MARKET RESEARCH STUDY

DOE | FLOATING SOLAR PHOTOVOLTAICS

August 2022

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1.0 Introduction

Although the siting of solar panels most frequently occurs on land, solar panels can also be effectively sited on water. Referred to as **floating photovoltaics (FPV) or floatovoltaics**, in this configuration solar panels are mounted on a structure that floats on water. The FPVs generate power that can be harnessed for various applications in urban areas, agriculture, aquaculture, and island communities and also provide additional benefits. This report addresses the potential market opportunity for floating photovoltaics - a market that has grown rapidly since the concept was first introduced less than fifteen years ago. This report provides a perspective on the size and growth rate of the FPV market, accompanied by supporting information on trends and factors that may influence its continued growth. Installed and planned capacity figures are included, accompanied by revenue projections. Insight into the bodies of water that may serve as potential sites for FPV sitings are also addressed. Although this report focuses on the U.S. market, relevant global data are also included.

With each FPV application area efforts have been made to identify examples within the U.S., while drawing attention to state and local incentives (if they exist), as well as potential bodies of water where domestic growth could be expanded. The primary application areas of potential interest in the U.S. include the generation of power for:

- Municipal wastewater
- Agriculture
- Aquaculture
- Coastal resources

Given the scope of these application areas, some may be covered together. For example, the literature in this area covers wastewater and reservoirs, which are addressed concurrently. Additionally, architectural, and coastal applications were not surfacing independently in the literature, however, given the increasing presence of hydropower FPV installations a section was added to cover that area.

This report also addresses the supply chain and key players in FPV. Vendors that are providing construction services within the U.S. on large scale floating photovoltaic structures are profiled. Additionally, this section identifies domestic companies that are providing floats and panels for floatovoltaics, as well as service providers sourcing these components.

2.0 Floating Photovoltaics Market

This report addresses the potential market opportunity for floating photovoltaics (FPV) by exploring the total market, application areas, and information on key players in this area.

2.1 Market Size

Floating photovoltaics (FPV) is one approach used by the solar industry to address land scarcity for PV installations. Presently, the ten largest projects in development are all in Asia, and the global installed capacity was 2.6 GW as of 2020. Of note, the estimated time to install 30 MW is 8 weeks, which is significantly shorter than land-based projects. Elsewhere, Europe's largest FPV plant, with a capacity of 41 MW of direct current, is under construction at Sellingen, Netherlands.[1]

Table 1: Top Five Global FPV Projects & Status

Top 5 FPV Projects	Status
Saemangeum FPV Project—2.1 GW, South Korea	Under development
Omkareshwar Dam FPV Project—600 MW, India	Production in 2023
Hangzhou Fengling Electricity—320 MW, China	In operation
Three Gorges New Energy FPV—150 MW, China	In operation
Cirata Reservoir FPV—145 MW, Indonesia	Production in 2022

Source: Frost & Sullivan[2]

Reprinted with permission from Frost & Sullivan

The FPV segment of the photovoltaics (PV) market is forecast to grow at the highest Compound Annual Growth Rate (CAGR) from 2020 to 2025 (5.4%). Floating PV modules, which are also known as floating solar modules, float on top of a water body. These modules are often deployed on lakes or along basins as the water is generally calmer than in oceans. It is also common to install floating solar structures on large man-made water bodies such as reservoirs. Due to land scarcity floating solar arrays are being increasingly adopted in the Asia-Pacific (APAC) region. According to frequently cited 2018 World Bank data, the overall global power potential of floating PV modules deployed on man-made water surfaces may exceed 400 GW in the next few years.[3]

Figure 1: The Altamonte Springs Water Facility is the Largest Floating Solar Array in Florida

Source: D3Energy[4]

The deployment of FPV modules is expected to accelerate due to the fact that other technologies are reaching maturity, thereby opening up new areas for the increased global consumption of renewable energy to a wide range of countries and markets.[5]

The global floating solar market is forecast to reach a valuation of $27.7 billion by the end of 2031.

The total global floating solar market was reported to be worth approximately $2 billion in 2021 and is forecast to reach a valuation of $27.7 billion by the end of 2031.[6] New FPV installations are anticipated to add a total capacity of 2.9 GWp in 2021 and 2022. This is more than in the 13-year period from 2008 to 2020 combined, and cumulative global FPV capacity could reach 13 GWp by 2025.[7]

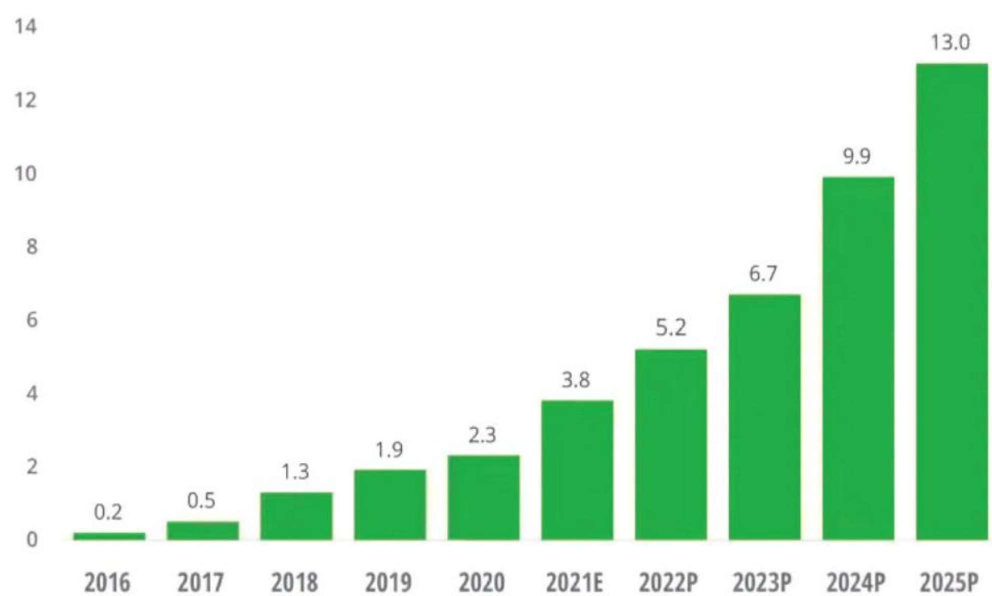
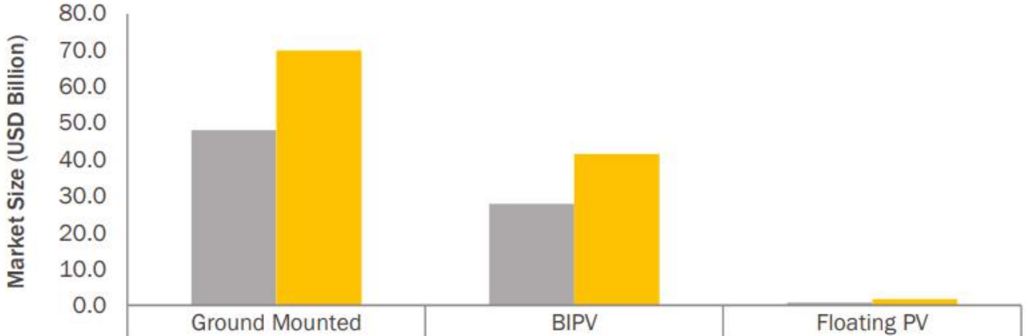


Figure 2: Global Cumulative Installed FPV Capacity, 2016-2025 (GWp)

Source: Deloitte[8]

Another way to look at the FPV market size is by comparing it to ground mounted and building integrated photovoltaics (BIPV).



	Ground Mounted	BIPV	Floating PV
2020	48.0	27.8	0.8
2025	69.9	41.5	1.7
CAGR (2020–2025)	7.8%	8.3%	15.4%

Figure 3: Floating PV Segment of Photovoltaic Market to Grow at Highest CAGR from 2020 to 2025

Source: MarketsandMarkets.[9]
Reprinted with permission of MarketsandMarkets.

A comparison of the installed costs for a 10-MW_{DC} base-scenario FPV system and ground-mounted PV system can be found in Figure 4 of the NREL report entitled "Floating Photovoltaic System Cost Benchmark: Q1 2021 Installations on Artificial Water Bodies."

For residential and commercial applications, the majority of the PV installations are building integrated, while for utility applications, the PV installations are generally ground mounted. Floating PV modules have emerged as a new concept in the PV market, and a number of countries across the world are making efforts to carry out these installations owing to more benefits offered by them than the traditional PV installation types.[10]

Table 2: Photovoltaic Market, By Installation Type, 2017–2019 (USD Billion)

Installation Type	2017	2018	2019	CAGR (2017–2019)
Ground Mounted	63.5	59.7	56.4	-5.8%
BIPV	42.2	39.3	40.4	-2.2%
Floating PV	0.9	0.9	1.0	5.4%
Total	**106.5**	**100.0**	**97.8**	**-4.2%**

Source: MarketsandMarkets[11]
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Table 3: Photovoltaic Market, By Installation Type, 2020–2025 (USD Billion)

Installation Type	2020	2021	2022	2023	2024	2025	CAGR (2020–2025)
Ground Mounted	48.0	51.6	58.2	62.7	66.5	69.9	7.8%
BIPV	27.8	30.1	34.1	36.9	39.3	41.5	8.3%
Floating PV	0.8	1.0	1.2	1.3	1.5	1.7	15.4%
Total	**76.6**	**82.7**	**93.4**	**101**	**107.3**	**113.1**	**8.1%**

Source: MarketsandMarkets[12]

Reprinted with permission from MarketsandMarkets.

The National Renewable Energy Laboratory (NREL) has published several reports on various aspects of FPV ranging from technical to market information. In one report NREL notes that the water-based configuration of FPV systems can be mutually beneficial by providing reduced evaporation and algae growth, lower PV operating temperatures and potentially reduce the costs of solar energy generation. Through its efforts NREL provided the first national-level estimate of FPV technical potential using a combination of filtered, large-scale datasets, site-specific PV generation models, and geospatial analytical tools.[13]

NREL identified 24,419 man-made water bodies in the contiguous United States as being suitable for FPV generation.

In addition to looking at the market from a revenue or installed capacity perspective, looking at potential bodies of water is another way to size this space. This section introduces these figures which are further broken down and explored throughout this report. As such, a total of 24,419 man-made water bodies, representing 27% of the number and 12% of the area of man-made water bodies in the contiguous United States, were identified by researchers as being suitable for FPV generation. FPV systems covering just 27% of the identified suitable water bodies could produce almost 10% of current national generation. Many of these eligible bodies of water are in water-stressed areas with high land acquisition costs and high electricity prices, suggesting multiple benefits of FPV technologies.[14] Human-made water bodies are preferable for their ability to be managed, and most are located near existing infrastructure and roads.[15]

Typically, a 1MW of FPV plant covers water bodies of about 17 to 25 acres and can generate electricity of 1,500MWh - the market is currently about 1.6 GW globally and GIA predicts it will move at a compound annual growth rate (CAGR) of 33.7% by 2026, reaching 4.8 GW. The Asia-Pacific region is expected to be the largest market share at around 60%, with China the fastest growing market with a CAGR of 59.4%. FPV's cost is much higher that that of stationary solar panels, which is the key obstacle to its growth.[16]

Table 4: Aggregated FPV Potential Data by State

State	# Potential Water Bodies	Surface Area (1000 Hectares)	Generation (TW-hr/yr)	Evaporation (10^6 m^3)	Avg. Land Value ($/Hectare)	Avg. Utility Rate (cents/kWh)
AL	176	2.6	0.9	45	6338	9.4
AR	281	12.7	4.4	213	6375	8.2
AZ	147	49.1	21.4	1306	20510	10.4
CA	992	184.6	75.7	3180	16816	15.5
CO	936	52.2	19.7	785	3299	9.8
CT	221	12.1	3.9	145	15988	17.8
DE	7	0.1	0.0	2	17359	11.2
FL	172	309.3	120.1	6454	18323	10.6
GA	527	15.3	5.7	273	8575	9.5
IA	2075	7.3	2.5	99	14085	8.5
ID	147	54.3	18.7	813	5683	8.1
IL	260	5.1	1.7	70	13405	9.3
IN	111	4.4	1.5	60	11861	8.8
KS	855	29.2	10.9	499	4127	10.1
KY	336	5.4	1.8	85	8031	8.0
LA	35	8.5	3.0	152	6449	7.6
MA	42	0.9	0.3	11	15988	16.9
MD	74	1.9	0.6	27	15605	12.1
ME	122	77.4	23.0	771	15988	13.0
MI	98	21.9	6.8	248	8772	10.8
MN	288	125.2	37.2	1426	7907	9.7
MO	1222	5.9	2.1	91	7042	9.3
MS	567	21.4	7.7	372	6017	9.6
MT	2541	68.0	21.2	912	2051	8.9
NC	439	30.0	10.7	475	10712	9.4
ND	156	5.4	1.8	70	3497	8.9
NE	1570	34.6	13.0	546	7117	9.0
NH	94	7.0	2.1	71	15988	16.0
NJ	94	7.4	2.4	90	31506	13.9
NM	286	146.2	64.4	2673	2224	9.7
NV	134	74.1	31.5	1881	-	9.5
NY	492	54.4	16.4	598	4917	15.3
OH	14	0.3	0.1	4	10996	9.9

OK	2338	258.8	96.4	4766	3842	7.8
OR	499	34.4	12.2	517	4213	8.8
PA	76	1.8	0.6	23	10873	10.4
RI	47	3.4	1.1	41	15988	17.1
SC	212	75.1	26.8	1305	6672	9.5
SD	1440	4.9	1.7	73	5609	9.3
TN	145	3.4	1.2	52	8822	9.4
TX	1920	76.0	29.4	1582	4312	8.6
UT	349	19.3	7.0	310	5412	8.6
VA	383	79.3	27.5	1236	10329	9.3
VT	48	1.9	0.6	21	15988	14.4
WA	227	77.4	23.6	1041	4448	7.4
WI	136	13.0	4.2	149	8896	10.9
WV	168	1.5	0.5	21	6400	8.1
WY	920	56.4	20.5	821	2323	8.0
TOTAL	**24419**	**2141**	**786**	**36403**	**9738**	**502**

Source: NREL[17]

Many of these identified water bodies are located in water-stressed areas with high electricity prices and high land-acquisition costs. Idaho, Maine, New Mexico, and Oklahoma have been identified as having more FPV potential than their in-state electricity consumption and could even become solar electricity exporters to the rest of the country.[18] "Florida and California are both states that have a relatively large amount of potential water surface area while also having relatively higher cost land values of $18 323/hectare [sic] and $16 816/hectare [sic], respectively. Six of the seven FPV projects currently installed in the United States are located in these two states. New Jersey has the highest average land value of $31 506/hectare sic] and is home to the seventh FPV project."[19] For reference, the national average is about $9738/hectare [sic].[20]

