental Protection Agency. 2008. Green Roofs, in "Reducing Urban Heat Islands: Compendium of Strategies". Draft. https://www.epa.gov/heat-islands/heat-island-compendium

[20] See id.

[21] William Reshmina et al. An Environmental cost-benefit analysis of Alternative Green Roofing Strategies. Ecological Engineering Volume 95, October 2016. https://www.sciencedirect.com/science/article/abs/pii/S0925857416304165

Intensive green roofs have the potential to provide more cooling and energy savings benefits than extensive green roofs. The increased soil depth and plant density of intensive green roofs prevents heat from moving down to interior ceiling heights. Studies at the National Research Council of Canada (2003) have shown that green roofs can reduce the heat flow through the roof by 70% to 90% in the summer and 10% to 30% in the winter.[22] This effect is more significant in hot, dry climates than in humid or temperate climates.

Data was not available for quantifying the non-building value of reduced UHI effects in urban areas. Anecdotally, reduced surface temperatures will have greater community health benefits in lower-income communities due to the higher share of impermeable surfaces found in those communities. A California study found that ambient temperatures were as much as 5 degrees warmer in low-income neighborhoods compared with median income neighborhoods.[23] Green roof temperature effects on very warm days have the potential to positively impact comfort and reduce heat related illness and mortality. This potential is particularly important in low income or other disadvantaged communities where temperatures are generally warmer compared with temperatures in median income or more affluent communities.

5.3 FOOD PRODUCTION

Green Roofs as spaces for urban agriculture is not a new concept but in general has not yet seen wide- spread application, despite the potential to provide new opportunities for local urban food production, and for creating potential economic and social benefits not available on conventional roofs. Depending on the size and scale of food production, fresh produce could be marketed to local businesses and restaurants or could help meet the needs of the building occupants.

Green roof food production provides a number of potential benefits, including the following:

- Increased property values and added marketability
- Potential venue to educate urban residents about food production
- Revenue and reduced costs associated with providing fresh produce locally
- Environmental benefits from reduced transportation, potentially less packaging and localized control of agricultural chemicals
- Increased security of the growing operation and isolation from damage by vermin
- Support of the local economy in growing, processing and distributing, and through potential job creation

Although some crops such as herbs can be grown in extensive green roofs, growing food crops would typically require deeper growing media which requires specifically designed and engineered green roofs that can structurally support intensive beds and ancillary systems for plant nutrition and irrigation.[24] Many (if not most) existing large flat roofs may not have the loading capabilities to support food crop production, some roofs will, and more new roofs will be appropriately designed as the concept enters the mainstream. In addition, many existing balconies in urban areas are ideal for small-scale food production.

---

[22] Tolderlund, “Design Guidelines and Maintenance Manual for Green Roofs in the Semi-Arid and Arid West”, University of Colorado, Denver CO, 2010

[23] Dialesandro, John et al. Dimensions of Thermal Inequity: Neighborhood Social Demographics and Urban Heat in the Southwestern U.S. Environmental Public Health 2021.

[24] United States General Services Administration, “The Benefits and Challenges of Green Roofs on Public and Commercial Buildings”, May 2021

Several vegetable growing rooftop gardens have been implemented in Seattle[25] including single family residences. The Stack house Apartments is home to a 1,000 square foot roof top garden. The garden is maintained by a third party and produce is provided free to the apartment residents. These apartments are considered premium value with monthly rent currently in the range of $1,700-$12,000. Similarly, the Angeline apartments includes a 1,000 square foot edible garden that offers residents u-pick foods 10 months out of the year. A studio apartment at Angeline starts at $2,100 per month. These rent levels are typical of Seattle apartments suggesting that edible gardens add value without increasing the monthly cost.

In another example, Quality Athletics in Pioneer Square has implemented a rooftop edible garden where the produce is served in the restaurant. Restaurant seating and gathering space complement the rooftop garden.

5.4 BIODIVERSITY, ECOSYSTEM HEALTH AND HUMAN QUALITY OF LIFE CONSIDERATIONS

Healthy green roofs can sustain a variety of plants and invertebrates, and provide new habitat in urban areas, increasing local biodiversity. They provide excellent urban habitat for various bird species, and by acting as a transitory habitat for migrating birds they contribute to linking sustaining habitat that would otherwise be fragmented.

The most important factors in encouraging biodiversity in a green roof are vegetation type, growing medium depth and variation in plant height and spacing.[26] In addition, green roof topography and adjacent local landscape areas, can affect a roof's ability to enhance biodiversity.

Increasing biodiversity and available habitat can provide significant benefits in three fundamental areas:

Ecological – Diverse ecosystems are better able to support higher and more robust levels of productivity and provide resilience to potential changes or disturbances compared with those hosting fewer species.
Economic – Healthy and stable biodiversity supports economic activity and provide effective and ecosystem services (maintains hydrological cycles, air and water quality, storage and cycling nutrients)
Social-Environmental diversity and visual aesthetics can have positive impacts on community health and human well-being.

Green roofs provide additional benefits to humans. The ability of green roofs to reduce air pollution and improve water quality has direct positive influence on overall human health and associated demands for healthcare. Green roofs can serve as community hubs, increasing social cohesion, sense of community, and public safety.

Green roofs are more effective at noise reduction especially in areas with heavy motor or air traffic, and at countering urban heat island effects than convention roofs. Green roofs are an attractive space for tenants (and for occupants of neighboring buildings), providing a place of refuge recreation and relaxation, potentially reducing stress and improving worker productivity. They can offer quality outdoor spaces that may add value for building owners. Green roofs are an important component of "urban greening" and the larger strategy for beautifying the

[25] https://www.seattleurbanfarmco.com/
[26] Kessling et. al., "Feasibility of Combining Solar Panels and Green Roofs on the Activities and Recreation Center"

built environment and increasing investment opportunity. Aesthetic and quality of life benefits from green roofs are tangible but difficult to quantify.[27]

5.5 STORMWATER QUANTITY AND PEAK FLOW BENEFITS

Stormwater benefits include reduced total runoff, reduced peak flow and contribution to Combined Sewer Overflow (CSO) events. The Seattle climate (and much of Western Washington) experiences periods of extensive rainfall followed by very dry summer months. During storm events the wet weather results in CSO events where the partially separated sewer and storm drain systems become overloaded. The City of Seattle plans its capital outlay to reduce these events to 1 outfall per year for each of the 82 sewer outfalls. Reducing or delaying stormwater runoff for new buildings could impact the City's capital improvement expense. Additionally, reducing stormwater flows through treatment facilities will have a direct impact on the variable cost of operating the stormwater utility.

A study by the University of Washington[28] provides some specific data for green roofs in the Seattle area. This study reiterated the difficulty in quantifying the hydrologic performance of these structures. Over a 12-month period, 5 test panels were used of varying growing depths, plant types, drainage media and layers. The study resulted in a wide variation of rainfall retention (30-56 percent) over one year, with better performance by panels with deeper soil and a layer of moisture retention fabric. The best retention occurred in all panels during the month of August when the least amount of rainfall occurred, with the worst retention happening, when back-to-back rainstorms occurred in November. The results mirror what is found in other studies: the factors that determine the amount of stormwater retained include the surface area of the roof, the depth and type of growing medium, the slope and type of plants selected.[29]

Reduced or delayed runoff will be impacted by several site-specific conditions including the following:

- Size, shape, and slope of roof
- Antecedent soil moisture conditions
- Magnitude, duration, and distribution of rainfall event
- Vegetative conditions, and
- Runoff travel path.[30]

The capacity of green roof systems to provide seasonal runoff volume reduction varies. The effectiveness is reduced for sustained or repeated storm systems during the rainy season. However, the reduction in peak flow was found significant in a Seattle Study. The peak flow reduction for three of the sampled green roofs varied from -15-63%.[31] The percentage of rainfall measured in runoff was also measured. The findings are summarized in Table 5.2.

---

[27] United States General Services Administration, "The Benefits and Challenges of Green Roofs on Public and Commercial Buildings", May 2021

[28] Yocom, Ken and Ben Spencer. Greenroof Performance Study: Puget Sound Region. Seattle WA. 2012 /https://thecela.org/wp-content/uploads/GREENROOF-PERFORMANCE-STUDY.pdf

[29] U.S. Environmental Protection Agency. Stormwater Best Management Practice. Green Roofs. December 2021. Available at: www.epa.gov/system/files/documents/2021-11/bmp-green-roofs.pdf

[30] Cardno TEC, Inc. Green Roof Performance Study. Prepared for Seattle Public Utilities. June 2012. Available at : https://www.seattle.gov/documents/Departments/OSE/Green-Roof-Performance-Study-2012.pdf

[31] See id.

TABLE 5.2: SUMMARY OF FINDINGS GREEN ROOF PERFORMANCE STUDY, 2012

Roof	Peak Reduction Estimate	Runoff Volume as a Percentage of Rainfall	Other Details
Seattle Facilities: Fire Station 10 (FS10)	7% - 40%	32% - 100%	2" drainage later + 4" growth layer 6,400 square feet. Slope 1:24 Shorter runoff path and impervious surfaces compared with EOC
Seattle Facilities: Emergency Operations Center (EOC)	35% - 65%	27% - 93%	2" drainage later + 4" growth layer 7,475 square feet Slope 1:24
Zoomazium Woodland Park Zoo	-15% - 63%	7% - 87%	6" soil, vegetation quality high 8,000 square feet Slope variable: 0:12 to 3:12

Another study estimated 10-25% annual runoff reductions could be achieved when only 10% of the Seattle watershed is converted to green roof. This study found these results based on simulation analysis of the Seattle area.[32]

The DOE manual for Western WA refers to a runoff model using modeling software to represent the changes to stormwater "flow control" when utilizing a green roof. This model, along with any possible credits from local agencies, is what is used by engineers to determine if a green roof is viable for new development.

Simlar DOE screening criteria for Eastern Washington is determined by the wet load capacity of the roof due to wet soil and snow loads customary to that part of the state. Models of two different-sized roofs (average 34,355 and office 22, 970 sq ft) were undertaken using the Western Washington Hydrology Model;[33] the percentage of mitigation from a flow and percentage perspective were relatively the same for both sizes (about 51.6% reduction). The model output did not change when the roof slope or depth of soil were increased; these variances have more impact to ongoing maintenance than to stormwater mitigated.

5.5.1 Stormwater Benefit Modeling

Arizona State University has developed a calculator for measuring energy and stormwater savings resulting from green roofs.[34] The calculator results were the same for any size building, similar to the modeling efforts previously discussed. In addition, it only had Seattle and Spokane, so Fresno CA was used since it has similar rainfall to Yakima. While most installations recommend irrigation of some kind, drought-tolerant species of plants in Western WA can prosper once established without irrigation. Vendors surveyed for this project stated that irrigation in Western Washington is recommended in the first 1-2 years. All plant mediums will require some

---

32 Barnhart, Brad et al. Modeling the hydrologic effects of a watershed-scale green roof implementation in the Pacific Northwest United states. Journal of Environmental Management Volume 277, 1 January 2021.

33 Solutions, Clear Creek. Western Washington Hydrology Model Version 4.2.19. Accessed April 2023.

34 Arizona State University. https://sustainability-innovation.asu.edu/urban-climate/green-roof-calculator/ *NOTES: Over the course of a simulation year the net water inflow may not balance outflow due to changes in soil moisture. Also, water balance dynamics are sensitive to growing media composition, compaction, etc. As these variations are not captured in the present tool, the runoff results should be considered as order-of-magnitude estimates.*

degree of maintenance and re-planting over the life of the roof. This would offset the reduced maintenance of the roof itself as the membrane, when protected by sunlight, has a longer service life than a typical roof.

TABLE 5.3: CHANGES IN STORMWATER RUNOFF WITH GREEN ROOFS

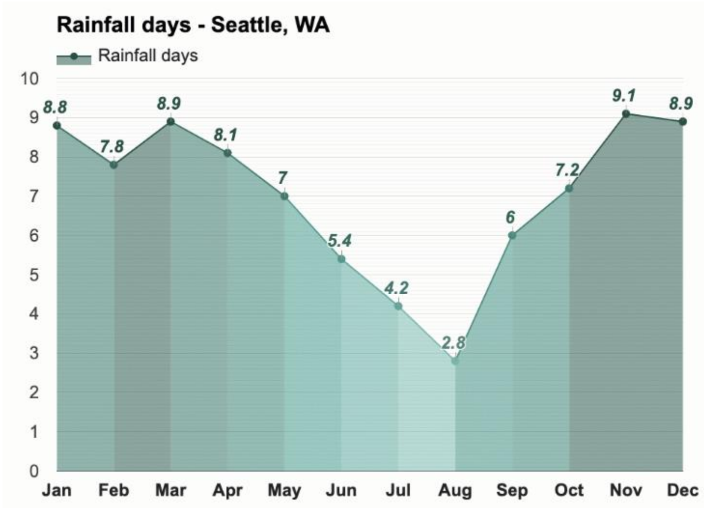
	Seattle	Spokane	Yakima*
Rainfall, Inches	**34.8**	**14.5**	**7.6**
Scenario 1: 70, 4, Y			
Evapotranspiration	18.8	15.2	12.2
Irrigation	11.7	11.7	11.7
Net Runoff	26.4	11.1	8.2
Reduced Runoff	8.4	3.4	-0.6
gal/year	62.748	25.398	-4.482
Scenario 2: 30,4,Y			
Evapotranspiration	8	6.5	5.2
Irrigation	5	5	5
Net Runoff	31.2	13	7.9
Reduced Runoff	3.6	1.5	-0.3
gal/year	26.892	11.205	-2.241
Scenario 3: 50, 6, Y			
Evapotranspiration	13.4	10.9	8.7
Irrigation	8.4	8.4	8.4
Net Runoff	28.8	12.1	8
Reduced Runoff	6	2.4	-0.4
gal/year	44.82	17.928	-2.988
Scenario 4: 70, 6, Y			
Evapotranspiration	19.7	15.6	12.8
Irrigation	11.7	11.7	11.7
Net Runoff	25	10.4	8
Reduced Runoff	9.8	4.1	-0.4
gal/year	73.206	30.627	-2.988
Scenario 6: 70, 6, N			
Evapotranspiration	14	9.7	6.9
Irrigation	0	0	0
Net Runoff	19.1	4.7	2.3
Reduced Runoff	15.7	9.8	5.3
gal/year	117.279	73.206	39.591
Scenario 7: 50, 6, Y			
Evapotranspiration	14.1	11.1	9.1
Irrigation	8.4	8.4	8.4
Net Runoff	27.9	11.6	7.9
Reduced Runoff	6.9	2.9	-0.3
gal/year	51.543	21.663	-2.241
Scenario 8: 30, 6, Y			
Evapotranspiration	8.5	6.7	5.5
Irrigation	5	5	5
Net Runoff	30.7	12.7	7.8
Reduced Runoff	4.1	1.8	-0.2
gal/year	30.627	13.446	-1.494

*Fresno, CA used to model Yakima. Annual rainfall in Yakima is 8.0 inches.
Scenario legend (Green Roof Coverage %, Media Depth, Irrigated Y/N)
All scenarios were given a "leaf index" value of 2. (Bare ground =0 Dense Forest = 6)

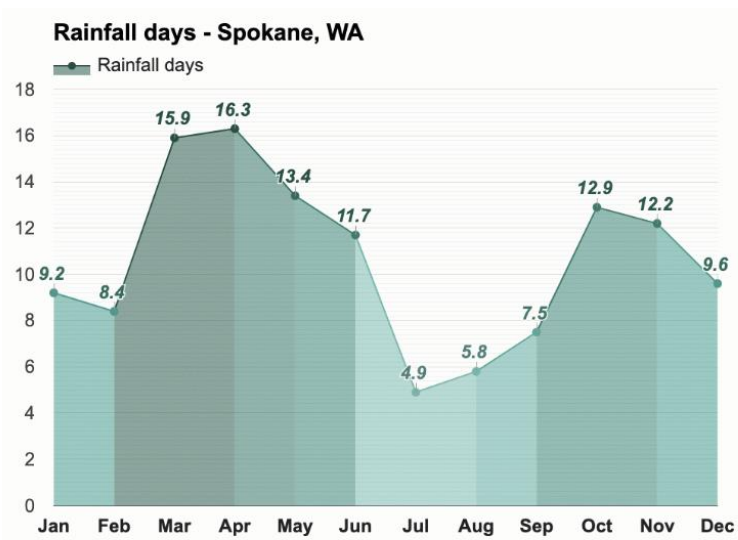
The above analysis does not appear to consider the seasonality of irrigation in each of the regions. Therefore, the Project Team evaluated how irrigation systems would operate in each month to determine the net runoff where irrigation is needed only in dry months. The charts below illustrate the monthly rainfall days.[35] It was assumed that months with less than 1.5% rainfall days would require irrigation. The irrigation contribution to annual run off is then adjusted based on that assumption. Figure 5.1 shows the months where irrigation would impact runoff volumes (yellow shaded months). Tables 5.4 through 5.6 show the impact of the seasonality adjustment for irrigation. Spokane soil depths were adjusted to 6 inches for extensive and 10 inches for intensive so that irrigation systems were no longer needed.

[35] Data sourced from Weather-us.com.

