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Estimated air emissions savings from partially removing and reefing the jacket of a large California oil and gas platform

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ABSTRACT

This paper estimates the potential emission savings that could be achieved if the jacket of a large California oil and gas platform is partially removed and converted to an artificial reef rather than fully removed. The platform selected for study is Platform Harvest which is located on the federal Outer Continental Shelf (OCS) offshore Point Conception in Santa Barbara County, California. Platform Harvest, a large steel jacketed structure located in 675 feet of water, ceased production in 2015 and plans are now being developed for removing the structure. Under the partial removal option, the upper sections of the jacket would be removed to a depth of 85 feet below the ocean surface with the remainder left *in-situ* to serve as an artificial reef. The full removal option involves removing the entire jacket by cutting the jacket legs and piles off 15 feet below the seabed, cutting the jacket into sections for lifting by a heavy lift vessel, and transporting the jacket components on cargo barges to shore for recycling or disposal. The results of the study show the partial removal jacket option would result in a 10-fold reduction in emissions of nitrogen oxide, sulfur dioxide, green-house gases, and other criteria pollutants as compared to the full removal option.

1. Introduction

There are currently 27 oil and gas platforms located offshore California, four in state waters which extend from the coastline to a distance of three nautical miles offshore, and 23 on the federal OCS (Fig. 1). The OCS platforms are located in water depths ranging from 95 to 1198 feet, and with the exception of Platform Gina (1380 tons), have total estimated removal weights ranging from 4000 to 86,500 tons[1] (TSB, 2016). Platform Harvest, which has a combined topside and jacket weight of 29,040 tons, is one of more than a half dozen platforms offshore California likely to be decommissioned and removed within the next five to six years (2021–2026). Other platforms likely to be decommissioned within this time-period are Platforms Hermosa, Hidalgo, Gail, and Grace on the OCS, and Platform Holly in state waters (Smith and Byrd, 2020). The majority of these platforms have been shut-in since May 2015.

The platform decommissioning process will consume large quantities of energy and impact air quality in a region where air quality is a crucial concern for state, federal and local regulatory agencies, as well as the public. The vast majority (80–90 percent) of the emissions will be generated offshore by diesel powered engines on vessels and equipment used to dismantle the platforms and transport the materials to shore for recycling or disposal. The types of vessels involved include large heavy lift vessels (HLV's), smaller crane barges, dive support vessels, anchor handling vessels, supply vessels, tugs and cargo barges, and crew boats. There also will be impacts onshore at port-side facilities where platform materials are offloaded and processed for transport to scrap-metal processing facilities (smelters) or landfills for disposal.

The commencement of large-scale oil and gas facility decommissioning projects offshore California will have the potential to adversely affect air quality in the coastal areas of the four counties (Santa Barbara, Ventura, Los Angeles, Orange) that lie adjacent to the offshore oil and gas platforms. The quantity of energy consumed and associated air emissions released during future decommissioning projects would be significantly reduced if platform jackets are partially removed and reefed *in-situ* rather than fully removed. The California Marine Legacy Act (AB 2503), enacted in 2010, allows OCS oil and gas platform jackets to be partially removed and converted to an artificial reef managed by the California Department of Fish and Wildlife if

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[1] All weights cited in this paper are reported in short tons (2000 pounds).

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certain conditions are met. One of the conditions requires that the creation of the reef results in a *"net environmental benefit"*.

In 2017, Senate Bill 588 (SB 588) was introduced in the California Senate to streamline the permitting process set-forth in AB 2503 and expand the criteria for determining *"net environmental benefit"* by including consideration of air quality and greenhouse gas emissions (Senate Rules Committee, 2017; Hertzberg, 2017). The bill did not pass out of committee in 2017 and as of June 2020 no further legislative action on the bill had been taken. As decommissioning projects move forward offshore California, new bills to streamline AB 2503 and include air emissions in the "*net environmental benefit*" determination will likely be introduced in the California Senate or Assembly.

1.1. Platform decommissioning methodology

Fig. 2 shows the typical components of a steel-jacketed oil and gas platform. The two major components of a platform are the topsides and the supporting jacket structure. The topside is the upper portion of the structure that includes decks where the drilling and processing equipment and accommodations for crew are located. The jacket is the steel frame which supports the topside. The jacket is secured to the seabed by piles that are driven through the legs of the platform or through skirt-piles attached to the base of legs of the platform.

