ABS WHITEPAPER

EMISSIONS REDUCTION INSIGHTS FOR OFFSHORE FLOATING PRODUCTION INSTALLATIONS

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ABS

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INTRODUCTION

Floating production installations such as Floating Production Storage and Offloading (FPSOs), Floating Storage and Offloading (FSOs), spars, Tension-Leg Platforms (TLPs), and semi-submersibles are vital units in the offshore oil and gas industry. Attention to these offshore installations is important due to their operational characteristics and potential contribution of emissions and greenhouse gases (GHG). GHGs include carbon dioxide (CO_2), methane (CH_4), fluorinated gases, nitrous oxide (N_2O), nitrogen oxides (NO_x) and sulfur oxides (SO_x). The Paris Agreement, adopted by the United Nations Framework Convention on Climate Change (UNFCCC) in 2015 and ratified by 196 international Parties, aims to limit global warming to well below 2° C and preferably limited to 1.5° C above pre-industrial levels. To achieve this goal, the focus is on finding ways to limit GHG contributions. Depending on a variety of factors, such as operating country, operator, contractor, reservoir, field infrastructure, and unit design, there are many permutations to achieve these goals.

ABS leads the market in sustainability solutions for the marine and offshore industries and proposes methods of providing lower emissions options for floating production installations while respecting the complexity of the operations, the various approaches and techno-economic cases of each situation.

For this paper, current emissions-related challenges associated with floating production installations are discussed. Options such as low carbon technologies, de-manning and renewable power solutions are considered.

Offshore assets can be subject to international, national, and flag state regulations. These are provided to establish a baseline of safety and integrity for operations and are often verified by a local authority or a Classification Society.

The International Convention for the Prevention of Pollution from Ships (MARPOL 73/78) applies to ships flagged by a Party to the Convention or that operate under the authority of a Party. Member flags of the International Maritime Organization (IMO) therefore also follow MARPOL Regulations to protect the natural environment from various types of pollution from ships in international waters.

MARPOL regulations are also applicable to the offshore oil and gas industry. It contains Annexes that cover the prevention of pollution from various ship-borne sources, all of which apply to floating production installations in both marine and industrial services.

MARPOL ANNEX	SUBJECT
Annex I	Prevention of Pollution by Oil
Annex IV	Prevention of Pollution by Sewage from Ships
Annex V	Prevention of Pollution by Garbage from Ships
Annex VI	Prevention of Air Pollution from Ships

Table 1: MARPOL Annex Titles Applicable to Floating Production Installations

Many flag states also adopt MARPOL regulations or similar regulations focused on reducing marine pollution within national exclusive economic zones (EEZ) or on the continental shelf extending beyond the EEZ limit of 200 nautical miles from shore.

Flag states and local governments may enforce specific environmental protection regulations, for example, environmental protection agencies or petroleum industry associations. Some examples of these regulatory requirements include a carbon tax for burning or releasing hydrocarbons, enforced reporting of emission releases, and fines or penalties for exceeding allowable emission limits. It is common for local authorities to regulate emissions to air as well as water pollution such as the release of oil or oily water, chemicals, effluents, sewage, garbage, produced water, or other industrial fluid waste. Countries with established offshore petroleum industries often have regulations or policies in place to protect the local or national ecology from offshore petroleum activities. As member states work towards achieving reduced emissions according to the Paris Agreement and other international drivers, these national or local policies may also reflect more stringent pollution standards or regulations.

The information contained in this whitepaper is intended to help provide offshore asset operators with information to manage the transition to low and zero-carbon futures. This whitepaper is offered solely as a comprehensive set of reference documents and should not in any way be seen as making recommendations, or as an advisory.

OFFSHORE INDUSTRY OVERVIEW

Floating production installations assist in the production and processing of hydrocarbons from drilled wells in the ocean. They can produce oil and gas from subsea well/manifold/templates and process, store, and transfer hydrocarbons. Once produced and processed, hydrocarbons can be stored or exported through pipelines. Stored hydrocarbons are typically offloaded to offtake (shuttle) tankers for transport. Floating production installations are convenient for ocean applications, deep-water operations, and are permanently moored in place.

Figure 1. Spar Installation

CURRENT CHALLENGES

As the search for oil continues in offshore deep-water environments, there is a need to build new installations for these locations. To align with the sustainability goals set by the UN, the first step is examining the challenges faced in creating a low emissions floating production facility unit. Offshore installations operating in remote locations have limitations compared to land-based operations. Often these installations are located offshore in deep to ultra-deep-water depths. The topside production footprint is limited due to space constrictions, which creates obstacles for accommodating additional equipment. Land-based technologies may not be directly applicable for these installations due to this restriction. To make a facility low emissions would require the adoption of new or land-based technologies that can be incorporated on this smaller footprint. Other challenges include:

- Most installations use gas turbines to generate electricity on the installations which contribute to an estimated 80 percent of the CO_2 emissions from offshore activities, a number exacerbated by their low efficiency (Publishers, 2020). Equipment such as compressors utilize the power generated from turbines that are powered by natural gas sourced from reservoirs. Though this method was implemented as an economical option and can provide a useful alternative to flaring excess natural gas, GHGs or other emissions are still generated by this process. The use of emissions capturing technology, or post-combustion emissions treatment processes should be considered.