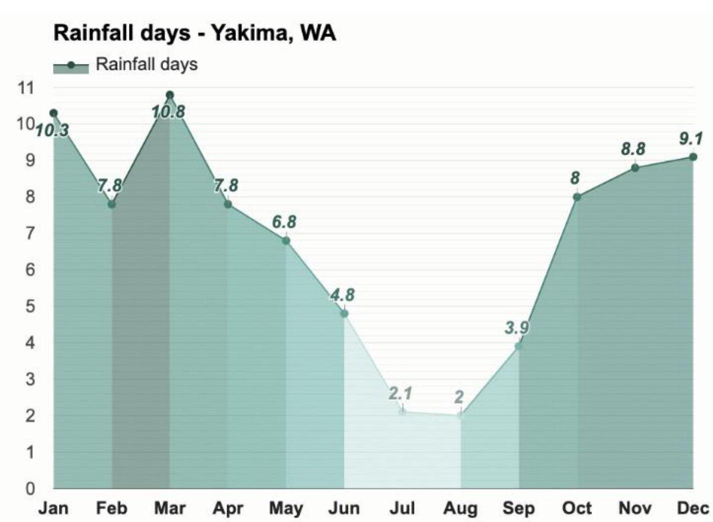
FIGURE 5.1: MONTHLY RAINFALL DAYS DATA



Jan	8.8	2.41%
Feb	7.8	2.14%
March	8.9	2.44%
April	8.1	2.22%
May	7	1.92%
June	5.4	1.48%
July	4.2	1.15%
Aug	2.8	0.77%
Sept	6	1.64%
Oct	7.2	1.97%
Nov	9.1	2.49%
Dec	8.9	2.44%



Jan	9.2	2.52%
Feb	8.4	2.30%
March	15.9	4.36%
April	16.3	4.47%
May	13.4	3.67%
June	11.7	3.21%
July	4.9	1.34%
Aug	5.8	1.59%
Sept	7.5	2.05%
Oct	12.9	3.53%
Nov	12.2	3.34%
Dec	9.6	2.63%



Jan	10.3	2.82%
Feb	7.8	2.14%
March	10.8	2.96%
April	7.8	2.14%
May	6.8	1.86%
June	4.8	1.32%
July	2.1	0.58%
Aug	2	0.55%
Sept	3.9	1.07%
Oct	8	2.19%
Nov	8.8	2.41%
Dec	9.1	2.49%

TABLE 5.4: SEATTLE GREEN ROOF NET RUNOFF

	Seattle
Rainfall	34.8
Scenario 1a: 70, 4, Y	
Evapotranspiration	18.8
Irrigation	1.95 (2/12 of 18.8)
Net Runoff	17.95
Scenario 2a: 30,4,Y	
Evapotranspiration	8.0
Irrigation	0.83 (2/12 of 5.0)
Net Runoff	27.63
Scenario 3a: 50, 4, Y	
Evapotranspiration	13.4
Irrigation	1.4 (2/12 of 8.4)
Net Runoff	22.8
Scenario 4a: 70, 6, Y	
Evapotranspiration	19.7
Irrigation	1.95 (2/12 of 11.7)
Net Runoff	17.05

Based on rainfall days for the Seattle region, months with the least amount (less than 1.5% was chosen arbitrarily for all cities) are July and August or 2/12 months of the year. Irrigation rates from earlier scenarios were adjusted to reflect irrigation for only two months. The net runoff was then approximated. The resulting runoff is considerably reduced for the roofs with the largest area.

TABLE 5.5: SPOKANE GREEN ROOF NET RUNOFF

	Spokane
Rainfall	14.5
Scenario 6: 70, 6, N	(from above)
Evapotranspiration	9.7
Irrigation	0
Net Runoff	4.7
Scenario 6a: 30, 6, N	
Evapotranspiration	4.1
Irrigation	0
Net Runoff	10.3
Scenario 6b: 70,10,N	
Evapotranspiration	9.8
Irrigation	0
Net Runoff	4.4
Scenario 6c: 30,10,N	
Evapotranspiration	4.2
Irrigation	0.0
Net Runoff	10.2

Based on rainfall days for the Spokane region, there is consistent rain each month (only one month less than 1.5%). For this reason, the model was adjusted by increasing the amount of growing media in the soil from 6-inches (Scenario 6 above) to retain the rainfall instead of irrigating. The end result had a very slight reduction in net runoff.

TABLE 5.6: YAKIMA GREEN ROOF NET RUNOFF

	*Yakima
Rainfall	7.6
Scenario 1a: 70, 4, Y	
Evapotranspiration	12.2
Irrigation	3.9 (4/12 of 11.7)
Net Runoff	0
Scenario 2a: 30,4,Y	
Evapotranspiration	5.2
Irrigation	1.7 (4/12 of 5.0)
Net Runoff	4.1
Scenario 3a: 50, 4, Y	
Evapotranspiration	8.7
Irrigation	2.8 (4/12 of 8.4)
Net Runoff	1.7
Scenario 4a: 70, 6, Y	
Evapotranspiration	12.8
Irrigation	3.9 (4/12 of 11.7)
Net Runoff	0

*Modeled based on Fresno, CA annual rainfall inches.

Based on rainfall days for the Yakima region, there are 4 months with the least amount (less than 1.5% was chosen arbitrarily for all cities) rainfall, or 4/12 months of the year. Irrigation rates from earlier scenarios were adjusted to reflect irrigation for only four months. The net runoff was then approximated. The resulting runoff is considerably reduced for the roofs with the largest area.

The resulting stormwater reduction estimation is presented in gallons per year below. The irrigation impacts results in negative gallons or an increase in runoff. This finding will be analyzed further in the next phase of our analysis. The modeling above does not consider the seasonality of irrigation vs. stormwater storage or delayed runoff.

TABLE 5.7: CHANGE IN RUNOFF PER SQUARE FOOT OF GREEN ROOF PER YEAR

	70% Green Roof	30% Green Roof		50% Green Roof	
Gallons/year	Extensive Commercial	Extensive Commercial	Intensive Multifamily	Extensive Commercial	Intensive Multifamily
Yakima	5	2	0	4	4
Spokane	6	3	3	7	7
Seattle	10	4	5	7	8

Valuing the change in stormwater runoff is challenging since stormwater systems are sized to handle specific maximum flow events. The majority of stormwater costs are fixed; however, reduction in peak flows and quantities will reduce the capital investment needed in future years. Stormwater utility infrastructure in each of the three selected regions will vary depending on total rainfall, watershed size, development level, and severity of storm events As mentioned above, the stormwater infrastructure in Seattle is partially combined with the sanitary sewer system. This is the case for many urban areas originally designed and contucted with combined systems. City stormwater budgets were reviewed and compared with the quantity of stormwater handled by the stormwater system. Treatment costs for stormwater are considered variable costs. Spokane and Seattle both treat some of the stormwater runoff captured in the combined sewer systems. Yakima does not currently treat stormwater. The table below summarizes the annual stormwater treatment water expenses for each of the cities and estimates the unit cost of one gallon of stormwater. The values for Seattle are highest given the amount of annual rainfall and population density. The quantity of treated stormwater in gallons was not available from each

City. Therefore, the resulting variable values should be considered indicative of the relative importance of stormwater management rather than the true cost of avoiding 1 gallon of stormwater.

TABLE 5.8: ANNUAL STORMWATER COSTS, PER GALLON

	Stormwater Treatment Budget (2024)	Gallons of Stormwater per Year (treated and untreated)	$/Gallon of Stormwater
Seattle	$9,800,000[36]	400,000,000[37]	$0.0245
Spokane	$8,798,550[38]	1,000,000,000[39]	$0.0088
Yakima	$0[40]	275,000,000[41]	$0.0000

Combining the above values results in the value of stormwater reduction per square foot of green roof for each city as shown in Table 5.9.

TABLE 5.9: ANNUAL STORMWATER BENEFITS, PER SQUARE FOOT ROOF AREA

	70% Green Roof	30% Green Roof		50% Green Roof	
Gallons/year	Extensive Commercial	Extensive Commercial	Intensive Multifamily	Extensive Commercial	Intensive Multifamily
Yakima	$0.00	$0.00	$0.00	$0.00	$0.00
Spokane	$0.05	$0.02	$0.02	$0.06	$0.06
Seattle	$0.26	$0.11	$0.12	$0.18	$0.19

Deferred capital investments due to reduced stormwater quantities were not estimated. Current stormwater capital budgets address current needs that are unlikely to change in the near term are the result of green roofs on new construction. In order to estimate the deferred capital investment, detailed studies would need to be conducted that evaluate planned infrastructure, new development vs existing issues, and flow impacts from green roofs on new development. These studies are not readily available; therefore, the value is not included in the benefit-cost analysis.

[36] City of Seattle Drainage Wastewater Rate Study. https://www.seattle.gov/documents/Departments/SPU/Services/Rates/2022-2024_DrainageWastewater-RateStudy.pdf

[37] Seattle Public Utilities and King County. Green Stormwater Infrastructure 2017-2018 Overview and Accomplishment Report. https://www.seattle.gov/documents/Departments/SPU/Documents/Reports/GSI-ProgressReport2018.pdf

[38] City of Spokane 2023 Adopted Budget. https://static.spokanecity.org/documents/budget/2023/2023-adopted-budget-detail.pdf

[39] City of Spokane notes 1 billion gallons of stormwater runoff feeding the Spokane River.

[40] City of Yakima 2024 Preliminary Budget. https://www.yakimawa.gov/services/finance/files/2023-2024-Revised-Preliminary-Budget-Qtr-Amend.pdf

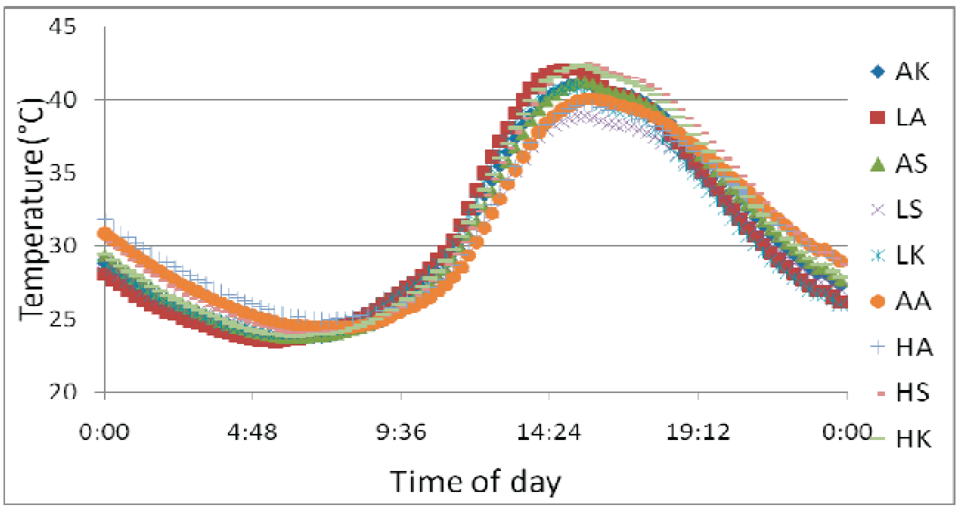
[41] Estimated based on annual rainfall and land area.

5.6 BUILDING PERFORMANCE ENERGY IMPACTS

Our analysis of the energy effects on agrivoltaic buildings began with a literature review of applicable studies, primarily scientific journal studies and white papers. It was observed that the prevalence of available data focuses on the thermal resistance (R-value) of a green roof assembly, often in cooling climates where the insulative benefits would be greater as compared to a black commercial roof, but some data did exist for temperate or heating climates. From these reports, there did not seem to be a universally aligned expectation for the green roof impact on the building energy due in large part to the variation in design, installation practices, and limited number of projects with available data. Rather, there was a range of estimated impacts on the savings, from minimal/zero to 30%. Further, as the primary focus of the available reports was on the thermal transfer through the green roof assembly itself, little analysis was performed on the overall energy impacts to the building heating and cooling systems.

Some reports noted a calculable energy usage reduction with no real utility billing or building energy consumption data to support the claims, often only discussing the thermal transfer benefits of the green roof components and substrates as having energy reduction benefits.[42]

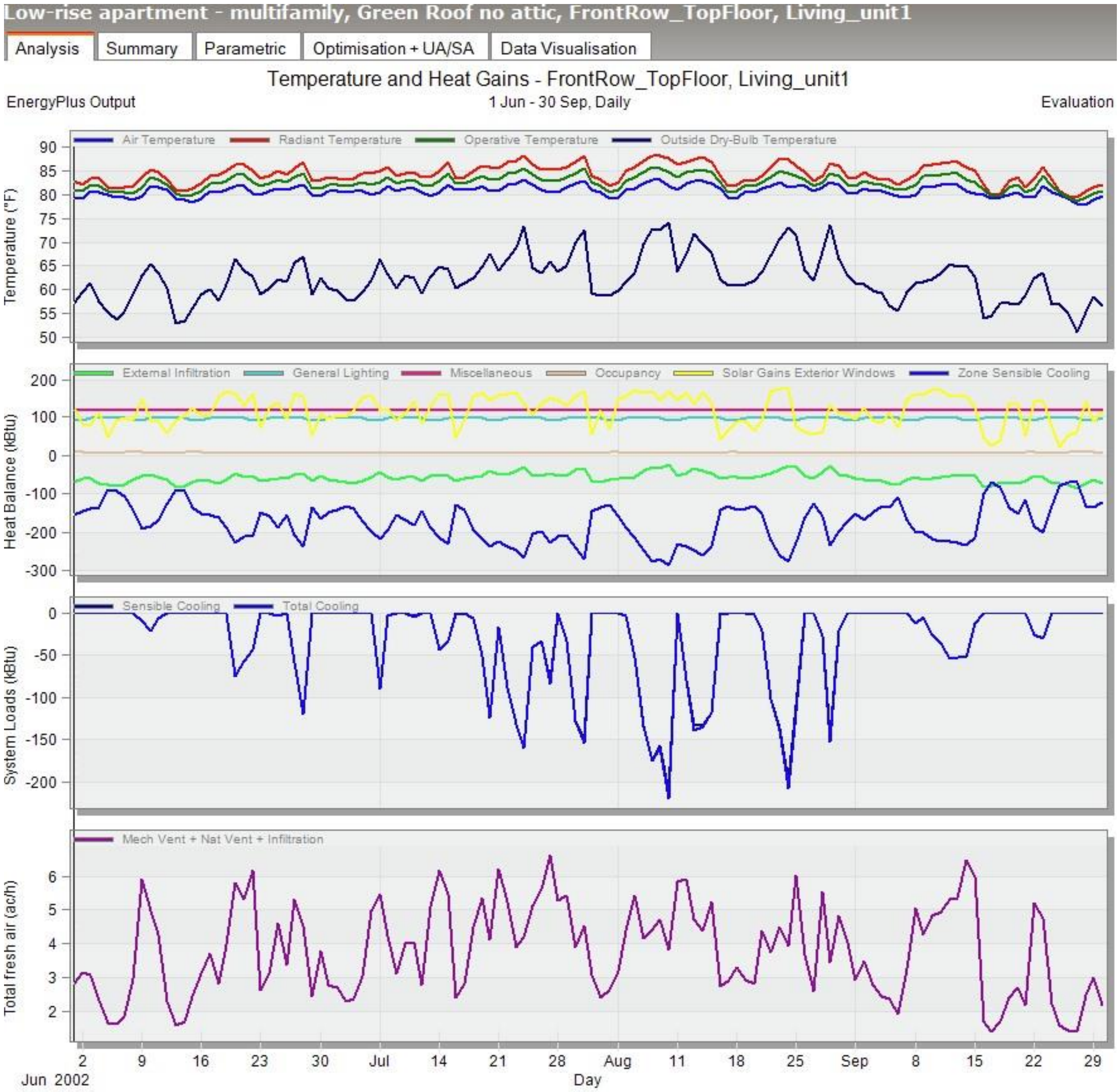
FIGURE 5.2: TEMPERATURE DATA FOR VEGETATED COMBINATIONS (CELIK, PURDUE 2010)



Following this initial research on market data, our Team selected the DesignBuilder 3-D modeling program for use in performing energy models of the various building types in our study. The program has developed a solid reputation in the building design industry for variability and is known to have a very reliable green/eco roof feature that can be adjusted to fit almost any type of building. Backed by an EnergyPlus (Department of Energy) engine, the program produced annual consumption outputs for electricity, gas, and water by end use so that EES Team could compare the conventional roof performance to the intensive and extensive green roof coverage models at 30%, 50%, and 70% coverage. Temperature balance and heat transfer by component can be reviewed in these models, as shown below in the Multifamily (low rise) 50% green roof model:

[42] Besbes, Karim et al. Green Roofs Impact on Buildings Cooling Load. Purdue University 2012. https://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=1068&context=ihpbc

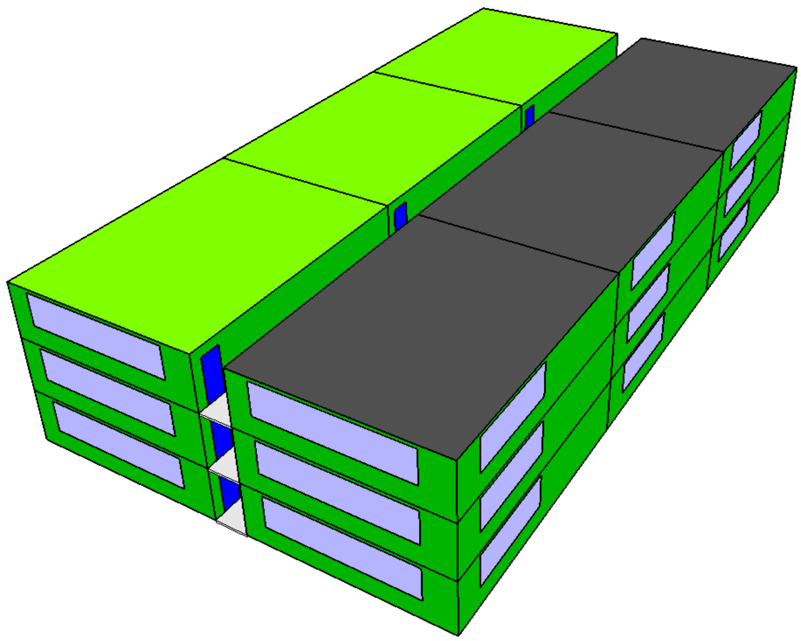
FIGURE 5.3: MULTIFAMILY GREEN/ECO ROOF PARAMETER OUTPUT FOR SUMMER COOLING (JUN-SEPT)



Initial comparisons of the 50% coverage green roof models vs. standard construction commercial buildings in the Seattle area showed a small but measurable difference in both heating and cooling energy. The differences are more pronounced in areas with the higher heating degree days, with some heating loads actually increasing notably due to the absence of a low albedo (reflective) roof decking. For example, the modeled green roof (50%) "Assembly" facility in the Seattle area draws approximately 104 kBtu more annually to heat than its conventional roof counterpart, but the heating energy differential for the modeled building *in Yakima* expands to approximately 3,074 kBtu more to heat the green roof version of the same building.