There are several methods that can be used to remove an offshore oil and gas platform. The method selected to remove platform topsides and jackets depends on a number of factors including the size and type of structure, the availability of HLV's and equipment, proximity to onshore materials processing and disposal facilities, and overall costs. The three primary removal methods used are commonly referred to as (1) piece small, (2) reverse installation, and (3) single lift. Piece small involves removal of the topsides in small pieces weighing less than 100 tons in general. The small pieces are lifted onto a supply boat or transport barge by existing platform cranes or temporary cranes installed on the platform or on nearby crane barges. Piece small removal may also be applied to small jackets, but it is not practical for larger structures. For these the jackets will need to be removed in a single lift or cut into sections for removal by a heavy lift vessel/derrick barge (HLV/DB). Reverse installation, also referred to as piece large, involves removing topside sections (modules) in reverse of the order in which they were installed. Reverse installation can also be used to remove smaller jackets which can be lifted in a single piece by a conventional HLV/DB. Larger jackets must be removed by using mechanical and abrasive cutting tools to cut the jacket into sections for lifting by an HLV/DB. The lifts can range in size from as little as a few tons to more than 10,000 tons. Single lift may also involve using a large HLV/DB to lift the topsides in a single unit if it is designed to allow that. One such HLV, the *Pioneering Spirit*, which has been used to remove large topsides in the North Sea, is designed to lift topsides weighing up to 53,000 tons and jackets weighing up to 27,500 tons in a single lift (Offshore Magazine, 2017). The use of the single lift method

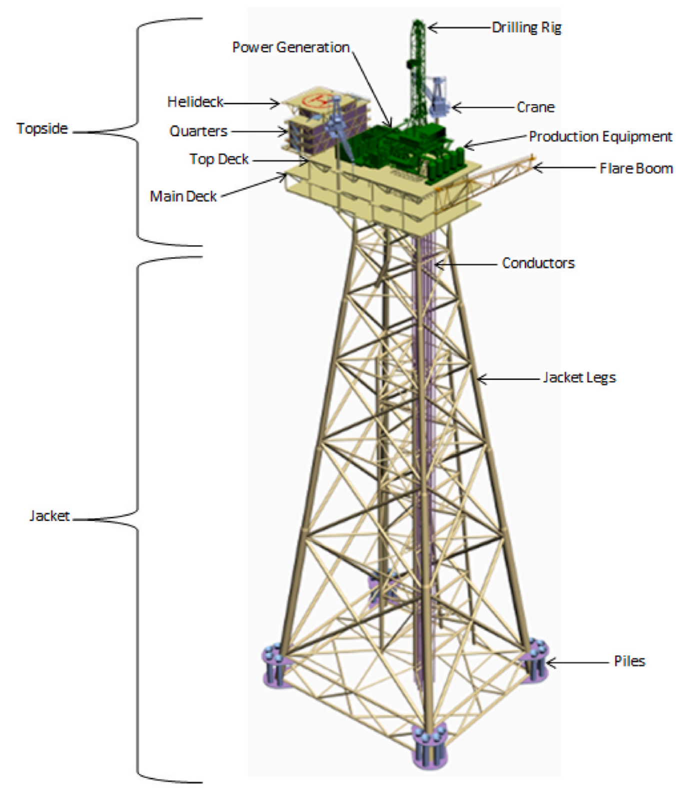

Fig. 2. Typical components of a fixed jacket oil and gas platform..

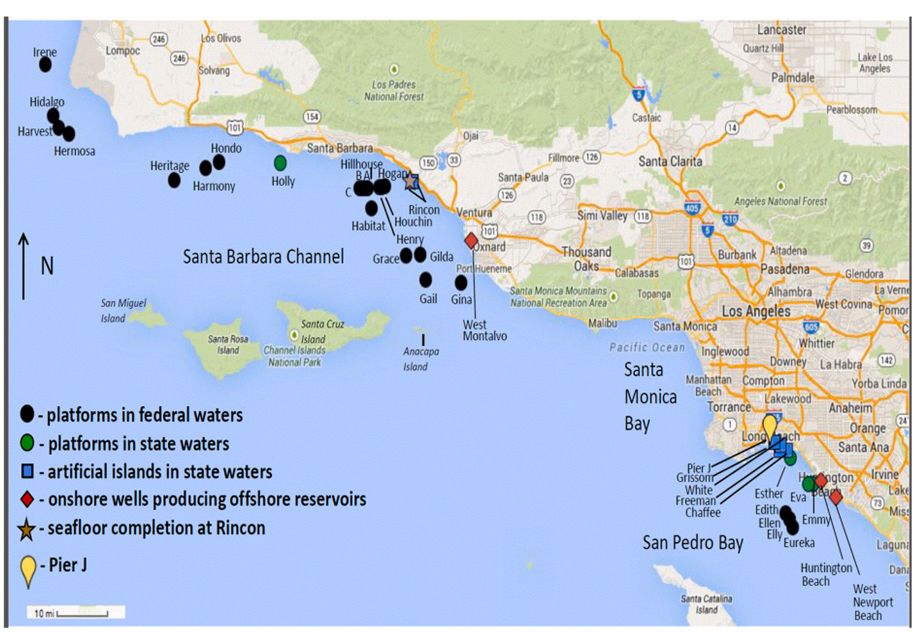

Fig. 1. California offshore oil and gas Facilities.
(Source: Lawrence Berkeley National Laboratory, 2015).

requires access to deep-water ports and disposal yards where the topsides and jackets can be towed and offloaded, which are lacking on the U.S. west coast.