- Venting typically occurs for cargo tanks with the release of hydrocarbon vapors and harmful gases to the atmosphere. The vented vapor composition depends on the crude oil in the tanks and the processes ongoing. The amount of hydrocarbon that is mixed with the inert gas in the cargo tanks depends on many variables. It may vary from total inert gas with a combination of nitrogen, CO_2, oxygen and traces of NO_x and SO_x to complete hydrocarbon mixtures. Pressurized systems and some loading phases may have higher concentration levels of hydrocarbons. These vapors may be cold vented to the atmosphere if there is no emissions control system implemented. There is guidance in IMO Circular MEPC.1/Circ.680 and the International Convention for the Safety of Life at Sea (SOLAS) pertaining to venting hydrocarbon vapors and tank venting systems. These are heavily regulated and controlled, however, and it is important to focus on operations and technologies that may reduce or eliminate the need to vent these gases.

Figure 2: Tension-Leg Platform

- Flaring from FPSOs contributes about four (4) percent of the world's total flaring and 21 percent of all offshore flaring (Charles & Davis, 2021). Operators may flare excess gas for various reasons including lack of local market capacity or demand, lack of infrastructure and transportation systems, government tax incentives, operational challenges, original design limitations, and changing reservoir performance. Flaring also occurs during exploration well testing with limited well producing data. Following the drilling campaign, companies may choose to conduct a well test to estimate the production levels during development. The excess gas that is produced during these production flow tests is burned on site. During flaring, methane is oxidized to CO_2 and water through combustion. This method is more favorable than venting, as CO_2 is less impactful than methane as a GHG over a longer time span. Methane however may still escape unburned depending on the efficiency of the equipment and gas composition (US Department of Energy, 2019). If there is a limited market demand and lack of capacity for excess, many operators elect to flare. This may often be the case for older floating production installations that have limited capacity for the excess product and limited equipment for processing or storage. Older units were built without the concern for minimizing or optimizing flaring operations. Current flaring volumes based on hull age indicate higher amounts than those that were built within the last 10 years. Other issues include operational challenges such as gas injection start up or emergency scenarios that lead to flaring. (Charles & Davis, 2021).

- Fugitive emissions are defined as unplanned releases of hydrocarbon gases and vapors that may be caused by leaks, faulty equipment, or operational issues except the contribution from fuel combustion. For floating production installations, these can occur during maintenance, piping joint leakage, valve leakage, faulty equipment, relief valve discharge, and flaring operations.
- Water associated with floating production installations such as produced water, hydrostatic testing water, cooling water, desalination brine, and other wastewater (sewage, food waste, bilge, etc.) should be evaluated. Produced water or flow back water comes from oil and gas reservoirs that may contain oil, gas, metals, and naturally occurring radiative material (NORM). After production fluid has been processed by separating the oil, gas, and water, the remaining water should be treated prior to disposal per local regulations.
- Hazardous waste is material that can be harmful to the environment or people. Hazardous materials such as chemicals, trash (gloves, rags, pads), oily water, paints, coatings, and solvents should be either disposed of or recycled properly.
- Storage, processing, and offloading operations can lead to spills, noise generation, and increased carbon footprint from transport.
    a. Spills of hazardous material are harmful to marine life and create issues such as acidization of seawater. Careful operational considerations, proper maintenance of equipment, and comprehensive clean-up procedures should be considered to assist in minimizing damage created by hazardous material spills into the ocean.
    b. Considerable noise is generated from topside processing and supply vessel operations associated with floating production installations. This noise generation is disruptive for marine life with potentially significant repercussions. Marine life flees from noisy areas which shrink their habitats where they have migration routes, food sources and breeding grounds. Populations may decrease and reduce ocean biodiversity. Implementing noise reduction technologies and operational changes can improve these issues.

HOW DO WE GET TO A LOW EMISSIONS FLOATING PRODUCTION INSTALLATION?

Figure 3: Floating Production Storage and Offloading Vessel

AIR EMISSIONS REDUCTION

Operations associated with floating production installations produce a variety of emissions that contribute to GHGs and other emissions. Methane, CO_2, NO_x, SO_x, volatile organic compounds (VOCs) and particulates are found to be released from these units. This section discusses the methods of reduction.