Similar differentials can be seen amongst the other building types, such as the low-rise Multifamily structure (shown below as the 50% green/eco roof) where the Yakima based building has a 6,109 kBtu higher heating load for the green roof than the standard dark albedo roof but a lower difference between the buildings in the Seattle weather zone of 2,260 kBtu. As expected in both cases, the cooling load is higher for the conventional roof but by a nominal amount.

FIGURE 5.4: LOW-RISE MULTIFAMILY WITH 50% GREEN/ECO ROOF



For purposes of modeling, the Project Team looked at the energy impact per square foot of building space and determined that the heating and cooling energy differentials were not significant, as the registered values hovered around .0001-.01 MMBtu/sf for any of the modeled scenarios. This is to be expected, given that the green/eco roof installation technically sits outside of the building envelope, supported by a concrete roof decking in most situations. Additionally, the climate zone impact is less remarkable in the relatively temperate cooling and heating zones and more pronounced in the high temperature variability areas. Finally, conventional building science theory points to the naturally low impact of the roof component of the commercial building shell in any scenario, as the energy impacts of the vertical components (walls, windows, doors) and the building activity type are traditionally more influential to the overall HVAC consumption.

5.7 LEADERSHIP IN ENERGY AND ENVIRONMENTAL DESIGN (LEED) CREDITS

LEED certification is recognized as a symbol of sustainability achievement and leadership. LEED buildings have higher resale value and use less energy and water than non-LEED counter parts. At least 40 LEED credits are required to become certified. A 2021 study found that a LEED certified office building was rented at a rate 11.1%

higher than a non-LEED counterpart and experiences less vacancy. Additionally, LEED-certified assets held value 21.4% higher than average market rates over non-LEED buildings.[43]

The value of LEED credits is estimated based on a marginal cost analysis. Green buildings cost on average just 2% more than their non-green counterparts.[44] These costs are primarily attributed to soft costs such as increased architectural and engineering design time, modeling costs, and time needed to integrate sustainable building practices. This is estimated to add $5 to $10 per square foot to building construction costs. LEED Certification level can vary; however, the first 50 LEED credits (approximately Certified/Silver level) can provide significant benefits in terms of energy and water use savings and building comfort.

This one-time benefit is realized in year 1. Afterward, a return on equity calculation is used to value the sustained earnings attributable to the original investment. A return on equity value of 10% is used consistent with private equity returns in the state of Washington. The annual benefit for each LEED credit is $0.04/square foot over the study period of 15 years. This benefit assumes that the building owner installing the rooftop solar or green roof has already decided to obtain LEED certification. The cost to become LEED-Certified can range significantly from a few thousand to $60,000.[45]

5.7.1 Green Roof LEED Credits

Depending on building design and integration with the building systems, green roofs could contribute as much as 15 credits. Direct credits for green roofs may be obtained for the following:

- Reducing site disturbance, protect or restore open space (2 points)
- Landscape design that reduces urban heat islands (2 points)
- Stormwater management (2 points)
- Water efficiency landscaping (2 points)
- Innovative wastewater technologies (2 points)
- Regional materials (2 points)
- Building Efficiency (up to 19 points)
- Innovation in design (up to 5 points)

This study assumes that the average green roof would meet some but not all of the above requirements. To avoid double counting benefits, where values are estimated elsewhere, such as stormwater, LEED credits for stormwater management are not included. The following LEED credits are assumed based on the measure design and construct of the benefit-cost analysis:

- Reduce Heat Islands (2)
- Regional Materials (2)
- Innovation in Design (intensive roof 5, extensive roof,1)

The total LEED credits attributable to extensive green roofs is 4 where the total LEED credits for intensive green roofs is 9. The above credits are applied regardless of green roof area coverage. More points may be available

[43] Cushman & Wakefield. Green is Good: Sustainable Office Outperforms in Class A Urban Markets. August 2021. https://cw-gbl-gws-prod.azureedge.net/-/media/cw/americas/united-states/insights-pdfs/green-is-good-spotlight_final1.pdf?la=en&rev=e26315797d7d49faa6c58ca7762f91a6&hash=7D9FDF170FDB5E46A373233AD8F2999F
[44] Kats, Gregory H. Green building Costs and Financial Benefits. Massachusetts Technology Collaborative. 2003. https://www.wbdg.org/files/pdfs/green_bldg_costs_kats.pdf Figure 1.
[45] USGBC. Leed Certification Fees. https://www.usgbc.org/tools/leed-certification/fees

for higher coverages or additional features; however, for the purposes of this study, a conservative approach to LEED credits is applied as a proxy for value related to the unquantifiable benefits. These unquantifiable benefits include reduced heat islands, regional sourcing of materials, and aesthetic and use value for innovative design (intensive only). Depending on the building type, the LEED value for green roofs is estimated to range between $0.25 and $5 per square foot of total roof area.

5.7.2 Solar LEED Credits

Builders also accrue LEED credits for both rooftop solar panels and ground-mounted systems located at the project site. The proposed rooftop solar measures would be considered Tier 1 (on-site generation) and could earn up to 5 credits:

- 1 point = 2% electricity generation
- 2 points = 5% electricity generation
- 3 points = 10% electricity generation
- 4 points = 15% electricity generation
- 5 points = 20% electricity generation[46]

Based on the above point system and the solar generation as a share of estimated building energy use, Table 5.10 shows the build-up of the LEED credits. Because the study already values energy production from solar, the value for the below LEED credits is not included in the benefit/cost analysis.

TABLE 5.10: SOLAR LEED CREDITS

				Annual Solar kWh		
	Building Size, SF	**EUI kWh/SF**	**Building Energy Use, Annual kWh**	**10% Solar Coverage**	**25% Solar Coverage**	**50% Solar Coverage[1]**
Assembly	36,333	7.9	288,121	56,985	142,974	284,824
Grocery	23,625	40.2	950,434	55,867	138,506	278,123
Hospital	207,115	32.3	6,698,099	188,769	471,350	
Lodging	51,923	10.9	565,441	44,696	111,723	223,393
Mixed Commercial	44,515	15.2	676,183	55,867	140,740	280,357
Office	58,308	11.8	690,367	67,039	168,664	337,320
Other	13,000	6.4	83,070	25,703	63,688	127,337
Residential Care	61,360	14.7	904,446	88,265	222,276	442,310
Retail / Service	78,842	9.6	756,095	176,482	440,076	
School	73,000	7.4	539,470	145,208	363,009	726,007
Warehouse	71,838	3.7	267,237	139,623	348,489	698,083
Multifamily Low Rise (1-3)	15,897	9.7	154,201	2,236	4,471	8,941
Multifamily Mid Rise (4-6)	14,501	8.1	117,458	7,824	18,998	36,876
Multifamily High Rise (7+)	17,250	5.9	101,775	3,353	10,059	18,998

1. 1. Rooftops for hospitals and very large retail buildings are excluded from maximum solar coverage scenarios.

[46] https://unboundsolar.com/blog/do-you-need-leed-credits-heres-what-we-can-do

TABLE 5.11: SOLAR LEED CREDITS

	% Annual Usage			LEED Credits: Solar		
	10% Solar Coverage	25% Solar Coverage	50% Solar Coverage	10% Solar Coverage	25% Solar Coverage	50% Solar Coverage[1]
Assembly	19.8%	49.6%	98.9%	4	5	5
Grocery	5.9%	14.6%	29.3%	5	3	5
Hospital	2.8%	7.0%	0.0%	1	2	
Lodging	7.9%	19.8%	39.5%	2	5	5
Mixed Commercial*	8.3%	20.8%	41.5%	2	5	5
Office	9.7%	24.4%	48.9%	2	5	5
Other	30.9%	76.7%	153.3%	5	5	5
Residential Care	9.8%	24.6%	48.9%	2	5	5
Retail / Service	23.3%	58.2%	0.0%	5	5	
School	26.9%	67.3%	134.6%	5	5	5
Warehouse	52.2%	130.4%	261.2%	5	5	5
Multifamily Low Rise (1-3)	1.5%	2.9%	5.8%	0	1	2
Multifamily Mid Rise (4-6)	6.7%	16.2%	31.4%	2	3	5
Multifamily High Rise (7+)	3.3%	9.9%	18.7%	1	2	3

1. Rooftops for hospitals and very large retail buildings are excluded from maximum solar coverage scenarios.

5.8 GREEN ROOFS INSTALLATION COSTS AND OPERATION & MAINTENANCE (O&M) COSTS

Installation of a green roofs as an alternative to conventional roofs adds additional cost, but over time, savings can be realized over the life of the roof through stormwater management benefits, increased roof life span and building energy efficiency and improved real estate value.

Unit cost ranges quoted by service providers and found in published information vary widely, for both installation and O&M. Unit cost varies with the size and type of GR, with larger installations costing less per square foot, and with extensive ("shallow") systems costing less than intensive (deeper) systems. Other important cost drivers include the following:

- New vs. retrofit green roof
- Materials and installation equipment
- Labor market
- Configuration of building and ease of access – for both installation and O&M
- Required O&M – for the life of the roof

The vendor survey conducted as part of this project indicated cost per square foot ranges of $5-$15 up to $50 - $75. Reviewed published information (primarily from government agencies) indicated ranges of costs, summarized in the table below.

TABLE 5.12: LITERATURE REVIEW OF GREEN ROOF CAPITAL AND O&M COSTS

US General Services Administration (2011)	Installed cost premium (incremental cost over a conventional roof) for multi-course extensive (3-inch depth) green roofs ranges from $10.30 to $12.50 / sq.ft. Installed cost premium (incremental cost over a conventional roof) for semi-intensive (6-inch depth) green roofs ranges from $16.20 to $19.70/ sq. ft. Annual maintenance for a green roof is typically higher than for a conventional black roof, by $0.21 to $0.31 per sq. ft.
USEPA Office of Water, 4203M, Stormwater BMPs - GR (2021)	"Sources often cite the total cost of a green roof as $15 to $35 per square foot, with cost per square foot decreasing as size increases
USEPA Reducing Urban Heat Islands: Compendium of Strategies (Draft), Chapter 3 - Green Roofs (2008) https://www.epa.gov/heat-islands/heat-island-compendium	The costs of green roofs vary depending on the components, such as the growing medium, type of roofing membrane, drainage system, use of fencing or railings, and type and quantity of plants. A 2001 report estimated that initial costs start at $10 per square foot (0.09 m2) for the simpler, extensive roof and $25 per square foot for intensive roofs. Other estimates assume $15 to $20 per square foot. Costs in Germany, where green roofs are more prevalent, range from $8 to $15 per square foot. Prices in the United States may decline as market demand and contractor experience increase.
City of Portland OR. EcoRoofs Handbook (2009)	New GR construction (includes structural support): $10 - $20/SF Re-roofing (GR retrofit): $6 - $40/SF
Minnesota Pollution Control Agency (MPCA), Minnesota Stormwater Manual, Cost-benefit considerations for green roofs (2022)	Extensive GR: $10 to $30/sq.ft. for the components above the waterproofing assembly and a simple irrigation system.
Greenroofs.com, FAQs - Greenroofs.com (2023)	Extensive –Common range, $14 – $25/sq. ft., (including roofing membranes). Intensive – $25 – $40 and up
Greenroofs.org Green Roofs for Healthy Cities, About Green Roofs — Green Roofs for Healthy Cities (2023)	An installed extensive green roof with root repellent/waterproof membranes may be installed for $10-$24 (USD) per square foot.

Based on the above research and the vendor survey, capital costs of $20 and $35 per square foot were selected for extensive and intensive green roofs respectively. These costs are incremental to conventional roofing. O&M costs reported by the surveyed landscapers varied from $0.30/square foot to about $1.50/square foot. Based on this range O&M costs are estimated at $0.86/square foot per year. For very large green roofs (>30,000 square feet) the O&M cost is reduced to $0.50/square foot.

5.9 ELECTRIC SYSTEM BENEFITS

Electric system benefits of rooftop agrivoltaics include both electric building efficiency savings as well as the local solar resource energy production. The regional electric system benefits are modeled within the Power Council's ProCost worksheets leveraging some of the avoided cost assumptions from the 2021 Power Plan.[47] The ProCost model combines the annual kWh savings, or resource production in the case of solar, based on an hourly load/savings shape. Peak demand savings are valued according to the load shape value in Peak Period 1 or 2. The

[47] Northwest Power and Conservation Council. Regional 2021 Northwest Power Plan. March 10, 2022.

Project Team updated the wholesale price of energy based on Q1 2023 forward prices for electricity at Mid-C. The peak values are taken directly from the most recent Power Plan. The value of GHG savings associated with energy are calculated based on WAC-194-40-100 and updated to $2023 using the GDS deflator. Table 5.13 summarizes the electric system assumptions. Note that 2021 Plan values are adjusted to 2023 dollars using the GDP deflator. Each is described in more detail below the table.

TABLE 5.13: SUMMARY OF ELECTRIC SYSTEM COST AVOIDANCE, $2023

	Assumption	Source
Wholesale Electricity Price, 15-year Levelized $/MWh	$	NWPCC Baseline Market Price Forecast April 2023[48]
Social Cost of Carbon, $/metric ton, 15-year levelized	$30/MWh	WAC-194-40-100
Carbon Intensity Generic Resources, lbs/kWh	0.874	WA Dept. Ecology
Bulk System T&D Loss Factor	2.3%	2021 Plan[49]
Bulk System T&D Credit ($/kw-yr)	$4.47	2021 Plan
Bulk System T&D Credit - Applicable Peak Period (1,2, or 1 and 2)	Peak Periods 1 and 2	2021 Plan
Bulk System T&D I2R Loss Component (%)	90%	2021 Plan
Local System Distribution Loss Factor	4.74%	2021 Plan
Local System Distribution Credit ($/kw-yr)	$8.74	2021 Plan
Local System Distribution Credit - Applicable Peak Period (1,2, or both)	Peak Periods 1 and 2	2021 Plan
Local System Distribution I2R Loss Component (%)	70%	2021 Plan
Deferred Resource Capacity Credit ($/bulk kW-year)	$152.14	2021 Plan

5.9.1 Avoided Cost Overview

From a total resource cost perspective, energy efficiency and rooftop solar provide multiple benefits beyond the avoided cost of energy. These include deferred capital expenses on generation, transmission, and distribution capacity; avoided social costs of carbon emissions, and the reduction of utility resource portfolio risk exposure. Since energy efficiency measures provide both peak demand and energy savings, these other benefits are monetized as value per unit of either kWh or kW savings.

FIGURE 5.5: OVERVIEW OF PORTFOLIO REQUIREMENTS

Energy-Based	Capacity Based
• Energy Price at Mid-C • Social Cost of Carbon • Renewable Energy Credits • GHG-Free or Neutral Resources	• Generation Capacity Deferral • Transmission Capacity Deferral • Distribution Capacity Deferral

[48] Northwest Power and Conservation Council. Energy Forecasts. Wholesale Electricity Market Price and Avoided Emission Rates Forecasts (April 2023). https://www.nwcouncil.org/energy/energy-forecasts/

[49] See id.

The estimated values and associated uncertainties for these avoided cost components are based on the 2021 Power Plan, Washington-specific requirements such as WAC-194-40-100 and the Clean Energy Transformation Act (CETA), and updated market price forecasts. The timeline below summarizes the relevant milestones for Washington electric utility portfolio planning. The type of energy Washington utilities will need to procure is based on these requirements; therefore, the requirements set the avoided cost as it relates to capacity, renewable, and GHG-free power supply.

FIGURE 5.6: OVERVIEW OF ELECTRIC UTILITY PORTFOLIO REQUIREMENTS

5.9.2 Social Cost of Carbon

The social cost of carbon is a cost that society incurs when fossil fuels are burned to generate electricity. Both the Energy Independence Act (EIA) rules and CETA require that utilities include the social cost of carbon when evaluating cost effectiveness using the total resource cost test (TRC). CETA further specifies the social cost of carbon values to be used in resource analytics such as conservation potential assessments and integrated resource plans. These values are shown in the table below.

TABLE 5.14: SOCIAL COST OF CARBON VALUES[50]

Year in Which Emissions Occur or Are Avoided	Social Cost of Carbon Dioxide (in 2007 dollars per metric ton)	Social Cost of Carbon Dioxide (in 2018 dollars per metric ton)
2020	$62	$74
2025	$68	$81
2030	$73	$87
2035	$78	$93
2040	$84	$100
2045	$89	$106
2050	$95	$113

According to WAC 194-40-110, values may be adjusted for any taxes, fees or costs incurred by utilities to meet portfolio mandates.[51] For example, the social cost of carbon is the full value of carbon emissions, which includes the cost to utilities and ratepayers associated with moving to non-emitting resources. Rather than adjust the social cost of carbon for the cost of RECs or renewable energy, the values for RECS and renewable energy are excluded from the analysis to avoid double counting.

50 WAC 194-40-100. Available at :https://apps.leg.wa.gov/wAc/default.aspx?cite=194-40-100&pdf=true
51 WAC 194-40-110 (b).

The emissions intensity of the marginal resource (market) is used to determine the $/MWh value for the social cost of carbon. Ecology states that unspecified resources should be given a carbon intensity value of 0.437 metric tons of CO_2e/MWh of electricity (0.874 lbs/kWh).[52] This is an average annual value applied in all months. The resulting levelized cost of carbon is $30/MWh over 15-years.

5.9.3 Avoided Renewable Energy Purchases

Renewable energy purchases need to meet both RPS and CETA and can be avoided through conservation. Utilities may meet Washington RPS through either bundled energy purchases such as purchasing the output of a wind resource where the non-energy attributes remain with the output, or they may purchase unbundled RECs.

