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1 FORWARD

The Gulf of Mexico has seen very little investment in offshore renewable energy or the blue economy, largely due to three misconceptions:

- That the available renewable energy resources are low. (Can't make power)
- That the availability of low cost onshore renewable power means the offshore renewables are not competitive. (Can't make a profit)
- That the presence of the offshore oil and gas industry will limit the deployment of other offshore activities. (Project development will be more difficult)

This study shows not only are these assumptions incorrect, but that the opposite is true, there is a significant offshore renewable energy resource, that when while grid prices are low along the coast there are other higher value uses for the power, and the presence of oil and gas facilities, existing leases, and local support make the Gulf of Mexico add value to any development.

While the wind, wave, and tidal resources are lower than on the East and West coasts they are higher than commonly assumed, and when combined with offshore geothermal (unlikely on either coast) and Ocean Thermal Energy Conversion (not possible on the west coast or east coast north of Georgia) the total available resource per square kilometer is at least equal to and probably higher than the competing areas.

There is a great deal of onshore wind and solar among the Gulf Coast states, primarily in Texas, but it still makes up less than 25% of the primary electrical power. Nuclear and hydropower make up about 10% with coal and gas making up the remaining 65%. So, there is a significant need for more renewable energy. The price point is an issue, with wholesale prices into ERCOT (the Texas utility) averaging about $0.04/kWh in 2019 (EIA). What previous studies have not addressed adequately is the opportunities along the Gulf Coast to use offshore renewable energy for purposes other than grid power. In this study we examined these value-added or alternative market opportunities and found several that offer much higher potential return than simply selling green power to the grid.

The primary focus of this study is how to turn legacy oil and gas facilities into assts for accelerating the growth of offshore renewable energy and the blue economy in the Gulf of Mexico. While it is true that the Gulf coast economies are currently dependent on oil and gas, the presence of these platforms, wells, and pipelines makes the area more receptive to offshore renewables, not less.

Permitting offshore developments in the Gulf is commonplace and the local communities support development, which contrasts with the onerous and sometimes contentious permitting environments on either coast. Added to that is the fact that for active oil and gas leases there is an expedited permitting process possible under 30CFR 585 Subpart J. While the OCS is in theory Federally controlled, a simple look at the map of oil production in the Gulf of Mexico shows that the local state has the final word. There are no oil and gas developments off the Florida Gulf Coast, despite there almost certainly being reserves there.

The cost of construction for offshore facilities is much less on the Gulf coast, installation vessels are easier to find, and there is a skilled workforce from oil and gas looking for an outlet for their skills.

Gulf Coast fisherman know the value of offshore facilities to the ecosystem, and now typically oppose the complete removal of offshore facilities.

As we will show the legacy oil and gas assets have real value that has not been fully explored in previous similar studies.

Unlike the East and West coast, where drilling a new well, even if for geothermal or carbon sequestration purposes, would meet with resistance from local communities, in the Gulf wells are drilled nearly every day with very little fanfare.

The Gulf of Mexico is undoubtably the best place to test prototypes and new techniques. Low cost, predictable and generally more benign weather, punctuated by storms and high winds and waves gives an excellent range of data; experienced personnel and available vessel and crews; and friendly regulatory climate combine to make an attractive offshore test bed location. Add to that the availability of existing idle platforms that can be used as hosts and the Gulf Coast offers advantages not found anywhere else in the world.

In summary contrary to the perception the Gulf is the least desirable area for offshore renewable energy deployment un the US, the Gulf of Mexico is the best area in terms of economic opportunity. Addressing the initial misconceptions:

- The renewable energy resources in the Gulf are excellent and will be more reliable than the conventional wind developments being planned for the other coasts. (Can make MORE power)
- The combination of the need for more clean power onshore, proximity to the largest refinery complexes in the world that need hydrogen and produce carbon dioxide in recoverable concentrations, and the need to power offshore oil and gas development and Blue Economy industries means there is a large and growing market for offshore renewable power or the products you can make with it. (Potential for MORE PROFIT than selling power on the coasts)
- The presence of offshore oil and gas developments means leasing and permitting is simpler, development and operational costs are less, the legacy facilities can be used for energy hubs or hosts for aquaculture, the pipelines can be used for exporting power to shore or importing CO_2 for sequestration, and the wells can be used for carbon capture and storage or geothermal energy production. (Project development is cheaper, carries less risk, and execution times are shorter)

The DOE study provides detailed answer to the following questions:

- What is the potential utility of legacy platforms, wells, and pipelines to renewable energy and Blue Economy activities?
- What renewable energy systems are economically viable in the Gulf of Mexico and can be deployed safely on existing leases?
- What Blue Economy industries can be facilitated by using legacy assets in the Gulf of Mexico?
- Who can apply for and what is the process for repurposing existing assets or adding new assets to existing leases?
- What are the benefits to the current owners, the Gulf Coast Region, and environment?

Finally, the study provides the outline of a process that stakeholders can use to evaluate individual existing facilities for potential use in building a Blue Industrial base in the Gulf of Mexico.

2 ABSTRACT

This paper presents a summary of the results of a study of the potential for repurposing legacy oil and gas facilities in the Gulf of Mexico for Renewable Energy and Blue Economy uses. The Phase I Study Scope consisted of developing actionable plans for furthering the following activities:

2.1 Topic I - Permitting of legacy oil and gas facilities.

Gaps in the permitting process for legacy assets were identified by submitting applications for three jacket platforms on two separate leases, all of which were slated for decommissioning. A Joint Industry Project (JIP) is being organized that will clarify the specific requirements for inclusion into a Request for Alternate Use and Easement of a platform, pipeline, or well that is no longer active.

2.2 Topic II - Legacy Facility Repurposing Options & Methodology

The first task is to identify what activities are the facilities suited for possible uses for legacy platforms, pipelines, and wells were summarize. These possible use cases are then examined more detail.

2.3 Topic III - Methods of Renewable Power Generation in the Gulf of Mexico

Estimating the power generation potential, which consists of an evaluation of the available resource, and a technology review. Wind, wave, ocean currents, ocean thermal energy conversion, and offshore geothermal technologies were researched and areas where the work could most cost effectively be advanced identified.

2.4 Topic IV - Greening of Oil and Gas Production

Review of oil and gas activities where application of renewable energy would reduce the carbon load per barrel of oil equivalent. This includes powering existing platforms, producing new fields by long tie backs to platforms that would have been decommissioned, or even long tie backs to shore.

2.5 Topic IV - Green Hydrogen & Ammonia Production

Methods of generating, storing, and transporting pure hydrogen were examined, and several promising technologies for offshore use were identified for further development. One system is ideally suited for offshore use and potentially eliminates the need for energy intense hydrogen compression.

The use of offshore pipelines for transport of pure hydrogen was found not to be feasible. Storage of offshore hydrogen production is likely to be subsea and these systems are presented.

2.6 Topic VI - Synthetic or E-fuel Production

Requirements of a Power to Fuel Systems (so called synthetic or e-fuels) were identified. This technology to convert hydrogen and carbon monoxide (together called syngas) into hydrocarbons is well established but has seen growing interest and there are several companies working to reduce the cost of the process. The difficulty arises from difficulty in sourcing carbon dioxide from sources other than burning fossil fuels, and the high energy cost of green hydrogen.

2.7 Topic VII - Carbon Capture, Utilization and Sequestration (CCUS)

Direct Air Capture (DAC) technology is both large and requires significant amounts of energy. Alternative methods of pulling carbon dioxide were researched including Direct Water Capture (DWC), which is more efficient than DAC. Some of the DWC systems sequester the carbon in solid form, so capture and sequestration are combined in one activity.

The use of legacy offshore pipeline for transporting capture carbon dioxide for injection into legacy reservoirs is considered.

2.8 Topic VIII - Desalination and Water Treatment Options

Desalination technologies are proven, but because of growing demand more efficient, lower cost, and lower maintenance systems are being developed. A specific case for Willacy County was developed.

2.9 Topic IX - Mineral Extraction

Given the ever-increasing need for rare earth mineral, and the limited global supplies, local supply has become a security issue. Many minerals are present in potentially recoverable quantities in both seawater and produced well fluid.

2.10 Topic X - Aquaculture, and algae, and seaweed farming

Aquaculture development in the Gulf of Mexico has been under consideration since the early 1990’s and utilizing legacy oil and gas platforms was considered as recently as 2011. However, in each case only the effect of having a pre-built structure was included in the analysis. Possible synergies with other activities or use of legacy pipelines were not considered. The US currently has less than 1% of this 250-billion-dollar industry.

2.11 Topic XI - Use of existing platforms for Monitoring, Security, and Test Facilities

Research opportunities with the Department of Defense to test technologies and equipment on the offshore platforms and provide renewable fuels.

2.12 Topic XII – Target Platforms

This section provides an updated listing of those platforms that GORI is trying to acquire repurposing permits for. Following the failed attempt to permit PN975 an alternative approach is being proposed.

3 SCOPE LIMITS OF THE REPURPOSING STUDY

The term Blue Economy is defined by the World Bank as a sustainable use of ocean resources for economic growth, improved livelihoods and jobs, and ocean ecosystem health, encompassing:

- Renewable energy,
- Aquaculture and fisheries,
- Maritime transport and security,
- Tourism,
- Waste management and water quality
- Climate change mitigation

This study is confined to the repurposing of oil and gas facilities in the Gulf of Mexico, specifically platforms, wells, pipelines, leases, and rights-of-way. Both producing, idle, and abandoned assets were considered. The objective is to provide a map of how leveraging these existing facilities can reduce the carbon load of offshore oil and gas production, speed the energy transition by tapping the tremendous energy potential of the ocean, reduce US dependence on imported seafood and mineral, and create secure long-term jobs along the Gulf Coast.

While the study is Gulf of Mexico focused the techniques and technologies can be globally applied to any existing offshore oil and gas field.

4 WHY THIS IS URGENT

To speed up the energy transition of the Gulf of Mexico the current policy of removing non-producing assets must be stopped. These facilities, providing they are still in good repair, can be a tremendous asset that can accelerate the decarbonization of the Gulf Coast Region, and become the basis for an industrial transition that will create more employment and value than even the peak of offshore oil and gas. The Gulf of Mexico is the most developed offshore industrial area in the world, as can be seen in Figure 1, and the numbers are staggering, per BSEE:

- 55,000 wells drilled, 20,000 still active
- 75,000 km of pipeline laid, 40,000 km in use, (many legacy lines abandoned in place)
- 7160 structures installed since 1947, 1635 still exists, 900 still active

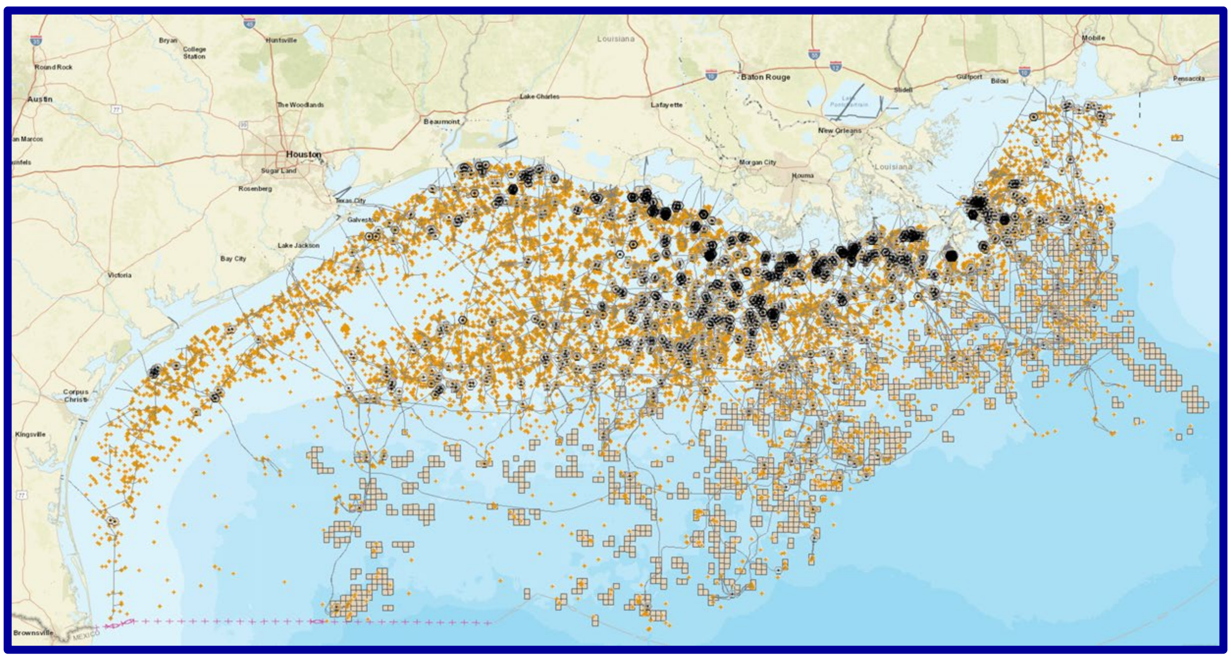
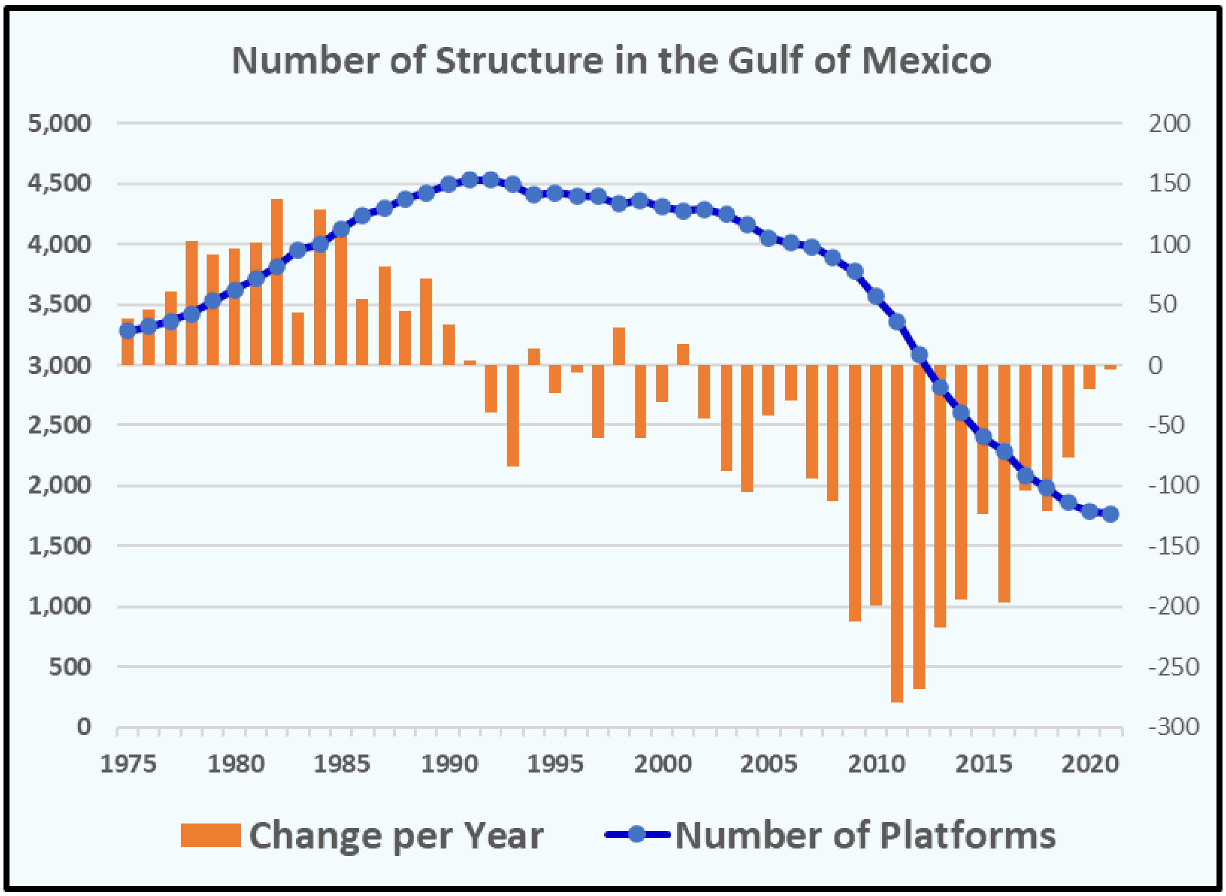


Figure 1 - Map of oil and gas lease, platforms, pipelines and wells (Source: BSEE)

The total number of platforms in the Gulf of Mexico peaked at around 4500 in the 1990's, and as recently as 2013 there were 3000 platforms. While there is still a large pool of legacy facilities that can be repurposed, since 2011 the rate of removal for platforms has accelerated and is shown in Figure 2 below. A combination of the reorganization of the old MMS into BOEM and BSEE in response to the Macondo incident, and then BSEE being left with platforms to decommission that had no previous owner made the agency change its policy regarding decommissioning bonds. The end result is that platforms that previously had been left in place, were now removed at an accelerated rate averaging about 200 per year since 2016. Per BSEE of the slightly more than 1600 platforms and structures still in the Gulf more than 600 of them either already have a submitted decommissioning plan or are on terminated leases.

While it has occurred without fanfare, that means for the first time since 1970 there are less than 1000 structures still in active service. Were there no other use for these facilities that would in general be a good policy. For years structures that should have been removed were allowed to sit, slowly deteriorating. Many being destroyed by hurricanes, requiring salvage work. Of the platforms slated for decommissioned it is expected a good portion will unfit for repurposing, but those that are still in good repair can be used to speed the transition of the Gulf to a major renewable energy center. But to do so will require changes in the policies and regulations. The rules in place are based on oil and gas facilities, which have a finite life span tied to how much oil or gas is in the reservoir. Renewable energy installations are not so constrained. This will be further explained in the next section on the required regulatory approach.

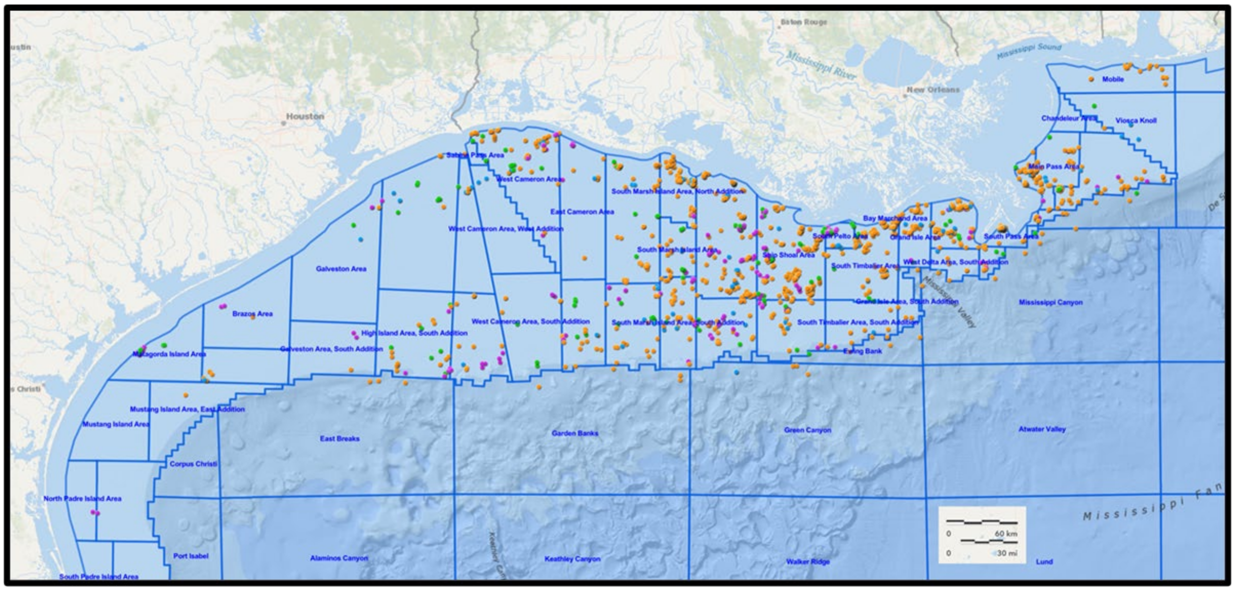


Source: BSEE Data Center

Figure 2 – Number of Platforms in the Gulf of Mexico

When mapped, shown below in Figure 3 the platforms slated for decommissioning or on terminated leases offer a wide range of repurposing activities, especially those near the escarpment, but BSEE's goal is to remove them as quickly as possible.

More complex are the wells. In most cases even for those platforms that will remain the wells need to be what is called "plugged and abandoned". This activity seals the well permanently far below the mudline. Once this is done there is no risk of oil or gas leakage, and the platform can be repurposed as a strictly renewable energy or blue economy structure. This has permitting and safety system implications. The situation becomes more complex if the wells are repurposed for either geothermal, brine mining, or carbon sequestration uses. While the policy regarding platform removals needs urgent action to stop removing sound structures, the policy regarding wells will need a working group to study and determine a suitable policy.



Sources: [BSEE Offshore Infrastructure Dashboard]

Figure 3 - Map of oil and gas platforms, slated for removal

TOPIC I - Permitting of legacy oil and gas facilities

5 REGULATORY APPROACH AND STATUS

There are four primary sets of regulations pertinent to repurposing efforts in the Gulf of Mexico. Those pertaining offshore mineral extraction (oil, gas, and mining), those for offshore renewable energy, those pertaining to aquaculture, and newly issued ones pertaining to carbon capture and sequestration. The scope of this paper does not allow an in-depth study of the permitting processes and requirements for each technology proposed. Instead, we will focus narrowly on the most applicable process to the repurposing of existing oil and gas facilities which is CFR30 585 Subpart J which pertains to the issuance of an Alternative Right of Use and Easement, often referred to simply as an ARUE.

Congress passed the Energy Policy Act of 2005 (EPAct) 17 years ago. This law forged the way for offshore renewable energy. Congress asked the Department of Interior to write regulations for offshore wind power and the re-use of the offshore platforms for marine-related purposes. The Bureau of Offshore Energy Management (BOEM) within the Department of Interior is responsible for issuing permits for these activities.

30CFR 585J can be used to expedite permitting the deployment of renewable energy in the Gulf of Mexico. This regulation specifically is written to allow addition of renewable energy and other marine activities on to existing oil and gas leases and is written broadly enough it can be applied to other Blue Economy activities.

§ 585.1000 What activities does this subpart regulate?

(a) This subpart provides the general provisions for authorizing and regulating activities that use (or propose to use) an existing OCS facility for energy- or marine-related purposes, that are not otherwise authorized under any other part of this subchapter or any other applicable Federal statute. Activities authorized under any other part of this subchapter or under any other Federal law that use (or propose to use) an existing OCS facility are not subject to this subpart.

Included in this study was a permit application for an ARUE for PN975, submitted to BOEM. PN975 which has been on the idle iron list for 8 years, and at the time was owned by Peregrine Oil and Gas LLP (Peregrine). Initially the permit application encompassed an area around the platform extending out 1 mile to allow for installation of test sites for renewable energy and aquaculture technologies, but to include that area would have required a new subsea archeological study and due to budget constraints, it was decided to remove these areas from the initial permit application.

Gulf Offshore Research Institute, one of the participating companies in the study, has entered into agreement with another oil and gas company to apply for AURUE permits for two additional platforms. These platforms are located off the mouth of the Mississippi River. Additional research is needed to determine the alternate uses of the platforms and the benefits to the ecosystem. The Phase II funding will be used to perform research on these alternate locations.

Regulatory Timeline for Peregrine PN 975 and PN 969 Platform Re-purposing	
Jul 2019	Initial meeting of GORI and Peregrine
July 2019	MOU signed between GORI and Peregrine
July 2019	GORI proposal to Peregrine and meeting of GORI/Peregrine/Excipio
Aug 2019	Peregrine ARUE request submission to BOEM for PN 975 and PN 969
Dec 2019	BOEM Request for Information (RFI)
Apr 2020	Peregrine submission of BSEE Platform Re-Use permit
Apr 2020	Peregrine AMENDED ARUE submission to BOEM
June 2020	BSEE Request for Information (RFI) to Peregrine
Nov 2020	Peregrine response to BSEE RFI
Mar 2021	BOEM letter of deficiencies and intent to reject ARUE Request if Peregrine does not address inadequacies in the BSEE permit application (I.e., platform underwater inspections
May 2021 inspections	Peregrine extension request to BOEM to complete the underwater
June 2021	BOEM issues rejections letter to Peregrine
July 2021	BSEE issues decommissioning order to Shell (the platform installer)
Aug 2021	Peregrine appeals the BOEM and BSEE rejections to the IBLA

Once a platform is slated for removal due to lack of productive use by the operator its control falls under BSEE to enforce its decommissioning, so while approval of the ARUE is the responsibility of BOEM, this case had BSEE as the lead agency. 30CFR 585J is clear for an active lease BOEM is the lead agency. This relationship between the two agencies was further clarified in December 2020 by a Memorandum of Agreement (MOA) between the agencies.