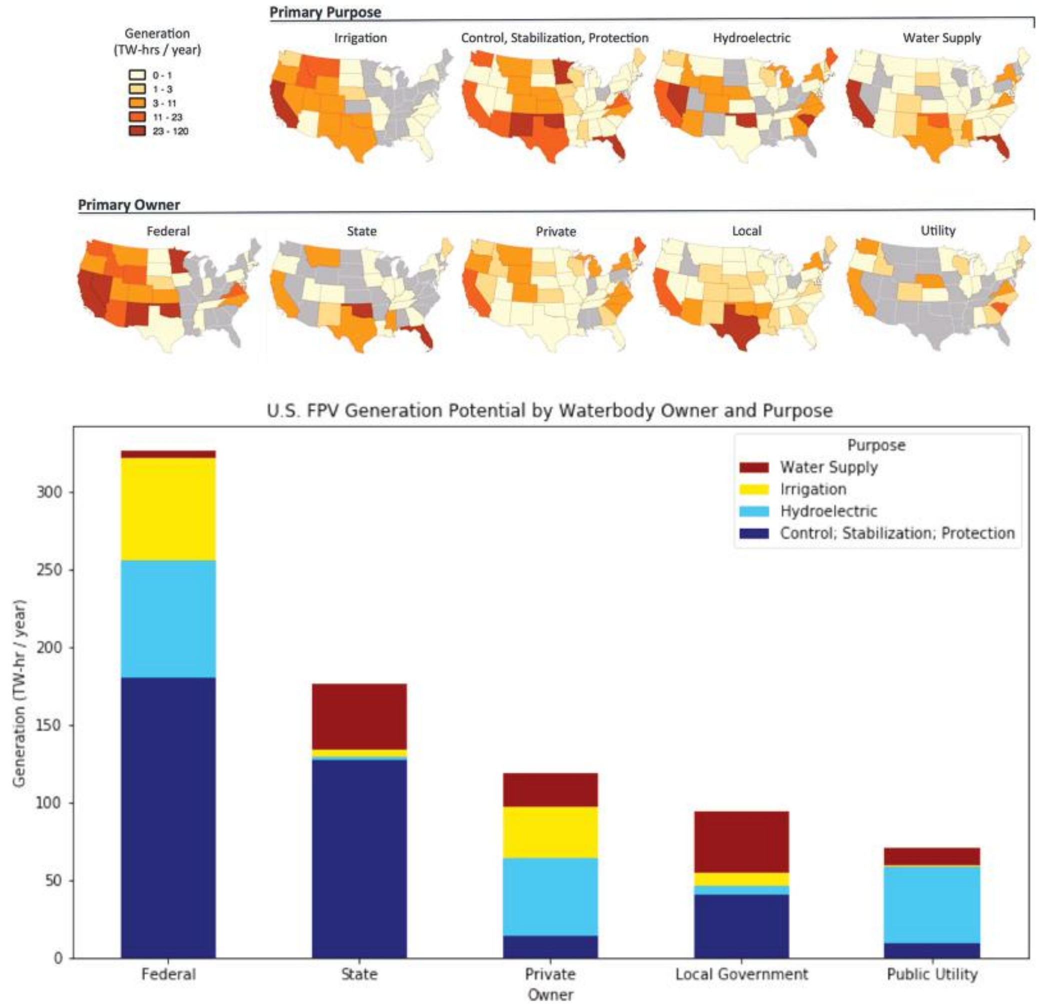

Figure 4: (Top) Potential Annual Generation of FPV Systems Covering 27% of Feasible U.S. Water Bodies, Categorized by The Primary Purpose and Primary Owner of The Water Bodies

Source: NREL[21]

Agricultural applications are explored in greater detail later in this report but from a high-level perspective, FPV potential from water bodies with irrigation as the primary purpose is concentrated in the western United States, whereas FPV potential from hydroelectric, water supply, and control/ stabilization/protection reservoirs is more uniformly distributed throughout the country. It is important to note that the control/stabilization/protection-purposed water bodies account for 47% of all FPV generation potential. Furthermore, federally-owned water bodies account for 42% of potential FPV generation. Federal- and state-owned water body FPV generation potential is dominated by control/stabilization/ protection water bodies but public utility and private owner reservoir FPV potential is dominated by hydroelectric FPV potential. Local government-owned reservoir FPV potential is primarily composed of control/ stabilization/protection and water supply purposes.[22]

2.1.1. U.S. Projects

Prior to 2016 the United States only had two FPV projects, however, by the end of 2020, more than twenty U.S.-based FPV installations had a cumulative capacity of approximately 12 MWDC. The relative abundance of land and lack of FPV incentives in the United States has slowed FPV growth as compared with the growth in some Asian countries. While the range of installed capacity of U.S. FPV systems is 100 kWDC – 5 MWDC, NREL uses a benchmark of a 10 MWDC system which represents the expected typical size of FPV systems to be installed over the next couple of years based on discussions with project developers. The table below lists U.S. FPV installed projects, with a project size greater than 100 kWDC with data available as of March 2021.[23]

While a complete listing of all existing U.S. based FPV installations is not available, the following two tables introduce projects in development, recently deployed, and the largest capacity installations in the U.S. based on the available sources.

Table 5: Largest Planned FPV Projects in the United States

Location	Capacity (MW)	Application Type	Date	Developer(s)
Millburn, New Jersey[24]	8.9 MW	Water Treatment Plant	Expected to be fully operational in the fall of 2022	NJR Clean Energy Ventures (CEV)
Solar Carver 1 & 3, southeast Massachusetts[25]	7 MW	Agricultural/Cranberry Bogs	TBD	Pine Gate Renewables
Cohoes, NY[26]	3.2 MW	Municipal Reservoir	TBD	Unspecified
Altamonte Springs, Florida[27]	0.96	Wastewater Treatment Facility	Expected 2022	D3 Energy

Table 6 below introduces that largest existing U.S. FPV installations that are fully operational.

Table 6: Largest Operational U.S. FPV Projects

Location	Capacity (MW)	Application Type	Date	Developer
Healdsburg, California[28]	4.78	Wastewater Treatment Facility	2021	White Pine Renewables
Sayreville, New Jersey[29]	4.40	Reservoir/pre-treatment water storage pond	2019	Ciel & Terre USA
Windsor, California[30]	1.78	Reservoir/water storage pool	2020	Dongfang Risheng New Energy Co., Ltd.
U.S. Army's Fort Bragg in North Carolina[31]	1.1 MW	Lake	Fully Operational June 2022	Ameresco & Duke Energy
Gidding, Texas[32]	0.99	Agriculture/wholesale nursery	2021	Bluebonnet Energy
Dixon, California[33]	0.61	Agriculture	2018	Sky Power Solar

Kelseyville, California[34]	0.25	Wastewater	2018	Ciel & Terre USA
Orlando, Florida[35]	0.25	Entertainment/Amusement Park	2021	D3 Energy
Miami Airport, Florida[36]	0.15	Transportation/Airport	2020	Florida Power and Light
Orlando Airport, Florida[37]	0.13	Transportation/Airport	2020	Ciel & Terre USA

Source: NREL[38]

According to Gorijan et al[39] market opportunities are mainly based on geospatial factors including location, size and other parameters representing the complexity of deployment which may be equal to or more expensive when compared to ground-mounted systems. Based on these projections the market potential in the U.S. is expected to include 1-5 MW projects that are primarily water utilities, commercial and industrial customers that install the projects for on-site competition, or behind-the-meter (BTM) projects. Without any major new policy developments at the federal and state level, the FPV industry in the U.S. through 2030 is expected to triple the amount of installed capacity from 2020 levels to 324 GW. This is primarily based on projections of falling prices while demand from utilities, states, distributed solar customers, and corporations continue to rise.[40]

2.1.2 Factors Influencing FPV

There are numerous identified advantages of installing floating solar arrays. For example, FPV systems eliminate the requirement of valuable land space as these installations can take up unused space on water bodies such as hydroelectric dam reservoirs and wastewater treatment ponds. Moreover, the water that hosts floating PV modules helps solar equipment to cool down, thereby resulting in high efficiency of panels that produce electricity in hot climates. The floating PV modules act as shields for water bodies and hence, reduce evaporation from them. This particularly is beneficial in areas that are susceptible to droughts. However, floating PV installations may require additional costs than most traditional solar installations do not require. This is due to the fact that floating PV is a relatively new technology that requires specialized equipment and niche installation knowledge. The development of grid-connected hybrid systems that combine hydropower and floating PV technologies is still at an early stage. However, a number of projects of high magnitude are being discussed or carried out across the world in this regard.[41]

The table below summarizes key factors impacting both floating and land-based FPV development potential.

Table 7: Factors Influencing FPV & Land-Based PV

Factors Impacting Development Potential	Floating PV	Land-Based PV
Site Assessment		
Solar Resource	• Global horizontal irradiance	• Global horizontal irradiance
Transmission Line Proximity & Substation Proximity	• Can utilize existing infrastructure • Ability to site with hydropower • Site within 50 mi. radius of transmission lines	• Interconnection costs often footed by developer (Can increase project costs by 3-33%)

Location	• Near load center & populated region
	• Must avoid airport boundaries
	• Likely existing access roads
	• Often utility-owned reservoirs (no lease/purchase cost for utility) or single-owner
	• Can exist in more populated areas, less NIMBYism
		• Majority on private land, some on BLM land
		  o Often multiple landowners
		• Must avoid:
		  o airport boundaries
		  o local, state, federal parks/ land
		• More often in less populated areas
		• May need to construct access road

Water/Land Surface Use	• Manmade reservoirs, hydropower dams, industrial water bodies, mine subsidence areas, irrigation ponds • Excludes reservoirs that any small, used for fishing, navigation, or recreation • Does not compete with agricultural, residential, or industrial land • Little to no ground excavation • Potential for integration with aquaculture • Freshwater, low hardness, low salinity • Saves 2.7x avg. land on capacity compared to land-based PV	• 5-10 acres/MW of generating capacity • Likely further from POI • Land excavation & grading required • Competes with land for agricultural, residential, industrial use
Feasibility Studies		
Market Assessment	• Emerging market	• Existing, well-developed market

Federal Regulations	• No existing FPV-specific federal regulations	• BLM right-of-way application, planning & environmental requirements
		  o Federal Land Policy and Management Act
		    ▪ Solar and Wind Energy Rule
		• NEPA review required

State Regulations & Permitting	• GIA • Ecological risk assessments • Hybrid projects sited with hydro under state jurisdiction	• Most projects qualify under RPS (38 states) Solar or distributed generation carve-out (22 states) • GIA • Ecological risk assessments
Local Regulations & Permitting	• Ability to permit in non-sensitive zones • Building permit or equivalent	• Solar ordinances • Avg. 3-5 years to complete permitting process

Source: Adrienne Dunham, Johns Hopkins University[42]

Presently, unlike land-based solar energy, the United States does not have any specific regulations or guidelines for FPV applications. It appears that the lack of established precedent for issuing permits for installations has hampered development in the United States. Due to the lack of specific FPV regulations in the U.S., developers will need to comply with each county's understanding of state regulations. FPV has various benefits when compared to land-based PV solar systems, though both technology systems are not completely free of environmental impacts.

Unlike land-based solar energy, the United States does not currently have any specific regulations or guidelines for FPV applications.

Additional advantages of FPV include:

- **"Water is Cheaper Than Land:** The leading advantage of floatovoltaics is that land is not required. This is particularly advantageous for areas where land costs are high, e.g., island nations and areas with valuable farmland.

- **Optimizing Existing Transmission Infrastructure:** For hybrid systems built adjoining existing hydroelectric dams, proximity to existing electrical transmission infrastructure can reduce construction costs as well as transmission losses.

- **Hybrid Systems Working Together:** Floatovoltaic-hydroelectric hybrid systems naturally balance each other and provide energy storage capabilities. The added solar power can be used to offset demand during the day when production is highest, saving the pumped-storage hydroelectric energy stored in higher-elevation reservoirs until demand peaks during night hours.

- **Improved Efficiency and Performance:** Solar panels are naturally more efficient at colder temperatures and less so at high temperatures. The water acts as a natural coolant, keeping the temperatures at more optimal levels, which has been shown to boost efficiency by 11% compared to land-based panels.

- **Minimizing Losses:** Being located on the water means that less dust is present, and water is readily available for regular cleaning of the panels. As a result, these systems experience reduced soiling losses compared to land-based projects. FPV systems can also expect reduced shading losses compared to land-based projects as there are typically little to no shading objects near floating arrays. Floatovoltaics shade the water, which reduces water loss due to evaporation. This is a tremendous benefit for reservoir systems, especially in arid climates where water scarcity is a serious issue.

- **Reduction of Algae**: The shade provided by solar panels also works to mitigate the issue of algae blooms by blocking sunlight from the water's surface. Extensive growth of algae prevents sunlight from reaching underwater plants and depletes the surrounding water of oxygen, which results in a "dead zone" where no aquatic life can survive. Algae blooms occurring in populated areas can release toxins that contaminate drinking water and cause health problems for nearby human and animal populations. By preventing algae blooms, FPV systems act to reduce water pollution and improve water quality, another essential aspect for water-scarce regions."[43]

Furthermore, while the list of potential advantages for FPV is extensive, FPV projects are not without challenges.

- **Construction: C**onstruction can be more complex and expensive in some cases. This is especially true when complex anchoring and mooring systems are needed, or when special planning must be made to account for rising and falling water levels

- **Electrical Safety:** Building and operating on the water requires the need for especially stringent electrical safety precautions, robust electrical equipment, and mitigation of increased difficulties of operation and maintenance which may require boats and sometimes diving personnel.

- **Early-Stage Development:** As a relatively new type of system in the solar industry, there is a limited track record of executed projects and uncertainty still exists regarding project costs. This can translate to FPV systems being perceived as less desirable for capital investment.[44]

The World Bank also provides a summary of potential risk assessments to be considered when planning FPV projects.

Table 8: Summary of Key Risk Assessments for FPV Projects

Risk Type	Description and Assessments
Political & legal environment	Assessment of current US legal and political framework, stability risks, new or changes to existing legislation, renewable energy incentives and targets, climate action plans.
Owner or sponsor	Experience in finance and technology, potential response to cost overruns.
Resource	Independent assessment of productivity, anticipated energy yield, solar irradiance resource at site, on-site data collection verification, climate change impact.
Technology	Track record of existing and emerging technologies, product reliability, product safety, environmental site assessment impact on technology.
Regulatory and Compliance	Current legal and regulatory environment in US, permits and licenses needed, land use rights, water rights, social and environmental impact assessment.
Construction	Assessment of engineering, procurement, and construction contractors, structure design and procurement, experience of float installers, testing and commissioning
O&M	Spare parts for maintenance, maintenance plan, system accessibility, insurability.
Decommissioning	Regulatory concerns, disposal or recycling plan, waste management considerations.

Source: World Bank[45]

In terms of the ecological concerns associated with FPV deployments at various locations, research has indicated that FPV installed on water surfaces has positive impacts on the environment such as carbon saving and water saving obtained from preventing the evaporation of water surfaces. Additionally, one study was carried out to observe the effect of FPVs on water quality and energy efficiency with results revealing that an increase in the total water quality was observed with a decrease in algae biomass. Furthermore, a decrease in the pH values measured at certain points along with an improvement in clarity, and an increase in the amount of organic carbon were observed. The results of some studies examining the reduction in carbon emissions by installing FPV systems are presented in Table 9 including the type of water basins, covering areas, and the amount of carbon saving.[46]

Table 9: Carbon Saving by Virtue of FPV Installations

Research	Covering Area (m^2)	Water Basin	Carbon Saving
Experimental	4490	Irrigation water reservoir	1454.19 tons of CO_2 saving over the lifetime of FPV
Simulation	87,650	Open-pit limestone mine	471.21 tons of CO_2/year
Simulation	---	1134 water reservoirs in Korea	1,294,450 tons of CO_2/year
Simulation	10,000 each of them	Lake and barrage	1773 and 1714 tons of CO_2/year
Simulation	50	Lake	14.44 tons of CO_2/year
Power Plants	---	Water reservoir	Nearly 85 tons of CO_2/year

Source: *Sustainability*, 2022[47]

With respect to the total life cycle of a system and the potential impact on the environment, Table 10 provides a summary of considerations that to this point do not appear to have been examined.