SOURCE	EMISSION TYPE
Production Storing (Venting)	Methane, Hydrocarbons
Gas Turbine (Power Generation, Compression)	CO_2, Methane NO_x, SO_x
Internal Combustion Engine (Generators- fuel dependent)	CO_2, Methane NO_x, SO_x
Boiler, Water Heater	CO_2, Methane NO_x, SO_x
Flare	CO_2, Methane, Hydrocarbons, NO_x, SO_x
Chemicals (processing)	Volatile Organic Compound
Fugitive Emissions (leaks)	Methane, Hydrocarbons

Table 2: Floating Production Facility Air Emission Sources and Emission Types.

GAS TURBINE REPLACEMENT

Gas turbines are extremely convenient and reliable for topside use on floating production installations. The use of reservoir-sourced natural gas also adds to this convenience. Gas turbines however, have high emissions due to their low energy conversion efficiencies which range between 20-35 percent (Office of Fossil Energy and Carbon Management, n.d.). Therefore, an alternative to gas turbines should be considered to reduce these emissions. Electric motors sourced with renewable energy may be an attractive replacement for this energy source. These motors can be paired with a complementary alternative energy source derived from wind turbine or solar panel farms to supply the installation with partial electrification. Or alternatively, the facility could convert to full electrification with the use of shore energy. Though these technologies are at their infant stages of implementation and feasibility, they should be considered as a method of emissions reduction. This is discussed later within this document.

FLARING REDUCTION METHODS

Current options to reduce floating production facility flaring include improved maintenance programs, gas reinjection, equipment upgrades, gas capture and export, and improved flare combustion efficiency if other methods are not applicable.

Improved Maintenance Programs – Implementing a robust operational maintenance program can reduce the various incidents or events that result in the need to flare. Preventative maintenance programs that can identify areas of concern prior to a shutdown or that can keep pressures within safe operating limits will assist in emergency or unplanned scenarios leading to flaring. A maintenance program can also assist in reducing fugitive emissions from any faulty equipment.

Gas Reinjection – There are a few options for injecting natural gas into existing wells. The gas may be pumped into natural porous rock formations such as the originating reservoir or depleted oil or gas reservoirs. This provides an economical way to pressurize the reservoir and store excess gas that would be unsold or otherwise flared. This technology has existed for many decades and may not be a solution for some areas as it is highly dependent on the conditions of the reservoir and regulatory aspects of the area.

Equipment Upgrades – Equipment and piping/pipeline upgrades such as the installation of booster compression modules to debottleneck export lines and installation of a vent recovery system may reduce the need to flare. Other modifications to existing processing equipment can improve equipment reliability and minimize the potential for fugitive emissions.

Gas Capture and Export – The method of capturing gas and sending it to shore has also been utilized in efforts to reduce flaring. Units that have performed flared gas capturing have been able to reduce flaring by 44 percent. Other operators have experimented with using excess gas to produce hydrogen or ammonia (Charles & Davis, 2021). Other technologies such as compressed natural gas (CNG), gas to liquid (GTL), and liquefied natural gas (LNG) can be considered depending on the availability of space on the facility. These technologies require additional equipment and exporting infrastructure that are not easily implemented on existing dedicated oil and gas floating production installations. More information on these topics can be found in the sustainability publications and whitepapers specific to gas topics listed in the ABS publications section of this document.

Flare Combustion Efficiency – This is a measure of the effectiveness of the combustion process to oxidize the gas/fuel. Proper maintenance and design of the equipment and associated piping can assist in improving the flare combustion efficiency. A system with an efficiency of 80 percent can emit up to six (6) times the CO_2 equivalent than that of a 97 percent efficient system (Charles & Davis, 2021).

Gas Lift – A type of artificial lifting process to increase production from a well that can be considered an alternative use of flaring gas. Artificial lift is a process used to bring oil reserves to the surface that otherwise would not be produced unassisted. This is done by injecting gas into the production tubing of a well to reduce the hydrostatic pressure of the fluid column by installing a downhole pumping system such as an electrical submersible pump or hydraulic pump. Gas lift occurs as injected compressed gas is pumped down the casing tubing annulus of a producing well into numerous entry points called gas-lift valves. As the gas enters the valves at various stages, bubbles form which lightens the fluids and lowers the pressure, which increases the production rate of the well. Once the effluent is brought to the surface, it must be processed to separate the oil and gas. Though this method does not significantly reduce flaring, it is an alternative use of flaring gas to eliminate the need to externally source gas for this purpose.