As stated above, the value of avoided renewable energy credit purchases resulting from energy efficiency or distributed renewable generation is accounted for within the social cost of carbon construct. The social cost of carbon already considers the cost of moving from an emitting resource to a non-emitting resource. Therefore, it is not necessary to include an additional value for renewable energy purchases prior to 2045 when all energy must be non-emitting or renewable.

5.9.4 Electric Wholesale Market Price

The Council has developed an updated wholesale electricity market price forecast since the 2021 Power Plan was finalized. The Baseline forecast is used to value energy production (solar) or savings (green roof) in this study. The levelized cost of energy is estimated at $0/MWh over the next 15 years..

5.9.5 Deferred Transmission and Distribution System Investment

Energy efficiency measure savings, demand response, and behind-the-meter solar reduce capacity requirements on both the transmission and distribution systems. Capacity expansions due to load growth through electrification may be avoided in part due to investments in energy efficiency and behind-the-meter resources. Capacity expansions may include investments in transformers, conductors, and substations. The Council's 2021 Power has estimated these avoided costs at $3.08/kW-year and $6.85/kW-year for transmission and distribution systems, respectively ($2016).[53]

5.9.6 Deferred Investment in Generation Capacity

Local resources such as rooftop solar and energy efficiency reduce the capacity need from generating resources. From a regional perspective, generating resource capacity is developed to meet peak demand at any given point in a year. Depending on the resource, different capacity credits can be attributed based on the time of year. A natural gas resource that can quickly ramp up or down to meet changes in loads is considered to provide its full capacity value regardless of the time of year. Other resources such as hydropower are credited capacity value depending on its operational constraints such as fish and wildlife mitigation, water rights, or water availability. Similarly wind or solar resources are intermittent based on sun or wind availability. The 2021 Power Plan bases the deferred investment in generation resources that provide peak capacity benefits on natural gas resources.

52 WAC 173-444-040 (4)

53 Northwest Power and Conservation Council Memorandum to the Power Committee Members. Subject; Updated Transmission & Distribution Deferral Value for the 2021 Power Plan. March 5, 2019. Available at: https://www.nwcouncil.org/sites/default/files/2019_0312_p3.pdf

In the Council's 2021 Power Plan,[54] a generation capacity value of $123/kW-year was explicitly calculated ($2016). This value is adjusted to 2023 dollars using the GDP deflator.

5.9.7 Northwest Power Act Credit

In accordance with the Northwest Power Act, a 10% adder is included as a bonus to the avoided costs for energy efficiency.[55]

5.10 ROOFTOP SOLAR

Energy production from rooftop solar is valued at local market prices based on the energy production profile in each solar zone. Not surprisingly, solar production for each of our solar zones was extremely consistent across building types, with the exception of the smallest systems (under 5kW) which seem to produce slightly less energy per kW. This is likely due to the very small size of the PV systems compared to systems on all other building types which were all over 5kW and predominantly over 20kW. Overall, solar generation in zone 1 is about 29.4 kWh/sq. ft. of solar panel coverage, whereas in zone 3 generation is estimated at about 37.7 kWh/sq. ft. of solar panel coverage (when not including systems under 5kW).

Solar PV production estimates do not take into account any increased production due to installation of a green roof, which may lead to an increase in production due to the cooling effects of the plants. Currently there are limited studies showing additional energy generation due to the inclusion of plants under the panels. However, according to Cavadini and Cook, for a flat rooftop PV installation near Zurich, Switzerland (temperate climate), results show that, compared to a conventional roof, green roofs can increase annual PV energy yield, on average, by 1.8%, whereas cool roofs can increase it by 3.4%.[56] In addition, a study done at the University of Technology in Sydney, Australia comparing how much energy two solar systems produced over an 8 month period found "the "green roof" improved performance by as much as 20 per cent at peak times and by 3.6% over the length of the experiment."[57]

The expected monthly generation for each solar zone 1 and zone 3 can be seen in the figures below. Note production is based on a 100kW PV system using bifacial panels, standard efficiency modules, 96% efficient inverters, system losses of 14.08%, tilted at 20°, and an azimuth of 180°.

54 https://www.nwcouncil.org/energy/powerplan/7/home/

55 in 16 U.S.C. § 839a of the Pacific Northwest Electric Power Planning and Conservation Act

56 Cavadidi, Giovan and Lauren Cook. (2021). Applied Energy 296 (2021) 117082. Green and cool roof choices integrated into rooftop solar energy modeling.

57 Irga, Peter et al. Green Roof & Solar Array – Comparative Research Project. Final Report July 2021. University of Technology Sydney.

FIGURE 5.7: ESTIMATED SOLAR GENERATION FOR YAKIMA (LEFT) AND SEATTLE (RIGHT)

RESULTS

Print Results

143,250 kWh/Year*

System output may range from 138,222 to 146,329 kWh per year near this location.
Click HERE for more information.

Month	Solar Radiation (kWh / m^2 / day)	AC Energy (kWh)
January	2.14	5,597
February	3.53	8,246
March	4.56	11,461
April	5.81	13,756
May	7.13	16,913
June	7.67	17,261
July	8.14	18,661
August	7.13	16,414
September	5.98	13,613
October	4.19	10,369
November	2.58	6,493
December	1.70	4,467
Annual	5.05	143,251

RESULTS

Print Results

111,723 kWh/Year*

System output may range from 106,617 to 115,488 kWh per year near this location.
Click HERE for more information.

Month	Solar Radiation (kWh / m^2 / day)	AC Energy (kWh)
January	1.60	4,015
February	2.47	5,602
March	3.39	8,332
April	5.11	11,868
May	6.07	14,167
June	6.05	13,513
July	6.46	14,799
August	6.40	14,681
September	4.61	10,492
October	2.88	7,003
November	1.60	3,887
December	1.33	3,365
Annual	4.00	111,724

5.10.1 Solar O&M

Operation and maintenance of a PV system can have a significant impact on its productivity and profitability. According to National Renewable Energy Laboratory (NREL), O&M costs can range from $18-$28/kW/year and putting a commercial system closer to the $18/kW/year estimate. Considering a lifetime of at least 25 years for the system, O&M costs can be significant. O&M includes module cleaning, system inspections, component replacements (such as inverters at 15 years), and overall system monitoring.

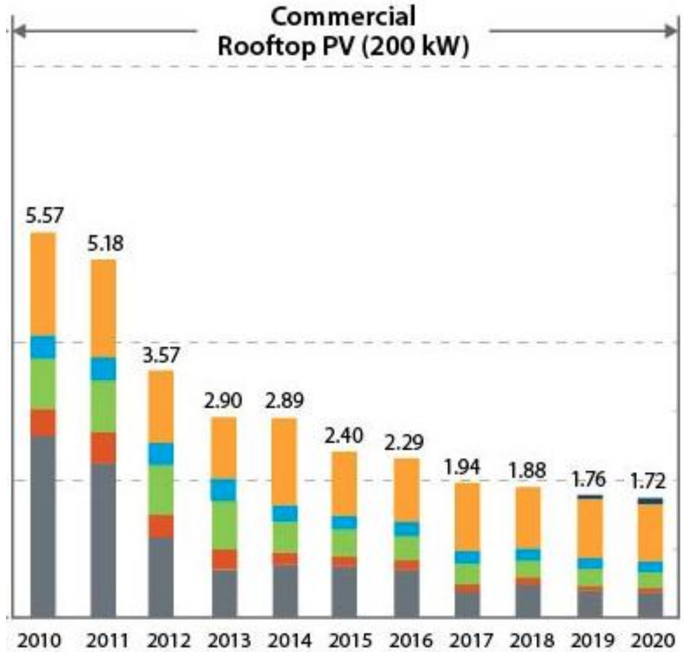
5.10.2 Solar Capital Costs

The cost of solar PV systems has decreased dramatically over the last 10 years. In 2010 a commercial rooftop PV system cost approximately $5.57/watt, but by March 2022, NREL estimated the price of installing a commercial PV system to be about $1.84 per watt DC.[58] Estimates from CoveTool from May 2023 show commercial PV costs at about $175,000 for a 100 kW system, or about $1.75/watt and provide and overall estimate of $1.83/watt for all commercial systems.[59] These costs include panels, racking, inverters, etc. and do not include any available tax credits. When accounting for tax credits, overall system costs can be reduced. Commercial rooftop PV costs since 2010 can be seen in the figure below.

[58]Feldman, David et al. U.S. Solar Photovoltaic System and Energy Storage Cost Benchmark: Q1 2020. National Renewable Laboratory Technical Report. January 2021. Available at: https://www.nrel.gov/docs/fy21osti/77324.pdf

[59] Cove Tool. Solar Panel Cost – Residential + Commercial. https://help.covetool.com/en/articles/4529706-solar-panel-cost-residential-commercial

FIGURE 5.8: U.S. SOLAR PV SYSTEM COSTS 2010-2020[60]



5.11 BATTERY STORAGE

When battery storage is combined with solar PV, on-peak wholesale power costs can be avoided when the solar resource is not generating. A typical battery analysis would consider the building load profile, retail electric rates, total size of the solar PV resource.

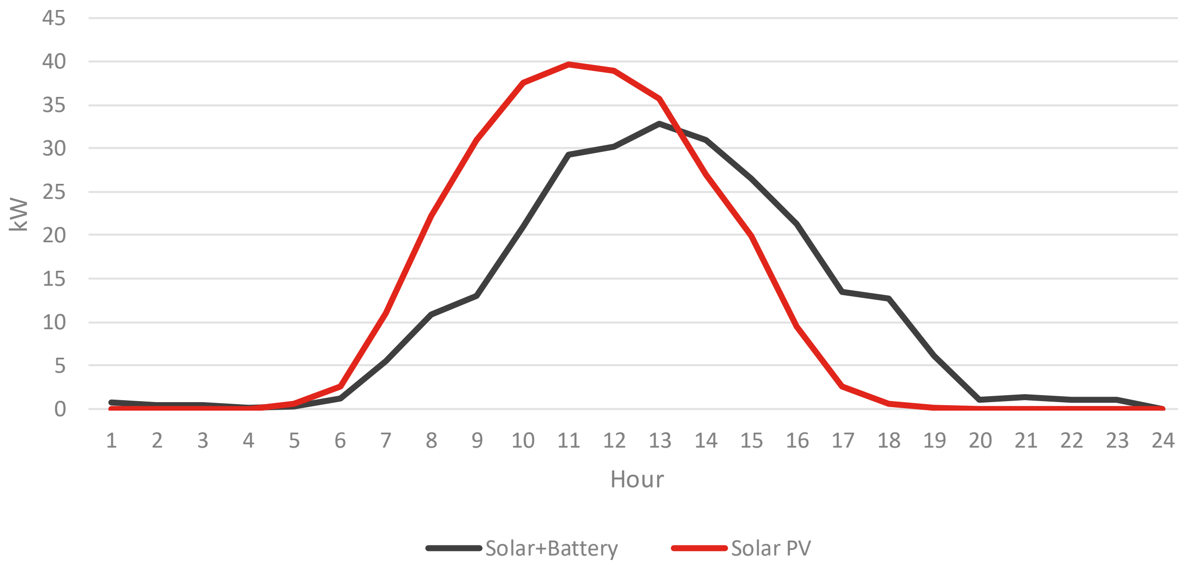
To illustrate the impact of a short duration battery on rooftop agrivoltaic economics, a representative building was selected for battery optimization. The selected representative building is a hospital. This was selected in order to support a larger battery installation. The battery optimization included the following assumptions:

- The dispatch model applied was tuned for peak reduction.
- Load assumed was 200 kW peak with a residential/commercial mixed load profile
- The battery was sized at 50% of the solar PV nameplate and is 4-hours in duration.
- Solar PV max output was 137 kW ac, thus Battery size is 69 kW ac
- Charging efficiency is 90%
- 194 annual equivalent cycles on the battery (or 53,000 kWh/year)
- This example served 25% of the annual building load

Figure 5.9 illustrates an example generation profile of the solar resource with and without the battery. The battery is charged during the first part of the day and discharged in the afternoon when wholesale prices for electricity are higher.

[60] National Renewable Energy Laboratory. Documenting a Decade of Cost Declines for PV Systems. February 10, 2023. Available at: https://www.nrel.gov/news/program/2021/documenting-a-decade-of-cost-declines-for-pv-systems.html

FIGURE 5.9 AVERAGE DAILY GENERATION PROFILE SOLAR AND BATTERY MONTH OF JULY



5.11.1 Battery O&M

For both rooftop agrivoltaic and conventional building solar+battery systems, an effective Operation and Maintenance (O&M) program or plan provides certainty that a system will perform at or above its production estimate and costs over the useful life. Therefore, a long-term performance management strategy will assure the expected benefits of an asset and should be properly considered in the budgeting phase of the project and sustained over time through monitoring and performance guaranties. Key considerations for building operators are listed below:

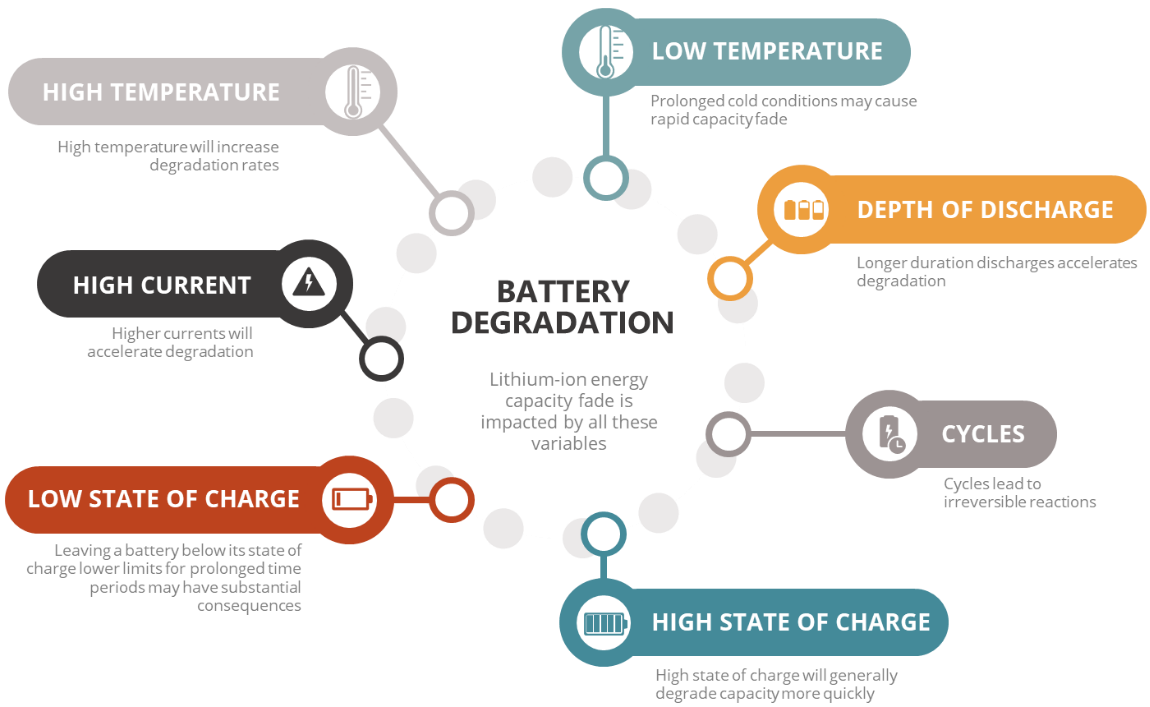
O&M Plans: Strategies exist to provide O&M services to manage the desired performance expectations. The ownership model largely determines the maintenance approach of the system over the useful life. Solar and energy storage service and maintenance programs are well developed throughout industry which should be presented by the contractor including regular maintenance tasks to maintain the warranties of equipment.

Lifecycle Management strategies are necessary to deal with the certainty of decaying battery performance. Battery degradation occurs every time there is a charge or discharge cycle, and it is a function of depth of discharge, current rate, and average state of charge. The battery's energy capacity, the duration that the battery can serve the load, fades over time, which can be managed by proper initial sizing and a strategy to maintain the system performance over the life. Typically, the battery is slightly oversized to account for degradation and allow the system to provide the appropriate duration over the contract term. Tier One lithium-ion suppliers offer up to 10-year warranties and LTSAs with contractors can help manage those warranties and act as the guaranteeing party for the term of the agreement.

Mechanisms of Degradation in lithium-ion batteries are primarily due to the innate chemical reactions that occur between the electrolyte and anode as well as mechanical breakdown of the electrodes due to usage. The two primary mechanisms of battery aging are resultant of usage and the passage of time. It is worth noting that cycle life and discharge throughput through a lithium-ion battery are directly proportional, but not in a linear fashion, and the relationship differs by cell based on the exacerbating variables.

Cycling Degradation from charging and discharging of a lithium-ion battery results in the repeated intercalation and deintercalation of lithium ions into and out of the crystalline electrode structures forcing repeated expansion and contraction of such electrodes with each cycle. As with any mechanical movement, over time the underlying electrode materials or the composite electrode structure will become fatigued from stress and fail and/or a current collector can separate from its electrode. The rate at which mechanical damage occurs increases under certain conditions. Under controlled cycling, the mechanical damage develops over time and manifests as an increase in internal resistance and reduced charge-carrying capacity; however, accelerated degradation can occur if such fatigue breaks through the solid electrolyte interface (SEI) layer and wear through the separator shorting the electrodes.

FIGURE 5.9: BATTERY DEGRADATION FACTORS



5.11.2 Battery Capital Costs

Understanding the financial implications of a power system installation is crucial for understanding the feasibility. The cost analysis examines the project costs based on the agreed upon system specification as well as local and federal financial incentives such as the investment tax credits, federal and state incentives, and depreciation benefits that may apply to the project.

