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Alternate uses of retired oil and gas platforms in the Gulf of Mexico

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ABSTRACT

The number of fixed oil and gas platforms are declining in the Gulf of Mexico, there were ~3674 platforms installed the since 1942 and today there are ~1320. Eventually, ~30,000 jobs will be lost in related industries because of platform removals. Retired oil and gas platforms could be redeployed for alternate uses such as CO_2 capture and storage, renewable wind energy, and sustainable fisheries and employ citizens in coastal areas. Elsewhere around the world, offshore platforms are used for purposes other than producing oil and gas. U.S. Federal legislation (Energy Policy Act 2005 Section 388 of Public Law [PL] 109-58); 30 CFR 285.1000 Subpart J) authorizes the use of retired oil and gas platforms for alternate uses. If the retired oil and gas structures are preserved, the infrastructure could also be used to recover stranded petroleum using CO_2 enhanced oil recovery (CO_2-EOR). We examined the socio-economic incentives, environmental impacts, and regulatory issues associated with the alternate uses. We suggest that CO_2-EOR is the most economically efficient way to store CO_2 offshore and that offshore wind turbines may assist with the energy requirements for oil and gas production and CO_2-EOR. Data suggest that in our study area offshore platforms are more successful at producing fish and invertebrates if they are left standing instead of toppled over. The greatest regulatory issue facing the use of retired platforms is the transfer of liability. If the structures are redeployed, the previous oil and gas owner/operators are still responsible for eventual removal and catastrophic events. A variety of future economic activity in the Gulf of Mexico could take advantage of this infrastructure, if it remains in place.

1. Introduction

1.1. Background of the offshore oil and gas platforms, Gulf of Mexico

The oil and gas industry has installed ~3674 fixed offshore oil and gas platforms since 1947, although they are rapidly disappearing, and today there are only ~1320 (Bureau of Safety and Environmental Enforcement [BSEE] 2018). There are a several types of offshore structures, spars, tension-leg platforms, caissons, well protectors, and fixed platforms. Fixed platforms are the largest of the stable structures (jackets and decks) and they are installed in waters < 400 m. They constitute ~60% of all the various production structures in the Gulf of Mexico and are suitable for managing the alternate use operations described below. Based on an average production life of 17 years, most of the remaining structures could be decommissioned by 2025 (BSEE, 2018). Table 1 presents the number of fixed platforms installed and removed, cumulatively existing structures in the Gulf of Mexico over time.

In the Gulf of Mexico, the offshore platforms are currently used only to produce hydrocarbons, although sometimes retired platforms are toppled over to create artificial reefs (Kaiser and Pulsipher, 2005). Elsewhere, offshore platforms are used for purposes other than producing hydrocarbons.

The concept of utilizing offshore platforms for alternate uses has been addressed before. The idea was discussed previously in reports and literature: Reggio, 1989,1996; Kaiser JB et al., 2003; Louisiana Department of Natural Resources (LDNR) 2005; Kolian and Sammarco 2005, 2008, 2018; Love et al., 2006; Minerals Management Service (MMS) 2007; Kaiser MJ et al., 2010, 2011; Legorburu et al., 2018.

1.2. Carbon sequestration - CO_2-EOR processes

Around the world, five offshore CO_2 storage demonstration projects are currently or are about to be put into operation, with plans to store 4 to 7 million metric tons of CO_2 per year. Another five projects using offshore platforms are planned for 9 million metric tons per year (GCCSI, 2017). The most notable of these projects in operation is the Sleipner project off the coast of Norway. As of June 2016, they had

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Table 1
Offshore Platforms in the Gulf of Mexico.
Source: BSEE 2018, List of all platform structures, 1 Jul 18.