BSEE required inspections, that were planned for after receipt of the ARUE, be accelerated to be done prior to issuance, with no guarantee of approval. Despite the risk Peregrine agreed but requested an extension so the work could be done later in the year when weather would be better. BSEE declined the extension, and Peregrine saw too much risk to proceed, and the ARUE was denied on that basis. The platform has since reverted to Shell Oil Company control, as the original responsible party when Peregrine declared bankruptcy.

One of the issues identified is that for an active lease, with a platform still in service, placing renewable energy devices on the block requires the operator to show only that it will not interfere with existing operations. However once platform is idle, abandoned, or has a planned decommissioning date the regulations are not clear on what is required. Whereas the assumption for an active facility is that it is structurally sound, and fit for service, once deactivated BSEE assumes that the facility is no longer sound and requires the operator proposing the ARUE to show otherwise. This creates uncertainty and makes the decision for an operator to repurpose unnecessarily complicated. Most will not want to repurpose an active platform, yet once they declare it not active the requirements are not defined.

Clarity around this issue is key to bringing renewable energy to the Gulf of Mexico. The ability to repurpose a lease, without going through a new lease round will be a powerful draw to the area and will be an important differentiator for Gulf of Mexico projects when compared to the East or West Coast. Permitting outside of the western Gulf of Mexico is a complex process with stakeholders who are not familiar with offshore development. This delays the process even in locations that publicly welcome renewable energy. Even a greenfield development in the Gulf of Mexico will be welcomed by the local population, and unlike either coast, many local communities want facilities located offshore because of the jobs they bring to the local economy. What 30CFR Subpart J potentially does is cut the required permitting time down, because if there is an existing oil and gas facility than most of the survey, outreach, and environmental impact statements are in place.

As a final bonus because the Gulf of Mexico is a prime bird migratory route, it is well studied. While the presence of these migratory routes means conventional wind may be restricted in some areas, it also means that the required bird studies are also largely in place.

In summary, in terms of length of time from application to permit, it is unlikely that any location in the US can compete with an existing active offshore oil and gas lease. Figure 4 below shows a typical application sequence.

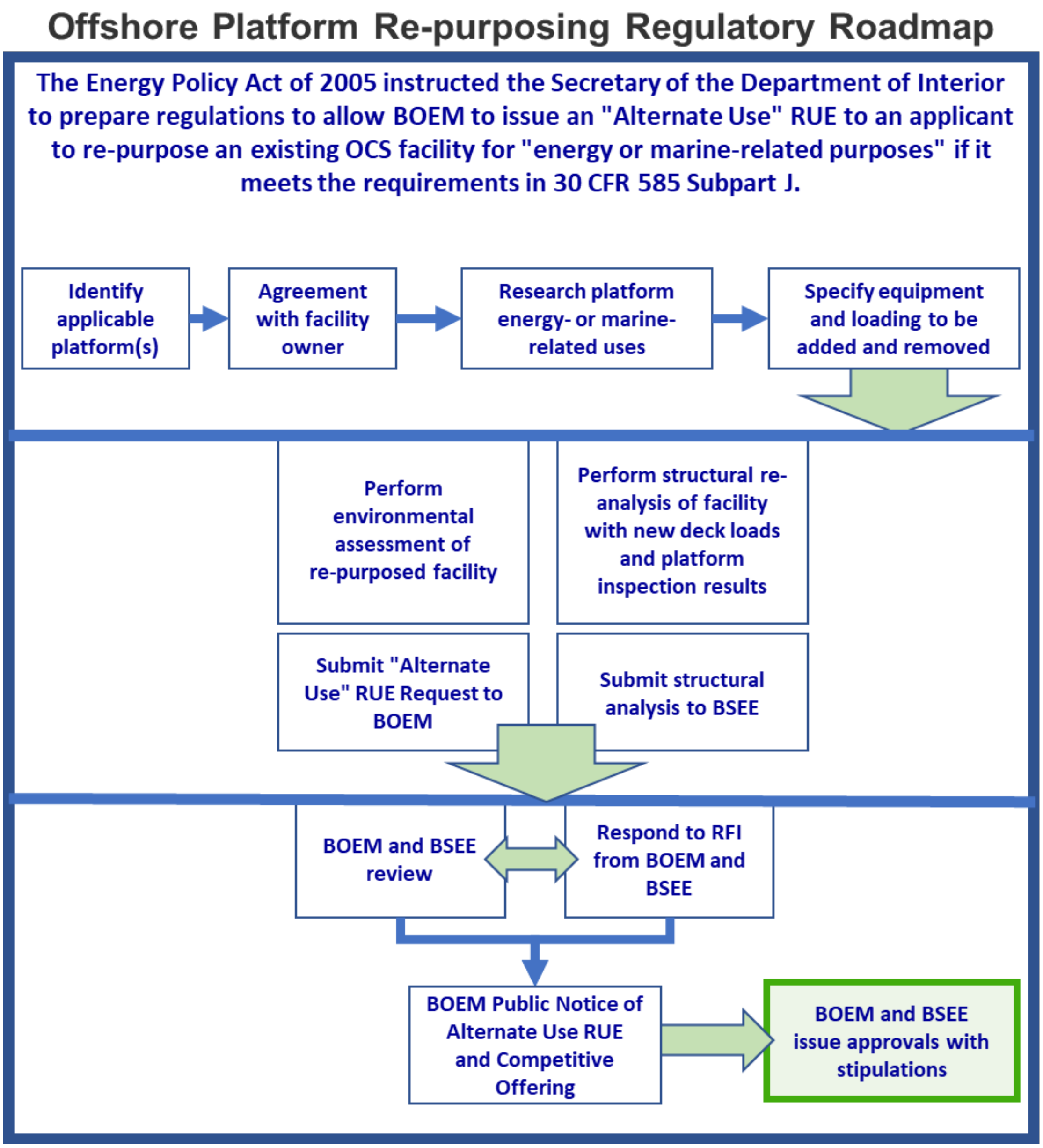


Figure 4 – Offshore Application for an Alternate Right of Use and Easement

6 ENERGY RESOURCE POTENTIAL AND DEFINITION

6.1 NREL/BOEM Resource Estimates

In 2020 NREL, at BOEM's request authored a report, OCS Study BOEM 2020-017 "Survey and Assessment of the Ocean Renewable Energy Resources in the US Gulf of Mexico". NREL divides resource assessments into Gross and Technical Potential. Gross is intended to be the total available resource. Technical is based on NREL's assessment of how much of the resource could be captured economically using proven technology. The report covered all the renewable energy technologies included in this study with the exception of offshore geothermal. Details are included here because the NREL/BOEM report has caused some questions to be raised by those reviewing the DOE report, as our study includes the use of wave energy which is listed as having zero technical potential within the Gulf of Mexico by NREL.

The NREL report methodology makes conservative assumptions regarding the gross potential resources, but it is used for this report as a starting point for estimating the energy potential in the Gulf of Mexico. The actual gross potential is higher, but it was not within the scope of this study to fully quantify by how much for each technology. Per NREL, the Gross potential number for wind also includes an assumed capacity factor, which should more correctly be part of the "Technical Potential" as it is technology specific. For Gross wind an assumed capacity factor of 47% was assumed by NREL, actual Gross potential would therefore be 4,000 MW, not 1,800 MW in the report. This is important because different wind technologies have differing capacity factors. The same may apply to solar, wave and ocean flow energy capture technologies, but lacking the specific factor used by NREL the published gross potential for those technologies must be assumed.

The Technical Potential assessment is simply incorrect. The source of the error lies in what NREL consider as available technologies, and the assumption that a development would be a single technology deployment. Combined systems, where more than one technology is deployed as part of a single project and capital costs are shared are not considered in their models. This alone would make wave energy recovery for example practical, which the report lists as having a Gulf of Mexico Technical Potential of zero. There are technological solutions available where even standalone wave energy projects are feasible in the Gulf of Mexico. The definition of what is Technically recoverable is subjective, and even within NREL changes. For example, in the 2016 wind assessment the Gross wind potential in the Gulf is the same at 1800 GW, but the Technical Potential has decreased by the 2021 BOEM report from 577 GW to 508 GW with no explanation of why. The Technical potential is really the "Economic" potential in that it is based on NREL's estimation of what is proven and could be installed to sell power to the grid at a reasonable price. The sale of value-added commodities such as hydrogen or the value the power would bring to an oil and gas platform, or aquaculture development do not factor into the NREL definition of "Technical Potential."

6.2 Gulf of Mexico Site Specific Resource Data

The quantity and quality of available metocean data in the Gulf of Mexico is unique in US waters. Data on wind, wave, currents, and water temperature are critical to oil and gas activities and good data sets go back 40 years or more. As a result, it is comparatively easy to develop very localized resources assessments, as was done for this study at considered locations. For any entity wishing to repurpose an oil and gas facility the first exercise is to have this data collected and analyzed to generate site specific gross potential and characteristics. For thus study available buoy data was utilized to characterize the response of the technologies reviewed at three locations, the PN 975, WC 465, and SP 83. These differed enough from the published data that it is clear a better resource modeling tool is needed. In particular a model that will examine joint probabilities of coincidence for wind, wave, current, and temperature.

The resource evaluation is a key starting point as from it the best technologies to fit the site can be determined. Different wind turbine designs for example work better in different wind distributions, and wave energy devices are sensitive to both period and height, with some working best in short choppy waves, and other working best in long constant swells.

Ocean currents in the Gulf of Mexico are generally low velocity with loop currents being an exception. Loop currents are however difficult to predict in terms of exact location, duration, and intensity.

7 INTEGRATED RESOURCE MODEL FOR WIND, WAVE, AND CURRENT ENERGY

There is a widely identified need for robust and efficient wind, wave, and current resource characterization, and environmental and operational monitoring for marine energy (ME) sites. A user friendly software tool for ME site characterization and monitoring will make ME siting and monitoring, and ease of computing annual energy production (AEP) possible for a range of Powering the Blue Economy (PBE) applications. Further, by ensuring that such a tool adheres to international standards (e.g., International Electrotechnical Commission [IEC] TC 88 and TC 114) will allow ME deployments to develop both the regulatory and financial assurances required for success.

Knowledge of regional ME resource characteristics, specific to the Gulf of Mexico (GoM), enables an understanding of the unique design criteria and characteristics of ME technologies for PBE applications. To fully investigate opportunities for ME technologies to support PBE applications, a thorough ME focused integrated resource model is needed. The sections below discuss the qualification of the Integral team who will be developing the model, and the methodology to be followed.

7.1 Integral's Qualifications

Integral is an internationally recognized science and engineering consulting firm with an exceptionally strong marine sciences and engineering practice. Our staff brings a diverse skill set of technical knowledge, innovative approaches, and experience to address needs in the offshore environment. The Integral team distinguishes itself from other metocean providers by providing real-world experience in the GoM and oceanographers that have ongoing high resolution wind, wave, and circulation models running in the region. Integral staff members have decades of experience working on offshore projects worldwide, including metocean analyses and geophysical and environmental surveys; and therefore, have a practical understanding of the overall challenges facing companies working along the coastline of and within the GoM. Most recently, Integral has supported multiple North American offshore metocean and environmental surveys that were needed to meet regulatory requirements for securing permits. Specifically, Integral has conducted field support, analysis, and reporting for site characterization programs at sites for Equinor, Shell, Ørsted, BP, BHP, Total, Petronas, Hokchi, and others, which included metocean analyses and measurements.

We strive for the highest possible data quality and analysis procedures through effective data collection and implementation of data analysis protocols following internationally approved standards (e.g., DNV, International Organization for Standardization [ISO], IEC), and adherence to strict data quality assurance, data storage, and database management for easy access of information.

7.2 Methodology

The metocean conditions, wind, waves, currents, and water level, for possible ME siting areas in the GoM will be established on the basis of readily available data (both measured and modeled). The primary datasets that will be used for the proposed analyses are from reanalysis of hindcast data assimilative models. To date, these are the most robust datasets that meet the needs of metocean analysis for ME applications. Table 1 lists the primary parameters, analyses to be conducted, and the likely data sources to be used. Primary datasets are listed first, with a backup dataset provided where available.

Parameter	Analysis	Data Source(s)*
Wind	Time series, annual and monthly statistics, wind roses, wind speed direction occurrence matrices, and persistence of wind speed at 90 m above sea level (ASL). Characteristic ambient turbulence intensity and standard deviation of the turbulence intensity at 90 m ASL as a function of wind speed and wind direction. Site specific wind shear profile for normal conditions.	NREL, ERA5
Waves	Time series and annual and monthly statistics, wave roses, and scatter plots of significant wave height and peak wave period and direction occurrence matrices. Joint probability of wind/wave misalignment versus significant wave height, of wind/wave misalignment versus mean wind speed, and of significant wave height/wind speed per wind direction. Normal sea states as per definition of defined in IEC 61400-3. Where relevant, the wave regime shall be split into local sea and distant swell regimes. Spectral shape parameters for waves shall be specified for the day-to-day conditions.	NREL, NOAA
Currents	Time series and annual and monthly statistics, current roses and current speed direction occurrence tables for 3 levels in the water column Annual variation in sea surface temperature.	GOFS 3.1, ROMS
Water Levels	Astronomical water levels (LAT, MLWS, MLWN, MSL, MHWN, MHWS, HAT) and time series of tides.	NOAA

*Data sources subject to change based on initial study findings.

Table 1. Metocean Parameters, Analyses, and Data Sources Anticipated for Use with the Integrated Resource Model

In addition to the analyses described in the above table, the option for extreme event analysis is also a useful tool for ME developers. Upon assessment of these extreme events, long-term statistics of the available data and model hindcasts will be conducted to determine the probability of individual event occurrence as well as the joint probability of multiple parameters during an extreme event. For example, the joint probability of extreme wind, waves, and currents during a large storm event. The integrated resource model will at a minimum will include the parameters listed in Table 2.

Table 2. Extreme Value Analysis Specifications for Selected Metocean Parameters.

Parameter	Recurrence Intervals	Analysis
Winds	1, 10, 50, and 100-year	Mean, gust, and probable maximum wind velocity Wind direction
Waves	1, 10, 50, and 100-year	Mean, significant, and probable maximum wave height and period for swell and seas Wave direction
Currents	1, 10, 50, and 100-year	Mean current velocity Current direction

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7.3 Primary Data Sources

The basis for the data provided by integrated resource model will follow a standard methodology for investigating the metocean parameters and analyses identified in the tables above. These parameters and analyses are guided using protocols that follow internationally approved standards. Site specific measurements and available hindcast data and model results will be compiled into a database that will form the back end of the integrated resource model. Integral staff have deep familiarity with the most recent hindcasts and data inventories available to perform these standard analyses. The metocean datasets referenced in Table 1 above are discussed in more detail below.

7.3.1 Wind – National Renewable Energy Laboratory

The wind data provided by the National Renewable Energy Laboratory (NREL), is a 21-year wind resource dataset for offshore of the continental United States (U.S.). This dataset replaces NREL's Wind Integration National Dataset (WIND) Toolkit, a 7-year dataset that is currently the principal data set used by stakeholders for wind resource assessment in the continental U.S. These data are provided at 2 km horizontal resolution. Both the WIND Toolkit and the offshore dataset were created using the Weather Research and Forecasting (WRF) numerical weather prediction model. As a benefit, the offshore dataset uses an updated version of the ERA5 reanalysis to force the updated WRF model, overall providing an enhanced wind dataset.

7.3.2 Waves – National Renewable Energy Laboratory

The NREL U.S. Wave Dataset was funded by the U.S. Department of Energy to improve our understanding of the U.S. wave energy resource and to provide critical information for wave energy project development and wave energy converter design. This high resolution, publicly available, long-term wave hindcast dataset currently encompasses the Atlantic Coast and GoM (Figure 5).

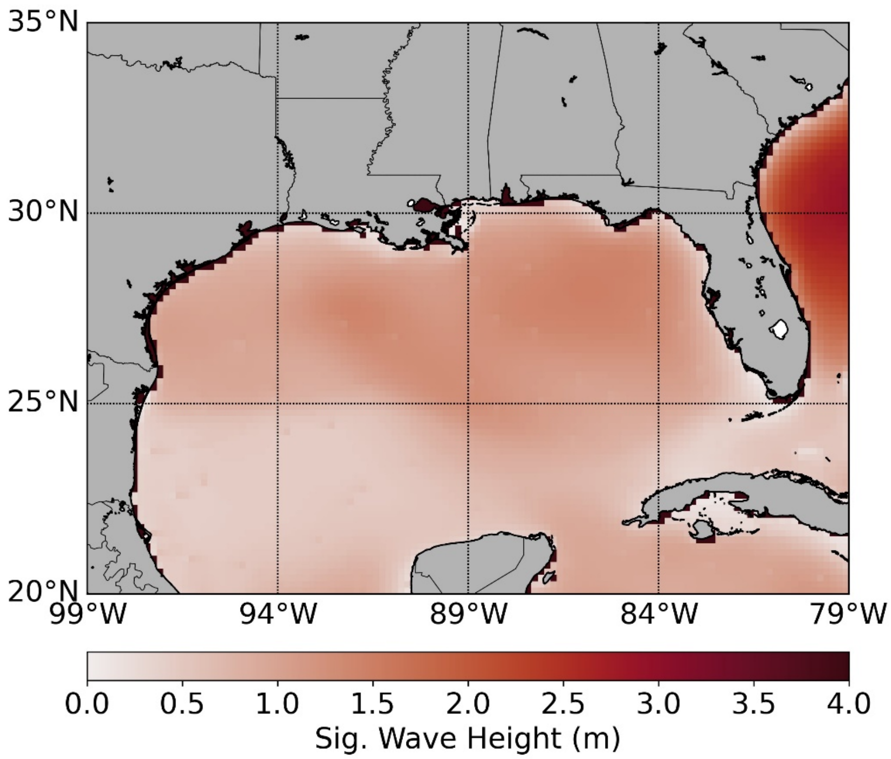


Figure 5. Significant Wave Height Snapshot for the GoM Region from the Specified Model Data Sources

7.3.3 Currents – GOFS 3.1 Global Reanalysis

The Global Ocean Forecasting System (GOFS) 3.1 Global Reanalysis data set is a modeling system combining the Hybrid Coordinate Ocean Model (HYCOM) and the Navy Coupled Ocean Data Assimilation system (Figure 5). These data were provided by the HYCOM consortium, a multi-institute project sponsored by the National Ocean Partnership Program as part of the U.S. Global Ocean Data Assimilation Experiment. The horizontal resolution is 0.04°, provided at 32 vertical layers. The bathymetry is derived from the General Bathymetry Chart of the Oceans dataset. Surface forcing is from 1-hourly National Centers for Environmental Prediction Climate Forecast System Reanalysis and includes wind stress, wind speed, heat flux, and precipitation. Sea surface height data are available from this reanalysis dataset, though at 3-hour intervals, which is too coarse for the proposed water level analysis.

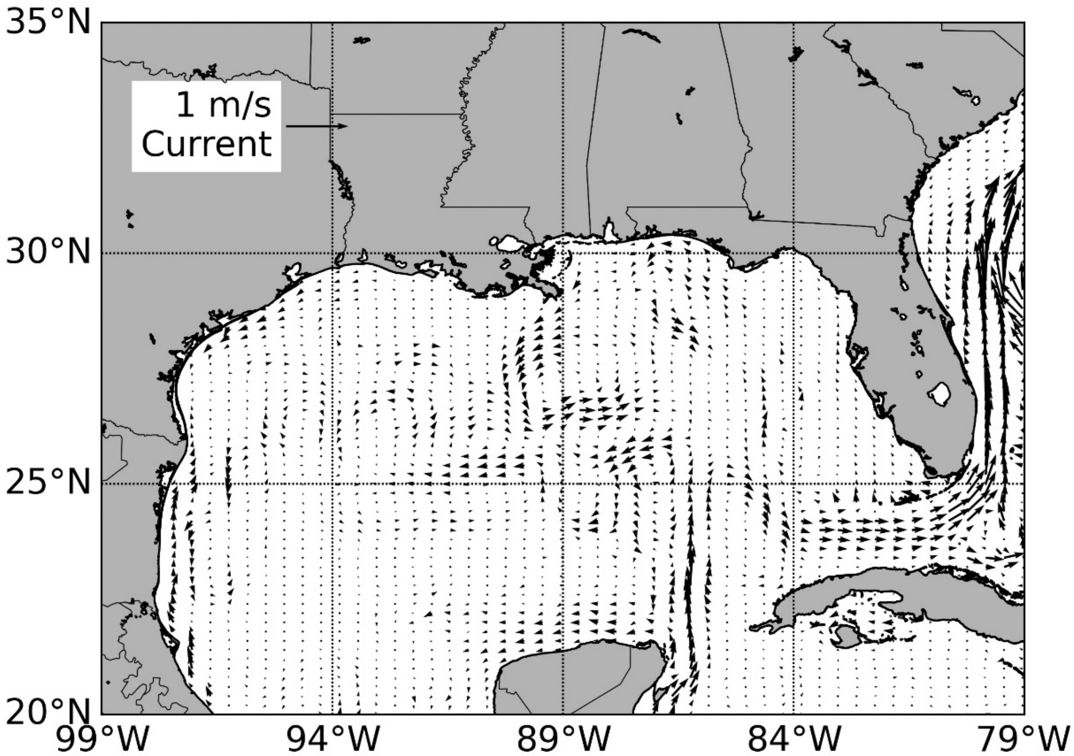


Figure 6 Surface Currents Snapshot for the GoM Region from the Specified Model Data Sources

7.3.4 Water Levels – NOAA Northern Gulf of Mexico Operational Forecast System

The National Atmospheric and Oceanic Administration (NOAA) U.S. Northern Gulf of Mexico Operational Forecast System (NGOFS2) is a 3-D model developed by a large scientific consortium consisting of governmental agencies and academic institutions. The hourly NGOFS2 wind data are generated by spatial and temporal interpolation from meteorological data products provided by the National Weather Service and the North American Mesoscale Forecast System. This dataset, provided along the GoM Coast and at selected time series stations, offers water level, currents, sea surface temperature, and salinity information.

7.4 Integrated Resource Model

A user friendly software tool for ME site characterization and monitoring will make ME siting and monitoring, and ease of computing AEP possible for a range of PBE applications. There is a need to understand the physical environment at a potential deployment site, not only for resource characterization, but also for optimization of the ME devices, power conversion performance, and system operation. The integrated resource model, specific to PBE applications of wind energy, will focus on siting, wind measurement, and estimation of AEP.

The integrated resource model will consist of back-end firmware and software, and user-friendly front-end software and hardware to rapidly characterize the wind, wave, and current resources, focused around the GoM. To satisfy IEC's requirements, the integrated resource model dashboard will be developed to include the above defined metocean parameters and analyses, resource assessment, and site specific monitoring parameters. The proposed model will be a low-cost, user-friendly, autonomous, and real-time assessment network capable of:

- Low-cost, rapid assessment of wind, wave, and current energy resources

- Wind energy resource assessment compliant with international standards (IEC TS 61400-1)
- Wave energy resource assessment compliant with international standards (IEC TS 62600-101)
- User-friendly wave resource assessment dashboard for monitoring physical and environmental conditions at ME sites from anywhere in the world in real-time
- Support of PBE applications in remote areas.

Finally, the Integral team will define the IEC Wind Class to be adopted for the site, based on the data assessment and in accordance with IEC 61400-15.

The database will be designed to comply with IEC standards in terms of wind, wave, and current parameters and analyses and will provide enough flexibility to allow future needs to be satisfied elegantly (Figure 6 &7). The standard parameters will be documented in a metadata structure, allowing easy and rapid access to the required data from the front end interface.