1.2. Platform Harvest

Platform Harvest is a large eight-leg, steel jacketed oil and gas drilling and production platform located on the federal OCS about seven miles offshore Point Conception in Santa Barbara County, California (Figs. 1 and 3). The platform is located in 675 feet of water and the combined weight of the topsides (9024 tons), jacket and piles (20,016 tons) totals 29,040 tons. Platform Harvest, along with its companion Platforms Hermosa and Hidalgo, are located on OCS leases that expired in 2018. The Bureau of Safety and Environmental Enforcement (BSEE) has called on the former lessees, Chevron U.S.A. Inc. (Chevron) and Freeport McMoRan Oil and Gas, LLC (FMC) to decommission the platforms and remove all existing oil and gas infrastructure on the leases. Chevron and FMC are currently plugging and abandoning the platform wells and removing the platform conductors. This work is expected to be completed in the 2021–2022 time-period. Chevron and FMC are also required to submit a decommissioning application to BSEE for approval that describes how it will remove the platforms. The decommissioning application is expected to be submitted to BSEE in 2021 or 2022.

2. Air emission regulatory framework

Under the Clean Air Act, the Environmental Protection Agency (EPA) has established National Ambient Air Quality Standards (NAAQS) for six primary pollutants of concern to public health and welfare. The pollutants, known as "criteria pollutants'", are ozone (O_3), carbon monoxide (CO), nitrogen oxide (NOx), sulfur dioxide (SO_2), particulate matter (PM10 and PM2.5) and lead (Pb). The California Air Resources Board (CARB) has also established separate standards, the California Ambient Air Quality Standards (CAAQS), for the six criteria pollutants. In general, the CAAQS standards are more stringent than the NAAQS established by EPA under the Clean Air Act. The EPA and CARB have also designated areas that are in attainment or nonattainment of the standards. In 2018, the four coastal counties (Santa Barbara, Ventura, Los Angeles, and Orange counties) bordering offshore oil and gas installations were reported to be in attainment with EPA and CARB standards for CO, NOx, and SO_2, while one or more counties were in nonattainment for one or more of the other criteria pollutants (Argonne National Laboratory, 2018).

Fig. 3. Platform Harvest.

Under the Federal Code of Regulations (40 CFR Part 55) the EPA has promulgated requirements to control air pollution from California OCS oil and gas sources. The EPA has delegated authority for enforcing these requirements to the local air pollution control districts in Santa Barbara, Ventura, and Los Angeles/Orange County. The local air districts regulate emissions from platforms and other oil and gas related operations through the issuance of Authorities to Construct (ATC) and Permits to Operate (PTO). The ATC/PTO's set limits on the level of permitted emissions from specified platform-based equipment (e.g., diesel engines) and service vessels. Table 1 shows the current permitted annual emission levels for the 23 federal OCS platforms. The permitted emissions cover only routine day-to-day operations.

Companies conducting oil and gas decommissioning projects offshore California will also need to comply with Airborne Toxic Control Measures (ATCM) issued by CARB and the county Air Pollution Control Districts (APCD's). These measures include:

1. The Portable Engine ATCM that applies to portable engines greater than 50 horsepower (17 CCR § 93116).
2. The ATCM requiring that the sulfur content of diesel fuel used in diesel engines, other than those engines used on "ocean going vessels", contain no more than 15 parts per million by weight (ppmw) sulfur (0.0015% sulfur) (17 CCR, 93114, 13 CCR 2281).
3. The ATCM for commercial harbor craft, that applies to tugs, crew and supply vessels, requires the use diesel fuel containing no more than 15 ppmw sulfur, and the replacement of older engines with engines meeting new emission standards (13 CCR § 2299.1, 17 CCR § 93118.5).

Companies conducting oil and gas decommissioning operations offshore California will also need to comply with sulfur fuel regulations issued by CARB for "ocean going vessels" (OGV) operating within the California OGV regulatory zone, which extends 24 nautical miles from the coastline, including islands (CARB, 2013). The CARB OGV fuel regulations require the marine gasoil (DMA) and marine diesel-oil (DMB) used on OGV's to use fuel having a maximum sulfur content of no more than 0.10 percent sulfur (1000 ppmw).