Years	Installed	Removed	Existing Fixed Platforms
1942–1969	719	–	719
1970–1979	768	23	1464
1980–1989	875	153	2186
1990–1999	766	508	2444
2000–2009	486	724	2206
2010–2018	60	946	1320
Total	3674	2354	

The number of installed, removed, and existing fixed platforms in the Gulf of Mexico.

stored over 16 million metric tons of CO_2 (Furre et al., 2017). Nonetheless, the CO_2 storage offshore potential is most promising if the CO_2 is used to help extract stranded oil utilizing methods such as CO_2 enhanced oil extraction (CO_2-EOR). The potential of this hydrocarbon recovery method is large, and is globally dispersed (Dahowski et al., 2009; DOE/NETL 2014; International Energy Agency Greenhouse Gas (IEA GHG) 2009a, b; Vidas et al., 2012; Asia-Pacific Economic Cooperation [APEC] 2013).

1.3. Wind energy and platforms

A number of offshore wind projects have been initiated along the U.S. Atlantic seaboard using structures similar to the oil and gas platforms (Kaiser et al., 2010); however, to date, no projects using retired platforms have been implemented in the Gulf of Mexico. Other countries are using offshore platforms to produce wind-energy (Higgins and Foley, 2014). For example, in the Scottish North Sea, offshore wind turbines have been installed next to the Beatrice offshore platforms to supplement their energy needs for hydrocarbon extraction (Bilgili et al., 2011; Legorburu et al., 2018).

1.4. Sustainable fisheries and platforms

Offshore platforms are known to host some of the most prolific ecosystems in the oceans (Wilson et al., 2003; Claisse et al., 2014). They are habitat for protected, threatened, and endangered species, such as sea turtles (Gitschlag et al., 1997), coral (Sammarco et al., 2004, 2012a,b; Kolian et al., 2013, 2017), and fish (Stanley and Wilson, 2000; Shipp and Bortone, 2009; Ajemian et al., 2015). Offshore platforms are home to coral, algae, sponges, and bacteria possessing bioactive compounds shown to have valuable pharmaceutical properties (Rouse, 2009; Schippers et al., 2012; Florida Atlantic University, 2016).

1.5. Authorization for alternate uses of offshore platforms

The Energy Policy Act (EPAct) of (Public Law [PL] 109-58) authorizes the use of Outer Continental Shelf (OCS) facilities (offshore platforms) for alternate uses. On June 29th, 2009, the Minerals Management Service (MMS) implemented the "Renewable Energy and Alternate Uses of Existing Facilities on the Outer Continental Shelf" program (30 CFR 285.1000 Subpart J). This Federal program allows retired oil and gas platforms to be utilized for alternate uses such as the wind, wave, and current energy production, or any "marine related purpose".

1.6. Existing oil and gas industry

In the Gulf of Mexico, the offshore oil and gas fields are aging and the oil and gas industry is presently spending $1.2 billion per year removing platforms, and the total cost could reach $45 billion for removal by the time the shelf is cleared (Decomworld, 2010, 2015). Regulations that provide incentives to leave the platforms offshore are helpful, but the oil and gas companies and the relevant managing Federal agencies are reluctant to do so because of concerns over lingering liability (Notice to Lessee [NTL] 2010-G05).

Greater than 60 years of experience have demonstrated that fixed offshore platforms are the most efficient method to provide housing for workers and production equipment, and they are operational and accessible > 95% of the time. They are designed to survive up to 100 years standing in place (Kaiser et al., 2011), and if they are toppled over and used as artificial reefs, it is estimated that they could maintain their structural integrity for up to 300 years (Reggio, 1989).

1.7. Research questions and objectives

Here, we examine the following questions regarding the use of these offshore structures in a post-petroleum production phase for CO_2 capture and storage, CO_2-EOR, wind energy, and sustainable fisheries. Specifically, we raise the following questions and discuss their potential answers:

- What are the potential alternate uses for retired platforms, and are they viable?
- What areas or depths in the Gulf of Mexico are suitable for such operations, and why?
- What potential energy resources are associated with these platforms?
- Likewise, what are the fishery resources, and
- What are the probable environmental and socioeconomic impacts of implementing such activities?
- What regulatory issues must be addressed if alternate uses of platforms are to be successfully implemented?