An agreed upon set of performance requirements is the most influential component of the solar/storage development process. It influences the installation requirements, integration costs, operational requirements, and timeline. The cost of the equipment from a specific vendor will likely not change very much from site to site. However, the cost of interconnection, development, and acquisition of physical space to accommodate the solar/storage system can vary significantly.

Our Team utilized some public data sources such as the Lazard report on Levelized Cost, published in April of 2023, as well as proprietary vendor quotations for solar+storage equipment as a part of recent EES Team project work.[61] Following the analysis, we concluded that the current average for installed storage system cost is approximately $873/kWh and this was used as a basis for capital installation cost. The operation and maintenance costs for the average storage system size used in this study, roughly 275 kWh, hovered around $1.00/kWh annually.

5.12 COLOCATION BENEFITS OF GREEN ROOFS WITH PHOTOVOLTAIC ARRAYS

As demand for space on flat roofs increases, along with the awareness of potential opportunities associated with making good use of rooftop space, colocation of photovoltaic (PV) panels and green roofs on the new developments is increasing. The two systems are no longer regarded as mutually exclusive, and if designed correctly, both can occupy the same roof space and function as intended.

PV panels are not typically integrated into the green roof system but are mounted on it via a metal frame secured to the structural (non-green roof) components of the roof. This integrated mounting design allows the green roof vegetation and substrate to provide the ballast and support to the PV array and eliminates the need to penetrate the layer waterproofing to secure the mounting units directly to the roof itself.[62]

The key issue in co-locating green roofs and solar panels is the distance between each solar array. Maximizing available roof area attributed to solar panels can have detrimental effects on both systems. In addition, proper staging of the installation is critical to ensure that both systems (including the vegetation) are not damaged. Consistent coordination with both green roof and solar contractors during both the installation and for periodic O&M is essential.[63]

"Solar green roofs" have been implemented in various ways for decades. Colocation has a number of advantages:

- increased efficiency of the solar system through temperature moderation
- protection of the waterproof layer by avoiding penetration and providing cover from thermal and mechanical stress
- providing a degree of shelter and shading to plants
- increase in biodiversity (over solar-only roofs)

The electrical output of PV panels is most efficient within an operating temperature range; outside this optimal range, electricity generation becomes less efficient. Colocation with a green roof maintains a more constant temperature, resulting in PV panels working more efficiently throughout the day. An Australia study[64] found that solar PV efficiency increased by up to 20% and by an average of 3.6%. This study assumes a 3.6% adder for kWh for the case where the solar PV and green roof are collocated. The adder amounts to an additional 877 kWh per year for a multifamily mid-rise building (25% solar PV coverage), or enough to provide total electricity demand to one apartment for one month.

---

[61] Lazard. 2023 Levelized Cost of Energy+. April 12, 2023. Available at: https://www.lazard.com/research-insights/2023-levelized-cost-of-energyplus/

[62] European Federation of Green Roofs and Walls, https://efb-greenroof.eu

[63] Green Roof Organization (GRO), "The Gro Green Roof Code, Green Roof Code of Best Practice - Incorporating Blue Roofs and BioSolar Applications" 2021

[64] Irga, Peter et al. Green Roof & Solar Array – Comparative Research Project. Final Report July 2021. University of Technology Sydney.

The solar array in turn creates wind and sunshade if orientated correctly, improving vegetation productivity and the potential for increased biodiversity by creating microenvironments with varying solar exposure.[65]

5.13 ECONOMIC DEVELOPMENT

Green roof programs have the potential to promote economic growth directly through job creation. Effective programs could create additional jobs in architecture, building/green roof installation, and operation and maintenance. Based on interviews with installers, about half the cost of green roof is labor expense. If more green roofs are installed there is potential for job growth and additional economic investment. Multiplier impacts are not calculated in this study since any rooftop agrivoltaic program would need to be evaluated as a whole compared with current conditions.

5.13.1 Solar PV Economic Impacts

Similar to green roofs, solar PV installation and operation creates local jobs. The Project Team used NREL's Jobs and Economic Development Impact Model (JEDI) to estimate the jobs and economic impacts for rooftop solar installations. The model can be customized for Washington state and average project size. Commercial rooftop solar was selected and the sales tax value modified to reflect Washington State's exemption for solar PV. Each system supports 1.2 jobs during construction and installation. Operation and maintenance for the same system supports 0.024 jobs. The wages paid to these workers are accounted for in the benefit-cost analysis under the O&M and capital cost assumptions.

TABLE 5.15: JEDI OUTPUT SOLAR PV 100 KW SYSTEM IN WASHINGTON STATE

LOCAL ECONOMIC IMPACTS

	Jobs	Earnings	Output	Value Added
During construction and installation period		**$000 (2023)**	**$000 (2023)**	**$000 (2023)**
Project Development and Onsite Labor Impacts				
Construction and Installation Labor	0.2	$13.0		
Construction and Installation Related Services	0.3	$19.7		
Subtotal	0.5	$32.7	$66.5	$51.0
Module and Supply Chain Impacts				
Manufacturing Impacts	0.0	$0.0	$0.0	$0.0
Trade (Wholesale and Retail)	0.1	$8.0	$27.2	$17.6
Finance, Insurance and Real Estate	0.0	$0.0	$0.0	$0.0
Professional Services	0.1	$5.0	$16.1	$10.2
Other Services	0.1	$15.1	$42.2	$26.8
Other Sectors	0.2	$5.0	$14.8	$9.2
Subtotal	0.4	$33.2	$100.3	$63.8
Induced Impacts	0.2	$14.6	$51.4	$32.5
Total Impacts	**1.2**	**$80.5**	**$218.2**	**$147.3**

		Annual	**Annual**	**Annual**
	Annual	**Earnings**	**Output**	**Output**
During operating years	**Jobs**	**$000 (2023)**	**$000 (2023)**	**$000 (2023)**

[65] Walston et. al., "Opportunities for Agrivoltaic Systems To Achieve Synergistic Food-Energy-Environmental Needs and Address Sustainability Goals", Frontiers in Sustainable Food Systems, 2022

Onsite Labor Impacts				
PV Project Labor Only	0.0	$1.0	$1.0	$1.0
Local Revenue and Supply Chain Impacts	0.0	$0.3	$1.0	$0.6
Induced Impacts	0.0	$0.1	$0.5	$0.3
Total Impacts	**0.0**	**$1.4**	**$2.5**	**$1.9**

Jobs: Full Time Equivalent (FTE) 2,080 hours/year
Earnings: Earnings refers to wage and salary compensation paid to workers and benefits.
Output: Output refers to economic activity or the value of production in the state or local economy.

Value Added: Value added is the difference between total gross output and the cost of intermediate inputs. It is comprised of payments made to workers (wages and salaries and benefits), proprietary income, other property type income (payments from interest, rents, royalties, dividends, and profits), indirect business taxes (excise and sales taxes paid by individuals to businesses, and taxes on production and imports less subsidies.

The above modeling can be leveraged to evaluate future rooftop agrivoltaic programs and their impact on the local economy. As with green roofs, economic development impacts for solar PV would need to be estimate in the context of a new program and compared with the business as usual case.

5.14 SUMMARY OF QUANTIFIED BENEFITS AND COSTS

Table 5.16 summarizes the costs and benefits for green roofs paired with solar PV. Some of the benefits have multiple quantitative measures. For example, green rooftop agrivoltaics both sequester carbon within the plants and also reduce carbon emissions through solar PV production. Each quantitative benefit is defined separately and included in the benefit-cost model.

TABLE 5.16: SUMMARY OF ROOFTOP AGRIVOLTAIC BENEFITS AND COSTS

Perspective	Quantitative	Qualitative
Building Owners/Occupants		
Benefits	Reduced energy use through Efficiency and Solar PV generation plus colocation benefits LEED Credits for Innovative Design, Local Materials, Reduced Heat Islands	Noise reduction Increased Comfort Food production Increased aesthetic
Costs	Architecture/Engineering Installation Capital O&M	
Public		
Benefits	Reduced Stormwater Quantities Reduced or Sequestered GHG Local generation decreases long-term need for electricity transmission and distribution Economic Development	Reduced air pollutants Health Benefits Natural Habitat Fire Safety Increased Stormwater Quality Reduced Surface Temperatures
Costs	Program administration	

6 Benefit-Cost Analysis Results

The benefits and costs for green roofs are evaluated using the Power Council's methodology for evaluating energy efficiency measures. The Power Council has developed a Pro-Cost tool to value the energy savings that can be applied to rooftop agrivoltaics. ProCost was modified to evaluate the following:

1. Rooftop agrivoltaic measure definitions including green roof type, building type etc. in $/square foot.
2. Energy savings from behind-the-meter solar pv production. Solar PV generation profiles can be compared with market prices on an hourly basis or within segments as defined by the Power Council.
3. Local generation provides distribution system and transmission system benefits. Deferred investment in the electric system will be valued and applied to regional and local coincident peak demand savings estimates.
4. Colocational benefits of green roofs and solar PV are quantified based on available research.
5. Reductions in greenhouse gas emissions due to energy savings and solar PV production can be valued when compared with the carbon intensity of the electricity market.
6. Non-energy benefits such as water savings, impacts to stormwater treatment systems, and others identified in the study are included.
7. Costs include capital costs for equipment, materials and labor needed to install rooftop agrivoltaic systems, annual operation and maintenance costs (O&M).
8. The useful life of the technology was evaluated based on the shortest useful life of green roof and solar components. Once the useful life expires, significant capital investment would be needed to continue project operation (discussed below).

The benefit-cost model will value the costs and benefits of each measure from a total resource cost perspective. Costs and benefits will be included regardless of to whom they accrue. We recommend the use of the Power Council framework since it is consistent with existing state legislation regarding resource evaluation for electric utilities.[66] The results of the benefit-cost modeling include net present value of benefits and costs over the life of the measure.

6.1 FINANCIAL ASSUMPTIONS

The benefit cost analysis requires a time period for the analysis as well as discount rate assumptions to convert costs and benefits to current dollars. These assumptions are discussed first then results are provided.

6.1.1 Measure Life

Rooftop agrivoltaics is essentially a bundle of measures including some or all three parts: green roof, solar PV, and battery. Each individual measure has a unique useful life. The useful life of the measure is defined as the period of time the technology or measure is expected to exist before needing replacement or major repairs. Table 6.1 below summarizes the useful lives for the main components for rooftop agrivoltaics.

[66] Energy Independence Act and Clean Energy Transformation Act both reference NWPCC regional power plans.

TABLE 6.1: USEFUL MEASURE LIFE

	Useful Life, Years
Solar PV	**15**
Cells	20
Inverter	15
Green Roof	**40**
Membrane	40
Other Components	40
Battery	**10**

The Project Team evaluated the time period over which to calculate the costs and benefits. To combine all of the above components, the useful lives would need to be similar. In order to have similar useful lives, a few options were considered:

1. Use the shortest useful life so that all components are in good working order without major repair and replacement
2. Add replacement costs for each component to extend the useful life to the longest time period as defined in Table 6.

Neither of these methods are likely to produce perfect agreement between replacement costs and useful life. Some repair and replacement costs may extend the useful life of a particular component beyond the maximum useful life being evaluated. Therefore, the Project Team selected the first option to evaluate the benefits and costs. This option is preferred for the following reasons:

1. The longer the planning period, the greater the uncertainty associated with forecasted values.
2. Building owners are likely more willing to accept shorter payback periods for building investments
3. Similar to (1) above, changes in technologies, climate, or regulatory have a greater chance of interrupting the benefit and cost analysis when evaluated over a longer period of time.

Therefore, the measure life of 15 years is used in the analysis. After 15 years, inverters on the solar PV resource will need to be replaced. When a battery is included, the measure life drops to 10 years.

6.1.2 Discount Rate

The discount rate is used to adjust future value streams to current 2023 dollars. The 2021 Power Plan used a discount rate of 3.75% which reflects the real weighted average cost of capital. This discount rate is assumed in the benefit-cost analysis as well.

6.2 RESULTS: GREEN ROOF AND SOLAR PV NO COLOCATION

The benefit-cost analysis results in mixed cost-effectiveness levels. The solar analysis and green roof analysis are prepared separately since the solar generation profile differs from the energy efficiency profiles for building HVAC. Because the analyses are prepared separately, their results can also be viewed separately. Mainly, solar PV was not cost-effective in any of the cases when a 15-year lifecycle is assumed. This result is not all that surprising from a wholesale energy perspective. Most rooftop solar installations are deemed cost effective when compared to retail utility rates which include costs that are considered transfers in this benefit cost analysis.

In some instances green roofs alone were cost-effective. This is the case when stormwater benefits are quantified such as in Seattle or Spokane. Green roofs in Yakima are not cost effective, which is not surprising considering the low average annual rainfall and related stormwater utility infrastructure. Table 6.1 summarizes the BCA results by combining all roof coverages for solar and green roof. Detail by coverage share is provided later in this section.

TABLE 6.1: BCA RESULTS GREEN ROOF PLUS SOLAR PV ALL COVERAGES

Building Type	Seattle	Spokane	Yakima
Assembly	0.82	0.50	0.41
Grocery	0.81	0.46	0.37
Hospital	0.91	0.72	0.65
Lodging	0.88	0.56	0.50
Mixed Commercial*	0.88	0.52	0.46
Multifamily High Rise (7+)	0.96	1.59	NA
Multifamily Low Rise (1-3)	0.92	0.56	0.51
Multifamily Mid Rise (4-6)	0.92	0.81	0.75
Office	0.88	0.51	0.45
Other	0.87	0.46	0.40
Residential Care	0.87	0.48	0.41
Retail / Service	0.88	0.52	0.46
School	0.86	0.46	0.40
Warehouse	0.86	0.47	0.40

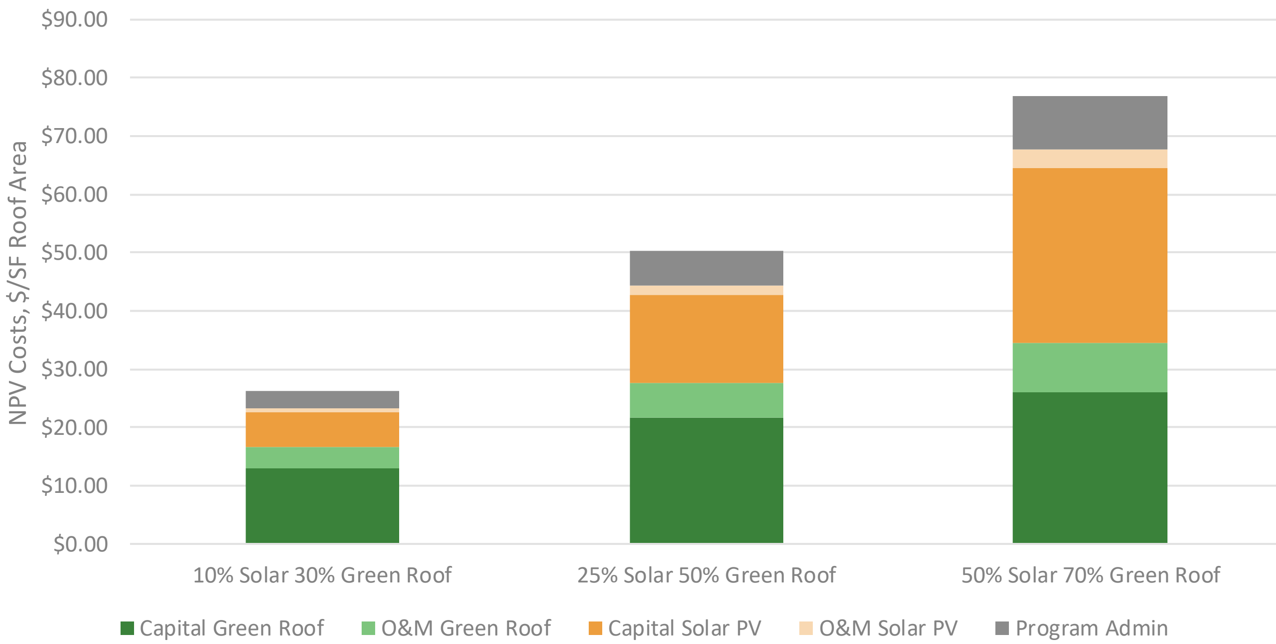
Green roof installations on multifamily buildings have been most common in the literature and many examples of green roofs on multifamily buildings have been identified in Seattle. Table 6.2 shows the BCA results for Mid-Rise multifamily buildings (4-6 stories).

TABLE 6.2: BCA RESULTS MID-RISE MULTIFAMILY BUILDINGS INTENSIVE GREEN ROOF, $/SQUARE FOOT ROOF AREA

		Solar Production Electric System Benefits	GHG Sequestration, LEED Credit, Stormwater Management	Total NPV Benefits	Total NPV Costs	Benefit/Cost Ratio
Seattle	10% Solar 30% Green Roof	$4.69	$32.72	$37.41	$26.37	1.42
	25% Solar 50% Green Roof	$12.10	$43.06	$55.16	$50.32	1.10
	50% Solar 70% Green Roof	$24.20	$47.14	$71.34	$76.87	0.93
Spokane	10% Solar 30% Green Roof	$5.77	$28.02	$33.79	$26.37	1.28
	25% Solar 50% Green Roof	$14.43	$31.98	$46.41	$50.32	0.92
	50% Solar 70% Green Roof	$28.86	$23.35	$52.21	$76.87	0.68
Yakima	10% Solar 30% Green Roof	$6.20	$26.87	$33.07	$26.37	1.25
	25% Solar 50% Green Roof	$15.50	$26.92	$42.42	$50.32	0.84
	50% Solar 70% Green Roof	$31.00	$17.15	$48.15	$76.87	0.63

In each city, the green roof is cost-effective at 30% coverage, but when adding additional solar and green roof, the rooftop agrivoltaic measure cost-effectiveness decreases. Figure 6.1 compares the share of cost for solar and green roof measures. Figure 6.1 also shows that the cost per square foot of roof area increases as coverage increases for solar and green roof installations.