Table 10: Possible Environmental Impacts of FPVs During Construction and Operation

Stage	Effects
Installation and decommissioning (short and long-term effects)	• Short-term air pollution from project construction equipment • Noise, affecting people and wildlife, from project construction equipment • Turbidity from installation and dismantling of mooring and anchoring systems • Potential release of oil and lubricant spills related to project construction equipment • Loss of habitat and marine species • The increase in waste during construction and delivery of the equipment
Operation and Maintenance (long-term effects)	The failure in water quality: • Increased temperature • Decreased dissolved oxygen • Limited mixing • Leaching/chemical risk • Loss of benthic habitat • Impact on primary production • Loss of avian wildlife • Loss of marine species • Loss of aesthetic value

Source: *Sustainability*, 2022[48]

2.1.3 Industry Standards

While no set standards for FPV exist in the U.S. at present, DNV, a leading quality assurance and risk management company operating in more than 100 countries[49] has proposed a set of requirements, recommendations and guidelines for design, development, operation and decommissioning of FPV systems, *DNV-RP-0584 Design, development and operation of floating solar photovoltaic systems: Recommended practice*. The document targets end users such as developers, suppliers, investors, authorities and other stakeholders for FPV systems, providing direct guidance or reference to other existing relevant guidelines and standards.

> "This RP focuses on FPV systems located in sheltered, in-land water bodies, while still being applicable for near-shore locations. A near-shore water body is intended as any water body, with salty, brackish or fresh water, geographically located close to a shoreline, in reasonably sheltered areas and with significant wave heights up to 2-3 m. Any offshore location, or location with harsher conditions, is considered explicitly out of scope of this RP. For these locations, this RP or parts of it may only be used as general guidance or as a reference.
> …
> The requirements and guidelines listed in this document can never overrule any local, national and international applicable standards and regulations, which shall always be adhered to. The requirements and guidelines listed in this document are meant to provide guidance and to be used in absence of or in addition to such existing national standards and regulations."[50]
>
> A preview copy of DNV-RP-0584 is available here (PDF)

These recommendations are the result of a joint industry project (JIP) in which the following organizations (listed in alphabetical order) participated in the JIP:

- Acciona,
- BayWa r.e,
- BlueC Engineering,
- Carpi Tech,
- Ciel & Terre International,
- CNR – Compagnie Nationale du Rhone,
- EDF - Électricité de France,
- EDP - Energias de Portugal, Equinor,
- Innosea - part of Aqualis Braemar LOC Group,
- Isigenere, JLD International,
- Mainstream Renewable Power,
- Makor Energy Solutions,
- Noria Energy,
- QuantSolar,
- RWE,
- Scatec,
- Seaflex,
- SolarMarine Energy,
- Statkraft,
- SunRise E&T Corporation,
- TNO,
- Total.[51]

3.0 Technical Challenges

Given that deployment of FPV is relatively new, a host of technical challenges and questions regarding the long-term durability and sustainability of these systems are not yet fully understood or addressed. However, researchers have identified potential technical challenges and included proposed solutions or mitigation measures. For example, the degradation of FPVs is a leading concern due to the effects of humidity on the PV panels, which can influence the performance of PVs in land-based systems. While evaporative cooling has been seen to have a positive effect on the improvement in energy efficiency, and the longevity of FPV modules, the closeness to water surfaces of FPV naturally leads to a large increase in the exposure to humidity.[52] The challenges and proposed mitigation methods for FPV are summarized in Table 11.

Table 11: Potential Degradation Modes and Mitigation Methods

Environmental Stress	Failure Mode	Mitigation Strategies
Moisture	Corrosion Hydrolysis PID	• Moisture-hardened materials • Back sheet: glass, aluminized PID-resistant cells • System-level PID compensation
Mechanical Stress	Interconnect fatigue Cell cracking	• Increase module stiffness • Cells and string on the neutral axis • Cut cells • Lower modulus encapsulants • Multi-wire interconnections
Hot Spot/Shading	Arcing/melting/cracking Diode failure	• Less cells per bypass diode • Higher RTI materials • Anti-soiling coatings

Source: *Sustainability*, 2022[53]

Another concern, related to the lack of industry standards is the lack of technology convergence with respect to floating FPV structures. While many different concepts are under development or being tested in controlled or real-world environments there is yet to be a formally recommended or standard design for these deployments.[54]

The seminal publication from the World Bank, *Where the Sun Meets Water: Floating Solar Handbook for Practitioners,* also addresses the overarching technical challenges presented by FPV systems.

Table 12: Impact of Environmental Stresses on Module Degradation in Various Operating Environments

Environmental stresses	Impact of operating environment on the module degradation — Lower impact				Higher impact
Moisture	♦		●	▼	▨
Mechanical stresses		♦	●	▼	▨
Hot-spot/shading			●	▨ ▼	♦
UV			▨ ●	▼	♦
High temperature		▨	●	▼	♦
Low temperature	▼	▨	●		♦
Temperature cycling	▼	▨	●		♦

● Temperate environment ♦ Desert environment ▼ Tropical environment ▨ Floating PV systems

Source: World Bank[55]

The World Bank report does note that, broadly speaking, the standard photovoltaic module has performed well under a variety of conditions and represents much of the installed base worldwide, a sentiment echoed by other sources.

Table 13: Potentially Accelerated FPV Module Failure Modes and Mitigation Strategies

Environmental stresses	Failure mode	Mitigation strategies
Moisture	• Corrosion • Hydrolysis • PID	• Moisture hardened materials • Encapsulants: TPO, POE, ionomer • Backsheets: glass, aluminized PID resistant cells • System level PID compensation
Mechanical stresses	• Interconnect fatigue • Cell cracking	• Increase module stiffness • Cells and string on neutral axis • Cut cells (for fatigue) • Lower modulus encapsulants • Multi-busbar/wire interconnects
Hot-spot/shading	• Arcing • Melting/cracking • Diode failure	• Less cells per bypass diode • Higher RTI materials • Anti-soiling coatings

Source: World Bank,[56] Adapted from Harwood 2018[57]

Note: PID = potential induced degradation; TPO = thermoplastic polyolefin; POE = polyolefin; RTI = relative temperature index.

3.1. Challenging FPV Environments and Potential Solutions

While many sources discuss the impact of highly corrosive saltwater environments that may also have forceful waves impacting FPV systems, other sources also explore the use of FPV in brackish water. In a study conducted in South Sumatra, results indicate that FPV panels can be installed over brackish water, and at this location the efficiency of floating PV panels was, on average, 4% higher than that of a ground installation.[58] Additional research out of Indonesia also reports on the impact of salt soiling on these systems and their efficiency. A 2019 case study shows that there were significant differences in production and efficiency between normal and salt-covered PV modules. Over a span of three days, the average output power difference between the normal condition and salt-doused PV module was 1.3778 Watt, and the efficiency difference is 0.948.[59] Research out of MIT, although targeting desalination, does explore a salt-rejecting floating solar still that may be of relevance to this technical area.

Biofouling is explored in research from the European Union. The results of the study are reported in the figure and description below.

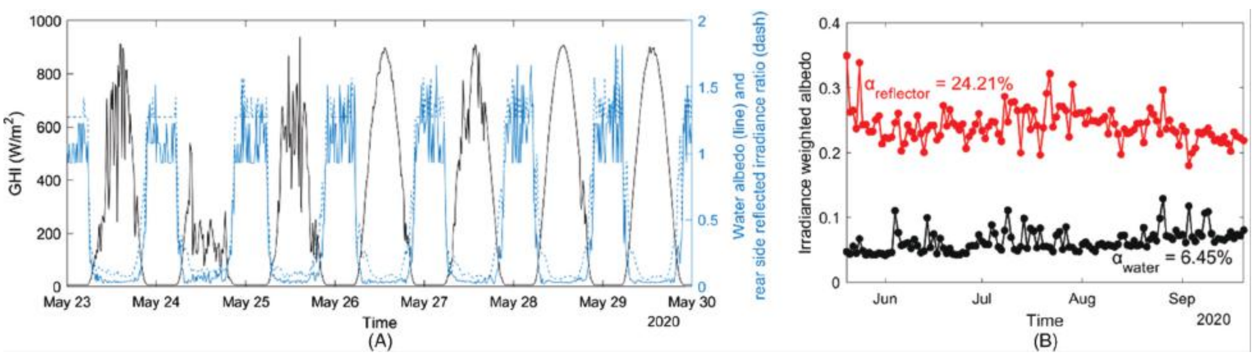

Figure 5: Bifacial PV Module Efficiency Impacting Factors

Source: Progress in Photovoltaics[60]

(A) Global horizontal irradiance, the albedo of the water, and the ratio of the reflected light on the rear side of the bifacial photovoltaic (PV) module, for one week in May 2020. The average daily water albedo and the rear side irradiance ratio of the floating bifacial PV module equipped with an orange-color reflector are 11.6% and 23.4%, respectively. For clear and cloudy days of May 28 and May 24, the water albedo is, respectively, 10.6% and 14.6%, whereas the rear side irradiance ratio is, respectively, 24.3% and 22.9%. The values were obtained excluding the nighttime recordings. (B) Irradiance weighted albedo of water and reflector from May 20, 2020, to September 20, 2020. **Mean values are depicted on the graph, which shows bio-fouling severely reduces the effective albedo of the reflector from 68.49% to 24.21%.[61]**

This research also addresses temperature variances in floating bifacial photovoltaic solutions for inland water areas. The research theorizes that there should not be an overall significant temperature difference between the floating and land-based PV systems when they are placed close to each other, as long as they use the same PV technology.[62]

Another challenge for these FPV systems is the impact of waves. SINN Power is working to address this challenge through its Ocean Hybrid Platform designed for unprotected maritime environments.

3.2. Power Electronics

With respect to the broader questions regarding the performance of power electronics in marine and aquatic environments, many potential challenges are noted. For example, cadmium chloride is the main constituent of photovoltaic solar cells—it is also very poisonous and costly, which leads to concerns regarding both price and water quality. However, saltwater includes magnesium chloride that can be substituted for cadmium chloride. Additionally, the materials for floats are also selected with their specific environment in mind— the floats are typically made of high-density polyethylene (HDPE) or Glass fiber reinforced plastic (GRP) known for its strength, UV resistance and corrosion resistance. Further along in the FPV process, the generated power is transported to the local site, to date, in commissioned projects, the cable has been kept on the water surface. Researchers note that, while these electrical cables and components are presently kept on the surface of the water, ***waterproof junction boxes which are IP67 rated are still essential for solar floating systems*. Also, in current system designs, the additional electrical instruments like solar PV inverters and batteries are still dry places.**[63]

While the majority of FPV deployments currently reside on freshwater, corrosion in salt water is generally not a problem. However, for offshore applications, it becomes important to verify the effect of sea water on the structure and functioning of the photovoltaic modules. The literature notes that further research is needed in this area.[64]

Although we have noted that industry standards for FPV systems have not yet been adopted, some standards at the component level should be used. The solar modules should be tested by accredited testing laboratories under relevant standards such as **IEC 61215, IEC 61730, among others, and ideally, modules should be further certified by a Certification Body or Certification Body Testing Lab. Another level of oversight for developers is following country-specific requirements. Inverters, specifically, should be compliant with grid standards from the country where the systems are located as well as international standards such as IEC 60364, IEC 61000, IEC 61727, IEC 62109-1/2, IEC 62116, IEC 62920, and IEEE 1547.**[65] Power quality requirements are usually defined using the following parameters:

Table 14: Floating and land-based photovoltaic systems: A comparison of testing and commissioning aspects

	Floating PV	Land-based PV
Testing	• No international standards exist for verifying floats	• Testing and commissioning procedures are well-established
Grounding	• Grounding module frame or mounting structure may be challenging if constant motion causes bonding conductor to loosen or snap	• Grounding module frame or mounting structure is well-established

Source: World Bank[66]

Additionally, connectors and junction boxes may follow some of the relevant testing standards such as:

- IEC 61215 (module design)
- IEC 61730 (module safety)
- IEC 62790 (junction box safety)
- IEC 62852 (connector safety)
- IEC 61701 (salt-mist corrosion)
- IEC 62804 (potential induced degradation)[67]

As noted earlier, existing systems keep the cables above water. However a 2021 study, *Floating photovoltaic systems: photovoltaic cable submersion and impacts analysis, reports that the submersion of photovoltaic cables with a rubber sheath in saltwater can lead to accelerated degradation to a cable, with reduction of its electrical insulation and consequently, copper release into the aquatic environment.*[68] While the standards for FPV are under development, some suggest looking to state-of-the-art offshore standards for planning and execution that are already available, such as DNV GL, 2011.

In addition to concerns regarding degradation of materials from saltwater, marine growth can cause many problems in offshore structures in other industries. Marine growth can include algae, marine invertebrates and other small organisms that adhere to and accumulate on submerged members of offshore structures. FPV systems could potentially create an artificial shelter for aquatic life in the surroundings and attract them. Birds and biofouling is also a noted concern in FPV. Therefore, operations and maintenance (O&M) activities will need to be carried out more frequently in order to keep power production unaffected while ensuring that water quality is not affected by avoiding chemical cleaning products.[69] The impact on worker safety to clean and maintain FPV systems has been explored in the literature, and preliminary results indicate that the risk to workers in these environments is potentially hazardous.[70]

4.0 Application Areas for FPV in the U.S.

In this section numerous application areas are discussed. A distinction is drawn between industry applications and application by water source. With each FPV application area efforts have been made to identify examples within the United States while drawing attention to state and local incentives (if they exist), as well as potential bodies of water where domestic growth could be expanded. The primary application areas of potential interest in the U.S. include the generation of power for:

- Municipal wastewater
- Agriculture
- Aquaculture
- Coastal resources

Given the scope of these application areas, some may be covered together. For example, the literature in this area covers wastewater and reservoirs concurrently. Additionally, architectural and coastal applications were not surfacing independently in the literature, however, given the increasing presence of hydropower FPV installations a section was added to cover that area.

4.1 Municipal Wastewater & Reservoirs

The terms reservoir, dam, and manmade lake are used inconsistently among sources making it difficult to provide an exact count for each body of water in the U.S.

The literature in this space appears to combine wastewater treatment reservoirs and other municipal reservoirs,[1] therefore, the figures in this section reflect both of those interest areas. Furthermore, the definitions used by EPA for these bodies of water includes the term man-made lakes and reservoirs. Using the EPA definition of man-made reservoirs as “waterbodies that were constructed” that goes on to explain that reservoirs are typically created to serve specific municipal or water resource management needs, such as drinking water supply, agricultural irrigation, industrial cooling for a water supply, flood control, fisheries, recreation, or navigation, and are often created by damming rivers or streams and flooding the surrounding floodplain – there were 53,119 man-made reservoirs in 2012.[71] Another source, the Global Reservoir and Dam Database (GRaND), lists 1,920 large dams and reservoirs in the United States,[72] and figures from the U.S. EPA Government Performance and Results Act (GPRA) Inventory Summary Report that there are approximately 147,000 publicly-owned water systems providing piped water for human consumption in 2021.[73]

In March 2021, the Healdsburg Solar Project came online in the city of Healdsburg, California, and is now ranked as the largest FPV project in the United States at 4.78 MW. The project was developed, financed, and built by White Pine Renewables and spans two wastewater treatment ponds in Sonoma County. This project will provide 6% of the city’s energy needs by generating over 6.5 million kWh annually and was financed through a 25-year power purchase agreement (PPA) that will offer the city a low, fixed-rate for electricity and extended savings on utility rates. The project is also expected to deter rising utility rates and operation & maintenance (O&M) costs as White Pine Renewables will be responsible for maintaining the project.[74]

There are more than 16,000 publicly-owned wastewater treatment systems of various sizes serving the majority of wastewater needs in the United States. Growing urban environments are seen as signaling a trend that centralized wastewater treatment plants (WWTP) will increasingly accommodate a larger portion of the nation’s wastewater demand.[75]

Wastewater infrastructure may be funded by local user fees and taxes, state-specific grants or discretionary set-asides, and federal grants or financing mechanisms. State and local entities shoulder the majority of capital projects and O&M expenses, which were approximately $20 billion in 1993 and increased to $55 billion by 2017.[76] About 2% of U.S.