2. Using CO_2 capture and sequestration on offshore platforms

Carbon capture and storage (or sequestration) is the process of capturing CO_2 from large point-sources and transferring it to an underground geological formation. The aim is to reduce the release of large quantities of CO_2 into the atmosphere, and mitigate the contribution of fossil fuel emissions to global warming and ocean acidification. Substantial opportunity exists for storing CO_2 offshore, both in depleted oil and gas fields and in deep saline aquifers. Accessibility to existing offshore petroleum infrastructure is likely to be essential to make the storage of CO_2 economically feasible.

Perhaps the most commercially viable alternate use of existing offshore platforms is enhanced oil recovery using carbon dioxide (CO_2-EOR). Enhanced oil recovery (EOR) is a generic term for a wide variety of techniques to increase the amount of crude oil that can be extracted from an oil field. The CO_2-EOR process is one where CO_2 is injected under high pressure into deep, oil-bearing submarine geological formations/strata to increase recovery of oil and gas in partially depleted fields. CO_2 injection is presently the most-commonly used approach for EOR. Oil displacement by CO_2 injection relies on the phase behavior of the mixtures of gas and crude oil. These behaviors are strongly dependent on reservoir temperature, pressure and crude oil composition. CO_2-EOR results in CO_2 being introduced into the reservoir as part of the process, and thus is stored for the long-term. CO_2-EOR can help maintain profitable offshore oil production into coming decades.

2.1. Energy resources on the GOM continental shelf

In a report, the U.S. Department of Energy (DOE) considered the future of retrievable oil reserves in the Gulf of Mexico. They concluded that, depending future technological developments, and assuming oil prices of $90 per barrel and a CO_2 cost of $50/MT, economically viable recovery of oil could produce an additional 15 billion barrels. This would require nearly 4 billion metric tons of CO_2 to facilitate that recovery (DOE/National Energy Technology Laboratory [NETL] 2014), which would ultimately be stored.

2.2. Suitable areas for CO_2 storage and to utilize CO_2-EOR

To date, most investigations of CO_2 storage in North America have focused on onshore geologic formations, particularly deep saline formations and oil and gas reservoirs. Hendriks et al. (2004) estimated that roughly one third of the global CO_2 storage capacity in depleted oil and gas fields is located offshore, amounting to over 400 billion metric tons in depleted offshore oil and gas fields. Fields remaining to be discovered can account for storage of another 300 billion metric tons. Dooley et al. (2005) estimated that about 40 percent of the global capacity in deep saline aquifers is located offshore. In the U.S., efforts are currently underway to develop a more comprehensive assessment of CO_2 storage capacity in offshore regions (DOE, 2015; DOE NETL, 2017).

The use of offshore locations for CO_2-EOR has several advantages over onshore applications. First, the potential collection of Federal royalties on offshore production allows for the co-alignment of interests between CO_2-EOR producers, the Federal government, and, possibly, suppliers of CO_2. Second, the large fields offshore provide attractive sites, because of their large capacity, high permeability and porosity (facilitating greater capacity), and remoteness. Finally, newly-discovered and less mature offshore fields can provide opportunities for implementing the deployment of CO_2-EOR earlier that towards the end of primary/secondary production operations improving incremental production potential, economic viability, and total CO_2 storage potential.

Use of offshore locations is not, however, without its potential disadvantages. The first pertains to the larger capital and operational set-up costs, such as those necessary for on-site gas processing/CO_2-recycling facilities, and, most likely, new wells for injection. These apply even when existing platforms and infrastructure can be utilized.

2.3. Environmental impact of use of CO2-EOR

Using the existing infrastructure as the basis for alternate offshore uses could create moderate environmental impacts, similar to those associated with current oil and gas operations. Assuming historically-based values for CO_2 utilization, most life cycle analyses (LCAs) of CO_2 storage in association with CO_2-EOR show that emissions associated with producing, processing, transporting and/or utilizing the incremental oil produced are greater than the CO_2 injected and stored in association with CO_2-EOR. This causes many to downplay the environmental benefits associated with producing oil by CO_2-EOR. Current CO_2-EOR operations, however, are achieving much higher utilization values; and, assuming the application of “next generation” technologies, even greater utilization values are realizable. Recent work shows that “next generation” CO_2-EOR uses, on average, about 0.45 metric tons of CO_2 per barrel of oil (Godec et al., 2004).