On May 29, 2019, the SBCAPCD, Ventura County Air Pollution Control District (VCAPCD) and the South Coast Air Quality Management District (SCAQMD) jointly issued air quality guidance for decommissioning offshore oil and gas platforms (SBCAPCD, 2019). The guidance confirmed a district issued ATC permit is required for decommissioning and demolition of oil and gas platforms and that the equipment subject to permit includes vessels that are physically attached to the seafloor. Examples of the types of equipment that may be subject to permit include: drill rig engines, flares, oil storage tanks/vessels, support/utility boat main propulsion and auxiliary engines, support/utility boat main work engines (water blasters, welding, jet pumps, roto-screws, compressors, pumps, winches, cranes), derrick barge/heavy lift vessel work engines (main power, winches, hoists, cranes, compressors, welding, backup power).

The air pollution control districts issue permits that typically specify hourly, daily, and annual emission for criteria pollutants and key precursors such as ozone. The air quality regulations issued by the districts also require projects that exceed air quality standards to mitigate project emissions below emission thresholds to assure a net air quality benefit from the project. Oil and gas platform decommissioning projects would also be subject to district New Source Review standards which would likely require use of Best Available Control Technology (BACT) on non-propulsion related equipment (MRS Environment Inc., 2019). Conventional HLV's that do not have clean-burning engines will therefore likely be required to undergo expensive retrofitting before they can operate offshore California.

Table 1
Local air quality district permitted emissions for California OCS oil and gas platforms (MRS Environmental Inc., 2019).

Platform	Local Air Quality District	Permit Number	Permitted Facility Emissions (tons per year)						
			NOx	ROC	CO	SOx	PM[a]	PM10	GHG[b]
A	SBCAPCD	9110-R4	24.3	45.9	24.1	0.7	2.4	2.4	2106
B	SBCAPCD	9111-R4	23.2	46.3	22.1	1.3	2.7	2.7	1775
C	SBCAPCD	9112-R4	23.6	34.3	22.4	1.4	2.7	2.7	1867
Edith	SCAQMD	166073-R9	92.0	148.3	654.1	24.3	58.9	–	–
Ellen	SCAQMD	166073-R9	92.0	148.3	654.1	24.3	58.9	–	–
Ely	SCAQMD	166073-R9	92.0	148.3	654.1	24.3	58.9	–	–
Eureka	SCAQMD	166073-R9	92.0	148.3	654.1	24.3	58.9	–	–
Gail	VCAPCD	01494	60.9	24.2	203.0	3.5	8.1	–	–
Gilda	VCAPCD	01492	82.3	26.4	24.7	2.9	5.1	–	–
Gina	VCAPCD	01491	26.4	5.23	7.9	4.8	1.6	–	–
Grace	VCAPCD	01493	46.7	17.4	122.0	2.8	4.0	–	–
Habitat	SBCAPCD	9107-R4	21.5	42.9	18.9	1.7	4.3	4.2	–
Harmony	SBCAPCD	9101-R5	220.0	73.9	122.0	74.3	19.9	19.6	34,133
Harvest	SBCAPCD	9103-R5	366.0	122.0	199.0	43.2	26.0	25.6	227,888
Henry	SBCAPCD	9113-R4	23.4	20.9	23.6	1.3	3.2	3.1	2056
Heritage	SBCAPCD	9102-R5	223.0	75.8	121.0	73.5	20.0	19.7	34,222
Hermosa	SBCAPCD	9104-R5	195.0	88.0	107.0	36.9	17.1	16.6	129,667
Hidalgo	SBCAPCD	9105-R5	197.0	74.4	86.7	26.5	17.2	16.8	–
Hillhouse	SBCAPCD	9114-R4	30.1	53.1	23.5	1.4	3.2	3.1	2544
Hogan	SBCAPCD	9108-R4	67.9	16.3	23.0	0.3	7.2	7.0	5260
Hondo	SBCAPCD	9100-R5	153.0	84.9	75.1	60.1	14.1	13.9	17,830
Houchin	SBCAPCD	9109-R4	87.0	18.5	34.6	0.3	8.4	8.5	9650
Irene	SBCAPCD	9106-R7	51.5	32.3	20.0	9.1	5.5	5.4	3305

[a] Particulate matter (PM) is the general term used to describe solid particles and liquid droplets found in the air. PM can be divided into size categories. PM10 emissions are defined as PM emissions that are less than ten (10) microns in diameter; PM2.5 emissions are less than 2.5 microns in diameter.

[b] Greenhouse Gas (GHG) are human-produced gases (carbon dioxide, methane, water vapor, methane, nitrous oxide, ozone) that trap heat within the earth's atmosphere; the burning of fossil fuels is the largest source of GHG.