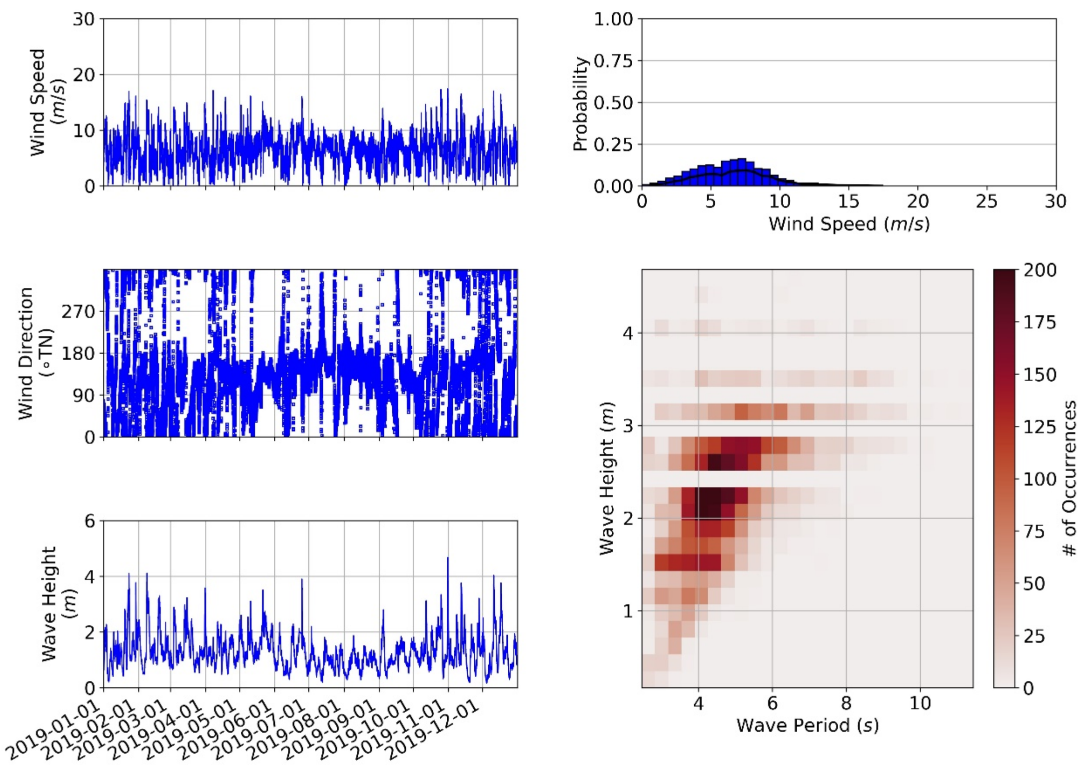


Figure 7. Initial Analysis Based Approach of Multiple Wind and Wave Datasets from a GoM Site to be implemented into the Integrated Resource Model

TOPIC II – Legacy Facility Repurposing Options & Methodology

8 EVALUATION

The evaluation process can be summarized as answering the following in order of precedence:

1. What is the physical condition and capacity of the existing facility or facilities being considered, including BOEM/BSEE status?
2. Are there any special environmental considerations (Dead Zone, migratory route, breeding grounds etc.)?
3. Are the any special stakeholder considerations (native lands, DoD areas, shipping lanes etc.)
4. What are the available renewable energy options given the location and results of the facility review?
5. How much power if any does the facility or facilities currently use and what is its current carbon footprint?
6. Are there nearby facilities that could benefit by a joint development?
7. What value added Blue Economy activities are suitable for the facility location and condition?
8. How much will the modifications or new installations cost?
9. What is the projected new or additional revenue, tax relief, or credits?
10. Does the proposal meet an acceptable Financial Investment Decision threshold?

9 REVEIW

By answering the above, it can be determined if there is potential for repurposing the facility. If the conclusion is yes than the processes of repurposing can begin which consists of:

- Develop a Repurposing Plan and Schedule, described below.
- Prepare and submit an application package to BOEM for an Alternate Right of Use and Easement (RUE), which may include additional surveys and inspections.
- Award contracts for collecting or evaluating any resource or survey data that is lacking for detailed design.
- Award contracts for required facility modifications or services, renewable energy, and Blue Economy activities if not already contracted as part of the Evaluation.

10 REPURPOSING PLAN AND SCHEDULE

While the intent is to eventually repurpose oil and gas facilities in some cases there will be overlapping renewable energy and Blue Economy activities with traditional oil and gas activities. For facilities still in use for oil and gas production simultaneous operations and safety planning will be of paramount concern.

The Repurposing Plan should identify those activities that can, or needs be, done while the facility is still operational, and those that can only take place once use as an oil and gas producer are completed. The safety and monitoring requirements and therefore costs of maintaining offshore oil gas facilities are different from purely renewable energy or Blue Economy activities so the transition point should be clearly established in the Repurposing Plan and Schedule. An example would be placing renewable energy assets on or around an existing producing facility to replace onboard power can and should be done, but surrounding a producing facility with aquaculture, possibly requiring a manned presence on the platform may raise safety issues.

Another example would be increasing the frequency and level of detail for active platform structural inspections if it is planned to apply for an ARUE at or near the end of its life as an oil and gas producer.

In an ideal scenario, existing facilities are incrementally transitioned from oil and gas to renewable energy and Blue Economy centers over their lifetime and new facilities are built with a Repurposing Plan already in place.

BOEM's sister agency, the Bureau of Safety and Environmental Enforcement (BSEE), has the responsibility to approve the platforms for their use or re-use and to see that the platforms are removed once they are no longer producing oil and gas through their "Idle Iron" program. If BOEM approves the ARUE, the platform can continue to be used once BSEE approves the structural re-use permit. BSEE requires that all the platform loads for the ARUE are accounted for and the platform be analyzed with the new loading.

11 OFFSHORE PLATFORMS

The value of an offshore platform to renewable energy and Blue Economy activities will be dependent on the following factors:

- Platform location
- Available renewable energy resources
- Proximity to the Dead Zone
- Access to legacy pipelines
- Platform condition and design, including size
- Proximity to onshore market need (power, water, hydrogen, CO_2 export)
- Proximity to an offshore market need (powering other platforms)

The potential uses included here assume that the platform is, or can be made to be, structurally safe. At a high level, production and quarters platforms can be suitable for use as hosts to energy conversion activities (hydrogen and efuel production), aquaculture, marine research stations, marine monitoring including security and search and rescue, and if they have access to deepwater they can host Ocean Thermal Energy Conversion plants (OTEC). Wellhead platforms may be candidates for offshore geothermal energy production.

The smaller wellhead platforms can support aquaculture, support remote charging stations for AUV's and/or electric crew boats, and host marine sensors.

Many platforms could be repurposed for supporting conventional offshore wind substations, though the cost benefit vs a new build substation may be marginal.

Placing renewable energy devices on legacy platforms, other than OTEC or geothermal will only supply small amounts of power. Retrofitting large wind turbines to oil and gas platforms is at best difficult, and usually impossible without extensive structural modification because the loads are not like those of drill rigs. Even where it could be done the value of a single conventional 3 bladed wind turbine is small. Certain wave energy devices can be retrofitted to existing platforms, and they may provide enough power to support activities like aquaculture, but they will not generate surplus power to be sold.

The most valuable use for legacy platforms is in the form of a multiuse Hub platform where new renewable energy installations feed back into the Blue Economy system built on the legacy platform. An example of what can be done is shown in Figure 8 below. While not all platforms could host the full array of technologies, the objective should be to maximize the revenue potential of each installation.

One shortcoming of the repurposing study done by BOEMRE in 2011 is it assumed the platform would be used either as a standalone fin-fish farm or wind energy hub. The use of legacy pipelines and wells was not seriously considered, nor was integrating other systems.

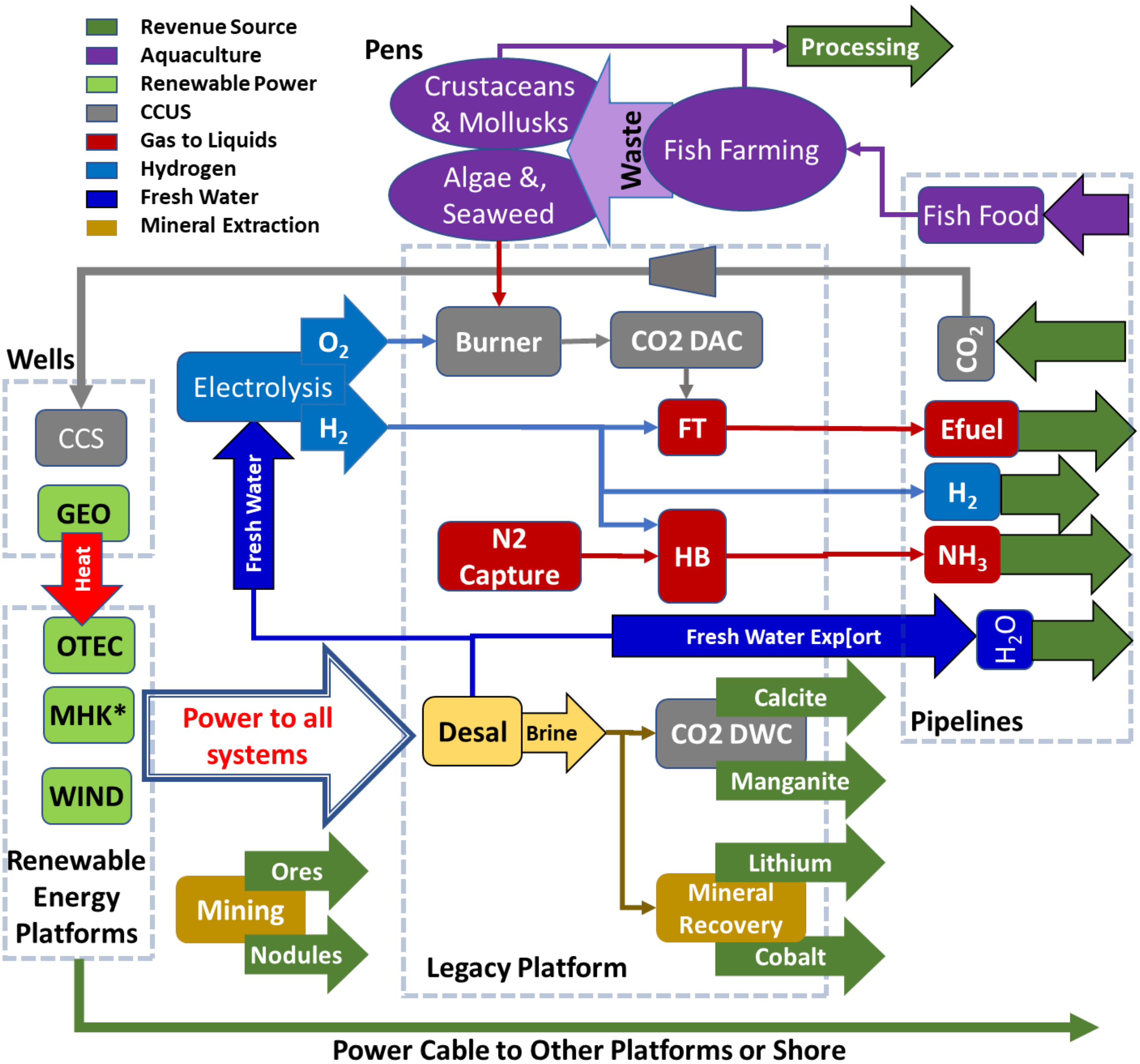


Figure 8 Range of Repurposing Activities for Oil and Gas Facilities

12 PIPELINES, UMBILICALS, AND CABLES

Existing pipelines cannot be used for exporting hydrogen, and may be difficult to repurpose to CCS, but they still hold value. Repurposed or reactivated pipelines can carry freshwater to shore, carry fish feed out to fish farms, carry algae products back to shore, and even be used to transmit power in the form of pumped water or gas.

CAN

- Be used to export energy and power by pumped gas or liquids
- Carry fish feed and other inputs for aquaculture to the platforms
- Transport fresh water.
- Take e-fuels and biofuels to market.

CAN – with qualifications

- Carry seawater or brine but requires internal coating of the line.
- For transport of CO2 to the platforms for use or sequestration but CO2 must be free of water.
- Pipeline can carry ammonia, but only if all brass, copper, zinc, galvanized steel, or cast iron is removed from the system.

CAN'T

- **Safely carry pure hydrogen.**

In the Gulf of Mexico as of 2017 there were approximately 40,000 km of pipelines in use, with approximately 35,000 km abandoned in place. Most of the abandoned pipelines are in the shallow waters, less than 150 meters, reflecting the decline in shallow water production. (Ref. Empirical Analysis of the OCS Pipeline Network in the Gulf of Mexico, Mark Kaiser, Center for Energy Studies). It is the abandoned lines that can be repurposed in the short term, and 2 of them from shore to PN975 were examined as part of the study.

Transport of CO_2 by some of these lines, with proper refurbishment, may be possible. For transporting CO_2 in gas form safely it must be virtually free of water. In the presence of water CO_2 under pressure forms carbonic acid which can corrode steel pipe, causing failure within weeks or even days. This can be mitigated somewhat by transport in a supercritical state providing the pipeline can withstand the required pressures safely. CO_2 transport using these legacy pipelines should be considered possible but not certain and will require case by case analysis.

Hydrogen transport by legacy pipelines is not possible. The requirements of ASME B31.12 are clear and unambiguous, and no offshore pipeline in the Gulf of Mexico was built to those strict guidelines. At typical operating pressures anything more than 3% hydrogen requires a review, and over 5% a detailed material analysis. The high strength steels typical of offshore pipelines (API5L X52 and above) run the risk of hydrogen induced cracking, loss of fatigue resistance, and failure at anything higher than 5% pure H_2 by volume if the pressure is over 1000 psi. To transport pure hydrogen to shore via these pipelines is therefore considered unlikely. There are no approved retrofit coating systems that can mitigate this problem. There are some liners that would work for short distances and smaller diameter lines, but these require access to both ends, and are limited to about 25km maximum pull length. It should be assumed for any economic analysis that if the hydrogen is not used onsite for efuel or other purposes new build pipelines will be required. Transport of hydrogen is difficult and that is a reason why roughly 95% of hydrogen is produced within the same industrial complex where it is used. The few hydrogen pipelines that exist are made of low strength steel and resistant to hydrogen induced cracking. Much press has been made around the fact there are 1600 km of hydrogen pipelines in the USA (all onshore) but that is out of a total of more than 4,200,000 km (0.04%). Hydrogen can be converted into ammonia, which is transported by pipelines, but ammonia is a hazardous substance and repurposing abandoned lines for this purpose will require careful review which is beyond the scope of this work. Mixing hydrogen with methane for export is also being considered as a way to green up the gas grid. The issue here is that even at 20% by volume (considered the absolute upper safe limit) you only reduce the resulting green greenhouse gas (GHG) emissions by 5% because the heat content is lower and therefore need to burn more gas by volume. If the hydrogen is not fully green you actually increase the GHG emissions.

While exporting hydrogen in gas form is not practical existing pipelines can be used in novel ways. Energy can be sent to shore via compressed air or pumped as water. The McIntosh Power Plant in McIntosh, Alabama, is a utility-scale Compressed Air Energy Storage (CAES) facility and one of just a handful in the world. CAES works, but it suffers from inefficiencies. Pumped water storage of renewable energy, which is common, is where renewable energy is used to lift water up filling a reservoir when there is excess power and then released downhill through a turbine when needed. Some technologies, like the SeaDog wave energy devices skip making electricity at the device to run a pump and instead act directly as pumps. In all these instances the pipelines are used to pump water to shore and through a generator instead of having to run high voltage subsea cables. This is significant as a 3GW cable 200km long to provide power to the deepwater Gulf of Mexico was estimated to cost more than $3billion dollars.

Fresh water itself can also be a valuable commodity, and many of the abandoned pipelines could be used for this purpose. The Willacy County case study included in the Report is a case in point.

The pipelines also have utility for aquaculture activities. Both fingerlings (baby fish) and fish food can and have been transported by pipelines. It would be expensive to build a new offshore pipeline for these purposes but using a legacy pipeline that goes to an existing platform greatly reduces the transport and feeding cost. This was not considered in the 2011 repurposing study. In a similar manner algae products can also be sent through the pipelines to process centers either onshore or on other repurposed platforms.

In theory the algae products could be mixed into the flow of water to the onshore power turbine, yielding even more savings.

13 WELLS

Per BOEM more than 55,000 wells have been drilled in the Gulf of Mexico. About 20,000 are still active, with the rest abandoned. It is beyond the scope of this study to determine how many current or abandoned wells can be repurposed but there three options to consider. Wells can be used for carbon dioxide sequestration, they can be used for producing geothermal power, and there are some they may be suitable for recovery of valuable minerals via brine processing. Even where the legacy wells cannot be use, the presences of well slots and/or drill rigs means new wells for these purposes can be drilled at a reduced cost.

14 RESERVOIRS

In the Gulf of Mexico there is well data on 53,000 wells, and some of the fields have been producing for more than 40 years. The reservoir structures are well understood. There are three uses being considered for those reservoirs that are no longer producing commercial quantities of oil or gas.

The option getting the most attention is for carbon dioxide sequestration. Talos and Cabonevert are working on government funded project to build a prototype system. The attraction of using the Gulf of Mexico reservoirs is that they are in proximity to the Gulf Coast Refineries which alone account for more than 50% of the 345 million metric tons of CO2e released by refining and chemical production per the EPA Greenhouse Gas Reporting Program (GHGRP). There are in some cases legacy pipelines that lead directly to the refineries and chemical plants that could be repurposed for CO2 export to the platforms for compression and injection into the reservoir.

H2 Storage is being considered for the salt dome structures that have been emptied of oil and gas, but this area is still under study. Hydrogen has the ability to leak from structures that would hold other gasses, and this is a technology that still needs more study to be considered mainstream.

In most cases wells from legacy reservoirs and those found by failed exploration wells still could produce water in the form or brines. These brines can contain recoverable quantities of minerals including lithium and cobalt that are central to current electrification technologies. The possibility exist that these resources could be tapped. This is especially critical as most of these metals are imported into the US, with 80% of the global refined Cobalt supply coming from China (70% of the ore is sourced in the DRC). The US imports 78% of its Cobalt per the USGS and 25% of its Lithium. Being able to pull significant quantities from legacy reservoirs could reduce the dependence on imports. As a stand alone project this type of activity would is not likely to be profitable, but the water form these reservoirs is typically hot opening up the possibility of combining ore recovery with geothermal power production.

15 LEASES

One of the most valuable assets in the Gulf of Mexico are the Block leases themselves. Permitting offshore renewable energy and Blue Economy activities can be a very long and uncertain process. Applying for an ARUE to deploy renewable energy and Blue Economy assets on an existing oil and gas lease can be an expedited process. These sites have already been established as locations where energy infrastructure can be deployed safely, and the existing facilities carry with them more risk than any of the planned additions. Time saved in the permitting process has direct monetary value as well as resulting in more renewable energy being brought online faster.

Topic III - Methods of Renewable Power Generation in the Gulf of Mexico

16 RENEWABLE ENERGY SYSTEMS SUITABLE FOR THE GULF OF MEXICO

Renewable energy can support decarbonizing offshore oil and gas production. This can be accomplished by installing renewable energy systems and connecting them back to the platforms, or in some cases by installing equipment directly on the platform. Power needs of many platforms are relatively low, and overbuilding pays off. The excess power can be used to support other revenue creating activities, like aquaculture, hydrogen production and/or brine mineral extraction. This also establishes the platform as a renewable power hub allowing a smooth transition from one function to the other.

The Blue Economy technologies most suited to current operations are offshore geothermal, carbon sequestration, and green hydrogen production. Old wells can be reentered, current wells can be modified, and new wells can be designed to accommodate geothermal. Old reservoirs and wells can be used for CCS activities. Green hydrogen production has similarities with natural gas production, but new pipelines for export to refineries will be required.

Offshore renewable energy is the fastest growing segment of renewable energy, led by offshore wind. Offshore renewable energy is defined as technologies which generate power or directly take the place of powered equipment (usually pumping or cooling equipment). The technologies considered in this study are as follows:

- Offshore wind, fixed foundation and floating
- Wave energy capture
- Ocean currents and tidal energy
- Ocean Thermal Energy Conversion (OTEC)
- Offshore Geothermal Energy (OGE)
- Seawater Air Conditioning (SWAC)
- Solar Energy

With the exception of offshore geothermal energy, the resource potentials in the Gulf of Mexico were analyzed by NREL for BOEM and the study uses those values for Gross Resource Potential unless otherwise stated. Where possible modifications to the Gross Resource in the report to account for assumed capacity factor were removed.

The study considered proven and experimental devices for use. Where significant gains in performance could be gained by further development of promising technologies these were highlighted as this was a specific goal of the DOE study. The viable option are summarized in Figure 9 below.

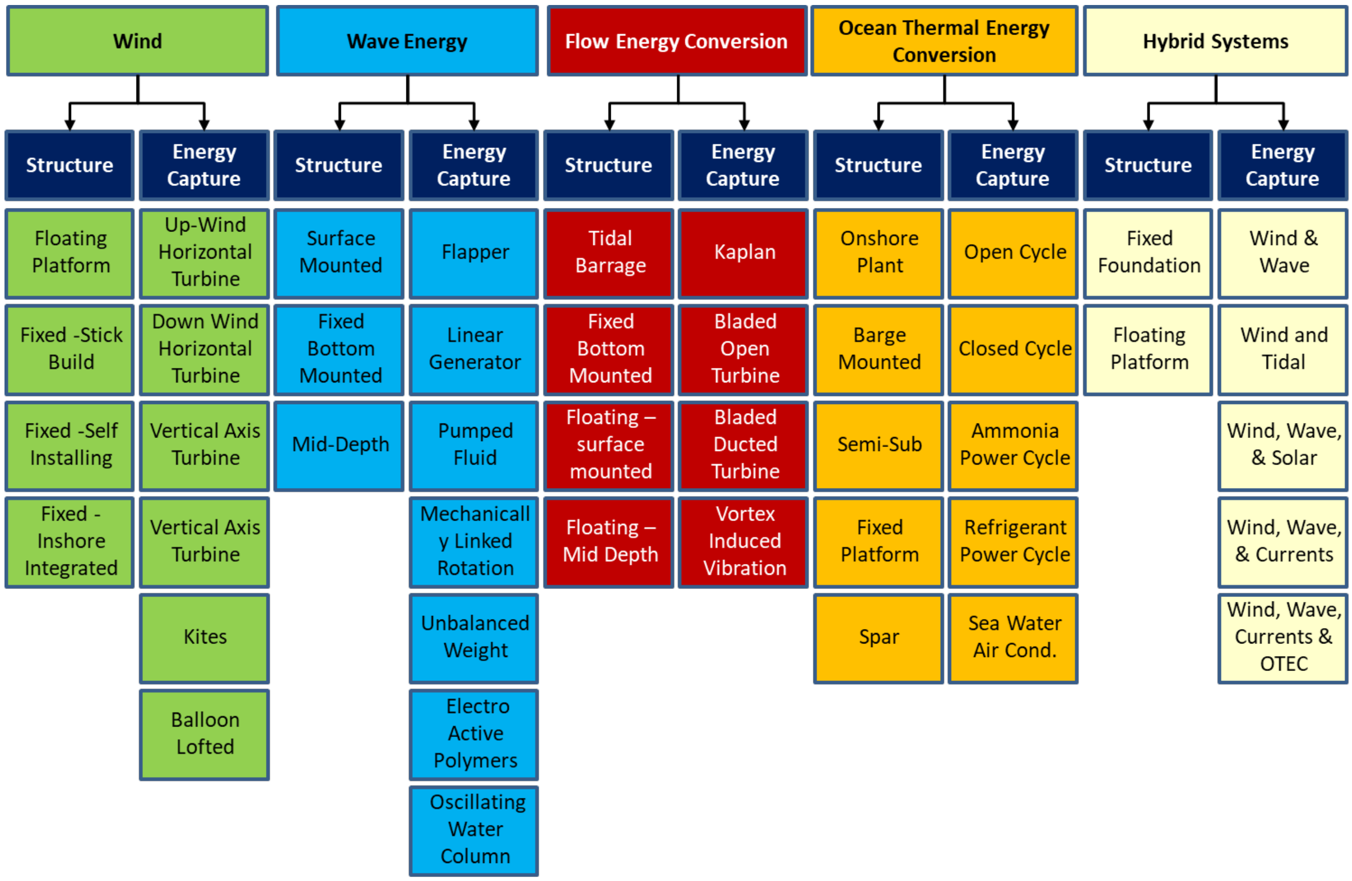


Figure 9 Traditional Offshore Renewable Technology Options

In addition to the above offshore geothermal has in the last 5 years become to be considered.

17 THE VALUE OF INTEGRATED SOLUTION

17.1 Disclosure

Excipio Energy Inc. (Excipio) the leaders of this study and authors of this report have a patented technology for integrating various systems, which we have excluded from the report to avoid a conflict of interest. Excipio is known for championing integrated systems, but this view comes from our work analyzing offshore renewable energy technology economics. Everything spelled out in this section is applicable regardless of how it is integrated.

17.2 The Value of Shared Costs

Oil and gas produce a commodity and sell it. It is a very simple business model, but for repurposed facilities to be profitable no single technology or new replacement commodity will give comparable returns. Only combined returns from sales of some combination of power, hydrogen, synthetic fuels, minerals, water, and aquaculture production can achieve attractive returns, without factoring in subsidies or carbon credits. Rents from tenant use and fees for accepting and disposing of CO2 can add even more value. To do this will require a systems view of offshore development. It is not just oil and gas that have a myopic focus, the offshore renewable energy industry is highly siloed, with wind energy, wave energy, ocean thermal energy, tidal and flow energy, solar, and geothermal seeing each other as competitors. In a similar fashion aquaculture also works in isolation. While it would seem to make sense to have fish, seaweed, and mollusks all raised together, mimicking nature and mitigating some environmental issues, it is not how the industry developed. Instead they see each other as competitors for space, and in turn commercial fisherman see aquaculture as encroaching on their space.