There are several projects that are achieving higher values of CO_2 utilization using CO_2-EOR. These utilization values are over double those assumed in most traditional LCA analyses applied to CO_2-EOR operations, and even greater utilization values are possible. Emissions associated with the production, transport, refining, and, ultimately, the combustion of the incremental oil produced are estimated to be 0.42–0.43 metric tons per barrel. Given these values for CO_2 utilization with CO_2-EOR, the amount of CO_2 injected and stored in the reservoir during CO_2-EOR can generally be greater (carbon negative) than the emissions associated with the extraction, production, and eventual combustion during industrial and civic uses of the incrementally produced oil and gas (Godec et al., 2004).

2.4. Socioeconomic issues associated with CO2-EOR

Assuming that 4.0 billion barrels of potential oil resources in the Gulf of Mexico (out of a potential total of 15 billion barrels) is developed over 40 yrs, the resultant benefits of using CO_2-EOR to assist in accessing stranded oil would amount be:

- Incremental production of 200,000 to 250,000 barrels per day
- More than 8000 jobs retained by the Gulf oil and gas industry
- Increased economic activity amounting to $500 million per year to coastal communities, and
- Increased State and Federal revenues of more than $250 million per year, with greater than 90%, going to the Federal government under current fiscal arrangements.

CO_2-EOR appears to be the most promising method to use the retired structures and should be considered for a pilot or demonstration project. This opportunity would be lost if the oil and gas infrastructure were to be removed.

2.5. Regulatory issues associated with CO2-EOR implementation

Globally, the injection of CO_2 under the seabed is governed under the London Protocol. The *Protocol's Guidelines for Assessment of Carbon Dioxide Streams for Disposal into Sub-Seabed Geological Formations* (London Protocol, 2012) were developed to allow countries to assess permit applications for projects in their territorial waters. One permit has been approved to date under these guidelines – the Rotterdam Capture and Storage Demonstration (ROAD) Project in the Netherlands. In the U.S., CO_2-EOR operations would be managed under the existing oil and gas regulations, under the Bureau of Ocean Energy Management (BOEM).

If the project is limited only to injecting CO_2 into saline aquifers and not be involved with the production of hydrocarbons, the operation would be managed under the new “Renewable Energy and Alternate Uses of Existing Facilities on the Outer Continental Shelf” program (30 CFR 285.1000 Subpart J). This provides BOEM with the authority to issue an Alternate Use (AU) Right-of-Use Easement (RUE) to applicants to use retired platforms for “marine related purposes”. The Federal permits will require a National Environmental Policy Act (NEPA) evaluation and financial assurance to ensure that the structure would be removed and the site cleared at the end of its production life.

3. Wind energy and offshore platforms

Kaiser et al. (2011) discussed several methods to utilize retired the structures for the production of wind energy. A given platform could be re-fitted and relocated to a wind farm site and used to support a wind turbine. Secondly, platforms could be left in place and wind turbines could be installed on top the existing platform deck. Thirdly, platforms could be left in place and used as centralized electrical service platforms for independent wind turbines adjacent or close by. These platforms could collect the energy generated from the local turbines and increase the voltage and direct it along a single submarine cable to an onshore facility (Kaiser et al., 2011). Given the large working area on the platforms, they could provide a stable, local base in the marine environment which could provide docking facilities for watercraft and helicopter landing pads, communications, and suitable personnel accommodations for operations.

The production of oil and gas requires a great deal of energy, and the wind energy produced on-site could supply the necessary power for this task. Oil and gas operations normally use diesel or natural gas for this purpose, and wind energy could supplement these power needs (Kaiser et al., 2011; Legorburu et al., 2018).