1 A “municipal reservoir” is defined as a reservoir, lake, pond or other receptacle of water storage area connected with any park, open space or environmentally protected land (Law Insider). The word reservoir is commonly used to describe an artificial lake where water is stored – mostly by constructing dams across rivers. Although the word “reservoir” may be proceeded by an adjective such as wastewater reservoir, mining reservoir, oil and gas reservoir, chemical reservoir – it is questionable whether these are considered a subset of “municipal reservoirs,” as defined.

electricity use goes towards pumping and treating water and wastewater. In 2013, energy-related emissions resulting from publicly owned treatment works (POTW) operations, excluding organic sludge degradation, were 15.5 teragrams (Tg) CO_2-equivalents (CO_2e), 22.3 gigagrams (Gg) SO_2, and 12.7 Gg NOx. SO_2 and NOx contribute to acidification and eutrophication. In 2019, an estimated 18.4 and 26.4 MMT CO_2e of CH_4 and N_2O, respectively, resulted from organic sludge degradation in wastewater treatment systems, about 0.6% of total U.S. GHG emissions.[77]

Reservoirs are attractive host projects for FPV as they are already managed, have access roads and infrastructure.

Table 15: Wastewater Funding and Financing Mechanisms

Federal Agency	Program	Details
U.S. Department of Agriculture	Rural Utilities Service: Water and Waste Disposal Programs	The purpose of this program is to provide basic human amenities, alleviate health hazards, and promote the orderly growth of the nation's rural areas (communities with populations of 10,000 or less) by meeting the need for new and upgraded drinking water, wastewater, stormwater, and solid waste infrastructure.
U.S. Department of Housing and Urban Development	Community Development Block Grants (CDBG)	The program's primary objective is to develop viable communities by providing decent housing and a suitable living environment, and by expanding economic opportunities, principally for persons of low and moderate income. Accordingly, CDBG resources are not limited to drinking water, wastewater, and/or stormwater infrastrucure, but these projects must compete with other eligible activities including historical preservation, energy conservation, lead-based paint abatement, and more. The block nature of the CDBG distribution enables local government's to exercise discretion and on-the-ground knowledge when selecting appropriate projects that achieve program objectives.
U.S. Environmental Protection Agency	Water Infrastructure Finance and Innovation Act Program (WIFIA)	Established in 2014, the WIFIA program provides credit assistance through long-term, low-cost supplemental loans for regionally and nationally significant infrastructure projects. WIFIA authorizes EPA to provide credit assistance directly to an eligible recipient for a broad range of drinking water and wastewater projects that generally cost $20 million or more.
U.S. Environmental Protection Agency	Clean Water State Revolving Fund Loan Program (CWSRF)	Established in 1987 by amending the Clean Water Act, federal funds are directed to CWSRF programs in all 50 states and Puerto Rico to capitalize state infrastructure loans. CWSRF resources must be matched by 20% state-backed funds. Various projects from CWSRF include new construction and upgrades of wastewater treatment plants, stormwater infrastructure, nonpoint source pollution management plans, and more.

Source: 2021 Infrastructure Report Card [78]

Reservoirs have been identified as particularly attractive project hosts for FPV as they are already managed, have access roads and infrastructure that would make system installation easier and less expensive, and have fewer environmental concerns than a natural water body. These figures demonstrate the vast potential for the expansion of the field to scale up solar generating capacity.[79]

In addition to the number of bodies of water, the capacity that may be covered for a system is important. The current median range for existing FPV projects uses no more than 27%

of the water surface area for the FPV system. However, the percent water surface area coverage can range from <2% to >80%, and there has not been a significant connection between installation coverage and water body area. The range is due to the fact that many panel coverage percentages are determined by point-of-use power needs, grid capacity constraints, and alternative uses of the water body. However, *any man-made reservoirs that are small, used for fishing, navigation, recreation, are within an airport boundary, or are located over 50 miles from a transmission line are currently not considered feasible for FPV development and should be filtered out from any initial site considerations*.[80] Reservoir operation can also impact water level variation due to hydropower generation or irrigation, which must be taken into account when siting the FPV project.[81]

FPV has the potential to improve several critical factors for reservoirs such as evaporation, water quality, reduced water movement to minimize erosion, and reduced dust accumulation.

Additional factors impacting FPV include:

- Solar irradiance
- Climate conditions at the site
- Wind and anticipated wave characteristic subsurface soil can impact anchoring methods
- Environmental impact on minerals or aquatic.[82]

FPV has the potential to improve several critical factors for reservoirs such as evaporation, water quality, reduced water movement to minimize erosion, and reduced dust accumulation - these factors are especially significant at the United States' two largest man-made reservoirs, Lake Powell, and Lake Mead. These are both located in Southwestern drought-prone desert areas. The U.S. Bureau of Reclamation estimated **Lake Mead** loses 800,000 acre-feet of water (6% of the Colorado River's annual flow) from surface evaporation due to the desert sun on average each year. Lake Powell loses nearly 860,000 acre-feet due to evaporation and bank seepage.[83] While there are no current or planned installations at these locations there have been several articles written on the potential for FPV at these sites.

Existing and planned installations in the U.S. include Sayreville, New Jersey, which hosts the first ever floating solar array on a reservoir in the U.S. and Cohoes, New York, which will install the first floating solar array developed with public funds. The Cohoes, New York site will be a 3.2MW floating solar demonstration project expected to cost about $5.9 million, with federal funding of $4.788 million and a non-federal share of $1.209 million. This project is seen as a demonstration of both the technology and a model for how other municipalities can invest in their own energy infrastructure. The Cohoes installation is expected to erase around $500,000 in annual electricity costs with 40% of the generated electricity remaining for civic use. Furthermore, the Floating Solar Explorer tool was developed as part of the planning process for the Cohoes project – the exploration tool is available online and includes a map of all the suitable reservoirs identified by the National Renewable Energy Laboratory (NREL), as well as congressional district-scale low- and moderate-income (LMI) information layered over New York. The New Jersey and New York projects were developed with Laketricity subsidiary Ciel & Terre technology and the developer BlueWave Solar. The group is also interested in launching floating solar arrays in Massachusetts and other parts of the Northeast.[84] Massachusetts is offering Floating Solar Tariff Generating Units for installations on man-made bodies of water.

4.1 Agriculture

Agricultural irrigation canals and reservoirs tend to be shallow and slow moving, which can lead to water loss from evaporation, and algae growth, however, FPV is one possible way to curb these issues while also providing a power source to fuel a farm or ranch. The presence of existing irrigation canals and agricultural reservoirs are well suited to FPV due to the relative stability of the water's surface. Floating solar can provide low-cost energy to farmers without using any of their valuable land space. These factors are discussed throughout the literature, and often reference the example of Central Valley, California for the use of FPV in agriculture.

In terms of potential bodies of water for FPV in agriculture, the most frequently cited figures related to pond inventory (including agricultural) dates from 2006, the USGS report, *The global abundance and size distribution of lakes, ponds, and impoundments*[85] reports that U.S has 21,600 square kilometers (8,340 square miles) flooded by small ponds. Concentrations of ponds exist in Tennessee and Mississippi, where ponds take up 3 to 4 percent of the agricultural land. Another source for this type of information is The U.S. Department of Agriculture (USDA) Census of Agriculture.

The most recent Census of Agriculture (the 2017 Census of Agriculture) was released in April 2019. The 2018 Irrigation and Water Management Survey falls under the umbrella of the Census of Agriculture and provides data relating to on-farm irrigation activities – per this latest census there were **294,235 irrigated farms in 2017: 119,235 used irrigation wells, 98,490 were irrigated with off-farm water, and 4,829 were using recycled or reclaimed water**. Of note**, 3,047 were using solar-powered pumps** at the time of this survey – 740 pumped surface water only, and 2,110 pumped well water only. The survey notes that the solar pump data were not published at the state level because of low data reliability at the state level, given that there are few operations with solar pumps in the population.[86]

Table 16: Solar Pumps and Other Pumps Without Direct Energy Expense: 2018

Geographic Area	Farms 1	Pumped Surface Water Only		
		Farms	Pumps Powered	Acres Irrigated
United States	3,047	740	1,340	70,134
Water Resources Regions				
Region 01 New England	102	30	(D)	7
Region 02 Mid-Atlantic	123	24	24	24
Region 03 South Atlantic-Gulf	74	39	72	10,161
Region 04 Great Lakes	80	7	7	--
Region 05 Ohio	93	63	63	192
Region 06 Tennessee	67	67	67	135
Region 07 Upper Mississippi	78	31	85	85
Region 08 Lower Mississippi	--	--	--	--
Region 09 Souris-Red-Rainy	--	--	--	--
Region 10 Missouri	125	67	121	7,283
Region 11 Arkansas-White-Red	80	8	(D)	16
Region 12 Texas-Gulf	81	-	-	-
Region 13 Rio Grande	173	7	14	7
Region 14 Upper Colorado	34	34	102	(D)
Region 15 Lower Colorado	66	--	--	--
Region 16 Great Basin	41	30	30	(D)
Region 17 Pacific Northwest	233	126	189	978
Region 18 California	1,590	214	535	46,995
Region 19 Alaska	6	--	--	--
Region 20 Hawaii	1	--	--	--

[1] Operations with both well water and surface water are included. The individual categories may not sum back to the total [Excludes institutional, research, and experimental farms. For meaning of abbreviations and symbols see introductory text.]

Source: USDA[87]

In terms on incentives for FPV in agriculture, the Natural Resources Conservation Service (NRCS) has allocated funds through the Environmental Quality Incentives Program (EQIP) as part of the 2018 Farm Bill. While not specifically focused on FPV these funds do target irrigation and energy. It is designed to provide, "technical and financial assistance to producers to address natural resource concerns and deliver environmental benefits such as improved water and air quality, conserved ground and surface water, increased soil health and reduced soil erosion and sedimentation, improved or created wildlife habitat, and mitigation against drought and increasing weather volatility."[88] On the state level, one example of this funding was found in South Carolina:

> Cost-share for all projects is not guaranteed, but technical assistance is. However, "beginning in 2020, States may provide increased payment rates for high-priority practices. In consultations with the State Technical Committee, State Conservationists may designate up to 10 practices to be eligible for increased payments." National and South Carolina priorities related to the installation of a reservoir include reducing non-point source pollution (e.g., sediment, nutrients, pesticides, salinity) and conserving ground and surface water resources to mitigate drought.[89]

4.2 Aquaculture

The United States had 2,936 aquaculture farms in 2018.

In terms of potential sites for FPV deployment, the United States had 2,932 aquaculture farms in 2018 as compared to fewer than thirty FPV deployments. Aquaculture in the U.S. represents a $1.5 billion industry annually, which largely depends on access to geographic features that support production, meaning that some regions of the U.S. are more conducive to aquaculture than others. The South leads the U.S. in aquaculture production with nearly $850 million in annual sales from aquaculture. This can be attributed to strong production of freshwater fish, especially catfish, in the areas around the Mississippi River watershed, and saltwater production in the Gulf of Mexico and Atlantic Ocean. The West produces $475 million in aquaculture sales each year, primarily from Washington and California, which are leaders in shellfish production but also have strong saltwater and freshwater production of fish like trout, tilapia, and salmon.[90]

Table 17: Sources of Water Used for Aquaculture Production, 2018 and 2013

Geographic Area	Total Farms	Number of Farms By Sources of Water								
		Groundwater			On-farm Surface Water		Off-farm Water		Saltwater (See Text)	
	2018	2013[1]	2018	2013[1]	2018	2013[1]	2018	2013[1]	2018	2013[1]
United States	3,456	3,093	1,532	1,304	1,214	1,204	230	137	1,035	872
Alabama	120	156	58	100	102	93	1	3	4	6
Alaska	46	22	5	--	15	--	5	--	38	22
Arizona	9	13	5	10	3	3	5	3	--	--
Arkansas	82	85	71	75	25	20	6	3	--	--
California	116	124	49	68	29	16	33	24	21	33

Colorado	47	16	33	6	20	9	3	3	--	1
Connecticut	42	28	13	3	1	1	3	--	26	25
Delaware	1	3	1	3	--	1	--	--	1	-
Florida	334	393	153	194	32	53	6	13	178	169
Georgia	43	62	17	36	24	22	3	--	3	6
Hawaii	49	45	11	9	11	11	15	16	23	16
Idaho	41	28	9	6	35	21	5	3	--	--
Illinois	34	23	19	10	18	10	7	3	--	1
Indiana	23	7	10	4	16	7	2	--	--	---
Iowa	20	31	9	12	16	22	2	2	--	--
Kansas	10	4	8	2	8	4	1	1	--	--
Kentucky	31	30	9	10	18	23	13	1	--	--
Louisiana	525	500	368	286	141	235	46	19	30	48
Maine	75	35	8	6	17	9	--	--	56	25
Maryland	43	18	15	6	4	1	--	--	28	12
Massachusetts	180	145	14	6	8	9	6	--	161	133
Michigan	41	32	21	18	27	22	1	--	--	--
Minnesota	39	35	20	16	31	24	5	5	--	--
Mississippi	176	224	109	99	92	159	1	--	--	--
Missouri	37	35	16	17	28	22	3	--	--	--
Montana	22	4	14	1	11	3	--	---	--	--
Nebraska	26	21	20	19	10	8	2	--	--	--
Nevada	8	--	3	--	3	--	3	--	--	--
New Hampshire	32	7	13	6	3	--	3	1	21	1
New Jersey	57	59	11	4	6	6	--	--	42	50
New Mexico	14	2	7	2	10	--	--	--	--	--
New York	68	44	27	18	34	21	3	3	21	16
North Carolina	137	146	58	56	55	78	1	--	39	26
North Dakota	3	--	--	--	1	--	2	--	--	--
Ohio	74	61	30	20	52	43	4	3	--	3
Oklahoma	8	7	2	1	6	7	3	-	--	--
Oregon	40	37	16	7	19	13	2	2	15	17
Pennsylvania	72	56	47	25	48	43	1	5	-	-
Rhode Island	33	21	6	--	--	--	--	--	27	21
South Carolina	29	32	11	13	13	16	--	--	14	10
South Dakota	9	7	9	3	4	5	1	--	--	--
Tennessee	34	15	13	4	22	13	4	1	--	--

Texas	107	98	56	50	34	40	15	11	15	14
Utah	23	9	13	4	9	7	5	--	--	--
Vermont	11	6	9	6	7	--	--	--	--	--
Virginia	202	119	13	9	36	24	4	2	157	89
Washington	151	143	23	7	31	14	1	3	115	128
West Virginia	29	19	8	2	23	16	--	1	--	--
Wisconsin	87	80	63	43	44	47	4	5	--	--
Wyoming	16	6	9	2	12	3	--	1	--	---

Source: U.S. Census of Aquaculture[91]

Presently, mainstream energy sources are used for aquaculture, including oil, diesel, and fossil fuel, but the industry is looking to solar and FPV as an alternative.[92] The 2017 paper from Michigan Technological University provides a comprehensive backdrop for the topic titled, *Aquavoltaics: Synergies for Dual Use of Water Area for Solar Photovoltaic Electricity Generation and Aquaculture*,[93] *and several other papers have* since been published exploring the topic in greater detail. While the body of research in this area continues to grow it does not appear to be deployed frequently in the U.S., but several projects across the globe have surfaced in recent years. As aquaculture production has dramatically increased, the more intensively energy has been consumed, most frequently from nonrenewable sources. Furthermore, as the price of energy increases, it strongly impacts on aquaculture industry activities.