So why not let these industries go along as they have for the last 50 years of so, letting them compete for space on the repurposed platforms and investment in their individual technologies? The reason is the gains that can be made by cooperating:

1. Integration for offshore activities reduces the capital expenditure on a proportional basis.
2. One of the main operation costs for open water facilities is the transport to and from the facility. As an example, NREL assigns 80% of offshore wind OPEX for this. By combining systems, they share this cost across the systems.
3. Often the waste stream from one activity has value to another. An example is the brine produced by desalination can either be mined for minerals or sent to a direct carbon capture and sequestration system.
4. Some systems share a required input – several process can use the heat generated by geothermal systems and by some process reactions for example.
5. For power generation and sales, having multiple systems reduces or eliminates the need for energy storage and peaking plants and makes the value of the electricity greater to grid operators. It also means that in the event of a breakdown it is less likely to need an emergency repair, again reducing OPEX.
6. By capturing, using, and/or reducing waste the environmental impacts are more likely to be positive. The presence of Blue Economy developments should result in an overall increase in the local biosphere due to the added protection these development accord to local species. The installation become artificial reefs.

The offshore renewable energy industry suffers from a silo mentality. It is understandable how this silo mentality took hold. For a least the last 40 years wind, wave, tidal, and ocean thermal energy technologies have survived on research dollars, fighting over the same pool of money. They have come to see each other as competitors, and each has dreams of developing the "one" technology that will solve all the worlds energy needs. This is amplified by both traditional power companies and oil and gas companies because that "one tech" solution is appealing. This myopic view has caused developers of offshore renewable technology to focus on reducing the capital cost of standalone installations as the best way to reduce the Levelized Cost of Energy, better known as the LCOE. Put simple LCOE is the total amount of energy produced expressed in MWh, divided by all the costs (CAPEX + OPEX) over a systems life.

Using floating wind energy technology as an example the error in this approach becomes clear. The focus is on reducing the cost of the floating hull. But even if I developed a zero-cost hull the most it would reduce the LCOE is 10%, and once I achieve that milestone it is as good as it gets, it is a self-limiting path. The other approach is to let the hull cost take a secondary importance and focus instead on capturing as much value from a single installation as possible.

The challenge in the Gulf of Mexico is that it has a moderate wind resource. To deploy conventional wind only platforms in support of repurposing existing platforms would be economically challenging. Our analysis of the performance of a 6MW conventional turbine near SP83 indicates a capacity factor of approximately 26%. To be used to power an offshore facility you would need 4 times the required power and very large energy storage.

But if you look at what happens when systems are combined, the economics become interesting. Using 2016 NREL Data augmented by estimates for OTEC based on quotes from current companies the following table can be generated.

	FCR x CAPEX ($/kW/yr)	Fixed OPEX ($/kW/yr)	Net Capacity Factor (%)	AEP_{net} (MWhr per MW/yr)	LCOE ($/MWh)
Floating Wind	$498	$106	56.7%	49,669	$122
Wave Energy	$605	$200	45.0%	27,594	$204
Flow Energy	$445	$38	32.4%	5,672	$170
OTEC	$724	$383	90.0%	78,840	$140
	Combined into one system				
Floating Wind	$498	$106	56.7%		122
Wave Energy	$184	$60	45.0%		62
Flow Energy	$168	$11	32.4%		63
OTEC	$404	$249	90.0%		83
Integrated Platform Total	**$367**	**$138**	63.5%	**161,775**	**$91**
W/out OTEC	**$348**	**$79**	49.7%	**82,935**	**$98**
	Reduction in LCOE over wind alone:				**19% to 25%**

LCOE Definitions and calculation per USA National Renewable Energy Center ATB

Design Life = 25yr. Fixed Charge Rate (FCR) = 9.45%

Table 1 – LCOE Calculation

Where:

FCR = Fixed Charge Rate, and annualized reflection of interest

AEP = power generated over the life of the system expressed as MW hours per installed MW.

CAPEX & OPEX = expected total lifetime cost divided by the design life and KW installed.

The estimated result is a reduction in the LCOE of up to 25%. This would be the starting point, as the technologies improve, or ways to add different new technologies are found the economics will get better. All of the technologies included here are proven from a technical standpoint. They have not been widely deployed because their LCOE's are were too high. The values above are from 2016, largely because updated costs for wave and tidal machines is not widely available and it should be noted that the latest estimates for floating wind are now down to $100/MWh. Regardless of how low it gets, the effects shown above will hold true.

The majority of the savings come from the 23 major cost items listed below not changing regardless of how many energy systems are deployed providing they are installed at the same time and on the same structure:

CAPEX

1. Permitting & Legal fees
2. Project Management
3. Engineering
4. Insurance
5. Finance Charges
6. Surveys
7. Assembly/Construction of the supporting structure (Slightly higher)
8. Installation and hook-up per platform
9. Transmission to market

10. Substation (if any)
11. Hull and deck (only slightly more if a floating system)
12. Logistics
13. Certification
14. Stakeholder and Community Management
15. Owners Costs
16. Block Auction Costs
17. Resource Evaluation
19. Energy Storage (if any)

OPEX

20. Planned Maintenance (more total cost, less per MW)
21. Inspections (Jacket, Hull, Moorings, Cables, Equipment etc.)
22. Decommissioning (if any)
23. Block Royalties (if any)

17.3 Effect on OPEX

Again, using NREL data, they estimate that up to 80% of the OPEX for a floating wind farm will be the transport cost to/from offshore. Shared technology platforms, be they new or repurposed oil and gas platforms will therefore have a lower OPEX on a per MWh basis. In addition to the shared transport costs, having multiple systems means that it is unlikely that all of them will be down at once. This makes it less likely I will need to do an emergency (and therefore more expensive) service trip providing the other systems make enough power.

When trips are planned the technician will be maintaining several systems, which may even share some of the electrical components.

17.4 Secondary Effects

Having multiple power generation technologies means that the requirements for energy storage are reduced or even eliminated. OTEC and Geothermal energy are baseload power systems and can operate 24/7. Even just combined wind and wave systems will have a more constant generation curve.

Using multiple systems reduces the risk profile of the platform. Providing the system can operate independently they are less susceptible to environmental impacts. Wave devices may get entangled in sargasso but that has no effect on wind, wind turbines have to turn off in high winds, but those winds make large waves and even surface currents, so while the wind generator turns off other systems make more energy.

17.5 Effect on Output Power

Once it’s established that more systems increase the value, it opens up other possibilities. The same logic applies to aquaculture or other added systems. It leads to the options shown in Figure 9 above, but the real value comes from the reduction in LCOE to the point it can compete against the diesel and gas generators currently powering offshore oil and gas platforms in the Gulf of Mexico.

To illustrate the effect combined technologies Figure 10 gives a comparison of conventional wind to multi-technology systems using the NREL corrected Gross resources potential. Note that the below does not incorporate the potential from offshore geothermal. The dead area near Florida is in part due to the very low wind and waves but may also reflect the lower data quality. The western Gulf has had up to 5000 platforms continuously collecting data since 1947.

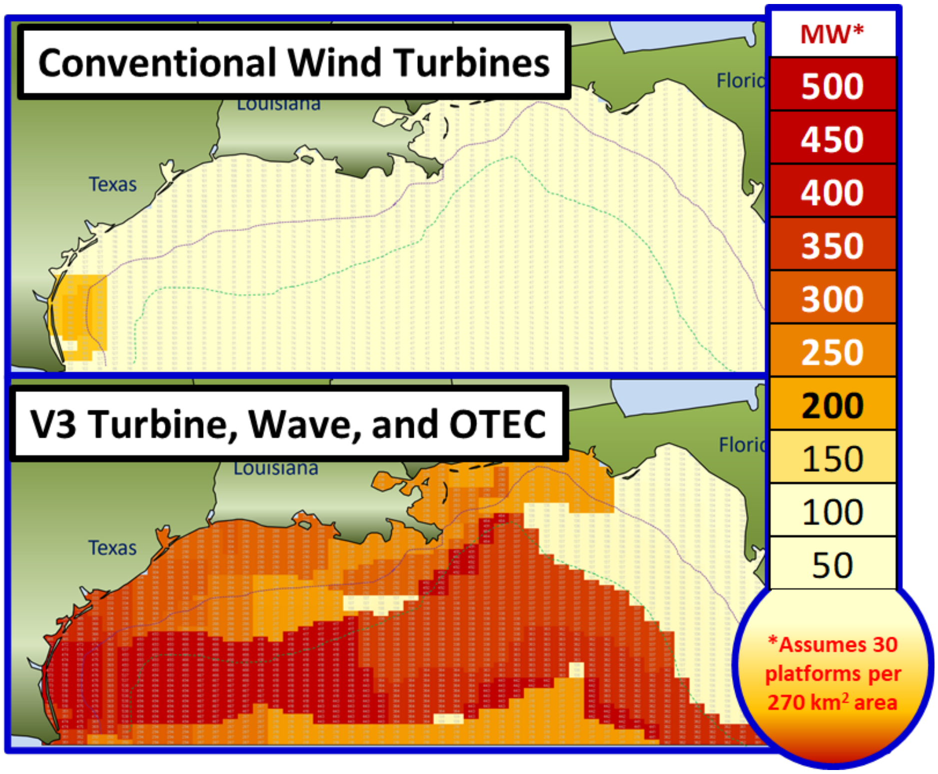


Figure 10 – Offshore Application for an Alternate Right of Use and Easement

The following section describe what systems could be used on Gulf of Mexico platforms, but it is assumed that any repurposing will use a combination of power technologies.

18 FIXED WIND ENERGY

When offshore renewable energy is mentioned it often really means offshore wind. It is the only is the most commercially successful of the competing technologies. Offshore wind is first divided into two broad subgroups, fixed foundation and floating, this section delas with the issues around fixed wind deployment in the Gulf of Mexico. Conventional wind energy developed in Europe based on fixed foundations. Limitations in the installation method limit fixed wind farms to water depths less than 60m. In the US there is an added concern in that there are no Jones Act compliant vessel. Past 60m floating systems are required.

The resource values given by NREL for the Gulf of Mexico reflect assumption about the type of wind turbine to be deployed. It is correct to say that conventional wind turbines of the type widely used in Europe and Asia will not perform well in the moderate winds found in much of the Gulf of Mexico, and the survivability of these turbines in hurricanes is questionable considering what happened to the wind towers in Puerto Rico. The towers withstood the storm well, but the turbine blades were shredded. For this reason and because of potential Jones Act issues with conventional wind, alternatives to conventional 3 bladed turbines and jack up installation were sought out.

18.1 The Problem with Conventional Fixed Wind

This section is intended to identify the risks involved in conventional offshore fixed wind construction and identify possible ways to mitigate those risks using new technologies. The current offshore fixed wind industry developed organically in northern Europe starting in 1990. The first wind turbines were small devices, installed nearshore, using spud barge cranes. As the turbine size grew the nascent industry used the same methods as these early turbines.

Eventually constructing purpose-built installation vessels, and even then, the weights of the new turbines meant added lifts compared the original wind turbines. Today these specialized wind installation lift boats carry some of the biggest cranes and highest day rates of any offshore vessel, with the largest working vessel having a 3000-ton crane, and one with a 5000-ton crane overdue. Table 1 below details the evolution of the size of the turbines and the required lifts.

Project	Year	Water Depth Max.	Turbine size and diameter	Hub Height	Heavy Lifts	Heavy Lifts per Turbine *
Vindeby	1991	4 m	0.45 MW	37.5m	27 MT	4
Middelgrunden	2000	6 m	2 MW 64m	64m	Nacelle 82.5 MT Hub 52 MT	4
Anholt	2010	19 m	3.6 MW 120m	82m	Nacelle 125 MT Hub 100 MT	5
Westermost Rough	2015	26 m	6.0 MW 154m	102 m	Nacelle + Hub 360 MT	7
Kriegers Flak	2020	30 m	8.4MW 167m	105 m	Nacelle + Hub 450 MT	7
Vineyard Wind	2023	55 m	13 MW 220m	137m	Nacelle + Hub 600MT	7

*Includes foundation

Table 2 Example Projects

Offshore wind turbines do not have the same limiting factors with regards to blade transport and foundation size that onshore wind turbines do, and the result is ever larger, and therefore more cost efficient, turbines, but at a price in constructability. The largest now is the Siemens-Gamesa 14MW prototype with a blade o 120m long but designs up to 25MW are being considered. Even onshore these lifts are complex as is shown in Figure 11 below.

Figure 11 Installation of the 570 MT, GE 12.5MW Prototype by Dual Lift (Source: GE Renewable Energy

This increase in size has also led to very specialized wind turbine installation vessels (WTIV's), that by repetition have become very efficient at installing wind turbines offshore.

In the USA there are two problems that arise. Firstly, there are no Jones Act compliant wind turbine installation vessels, though a one is under construction. Second each wind turbine location is considered a "port" under the Jones Act which means only US Flagged and manned vessels can transport goods "between ports." This will impact the development of the US wind market in profound ways. It means shuttle boats will need to bring out the components one by one if a non-US flagged vessel is doing the installation. What is more they cannot transfer multiple complete assemblies to the WTIV at a time, which they would normally do, as under the act when the WTIV moves from site A to site B it will violate the Act. This requires the equipment to stay onboard the smaller, floating transfer vessels. This alone will slow down the installation, but it will also be far more susceptible to weather risk. It is likely that the early US projects will suffer significant construction delays just from this activity.

This risk is unnecessary as there are alternatives to mitigate or eliminate these risks. Before we address that lets briefly described the typical offshore wind turbine installation.

18.2 Conventional Offshore Wind Construction

18.2.1 Limits of the Review

For purposes of this section, we will focus on the installation of conventional 3 bladed wind turbines, starting with the foundation and scour protection to the last blade. This is where the biggest impact of new technologies and systems will be apparent. Other activities include installing the Electrical Support Platform/Substation, cables, and scour protection, and commissioning. These activities are commonplace in the Gulf of Mexico as they have identical equivalents in the oil and gas sector.

18.2.2 Foundations – Monopiles, Jackets, and GBS

While there are many fixed wind foundations designs, they fall into the following families: Monopiles, piled jackets, and gravity-based structures commonly called a GBS. Tripod and suction pile designs, which are types of jackets are sometimes considered separately. While GBS foundations are sometimes floated out, in general setting the foundation requires a heavy crane. Monopiles can weigh more than 1000 MT, with the record being the 7.8 m OD, 84.5 m long, 1400 MT piles for the Veja Mate offshore wind park. Jackets and GBS have lifting and installation requirements typical of similar oil and gas platforms. Jackets, if not on suction piles, are usually attached to the seabed by pin piles.

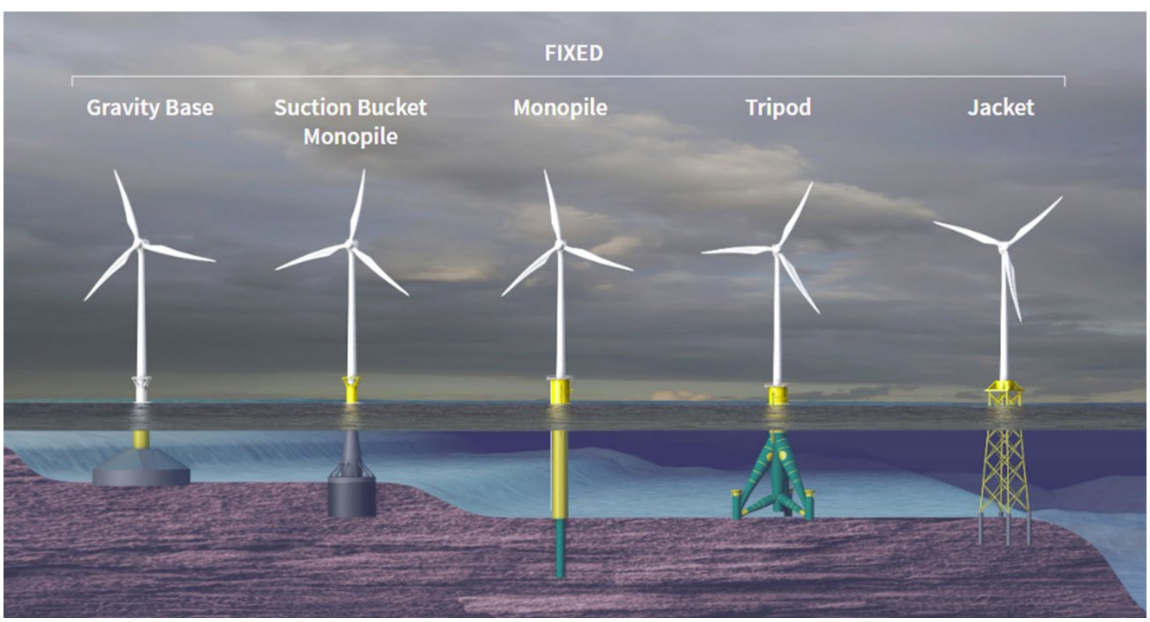
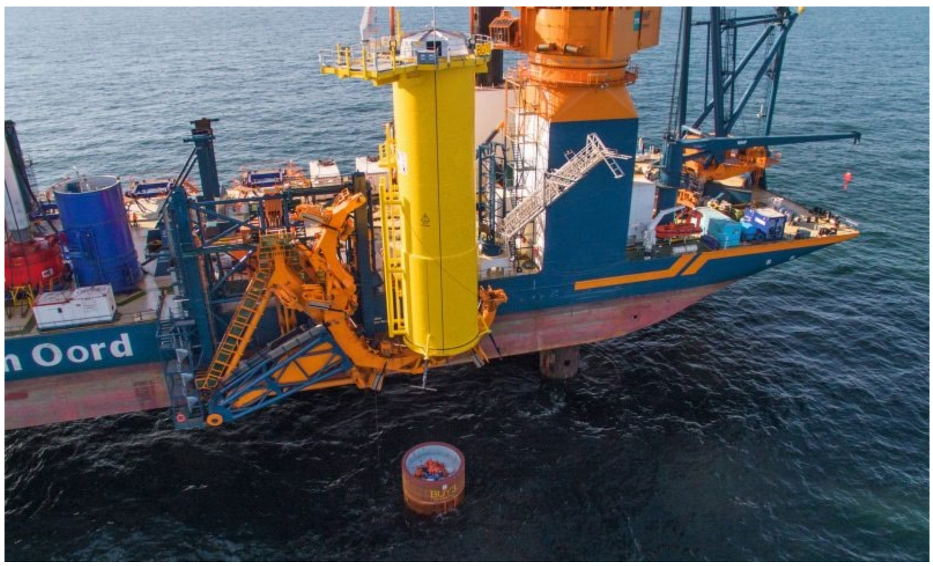


Figure 12 Foundation Types (Source: Tethys)

The foundations are often installed by one vessel while the transition piece, tower, turbines, and blades are installed by another. This is because the lifting requirements in terms of height, weight, reach, and level of control are significantly different. The foundation vessels needing more lift, farther reach, but lower height and precision than the WTIV. The use of float out foundations, primarily GBS and some suction pile designs, does reduce the need for a big WTIV's.

18.2.3 Transition Piece

The transition piece is intended to ensure that the tower connection, which is almost always a bolted connection, is not damaged during the monopile installation. The transition piece connects to the monopile and is either bolted, grouted, or both to the top. The transition piece is the yellow portion of the wind tower, rising just above the water and typically includes the boat landing. There are new monopile designs where the monopile and transition piece are single units to reduce the number of offshore lifts, but these are not in common use. Figure 13 bleow shows a typical offshore transition pieces installation.



(Note the personnel within the foundation top)
Figure 13 Offshore Installation of a Transition Piece (Source: Van Oord)

18.2.4 The Tower

Usually installed in one lift, for the larger turbines (those larger than 10MW) these may be done in two lifts, each with a flange bolted connection. The towers are large diameter steel tubes 8 to 10 m at the base, usually with pre-mounted cable, ladder, and elevator systems internally. They narrow at the top and the last part of the climb is by ladder only. The end is a bolted flange that will be mated with the nacelle. Figure 14 shows single piece towers being loaded onto a WTIV for installation.

Figure 14 Wind Towers Being Loaded Out (Source: MHI Vestas)

18.2.5 Nacelle

The nacelle is the interface between the tower and the turbines blades. It supports the hub and houses the generator, hub gears, main bearing gears (used to keep the blades into the wind), cooling equipment, and in older turbines the generator gearbox. The latest designs are direct drive with no generator gearbox, such as the GE 12.5MW design. Lifts of 400 metric tons are common and the maximum is closer to 670 metric tons. The nacelle is located at the very top tower. This necessitates as 600+ metric ton lift, at a stick height of more than 120 m, while aligning 250+ large diameter bolts. Some new designs are expected to have 1000 ton nacelles. It is easy to see why it requires a fixed crane and a fixed tower. Nacelles contain the most sensitive machinery in a wind turbine. In general, they must be kept level and procedures are conducted to minimize the ingress of humid air.

Figure 15 GE 12.5 MW Direct Drive Nacelle (Source: GE Renewables)

18.2.6 Hub

The hub is the portion at the front of the nacelle where the blades attach. In some instances, it is installed separately, but for most of the larger modern turbines it is included in the nacelle lift. In the early years of offshore wind, the hub was lifted with the 3 blades attached.

18.2.7 Blades

The source of the wind turbines power and weighing up to 60 metric tons each for a GE 12.5 MW turbine the blades are lifted and installed one at a time using special lifting gear. Like the tower and nacelle, the connection to the hub is a bolted one. Offshore Turbine blades are much larger than onshore blades, 107m to 120m long up to 8 m wide at the root. For that reason, they must be manufactured in facilities with direct access to a water route. They are too long for either truck or rail transport. Wind turbine blades suffer from bad press due to their high CO2 footprint and the fact they are difficult to recycle into anything useful.

Figure 16 Offshore Blade Installation (Source: SSE Renewables)

18.3 Sequence and Timing

In Europe there will be at least one vessel installing monopiles, and one installing the wind turbine assemblies. There will be several smaller support vessels taking care of scour protection, cables hook up, and pre-commissioning. The largest vessel is the WTIV, and it can typically hold multiple complete turbine assemblies on its deck. It will follow the monopile vessel and install turbines until empty, return to the mobilization port, reload, return to the field, and start over. The monopile vessel does the same with the monopiles. While heavier than the other parts, monopiles often have a shorter lift height requirement and the lift is not as exact. Overall installation rates vary but from monopile lift to installation of the last blade in Europe can be as fast as 12 hours, with a total rate of 1 per day counting the vessel moves. It is telling that in the Vineyard wind schedule submitted as part of their permit they have allowed about 3 days per turbine.

The whole offshore operation takes a small fleet of vessels under normal circumstances, in the US additional transfer vessels will be needed. The Vineyard Wind plan, which would be similar to any Gulf of Mexico shallow water deployment, calls for an average of 25 vessels in the field. Figures 17 & 18 describes a typical installation sequence. Figure 19 shows the WTIV activities modified for a US installation with a non-Jones Act complaint vessel. The Foundation sequence would be similarly modified.