3.1. Wind energy resources, Gulf of Mexico

In north central and western Gulf of Mexico, wind resources are typical of offshore areas although offshore of Louisiana wind resources tend to increase with distance from shore (National Renewable Energy Laboratory (NREL) 2011). Wind speeds are greater and more erratic in the winter season than in the summer because of more variable pressure changes and frontal passages. Average annual wind speeds across this region range from 6.0 to 9.0 m/s at a height of 90 m (NREL, 2011). Minimum monthly averages occur during July and August, with wind speeds range from 3.9 to 5.1 m/s (Minerals Management Service, 2007). For large turbines that have 80 m rotor dimeter, they produce electricity when speeds reach a minimum of 4 m/sec and shut down at speeds greater than 25 m/s (Volker et al., 2017).

3.2. Suitable areas for wind energy operations on platforms

The most desirable sites for winds are offshore of Texas, where year-round wind speeds are greater than elsewhere in the northern Gulf (monthly maxim ~9 m/s), and coastal communities are in close proximity to beach areas (NREL, 2011). If a wind farm were to be installed specifically to service other offshore platforms, then offshore platforms at > 50 m depth would be good candidates. Utilizing wind energy resources in these deep-water regions would be more attractive to oil and gas operators than shallow-water regions because the cost of fuel for any operation increases with distance to shore, due to higher costs of transporting the fuel.

3.3. Environmental impact of use of wind turbines on platforms

There are environmental impacts associated with operating an offshore wind turbine unit, but they are considered by BOEM to be moderate (MMS 2007). The mortality of migratory birds during operations ranks as the primary concern. A wide range of seafaring birds may collide with the turbine during north-south migration. There has been a recent technological advance which could be utilized to address this issue, and that is a wind turbine design for a sail carousel wind turbine (King and Tehachapi, 2011), which rotates in the horizontal rather than the vertical. The blades would be avoided by the birds, because the blades appear to be opaque and are easily seen. Other minor impacts could occur during construction and operation.

Detailed information on environmental impacts due to the implementation of wind farms may be found in a Programmatic Environmental Impact Statement for the Alternative Energy Development and Production and Alternate Use of Facilities on the Outer Continental Shelf, Final Environmental Impact Statement, October 2007.

3.4. Socioeconomic impacts of using wind energy from platforms

For wind power developers, the foundation for the bases along with installation expenses, represent ~20% of the capital costs of offshore wind farms. Recycled platforms will sell for about 30–50% of their original fabrication costs. By using a recycled foundation over a new foundation, developers may be able to save 10% of their total capital costs (Kaiser et al., 2011). A standard wind farm operation would include an onshore administration building, switchyard, and transmission facilities. Activities would involve manufacturing, marine transport, construction, and the installation of transformers and cables.

Much of the knowledge of offshore operations and production infrastructure required to complete these tasks already exist in the local oil and gas industry. Our highly conservative estimate of job generation is that approximately one job per wind turbine would be created directly during the construction phase, and one job per turbine during the operation phase and one during the decommissioning phase. Typically, an offshore wind farm contains ~80 wind turbines, and each wind turbine produces ~6 megawatts. Thus, collectively, one wind farm could provide 240 jobs and enough electricity to support 480,000 homes (Morgan et al., 2003).

4. Regulatory issues associated with alternate uses for platforms

Wind farm applicants would obtain leases to own and operate through BOEM. BOEM is authorized under the Outer Continental Shelf (OCS) Lands Act, as amended by the Energy Policy Act of 2005, to oversee activities on the OCS that "produce or support production, transportation, or transmission of energy sources other than oil and gas [43 U.S.C. 1337(p)(1)] and are authorized by a lease, easement, or right-of-way issued by BOEM." Under current regulations, commercial leases would likely be for 30 years and would include a 6-month planning period, a 5-year assessment period, and a 25-year construction and production period. The Federal permits would require a National Environmental Policy Act (NEPA) evaluation and financial assurance to ensure that structure removal and site clearance operations will be performed at the end of their production life or in the event the operator goes bankrupt.