3. Emission assumptions and methodology

This study was conducted to estimate the quantity of emissions that could be saved if a large California OCS oil and gas platform jacket is partially removed and converted to an artificial reef rather than fully removed. The study focuses only on platform jacket removal and therefore excludes other steps in oil and gas platform decommissioning process such as topsides removal, well plugging and abandonment, and pipeline and power cable removal. These activities will also produce significant emissions. By far, the largest quantity of emissions, more than 80 percent, will occur during the topsides and jacket removal phases of a decommissioning project. The major source of emissions will be from the diesel engines on the vessels deployed to dismantle and remove the platform topsides and jacket.

This study assumes a state-of-the-art semisubmersible crane vessel (SSCV) and an anchor handling tug and support (AHTS) vessel will be mobilized from the Gulf of Mexico (GOM) to remove Platform Harvest. The other support vessels used to remove the Platform Harvest jacket are all assumed to be mobilized from ports located in southern California or other west coast locations. The support vessels include a dive support vessel, supply vessel, and specialized tugs having ocean towing capability. All support vessels considered in this study have Tier 3 engines which have advanced emission control systems that can significantly reduce the amount of nitrogen oxide (NOx), particulate matter and other pollutants released by the engines. Specifics on the vessels and their power systems are described in greater detail below.

The methodology used in this study to develop emission estimates for fully and partially removing the Platform Harvest jacket involved the following steps:

1. Developing vessel spreads for fully removing and partially removing the jacket.
2. Compiling information on the number of primary propulsion engines (mains), thrusters, and auxiliary generators on the vessels, and the total energy in kilowatt hours (kW-hrs.) those engines are capable of generating.
3. Applying emission factors (grams per kW-hr.) to the energy generated by the main engines and auxiliary engines of the vessels to develop estimates of the quantity of emissions generated for NOx, SOx, ROC, CO, CO_2, PM10 and PM2.5.
4. Determining the marine engine duty cycles, which define on a percentage basis the power and annual hours of usage that are expected of an engine; marine engine duty cycle information was obtained from the Industrial Motor Power Corporation (http://www.impcorporation.com/blog/marine-engine-duty-ratings).
5. Estimating the number of hours each vessel would be operating daily and the total number of vessel days required to fully and partially remove the jacket.
6. Calculating the total energy consumed by the vessel engines and the quantity of emissions released for each criteria pollutant.

This methodology was also used in a similar study conducted in 2015 that calculated energy use and emission estimates for fully and partially removing the Platform Harmony jacket, which is located in 1200 feet of water and is the largest and heaviest California OCS platform (Cantle and Bernstein, 2015). The 2015 study assumed the *DB 50*, a monohulled crane barge having a 3500-ton lifting capacity, would be used to remove the Platform Harmony jacket. This study, in contrast, assumes a large SSCV will be used to remove the Platform Harvest jacket, which we believe is a more realistic option. This study also involves a different vessel spread than the 2015 study and includes more detailed information on vessel operating times and logistics.

3.1. Vessel spread assumptions

This study assumes a SSCV having a 3600-ton lift capability will be mobilized from the GOM to remove the Platform Harvest topside and jacket. The jacket removal concept involves cutting the jacket into 10–15 large sections (packages) weighing up to 2000 tons each for lifting by the SSCV. In addition to the major lift packages, more than one hundred lighter lifts would be made to remove smaller pieces.

Table 2 shows the specific vessel spread and power system assumptions that are used in this study to calculate energy use and emission estimates for fully and partially removing the Platform Harvest jacket. The information on main engines (mains), thrusters, and generators was obtained from the vessel specification documents posted by vessel owners on company websites. The assumptions and rationale for selecting the vessels are described below along with the estimated number of operating days for each vessel. The number of vessel days shown for the SSCV and AHTS in the partial removal case is reduced by 90 percent compared to the full removal case due to the fact only the upper 85 feet of the jacket (675′wd.) would be removed. The SSCV and AHTS vessels days include only time on-station at Platform Harvest. There would be a significant quantity of emissions produced by the SSCV and AHTS during the long transit from the GOM to California but these emissions are not considered in this study because the vast majority of the emissions would occur in international waters and would not directly affect local air quality.

Heavy Lift Vessel (HLV): An SSCV having dual cranes rated at 1800 tons each, and a maximum 3600-ton lift capability similar to the *Gretha* (Fig. 4), is assumed to be used to remove the Platform Harvest jacket. An SSCV is considered superior to a monohulled type HLV because it provides a more stable platform for operating in challenging marine ocean conditions like those that exist offshore Point Conception where Platform Harvest is located. The offshore working season for conducting heavy lifts in this area is approximately 120 days. The SSCV is projected to fully remove the jacket in 100 days, including 10 days for weather downtime, and partially remove the jacket in 10 days. The SSCV is assumed to be on station and operate 24 h each day.