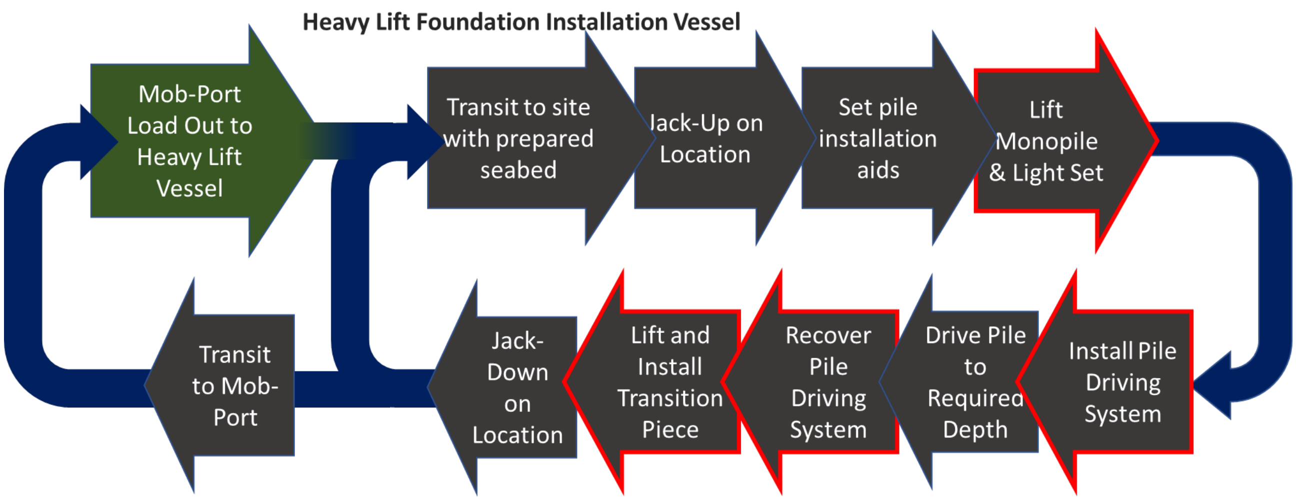


Figure 17 Typical Foundation Installation Sequence

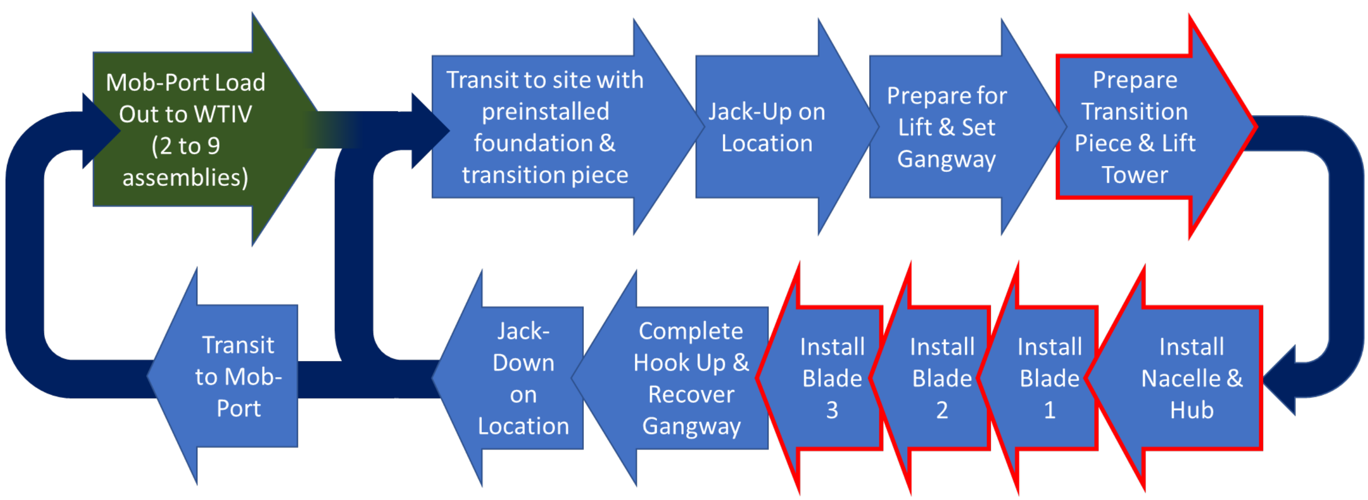


Figure 18 Typical WTIV Installation Sequence

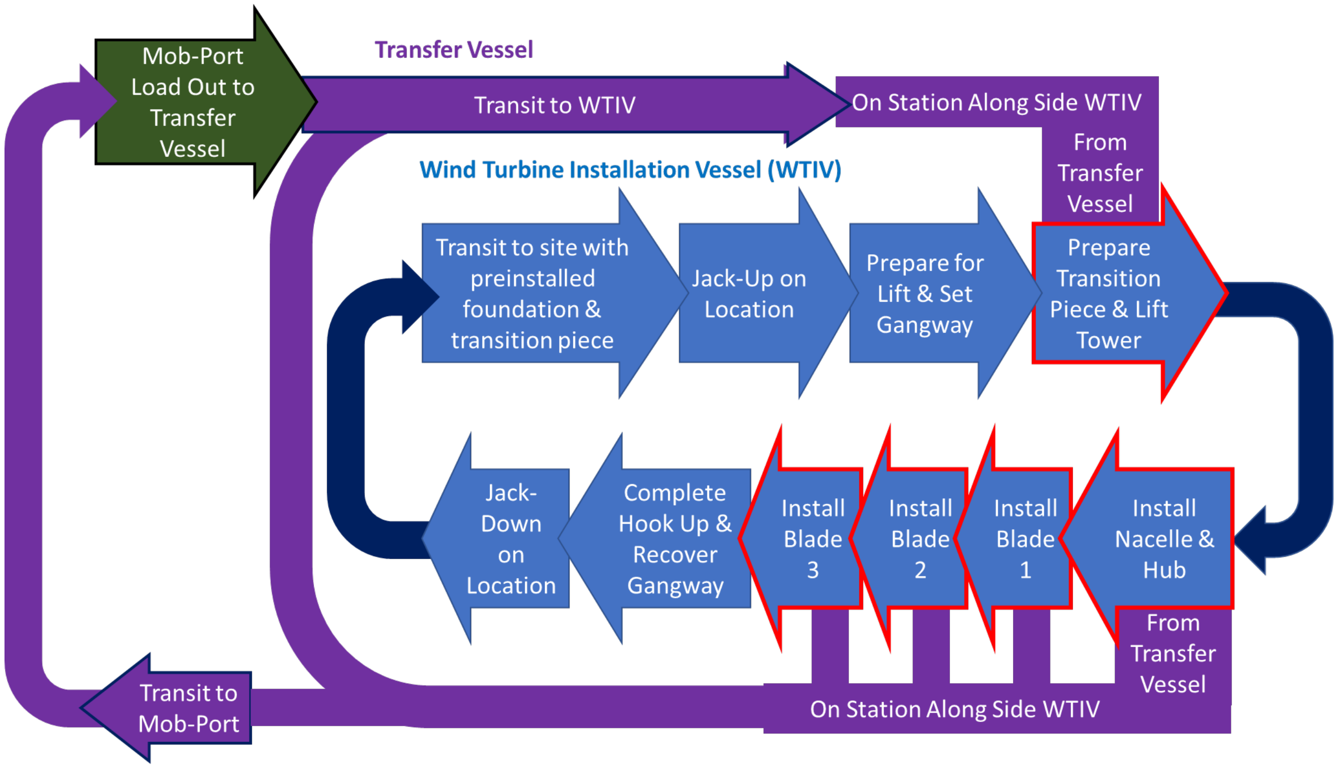


Figure 19 WTIV Installation Sequence in USA with Non-Jones Act Vessel

The regulatory limits imposed in the US presents an opportunity to improve on the European system.

18.4 Summarizing the Fixed Wind Problem

18.4.1 The Golden Rule

For anyone with a background in offshore construction the “Golden Rule” is, you do nothing in port you can do onshore, and nothing offshore you can do in port. Because what costs $1 onshore, costs $2 in port, and $10 dollars if done offshore with the added effects of weather risk. Unfortunately, the offshore fixed wind industry developed a model that executes the most costly and difficult parts of the assembly offshore.

18.4.2 Limited WTIV Fleet

Jones Act issues aside there is a rush to build offshore wind. There simply are not enough vessels to meet global demand though more are being built. At the very least this will drive up the day rate of these vessels and slow down the rate at which offshore wind is installed.

As of 2021 there were 19 wind turbine installation vessels (WTIV’s) with 4 more due out by 2023. The utilization rate at the end of 2021 was around 90%. Projections are for an additional 200 GW of offshore wind by 2030. It is worth noting those projections were made before the data for China in 2021 came out. In 2020 6.1 GW of onshore wind were added globally, in 2021 China alone added 16 GW. The result is predictable, day rates in Asia quadrupled. The operators and EPC contractors recognize this, and placed orders for 17 new vessels in 2021, with options for an additional 9, more than doubling the fleet once built. A GE executive noted however only 7 of these vessels could manage the biggest turbines.

To make the sequence more efficient it also needs at least two heavy lift vessels and their supporting vessels. One for monopile or jacket installation, the other for the more difficult tower and turbine installation. This compounds the vessel shortage.

18.4.3 Water Depth and Weather Limitations

The water depth that fixed wind can be installed in is limited not by the tower and turbine technology, but by the jack up capabilities of the installation vessels. It is a direct result of the evolution from very shallow waters (an average person could walk out to the Vindeby towers) and relying on bolted connections that require exact alignment. While the vessels have dynamic positioning capabilities and heave compensated cranes in some cases, the heavy lifts are done only when jacked up. The effect is to have a fixed point to fixed point lift.

There are plenty of images of offshore wind installation on the web, and in every case, you will notice they have something in common. A calm sea, wave height limitations are between 1 meter and 2 meters, with wind limits depending on the component being installed of between 4m/s and 10 m/s. (8knts to 20knts)

18.4.4 Current Cost & Schedule

The fixed wind industry is justifiably proud of how much they have reduce the cost of offshore fixed wind. Bids as low as $50/MWh are a reality, where as recently as 2017 $65/MWh was a goal. But the current method is relatively slow in the all-critical installation phase and prone to construction risk. It now has the added pressure of a shortage of installation vessels. If those risks can be eliminated it will bring down the cost not just in the Gulf of Mexico but globally.

18.4.5 Jones Act

As far as the US market goes there is no getting around the Jones Act, or more accurately the “Merchant Marine Act of 1920”. It has been in place since 1920 and has been challenged time and again. If anything, it is stronger now than it was then. This means that for the near future the use of shuttle boats to carry equipment will be the norm if conventional wind installation methods are used. This will take what is already a complex and slow process and make it more complex and slower.

Per the American Clean Power (ACP) organization the Jones Act *“requires that U.S.-flagged vessels transport merchandise, such as wind turbine blades, between two U.S. ‘points.’ U.S.-flagged vessels are built in the U.S., registered in the U.S., and primarily crewed by Americans.”*

Put simply it is the only reason there is still a shipbuilding industry or merchant marine capability. The US shipyards and sailor could not compete on a head to head basis with low cost countries such South Korea and China for shipbuilding, or the cost of crews and captains from low income countries. Any attempt to get around the act and even non-union ports will shut down an operation. So it is a matter of complying if we are to build offshore renewable energy.

18.4.6 Overall Speed of Deployment

The current accepted practice is slow. It does not allow for industrialization of the production of offshore wind turbines. The components some out of industrialized facilities but are then assembled in the field. An analogy would be if Tesla built his supply chain, but then assembled each Model X in your garage. No matter how efficient that became it would not compete with those built in a factory on time and cost.

We need to deploy 1000’s off offshore platforms per year not hundreds if we are to come close to our stated renewable energy goals. The prediction of an additional 200 GW globally over the next 8 years is low as it is based on current activity. As countries around the world decide to join in the number will increase, but only if the cost is attractive. A solution where the 5-billion-dollar investment spent on new installation vessels in 2021, went instead to building new towers will speed up the overall deployment.

18.5 Viable Alternatives

18.5.1 Definition of Viable

To be considered a viable alternative for this paper the technology needs to meet the following criteria. It needs to fundamentally change how offshore fixed wind is constructed either by reducing or eliminating offshore activities, reducing the construction times, reducing, or eliminating offshore heavy lifts, or otherwise reducing the overall cost. The paper does not set a minimum Technical Readiness Level (TRL) level, though as a minimum the system either must have a patent and/or has been prototyped. While subjective all the technologies here have been evaluated by the authors and found to be sound from an engineering and offshore construction perspective. Lastly there are numerous alternatives out there, but the scope of this paper does not allow for us to give a comprehensive review of each one. The selected technologies are meant to be examples of what is available and are not meant as a substitute for due diligence. Finally, the authors have no financial connection to any of the companies or solutions proposed, and the purpose of the list is to provide a starting point for those looking to change the way offshore fixed wind is built. We will first describe the systems then examine the possible effects in the next section.

18.5.2 In-Port Assembled Platforms

The most obvious solution to the problems inherent in the current offshore stick-built approach are the proposed in-port integrated fixed designs. Table 4 below provides a list of In-Port Assembled platform designs that have been considered.

Platform Name/Type	Company	Status	Country of Origin
Elisa Gravity Base Structure (GBS)	Estyco	Prototype installed in 2017	Spain
Composite Bucket Foundation (CBF)	Tianjin University and Daoda Marine Heavy Industry	Fully functioning, 17 platforms installed since 2013, largest 6MW	China
Titan Jack-Up	Offshore Wind Power Systems of Texas (OWPST)	ABS certified design	USA

Table 4 In-Port Assembled Platform Options

The Elisa has been deployed as a prototype, the Titan has not been built as a wind turbine foundation but comes from firm with long experience in designing offshore drilling jack-up and the design is ABS certified. The Chinese CBF Vessel has been used commercially. The use of these types of systems would allow serial fabrication in ports either quayside or in purpose built graving docks.

These systems all allow construction and pre-commissioning to take place in port, they differ in installation approach.

As shown in Figure 20 the Elisa design uses a reusable collar to float out a GBS design. One unique feature is the telescoping concrete tower. This keeps the dockside lifts lower as well as keeping the center of gravity low during tow-out. The GBS is lowered to the bottom and ballasted, the floatation collar is removed and returned to port for use on the next tower, and the completed wind turbine is raised on the telescoping tower using strand jacks.

Figure 20 Estyco Elisa Being Towed to Location (Source: Elican Project)

The CBF Vessel, Figure 20, uses a double-ended specially built vessel to carry and deploy two in-port assembled GBS-suction base type platforms. It was successfully used at small scale in 2013 and has installed turbines up to 6MW in size as late as 2019.

Figure 21 the Tianjin University and Daoda Company Composite Bucket Foundation (CBF)

The Titan, shown in Figure 22 looks like a modified drilling jack-up platform and that is its heritage. Titan plans to build the units entirely onshore, then load them out two or more at a time onto a delivery barge. The unit is centered with the legs of the Titan extending over the side of the barge. Once onsite the legs are lowered, lifting the turbine off the barge, which is then pulled out from underneath and taken either to the next location or back to port to be reloaded.

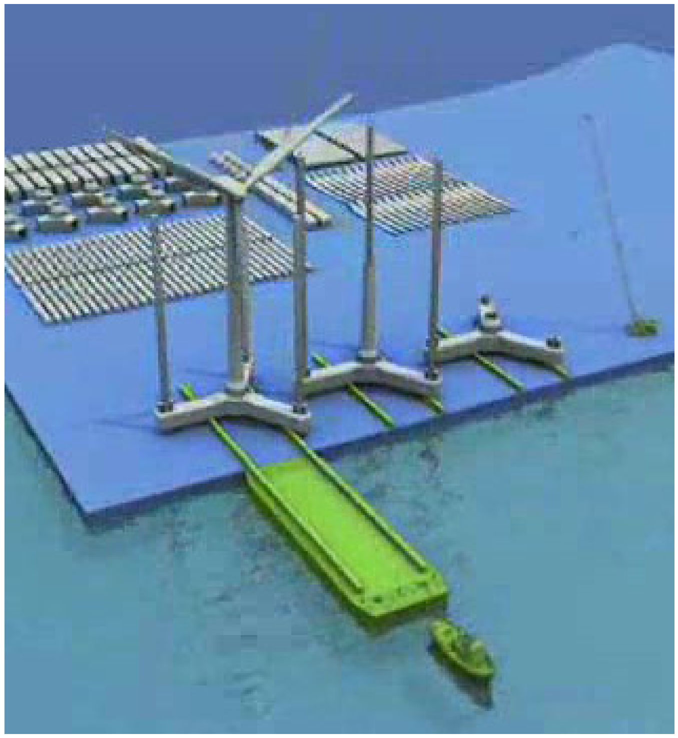


Figure 22 the Titan (Source: OWPST)

What all these methods have in common is they eliminate much of the offshore activity associated with a typical wind farm, and the assembly will be less susceptible to weather impacts. Below in Figure 23 is the installation sequence in the same format was presented above for comparison. You don't need to be an experienced offshore development manager to see the potential benefits.

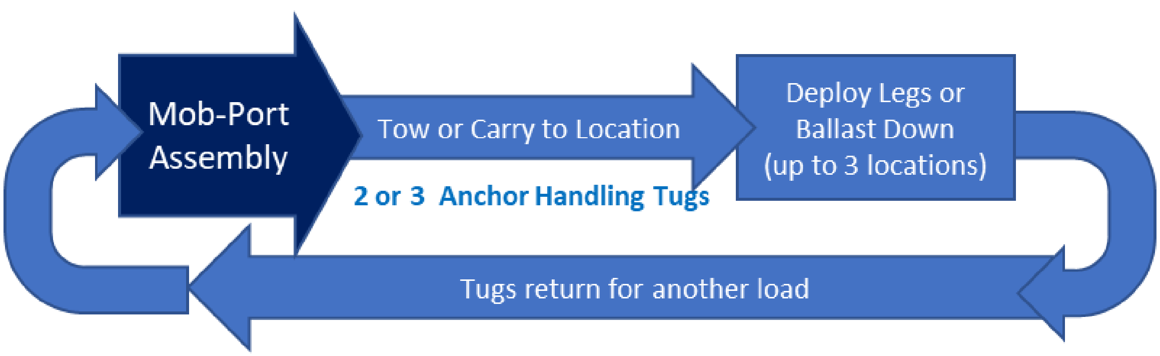


Figure 23 Installation Sequence using a Self-Installing Concept

18.5.3 Revised Assembly Method

The least radical alternative construction method is to keep the same basic sequence but eliminate the need for the big heavy lift vessels. There are a several companies working on concepts that use what is best described as big robots to assemble the turbines using the structure themselves. The monopile, transition piece, and a lower section of the tower need to be installed, then a typical MSV crane is used to install the "robot" which proceeds to assemble the tower, install the nacelle, and blades without the need for a heavy lift crane. There are several designs listed below in Table 5.

Company	Technology	Limits

CLS Wind	Robotic Assembly	Plans for 1000-ton capacity
Huisman	Windfarm Installation Vessel (WIV); a semi-submersible vessel with a 3D-motion compensated WTG installation system.	Unknown
Sumitomo / Mammoet	Robotic Assembly	Unknown, assembled in small sections.

Table 5 Alternative Assembly Methods

Of the three the CLS design shown in Figure 24 below, works with the current design of towers and nacelles effectively and is in the prototype testing phase of development.

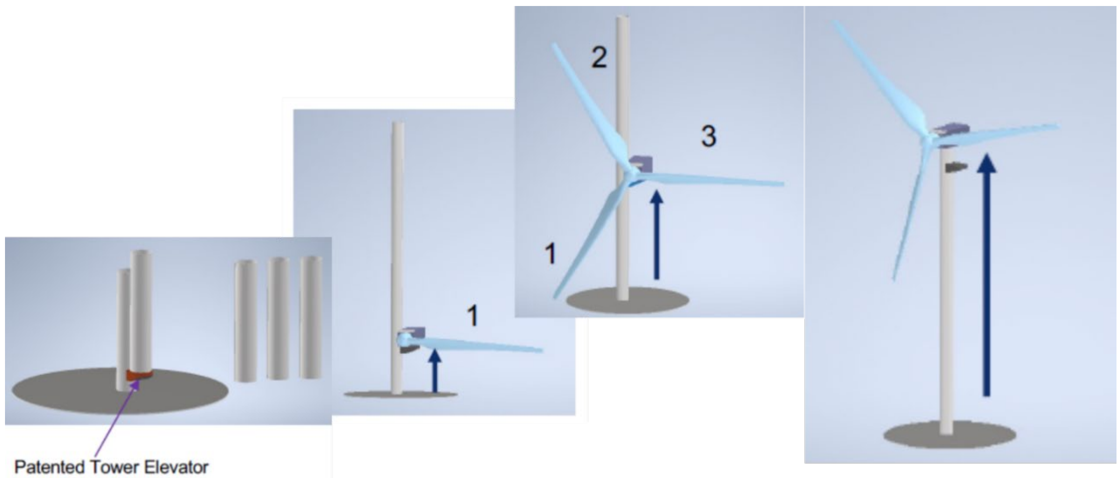


Figure 24 CLS Wind Assembly Sequence

The proposed Huisman vessel, Figure 25, also could install turbines as they are currently designed but would require a fleet of new vessels of this type to be built.

Figure 25 3D Rendering of Huisman Windfarm Installation Vessel

The Mammoet/Sumitomo design requires the tower to be assembled in rings as shown in Figure 26. We have not included other designs that were not seen to give an advantage to offshore construction, including another Mammoet design and the Enercon LCC140 crane which are designed for onshore use.

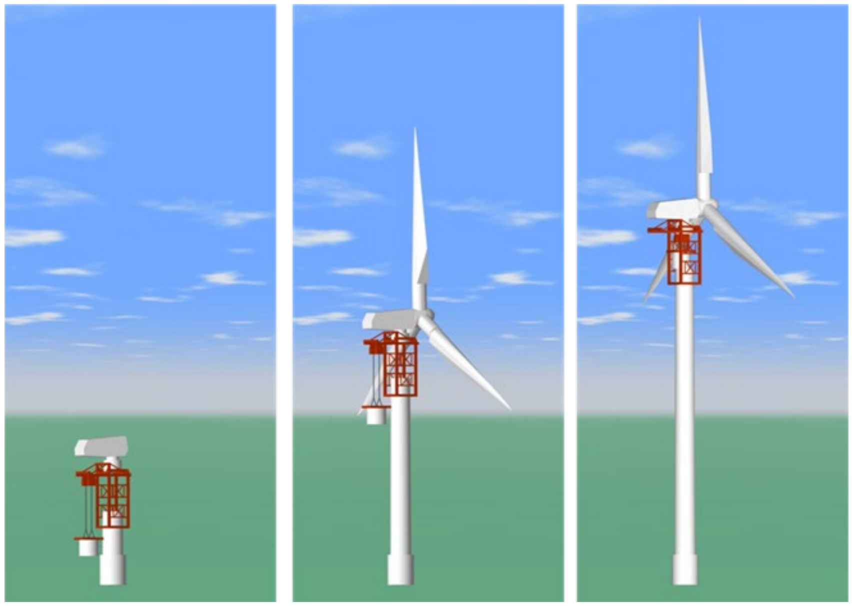


Figure 26 Mammoet/Sumitomo/FLECHOR Turbine Assembly

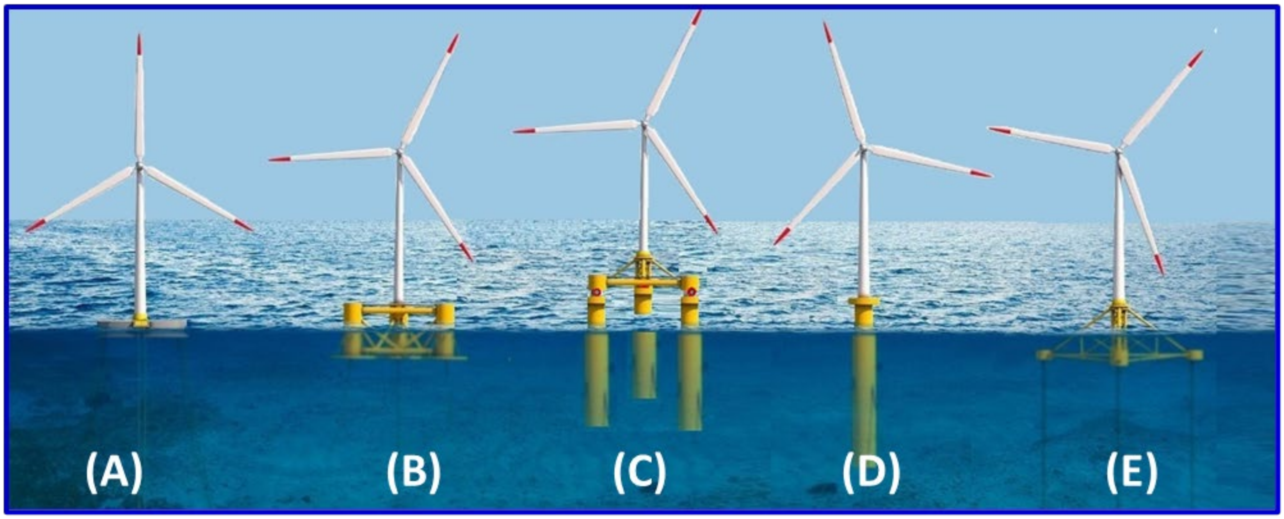
18.5.4 Connectors and Tower Assembly

Another improvement being developed is the use of connector instead of bolts. The time savings here are obvious, but by itself it does not reduce the need for the specialized heavy lift vessels. There are at least two systems being considered for offshore wind use, one is the Van Ord slip joint which has been used. It is designed only for the transition piece installation and eliminates the requirements for bolting and for grouting the joint. Another is repurposing the GMC pipe connector for use in the transition piece and tower joint connection. Finally, there is the telescoping tower design use on the Elisa, which while it still uses bolts to lock it into place and requires strand jacks, does not require the complex and risky alignment of multiple bolts. The Elisa also uses an experimental concrete tower design.

19 FLOATING WIND

Floating wind has yet to develop a dominant design, and the options are too numerous to list here, but Figure 27 gives an overview of the main types of floating wind systems. What most have in common is that hey are focused on reducing the cost of supporting a 3 bladed upwind turbine, similar to but much larger than those used offshore. They are moored to the seabed, and it is intended that power be exported through dynamic cables. These systems can be integrated in Gulf of Mexico ports (with the exception of the spar design) and deployed in the vicinity of existing platforms. If deployed in an oil and gas field or near existing pipelines and cables care must be taken with the anchor design. In a hurricanes the most significant risk would be from a dragged anchor.