FIGURE 6.1: INTENSIVE GREEN ROOF ON MID-RISE MULTIFAMILY BUILDINGS, ALL CITIES, NPV $/SF ROOF AREA



When looking at just Seattle, the benefit-cost ratios in Table 6.3 show that adding additional solar (increased from 10% to 25% coverage) reduces the cost-effectiveness across all building types. Conversely, increasing the green roof coverage in Seattle from 50% to 70% increases the benefit-cost ratio in all cases.

TABLE 6.3: SEATTLE ROOFTOP AGRIVOLTAIC BENEFIT-COST RATIOS

	10% Solar 50% Green Roof	25% Solar 50% Green Roof	10% Solar 70% Green Roof
Assembly	0.76	0.73	0.90
Grocery	0.70	0.68	0.85
Hospital	0.97	0.88	NA
Lodging	0.92	0.85	1.02
Mixed Commercial*	0.81	0.76	0.93
Multifamily High Rise (7+)	2.09	1.58	1.74
Multifamily Low Rise (1-3)	0.84	0.77	0.94
Multifamily Mid Rise (4-6)	1.13	0.95	1.12
Office	0.83	0.78	0.95
Other	0.72	0.70	0.87
Residential Care	0.78	0.74	0.91
Retail / Service	0.70	0.68	NA
School	0.72	0.70	0.94
Warehouse	0.72	0.70	0.94

The benefit-cost analysis for Spokane shows the opposite. In Spokane, adding more solar increases the benefit-cost ratio. In most cases, however, the benefit-cost ratio is below 1.0.

TABLE 6.4: SPOKANE AGRIVOLTAIC BENEFIT-COST RATIOS

	10% Solar 50% Green Roof	25 Solar 50% Green Roof	10% Solar 70% Green Roof
Assembly	0.49	0.56	0.40
Grocery	0.43	0.51	0.36
Hospital	0.68	0.70	
Lodging	0.65	0.67	0.44
Mixed Commercial*	0.54	0.59	0.36
Multifamily High Rise (7+)	1.86	1.41	1.16
Multifamily Low Rise (1-3)	0.57	0.60	0.36
Multifamily Mid Rise (4-6)	0.90	0.78	0.55
Office	0.56	0.60	0.38
Other	0.46	0.53	0.30
Residential Care	0.51	0.57	0.34
Retail / Service	0.44	0.51	
School	0.45	0.52	0.32
Warehouse	0.46	0.53	0.32

Table 6.5 shows that the benefit-cost ratios for Yakima are always below 1.0. Solar PV in Yakima improves the cost-effectiveness of rooftop agrivoltaics but without the stormwater benefit in this city, none of the measure permutations are cost-effective.

TABLE 6.5: YAKIMA ROOFTOP AGRIVOLTAIC BENEFIT-COST RATIOS

	10% Solar 50% Green Roof	25% Solar 50% Green Roof	10% Solar 70% Green Roof
Assembly	0.37	0.47	0.28
Grocery	0.30	0.42	0.23
Hospital	0.54	0.61	NA
Lodging	0.52	0.59	0.40
Mixed Commercial*	0.41	0.51	0.31
Multifamily High Rise (7+)	NA		
Multifamily Low Rise (1-3)	0.51	0.52	0.32
Multifamily Mid Rise (4-6)	0.79	0.70	0.50
Office	0.43	0.52	0.33
Other	0.33	0.44	0.25
Residential Care	0.38	0.49	0.29
Retail / Service	0.31	0.43	NA
School	0.33	0.44	0.27
Warehouse	0.33	0.45	0.27

6.3 RESULTS: GREEN ROOF AND SOLAR PV WITH COLOCATION

The literature review concluded that colocation benefits of rooftop agrivoltaics could increase solar production by up to 20% during very warm periods and by 3.6% on average. Adding colocation benefits of solar to Yakima or Spokane rooftop agrivoltaic measures will not increase the cost-effectiveness above the 1.0 threshold. However, Table 6.6 shows the impact to selected measure permutations of adding in the colocation benefits.

TABLE 6.3: SEATTLE ROOFTOP AGRIVOLTAIC BENEFIT-COST RATIOS WITH COLOCATION BENEFITS

	10% Solar 50% Green Roof	25%Solar 50% Green Roof	10% Solar 70% Green Roof	50% Solar 70% Green Roof
Assembly	0.76	0.74	0.90	0.80
Grocery	0.70	0.69	0.85	0.77
Hospital	0.97	0.89	NA	NA
Lodging	0.92	0.85	1.02	1.31
Mixed Commercial*	0.81	0.77	0.94	0.83
Multifamily High Rise (7+)	2.09	1.59	1.74	0.94
Multifamily Low Rise (1-3)	0.85	0.78	0.94	0.82
Multifamily Mid Rise (4-6)	1.13	0.96	1.13	0.83
Office	0.83	0.79	0.95	0.78
Other	0.73	0.71	0.87	0.81
Residential Care	0.78	0.75	0.91	1.31
Retail / Service	0.71	0.69	NA	NA
School	0.72	0.71	0.94	0.82
Warehouse	0.73	0.71	0.95	0.82

Because the colocation benefits are relatively small, the benefit-cost ratios did not improve significantly when they are included.

6.4 RESULTS: GREEN ROOF, SOLAR PV, AND SHORT-TERM BATTERY STORAGE

Adding short-term battery storage to the solar PV increases the cost-effectiveness given the modeled assumptions. The Procost model assigns value to peak load reductions at the time of the regional system peak. The production from the solar+battery is valued higher from primarily a capacity perspective compared with solar alone. Table 6.4 illustrates the results of the benefit-cost analysis for 10% solar coverage on the representative hospital.

TABLE 6.4 SOLAR + BATTERY BENEFIT-COST RESULTS,10% ROOFTOP COVERAGE HOSPITAL, $/SF ROOF AREA

	Electric System Benefits Energy	Electric System Benefits Capacity	Reduced GHG	Total Benefits	Total Costs	BCR
Seattle	$2.16	$1.43	$1.67	$5.26	$17.17	0.31
Yakima	$3.08	$0.33	$2.75	$6.15	$17.17	0.36
Spokane	$2.76	$0.27	$2.45	$5.48	$17.17	0.32

Table 6.5 shows the results when solar+battery is combined with a 30% coverage green roof.

TABLE 6.5 30% GREEN ROOF, 10% SOLAR + BATTERY BENEFIT-COST RESULTS, HOSPITAL $/SF ROOF AREA

	Total Benefits	Total Costs	BCR
Seattle	$22.25	$33.74	0.66
Yakima	$17.67	$33.74	0.52
Spokane	$16.65	$33.74	0.49

7 Key Findings

7.1 STUDY FINDINGS

The research and modeling revealed several key findings, some of which are specific to Washington State.

1. Increasing soil depths on green roofs in Spokane results in not needing irrigation systems due to consistent monthly rainfall.
2. Stormwater benefits in this study are dependent on the variable cost of stormwater treatment. Not all areas in Washington State will experience a reduction in water treatment cost due to green roof installations. Yakima is an example from this study where wastewater treatment facilities are impacted more significantly from irrigation leakage during the summer months than in winter from stormwater.
3. The primary benefit of green roofs is stormwater retention. Energy savings from the added R-value from green roof minimally impacted new building energy efficiency when the most recent Washington building codes are factored into the analysis. Stormwater retention potentially reduces flooding and severity of storm damage.
4. The primary quantified benefit of green roofs is the stormwater impact, and this benefit varies widely depending on the local stormwater infrastructure, operating characteristics, and annual precipitation. Studies that have shown positive cost/benefit results for green roofs have relied on quantifying softer benefits such as increased occupant productivity, comfort, or energy savings based on buildings that are not as efficient as required in Washington State. Utilizing green roofs to mitigate stormwater in Western WA also has an economic development component as it leaves more land area available for development or reduces the cost of underground storage when required.
5. In practice, rooftop agrivoltaic projects are not common. Most often when solar and green roofs are combined on the same roof, they exist separately leaving colocation benefits unrealized.
6. Rooftop solar programs are well-defined in Washington State. The cost of the infrastructure is also well-known. Washington has already implemented several programs to promote increased adoption of rooftop solar including solar-ready buildings, sales tax rate exemptions, and grant monies for qualifying projects. Additionally, significant incentives are available at the Federal level from the American Recovery and Reinvestment Act.
7. The colocation benefits of solar PV and green roofs related to energy production is not significant. The study identified qualitative colocation benefits for green roofs from solar PV shading; however, the data available was insufficient for quantifying those benefits.

7.2 BARRIERS ASSESSMENT

The barriers assessment includes both cost-related barriers as well as implementation barriers.

Based on the interviews with green roof installers and architects implementation barriers exist for implementing green roof and green roofs paired with solar.

1. Many green roof installations are motivated by the permitting process in Seattle that expedites buildings with green roof features. Without an incentive or mandate, most building developers choose conventional roofing.
2. There is a perception that co-locating solar and green roofs would interfere with O&M for the green roof and solar panels separately.
3. Green roofs on multifamily buildings are most popular due to the real estate value added.

4. There is a perception held by some roofing companies that green roofs will eventually leak and cause damage to the building.
5. The variability in climate conditions across the State makes it difficult to establish a best practice for green roof or solar coverage. Examples of green roofs in the East side of the state are limited.
6. Washington's commercial building codes already require a high level of building energy efficiency. Even in relatively colder/hotter climates like Spokane or Yakima, green roofs provide minimal additional energy efficiency savings.
7. The number of landscape companies implementing green roofs does not appear to be limited in the Seattle Area. If a program is implemented in Washington State, there is opportunity for landscape installers to expand their business to green roof work.

Cost related barriers include the up-front capital cost for implementing the green roof plus the solar resource. The incremental cost of the green roof outweigh the benefits quantified in this study especially in drier regions such as Spokane and Yakima. When combined, the cost of rooftop agrivoltaics is as much as twice the cost of the benefits quantified. When battery storage is added to rooftop agrivoltaics, electric system capacity benefits are realized; however, those benefits do not outweigh the cost of capital for the battery.

7.3 RECOMMENDATIONS

From this study it can be concluded that rooftop agrivoltaics is not wholly cost-effective. Despite the economic viability of rooftop agrivoltaics, the State may wish to promote rooftop agrivoltaics for economic reasons that are difficult to quantify based on the current literature. If the State were to move forward with a rooftop agrivoltaic program, the Project Team makes the following general recommendations:

1. Develop certification for O&M providers specific to green roof needs. Green roof maintenance should address erosion, roof drains, gravel stops, utilities, dead plants, fertilization, weeds, irrigation system, summer watering, mosquitos, and nuisance animals.
2. Green roofs should be given priority as a method to satisfy local stormwater management requirements in regions such as the Greater Puget Sound where stormwater runoff costs can be marginally impacted.
3. Scoring for increased square footage, tax abatements, and stormwater credits can be based upon depth of soil media and green square footage.
4. The value of stormwater reductions in terms of reduced long-term infrastructure costs can be passed onto developers in the form of tax reductions, utility fee reductions, or direct incentives. These programs are best suited for stormwater district administration which would include cities and counties.
5. If green roof mandates are considered, it is recommended to create multiple solutions for developers to meet the requirements. An example is the San Francisco model which lets builders choose between solar, green roof, or both.
6. Evaluate program spending or rooftop agrivoltaic potential based on specific parameters (mandate, incentive structure, grant funding level) for economic development impacts.
7. Carve out additional incentives for development incorporating rooftop agrivoltaics near highly impacted communities.

8 References

Arizona State University. Green Roof Calculator. https://sustainability-innovation.asu.edu/urban-climate/green-roof-calculator/

Akther et. al., "A Review of Green Roof Applications for Managing Urban Stormwater in Different Climatic Zones", *Sustainability* 2018, *10*(8), 2864;

Barnhart, Brad et al. Modeling the hydrologic effects of a watershed-scale green roof implementation in the Pacific Northwest United states. Journal of Environmental Management Volume 277, 1 January 2021.

Besbes, Karim et al. Green Roofs Impact on Buildings Cooling Load. Purdue University 2012. https://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=1068&context=ihpbc

Cardno TEC, Inc. Green Roof Performance Study. Prepared for Seattle Public Utilities. June 2012.

Cavadidi, Giovan and Lauren Cook. (2021). Applied Energy 296 (2021) 117082. Green and cool roof choices integrated into rooftop solar energy modeling.

Collazo-Ortega, Margarita, Ulises Rosas and Jeronimo Reyes-Santiago. Towards Providing Solutions to the Air Quality Crisis in the Mexico City Metropolitan Area: Carbon Sequestration by Succulent Species in Green Roofs. March 2017. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5400495/#:~:text=The%20species%20displayed%20their%20typical,meters%20in%20the%20short%20term.

Cove Tool. Solar Panel Cost – Residential + Commercial. https://help.covetool.com/en/articles/4529706-solar-panel-cost-residential-commercial

Cushman & Wakefield. Green is Good: Sustainable Office Outperforms in Class A Urban Markets. August 2021. https://cw-gbl-gws-prod.azureedge.net/-/media/cw/americas/united-states/insights-pdfs/green-is-good-spotlight_final1.pdf?la=en&rev=e26315797d7d49faa6c58ca7762f91a6&hash=7D9FDF170FDB5E46A373233AD8F2999F

Dialesandro, John et al. Dimensions of Thermal Inequity : Neighborhood Social Demographics and Ubran Heat in the Southwestern U.S. Environmental Public Health 2021.

European Federation of Green Roofs and Walls, https://efb-greenroof.eu

Feldman, David et al. U.S. Solar Photovoltaic System and Energy Storage Cost Benchmark: Q1 2020. National Renewable Laboratory Technical Report. January 2021. Available at: https://www.nrel.gov/docs/fy21osti/77324.pdf

Getter et. al., "Carbon Sequestration Potential of Extensive Green Roofs", Environ. Sci. Technol. 2009, 43, 19, 7564–7570

Gnecco et. al. "The Role of Green Roofs as a Source/Sink of Pollutants in Storm Water Outflows", Water Resources Management Vol 27, pgs. 4715–4730 (2013)

Green Roofs for Healthy Cities, "2018 Annual Green Roof Industry Survey Executive Summary", (www.greenroofs.org), October 2019

Green Roof Organization (GRO), "The Gro Green Roof Code, Green Roof Code of Best Practice - Incorporating Blue Roofs and BioSolar Applications" 2021

Irga, Peter et al. Green Roof & Solar Array – Comparative Research Project. Final Report July 2021. University of Technology Sydney.

opus.lib.uts.edu.au/bitstream/10453/150142/2/City%20of%20Sydney%20Final%20Report%20EPI%20R3%20201920005.pdf

Lazard. 2023 Levelized Cost of Energy+. April 12, 2023. Available at: https://www.lazard.com/research-insights/2023-levelized-cost-of-energyplus/

Lim, "What happens to nitrogen and phosphorus nutrient contributions from green roofs as they age? A review", Environmental Advances, Vol. 12, July 2023, 100366

Liu et. al., "Thermal Performance of Green Roofs Through Field Evaluation", In Proceedings: The First North American Green Roof Infrastructure Conference, Chicago, IL, 2003 (pgs. 1-10)

Kats, Gregory H. Green building Costs and Financial Benefits. Massachusetts Technology Collaborative. 2003. Available at : https://www.wbdg.org/files/pdfs/green_bldg_costs_kats.pdf

Kessling et. al., "Feasibility of Combining Solar Panels and Green Roofs on the Activities and Recreation Center"

McIntosh, "Green Roofs in Seattle - A Survey of Vegetated Roofs And Rooftop Garden", prepared for the City of Seattle, Dept of Planning & Development and the University of Washington Green Futures Lab, August 2010

National Renewable Energy Laboratory. Documenting a Decade of Cost Declines for PV Systems. February 10, 2023. Available at: https://www.nrel.gov/news/program/2021/documenting-a-decade-of-cost-declines-for-pv-systems.html

Northwest Power and Conservation Council Memorandum to the Power Committee Members. Subject; Updated Transmission & Distribution Deferral Value for the 2021 Power Plan. March 5, 2019. Available at: https://www.nwcouncil.org/sites/default/files/2019_0312_p3.pdf

Northwest Power and Conservation Council. Regional 2021 Northwest Power Plan. March 10, 2022.

Okita, et. al., "Effect of Green Roof Age on Runoff Water Quality in Portland, Oregon", Journal of Green Building (2018) 13 (2): 42–54

Paladino & Company, Inc., Green Roof Feasibility Review. February 2006. Available at: https://kingcounty.gov/~/media/depts/dnrp/solid-waste/green-building/documents/KC_Green_Roof_case-study.ashx?la=en

Reshmina, William et al. An Environmental cost-benefit analysis of Alternative Green Roofing Strategies. Ecological Engineering Volume 95, October 2016. Available at: https://www.sciencedirect.com/science/article/abs/pii/S0925857416304165

Seattle Urban Farm Co. https://www.seattleurbanfarmco.com/

Seattle Public Utilities Drainage Wastewater Rate Study. Available at : https://www.seattle.gov/documents/Departments/SPU/Services/Rates/2022-2024_DrainageWastewater-RateStudy.pdf

Seattle Public Utilities and King County. Green Stormwater Infrastructure 2017-2018 Overview and Accomplishment Report. Available at: https://www.seattle.gov/documents/Departments/SPU/Documents/Reports/GSI-ProgressReport2018.pdf

Seyedabadi et. al., "Plant Selection for Green Roofs and Their Impact on Carbon Sequestration and the Building Carbon Footprint" Environmental Challenges, Vol. 4, August 2021, 100119

Shafique, et. al., "An overview of Carbon Sequestration of Green Roofs in Urban Areas", Urban Forestry & Urban Greening, Vol. 47, January 2020, 126515

Solutions, Clear Creek. Western Washington Hydrology Model Version 4.2.19. Accessed April 2023.