Presently, mainstream energy sources are used for aquaculture, including oil, diesel, and fossil fuel, but the industry is looking to solar and FPV as an alternative.

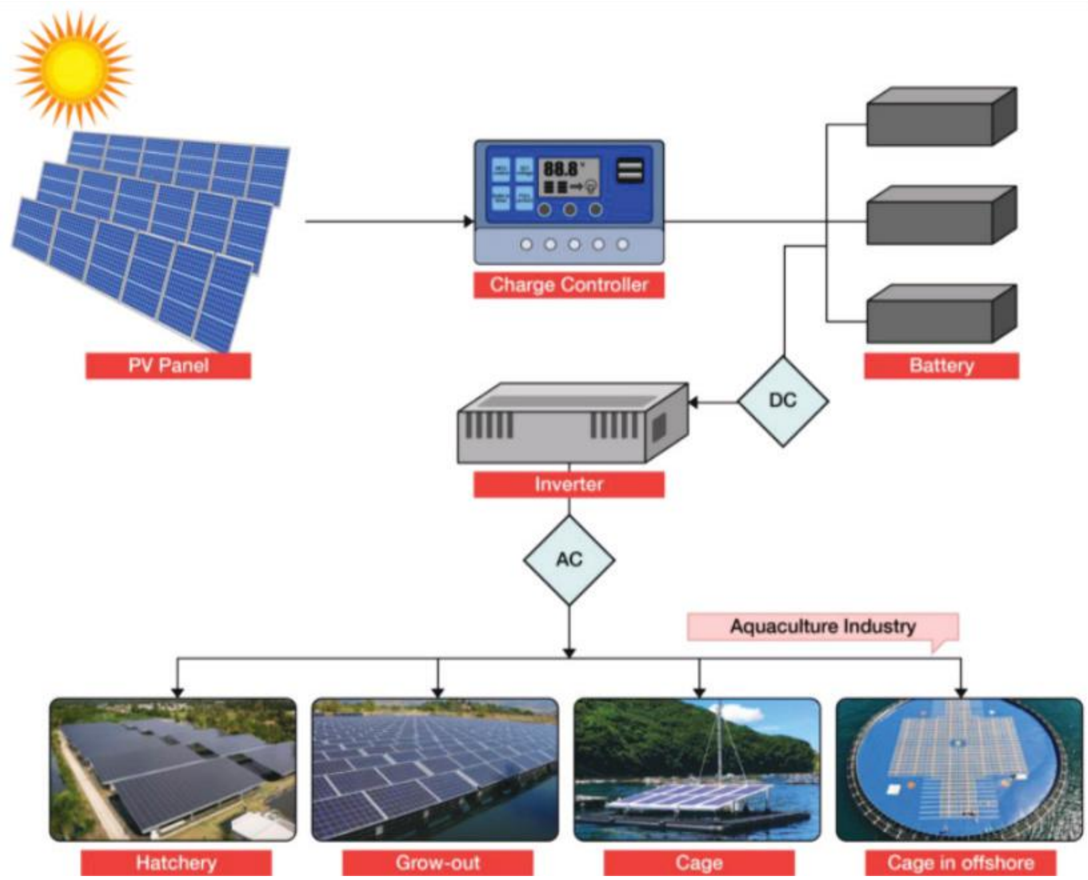

Figure 6: Applications Solar Power in Aquaculture
Source: Thu Em Vo et al.[94]

While there is not one universal method for calculating the amount of energy generated from FPV at aquaculture sites, one study estimated that, with approximately 40,000 ha (hectares) of aquaculture ponds in Taiwan, the deployment of FPV on fish ponds in Taiwan could accommodate an installed capacity more twice as high as the government›s objective of 20 GW solar power by 2025.[95] However, the Engage Energy Modeling Tool (Engage™) is a publicly available, free web-based energy planning model developed in collaboration with the Hawaii State Energy Office with funding from the Department of Energy's Energy Transitions Initiative ETI) and Solar Energy Technologies Office (SETO). Engage™ is used for rapid multi-sectoral scenario exploration and was used by NREL to model different configurations of stand-alone FPV and hybrid FPV-hydropower systems in its June 2022 report, "Enabling Floating Solar Photovoltaic (FPV) Deployment: Exploring the Operational Benefits of Floating Solar Hydropower Hybrids." This tool may be beneficial when looking to calculate the FPV potential for aquaculture and other sectors.

In aquaculture, energy intensity depends on cultured species, scale, system, technology, production, and local conditions. Many studies have been conducted to determine the energy intensity used in different culture systems with various aquatic species. The table below shows the use of energy in aquaculture for more than ten years, year-round – these energy figures may be helpful when determining if certain species are better suited to FPV deployment in the aquaculture sector.[96]

Table 18: Energy Used in Aquaculture

References	Species	System Intensity	Culture Technology	Energy Intensive (MJ/kg Production)
Ayer & Tyedmers	Salmon	Intensive	Net-pen, marine	27
	Salmon	Intensive	Flow-through, land-based saltwater	98
	Salmon	Intensive	Re-circulating, land-based freshwater	353
	Salmon	Intensive	RAS	92
	Salmon	Semi-intensive	Flow-through	48
	Salmon	Semi-intensive	Floating bag system	6
	salmon	Semi-intensive	Net pen	3
Pelletier et al	Salmon	Intensive	Canada	31
	Salmon	Intensive	UK	48
	Salmon	Intensive	Norway	26
Heeb & Wyss	Tilapia	Intensive	RAS	772
	Tilapia	Intensive	RAS	570
Eding et al	Tilapia	Intensive	RAS	19
Aubin et al	Turbot	Intensive	RAS	281
	Trout	Intensive	Flow-through Raceway	68
	Seabass	Intensive	Cage	49
Gál et al	Catfish, tilapia, carp, mussel	Intensive	Pond	78
	Catfish, tilapia, carp	Intensive	Pond	37
	Catfish	Intensive	Pond	68
	Catfish, tilapia, carp, mussel	Extensive	Pond	30
	Catfish, tilapia, carp	Extensive	Pond	27
	Catfish	Extensive	Pond	32
	Catfish, tilapia, carp, mussel	Extensive	Pond	10
	Catfish, tilapia, carp	Extensive	Pond	9
	Catfish	Extensive	Pond	10
	Carp	Semi-intensive	Pond	23
	Carp	Semi-intensive	Pond	48

Pelletier and Tyedmers	Tilapia	Intensive	Lake-based	18
Costa-Pierce	Salmon	n/a	Tanks	45
	Oysters	intensive	Cage	586
	Shrimp	Semi-intensive	Pond	40
	Catfish	n/a	Pond	84
	Tilapia	Semi-intensive	Na	60
	Mussel	n/a	Longline	1
	Trout	intensive	Cage	40
	Tilapia	Semi-intensive	Pond	40
	Carp	intensive	Pond	40
Cao et al	White-leg shrimp Litopenaeus vannamei	Intensive	Ponds	62
		Semi-intensive		34
Iribarren	Galician mussels (Mytilus galloprovincialis)	Extensive	Rafts	3
Winther et al	Blue mussels (Mytilus edulis)	Extensive	Longline	3
Meyhoff Fry	Blue mussels (Mytilus eduli)	Extensive	Longline	1
	Oysters	Extensive	Bag and trestle	4
Kim et al	Tilapia	Semi-intensive	RAS (aquaponics)	16
Kim et al	Red drum	Intensive	RAS	81
Boxman et al	Red drum	Semi-intensive	RAS (aquaponics)	25

Source: Thu Em Vo et al.[97]

The use of renewable energy for cultivating aquatic organisms is an important innovation in sustainable aquaculture, and efficiently produced energy can be used for aeration, feed dissension, water pumping, and light sources.[98]

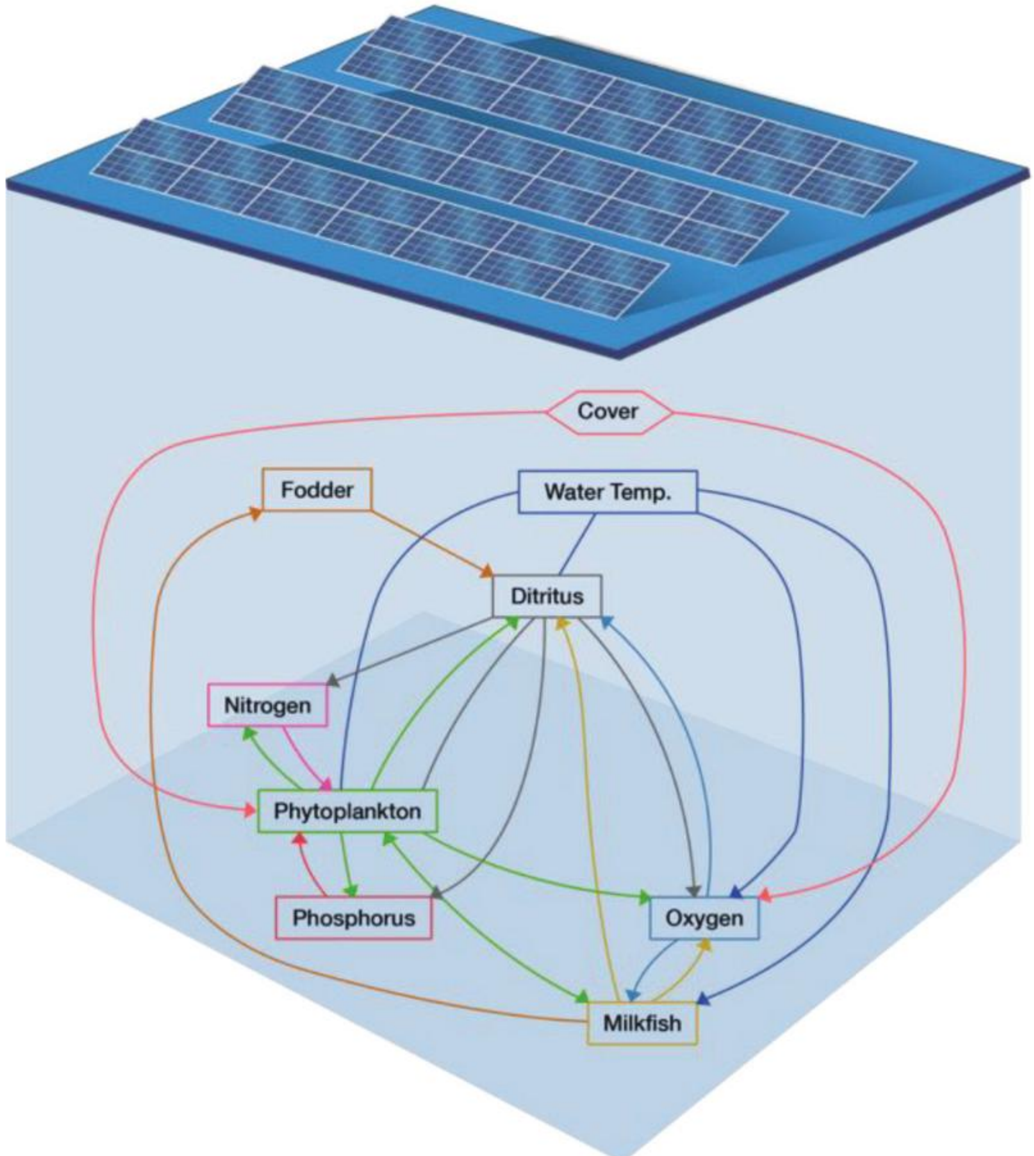

Figure 7: Floating Photovoltaic in a Milkfish Pond
Source: Thu Em Vo et al.[99]

In early 2022 French start-up HelioRec formed a consortium with +ATLANTIC CoLAB to develop a floating solar project for the aquaculture sector to provide clean energy for fish or algae farms from the floating solar power plant. However, the developers are still looking for fish or algae farms interested in implementing the floating solar systems for their operations. The planned FPV plant installation would be rated at 10kWp, equipped with 24 solar panels, and span the area of 130 m2 with a compact design intending to make it easy to transport and set up.[100]

The two leading concerns regarding fishing and FPV include the development of the fish population itself and the potential economic losses due to limited access of fishermen and women to fishing grounds which are covered by FPV arrays.

While FPV in aquaculture remains an emerging area, an April 2019 paper from the Office of Energy Efficiency and Renewable Energy (EERE) discussed potential partners in the U.S. and abroad in Offshore Marine Aquaculture. Examples of potential partners in this space include: NOAA Aquaculture Office and other U.S. Department of Commerce offices; U.S. Fish and Wildlife Service (Game) departments; and agriculture departments in coastal states (for example, Alaska Department of Fish and Game, California Department of Fish and Wildlife, Oregon Department of Agriculture, Washington Department of Agriculture, and Hawaii Division of Aquatic Resources, Animal Industry Division). Additionally, marine energy and aquaculture companies that are already active in linking marine energy to aquaculture, or with strong interests in doing so, include international companies, particularly in Scandinavia and Scotland, such as Wave Dragon, Albatern, and Waves4Power. U.S. companies include Atmocean and Columbia Power (C-Power). Furthermore, U.S. companies with offshore aquaculture interests include Kampachi Farms, Catalina Sea Ranch, Manna Fish Farms, and Innovasea.[101]

While many papers discuss the beneficial implications of FPV deployment in the aquaculture sector, it is also important to note that others have sought to identify and analyze the potential drawbacks. For example, the two leading concerns regarding fishing and FPV include the development of the fish population itself and the potential economic losses due to limited access of fishermen and women to fishing grounds which are covered by FPV arrays. Based on a 2020 literature review, scientific studies indicate that FPV either increases or only slightly decreases fish production with high levels of modules covering more than 30% of the water body with solar. Relative to access to fishing areas, the literature recommends positioning floats at a distance from the waterfront and separating the larger installations in islands with the possibility to give special permission to fisherman to navigate in between floats, allowing them to catch even more fish.[102]

4.3 Coastal & Offshore Resources

This section covers coastal and offshore locations for FPV installations – these broad terms include fresh and saltwater locations. Currently, the five largest markets for FPV technologies are China, Australia, Brazil, Canada, and France. China and the Netherlands were the first countries to set up FPV systems in offshore areas, but the majority of FPV projects worldwide are installed in onshore water bodies (i.e., lakes, ponds, reservoirs). There are several challenges with offshore FPV installations, such as the lack of commercially available mooring and anchoring systems for FPV installations. Additionally, there are challenges with transporting, lifting, maneuvering, and positioning the heavy structures needed for offshore FPV projects, which make it cost prohibitive as compared to alternatives such as wind power. The seawater itself poses the challenge of corrosion and degradation of structures, while marine organisms can attach themselves to submerged offshore structures, changing their physical properties and size. One interesting area that shows potential is the combination of marine FPV systems with offshore wind farms.[103]