It should be mentioned that only one floating platform (of about 300) in the Gulf of Mexico has been lost to a hurricane (the Typhoon TLP), and it was due to the loss of a tendon. The wind turbines may not fair so well, but providing the mooring design is robust hurricane survival of floating platforms has an excellent record. This study will not get into the pros and cons of each floating wind design. As a group they will perform as designed and may be considered a proven technology.



(A = Barge type) (B = semi-submersible) (C =Articulated Spar Leg) (D = Spar) (E= TLP)
Figure 27 Floating Wind Platform Types

20 ALTERNATIVE TURBINE DESIGNS

There are many alternatives to the 3 bladed upwind turbine. The scope of this study does not allow for a comprehensive review of the options, but some of the leading alternatives being considered are listed below in Figure 28. Most of these designs are variations on the orientation or blade type, not the basic concept of massive blades rotating around a central hub.

Figure 28 - Shown are L-R, the Seatwirl, the Senvion 2 Bladed Turbine, and he X-Wind

The authors however are aware of a radically new design. It is patented and has been subjected to wind tunnel testing of individual turbines and subjected to computer modeling but is still early in its development. It makes the list based on its potential. It uses no rare earth magnets in its generators, the components fit on a standard heavy truck meaning the supply chain can extend far from the coast, unlike offshore wind which depends on massive coastal monopile, tower, and blade factories. If it meets its design expectations, it will also have a significantly better capacity factor in lower wind regions like the Gulf of Mexico.

The design does not perform as well in higher winds, but its many times better at capturing the much broader low wind section of the wind distribution curve as shown in Figure 29 which is from a study done for a Gulf of Mexico operator. Based on an analysis of the wind data approximately 150 km off the eastern coast of Louisiana and applying it to the performance curves for the equivalent turbines above yielded a clear difference in performance. The resulting capacity factor for the V3 was 75%, while the traditional 3 bladed G4500 was 26%.

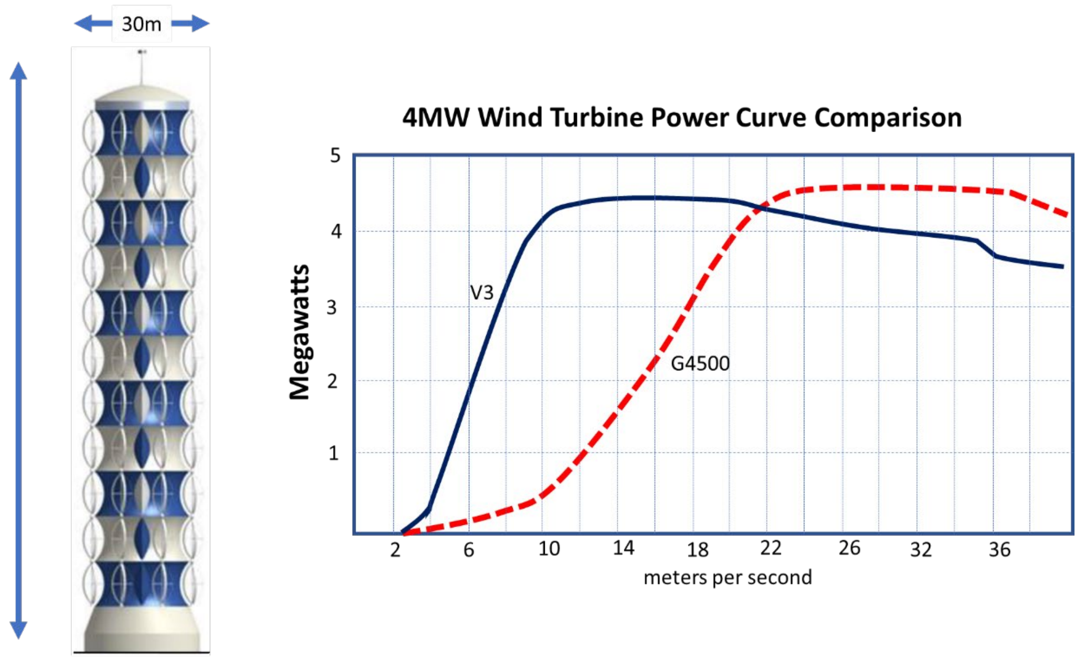


Figure 29 V3 Turbine Performance

The V3 is fully recyclable, will have less impact on birds and bats, all maintenance and repairs are done inside the tower, eliminating the rope access activities required to maintain conventional wind turbines. The individual turbines can be withdrawn inside the tower during a storm increasing its survivability. The V3 turbine also has a different load profile to conventional wind and will likely require smaller support structures. By the nature of its design the separation distance required, which approaches 1.6 km for the largest turbines can be cut by 2/3rds. Assembly does not require a heavy crane, and as the V3 is built one level at a time, they could in theory be deployed to existing platforms at a reduced size.

21 EFFECT OF THE ALTERNATIVE WIND ENERGY CONCEPTS

In terms of impact the self-installing platforms are a needed innovation. Regardless of other drivers, the self-installing platforms and robotic assembly eliminate the need for highly specialized, scarce, and costly vessels. These alternatives also decouple the speed at which offshore wind can be deployed from the limited number of available and planned WTIV's. These designs would also drive more of the work and cost into the local economies. In the Gulf of Mexico and in the US in general they facilitate compliance with the Jones Act. This design can't help but

The revised turbines can also have a similar effect. As V3 turbine for example does not have the heavy lift and alignment issues of either the current turbines or most of the proposed alternatives. For new construction the monopile or jacket can be installed in the most appropriate location, regardless of water depth, and V3 turbines assemble on site with no more than a barge and a typical MSV. In the Gulf of Mexico the V3 is essential. The V3 turbine will outperform the convention 3 bladed turbine in the moderate winds of the Gulf by up to a factor of 3. V3 Turbine can also be built one level at a time, meaning that the loads can be adjusted should an operator wish to put one on an existing platform.

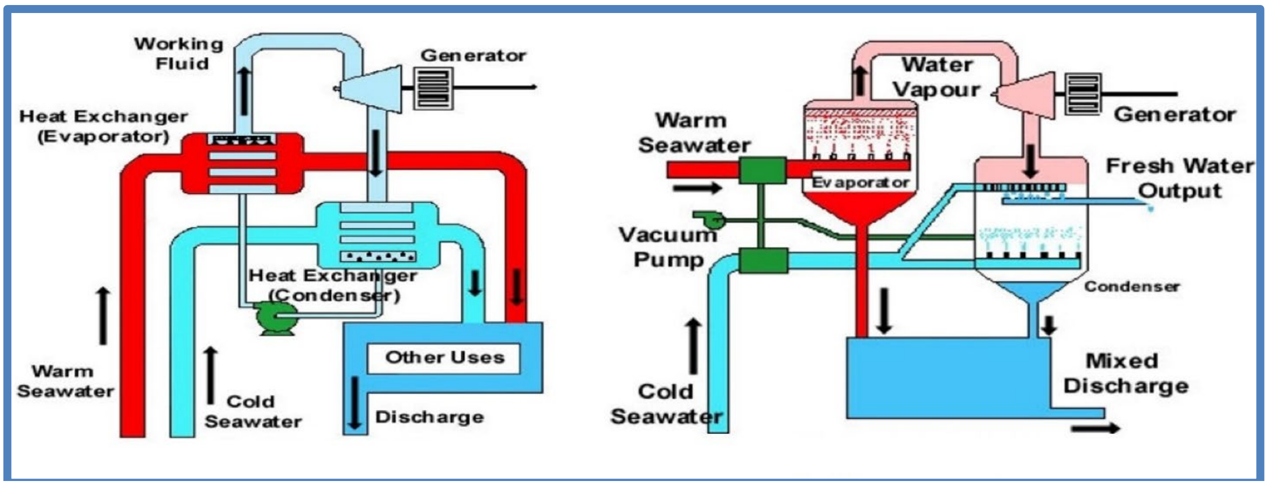
The alternative connectors will be the least impactful on current installation methods, but they are likely to have a notable cost and safety impacts over conventional wind tower assembly methods, especially if combined with the robotic assembly equipment. They will be a useful addition to either conventional construction or in-port fabrication of current wind turbine designs.

To really meet the global stated offshore wind goals all of the above should be applied. Titan or similar platforms with V3 turbines could be deployed quickly and at low cost, with capacity factors unheard of for wind, possibly eliminating, and certainly reducing, the need for storage or peaking plants. In areas with higher winds where the present turbines may perform better, they should still be assembled in port using one of the robotic systems on a self-installing platform.

22 OCEAN THERMAL ENERGY CONVERSION (OTEC)

While the wind and wave resources are not as high as those on the North East and West Coast of the US the Gulf of Mexico can support Ocean Thermal Energy Conversion (OTEC) and has existing facilities that can be transitioned to offshore geothermal, something not found on either coast. While both technologies are still being perfected OTEC and Offshore Geothermal are 24/7 baseload power sources.

OTEC comes in two basic configurations, shown in Figure 30, Open Cycle and Closed Cycle. The concept is simple. Using a low boiling point fluid, like ammonia, a typical steam cycle power plant is run with ammonia replacing the water, the warm surface water (20 deg Celsius or higher) as the heater, and the cold (4 to 5 deg Celsius) depths of the ocean.



Closed Cycle OTEC **Open Cycle OTEC**

Figure 30 – Ocean Thermal Energy Cycles

A typical Closed OTEC uses either ammonia or other low boiling point fluid such as R124 in a turbine cycle identical to that used in an onshore power plant, whereas open cycle system use only seawater. The open cycle systems are less efficient but have the added benefit of making fresh water via the condenser.

OTEC is not a viable option in areas where the surface water temperature is cooler than 20 degrees Celsius. OTEC requires a minimum temperature difference of 15 degrees Celsius between the hot and cold-water intakes, with 18 degrees taken as the practical limit by NREL. These conditions only occur in warm tropical waters that have access to cold (typically 5 degree Celsius) water typically found below 1000m.

OTEC requires large amounts of cold water be brought up to the surface. This water, besides its temperature, is valuable in other ways. It is rich in nutrients, has a higher CO_2 content than surface water making direct seawater carbon capture more efficient, and is free of common parasites such as sea lice. All this means the discharge of an OTEC plant can have benefits beyond power generation, making the cost of the parasitic energy load of large pumps required for OTEC less of a burden.

OTEC is not without potential impacts, as is shown in Figure 31.

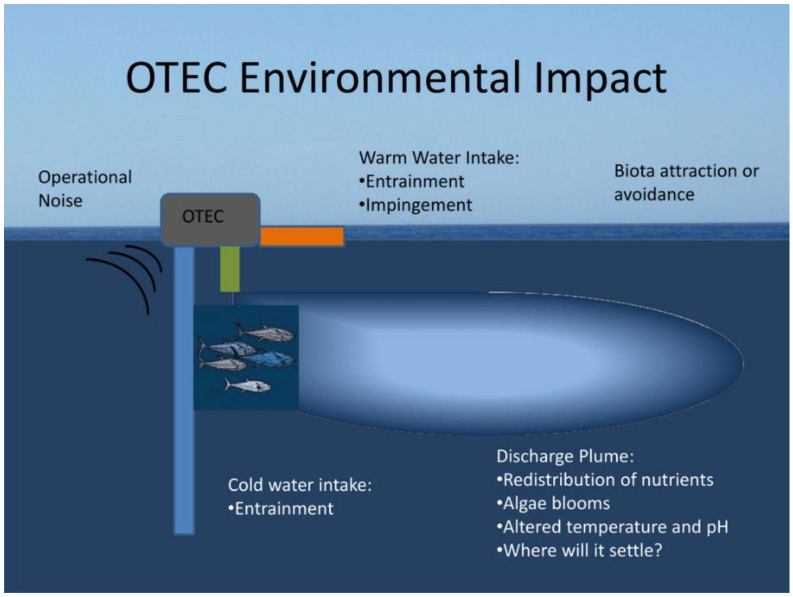


Figure 31 Environmental Concerns for OTEC Systems

However, years of research have shown ways to mitigate most of them. Of primary concern is the effect that brining up cold, nutrient rich, oxygen poor water from the depths, and discharging it closer to the surface. The simplified version is that prior to discharge the cold and warm surface waters are mixed and then discharged not at the surface but at a depth where the temperature difference is negligible and nutrient impacts minimize. Often down 150 m or more.

The only remaining technical hurdle with an OTEC system, which as a system was invented in 1890, the size of the cold-water pipe, which extends down to 1000m or more to access the chilled depths. The first commercial system performed well in 1926 but was only in service for 3 months in Cuba before being completely destroyed by a hurricane. Interest picked up in the 1970's oil crises, and led to the first permanent installation on Hawaii, albeit only a 100kW test unit run by Makai.

However, in response to the energy transition there are now several new companies developing OTEC systems, with two commercial plants about to go online within the year, on in Kiribati in the Pacific, built by KIRSO (1MW), and one in Sao Tome offs the coast of Africa, by Global OTEC (1,5MW). The OTEC being planned for San Tome shown below in Figure 32.

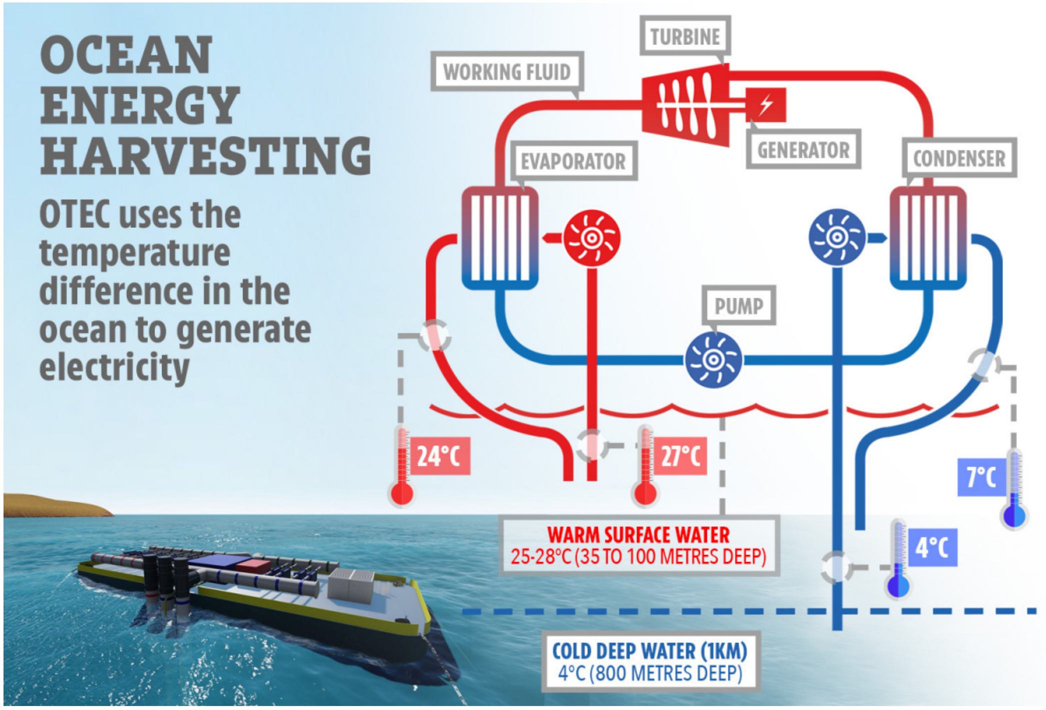


Figure 32Closed Cycle Ocean Thermal Energy Conversion (Source: Global OTEC)

All are using closed cycle OTEC systems of a conventional design. This could pose a problem for if tried as a retrofit on existing platforms due to the size of the cold-water pipe. There are ways to address the problem, but they are not yet in the public domain, but the focus is on reducing the size of the deepwater riser and increasing the efficiency.

With regards to repurposing OTEC is seen as a viable technology for the deepwater of the Gulf of Mexico but only on purpose-built platforms. As a retrofit device it will require research to reduce the footprint and downpipe requirements.

23 WAVE ENERGY CONVERSION

Wave energy has a high energy density and is generally more constant than wind, but efficiently capturing it has proven to be a challenge. As of the date of this study, there are no offshore utility scale wave energy developments. The most successful commercial system is one that is used for low power ocean data collection activities.

Because of the promise of wave energy there are numerous designs, with more than 500 in the database used for this study. Commercially wave energy devices have struggled, in part because many designs target shallow waters where wave heights are amplified. The technical challenge becomes that the energy absorbing portion is designed for the mean wave height, but the structure must be designed to withstand the expected maximum storm condition. Moving into deeper water reduces the storm loads but can make energy capture more difficult. Only those types that were determined to have commercial potential in the Gulf of Mexico were included in the repurposing model.

The exact system will depend on the site-specific data. For longer period waves oscillating water column or systems that work on over pressure are considered a possible candidate, but only as part of larger systems. There is one system identified as a candidate for stand-alone deployment in the study, the SeaDog was deployed as a prototype offshore Galveston and met its design expectations.

Figure 33 SeaDog Prototype Deployed of Galveston Texas
(note the water jet discharge from the top)

If a full-scale system matches the prototype performance it has the potential to supply commercial quantities of power and water, and a deployment is being considered for the western Gulf of Mexico. It is the system that is proposed as the backbone of the Willacy County example project later in the study.

24 OCEAN CURRENTS AND TIDAL ENERGY

Ignoring tidal barrage options, where a dam is built across the bay and the water enters through gates that are then closed and the water is forced out through turbines, there are no commercial deployments of tidal machines. Tidal energy devices, like wave energy devices, suffer from the high cost of installing large equipment in challenging environments. Many tidal companies have targeted locations with currents of 8 to 10 knots, and most don't work in currents less than 2 knots (1m/s). The largest installed device is a 2MW installation by Orbital Marine Power. The areas of highest tidal currents also are often in environmentally or socially sensitive areas. If installed in open water, where the installation costs are lower, the currents are too low to make meaningful power. In the Gulf of Mexico, the best ocean current resource is loop currents, but these are unpredictable and sporadic and cannot be relied on for power. Despite these drawbacks ocean current devices are considered, but only if installed as part of a system. The devices themselves are relatively low cost but installing them as stand-alone energy machines is not. If they can be deployed for little or no extra cost than the ability to capture loop currents or storm driven currents may make them useful, but it will on a case-by-case basis. No stand out design was identified and the choice of device should be based on the expected lower current velocities that will be encountered.

25 OFFSHORE GEOTHERMAL ENERGY

The subsurface of Gulf of Mexico is one of the most surveyed and best understood parts of the world. Surveys and offshore drilling have been taking place there since Kerr-McGee drilled their first offshore well 1947. Per BOEM more than 53,000 wells have been drilled there. There have been more than 7000 platforms installed, of which 1600 remain, and 75,000 km of pipelines laid. All these activities required collection of seabed or subsurface data, or both.

Despite this, or perhaps because of it, the estimates for the potential geothermal resource have struggled to come up with consensus. The one thing that it agreed is the potential is large. One problem in locking down a resource estimate as NREL and BOEM did for other renewable energy systems, is that geothermal is more akin to oil and gas. The total geothermal potential for a given basin depends on as a minimum the following:

- Subsurface surveys and data interpretation
- Exploration drilling or data from existing wells
- Characterization of the reservoir fluids and physical parameters
- The number of wells that will be drilled, production and disposal
- The geothermal energy capture technology that will be employed
- The presence or absence of associated hydrocarbons.

Another certainty is that repurposing of existing oil and gas platform and wells will make the economics more attractive. It is possible to start the conversion to geothermal production while a facility is still producing oil or gas. It may even be possible in the future to reverse the flow out of water injection wells, tap the thermal potential and reinject the fluids into the original, now abandoned reservoir. The geothermal resource potential in the Gulf of Mexico may not have been accurately quantified, but it has been mapped, as shown in Figure 34 below.

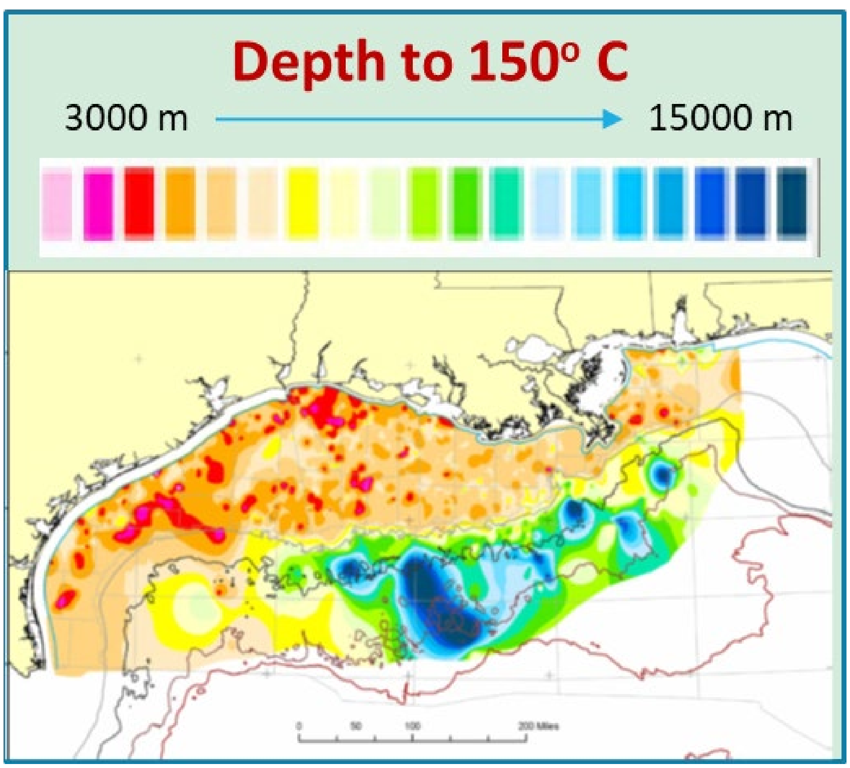


Figure 34 Map of Gulf of Mexico Geothermal Sources

26 SEAWATER AIR CONDITIONING (SWAC)

Sea water air conditioning or SWAC is where cold waters from deepwater offshore is brought in and used directly to cool the air, displacing the demand for energy intensive conventional AC units. SWAC is being considered for island and warmer coastal areas. It may have utility offshore as part of aquaculture activities and could be used to help relieve temperature stress on Gulf of Mexico coral formations. It can also reduce the carbon footprint of existing and new platforms by being used for air conditioning in place of conventional systems.

27 OFFSHORE SOLAR ENERGY

The NREL/BOEM resource report lists the gross potential of solar energy in the Gulf of Mexico as the highest of any of the technologies included, but it also correctly concludes that commercial offshore solar is not practical. Solar power should however be considered as part of a larger system. Offshore topside space is at a premium. If the deck of the largest platform current in the Gulf of Mexico was covered in solar panels and using a value of 100MW/km^2 as a basis, the installation would make only 1MW, when the sun was shining.

Free floating solar has been proposed but in areas like the Gulf of Mexico where hurricanes are a certainty the survivability of floating solar is questionable. For this study solar power is considered but only for small local power supply or for AUV charging. Novel systems that capture solar energy both as photons and as heat, because of the higher energy density were assumed in the base case example.

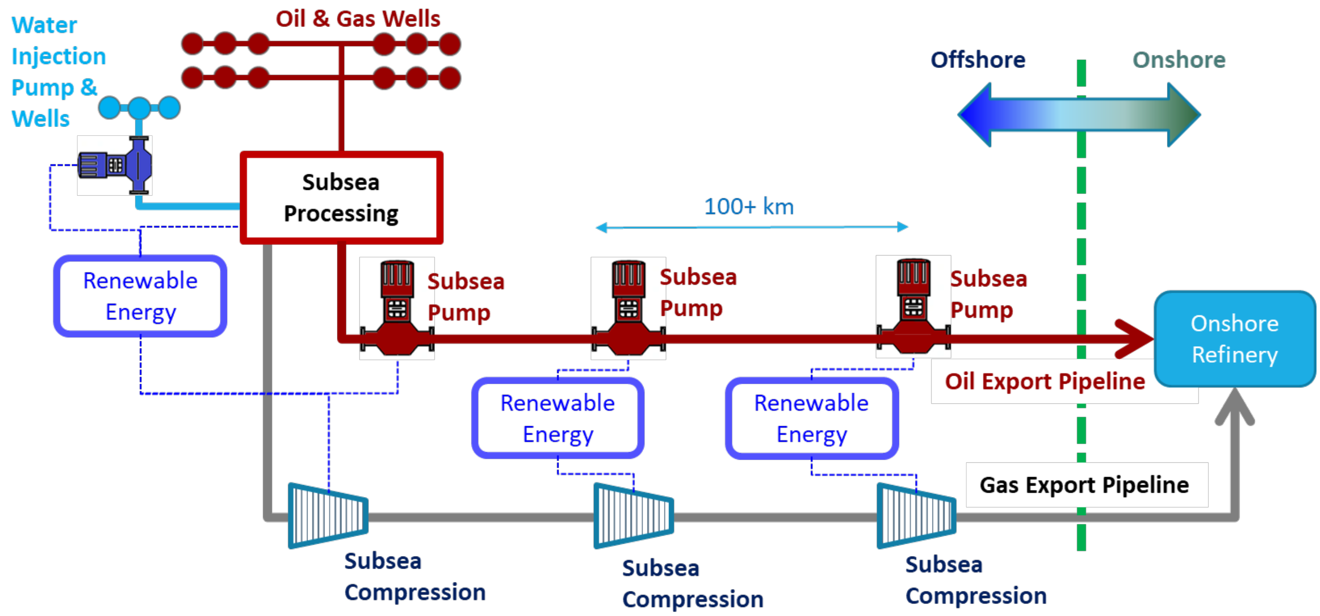
Topic IV - Greening of Oil and Gas Production

28 GREENING OIL AND GAS PRODUCTION

While fully supporting the energy transition it is unlikely that meaningful reductions in the total oil and gas produced will occur before 2050. Given that oil and gas production will be happening it is only responsible to minimize the added carbon footprint (so called "greening") of exploration, drilling, and production activities. Offshore oil and gas already have some of the lowest carbon footprints on a per barrel produced basis (Wood Mackenzie) about 50% of onshore production in the US, but it can be improved.