Spokane 2023 Adopted Budget. Available at : https://static.spokanecity.org/documents/budget/2023/2023-adopted-budget-detail.pdf

Tolderlund, "Design Guidelines and Maintenance Manual for Green Roofs in the Semi-Arid and Arid West", University of Colorado, Denver CO, 2010

Unbound Solar. Available at: https://unboundsolar.com/blog/do-you-need-leed-credits-heres-what-we-can-do August 10, 2023.

United States General Services Administration, "The Benefits and Challenges of Green Roofs on Public and Commercial Buildings", May 2021

U.S. Environmental Protection Agency. 2008. Green Roofs, in "Reducing Urban Heat Islands: Compendium of Strategies". Draft. Available at: https://www.epa.gov/heat-islands/heat-island-compendium

U.S. Environmental Protection Agency. Stormwater Best Management Practice. Green Roofs. December 2021. Available at: www.epa.gov/system/files/documents/2021-11/bmp-green-roofs.pdf

USGBC. LEED Certification Fees. https://www.usgbc.org/tools/leed-certification/fees

WAC 194-40-100 through 110. Available at :https://apps.leg.wa.gov/wAc/default.aspx?cite=194-40-100&pdf=true

WAC 173-444-040

Walston et. al., "Opportunities for Agrivoltaic Systems To Achieve Synergistic Food-Energy-Environmental Needs and Address Sustainability Goals", Frontiers in Sustainable Food Systems, 2022

Weather-US.com

Yakima 2024 Preliminary Budget. https://www.yakimawa.gov/services/finance/files/2023-2024-Revised-Preliminary-Budget-Qtr-Amend.pdf

Yocom, Ken and Ben Spencer. Greenroof Performance Study: Puget Sound Region. Seattle WA. 2012 /https://thecela.org/wp-content/uploads/GREENROOF-PERFORMANCE-STUDY.pdf

9 Appendix A Green Roof Installation Provider Contacts and Interview Questions

Sol Terra, info@SolTerra.com (206) 462-1103 https://solterra.com/ (Seattle)

McDonald & Wetle Roofing AnnaB@mcdonaldwetle.com 253-589-8999
https://www.mcdonaldwetle.com/seattle-metro-area/ (Seattle)

Cobalt Exteriors, (253) 844-5141 (serves Seattle, Bellevue, Bothell, Kirkland, Redmond, Renton, Tacoma, Woodinville) https://www.cobaltexteriors.com/roofing/green-roofing/

Element Smartroofing info@elementsmartroofing.com 425-968-3000 and (253) 642-7669
https://elementsmartroofing.com/services/roofing/green-roofs-2/
(Serves Eastern WA and Bellevue/Tacoma)

Green Roofs Olympia, 360-968-6120, jraines@olympiagreenroofs.com
https://www.olympiagreenroofs.com/ (Landscape Architect, messaged about leads on green roof installers/contractors)

Bark Kings (Blower truck service for green roof soils) 425-814-6444
https://www.barkking.com/services/green-roof-soil-installation/
(They're based in Kirkland but serve eastern WA)

Transblue, inquiries@transblue.com (844) 482-2583 https://transblue.com/locations/WA/monroe
https://transblue.com/locations/WA/tacoma
(Monroe, Tacoma and surrounding areas)

Pacific Landscape Management (503) 648-3900 info@pacscape.com
https://www.pacscape.com/sustainability/green-roofs.php (serves Puget Sound)

Terra Firma NW LLC 360-201-1366 http://www.tfnwllc.com/about_firm.html
(Orcas Island)

All Weather Roof 425-258-4400, info@allweatherroof.net http://allweatherroof.net/
(Based in Everett.)

Nussbaum Group 206-545-0111 michellep@nussbaum-group.com (PM)
https://nussbaum-group.com/ (Based in Redmond, serving regionally)

Alliance Landscape Services 425-359-7544, scott@alliancelandscapeservices.com
https://www.alliancelandscapeservices.com/home.html (Based in Snohomish, serving regionally)

Pacific Earthworks info@pacificearthworks.com 206-625-1749 and 360-794-7579 https://www.pacificearthworks.com/ (Based in Monroe, serving regionally)

PCL Construction tbkautz@pcl.com Tyler Kautz, Seattle District Manager (425) 454-8020 https://www.pcl.com/us/en/who-we-are/our-offices/seattle-buildings

Snyder Roofing (425) 402-1848 https://snyder-builds.com/ (Based in Snohomish.)

Northwest Landscape Services https://www.nlswa.com/ (They are now a part of Monarch Landscape Companies)

Monarch Landscape Companies 833-652-7233 info@monarchlandscape.com https://www.monarchlandscape.com/landscape-development (Washington)

MIG (SvR merged with them) 206-223-0326 info@migcom.com https://www.migcom.com/green-infrastructure Audrey West (Seattle Director of Landscape Architecture awest@migcom.com)

Berschauer Group (360) 539-7252 admin@berschauergroup.com https://www.berschauergroup.com/ (Based in Tacoma and Olympia.)

Weston Solutions (888) 404-4743 info@greengridroofs.com

Interview Questions

Introduction: Hello my name is Rachel with Peak Sustainability Group. We were hired by WA dept of Commerce to evaluate the benefits and costs of agrivoltaic projects on new commercial buildings sized 10,000 square feet or larger. We're specifically interested in the installation, O&M costs and considerations of green roof applications. If you have about 30 minutes we would like to interview you as of several companies we are looking to as we gather green roof industry information. Is there a time that works for you to have a chat? In the meantime, feel free to answer the list of questions below. This will help make us of our time and keep our call short.

1. Does your company install green roofs? If so, what services do you offer? (design, installation, O&M)
    a. What other types of companies, if any, do you interface with? (Architects, engineers, etc.)
    b. Can you recommend any individuals or firms to speak with from an architectural or engineering standpoint?
2. To what specific cities or regions do you provide these services?
3. What are the estimated number of green roof projects completed by your company per year?
4. Are green roof installations done for existing or new buildings? (one more than the other? Only new buildings?) – What is the estimated percentage split between existing and new?
5. For green roof projects, what are the primary motivations for building owners? (if known)
6. Are you aware of any green roof incentive programs?
    a. Which programs seem to be the most successful, or lead to more work for you?
7. Please describe the most requested projects in terms of the following:
    a. Building type (Retail, restaurant, multi-family, office, warehouse, municipal)
    b. Building size (is there a minimum or maximum, average SF roof size)
    c. Green roof design (extensive and intensive, food growing?)
        i. How often is irrigation required?
        ii. Are there standard irrigation specifications?
        iii. How do costs and maintenance for irrigation vary?
    d. Typical coverage for each type
8. What is the cost of green roof installation? Rough estimate in $/SF, or range of estimates. Cost to include materials, labor, design.
    a. Are there supply chain impacts on design, cost, or implementation?
9. What is the cost for O&M in $/SF/year (range or by building installation type?)
10. How long does it take for green roof to be established/successful?
    a. What contributes to variability in establishment?
11. Is there a specified plant palette that is used for extensive applications? How does the plant palette vary?
12. What is the lead time for a client from the time they contact you to when the project is finished?
13. What is the typical crew size for each project? (IE: 1 foreman, 4 laborers)
14. In your experience, what attributes/considerations make for successful green roof installation and maintenance?
15. What is the typical crew size for each project? (i.e. 1 foreman, 4 laborers)
16. What is the roof size to number of crews ratio? i.e. A 10,000 SF roof gets 2 crews working full-time and the job is finished in a week.
17. At what point would you need to hire more staff? How many projects would you need scheduled to expand your staff?
18. In the regions you provide services, can you install green roofs during all seasons or only in some months?
19. What Best Management Practices do you observe in your practice?

    a. Is there a standard followed?
20. Have you completed any projects that also include solar panels?
    a. What are the considerations for paired systems (green roof + solar?).
    b. When solar is included, does green roof design factor in co-benefits of solar shading plantings? If so, what assumptions/best practices are used?
    c. Are there specific maintenance considerations on roofs with PV's?
21. Is there anything else we should know about?
    a. Can specify examples such as policy, incentives, best practices, what not to do, etc.
22. Is there a modeling software or 3d modeling that you can share to help with energy savings analysis?
    a. File extensions xml idf
23. Is it ok if we follow up with other questions, if we have any?

10 Appendix B Interview Responses

1. Does your company install green roofs? If so, what services do you offer? (Design, installation, O&M)
    a. What other types of companies, if any, do you interface with? (Architects, engineers, etc.)
    b. Can you recommend any individuals or firms to speak with from an architectural or engineering standpoint?

(GreenGrid Weston Solutions – Michal Krol, in Glastonbury, CT, with several other offices across the nation.)

We used to do installations but not anymore. However, installation is easy, and we help customers decide on a proper system. We don't have enough people to install all the projects we do so we work closely with installers throughout the US.

The services we offer are design consulting, O&M, installation support, and onsite manufacturer's representative.

a.) Architects, engineers, general contractors, roofers, landscapers, homeowners, and green roof specialty companies.

b.) Depends on location and goals of project

(LMN Architects – Kjell Anderson, Office located in Seattle). We are architects and design green roofs.

a.) Landscape Architects, Engineers, etc.

b.) (we didn't have time for this) (McDonald & Wetle Roofing) we provide roofing installation; we're qualified to lay green roofs, but we don't because of the inevitability of leaking and other issues, and most landscapers won't do the maintenance. *(Though they were encouraged to, McDonald & Wetle Roofing was not interested in answering many questions because they are not fond of green roofs. Their next and last response is to question 19.)*

(MIG-SvR – located in Seattle) We are a group of landscape architects and urban planners, we work with other fields such as engineers and architects, landscape, and general contractors. Cerna Landscape is their contact for green roof installations. *(Cerna has been called by phone. They do not have a website or listed email address online.)*

(Olympia Green Roofs – Jana Raines, located in Olympia) We design green roofs, we don't do the installation or O&M. Other's that Jana interfaces with are Olympia Master Builders, contractors, and developers.

Jana recommends speaking with American Hydrotech *(listed for future contact)*, Columbia Green *(listed for future contact)*, Elizabeth Morris of Green Up Roofing in Portland *(listed for future contact),* and Olyssa Starry *(a professor at Portland State University, expert in green roofs and storm water management.)*

(Pacific Landscape Management – CJ, located in Seattle) We do maintenance and renovation work, and re-landscape. CJ interfaces with various engineers and architects and recommends contacting Malones Landscape and Green Effects for these interviews *(listed for future contact).*

(Landscape Professionals – Brian Mazzola, located in Seattle) We provide a variety of landscape installation services, and we install green roofs on apartments in Seattle (True Green often does the maintenance on them, but they are not educated or know what they're doing.)

   a.) Landscape architects, suppliers and their representatives, warranty companies (mainly Suprema, who provides a 20-year coverage i.e. if veg penetrates membrane they will cover it, but he's never seen it happen.) He also provides his own warranty on projects. He occasionally interfaces with someone from Seattle Public Works when tray systems are used in storm calculations for the City of Seattle.

b.) He does not have any recommendations of who to speak with.

2. To what specific cities or regions do you provide these services?

(GreenGrid Weston Solutions) Entire U.S., everywhere from Seattle, San Diego, Omaha, to the east coast. We even have done projects in both HI and AK.

(LMN Architects)
Pacific Northwest
(McDonald & Wetle Roofing) Seattle
(MIG-SvR) Seattle

(Olympia Green Roofs) South Puget Sound Region, if policy were created where people were installing them then they would offer to all of western Washington.

(Pacific Landscape Management) Throughout Portland and Salem, Oregon and Puget Sound (Issaquah, Mukilteo)

(Landscape Professionals) He provides service to the Puget Sound area.

3. **What are the estimated number of green roof projects completed by your company per year?**

   (Green Grid Weston Solutions) >100

   (LMN Architects) –

   (McDonald & Wetle Roofing) –

   (MIG- SvR) They have designed 2, but they were value engineered off the projects.

   (Olympia Green Roofs) 4-5 at best per year; there are more conversations than actual work – she had to get another job.

   (Pacific Landscape Management) The company is dominant in Oregon and gets 40-50 thousand projects a year (primarily residential and multifamily). Their recent expansion to Seattle is the result of an acquisition.

   (Landscape Professionals) We do 2-3 green roof projects per year.

4. **Are green roof installations done for existing or new buildings? (One more than the other? Only new buildings?) – what is the estimated percentage split between existing and new?**

   (GreenGrid Weston Solutions) Both, ~75% on new buildings and ~25% on existing buildings. It used to be retrofits but has shifted over the years to new construction.

   (LMN Architects) –

   (McDonald & Wetle Roofing) –

   (MIG- SvR) We have only designed for new buildings.

   (Olympia Green Roofs) We mostly design for new buildings but have done retrofits. It's about 60% new buildings and 40% retrofits.

   (Pacific Landscape Management) We're only getting work on existing buildings right now.

   (Landscape Professionals) We never work on existing buildings, only new buildings.

5. **For green roof projects, what are the primary motivations for building owners?**

   (Green Grid Weston Solutions) Amenity spaces, stormwater management, tax abatements, regulatory compliance, ESG reporting, and general sustainability that led to LEED certification.

   (LMN Architects) Occupiable space or anything that allows the developer or building owner to “sell”

   (McDonald & Wetle Roofing) –

   (MIG- SvR) creating open space for use by the building occupants (residential, office, commercial, etc.)

   (Olympia Green Roofs) doing the right thing and having occupiable space if possible.

   (Pacific Landscape Management) Residential, commercial, mixed use; higher apartment condos are for tenant use, mixed use is for creating usable space, commercial for employee break areas.

   (Landscape Professionals) Green Roofs help the developer get their building built, but they wouldn’t if they didn’t have to. Heating/cooling bills are often less overtime as well but that’s a secondary motivation.

6. **Are you aware of any green roof incentive programs?**
   a. **Which programs seem to be the most successful, or lead to more work for you?**

(Green Grid Weston Solutions) Yes; Upfront capital cost reductions, others that allow for enhanced building footprint, tax credits, sewer fee (credits back since you are discharging less)

(LMN Architects) Stormwater mitigation program/Policy in Seattle to mitigate stormwater (blue roofs and green roofs); for example, the Convention Center in Seattle, has 11 strategies with tiered options to mitigate stormwater (green factor); King County has a few as well. It doesn't pay back to reuse stormwater in the building until 10-15 years, but it does help get a high-level LEED certification for the building.

(McDonald & Wetle Roofing) –

(MIG- SvR) No, we haven't designed green roofs by the help of policy or incentives. Money talks, and developers (even those who are focused on affordable housing) are using Evergreen Sustainable Development Standards.

(Olympia Green Roofs) No policies or incentives are leading to more work in the south Puget Sound region.

(Pacific Landscape Management) Not aware of any incentives or policy. CJ has been working for this company for many years in Portland and recently (in the last 1-2 years) PLM expanded to the Seattle area.

(Landscape Professionals) Seattle has a "Green Factor" where the Landscape Architect must fill out a point sheet and a green roof adds a lot of points. Green Factor is the reason they get green roof projects.

7. **Please describe the most requested projects in terms of the following:**
    a. **Building type (Retail, restaurant, multi-family, office, warehouse, municipal)**
    b. **Building size (is there a minimum or maximum, average SF roof size?)**
    c. **Green roof design (extensive and intensive, food growing?)**
        i. **How often is irrigation required?**
        ii. **Are there standard irrigation specifications?**
        iii. **How do costs and maintenance for irrigation vary?**
    d. **Typical roof coverage for each type in 7a. above (what percent roof coverage is optimal)?**

(Green Grid Weston Solutions) a. Mixed-Use Buildings, b. Not really, they can be very small (~500sf) or large in size (>100,000sf); c. Extensive, i) TBD, depends on many factors (region, plants, etc.) but most extensive pre-grown modular systems don't require irrigation, ii) Surprisingly overhead spray is more effective than drip. Green roof media is very porous so in order to get water to reach every plant you'd have to space drip irrigation very close. More success with overhead spray. iii) Standard sedum green roofs are low maintenance but not "no maintenance". The biggest disappointment in the long run is the lack of maintenance. Sometimes all it takes is fertilizer once a year and hand weeding throughout the growing season. Well maintained = low effort. Green roof restoration is a lot more expensive than proper maintenance. D) Full coverage is optimal, lifecycle cost (covering entire roof), energy savings, stormwater (more linear as it's based on SF). Larger green roofs (more coverage) mean more energy savings and a positive effect on stormwater.

(LMN Architects)

a.) Seattle – multifamily primarily and some office projects are the most requested project's building types, because people feel like being outdoors (especially with Covid) and typically PV's as are used as trellis's.
b.) Building size is often 25,000 sf on the roof. The Vancouver Convention Center is 1,000,000 sf + has some PV some blue roof, some planters on the side that are stacked and mitigating storm water with Silva Cells (an underground tree rate that allows roots to spread out and down, and the structure serves as an underground bioretention area in tight urban spaces, assisting with stormwater management.). Townhomes in Seattle (3-4 stories) have occupiable roofs with greenery but no PV.
c.) Usually, green roofs are not growing food, but the case for food is potentially viable if, for example, herbs are grown for restaurants (since they are expensive and chef's want them fresh) or tomatoes are grown, but only for very motivated clients. The Vancouver Convention Center has been keeping on it and uses the honey in the restaurant and catering for the Convention Center. Food production is not happening as much though since the depth is 4" trays and there is only 4" of soil above the root blocker with some water retention texture.
i) Not sure Vancouver conv. Center, changed the plantings, using tall grasses now - those are successful and shallow;
d.) N/A for ii and iii

(McDonald & Wetle Roofing) –

(MIG- SvR) Multifamily residential where creating open space on the structure can be done sustainably (providing multiple benefits).

(Olympia Green Roofs) Family, multifamily. It's been very difficult to find any work designing green roofs. Many contractors and builders are not familiar with new technology for green roofs and shoot down the idea. She hasn't had wide enough installation experience to answer this set of questions.