The United States has a total of 30 coastal states with over 12,000 miles of ocean coastline. There are five different coasts of the United States: the Atlantic Coast (East Coast), the Pacific Coast (West Coast), the Gulf Coast, the Arctic Coast, and lake states. The NOAA Office for Coastal Management provides shoreline mileage of the United States – these figures include the shoreline mileage of the outer coast, which includes offshore islands, sounds, bays, rivers, and creeks to the head of tidewater or to a point where tidal waters narrow to a width of 100 feet. In the Great Lakes region, shoreline mileage was measured in 1970 by the International Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data and cross-referenced with U.S. Lake Survey measurements for each state. In all cases, mileage was determined by using a recording device on large-scale charts.[104]

Table 19: Shoreline Mileage of the United States

Location	Shoreline Mileage (Statute Miles)
United States	95,439
Alabama	607
Alaska (Pacific and Arctic)	33,904
Alaska (Pacific only)	31,383
Alaska (Arctic only)	2,521
American Samoa	126
California	3,427
Connecticut	618
Delaware	381
Florida (Atlantic and Gulf)	8,436
Florida (Atlantic only)	3,341
Florida (Gulf only)	5,095
Georgia	2,344
Guam	110
Hawaii	1,052
Illinois	63
Indiana	45
Louisiana	7,721
Maine	3,478
Maryland	3,190
Massachusetts	1,519
Michigan	3,224
Minnesota	189
Mississippi	359

New Hampshire	131
New Jersey	1,792
New York	2,625
North Carolina	3,375
Northern Marina Islands	206
Ohio	312
Oregon	1,410
Pennsylvania	140
Puerto Rico	700
Rhode Island	384
South Carolina	2,876
Texas	3,359
U.S. Virgin Islands	175
Virginia	3,315
Washington	3,026
Wisconsin	820

Source: NOAA Office for Coastal Management[105]

Although FPV technology has been installed onshore in many areas, in the U.S. it is still novel for offshore areas. Some studies in this area have made suggestions as to how to best develop technologies that limit risk and improve the efficiency of offshore FPV systems including:

- verifying the effects of sea water on the structure and function of PV modules;
- analyzing the impacts of electrical devices (converters) on the surface of water and on their efficiency and performance;
- investigating the effects of FPV systems on water quality, ecosystems, ecology footprint, and other environmental factors;
- expanding studies concerning the capacity and performance of FPV power plants;
- designing optimum FPV systems to decrease the effects of the marine • environmental factors;
- expanding the life cycle of FPV systems; and
- decreasing the material costs of FPV modules.[106]

4.4 Hydropower

Hydropower is frequently cited in the literature as an important area for FPV installation and is seen as having benefits over lakes and other bodies of water. As reported by

NREL there are 379,068 freshwater hydropower reservoirs around the world that would potentially be suitable hosts for FPV systems. Hybrid FPV/solar and hydropower projects have the potential to generate as much as 7.6 TW/year of potential power from the floating solar plants alone (not accounting for the power generated from the hydro power plant). Additionally, an analysis of the first twenty larger hydro power plants (HPP) around the world found that if 10% of the plant basin surface is covered with FPV, HPP production would increase by 75%. The same study analyzed 100 HPP in the U.S. with a total generating capacity of 32,574 MW. These studies report that to install FPV of power equal to that of the hydro power plant (HPP), only 1.19% of the surface would need to be covered to produce 40.5% of the hydroelectric energy production. These studies go on to note that installing an FPV plant equal to the hydro power plant output and reducing the hydro turbines' power production during peak sun hours would maintain the energy injected into the grid at a constant rate.[107]

The cost of FPV on dam reservoirs remains slightly more expensive than ground-mounted photovoltaic (GMPV):

> A cost comparison between 50 MWp of FPV and 50 MWp of GMPV in a 2019 study 'When the Sun meets Water' by the World Bank, ESMAP and Seris, put capex for FPV on a reservoir of just 10 m depth with minimum water level variations at US$ 0.73/Wp versus US$ 0.62/Wp for GMPV. Costs were most notably higher for the mounting system and for balance of system. Deroo acknowledged that FPV on a large dam reservoir would engender extra costs with respect to the mooring systems, which are more complex because of greater reservoir depths and water level variations, the longevity of the FPV because of large waves on reservoirs, and the need for various dam safety protective measures. But when taking into account certain benefits especially the better performance of FPV and the avoidance of land issues, it would have an almost equivalent levelized cost of electricity (LCOE), according to Deroo.[108]

There are several examples of these hybrid installations across the globe. An array of 840 FPV panels were installed on the reservoir of a hydropower facility on the Rabagão River that had a capacity of 220 kW exceeded expectations according to the project developer, EDP Renewables.[109]

In the U.S. there are conventional hydropower/hydroelectric facilities in nearly every state. Most hydroelectricity is produced at large dams built by the federal government, and many of the largest hydropower dams are located in the western United States.

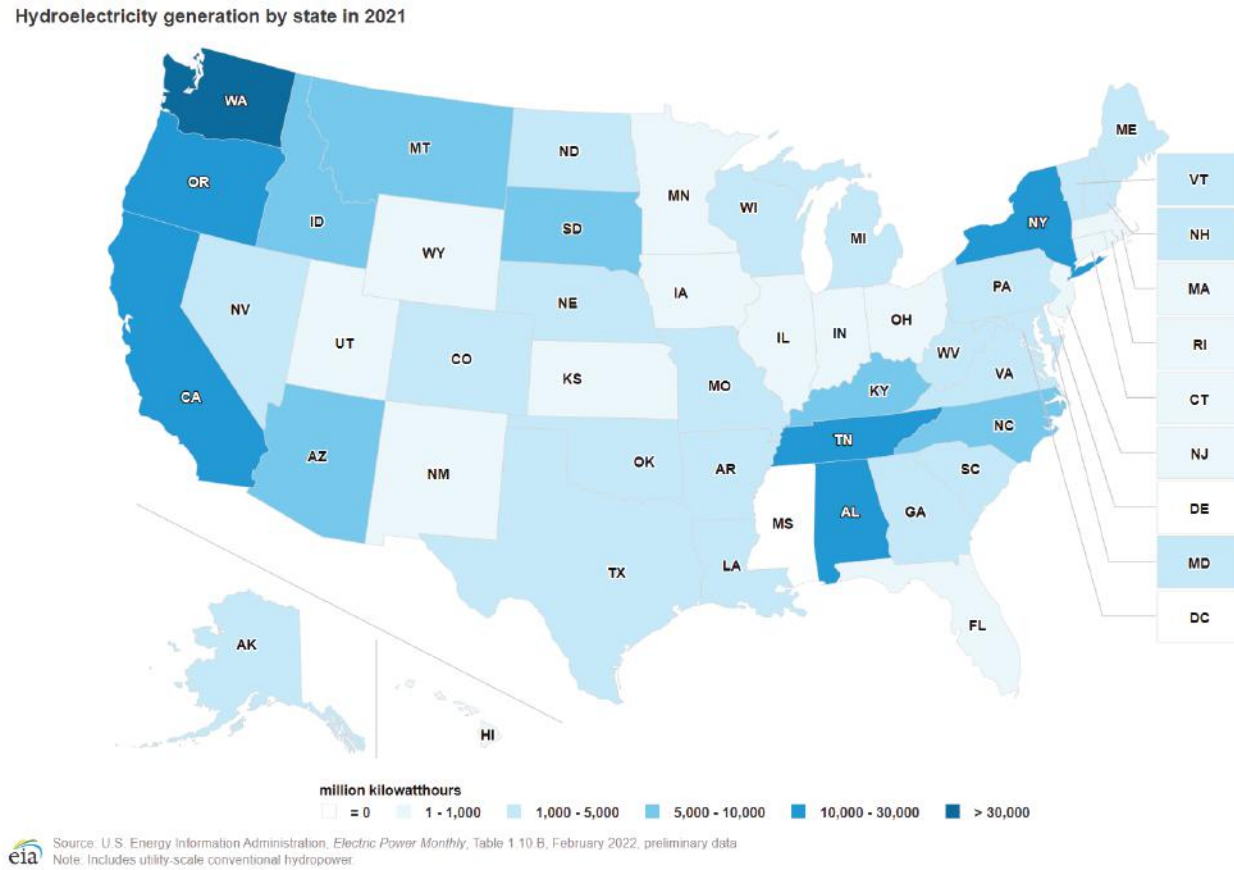

Figure 8: Hydropower Generation by State, 2021

Source: EIA[110]

Approximately half of the total U.S. utility-scale conventional hydroelectricity generation capacity is concentrated in Washington, California, and Oregon, but only a small percentage of the dams in the U.S. produce electricity. Most dams were constructed for irrigation and flood control and do not have hydroelectricity generators, but in 2012 DOE estimated that non-powered dams in the United States had a total of 12,000 MW of potential hydropower capacity.[111]

While not limited to the U.S., the table below reports what would happen if the twenty largest HPP basins in the world were equipped with FPV plants of the same power.

Table 20: Comparison Between Larger HPP and FPV Plants of Equivalent Power

Name	E_H	S_{FPV}	E_{FPV}	S_{FPV}/S_B	E_{FPV}/E_H	$FLH_{FPV,H}$
	TWh	km²	TWh	%	%	h
Three Gorges Dam	98,8	188	21,1	17,3%	21%	5330
Itaipu Dam	103,1	117	17,9	8,6%	17%	8646
Guri	53,4	85	15,8	2,0%	30%	6765
Tucuruí	41,4	70	12,6	2,3%	30%	6455
Belo Monte	39,5	61	8,5	13,9%	22%	6549
Grand Coulee	20,0	57	4,8	17,5%	24%	3644
Xiangjiaba	30,7	54	5,2	56,2%	17%	5573
Sayano–Shushenskaya	26,8	53	4,9	8,6%	18%	4958
Krasnoyarsk	15,0	50	7,7	2,5%	52%	3790
Nuozhadu	23,9	49	5,2	15,2%	22%	4966
Robert-Bourassa	26,5	47	5,1	2,0%	19%	5632
Churchill Falls	35,0	45	4,5	0,6%	13%	7286
Tarbela Dam	13,0	41	5,9	16,3%	45%	3870
Bratsk	22,6	38	3,5	0,7%	15%	5777
Xiaowan Dam	19,0	35	4,2	18,4%	22%	5534
Ust Ilimskaya	21,7	32	5,3	1,7%	24%	7031
Jirau	19,1	31	5,5	12,1%	29%	6565
Jinping-I	17,0	30	4,8	36,4%	28%	6052
Santo Antonio	21,2	30	5,4	6,1%	26%	7435
Ilha Solteira Dam	17,9	29	4,3	2,4%	24%	6437
Total/average	**665,6**	**1140**	**152,5**	**3,5%**	**23%**	5994

Source: Cazzaniga et al.[112]

However, a more detailed analysis was performed on the same topic but limited to the United States. These figures were provided by Cazzaniga et alia using data published by scholars covering about 100 hydro power plants (HPP) in the United States.

Table 21: Data for 100 USA HPP (Total Values and Average Data)

Power MW	Basin Surface km²	$\rho_{P,H}$ MW/km²	$\rho_{E,H}$ GWh/km²	$\rho_{P,FPV}$ MW/km²	$\rho_{E,FPV}$ GWh/km²
32574	22736	1.43	5.02	120	191

Source: Cazzaniga et al.[113]

Finally, the following table provides a worldwide analysis of hydroelectric basins to illustrate how large is the FPV surface necessary to install an equivalent power.

Table 22: Worldwide Analysis of Hydroelectric Basins

	HPP			FPV			
	S_H	P_H	E_H	S_{FPV}	E_{FPV}	$S_{FP}V/S_B$	E_{FPV}/E_H
	km²	GW	TWh	km²	TWh	%	%
Africa	24,197	34.4	114.1	287	41.28	1.2%	36.2%
America Central	2,899	7.7	23.0	64	9.24	2.2%	40.2%
America South	53,863	161	589.8	1342	193.2	2.5%	32.8%
Asia South East	22,929	44.8	143.4	373	53.76	1.6%	37.5%
Asia South without India	1,081	17.6	65.5	147	21.12	13.6%	32.2%
Australia	1,216	14	43.9	117	16.8	9.6%	38.3%
Canada	95,224	81	388.2	675	97.2	0.7%	25.0%
China	7,454	333	1,162.8	2775	399.6	37.2%	34.4%
Europe (North)	24,724	68	196.7	567	81.6	2.3%	41.5%
Europe (South)	2,066	85.9	175.3	716	103.08	34.6%	58.8%
India	13,361	47.6	128.8	397	57.12	3.0%	44.3%
Japan	130	12	91.3	100	14.4	76.9%	15.8%
Middle East	10,775	15.87	19.8	132	19.044	1.2%	96.2%
Russia	84,761	51	186.6	425	61.2	0.5%	32.8%
Turkestan	14,582	12.7	51.7	106	15.24	0.7%	29.5%
USA	21,686	103	261.8	858	123.6	4.0%	47.2%
Total	**380,948**	**1089.57**	**3,642.7**	**9,079.8**	**1307.5**	**2.4%**	**35.9%**

Source: Cazzaniga et al.[114]

Additional information on the hydropower space is available in a June 2022 report from the National Renewable Energy Laboratory (NREL) titled, **"Enabling Floating Solar Photovoltaic (FPV) Deployment: Exploring the Operational Benefits of Floating Solar Hydropower Hybrids," which looks at the potential value that hybrid FPV-hydropower systems can provide for power systems.**

5.0 Supply Chain for Floating Photovoltaics

To address the supply chain and key players in FPV, secondary information on firms providing construction services for large scale floating photovoltaic structures in the U.S.

are profiled in this section. Additionally, this section identifies which domestic companies are providing floats and panels for floatovoltaics, as well as service providers sourcing those components.

5.1 Background

The solar PV services market is forecast to increase from $9.98 billion in 2021 to $19.92 billion by 2030 with market potential pegged at $126.06 billion (2022-2030). The solar PV services market is highly fragmented, with the top eight prominent players cumulatively holding only 37.6 % of the 2021 market share. Standard solar PV service providers will have to meet a high degree of quality, professionalism, and minimum service standards and guarantees to thrive in the highly competitive market. Participants pursued growth by expanding to new markets primarily through strategic alliances and acquisitions.[115]

The solar PV services market is highly fragmented, with top 8 prominent players cumulatively holding only 37.6 % of the 2021 market share.

Context and Definition

- Unlike regular land-based PV systems, floating PV systems are harder to access and require skilled technicians to perform maintenance services.
    - They are likely to see additional wear and tear when compared to land-based panels.
    - They are more prone to oxidation and corrosion of the metal parts.
    - It may be challenging to employ robotic cleaning in this scenario.
- Key hotspots for APV are Italy, Spain, France, China, the US, Romania, and Israel.
- Key hotspots for FPV are China, Vietnam, Korea, Japan, Singapore, France, Germany, UAE, and Netherlands.

Call to Action

- Maintenance contractors should offer specialist services to IPPs and utilities by expanding capabilities and training employees.
- Service providers can leverage the business opportunity for retrofit PV coating services.
- Service providers could consider vertical integration by expanding into the production of coating materials.

Figure 9: Specialist Services for FPV/APV (Agro-Photovoltaics)
Source: Frost & Sullivan[116]

Reprinted with permission from Frost & Sullivan

Leading players in the FPV market include: Ciel & Terre, Groenleven, Ocean Sun, EN Technologies, Hangzhou Fengling Electricity Science Technology, Pembangkitan Jawa Bali Masdar Solar Energi (PMSE), Tata Power Solar, BHEL, Sembcorp, and Hanwha QCells.[117]

Figure 10: Overview of Companies Involved in FPV

Source: pv magazine[118]

The following subsections identify additional players in each tier of the supply chain. These include float suppliers, panel suppliers, FPV construction firms, and service provider sourcing. It is important to note that several of these players fall under multiple categories within the supply chain and/or have integrated relationships. While many firms are profiled in this section it should be seen, to an extent, as a representative sample of research findings and not an exhaustive list.