There are several ways to reduce the carbon footprint of offshore oil and gas. The most obvious is to replace the current gas and diesel generation system with renewable power. On smaller platforms in the Gulf this should be easily accomplished by combinations of wind, wave, and solar power, perhaps with a small battery back-up. But it would be difficult to maintain. A better way is to build out renewable energy hubs that feed the surrounding platforms of all sizes with the power they require. These projects could be built by owner operators who sell the power to the oil and gas producers in a Build-Own-Operate-Maintain arrangement, so called BOOM contracts. This would move the cost entirely to an operating expense. This could be accomplished by bringing power from onshore renewables as well, but the cost of a new high voltage HVDC or HVAC cable is comparable, and it will not offer the other synergies detailed in this report.

Another way to green up production is to minimize the requirements for new platforms. By using a combination of offshore renewable energy and subsea processing and pumping facilities, the so-called subsea factory, extended tie-backs to legacy platforms or even to shore is possible. The attraction to this methods is as the oil and gas reservoir empties (or demand becomes redundant) the renewable energy facilities can remain and use the pipelines and wells for power export or carbon capture.



Topic IV - Green Hydrogen & Ammonia Production

29 GREEN HYDROGEN PRODUCTION

Included in this study is a breakdown of green hydrogen production methods and export options. The possible uses for the hydrogen listed below. The key points are that green hydrogen, which is hydrogen produced by electrolysis using only renewable energy, is a power and water intensive activity. This makes offshore an ideal location as both are available in unlimited quantities.

While the proposed uses for hydrogen in the transition are many, the one use that is not debated is to replace hydrocarbon derived hydrogen in chemical plants and refineries. The Gulf of Mexico oil and gas facilities are connected by pipelines to these refineries, but the pipelines cannot be used for direct transport of hydrogen. An important consideration is that the high strength steels used for offshore pipelines cannot safely carry hydrogen, and if they could it would still be required to replace every seal, valve, flange, sensor, compressor, pig trap, and flow meter as they are not designed for the much smaller hydrogen molecule and will leak. But there is still an advantage to the Gulf of Mexico in that the rights of way and resistance to new pipelines construction that will be needed are low.

The Gulf Coast also has the highest need for green hydrogen in the US by virtue of its refineries and chemical plants.

Hydrogen is being proposed for the following uses:

- As a prime energy storage and transport medium (a replacement for natural gas)
- As feed stock for ammonia plants
- As feed stock to power to fuel systems
- Feed stock to chemical plants (roughly 60
- Alternative to coal for decarbonizing the steel sector
- Transport fuel

29.1 H2 as a Prime Energy Carrier or Transport Fuel

There are many efforts trying to create a Hydrogen transport market similar to LNG. In simple terms hydrogen seem like a good fit. It’s a gas, can be liquefied, and burns without emitting carbon. There are however several obstacles. The process of making green hydrogen is energy inefficient, losing between 30% and 45% of the green energy that goes into it for electrolysis, then another 10% to 30% in liquefying and shipping, more upon burring, less if used in a fuel cell. Hydrogen is not energy dense, even in liquid form it has less than ½ the energy per cubic meter. This means it will take twice the energy to transport the same amount of end use energy assuming the same sized ships, and it is more hazardous than shipping LNG. Hydrogen is notoriously hard to keep from leaking and is difficult to compress due to its small molecular size. It is odorless and has a very wide explosive limit.

Fuel	High Heat Value	Liquid Density	Energy Density
Hydrogen	120 MJ/kg	70 kg/m^3	8,400 MJ/m^3
Methane	50 MJ/kg	422 kg/m^3	21,100 MJ/m^3

Hydrogen could be made, liquefied, and shipped from offshore Gulf of Mexico facilities but the technical challenges are enough that it is not considered a deployable option at this time.

29.2 Feed Stock to Ammonia, Power to Fuel and Chemical Plants

This is the one use for green hydrogen that gets no push back, the benefits are clear, and the risks are manageable.

Ammonia is a vital chemical in many processes, and currently nearly all of it is made from high carbon load hydrogen. In a similar fashion pure hydrogen is used both in refining (though that need should dimmish over time) and in chemical and plastics production. Currently per the EIA the US sues 10 million metric tons of hydrogen a year, and roughly 50% of that is used in Gulf Coast refineries. The Gulf Coast refineries and gas plant also produce most of the US hydrogen, nearly all of it from the Stream Reformation (SMR) process. The plants are sued to handling hydrogen and unlike the general pipeline grid they have a system of interconnecting hydrogen specific pipelines making for an ideal market.

To be able to replace these 5 million tons with green, offshore generated green hydrogen can be done. It may require new dedicated pipelines or novel uses of existing ones to get it to shore, but the platforms can certainly support the require desalination and hydrogen production equipment.

The larger platforms can also host power to fuel plants, though the economics of doing so in the Gulf of Mexico may be questionable. It is unknown how the economics would compare to a system that sends the required components (hydrogen and non-fossil derived CO2) to onshore fuel processing plants. It would still be worth developing pilot plants however as the technology will have applications in more remote areas. For this reason, Power-to Fuel is examined in more detail later in the report.

Of particular interest is a system developed by GTA Inc. that works best as a subsea electrolyzer. This has the effect of reducing the electrolyzer cost and reducing or eliminating the need for hydrogen compression. The deeper the water the more effective it is.

29.3 Hydrogen Storage

For energy storage and peak shaving, hydrogen does have utility, and several methods of storage are examined. While topside storage in tanks is possible, the Floating Power Plant (FPP) design for example intends to store hydrogen inside the hull, this is inefficient due to the volume of the required tanks and the presence of stored hydrogen onboard presents a safety risk that can easily be avoided. Storing the hydrogen subsea will free up valuable space on the platform and the external pressure and cooler temperature will reduce the risk of leaks. Should the hydrogen leak into the environment subsea it poses no environmental risk. There are some novel solid storage technologies in development, where the hydrogen is bound into a compound, but further development is needed before they can be deployed. Solid storage system may be examined further in later Phases of the repurposing project.

There is consideration for using salt domes for storing large quantities of hydrogen as was stated in the section on reservoirs, but until the technology is more advanced it is not considered as deployable at this time.

The systems considered all use compressed hydrogen, not liquid hydrogen as this reduces costs, liquid hydrogen only has advantages if the gas is being transported, and subsea icing is a real risk with cryo-systems.

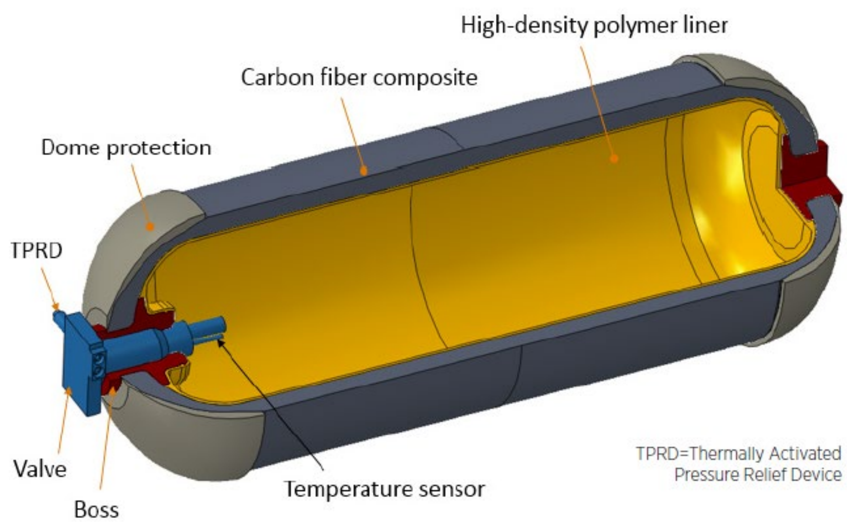
When used as a peak shaving system hydrogen is produced whenever the renewable energy system makes more power than the local needs demand. When the demand exceeds the renewable energy production the hydrogen will be used in a fuel cell to generate power. The efficiency can be increased by feeding both the produced hydrogen and oxygen into the fuel cell, but not all fuel cells can take the excess heat generated when pure oxygen is used.

Several options are identified, but any competent industrial tank manufacturer can supply the mild steel tanks, and with the growth in hydrogen there are new composite designs being developed daily.

This study was limited to identifying the possibilities for repurposing, and any storage system will require detailed design. The system scope and limits for such as design are defined as follows:

- It is designed for peak load local storage, meaning the size will be limited. Excess production will be exported to Gulf Coast refineries and chemical plants to supplant grey hydrogen currently used.
- As the storage system is subsea, and therefore safe, options to store the produced oxygen will also be considered.
- The tanks will be either mild steel or composite designs.
- Ammonia storage will not be considered to store hydrogen for this use case due to its energy inefficiency.
- Novel designs such as the printed concrete storage domes should be considered.

The basic component will be cylindrical tanks like the one shown below in Figure 35, set into arrays on the seabed.



Source: Process Modeling Group, Nuclear Engineering Division. Argonne National Lab (ANL))

Figure 35 Typical Hydrogen Storage Tank

GTA, the electrolyzer technology listed for further Phase II work, has a design for such a system, illustrated below in Figure 36.

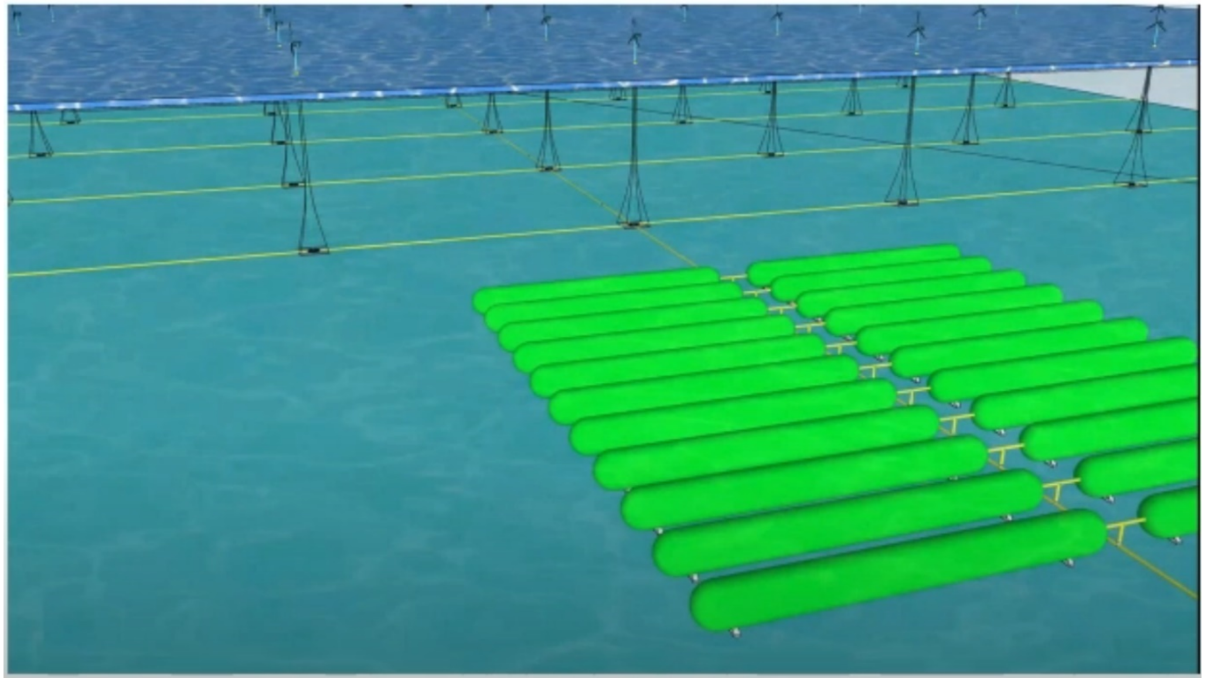


Figure 36 GTA Concept for Subsea Hydrogen Storage

30 AMMONIA AS ENERGY CARRIER OR STORAGE MEDIUM

Once green hydrogen is produced it can be combined with nitrogen taken from the atmosphere and combined into ammonia (NH_3). Ammonia is efficient at storing hydrogen, holding about twice as much by volume as liquid hydrogen does without being cryogenic. There is also a tremendous need for ammonia in the manufacture of fertilizer and other chemical processes. Ammonia made from green hydrogen is labeled green ammonia, and it is estimated that between 60 million metric tons and 90 million metric tons of green hydrogen will be needed to replace the current black (made from fossil fuel) ammonia by 2050. The Gulf of Mexico refineries can use this ammonia, and its production for that purpose is worth examining.

Ammonia has also been mentioned for possible use as marine fuel or as a way to transport hydrogen. The issue is that to be practical as a fuel you need anhydrous (pure) ammonia. Ammonia is a dangerous gas that can kill at even low concentrations (2700 ppm is fatal in minutes, 5700 ppm is considered instantly fatal), is caustic to flesh, and while hard to ignite poses and explosive hazard once heated. Anhydrous ammonia is typically produced and used within the same facility for these reasons. In diluted form (typically 50% water) it is one of the most shipped commodities. It is also used in commercial refrigeration and in OTEC power plants. The authors consider use of anhydrous ammonia as fuel is far too hazardous when there are other alternatives, but recognize that its production is definitely an option for repurposed platforms.

Source: DHS - Science and Technology Directorate

CSAC observed a white cloud of ammonia engulf a 1,000-gallon tank, spread to a diameter of over 109 yards (almost as large as a football field) and height of 16 feet, and then flatten.

Figure 37 Ammonia Tank Leak Behavior Testing, Dugway Utah

Topic VI - Carbon Capture, Utilization and Sequestration (CCUS)

31 CARBON DIOXIDE CAPTURE AND SEQUESTRATION (CCS)

Studies have shown that the reservoirs in the Gulf of Mexico are suitable for Carbon Sequestration. Per a quote by Exxon in a recent article, *".. U.S. Department of Energy estimates shows the storage capacity along the U.S. Gulf Coast is large enough to safely store about 500 billion metric tons of CO2. "* (Ref E&E News Energy Wire), other studies put that number as high as much as ten times that number. (Agartan et al. 2018). That is enough to store more than 100 years' worth of industrial CO2 production of the United States.

However, having the capacity to store carbon dioxide and implementation of CCS are different problems. The first problem with direct air CO2 capture is that to do so economically it must be done while burning hydrocarbon fuels. Even at the current elevated amount of 400ppm the concentration in the atmosphere is challenging and energy intensive to capture.

Direct air capture is being developed by companies but requires a significant amount of energy, and the equipment has a large footprint, too large for most platforms. If the energy supplied is not from renewable sources the process results in a net addition of CO2, if the energy is green than it is not displacing fossil fuel generated power on the grid.

Offshore there is a better option, direct seawater capture of CO2. Several companies, and three DOE ARPA-E Projects are studying direct water capture of CO2. In at least one of these systems the capture and sequestration are linked, as it produces solid calcite and/or magnesite, which in turn can be used to make low carbon concrete. Regardless of the technology employed capture of CO2 from seawater is more efficient than direct air capture, due in no small part to the high concentrations of both CO2 and other carbon containing elements compared to air. The oceans are the largest CO2 sink in the world, and while not directly removing the CO2 from the atmosphere if CO2 levels are reduced the ocean will pull atmospheric CO2 in to replenish what was removed. This has the positive side effect of reducing the increased acidity of the seawater due to increase atmospheric CO2.

With regards to repurposing offshore oil and gas facilities they have three roles in CCS.

1. Using new or existing wells CO2 captured at coastal industrial facilities can be sent via new or existing pipelines and sequestered.
2. The platforms can host power to fuel facilities, where either atmospheric or direct water capture CO2 is combined with green hydrogen to make efuels.
3. The platforms can host a seawater to calcite/magnesite combined capture and sequester system. In this instance allowance for handling of the produced solids must be included.

The first CCS project in the Gulf of Mexico was approved in 2021 by BOEM as part of a DOE pilot project. Talos Energy and Carbonvert, Inc. are working toward sequestering more than 200 million tons of CO2 by 2030. While there no Federal carbon credit market, slowly the US is moving to one. IN Europe the current price is over $100/ton of CO2 sequestered. This would value the Talos/Carbonvert project at $20 billion over 8 years.

Topic VII - Synthetic or E-fuel Production

32 POWER TO FUEL

Besides replacing the high carbon hydrogen uses in chemical plants, another promising use for green hydrogen is as feedstock for power to fuel systems making synthetic fuels, also known as efuels. This is distinct from the Green Hydrogen and means methanol, diesel or kerosene (aviation fuel) derived from green hydrogen combined with carbon dioxide. These technologies are not yet cost competitive with refined fuels, and are more costly than biofuels, but the technology is advancing rapidly, and costs are reducing. When compared to biofuels efuels can scale without issues of crop displacement, deforestation, or increase agricultural runoff.

As efuel technology advances repurposing existing offshore oil and gas facilities as efuel hubs has the following advantages for oil and gas companies looking to transition into renewable energy:

- The systems use process equipment very similar or identical to oil and gas
- Large production platforms have the space and are designed for safe handling and transport of hydrocarbon liquids
- Existing pipelines can safely carry methanol, diesel, and/or kerosene, the primary products, where they cannot carry pure hydrogen.
- The pipeline network is connected to the refineries facilitating distribution of the efuel
- Offshore facilities have ready access to renewable energy and water to make hydrogen
- Carbon capture, either direct air or derived from seawater, may be more cost effective offshore

The process for making them is show in Figure 38 below.

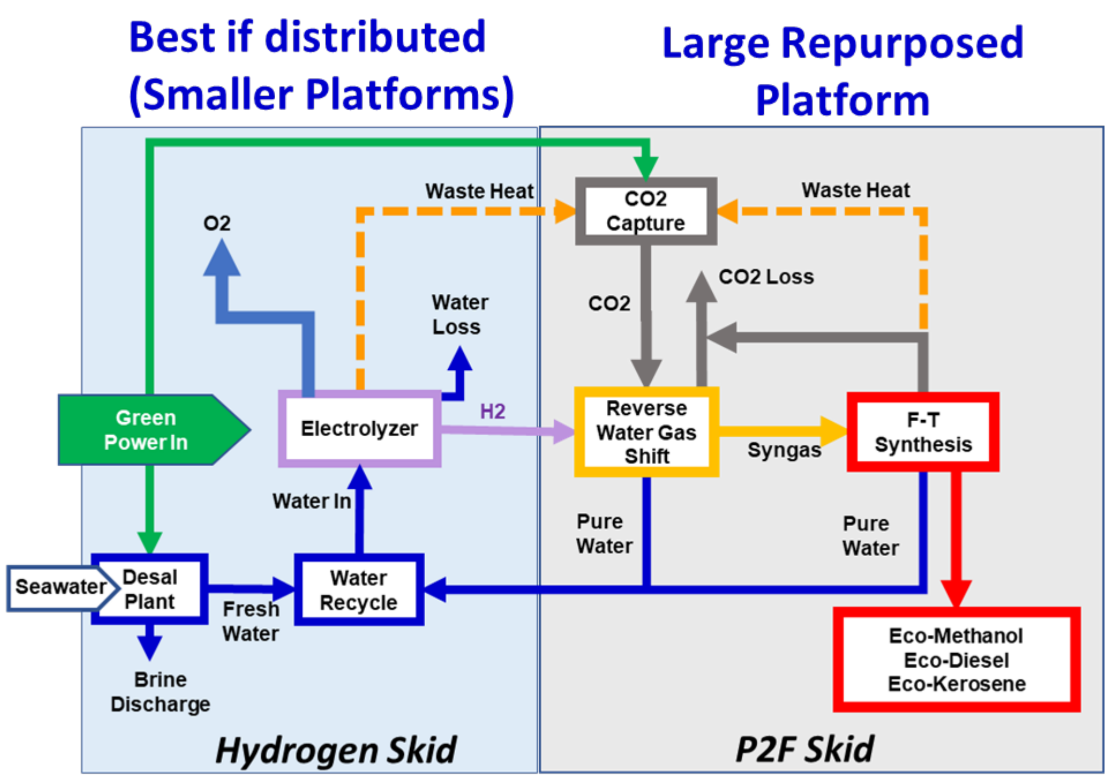


Figure 38 Simplified E-Fuel Flow Diagram

A recent onshore project in Chile at Haru Oni has demonstrated the potential of these systems. The Haru Oni project in Chile seeks to capture and export the exceptional wind resource of southern Chile. In this case the small pilot plant is making methanol, but the real value will be in aviation kerosene, which is a sustainable drop-in replacement allowing long distance flights to go green.

The energy landscape is changing. For a century oil and gas have powered the world, and access to this cheap and transportable energy source provided a century of unprecedented improvements in the average person's life. But there are downsides to running our economies on this naturally occurring form of stored solar energy. Geopolitical tensions and instability caused by a global dependence on access to affordable energy has caused wars, allowed dictators to flourish, and destabilized large parts of the world.

Whether the cause or only a contributing factor, the levels of CO2 effect climate, and the emissions from burning fossil fuels have had, and are having a measurable effect on the world. More importantly regardless of any personal view, or the uncertainties inherent in even good climate science, the world consensus is it is time to divorce ourselves from dependence on fossil fuels.

A "cold turkey" switch from fossil fuels to electric and hydrogen as the primary energy sources by 2050, which is the basis of some proposals, would require retooling the global industrial economy. Instead of having to rebuild the entire transportation grid and demolish and rebuild every petrochemical plant, we could convert to a carbon neutral/negative, renewable energy derived, hydrocarbon. You can effectively fill up your 1965 Mustang with wind and wave energy, drive to the airport and then fly to your destination in a jet powered by solar energy derived efuel.

The technology to accomplish this exists, and the basic principles are proven. Split water into hydrogen and oxygen, pull carbon dioxide out of the environment, combine the carbon and the hydrogen and you get a hydrocarbon not based on fossil resources. Hydrocarbons made in this way have several advantages:

- They are pure in that they contain none of the common trace elements in oil-derived fuels, the result being they burn much cleaner.
- The process can be tailored to produce hydrocarbons ranging from methane gas to heavy oils.
- They can be used to store and transport renewable energy from high resource, but unpopulated, areas to urban centers that need the energy; often using existing oil and gas transport networks.

The stumbling block has been the cost of these fuels could not compete with cheap natural gas and direct renewable electric power on a one-to-one basis.

That the cost dynamic is changing, the simple bbl-to-bbl cost comparisons that have been the focus of many papers ignores some key advantages of power to fuel systems, and that building offshore renewable energy powered industrial parks can be a near term and long-term solution yielding a green energy future.

The Gulf of Mexico has direct access to markets and refineries, and certainly it cant be said to fit the stranded resource argument that is the strongest one for e-fuels. Haru Oni located in Tierra Del Fuego is prime example of an ideal location, albeit onshore. The Gulf of Mexico is however an ideal location for developing and perfecting the required technologies. The original plan for Phase I was to develop a detailed design for a small test plant on PN 975, but the denial of the permit has caused a delay in that work.

There are advantages for these systems to be installed in places where existing infrastructure, like the Gulf of Mexico, can be repurposed instead of removed.

32.1 The Hidden Costs of Replacing Infrastructure

When accounting for the benefits of switching to renewable energy sources, particularly in transportation, the economic and social costs seem too often overlooked or ignored. To completely do away with hydrocarbon-based fuels means every car on the road will have to be replaced or undergo expensive retrofitting. Aircraft will require complete ground up redesign and because of decreased energy density will have less payload capacity.

The entire value chains that support internal combustion engines and turbines from the smallest weed-wacker to the largest gas turbine will need as a minimum retooling, or more likely replacement. The new plants are likely to be on average more automated than their legacy predecessors, not located in the same regions, and will require new skill sets.