(Pacific Landscape Management) a.) Multifamily; b.) range between 1500-5000 sf; c.) mostly using 4" trays, i.) Irrigation is always required. Green roofs are inhospitable spaces, not even xeriscapes do well due to sunlight and harsh conditions (he's been doing this for 15 yrs in the pacific northwest). ii.) regarding standard irrigation specifications, it depends on who designed and installed it. Drip is more efficient due to runoff and drainage. If the design and layout are not good for irrigation, then they use spray because it is more forgiving. D.) typical roof coverage is no more than 1/3 of the roof. Due to maintenance and weight, and possibly price. It depends on the building (the architect would know)

(Landscape Professionals)

a.) We install green roofs on apartment buildings.
b.) The typical roof size is about 3,000 SF, but we install projects from 200 SF to 13,500 SF and the buildings are midrise from 5-7 stories.
c.) Extensive green roofs are typical, but we have installed intensive roofs for growing grasses and vegetation. Some architects like to do a mix of both, but there is not much food production. Strawberries and raspberries would be ideal, and plants with shallow roots that aren't aggressive growers. They installed an Aegis senior living building that had galvanized steel 2'x6' planters for gardens.

d.) i.) Irrigation is always required for at least the first two years. It remains in place after that period in case it is needed again.
e.)
f.)

ii.) He tries to use spray when he can. Drip is used when the green roof is installed in late fall, so the plants can root through the winter and then in the spring they can get away with drip irrigation rather than spray. He typically uses spray heads with rotary nozzles because they work with lower pressure and distribute water more evenly than other sprinklers. If there is a serious lack of water pressure, he will use drip instead. This is due to building elevation since they lose ½ pound of water pressure per every foot of elevation. The higher buildings are better off having extensive green roofs for this reason, but drip is rarely specific in architectural plans.

iii.) Typically, maintenance costs for irrigation aren't much. In the spring the irrigation gets turned on and things are adjusted and fixed as needed every month.

d.) The optimal roof coverage is 1/3 - 1/2 of the roof and no more than that.

8. **What is the cost of green roof installation? Rough estimate in $/sq. ft., or range of estimates. Cost to include materials, labor, design.**
    a. **Are there supply chain impacts on design, cost, or implementation?**

(Green Grid Weston Solutions) $5-$15/sf, N/A

(LMN Architects) –

(McDonald & Wetle Roofing) --

(MIG- SvR) Doesn't remember rough estimate in $/SF but did say that irrigation costs are constantly changing based on the price of oil.

(Olympia Green Roofs) Extensive green roof with intention of agriculture (new construction) $50-75/sf, over-head cost; on a structurally secure building around $25-40/sf. Green roofs for healthy cities and other professional websites with numbers. Regarding supply chains: irrigation costs change when the price of oil changes.

(Pacific Landscape Management) Installation costs about $200-500/SF but it varies a lot, considering things like pavers or amenities. Everybody on all phases of the industry right now are experiencing supply chain issues, likely due to the war in Ukraine for fertilizer, and maybe effects of COVID.

(Landscape Professionals) Roughly speaking, a built-up system (that with no trays, just membranes, aluminum edging, soil and sedum mats) is $25-35 /sf; and extensive application using sedum trays is $32-33/SF.
a.) Supply chain impacts include soil, and truck drivers, but right now there aren't any supply chain impacts. Columbia Green used to ship soil from Oregon but now Cedar Grove is supplying soil so they are experiencing any supply delays.

9. **What is the cost O&M in $/sq. ft./year (range or by building installation type)?**

(Green Grid Weston Solutions) $0.50-$1.50/sf but it's driven by size and logistics to access. Intensive roof gardens are going to be very similar to ground maintenance which is driven by plant types and irrigation.

(LMN Architects) Doesn't remember

(McDonald & Wetle Roofing) --

(MIG- SvR) Doesn't remember

(Olympia Green Roofs) Extensive green roof with intention of agriculture (new construction) $50-75 per sf, over-head cost; on a structurally secure existing (?) building likely $25-40; Gr roofs for healthy cities and other professional websites with numbers;

(Pacific Landscape Management) $5 -$10/SF, but could be as low as $1, and approximately $8-15k/yr for a commercial building of 50,000 SF coverage with sedums plantings.

(Landscape Professionals) O&M costs are roughly $1000 per year. The biggest issues are weeds and bird poop and it's harder to maintain a bigger roof. Generally, 1 hour per week would do it for maintenance.

10. How long does it take for a green roof to be established/successful?
   a. What contributes to variability in establishment?

(Green Grid Weston Solutions) ~4-6 months pre-grown from cuttings at the nursery, option to reduce lead times to ~6 weeks with sedum mat option. ~6-9 months if pre-grown from seed.
a.) Region, weather, plant selection, etc.

(LMN Architects) 6 months – 1 year, it depends on the plants and growing conditions.

(McDonald & Wetle Roofing) --

(MIG- SvR) 6 months - 1 year

(Olympia Green Roofs) 6 months

(Pacific Landscape Management) Plant health is the determining factor for timing.

(Landscape Professionals) It takes 2 years to be established, and irrigation is discontinued after that. a.) Plant health is the biggest contributor to variability in establishment.

11. Is there a specific plant palette that is used for extensive applications? How does the plant palette vary?

(GreenGrid Weston Solutions) We use a mix of sedum that can vary from 6-16 different species. Plant palette can vary based on color specifications and sun exposure.

(LMN Architects) It depends on what is growing well and may need to be adjusted. Typically, plants that do well in the wind and rain and those that can handle some drought.

(McDonald & Wetle Roofing) –

(MIG- SvR) Sedums (variety for visual interest) grasses; Dianella (a New Zealand native) holds up well in the wind and is drought tolerant, keeps its shape and form well.

(Olympia Green Roofs) sedums and grasses but can also be shade plants.

(Pacific Landscape Management) Sedums, the top 35 plants in PNW.

(Landscape Professionals) Extensive applications only use sedums. Intensive applications require drought tolerant grasses (blue fescue, pennesetum, juncus, etc.)

12. What are the challenges for commercial green roof installations you've come across?

(GreenGrid Weston Solutions) Lead times, construction delays, improper phasing (green roof installed too early), Health and Safety (H&S; retrofits might not have accommodations for meeting H&S requirements, post-installation maintenance)

(LMN Architects) It costs a lot of money and there is no pay back, the client needs to think the project will be sellable (or incentives need to be provided), maintenance issues including access and proper timing.

(McDonald & Wetle Roofing) Green roofs prone to leakage, and finding landscape maintenance crews is very difficult.

(MIG- SvR) Long term risk of project failure; it's a costly installation; developers are concerned with owning a building long term, and that they have to deal with the issues that arise.

(Olympia Green Roofs) Lack of roofing companies being willing to learn to trade old for new.
These projects bring in another insurance component. People who were willing to have the conversations were young businesses, altruistic, but didn't have the overhead.

(Pacific Landscape Management) Moving material through surface elevators, cost of cranes depending on building height, logistics.

(Landscape Professionals) 12th floor – the wind was a big challenge. It's like a tunnel. We had to use special pieces to hold down sedum mats.

13. In your experience, what attributes/considerations make for successful green roof installation and maintenance? What have been lessons learned?

(GreenGrid Weston Solutions) Proper lead times and planning, maintenance piece is owner commitment. Project schedules and timing that don't add additional costs.

(LMN Architects) Occupiable roofs that have greenery and then green roofs that are not occupiable, occupiable roof can have a ton of people on it, and if it's not occupiable it needs to have maintenance workers on it and there needs to be a door, smokers have to be 25' away from the doors, client pays for it.

(McDonald & Wetle Roofing) --

(MIG- SvR) Plant performance considering harsh conditions. Installers for solar panels need to be very careful to not puncture the green roof membranes. Creating occupiable space is where projects get built, and using pots and 4" trays is the easiest for maintenance. Many don't want to pay the high overhead and those who are willing to go the extra mile are usually young and can't afford the high overhead costs.

(Olympia Green Roofs) Using the right products with the latest technology and having skilled labor to do the work. Projects are rare due to costs and lengthy waits for benefits to building owners. Maintenance and fear of failure deter the trades from being interested.

(Pacific Landscape Management) Craftmanship and design are important. Not everyone is as good at building things and often the outcome of the installation depends on the crew.

(Landscape Professionals) The biggest indicator of success is maintenance.

14. What is the typical crew size for each project? (IE: 1 foreman, 4 laborers)
(GreenGrid Weston Solutions) 1 foreman, 4 laborers

(LMN Architects) N/A

(McDonald & Wetle Roofing) --

(MIG- SvR) N/A

(Olympia Green Roofs) N/A

(Pacific Landscape Management) It depends on the project. It could even be just 2 laborers.

(Landscape Professionals) 1 foreman, 4 laborers.

15. How many hours of labor per 100 sq. ft.?

(GreenGrid Weston Solutions) 2,500 sf/day to start, +5,000 sf/day for multiple days. With GreenGrid products it takes 15-30 minutes to install 100SF.

(LMN Architects) N/A

(McDonald & Wetle Roofing) –

(MIG- SvR) N/A

(Olympia Green Roofs) N/A

(Pacific Landscape Management) 20-40 hours

(Landscape Professionals) 1,000 SF per day with a crew of 5 working 8 hours. Or, 2.5 hours per 100 SF.

16. In the regions you provide services, can you install green roofs during all seasons or only in some months?

(GreenGrid Weston Solutions) Depends on region, some allow for yearly installations other only during the warmer months (temps above freezing and no snow cover)

(LMN Architects) N/A

(McDonald & Wetle Roofing) –

(MIG- SvR) N/A

(Olympia Green Roofs) – We did not have time for this question.

(Pacific Landscape Management) We install in all seasons.

(Landscape Professionals) We install in all seasons.

17. What Best Management Practices (BMPs) do you observe in your practice?

a. Is there a written standard or set of referenced specification followed?

(GreenGrid Weston Solutions) Sum of everything that has already been said

(LMN Architects) Several Rules of thumb for solar, keep penetrations out of major areas of the roof, plumbing penetrations can result in losing several panels minimum. Laying it out, add 4-10 lbs to roof load per SF to support ballast and other systems to hold PV down. Keep plumbing penetrations out of the green roof medium. Yes, there is a standard to follow.

(McDonald & Wetle Roofing) –

(MIG- SvR) Using planters for plants on roofs makes easier maintenance and less goes wrong
BMP – making sure waterproof layer is protected – biggest issue is accidental penetration of the membrane.

(Olympia Green Roofs) Following the guidelines put out by the German Commission with those standards and protocols by Green Roofs for Healthy Cities; don't try to reinvent it.

(Pacific Landscape Management) We focus on staff training and follow all specifications on architectural drawings.

(Landscape Professionals) Columbia Green provides a great maintenance packet. The general maintenance person is the one in charge of maintaining the green roof.

They installed a gated dog run, but people didn't use it and they let their dog wander wherever causing them to pee and poo on the green roof area rather than the dog run. Most have a railing to keep people from falling off a building. The dog excrement affects the performance of the green roof.

a.) Columbia Green's package has good specifications and Brian can send it over if needed.

18. Have you completed any projects that also include solar panels?

a. What are the considerations for paired systems (green roof + solar?).
b. Are there specific solar-green roof configurations that are typically favored?
c. When solar is included, does green roof design factor in co-benefits of solar shading plantings? If so, what assumptions/best practices are used?
d. Are there specific maintenance considerations on green roofs with PV's?

(Green Grid Weston Solutions)

a.) They are complimentary, green roof keeps the roof cooler which makes the solar panels more efficient when they run cooler.
b.) Green roof in one area and solar in another or alternating.
c.) Project location and climate specific.
d.) Not typically, maybe in high snowfall areas maybe you wouldn't want green roof under where snow would pile up high.

(LMN Architects)

a.) Occupiable space, creating enough space for maintenance, proper installation.
b.) Trellis PV's for shading occupiable areas.
c.) No specific plants to report but yes there are co-benefits.
d.) 1/3 area is mechanical space, green roof is more rare than using PV, PV is inexpensive and screams sustainability, historically more green roof than PV but economics are changing and WA State energy code requires PV on roof although there are exceptions for it.

(McDonald & Wetle Roofing) No

(MIG- SvR) Yes; a.) There was a project where about 20% roof coverage were vines and 50% roof coverage was solar; b.) this was for an overhead parking structure; c.) It can, but our design wasn't focused on using co-benefits; d.) Proper access space.

(Olympia Green Roofs) Hot completed any projects, but have researched and designed. (The following answers are based on Jana's research.) a.) They work symbiotically together; the cooling environment is sustainable for colocation.

The engineering and intensive green roofs are quite heavy. 25-30% has to be green roof or solar and the weight can be dispersed on the structure (Denver policy). Areas that can't handle weight load must be non-vegetated.

b.) Contact Jennifer Buffalo from Colorado State University, she's an ag-voltaic expert.

c.) Sedums and grasses do well with shaded area; can get a greater diversity of plants to grow in shade
d.) Be careful to not damage the membrane and the solar panels.
There are many leakage options, and to avoid them everything needs to be kept in-place and well-sealed. The maintenance person needs education around the needs of both PV's and green roofs. Right now, anyone can do the work that wins the bid, and they aren't necessarily educated with the latest technology and installation methods. We need the labor field to be educated and standardized.

(Pacific Landscape Management) No, we have not done PV work.

(Landscape Professionals) Yes, we worked on a project with both green roofs and solar panels. It was in the lower Queen Ann area of Seattle and the PVs were outside of the green roof area.
a.) It’s best if green roofs and solar panels are kept separate for maintenance.
b.) He would say that it’s favorable to have the two systems kept separate and not integrated.
c.) N/A

d.) No maintenance considerations, just keep green roofs and solar panels separate.

19. Is there anything else we should know about?

a. Can specify examples such as policy, incentives, best practices, what not to do, etc.

(GreenGrid Weston Solutions) No.

(LMN Architects) Don't puncture the green roof membranes when installing PV's or plumbing. Provide adequate space for maintenance workers and mechanical needs (roughly 30% of roof space) be sure to include a door that maintenance folks can use to access the roof, but that others can't use in the case it's not an "occupiable space". Be sure there is space for smokers to be 25' away from the door if it *is* occupiable space.

Solar panels and green roofs are not mutually exclusive, especially with maintenance.
When wanting wind or rain protection, it makes sense to have a terrace use of PV on roofs.

A good example of green roof and solar project is the Austin Central Library in Austin, Texas – has an occupiable terrace for the public and a trellis of PV that blocks some sun and is compelling from an architectural point of view.

There is a case for using blue roofs in the pacific northwest (which stores water on the roof and delays stormwater.)
Green roofs are often used in urban areas because cities have less greenery and taller buildings where people want to add to a view or want to see the existing view with a specific space for viewing (a case for a green roof).
Other apt buildings around Seattle have an occupiable terrace on the roof with hardscape and landscape but none have combined landscape and PV, it's primarily hardscape under PV.
A project in Madison, Wisconsin had some PV on the terrace and used a green-blue roof to capture water for use in toilets, contributing to stormwater management.
Green roofs are best used in occupiable areas and for capturing rainwater, which could be used in the building for toilets only. If people are on the roof, then the water needs to be treated before it is used in the building, even for toilets.

(McDonald & Wetle Roofing) Policy and incentives would just anger the industry because suppliers are responsible for the technology. The problem lies in extreme amounts of water on the roof and it's not easy to clean. Environmentally it's a great idea, but they are hard to maintain. More of these are done in Portland due to their policies.

(MIG- SvR) - Money talks, Developers are using evergreen design standards (developers that focus on affordable housing). One of the deciding factors of a project that kept the green roof was having the roof space for use for residents and events, rather than the sustainability factor (insulation and stormwater). The last green roof project MIG-SvR had was 7 years ago and the green roof didn't go through the beginning phase of the design. We designed an agrivoltaic project that had vine trellises and solar panels over the parking garage of a government building, but it got value engineered out of the installation.)

(Olympia Green Roofs) Seattle's policy gets worked around and there's a handful of failures in the policy terms which aren't being lived up to, or developers have found ways around it (like the case in Denver where folks can pay their way out of it.)

Recommendations for policy (like Denver) needs to be a voter-driven policy change, we need signatures to put it on a ballot because the building industry has shot it down a few times and it needs to be a voter driven policy. A strong policy is needed, where there's a task force to figure out how to make it work. Another person to contact is Anna Thurston who wrote a thesis on green roof failures at Colorado State University's College of Agricultural Sciences.

Commercial scale projects should specify using American Hydrotech's waterproofing membrane systems for the ease of instruction and technology that simplifies installation.
Cities don't know what to do regarding permitting and what to inspect. The City or State needs codes that address problems like lengthy applications and proper practices (even just how to get a permit for a green roof). For example, a retrofit falls under re-roof and that doesn't require a permit, but new roofs do require a permit (at least for residential projects in Thurston, Mason, Clallam, and Jefferson counties.)

(Pacific Landscape Management) Anytime you give a rebate structure, you'll win as long as it's simple and not lengthy.

(Landscape Professionals) Green roofs and solar panels look good and have benefits. Bryan wishes the owners or management would want to take better care of them. There needs to be an emphasis on maintaining the landscape.

20. Is there a modeling software or 3d modeling that you can share to help with energy savings analysis? (File extensions in .xml .idf)

(GreenGrid Weston Solutions) No, but GreenGrid has system specific energy performance data that can be modeled using standard modeling software.

(LMN Architects) PV Watts for standard modules

(McDonald & Wetle Roofing) ----

(MIG- SvR) The engineers may have used modeling software for cost savings on government projects, but they don't typically use models. Usually when MIG is the lead they have a consultant doing to modeling.

(Olympia Green Roofs) SketchUp, but the Green Roofs for Healthy Cities website has cost-savings models.

(Pacific Landscape Management) No.

(Landscape Professionals) No

21. May we contact you with further questions?

(Green Grid Weston Solutions) Yes
(LMN Architects) Yes
(McDonald & Wetle Roofing) No
(MIG- SvR) Yes
(Olympia Green Roofs) Yes
(Pacific Landscape Management) Yes
(Landscape Professionals) Yes