Co-development and partnerships among developers, suppliers, and other public and private entities are a common mechanism for new FPV installation development.

5.2 Large-scale FPV Construction

This section focuses on firms with U.S. projects and relationships as a way to narrow the scope of the search and point out international collaboration among players in this space.

5.2.1. D3 Energy

D3Energy is a U.S. based floating solar developer that has installed FPV projects across the U.S. and across the globe. The company's experience ranges from early-stage development and engineering to installation, service, and maintenance. Its FPV projects cover a variety of sizes and types ranging from megawatt-plus systems to microgrids and creative marketing pieces. The company has an **exclusive manufacturing partner, Ciel & Terre.** Ciel & Terre has been developing large-scale floating solar projects worldwide since 2011 and is recognized as the leader of the floating PV market due to the development of their patented technology, Hydrelio®. Ciel & Terre has over 610 megawatts of power connected across 240 projects installed in 30 different countries.[119]

D3 Energy has developed several high-profile projects throughout the U.S. and integrated Ciel & Terre's technology; these projects are introduced below.

Figure 11: FPV at U.S. Army Fort Bragg, North Carolina

Source: D3Energy[120]

Fort Bragg is the largest military base in the country and is also home to the largest floating PV system in the Southeast United States. D3 Energy built the 1.1MW system coupled with a 2MWh Tesla battery to directly power the military base. The project involved a $36 million contract between Duke Energy and Fort Bragg designed to boost resilience and includes lighting and water upgrades, plus a 2-megawatt storage system tacked onto the solar project. **Ameresco, a Massachusetts-based renewables developer and energy efficiency company, also served as a developer on this project**.[121]

D3Energy has developed many projects throughout the United States. At Universal Orlando Resort® (Orlando, FL), D3 Energy developed an FPV installation at the entrance to the Universal Orlando® theme parks. This array is a first of its kind and uses a unique product, SolarSkin, to create the Comcast logo. D3 Energy built the installation at the Altamonte Springs Water Facility, which is the largest floating solar array in Florida - this 1MW system will directly power the Altamonte Springs Regional Water Reclamation Facility which delivers reclaimed water to the Central Florida region. D3Energy also built the pilot project for the Central Florida Expressway (CFX) to showcase the ability of FPV and batteries – the installation uses a retention pond along the highway, this microgrid then powers their emergency digital sign with solar and battery storage. D3Energy partnered with the City of Orlando and the Orlando Utilities Commission (OUC) to bring this floating solar array to the Orlando International Airport with an installation designed in the shape of the airport's logo and also at Miami International Airport (MIA) where it built a floating PV system for Miami-Dade County and Florida Power & Light (FPL) to bring South Florida its first floating solar array. In terms of international projects, in **partnership with the Vector Group**, D3Energy provided New Zealand with its first floating PV system, which is also the largest PV system of any kind. This 1.1MW system is situated directly on the wastewater reservoir for the plant.

5.2.2 Noria Energy and Collins Electrical Company

The Healdsburg Floating Solar Project was developed and is operated by White Pine Renewables. Noria Energy co-developed the project with White Pine Renewables and Collins Electrical Company, a California-based construction contractor, provided installation services. The Healdsburg project was completed in less than six months from procurement to commissioning.

An independent engineering report provides details on the scope and installed capacity of the Healdsburg project. The project entails two arrays that will be located on the north and south ponds of the city's wastewater treatment facility.

The 4,780.6kW-DC/3,000kW-AC floating solar project consists of:

- **Floating-ballasted arrays with fixed-tilt east/west racking** – these floating arrays hold 2 planes of modules back-to-back with one facing east and one facing west in a tent-looking structure.
- **A total of 11,660 bifacial modules** – these are double-sided modules that allow sunlight to convert into energy from both the top and bottom.
- **20 high-power, utility-scale string inverters** – these are used to convert the DC (direct current) output of PV solar panels into a utility frequency AC (alternating current) so that it can be fed into a commercial electrical grid.

  The project achieves two objectives for the City. First, the 4.78MW project would help generate approximately 7,181 megawatt hours (MWh) of clean energy annually. Second, the arrays help to mitigate algae growth in the pond.

  That amount of energy the Healdsburg Floating Solar PV project produces annually is enough to power roughly 1,110 California homes, which use an average of 6,471 kWh per year according to the U.S. Energy Information Administration (EIA, 2018). California is approximately 39% below the 2019 national average that states home electricity use as 10,649 kilowatt hours (kWh) annually.

5.2.3 RETTEW, Solar Renewable Energy (SRE) and J&J Solar

The Sayreville Floating Solar Farm in New Jersey is a 4.4 MW installation and is located on a retention pond in Sayreville, New Jersey. The 4.4 MW array was developed by engineering firm RETTEW alongside contractors Solar Renewable Energy (SRE) and J&J Solar. This installation provides 100% of the electricity needed to power Sayreville's water treatment plant and is made up of HT-SAAE 345-W panels, Ciel & Terre Hydrelio floats and ABB inverters. The array has a sawtooth design which matches the shape of the retention pond while also keeping a distance from the shore.[122]

5.2.4 Collins Electrical Company and Ciel & Terre

The Windsor Floating Solar Farm in California is 1.8 MW floating solar farm located on the town's largest recycled water Pond 7. Construction began in May 2019 and was a collaborative effort between local union contractor Collins Electrical Company and **Ciel & Terre. The solar array consists of 4,959 panels which cover 21.23%, approximately 4 acres, of the water surface at the pond, and will provide power for the Windsor Wastewater Reclamation Facility, Public Works Corporation Yard, and the Geysers pump station. The town of Windsor will receive discounted clean energy after entering into a** *25-year lease and power purchase agreement (PPA) with Ciel & Terre. Furthermore, the design of the floating solar array allows for expansion if extra capacity is required and had no impact on the operations of the water reclamation facility while the installation was taking place.*[123]

5.3 Service Provider Sourcing

5.3.1. U.S. Floating Solar & Sungrow

In 2021, U.S. Floating Solar partnered with Sungrow FPV (Floating PV) the act as its exclusive North American Agent for Sungrow's floating solar products. U.S. Floating Solar works with Sungrow FPV in marketing and selling Sungrow FPV products to utilities, EPC's, asset owners and developers in the renewable energy sector, target project sizes range from 1MW - 250MW+.

5.3.2. BlueWave Solar & Laketricity

BlueWave Solar is a solar and energy storage developer that partnered with Laketricity. Laketricity is a U.S. based development company owned by Ciel & Terre. BlueWave Solar and Laketricity signed a joint venture for projects in Massachusetts and have plans to expand throughout the Northeast U.S region. BlueWave has developed and sold more than 155 MW of solar projects to date, which collectively generate enough solar energy to avoid roughly 119,490 metric tons of carbon emissions annually.

> BlueWave is a Certified B Corporation. B Corp Certification requires a B Impact Assessment, which evaluates how a company's operations and business model impact the company's workers, community, environment, and customers. B Corp Certification demonstrates a company's stakeholder impact for the long term by embedding it into a company's legal structure. For its commitment to sustainability best practices, BlueWave has been named the Clean Energy Company of the Year in 2018 by the Northeast Clean Energy Council, one of the top 100 Impact Companies in the United States for each of the last two years as rated by Real Leaders Magazine, and a leading growth company by Inc. Magazine and the Boston Business Journal.[124]

5.3.3. Solential Energy

Solential is an Indiana-based renewable energy company that is reported to be in final negotiations with a major Midwestern city to install the region's first floatovoltaic solar system using floating PV racking systems from Ciel & Terre.

5.3.4. YSG Solar

YSG Solar is reported to be seeking suitable sites for floating solar projects across the country. If the location is viable, YSG Solar will work with individuals, businesses, municipalities, and other entities to lease out properties for floating solar farms just like those highlighted in this article. Presently, YSG Solar is focusing on the states listed:

- Arkansas
- California
- Connecticut
- Delaware
- Illinois
- Maine
- Maryland
- Massachusetts
- Michigan
- Minnesota
- New Jersey
- New York
- Pennsylvania
- Rhode Island
- Vermont
- Virginia

5.3.5 RENVU

RENVU is an international solar distributor headquartered in Mountain View, California. Among its recent products is Isifloating, which is a new product from Spanish company, Isigenere.

> Isifloating uses a patented floating solar technology which enables the covering of partial or entire water surfaces providing several benefits aside from the solar production that will be generated from the system. Isifloating consists of compact injection molded bays that can be nested and stacked for easy transportation. 1MW of racking takes up less than 8 - 40' containers of space. Each bay connects seamlessly to one another to create a continuous overlay on the water surface with modules being mounted 1 to 1 with each bay. This allows for flexibility to add to the system if needed and for the system to react and adapt to changing water levels, weather conditions, and other changing conditions. https://www.renvu.com/Floating-Solar-Photovoltaic-FPV-Systems

5.4 Panel Suppliers

The **global floating solar *panels* market is estimated to be worth 1.6 thousand MW in 2021 is projected to reach 4.8 thousand MW by 2026, registering a compound annual growth rate (CAGR) of 33.7% over the forecast period. Asia-Pacific represents the largest regional segment of the floating solar** *panels market, accounting for an estimated 62.2% share of the global total in 2020.*[125]

> Advantages related to setting up FPV panel plants in comparison with traditional plants are anticipated to boost the FPV panels' market growth. Shifting preference towards renewable energy resources such as solar and wind for power generation, rise in investments for renewable resources of energy, and various government initiatives to encourage solar

> energy are the prime factors driving the FPV panels' market growth. Generally, 1 MW of FPV plant covers water bodies of nearly 7 to 10 hectares, conserves water of 15 Ml, and generates electricity of 1500 MWh. However, **the FPV panels' overall cost is much high [sic] compared to the stationary solar panels, which is estimated to be the key factor hindering the FPV panels' market growth. Additionally, increased demand for energy, rising solar installers' networks, and decreased prices of FPV technology are estimated to augment the growth of the FPV panels' market.**[126]

Demand for FPV panels will also be supported by the fact that FPV panel installation doesn't require large land areas and the FPV projects tend to be cost efficient. Countries like India, China, Germany, the United States, and Japan have emerged as solar powerhouses, and the growing solar energy-based electricity production, in turn, boosted the market growth of FPV panels.[127]

5.4.1. Key Companies

Market participants in the panels segment include: Ciel et Terre, GCL-SI, Hanwha Group, ITOCHU Corporation, JA Solar Technology Co. Ltd., KYOCERA Corporation, LONGi Solar, Pristine Sun Corp., Sharp Corporation, Trina Solar; Vikram Solar Limited; Wuxi Suntech Power Co., Ltd.; Yellow Tropus Pvt. Ltd.; Yingli Solar, Glint Solar, FloatPac Solar, Adtech Systems Limited, Conrexx Technology, First Solar, Inc., Floating Solar Panel UK, Ltd., and others.

5.5 Float Suppliers

This section introduces float suppliers, many of which surfaced during previous sections of this report.

5.5.1 Ciel & Terre

Ciel & Terre commercialized its technology in 2011 and has installed more than 240 floatovoltaic systems around the world and is broadly considered a leader in the FPV market. Its Hydrelio® technology is a patented water-based PV concept made up of modular "lego-type" floaters assembled into rows and made from recyclable HDPE.

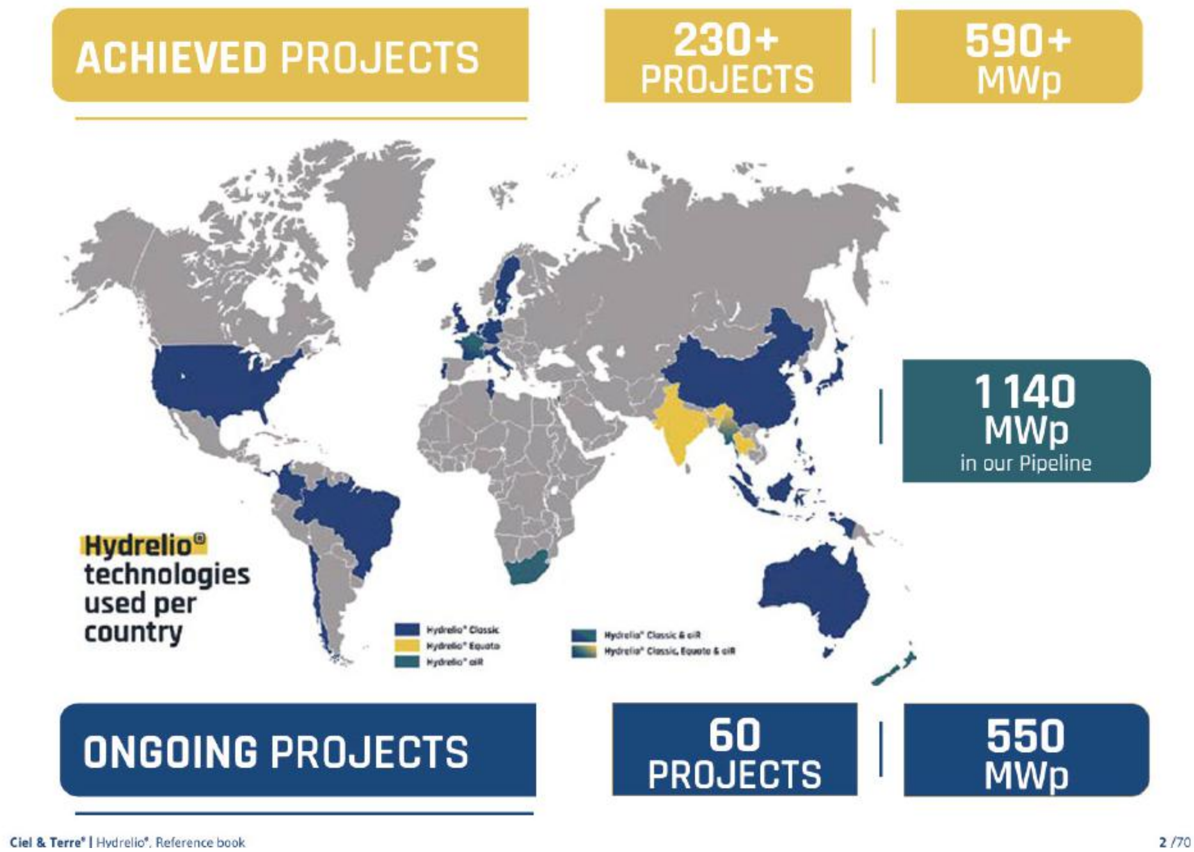

Figure 12: Ciel & Terre Ongoing and Completed Projects

Source: Ciel & Terre[128]

Ciel & Terre launched Laketricity in 2020, and additional partnerships and collaborations are included in the figure below.