Anchor Handling Tug Support Vessel (AHTS): An AHTS similar to the *Norman Master* is assumed to mobilized from the GOM along with the SSCV to install deep water mooring systems for the SSCV and other vessels. The AHTS will also serve as an emergency response and rescue vessel. The mooring systems installed by the AHTS will minimize the use of dynamically position systems on the SSCV, thus reducing air emissions which are strictly controlled offshore California. The AHTS will work along-side the SSCV and be on site 100 days in the full removal case, and 10 days in the partial removal case. The AHTS is assumed to be on station and operate 24 h each day.

Table 2
Vessel spread and power system assumptions for fully removing the platform harvest jacket.

Vessel Type & Power System	Power (Kw/ engine)	Horse Power (HP/ engine)	Number of Engines & Thrusters	Total Kw	Total HP
Semi-submersible Crane Vessel having 3600-ton lift capacity (similar to *Gretha*)					
• Mains	3860	5176	8	30,880	41,410
• Thrusters	3800	5096	6	22,800	30,575
Anchor Handling Tug Support Vessel (AHTS) (similar to *Normand Master)*					
• Mains	4320	5793	4	17,280	23,478
• Thrusters	1081	1450	4	4325	5800
DP2 Dive Support Vessel (similar to *Harvey Challenger* with Tier 3 emissions rating)					
• Mains	1485	1991	2	2969	3982
• Thrusters	336	450	4	1342	1800
• Aux. Generators	910	1220	2	1820	2441
Tug Boats 1 (similar to *Barbara Jean Mulholland* or *Jamie Renea* with Tier 3 emissions rating)					
• Mains	2554	3425	2	5108	6850
• Aux. Generators	170	228	2	340	456
Tug Boat 2 (similar to *Barbara Jean Mulholland* or *Jamie Renea* with Tier 3 emissions rating)					
• Mains	2554	3425	2	5108	6850
• Aux. Generators	170	228	2	340	456
Cargo Barges (CB 400 size)					
• None	N.A.	N.A.	N.A.	N.A.	N.A.
Supply Vessel (similar to *OSV Clean Ocean with Tier 3 emissions rating)*					
• Main	560	750	2	1119	1500
• Aux. Generator	100	134	2	200	268

Fig. 4. Gretha semi-submersible crane vessel.

Dive Support Vessel (DSV): A DSV similar to the *Harvey Challenger* is assumed to be mobilized from Port Hueneme in Ventura County, which is located 76 miles from Platform Harvest. The DSV will provide the remotely operated vehicle (ROV) and dive services required to prepare the jacket for removal by separating the risers and j-tube connections from pipelines and hose bundles, clear any obstructions to lifting, and provide other required support services. The ROV's and divers will deploy the mechanical, abrasive and other cutting tools required to sever the jacket into pieces (packages) that can be safely lifted by the SSCV cranes. A total of 500–700 separate cuts are estimated to be made to the jacket in the full removal case, and 60–84 cuts in the partial removal case. The DSV is projected to be on-site for a period on 170 days in the full removal case and seven days in the partial removal case. The DSV is assumed to operate 24 h each day.

Tugs Having Open Ocean Towing Capability: It is assumed that two tugs similar to the *Barbara Jean Mulholland* and the *Jamie Renea* will be mobilized from ports on the west coast to tow the loaded cargo barges from Platform Harvest to the Ports of Los Angles or Long Beach, which is located 130 miles from Platform Harvest. The tugs will make six roundtrips in the full removal case. Each roundtrip will take 48 h. Two tugs are estimated to be in service a total of 12 days in the full removal case. One tug will make one roundtrip and be in service 48 h, two days, in the partial removal case.

Cargo Barges: A total of six 400-foot by 100-foot size cargo barges (CB-400) will be required to transport the Platform Harvest jacket components to the Ports of Los Angeles or Long Beach in the full removal case. The cargo barges are estimated to be in service a total of 12 days in the full removal case. One cargo barge will be required for the jacket top in the partial removal case.

Supply Vessel: A supply vessel similar to the *OSV Clean Ocean* is assumed to make three trips per week to Platform Harvest to deliver supplies and equipment. The supply vessel is assumed to be mobilized from Port Hueneme, which is located 76 miles from Platform Harvest. The supply vessel is estimated to be in-service a total of 27 days in the full removal case, and six days in the partial removal case. The supply vessel is assumed to operate 18 h each day it is in service.

4. Emissions estimates for full and partial jacket removal

Table 3 shows the emission factors for marine diesel-oil main engines and auxiliary generators used in this study to calculate emission estimates for fully and partially removing the Platform Harvest jacket. The

Table 3
Emission factors for ocean going vessel and commercial harbor craft main and auxiliary engines.