VENTING AND FUGITIVE EMISSIONS

Venting gas from hulls may also directly emit methane, hydrocarbons and other gases to the atmosphere. Venting can occur intentionally when inert gas that is mixed with VOCs is released, or unintentionally due to leakage. Inert gas, in this context, is any gas that does not support combustion and is used to fill the void in cargo or other tanks. The traditional approach is to pump exhaust gases from the ship's boilers into the tanks as a blanket, or through a dedicated inert gas generation system. As cargo is loaded into the tanks, the gas is routed to a vent main and into the atmosphere. As today's environmental focus is emissions, tank vapor recovery should be considered to minimize the release of GHGs and other pollutants. The latest development is utilizing associated gas (hydrocarbon gas) to fill the cargo tanks. The associated gas can be recaptured and either recycled or sold to the market providing a more favorable alternative to venting. Equipment such as an ejector can be installed to recover the vent gas to a recycling system. More information can be found on ejectors in the available technology section of this paper.

From a design standpoint, the following should be considered to minimize unintentional leakages.

- Improve the type and/or strength of the mooring/station keeping system to endure expected metocean environments. Conditions such as strong winds or storms can contribute to the accidental release of gas from a hull.
- Improve the strength of the hull to minimize repairs and prevent leaks due to fatigue cracks or deck damage.

Maintaining the equipment and piping of the floating production installation along with these design considerations will also minimize fugitive emissions by reducing the potential for leaks and limiting start-up and shut-down operations.

Download the ABS *Carbon Capture, Utilization and Storage* whitepaper from www.eagle.org.

CARBON CAPTURE

The industry is focusing on developing new technology or adapting existing onshore technology. Currently for an existing floating production facility, a post-combustion carbon capture system would be most attractive as it requires minimal retrofitting. Proposed concepts use amine-based solvents, such as monoethanolamine (MEA), of varying concentrations. A recent study trialed the concept of installing a marine carbon capture storage unit on a very large crude carrier to investigate onboard production of methane or methanol by combining hydrogen from water electrolysis with the captured CO_2. Results yielded a capture rate of 86 percent with the installation of four towers for exhaust cooling, CO_2 absorption, exhaust treatment, and CO_2 regeneration along with required liquefaction and storage installations. More information can be found on this topic in ABS *Carbon Capture, Utilization and Storage* whitepaper.

REINJECTION

Gas reinjection is accomplished by pumping natural gas or CO_2 into natural porous rock formations such as depleted oil or gas reservoirs, coal beds, or saline aquifers. This can be a method for enhanced oil recovery (EOR) to stimulate the reservoir for additional returns or a method of disposal for the natural gas or CO_2. As unmarketable natural gas is typically flared, reinjection provides an alternative. Reinjection also provides a permanent storage option once captured as an emissions reduction option.

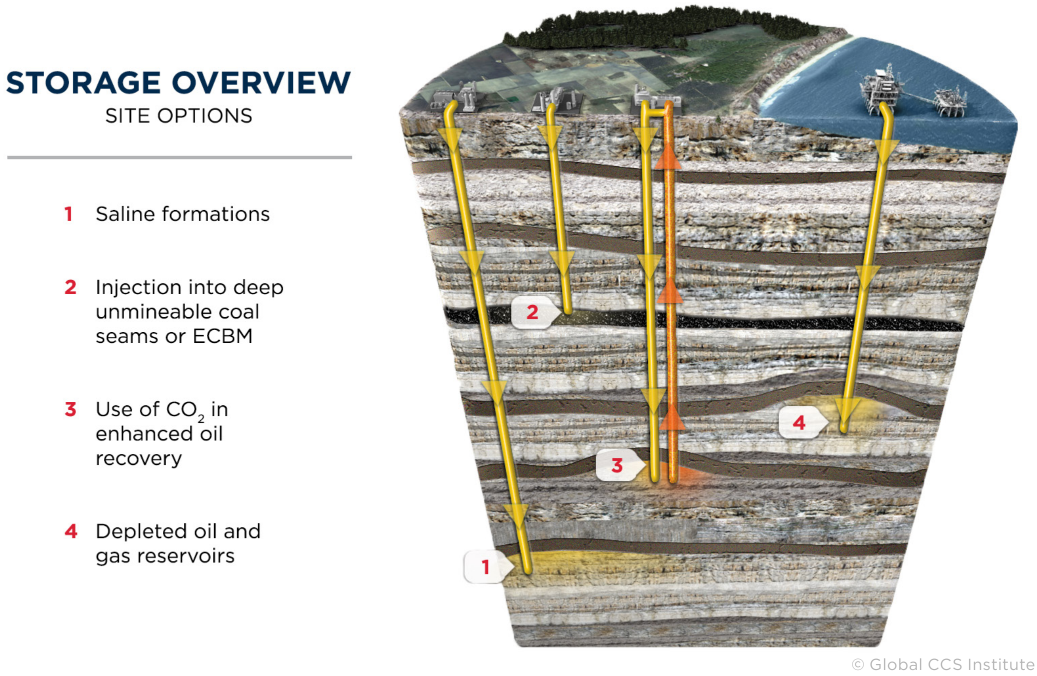

Figure 4: CO_2 Injection Storage Options

CO_2 may be injected and stored deep underground as a disposal method or as an EOR method. There is potential for storage in many depleted reservoirs or unmineable coal beds globally, provided that the formation conditions are satisfactory for such use. Deep saline aquifers are also potential locations for long term CO_2 storage. Considerations should be given in the selection of injection wells that can endure CO_2 injection pressures, temperatures, and chemical properties. More information can be found on this topic in ABS *Carbon Capture, Utilization and Storage* whitepaper.