5. Hybrid platforms, combining wind, wave, and ocean current resources for energy production

Ambient energy resource potential is greater in offshore areas than on land. The purpose of an integration between multiple renewable energy sources in this environment is to allow for a more reliable, continuous source of energy. Plans for integrating wind energy with other energy sources such as ocean waves, ocean currents, and solar has been discussed in the literature (Daniel and AmmasaiGounden, 2004; Perez-Collazo et al., 2005). Researchers have considered utilizing offshore platforms for wind energy-driven desalination projects in deep water, since such areas are characterized by cleaner sources of seawater (Mathioulakis et al., 2007). These alternate uses are compatible with CO_2 storage efforts and sustainable fisheries.

6. Sustainable fisheries on offshore platforms

If the platforms are left standing in place, they will increase the amount of habitat used by sport fish, not to mention ornamental fish. Ornamental fish is a generic term to describe aquatic organisms sold in the aquarium trade, including fishes, and invertebrates such as coral, sponge, crustaceans, and mollusks. The sport fish are sought after by sport fishermen, and ornamental fish could actually be farmed on the platform, as well as harvested from their natural populations there. In addition, some marine invertebrates that grow on the platforms possess novel compounds which can serve as pharmaceutical products, nutritional supplements, and natural health aids. The platforms left standing can support populations of these organisms, allowing them to grow and be harvested at a later date in a sustainable manner (Kolian et al., 2018).

Platforms could also improve fish production by providing necessary habitat for their growth and reproduction (Kolian, 2011). We propose to attach a low-cost, durable black plastic mesh on the pilings of these structures to encourage fish larval settlement and juvenile grow-out. These structures would provide suitable settlement sites and refuges for the planktonic larvae of reef-dependent, demersal fish.

Oil and gas platforms are a favored destination for Louisiana sport fishermen. Approximately 70% of the offshore fishing trips target these structures for this reason (Stanley and Wilson, 1989). Indeed, this interest group has voiced concern about the projected removal of almost all of these structures over the next 10 years off Louisiana.

It has been proposed that a "sea farm" (offshore fish mariculture unit) be constructed, incorporating salvage materials from shallow-water platforms (drawn from < 30 m depth) into a larger system, offshore of (> 30 m depth) and placed in traditional fish grounds (Reggio, 1996; Kolian and Sammarco, 2005). A standing deep-water platform, with 20 or 30 retired shallow-water structures placed around it, would create exceptional fish habitat.

6.1. Fishery resources associated with offshore platforms

Kolian and Sammarco (2018 unpublished) noted 21 different species of obligatory reef fish inhabiting the platforms. Approximately 10,000–60,000 fish will inhabit a structure found in waters > 30 m depth. Scleractinian corals (hard corals) and octocorals (soft corals) are common on deep-water offshore platforms (Sammarco et al., 2004; Kolian et al., 2017), and antipatharians (black corals) are also known to occur there (Boland and Sammarco, 2005). Coral abundances can exceed 1 million colonies on a single platform (Kolian et al., 2017). Many other desirable aquarium invertebrates are known to colonize offshore platforms such as marine algae, tunicates, sponge, bryozoans, and mollusks (Shinn, 1974; Driessen, 1989; Adams, 1996; Dokken et al., 2000; Boland, 2002).

Offshore platforms are populated with species known to possess novel bioactive compounds that represent potential sources of pharmaceutical agents, and other health products. The coral *Tubastrea* spp. is desirable in the ornamental trade and useful for medical purposes (Sakai and Higa, 1987; Pearce et al., 2007; Meyer et al., 2009). Rouse (2009) examined five platforms and found over 400 species of bacteria that produce bioactive compounds and novel secondary products. In addition, they found 24 species of microalgae or ~50% of those sampled to be bioactive. His research team found that 20% of these species appeared to found only on oil and gas platforms.

6.2. Suitable areas for fisheries operations on offshore platforms, Gulf of Mexico

Corals and ornamental fish populations are greater on platforms in deeper water (> 25–30 m depth), probably due to higher salinities, lower turbidities, more sources of recruitment, and more appropriate temperature ranges than in shallower water (Sammarco et al., 2012a,b, 2013, 2014; Kolian et al., 2017, Kolian and Sammarco, 2018, unpublished). Rouse (2009) found organisms with potentially useful bioactive organisms on all the study platforms in both deep and shallower water. He did find, however, that there were more varieties and greater abundances on platforms in deeper waters. At present, there are ~500 of these deep water (> 30 m) structures in the Gulf of Mexico.