Vessel Type & Power System	NOx	ROC	SOx[a]	CO	CO_2	PM10	PM2.5
Semi-submersible Crane Vessel							
• Mains	13.20	0.50	0.0040	1.10	646.08	0.47	0.43
• Thrusters	13.20	0.50	0.0040	1.10	646.08	0.47	0.43
Anchor Handling Tug Support Vessel							
• Mains	13.20	0.50	0.0040	1.10	646.08	0.47	0.43
• Thrusters	13.20	0.40	0.0040	1.10	646.08	0.47	0.43
• Aux. Gen.	13.90	0.40	0.0042	1.10	690.71	0.49	0.45
Dive Support Vessel							
• Mains	13.20	0.50	0.0040	1.10	646.08	0.47	0.43
• Thrusters	13.20	0.40	0.0040	1.10	646.08	0.47	0.43
• Aux. Gen.	13.90	0.40	0.0042	1.10	690.71	0.49	0.45
Tug Boats 1							
• Mains	13.20	0.50	0.0040	1.10	646.08	0.47	0.43
• Aux. Gen.	13.90	0.40	0.0042	1.10	690.71	0.49	0.45
Tug Boat 2							
• Mains	13.20	0.50	0.0040	1.10	646.08	0.47	0.43
• Aux. Gen.	13.90	0.40	0.0042	1.10	690.71	0.49	0.45
Cargo Barges							
• None	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Supply Vessel							
• Main	13.20	0.50	0.0040	1.10	646.08	0.47	0.43
• Aux. Gen.	13.90	0.40	0.0042	1.10	690.71	0.49	0.45

[a] EPA 2009 Report emission factor for SOx has been adjusted to address CARB mandate that marine gas-oil and marine diesel-oil used in ocean going vessels contain no more than 0.1 percent sulfur.

Source: EPA, 2009.

emission factors shown were published in an EPA report on methodologies for estimating emissions from ocean going vessels, which is a common source of generally accepted emission factors for a broad range of emitting equipment (EPA, 2009). As was discussed above, the emission factors were applied to the power capable of being generated by vessel engines to calculate the quantity of emissions (grams/kW-hr.) produced. This result was multiplied by a marine duty cycle (MDC) factor for main, thruster and auxiliary engines on the vessels to adjust for the percentage of time the engines are projected to be used during the project. The assumed MDC for both the full and partial removal cases for the SSCV, AHTS and DSV is 35 percent for the mains and 40 percent for the thrusters. For the tug boats and the supply vessel the estimated MDC for the mains is 60 percent. Using these inputs and the vessel operating times discussed above, emissions estimates were calculated for each of the criteria pollutants for both the full and partial jacket removal options.

The results of the calculations (Table 4) show the full removal option is estimated to produce approximately ten times more emissions for each criteria pollutant than the partial removal option, a ratio that largely reflects the time the SSCV and the AHTS are on station under each removal option. Table 5 provides a breakdown of NOx emissions for each of the vessels under the full and partial removal options. The table shows under the full removal option the SSCV produces 61 percent of the NOx emissions followed by the AHTS at 25 percent. Combined the SSCV and AHTS account for 86–92 percent of total NOx emissions under both the full and partial removal options. The next largest source of emissions is the DSV at 11 percent under the full removal option and five percent under partial removal option. The tugs and supply vessel combined account for only two to three percent of the total NOx emissions. These ratios are consistent for all of the other criteria pollutants.

Table 4
Comparison of vessel emission estimates for fully and partially removing the platform harvest jacket.

Removal Option	Emissions (tons)						
	NOx	ROC	SOx	CO	CO_2	PM10	PM2.5
Full	1147	43	0.35	95	56,187	41	37
Partial	107	4	0.03	9	5259	4	3

Table 5
Comparison of vessel NOx emission for fully and partially removing the platform harvest jacket.

Vessels	Full Removal		Partial Removal	
	Tons	Percent	Tons	Percent
Semi-submersible crane barge (SSCV)	696	61	70	65
Anchor handling tug supply vessel (AHTS)	292	25	29	27
Dive support vessel (DSV)	128	11	5	5
Tugs	26	2	2	2
Supply vessel	5	<1	1	1
Total	1147	100	107	100

Table 6 compares permitted emissions for Platform Harvest with the emissions estimated to be released during full and partial jacket removal options. As shown, the full removal option produces 1147 tons of NOx, which exceeds by a factor of three the permitted facility emissions for NOx (366 tons). In addition, the quantity of PM10 (41 tons) and PM2.5 (37 tons) emissions far exceeds the permitted facility emissions for both PM10 (26 tons) and PM2.5 (26 tons). Emission levels for partial removal, in contrast, fall well below the permitted facility emissions for the criteria pollutants. The partial removal option also results in a 90 percent reduction (56,187 vs. 5381 tons) in carbon dioxide emissions compared to the full removal option.