REDUCTION IN DISCHARGE TO SEA

There are a variety of discharges that are admitted to sea that originate from floating production facilities operations. The following table summarizes the discharge per source.

DISCHARGE	SOURCE
Produced Water, Hydrocarbons, Chemicals	Production/Processing, Pipelines
Drainage Water, Contaminated Water	Vessel
Produced Sand	Production/Processing
Hydrocarbons (liquid, gas)	Storage Accidental Release
Sewage and Food Waste	Vessel/Manning
Hydraulic Fluid	Control System Process and Subsea System
Consumable Chemicals (VOC)	Maintenance
Treatment Chemicals (hotel, cooling, process)	Cooling Water
Others: Noise	Vessel Operations/Transport

Table 3: Discharge to Sea with Corresponding Source

PRODUCED WATER

Produced water is a large corrosive byproduct to oil and gas processing on floating production installations that generally contains salt, dissolved solids, suspended oil, grease, dissolved hydrocarbons, and metals. The water is produced along with oil and gas that is brought to surface and treated through the processing equipment. Gravity separation, flotation separation, and hydrocyclone technology are the standard treatment methods to process produced water. Handling and disposing of very large volumes of produced water is among the major issues these units face. The two forms of disposal are to discharge to sea after treatment or re-inject into the reservoir. Discharge to sea is strictly governed at a local and international level. Primarily, regulations typically allow for less than 30 ppmv oil in water content. Though this number varies from location, some local regulatory agencies have more stringent requirements, and the industry is attempting to lower this requirement further.

Reinjection of the produced water into the reservoir is a more modern but less common approach. The water that is injected must be treated to prevent bacterial growth in the well and is mixed with sea water to increase the volume. For this operation, there are several restrictions and challenges that need to be taken into account, such as produced water reinjection may not be a solution for some areas as it is highly dependent on conditions of the reservoir.

OTHER DISCHARGE

Other discharge to sea such as drainage water, contaminated water, produced sand, chemicals and sewer and food waste have similar processing requirements prior to discharge to sea. Special attention should be given to equipment maintenance and routine inspections to prevent unplanned leaks and other failures leading to emissions.

NOISE POLLUTION

As an invisible threat to marine life, noise pollution can cause major disturbances and potentially deadly outcomes. Organizations like the International Maritime Organization (IMO) and the European Union (EU) are already making efforts to address concerns about underwater noise pollution affecting marine life and habitats. Sound can travel significantly further in water than in air, reaching distant ecosystems where marine life can be driven away from their natural habitats from industrial noise pollution. Special consideration should be given in identifying locations of operation in fields away from marine life natural habitats or migrating routes. Analysis and risk assessments can be performed to identify the impact to sea life prior to operations. More information can be found on underwater noise in ABS *Guide for the Classification Notation Underwater Noise and External Airborne Noise*.

LOW-CARBON POWER

There are various technologies that have been introduced to the marine industry for alternative use of energy, renewable energy, electrification, and power reduction. The following technologies listed have been researched, trialed, and/or implemented in the goal of providing a more efficient operation or a method of energy outside of traditional marine fuel oil.

Figure 5: Offshore Wind Turbines

COGENERATION

Cogeneration or combined heat and power (CHP) is a method of improved energy efficiency. It is the concurrent production of multiple forms of energy from one fuel source. The two forms of energy produced in this process are typically thermal (heating) and electric. The system is built by a prime mover such as a turbine, fuel cells or piston engine. If applicable, the prime mover is coupled with an alternator and converts the chemical energy stored in the fuel to electrical energy. As electricity is produced, heat is also created. The heat may be captured and applied to other applications. Cogeneration is efficient in converting energy which is more sustainable and economic. The technology and equipment can be implemented quickly with few geographic limitations. Natural gas, diesel, and hydrogen can also be used as the fuel. Gas turbines can be used for cogeneration technology due to their high-temperature exhaust which can generate process stream at conditions as high as 1,200 psig and 900° F or can be directly used for heating or drying. Though combustion emissions are still produced through this process, this combined method is a more efficient use of the produced gas on floating production installations (Yuksel, 2020).