6.3. Environmental impacts of utilizing platforms for fishery-related operations

These sustainable fishing operations could create miscellaneous operational pollutants from vessel traffic and platform maintenance. If the platforms are not used for alternate purposes, their removal would destroy the associated ecological communities that have developed on them. Using the structures for sustainable fishery work would preserve the coral community and associated organisms that inhabit the structures. A common coral inhabiting the structures are *Tubastraea* spp. These species are invasive to the Atlantic Ocean (Cairns, 2000; Fenner and Banks, 2004; Sammarco et al., 2013, 2014; Creed et al., 2017); however, they appear to be associated with a diverse community of obligatory reef fish (Kolian and Sammarco, 2018). *Tubastraea* spp. prefer pilings, piers, sunken ships, and artificial reefs and are uncommon on natural coral reefs in the Gulf of Mexico (Precht et al., 2014; Sammarco et al., 2016; Kolian et al., 2017).

6.4. Socioeconomic issues of fishery associated operations on offshore platforms

The platforms are currently used extensively by fisherman and divers. Their activities generate $324 million annually and create 5560 full-time jobs in the marine sport fishing and diving industries (Hiett and Milon, 2002). Elsewhere in the Gulf of Mexico, artificial reefs generate $2.8 billion of income annually and produce 34,900 jobs (Johns et al., 2001; Bell et al., 1998). Today's cost to replicate the equivalent area of the artificial reefs existing in the form of offshore platforms would cost ~$18 billion (Kolian and Sammarco, 2005, 2008).

The U.S. is the world's largest importer of ornamental coral reef resources at $200-$330 million annually (Wabnitz et al., 2003). Kolian et al. (2018) estimated that a single platform could generate ~$1,400,000 of ornamental fish and corals a year. The value of organisms bearing bioactive compounds that may be useful in the medical and nutritional industry is not yet known but is promising (Rouse, 2009).

6.5. Regulatory issues for fishery activities on offshore platforms

Permits to use offshore platforms for sustainable fisheries could be issued under the 30 CFR 285.1000, Subpart J program. These permits are mentioned above and called AU [alternate use] RUE [right of use easements]. They allow retired platforms to remain in the water, after oil and gas production ends. In that case, the marine organisms on the platforms would continue to grow and multiply and they could be harvested in a sustainable manner, as noted above.

At present, there are no fishery regulations which prohibit collecting ornamental organisms that live on offshore platforms. Corals and most of the ornamental fish that inhabit the platforms are not currently managed by the Gulf of Mexico Fisheries Management Council. The corals and other invertebrates living on the structures are not included in the Coral Reef Fisheries Management Plan for the Gulf of Mexico; this means that all the marine invertebrates on offshore platforms in Federal waters are not formally protected and can be harvested.

7. Discussion

Leaving the infrastructure for alternate uses could provide opportunities for wind energy to recover stranded petroleum and sequester CO_2. These technologies are also compatible with sustainable fisheries; however, the opportunities are dependent on saving the existing energy infrastructure in the offshore areas of the Gulf of Mexico.

The geologic basin below the Gulf of Mexico has been identified as one of the largest CO_2 storage settings in the U.S. The offshore platforms can be a promising technology due to several key advantages (Litynski et al., 2011):

- Add more CO_2 storage capabilities in the United States
- Avoid storing CO_2 beneath a population centers and contamination of drinking water
- Surface and mineral rights issues are government-controlled
- Existing oil and gas infrastructure meets the design criteria to process the CO_2
- CO_2 storage sites/platforms are near heavily industrialized areas along the Gulf coast

To realize this potential, it will be essential that we save the infrastructure (platforms, wells, and pipeline system). All things considered, it would help conserve this domestic CO_2 storage area and hydrocarbon resource endowment.

It will be important that when legal and regulatory frameworks are drafted for the purpose of verifying and accounting for reduction of greenhouse gas (GHG) emissions, they acknowledge the importance of CO_2 storage with CO_2-EOR in achieving GHG emissions reduction goals.