4.1. Comparison with 2015 study

The emissions estimates for removing the Platform Harvest jacket in this study are nearly double those reported in a 2015 study that estimated emissions for removing the Platform Harmony jacket (Cantle and Bernstein, 2015). The 2015 study estimated a total of 600 tons of NOx and 22,400 tons of CO^2 would be produced if the Platform Harmony jacket was fully removed. The emissions decreased to 89 tons of NOx and 4400 tons of CO^2 under the partial removal option, a decrease of about 85 percent. This study, in contrast, estimates the full removal of the Platform Harvest jacket would produce a total of 1147 tons of NOx and 56,187 tons of CO2; partially removing the jacket was estimated to produce 107 tons of NOx and 5259 tons of CO^2, a decrease of about 90 percent.

The large variation in emissions estimates between this study and the 2015 study is primarily due to differences in the vessel spreads used to estimate emissions, the size and number of propulsion and generator engines on the vessels, and the scope of work undertaken to prepare the jacket for removal. As noted above, this study assumes an SSCV is used to remove the Platform Harvest jacket due to the challenging oceanographic conditions that exist offshore Point Conception. The power system on the SSCV is much larger than the power system on the HLV (DB 50) that was used to estimate emissions in the 2015 study. The 2015 study also did not include a DSV in the vessel spread it used to estimate

Table 6
Comparison of permitted facility emissions for platform harvest and emission estimates for fully and partially removing the platform jacket.

Permitted Facility Emissions and Jacket Removal Emissions	Emissions (tons)						
	NOx	ROC	SOx	CO	PM10	PM2.5	CO_2
Permitted Emissions (tons per year)	366	122	43	199	26	26	227,888
Full Jacket Removal	1147	43	0.35	95	41	37	56,187
Partial Jacket Removal	107	4	0.03	9	4	3	5259

emissions. In this study, the DSV is considered an integral part of the jacket removal process because its services are required to prepare the jacket for removal by the SSCV and to provide required cutting services.

5. Summary and conclusions

This paper was prepared to inform legislators, regulatory agencies, industry, and the public about the potential emission savings that could be achieved if the jacket of a large California oil and gas platform like Platform Harvest is converted to an artificial reef rather than fully removed. The major findings of the paper are summarized below.

1. Fully removing the Platform Harvest jacket is estimated to produce 1147 tons of NOx and 56,187 tons of CO_2 emissions; this is equivalent to the quantity of CO_2 emissions from consuming nearly 120,000 barrels of oil, 6 million gallons of gasoline, or providing electrical power to 8600 homes annually.
2. Full removal produces 10 times more emissions of criteria pollutants and greenhouse gases (56,187 tons) than partial removal (5259 tons).
3. Approximately 85 percent of the total emissions are produced by the SSCV (61 percent) and AHTS (25 percent).
4. The quantity of NOx emissions (1147 tons) produced by fully removing the jacket exceeds by a factor of three the current permitted facility emission levels of NOx (366 tons) for Platform Harvest.
5. The quantity of all criteria pollutants produced by partially removing the jacket falls well below the annual permitted facility emission levels for Platform Harvest.

This paper shows fully removing a large oil and gas platform jacket has the potential to produce a large quantity of emissions of criteria pollutants and greenhouse gases. This will pose a major challenge to operators seeking to obtain ATC permits for decommissioning projects from air quality regulatory agencies. Operators will be required by regulatory agencies to reduce emissions to ensure air quality requirements are not exceeded and a net air quality benefit is achieved. To address agency concerns, operators may be required to modify their project and implement costly mitigation measures imposed by air quality regulatory agencies. Such measures could include requirements to retrofit engines on large HLV/DB's and AHTS's, and use other support vessels having higher tier marine engines, such as Tier 4 engines.

Operators also have the option of seeking approval from federal and state regulatory agencies to partially remove a platform jacket and convert the remaining structure to an artificial reef. The California Marine Legacy Act (AB 2503) mandates the conversion of a platform jacket to an artificial reef must result in a *"net environmental benefit."* Proposals have been made to amend the act to include consideration of air quality and greenhouse gas emissions. This paper shows emission levels could be reduced 90 percent if a large platform jacket is converted to an artificial reef rather than fully removed. Due to the wide variation in the size of OCS platforms, which range in weight from 1400 tons (Gina) to as much as 86,500 tons (Harmony), the vessel spreads and equipment required to remove the platforms will vary from project to project. The quantity of emissions that can be saved by reefing rather than fully removing a platform jacket will therefore need to be determined on a case-by-case basis. However, it is reasonable to conclude that the savings in air emissions will be proportional to the amount of material (steel) left in place rather than removed. This is considerable in the case of the larger jackets.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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