ELECTRIFICATION

Electrification of floating production installations directly allows for a low-carbon solution by sourcing power from renewable energy or by connecting to a grid of cleaner power. Norway sets an example by utilizing hydroelectric power paired with the highest carbon tax globally to advance their decarbonization efforts. Electrification can lower emissions, reduce maintenance and lower fuel requirements. Some challenges can hinder a move to electrification. For example, retrofitting existing installations can be difficult and costly, renewable energy can be intermittent and require backup generation, there may be limited footprint for equipment, and additional weight restrictions. A few methods to routing power to floating production installations include shore power, offshore wind power, solar, floating buoys, subsea charging stations and new battery technologies.

Power from shore is a concept widely being discussed and implemented for offshore installations. If a facility is located near shore, power directed from an on-land facility can be considered. Currently, both AC and DC current technology is being utilized for offshore platforms. The supply reliability and availability are very high for shore-sourced power which provides advantages such as a higher energy efficiency than offshore renewable power generation. The elimination of gas turbines could also benefit from reducing the headcount for maintenance oversight. This would also help in reducing the carbon footprint and costly logistics of air-lifting trained personnel and parts onto the platform.

ALTERNATIVE ENERGY

Offshore wind power can be a complementary source of renewable energy for electrified floating production installations. This technology can be divided into wind power generation systems that are floating or bottom fixed. Floating systems are highly anticipated as they can be located farther offshore than bottom fixed systems. Structures such as TLP and semi-submersible platforms can be converted to support wind turbines for these further offshore locations. TLPs can be used with the 10MW or larger turbines and offer stability with minimal mooring footprint. Semi-submersibles are better suited for locations where the seabed is not suitable for TLP foundation piles. Typical designs of offshore floating wind structures have three columns connected by upper and lower box girders with a turbine installed directly on top of one column. The lower box girders act as a pontoon and strength members which provide enough buoyancy to float once the wind turbine has been installed. These structures can be outfitted with a wind turbine in shallow water depths which reduces the cost of installation in docks and piers versus at sea. The wind turbine can be installed quayside and towed to site for installation. Maintenance can be performed offshore or towed back to quayside once the turbine has been de-installed. More information can be found in the ABS publications ABS *Offshore Wind Report Safety and Compliance Insights: Understanding U.S. Regulations for Offshore Wind Vessels* and the ABS *Guide for Building and Classing Floating Offshore Wind Turbines*.

Figure 6: WindFloat Atlantic Floating Foundation for Offshore Wind Turbines

Offshore solar energy is a developing concept for power to offshore structures utilizing solar photovoltaic (PV) panels. The technology has been developed and implemented around the world. For larger marine application, a dedicated island creating a floating solar power plant utilizing PV panels has been proposed. These floating islands could be located near a floating production facility site to provide electric renewable power. For smaller applications, the solar panels can be mounted and installed on the vessel. More information can be found in ABS G*uide for Hybrid Electric Power Systems for Marine and Offshore Applications*.

Hydrokinetics is power produced with motions of fluids. For offshore environments, the use of tidal currents or the power of waves is used to generate electricity at sea. There are three types of wave energy devices used to convert wave power into electricity which are: wave profile devices; oscillating water column devices; and wave capturing devices. Though these are established concepts and shallow water designs, the creation of an offshore hydroelectric power station with the capability to power a floating production facility is still limited. The challenges associated with these devices include costly or difficult maintenance and repair, and exposure to harsh weather conditions. The hydrokinetic installations are typically tethered, so installation and harsh environments limit them to shallow water locations.

Figure 7: 3D Rendering of Subsea Tidal Turbines

- Wave Profile Devices – The ocean's waves contain tremendous energy potential. Wave profile devices typically float on or near the surface of the sea so they may move in response to the wave motion. Submersible devices move vertically by the variations in underwater pressure as the waves pass by. Floating buoys are an example of a water profile device currently being utilized for offshore electric power. A floating buoy contains a buoy at the surface and a large heavy metal plate either moored or fixed to the seafloor. In between the buoy and plate, there is a large hydraulic cylinder with a piston inside. The piston is pushed and pulled as the buoy rises and falls with wave height, which forces hydraulic fluid through a hydraulic motor and runs the electrical generator.
- Oscillating water columns utilize the oscillation of the seawater inside a chamber or hollow opening. The semi-submerged chamber or hollow opening maintains a trapped air pocket above the water column. As waves occur, the column acts like a piston forcing the trapped air to oscillate. The compressed air is pushed through a turbine generator to produce electricity.
- Wave capturing devices are also known as overtopping wave power devices. This is a shoreline or near shoreline technology that captures wave energy by converting potential energy to electricity. The device sits at the surface of the sea and is either fixed or tethered to the seabed. The device uses a ramp to elevate part of the incoming waves above the natural sea level. As the wave enters the structure's ramp, it sits in the raised water impoundment reservoir as potential energy. This energy is harvested by utilizing gravity as the water returns to sea via a low-head Kaplan turbine generator which is located at the bottom of the reservoir. These devices can also be located at the shoreline where the waves are channeled through a horizontal chamber.