The economic recovery of this undeveloped offshore oil and gas resource will also depend upon:

. Future crude oil and natural gas prices;
. Cost of future supplies of CO_2 (perhaps influenced via incentives for reducing CO_2 emissions, such as the geologic sequestration of anthropogenic CO_2); and
. The economic risk associated with these projects, because of their

technological challenges (perhaps influenced through government risk-sharing programs via fiscal incentives to encourage CO_2-EOR).

In addition, more comprehensive assessments of the benefits of these usages will be required, and policy makers and industry decision-makers should be informed of these potentials.

For reasons outlined above, the transfer of electricity from a modified platform or wind farm to other offshore platforms appears more promising than transferring to shore as demonstrated in the Beatrice project offshore of Scotland. This would eliminate the need for high-voltage transmission to inshore communities. The feasibility will depend on a variety of factors. In general, diesel-powered platforms distant from shore will be more amenable to offshore wind-driven energy generation than natural gas-powered platforms and those close to shore. This is because the transport costs of fuel, as well as average wind speeds, increase, making wind power more profitable. Again, these structures are most likely to be the newest structures in the deep water furthest from shore.

Wind farms could also serve as a source of power for CO_2 capture and storage projects, and they could provide enough cheap electricity to make CO_2-EOR economically feasible in the Gulf of Mexico. We suspect that providing offshore wind energy to the adjacent oil and gas operators would be more successful in deeper waters (> 50 m).

Some retired platforms are converted into artificial reefs. Most if not all of these platforms are either toppled in place, or transported to a designated "Rigs-to-Reefs" area and toppled there. It should be noted that it is better, for the coral communities to leave a platform standing than topple it. This is because most of the resident organisms would not survive if the platform is reefed. Organisms surviving the transport and toppling procedure are generally not adapted to live in waters > 30m, which is generally the depths where the structure is relocated – a necessity, due to shipping needs. A total of 90% of the fish either perish or are lost to the biota when a platform is toppled over and converted into an artificial reef (Wilson et al., 2003). Most of the invertebrate community exhibits a preference for the upper 30 m of the water column beneath a platform (Sammarco et al., 2004; Dokken et al., 2000; Sammarco et al., 2014; Kolian et al., 2017).

Several categories of expenses will be associated with any venture utilizing retired offshore platforms. These include expenses associated with a platform removal bond, navigational aids, maintenance, liability insurance, and cathodic protection. The high cost of the platform removal bond could well prohibit the economic success of many types of alternative applications. Under current legislation, if an alternate use venture were to fail, the Federal government would hold the previous owner responsible for removing the structure. An indemnification program is needed to assure that the original owner is not responsible for removing the platform or the cost of such, and that the alternate use platform is ultimately re-deployed on the continental shelf as an artificial reef. This would alleviate the need to remove the structure, and relieve the previous owner from his responsibility to remove it. Successful implementation of a new alternate use program would depend on a clearly defined authorization to transfer the primary liability of the retired platforms from the previous oil and gas operator to the alternate use applicant. This liability issue is not currently addressed in the new Renewable Energy and Alternate Uses of Existing Facilities on the OCS, 30 CFR 285.1000, Subpart J legislation.

The U.S. is spending billions of dollars removing retired oil and gas platforms, while other countries are installing their own offshore platforms for purposes other than petroleum production. Our removal of offshore platforms and the dismantling of their associated pipeline systems is economically stranding a respectable volume of crude oil and natural gas on our continental shelf that could otherwise be recovered with new, emerging oil and gas CO_2-EOR technology. A variety of future economic activities in the Gulf of Mexico could take advantage of this infrastructure, if it remains in place. Evaluating alternate uses for offshore platforms that are no longer in production could help to preserve of platform-associated benthic and demersal communities and avoid the mortality of millions of protected organisms while simultaneously meeting the objectives of U.S. Federal environmental, energy, and fisheries legislation.

Conflicts of interests

The authors declare that there are no conflicts of interests.

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