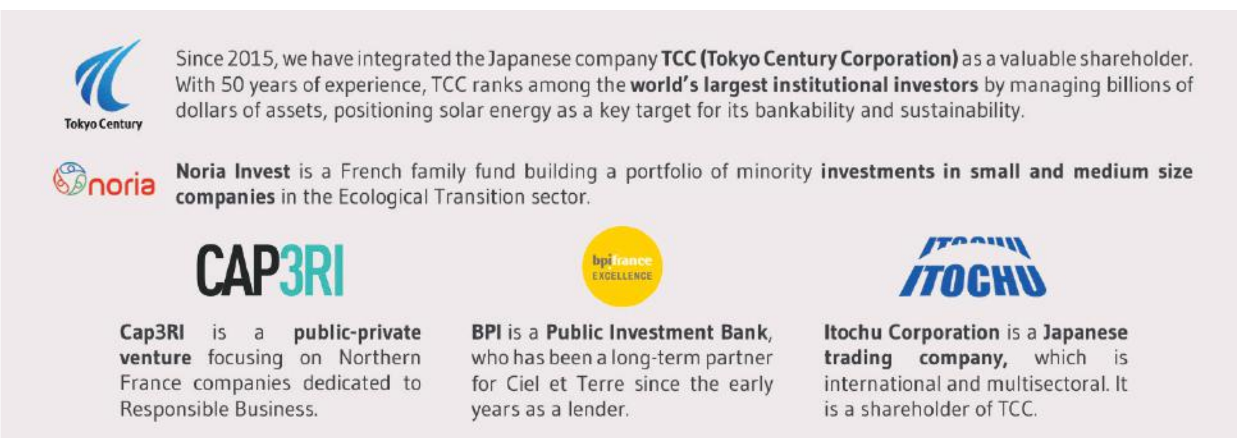

Figure 13: Collaborations & Partnerships[129]

5.5.2 HelioRec

Another French company, HelioRec, introduced ballast to its floater system for FPV. HelioRec recently signed a partnership with Dutch maritime company Van Oord to evaluate whether FPV can be used to charge electric boats, such as unmanned survey vessels.[130]

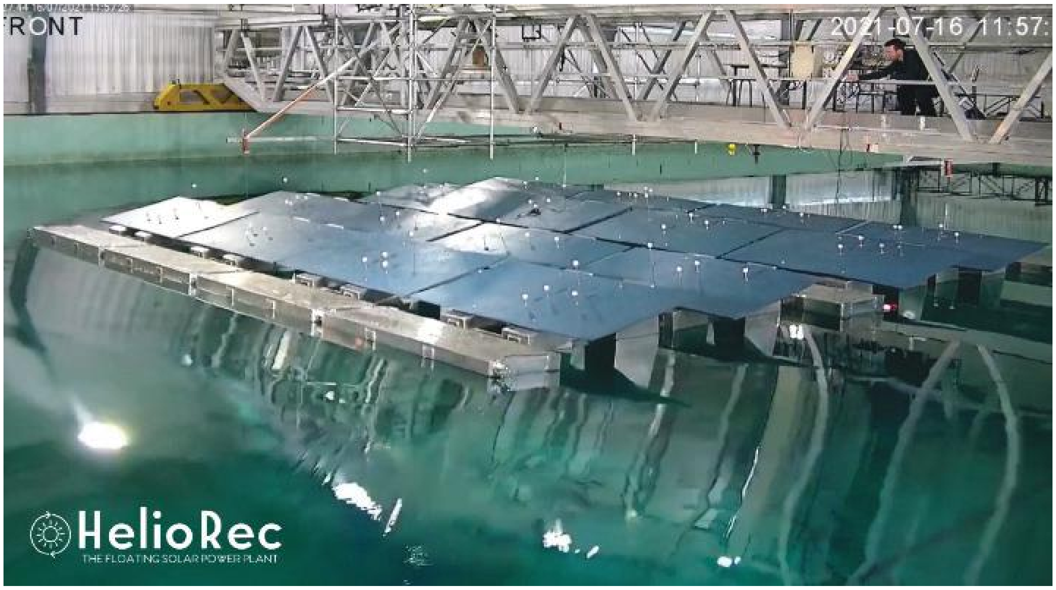

Figure 14: HelioRec Wave Tank Testing

Source: HelioRec[131]

5.5.3 Solar Duck

SolarDuck is a Netherlands-based technology company, founded in 2019, with multiple patents in floating structures. It remains privately held and has received approximately $173K in pre-seed investment funding. The company's focus is on achieving a sustainable future by harnessing abundant and affordable renewable energy. SolarDuck aims to become a leading provider of affordable offshore floating solar solutions. In 2021, the company demonstrated its first 65 kW floating solar array developed with Voyex.[132]

The floating solar platform developed by SolarDuck iscapable of withstanding wind velocity of more than 30 meters per second and wave heights of more than 5 meters, making it suitable for offshore applications. Its efficient mooring layout and durable electrical system offer improved performance and reduced cost. Also, the platform offers better safety and access by providing rigid walkways, safety fences, and low platform motion. Furthermore, the use of offshore grade aluminum, minimal salt deposits on panels, and the small surface floater area significantly reduces maintenance cost. The system has minimal impact on the environment because it allows for air and sunlight transmission. Its easy installation and assembly features make it especially attractive for deployment in offshore environments.[133]

SolarDuck plans to achieve a 15–20% market share in the offshore solar energy market in Europe. The company intends to install more than 300 MW of offshore solar planforms per year for the next 5 years, and is planning to set up pop-up assembly lines to ramp up the commercialization of its technology.[134]

SolarDuck—Investor Dashboard

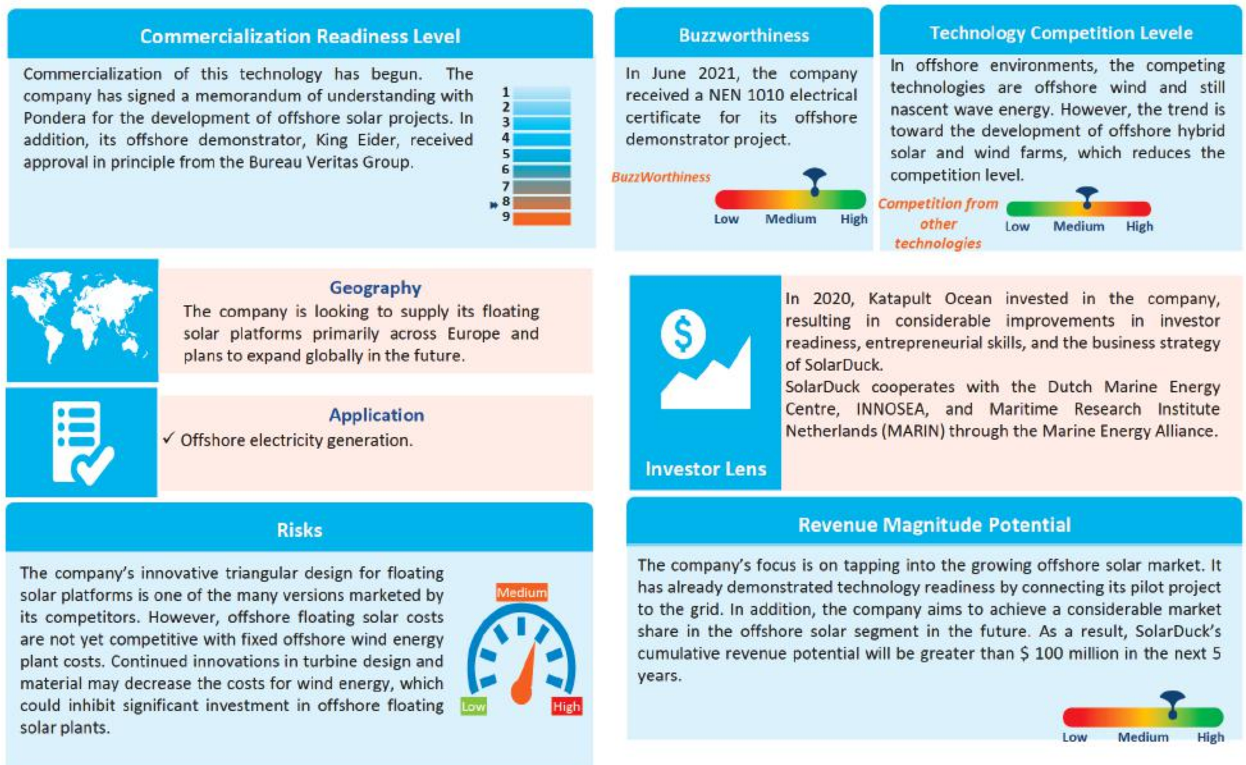

Figure 15: SolarDuck—Investor Dashboard
Source: Frost & Sullivan[135]

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5.5.4 Sungrow Group (Sungrow FPV)

Sungrow FPV is a wholly-owned subsidiary of Sungrow Group, which has 25 years R&D and production experience in the PV industry area. The company has applied more than 100 patents involving floating body, anchor system, inverter & booster floating platform, system operations and maintenance (O&M) and leads Chinese floating photovoltaic (FPV) technology standards. 1.7 GW floating system has been supplied around the world so far. Global market share retained #1 position for four consecutive years.[136]

Founded	1997
Headquarters	Hefei, China
Revenue (2019)	~USD 1.8 billion
Ownership	Public (SHE:300274)
Business Overview	Sungrow Power Supply engages in the R&D, manufacturing, and sale of solar PV inverters. The company's product portfolio includes PV grid-connected inverters, string inverters, central inverters, energy storage systems, monitoring systems, and other solar parts. The company is among the few players to offer the solution of floating power plants. In February 2020, Sungrow Power Supply signed an agreement with YUASA (Japan) to distribute PV and energy storage solutions across Japan. The company has more than 30 distributors globally. A few major subsidiaries of the company are Sungrow Australia Group Pty. Ltd., Sungrow Japan K.K., Sungrow USA Corporation, and Sungrow Power UK Limited.
Products/solutions/services Offered	▪ PV Inverters ▪ Storage Systems ▪ Floating Systems
Geographic Presence	The Americas, Europe, APAC, and MEA

Source: Company Website, Press Releases, and Annual Reports

Figure 16: About Sungrow FPV

Source: MarketsandMarkets[137]

Reprinted with permission from MarketsandMarkets

6.0 Conclusion

This report provides a detailed introduction to floating photovoltaics (FPV), providing both a global and domestic perspective on the opportunities FPV provides for inland lakes, ponds, and reservoirs, as well as for island and coastal communities. Domestic examples are provided for floatovoltaics used for power generation in wastewater treatment, agriculture, aquaculture and in island and coastal communities. The technical challenges associated with the long-term durability and sustainability of these systems are not yet fully understood or addressed. A comprehensive list of problems that need to be addressed is presented, making this field ripe for continued research.

While no set standards for FPV exist in the U.S. at present, DNV, a leading quality assurance and risk management company operating in more than 100 countries[138] has proposed a set of requirements, recommendations and guidelines for design, development, operation and decommissioning of FPV systems, *DNV-RP-0584 Design, development and operation of floating solar photovoltaic systems: Recommended practice*. Both standards and incentives are needed to spur the continued growth of floatovoltaics as an alternative to land-based and building-based solar.

This report also addresses the supply chain and key players in FPV. Vendors that are providing construction services within the U.S. on large scale floating photovoltaic structures are profiled. This report also identifies domestic companies that are providing floats and panels for floatovoltaics, as well as service providers sourcing these components.

Appendix

Table 1: Top 50 Operational Floating Solar Projects 2021 [Global]

Name of Plant/Region	Size (MW)	Country	Operational Year	Floating System Provider	Continent
Guqiao Huainan/ China Coal Subsidence	150.00	China	2019	Sungrow	Asia
Anhui Province	150.00	China	2018	Mixed Chinese	Asia
Yingshang Coal Mining Subsidence Area	130.00	China	2018	Mixed Chinese	Asia
Xinji Huanian / China Coal Subsidence	102.00	China	2017	Sungrow	Asia
Weishan Jining/ China Large-Scale Waters	100.00	China	2018	Sungrow	Asia
Hunan River	100.00	China	2019	Sungrow	Asia
Anhui Cecep, Lianghuai Mining Subsidence Area	70.00	China	2019	Ciel & Terre	Asia
Huancheng Jining / China Coal Subsidence	50.00	China	2018	Sungrow	Asia
Da Mi Hydropower Reservoir	47.50	Vietnam	2019	Narime-Qihua	Asia
Coal Mining Subsidence Area Of Huainan City	40.00	China	2016	Sungrow	Asia
Gia Hoet 1	35.00	Vietnam	2020	NA	Asia
Tam Bo	35.00	Vietnam	2020	NA	Asia
Coal Mining Subsidence Area of Huainan City	32.69	China	2017	Ciel & Terre	Asia
Weishan Jining / China Coal Subsidence	31.00	China	2018	Sungrow	Asia
Bomhofsplas	27.40	Netherlands	2020	PV-Floating / Zimmermann	Europe
Reservoir In Goheung County (Jeollanam Province)	25.00	South Korea	2020	Scotra	Asia

Xinyi/Anhui Province / Coal Subsidence	20.00	China	2016	Sungrow	Asia
O'mega1	17.00	France	2019	Ciel & Terre	Europe
Name of Plant/ Region	Size (MW)	Country	Operational Year	Floating System Provider	Continent
Kloosterhaar	15.70	Netherlands	2020	PV-Floating / Zimmermann	Europe
Sekdoorn	14.50	Netherlands	2019	PV-Floating / Zimmermann	Europe
Yamakura Solar Power Plant	13.74	Japan	2018	Ciel & Terre	Asia
Nij Beets	13.50	Netherlands	2020	PV-Floating / Zimmermann	Europe
Mining Subsidence in Dengkil	13.00	Malaysia	2020	Sungrow	Asia
Industrial Reservoir	12.50	Thailand	2020	NA	Asia
Pei County	9.98	China	2017	Ciel & Terre	Asia
Tynaarlo	8.40	Netherlands	2019	PV-Floating / Zimmermann	Europe
Agongdian Extension	7.67	Taiwan	2018	Ciel & Terre	Asia
Umenoki	7.55	Japan	2015	Ciel & Terre	Asia
Dessel	7.00	Belgium	2020	PV-Floating / Zimmermann	Europe
Hirotani Ike Floating Solar Plant	6.80	Japan	2018	Takiron Engineering	Asia
Jining Gcl	6.78	China	2017	Ciel & Terre	Asia
Queen Elizabeth Ii Reservoir	6.34	UK	2016	Ciel & Terre	Europe
Bui Hydropower Reservior	5.00	Ghana	2020	NA	Africa
Sayreville, New Jersey	***4.40***	***USA***	***2019***	***Ciel & Terre***	***North America***
Sugu #1	4.02	Taiwan	2018	Ciel & Terre	Asia

Jipyeong Province	3.00	South Korea	2015	LG CNS	Asia
Name of Plant/ Region	Size (MW)	Country	Operational Year	Floating System Provider	Continent
Otae Province	3.00	South Korea	2015	LG CNS	Asia
Cheongpung Lake	3.00	South Korea	2017	LG CNS	Asia
Sujang Reservoir Solar Park	3.00	South Korea	2017	Seaflex	Asia
Godley Reservoir Floating Solar PV	2.99	UK	2016	Ciel & Terre	Europe
Oda Ike	2.90	Japan	2018	Ciel & Terre	Asia
Kato Shi (2 Plants in Total)	2.87	Japan	2015	Ciel & Terre	Asia
Narasu Ike	2.80	Japan	2018	Ciel & Terre	Asia
Chip Mong Insee Cement (CMIC)	2.80	Cambodia	2019	Ciel & Terre	Asia
Hyoshiga Ike	2.70	Japan	2019	Ciel & Terre	Asia
Flooded Quarry in Saint-Maurice-La-Clouère	2.70	France	2020	Ako Industries	Europe
Deoku Reservoir, Myeoku Reservoir (3 Plants in Total)	2.70	South Korea	2016	NA	Asia
Katakami Oike	2.60	Japan	2019	Ciel & Terre	Asia
Hiragio Ike Floating Solar Plant	2.60	Japan	2017	Sumitomo Mitsui Construction	Asia
Ichigo Kasaoka Iwano Ike ECO Plant	2.60	Japan	2018	Ciel & Terre	Asia

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