DE-MANNING

Traditional floating production installations typically house operating personnel with some arrangements holding over 120 people. With personnel housing, the units must utilize space for living accommodations, provide food, housekeeping, and transportation to and from the site. Although the energy, consumables, and carbon footprint associated with these activities may be small compared to the overall facility, it is not negligible and must be considered. Some remote operations and de-manning technologies can lower the consumption of resources for these units requiring personnel onboard. Offshore installations have the potential for reduced manning or remote control and/or autonomous operation to reduce operating costs and consolidated management. Operators can consider one of the offshore facility categories listed in the table below for levels of autonomy and control methods applicable to offshore installations.

OFFSHORE FACILITY CATEGORY	DEGREE OF AUTONOMY*	LEVEL OF CONTROL			
		MONITORING	ANALYSIS	DECISION	ACTION
Manned - Conventional	1 (Manned)	Human On Board and/or Remote	Human On Board and/or Remote	Human On Board	Human On Board
Reduced Manning	2 (Remotely Controlled with Human on Board)	Human On Board and/or Remote	Human On Board and/or Remote	Human On Board and/or Remote	Human On Board and/or Remote
Unmanned - Remote Controlled	3 (Remotely Controlled with No Human on Board	Remote and/or Machine	Remote and/or Machine	Remote	Remote

Table 4: Levels of Autonomy and Control Methods
**This category is similar to IMO autonomous vessel categorization*

Some of the enabling technologies introduced in recent years include remote monitoring of structures and machinery, remote control and operation of process and support installations, and remote inspection and maintenance capabilities including the use of robots, drones, or closed-circuit TV. More detail on reduced manning is available in ABS *Reduced Manning on Offshore Facilities and the Guide for Autonomous and Remote-Control Functions.*

WASTE MANAGEMENT

Offshore floating production installations produce industrial and natural waste such as acids, aerosols, chemical mixtures, trash, oily solid waste, oily water, radioactive waste, etc. A list of waste found on floating production installations include:

WASTE CATEGORY	EXAMPLES
Acids/Alkali	Cleaning or Workover Acids
Chemical Mixtures	Anti-Scalents, Glycol, Contaminated Catalysts, Processing Fluids, Solvents
Oily Solid Waste	Rags, Filter, Gloves, Etc.
Oily Water	Slop, Tank Bottom Sludges
Radioactive Waste	NORM
Spill Absorbents	Oil Contaminated Pads
Human-related Waste and Trash	Food, Plastic Bags, Wrappings, Bottles, Etc.

Table 5: Floating Production Facility Units Waste Categories and Examples

There are limited methods available for dealing with waste from these units. Operators must plan to prevent, reuse, recycle, recover and dispose of all associated waste. Planning from a design standpoint to anticipate waste categories can assist in proper identification, quantification and disposal. A waste management plan should be established with information on waste segregation for onshore or offsite treatment. Space to store and facilitate transport should be allocated for the segregated waste containers. Shredders, compactors and other equipment can be considered to minimize waste volumes. Special consideration should be taken as some local regulations require segregated recycling collection and waste management.

SPILL PREVENTION

Preventing accidental release of hazardous fluids to the environment is an important aspect of floating production facility units. Special design and operational considerations should be taken of the unit to reduce the risk of spills. These considerations include: (Norsok, 2017).

- Topside equipment layout including a space for spill containment and control equipment
- Leak detection systems installed for offloading and subsea production systems
- Level transmitters or level gauges with alarms installed in storage tanks to indicate leaks or overflow
- Proper drainage sizing and pump configuration with automatic change over
- Sample points designed to prevent fluid spill into the sea
- Processing equipment designed with appropriate barriers
- Loading and offloading hoses properly stored to prevent wear and tear when not in use

AVAILABLE TECHNOLOGY

Post-combustion emissions-reducing technology such as scrubbers, selective catalytic reduction, exhaust gas recirculation, oxidation catalyst and particle filters are being introduced to the industry to reduce air emissions and pollutants. However, these may be technologies that are not easily installed and implemented onto floating production installations. The technology concepts introduced in the alternative energy section of this whitepaper provide an outlook in replacing the traditional gas-powered turbines found on these units today.

CARBON CAPTURE

The International Maritime Organization (IMO) has pledged to reduce the CO_2 emissions from the global fleet (on a "per transport work" basis) by at least 40 percent by 2030 and 70 percent by 2050 and to reduce GHG emissions from shipping by at least 50 percent by 2050, compared to 2008 levels. This ambitious target has introduced a variety of carbon capture technologies to tackle carbon emissions. The three major approaches to capturing carbon include direct source carbon capture (from exhaust/flue gas or direct air), pre-combustion, and oxy-fuel combustion. Post-combustion technology and CO_2 injection are applicable technologies for floating production installations. More information can be found on this topic in the ABS *Carbon Capture, Utilization and Storage* whitepaper .

ENERGY AND PERFORMANCE MONITORING

Monitoring parameters such as energy efficiency on a floating production facility units can benefit the operator in identifying key areas for improvement which result in satisfying sustainable goals. If the vessel can collect, interface with personnel, and report efficiency and performance metrics of emissions, main and auxiliary engine fuel consumption and voyage planning trends can be analyzed for improvements or deficiencies. An approved facility energy efficiency management plan should be implemented for sustainable units. The goal is to examine real-time performance with defined efficiency KPIs to provide a more efficient operation and reduce carbon footprint through efficiency awareness.

There are no specific functional requirements relating to this monitoring, however, tracking trends can indicate whether implemented applications provide improved performance. More information can be found on this topic in the ABS *Guide for Sustainability Notations*.

VENT GAS RECOVERY

The use of ejectors to recover tank blanketing gas into a recycling system is an available technology that can be applied. An ejector is a static device that channels high-pressure working fluid (liquid or gas) through a jet nozzle into a tube that narrows and then expands in a cross-sectional area. This converts the pressure energy into velocity and produces a vacuum using the Venturi effect. A low-pressure region is created in the narrowest section which will create a suction chamber that pulls gas from the low-pressure flow. This technology can be installed to recycle gas instead of venting to the atmosphere or flaring (Transvac, 2021).

ABS SUPPORT

ABS can provide guidance to owners, operators, shipbuilders, designers and original equipment manufacturers as they consider practical implications and risk assessments for a lower emissions floating production installation. Services offered by ABS include:

- Qualification of new technology
- Novel concept approvals
- Advancing floating production facility technologies by improving safety and performance with digital twins, cyber security strategies and remote technologies
- Providing digital solutions, such as My Digital Fleet™, that support business sustainability and improve asset management
- Strengthening FPSO standards with industry's first FPSO guidance documents, and continuing to provide the most complete suite of technical guidance for FPSOs
- Continuing to maintain strong partnerships with coastal state regulatory agencies and flag administrations
- Participation in industry standards committees for life extension of floating offshore installations

SUSTAINABILITY NOTATIONS

Recognizing the industry's interest in achieving the United Nation's adopted Sustainable Development Goals, ABS produced the ABS *Guide for Sustainability Notations*. This Guide provides a stepwise approach for installations to meet the Environmental, Innovative, and Human Elements requirements contained in the strategic goals set. The guide focuses on sustainability aspects of vessel design, outfitting, and layout that can be controlled, measured, and assessed. These include:

- Pollution and waste
- Coastal and marine ecosystems
- Energy efficiency and performance monitoring
- Low- and zero-carbon fuels
- Human-centered design
- Asset recycling

APPENDIX 1 — ABS PUBLICATIONS

ABS *Guidance Notes on Risk Assessment Applications for the Marine and Offshore Industries*, April 2020.

ABS *Guide for Hybrid Electric Power Systems for Marine and Offshore Applications*, October 2020.

ABS *Rules for Building and Classing Marine Vessels*, January 2021.

ABS *Advisory on Decarbonization Applications for Power Generation and Propulsion Systems*, April 2021.

ABS *Offshore Wind Report Safety and Compliance Insights: Understanding U.S. Regulations for Offshore Wind Vessels*, June 2021.

ABS *Setting the Course to Low Carbon Shipping – 2030 Outlook/2050 Vision*, June 2019.

ABS *Setting the Course to Low Carbon Shipping – Pathways to Sustainable Shipping*, April 2020.

ABS *Setting the Course to Low Carbon Shipping – View of the Value Chain*, April 2021.

ABS *Sustainability Whitepaper: LNG as Marine Fuel*, June 2020.

ABS *Sustainability Whitepaper: Ammonia as Marine Fuel*, October 2020.

ABS *Sustainability Whitepaper: Methanol as Marine Fuel*, February 2021.

ABS *Sustainability Whitepaper: Biofuel as Marine Fuel*, May 2021.

ABS *Sustainability Whitepaper: Hydrogen as Marine Fuel*, June 2021.

ABS *Sustainability Whitepaper: Carbon Capture, Utilization, and Storage*, August 2021.

ABS *Guide for Sustainability Notations*, December 2020.

ABS *Whitepaper: Reduced Manning on Offshore Facilities*, June 2021.

ABS *Guide for Autonomous and Remote Control Functions*, July 2021.

ABS *Guide for Crew Habitability on Offshore Installations*, February 2016.

ABS *Guide for Building and Classing Floating Offshore Wind Turbines*, June 2020.

APPENDIX 2 — REFERENCES

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