The distribution networks for oil and gas built up over 100 years will lose all utility and need replacement.

In short, the costs will be many trillions of dollars, the effects on job markets will be disruptive, and it is not clear how long it will take. Unless the governments of the world decide otherwise and give massive subsidies to average people to replace the existing equipment, the majority of the economic burden will fall on the lower end of the income scale as people are forced to pay for battery powered transport and tools.

Again, putting the scale of the problem in hard numbers, globally there are approximately:

- 30,000 commercial airliner and military planes
- 500,000 private aircraft
- 30,000 helicopters
- 1.4 billion cars
- 325 million commercial vehicles

All of the above are designed to run on hydrocarbon fuels, just 3 of which make up 90% of the fuel use per the US EIA:

- Diesel
- Gasoline
- Kerosene/Jet Fuel

The good news is all the above can be made using power to fuel technology, the problem is that as a practical replacement for fossil fuels the Power-to-Fuel industry is in its infancy.

32.2 USING RENEWABLE ENERGY FOR TRANSPORTATION

There are five primary methods being considered for using the energy produced by renewable energy sources for transportation.

1. Batteries – Lithium Ion, Flow Batteries
2. Burning hydrogen directly, stored and transported either as a liquid or high-pressure gas
3. Using fuel cells power by hydrogen or methane
4. Conversion of H_2 and N_2 to ammonia to be used as a fuel
5. Conversion of CO_2 and H_2 to hydrocarbon fuels,

Batteries have limitations in their application, particularly for aircraft. Added to that the batteries currently used require rare earth metals that restricted in their supply, are difficult to recycle, can burn in the event of an accident, have a limited life span, and are slow to recharge when compared to filling a gas tank.

Burning hydrogen directly is almost never a sound approach. Hydrogen is not an effective fuel due to its low volumetric energy density and difficulty in handling safely. Burning it in a turbine or on a gas burner does not make "only heat and water" as is often stated, but significant amounts of nitrous oxides as well, the base gas of smog. Hydrogen also has some costly material challenges and cannot, as is sometimes claimed, be used directly in most existing pipeline systems. Hydrogen also has a power density problem. While a kilogram of hydrogen has the heat energy of 1 gal of gasoline, even in liquid form a kilogram of hydrogen is only 70 kg/m3, meaning you can put 3.5 to 4 times the energy of hydrogen into the same tank if you use gasoline. It is the main stumbling block in direct use of hydrogen for aviation.

Fuel cells are more promising than direct combustion, but to date are too expensive and very sensitive to the purity of the activation gases.

Ammonia has also been considered as a replacement fuel for hydrocarbon-based fuels. The drawbacks here are pure ammonia is a very volatile and caustic liquid and would require the same level of re-tooling as either batteries or pure hydrogen as fuels. In controlled environments like petrochemical plants, ammonia is used safely, but tanks of pure ammonia being driven around as todays cars are raises some serious safety concerns. Ammonia used as fuel is not like the ammonia used in cleaning your home. While less likely than gasoline to ignite, pure ammonia is much more dangerous than gasoline when you consider that it is the fumes and contact with the liquid ammonia that are the hazard. If the ammonia tank in a car ruptures the released ammonia will give off toxic fumes that can kill a person in just one or two breaths. If it comes in contact with skin, it literally dissolves the skin and flesh off the bones.

Lastly, we get to power-to-fuel. If it can be made to work efficiently at the very least it would ease the transition to an economy based on other solutions, and it would more importantly allow the world to go carbon neutral much more quickly. It will allow the retirement and replacement of legacy hydrocarbon infrastructure as it wears out, rather than ripping out equipment still in its prime, and the carbon cost that entails.

32.3 The Offshore Advantage

Power-to-fuel is worth pursing, and we could build a power-to-fuel plant attached to every onshore wind and solar farm that converts any excess energy (energy not sold to the grid) to fuel. But doing so offshore, preferably in isolated locations with excellent resources, like the Central Gulf of Mexico makes more sense.

32.4 Water Access and Discharge

The first and most obvious point is access to water. To replace one years-worth of fuel consumed by the worlds current transportation needs would require more than 8 times the freshwater used by New York City in a year. Less obvious is the ability to dilute the discharge. The water that currently goes into an electrolyzer must be purified meaning that regardless of the source there will be a brine waste stream. Offshore for every 4.5 kg of water that goes into the hydrogen separation unit, 5.5 kg of brine are discharged. This is true even if the electrodes can use filtered seawater directly. Once the H_2 and O_2 are liberated the remaining liquid will be brine.

Likewise, other pollutants are concentrated. If for example an onshore plant was set up along the Mississippi river, then it is probable that the wastewater will require treatment before it would be allowed back into the river. Any waste products or chemicals in it would have been concentrated by the separation process to possibly dangerous levels.

The brine discharge offshore would also be an environmental problem if discharged in large quantities from a single location, such as if an FPSO type processing vessel is used with power supplied by offshore energy. For this reason, among others the authors have assumed a distributed model, with each energy platform making its own freshwater and hydrogen. Only the processing of CO2 and hydrogen and reformation will take place at a central location. Ideally on legacy platforms and repurposed FPS, and FPSO vessels.

32.5 Size and Efficiency

Onshore sites are more restricted in size than their offshore cousins and are becoming harder to permit near population centers. Onshore it is becoming more common to include solar power on the same site, but the energy density is still low compared to offshore. This is in part because the size of offshore wind turbines is on average larger than onshore. At sea, besides offshore wind, the possibility of capturing wave energy, tidal energy, or ocean thermal energy means the power per installation can be many times that of an onshore site.

Once the power is made and converted to hydrogen, transport offshore will be simpler and safer than it is onshore. While the capital cost of offshore pipelines is higher per mile than onshore pipelines, the permitting and routing are usually much simpler, with an overall economic advantage to the offshore solution. The installed lines are less likely to be damaged than onshore pipelines and if damaged the risk to people is much lower offshore.

While view shed (covered below) is an issue, most large urban centers are located near a coast. This means that the renewable energy sites, even if placed over the horizon can be within 25 miles of the final consumer.

Given a power to fuel solution, both onshore and offshore sites can transport the produced clean fuels using existing systems, but offshore systems (ships for liquids and long high-pressure pipelines for gas) are not open to onshore production.

Recent developments pushing offshore renewables to floating solutions will eventually lead to offshore turbines becoming even larger. Wind turbines to 25 MW are being designed, and these are not practical for current fixed wind designs. The authors are also of the opinion that very soon other offshore renewable sources will enter into the market at commercial scale, wave, tidal, and OTEC are all poised to leap from test tank to making fuel for gas tanks.

32.6 View Shed

View Shed, defined as the visual impact on the local community, is a real issue in wind farm siting. Onshore and near shore this is often the issue that kills a potential permit. Installations out of sight of land effectively remove that as an issue. Considering the speed at which the world must progress to meet its climate goals, and the quantity of power that will be required the only real answer to view shed issues is to move the energy farms far enough out to sea.

32.7 Wildlife Impacts

The wildlife impacts of onshore renewables are more negative than offshore installations providing the offshore installations are located far enough offshore. Onshore bird kills and bat kills are concerns the industry is working hard to correct, and should not be seen as a reason not build a wind farm, but offshore the issue is reduced or eliminated. Any sailor will tell you that one sign you are getting near shore is you start to see birds. In the open sea unless you are in a migration route there are no birds or bats.

What is also clear is offshore there are real benefits to marine life caused by renewable energy facilities. Within the confines of the site commercial fishing is often restricted, this is certainly true of floating installations. The hulls and moorings of floating systems, and the legs and piles of fixed systems offer habitat locations.

Even oil and gas platforms act as artificial reefs in places like the Gulf of Mexico. At its peak there were 4500 platforms in the Gulf of Mexico (now down to 1600), but once offshore renewables go global and floating that number will be dwarfed. To meet the required 15,000 GW of installed power using offshore facilities would, allowing for a 50% capacity factor, and 15MW per installation, mean more than 2 million installations worldwide.

Offshore that would create habitats on the scale of the Great Barrier Reef. Conversely onshore that many turbines would have a measurable negative impact on local bird and bat populations.

32.8 THE POWER TO FUEL CYCLE AND ECONOMICS

The study of power-to-fuel has taken on a renewed interest since the signing of the Paris Accords and the results of COP26. There are multiple studies underway and various national programs to encourage research into the technological components. While the systems are very different the basic functions and objectives remain the same. Enough of an advance in the technology has occurred that the construction of offshore prototype facilities is already being proposed for power-to-hydrogen plants, and power-to-fuel will not be far behind.

Figure 39 below shows a basic cycle, mass, and energy balance. It is not tremendously efficient in terms of value, producing roughly 8.4 barrels of liquid fuel per day for every 1 MWh of power. The interesting thing is even at that low output and ignoring allowance for things like carbon credits or tax incentives; the result is a nearly a break-even facility. As the technology advances, offshore facilities based on a cycle like the one below will be profitable without subsidy within a few years.

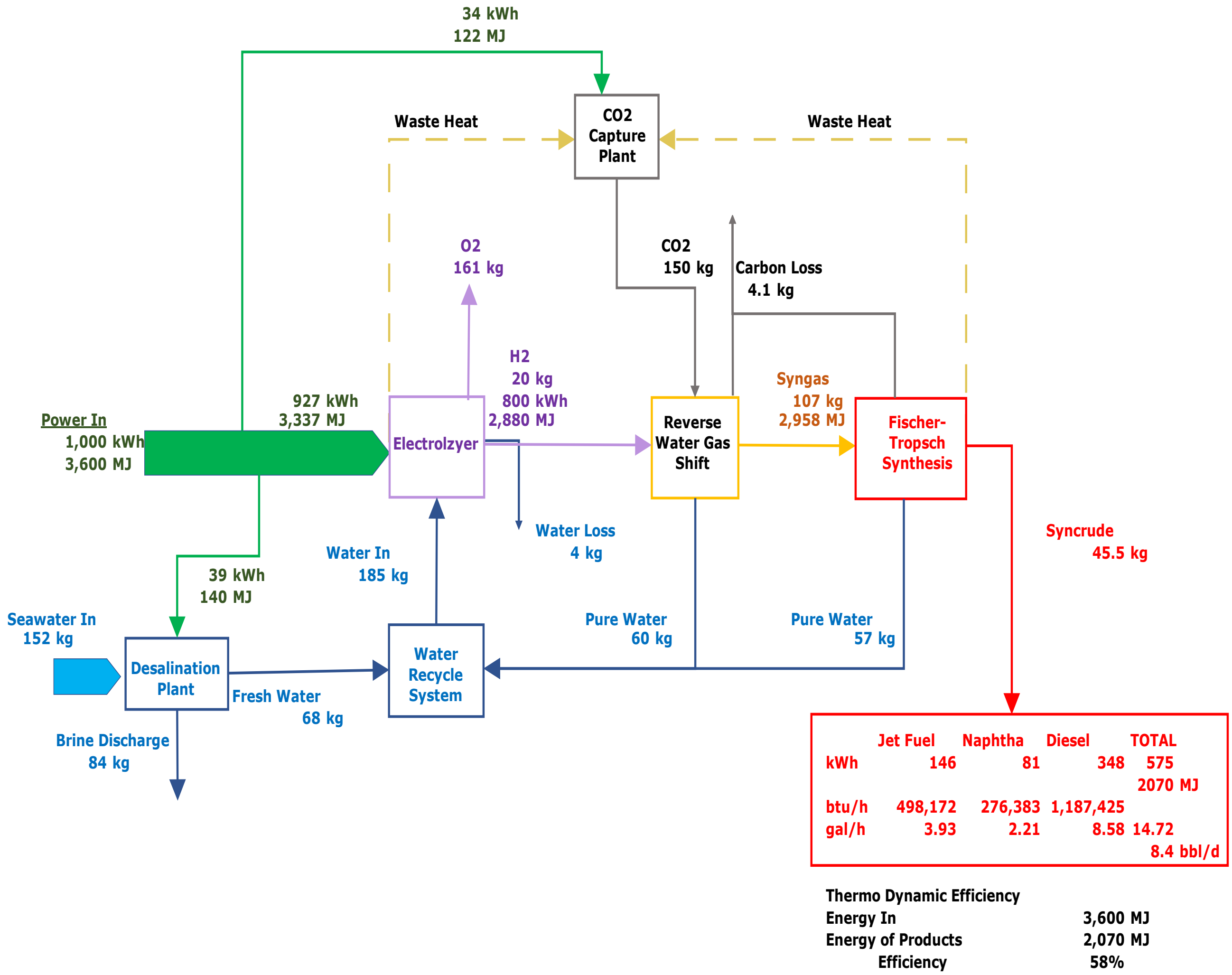


Figure 39: Energy and Mass Balance, Simplified

Many papers have gone into great and often misleading detail of how much a gallon of eco-diesel will cost to produce. There are many unknowns, and the technology is evolving at a pace that is astonishing, so predicting and exact break-even cost of production is at best a moving target with a very large diameter bullseye.

This paper is not trying to justify the economic value of power to fuel, but neither can the economics be ignored. To that end a simplified model was run, using the following assumptions:

1. Realized diesel price 1.5 times the current wholesale price (~$1.95 per gallon per EIA) on the assumption there would be a market for premium carbon neutral fuel.
2. No tax breaks or other incentives, including carbon credits were applied
3. An assumed overnight cost of $100 Million for a 30 MW, floating, renewable energy, Power-To-Fuel plant was assumed. The is based on what would be possible if the plants are mass produced.
4. A 30-year design life, and 1year fabrication and installation time were assumed.
5. A Capacity Factor for the renewable energy of 65%, and a plant availability of 95%.
6. A OPEX of $2 million per year
7. Decommissioning was assumed to be negligible.

Even at the low rate given in Figure 40 of 8.4 bbl/d/MW the IRR is 3%. A sensitivity using what we termed a Technology Factor, defined as the positive effect on production in terms of bbl/d/MWh of advancing technology gave the following result. It would require an improvement from the current thermodynamic efficiency of 58% to 95% (TF=1.64) and raising the price premium to 2 to achieve a marginal IRR of 13%.

In short it can be done, it can make money, but it will never be cheaper than mining fossil fuels. That, however, really is not the objective. For example, leather can be produced at 50% or less of the current cost of manufacture if discharge water in not treated, workers toil in unsafe conditions, child labor is used, and where the hides are sourced is ignored. As a society though people long ago chose to take the path that is better long term, even though it means that cowboy boots will cost more. Producing clean fuels instead of mining hydrocarbons is the same thing. As a society we must chose the sustainable path.

32.9 Is it Safe?

Safety and environmental concerns must always be compared to the status quo. In terms of safety a power to fuel platform would be much safer than a comparable oil and gas platform. With a drilling or production platform your greatest risk is an uncontrolled release from the reservoir, such as occurred with Macando. When a power-to-fuel plant suffers a failure likewise its greatest exposure would be to the incoming power and hydrogen from the supporting platforms. These would pose a safety risk, but virtually no environmental risk. The difference between the conventional oil and gas safety risk and the renewable energy risk is if the reservoir isolation fails you cannot “turn off” the reservoir pressure, whereas the renewable energy platforms feeding the power-to-fuel plant are fully under operator control.

Once the fuel is made its risks are the same as those of the transporting the fossil fuel-based version of the same fuel, be it a methane pipeline, LNG, liquid pipeline, or a tanker full of diesel. All are known and societally acceptable risks.

32.10 Gulf of Mexico Advantage

As a market for renewable electrical power the Gulf of Mexico is not economically attractive. Easy access to low-cost gas, more onshore wind and solar than other area of the USA, and an efficient open market means that electricity prices are some of the lowest in the OECD. Combine that with an offshore wind resource that is for the most part average and it is no surprise that developers have focused on the Northeast and West Coasts of the USA.

What the Gulf of Mexico does have is a massive potential for developing a robust offshore renewable power to fuel market. There are several places in the world where offshore oil and gas has developed a robust infrastructure, the North Sea, south east coast of Brazil, Indonesia to name a few, but none as extensive as the Gulf of Mexico.

If this existing oil and gas infrastructure was repurposed as shown in Figure 40 below instead of decommissioned it would significantly reduce the capital expenditure needed which would translate into cheaper fuel.

For pure power sales, as Gulf of Mexico oil and gas operators work to reduce their carbon footprints, they will be looking to replace the natural gas and diesel generators they currently use for primary platform power. The price point for this type of power is not the same as that for the onshore market and realized prices of more than $0.30/kWh are possible.

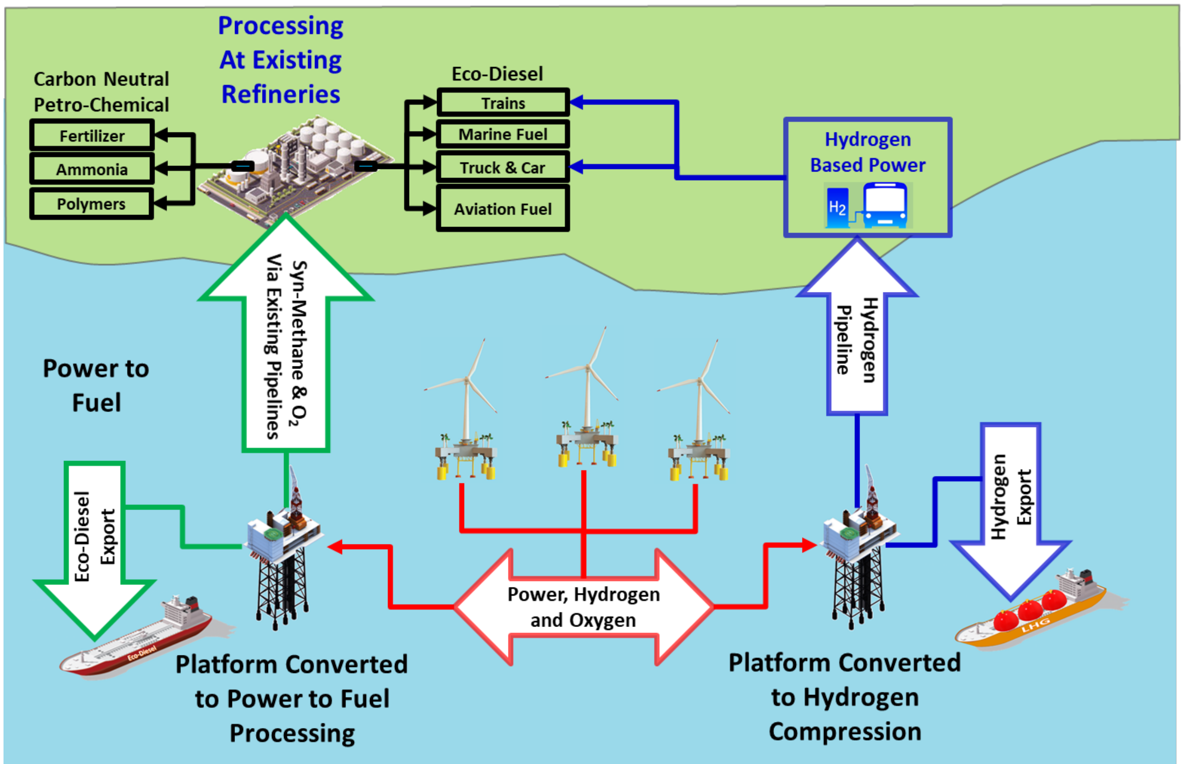


Figure 40 Gulf of Mexico Offshore Renewables Value Chain

While there are still technical and financial hurdles to overcome the obvious long-term benefits of offshore production of carbon neutral and carbon negative fuels using renewable energy has the potential to become the primary source of transportation fuels. No other solution offers the versatility, potential knock-on benefits, and minimal societal disruption that offshore renewable based power-to-fuels does. In one technology the answers to energy storage, energy transport, and low-cost low impact production are found. The advantages of offshore renewables are increased further is locations where legacy oil and gas equipment and infrastructure can be repurposed.

The economics of power to fuel can be further improved by taking advantage of:

- Shared use activities such as aquaculture and ocean mining
- Sale of additional product gases such as oxygen
- Tax incentives
- Carbon Credits
- Improved power generation and
- Improvements in the power-to-fuel component technologies.

It may not be possible to make fuels generated using renewable energy as cheaply as we can from mined fossil fuels, but as a society we must chose the sustainable path. There are other options such as direct use of hydrogen that may be the long-term solution, but power-to-fuel is the sustainable option that will be the least disruptive and costly, while still meeting those sustainable goals. It will allow a transition to completely fossil carbon free economy as current infrastructure is replaced.

VIII - Desalination and Water Treatment Options

33 WATER TREATMENT

33.1 Options for Offshore Water Treatment

Water treatment covers the following topics:

- Production of fresh water either for consumption or as feed stock to green hydrogen.
- Treatment of well water, from either oil and gas or geothermal wells.
- Treatment of municipal waste and agricultural runoff – such as the Gulf of Mexico Dead Zone

One of the tenants of the Blue Economy is to ensure that any activities do no harm to the marine environment and if possible, make the local ocean biosphere more productive. To accomplish that any waste stream generated by one Blue Economy activity must either be used in another process (preferred) or treated so as to be benign prior to release, or as a last resort sequestered or sent for further treatment.

33.2 Fresh Water

To produce 1kg of green hydrogen 9 kg of fresh water is needed, and 8kg of pure oxygen is released as a byproduct. In addition to that need the is sometimes a demand for fresh water for municipal uses, even along the Gulf coast. Production of freshwater where it is needed for this study is assumed to be by reverse osmosis using membranes. It is a proven and robust technology. The energy consumption is around 1 kWh/kg of fresh water. When using seawater as the feedstock approximately 11 kg of brine is produced for each 10 kg of fresh water. Water produced from oil and gas wells, or as part of a geothermal system can also by processed into a freshwater stream and concentrated well fluid stream but is case specific to the composition of the well. In some instances, the responsible solution will be to reinject the fluids back into the well, but other options for processing are described below.

33.3 Use of Brine

In typical seawater reverse osmosis plants, the brine is often diluted and discharge back into the sea. If done responsibly this is an acceptable way to dispose of brine, however brine can also be used in value added processes. Brine referred to in this study comes from either seawater reverse osmosis or from treatment of produced well water. The brine can be processed to retrieve valuable minerals, as described below.

33.4 Wastewater Treatment

As the concentration of people living on the coast increase so does the pressure on water discharge systems and amount of contamination in runoff is a significant problem for the marine environment of the Gulf of Mexico. Agricultural runoff coming into the Gulf of Mexico from the Mississippi river creates a Dead Zone that can be a large as the state of New Jersey. A simplified description of the Dead Zone is an area where an overabundance of nitrates and phosphates has caused algae blooms that then die and decompose removing oxygen from the water. There are Blue Economy activities, such as algae cultivation, that could make use of the high concentrations of nitrates and phosphates to grow algae that is harvested, and the water that is discharged from the process is then cleaned of these contaminants.

Topic IX - Mineral Extraction

34 BRINE PROCESSING & MINERAL EXTRACTION

Technologies for brine processing both for capture of valuable minerals and for direct water capture and sequestration of CO2 are advancing rapidly. One of the most promising uses is to extract Lithium, a vital component of batteries. As part of an offshore development this can be done in two ways. The brine could be sent to shore for processing in ponds via existing but abandoned pipelines, or one of the newer membrane filtration techniques could be employed offshore.

There are other minerals and chemicals, sodium and chlorine for example, that can also be recovered in the process. One of the hallmarks of making a sustainable system is to identify uses for what has been considered a waste stream. Often activities like brine processing and mineral extraction are not competitive economically if considered as a standalone activity, but when executed as part of the production process for green hydrogen and/or desalination the economics change.

Element	Concentration (mg/L)
Na^+	10800
Mg^{2+}	1290
Ca^{2+}	411
K^+	392
Sr^{2+}	8.1
Li^+	0.17
Rb^+	0.12
Ba^{2+}	0.021
Fe^{2+}	0.0034
$[UO_2(CO^3)^3]^{4-}$	0.0033
Cu^{2+}	0.0009
Co^{2+}	0.00039

GORI has been working with Dr. Maha Haji of Cornell University to assess the potential for harvesting critical minerals from seawater using the offshore platforms. Dr. Haji has previously conducted research on harvesting cobalt from seawater utilizing the offshore platforms in the Gulf of Mexico (Haji et al. 2019). GORI and Cornell have applied for funding to conduct seawater sampling at the SP 83 and WD 117 platform sites to determine if there are sufficient quantities of Lithium and Cobalt in the seawater of the Gulf of Mexico to conduct adsorption harvesting of the mineralss. The proposed technology is identical to that used for capture of uranium from seawater. Using adsorbent filled hollow spheres on a pulley arrangement to cycle them through the water and known as the Symbiotic Machine for Ocean uRanium Extraction (SMORE).

We propose to study in the Phase 2 funding various adsorption media and techniques to extract critical minerals from seawater using the offshore platforms.

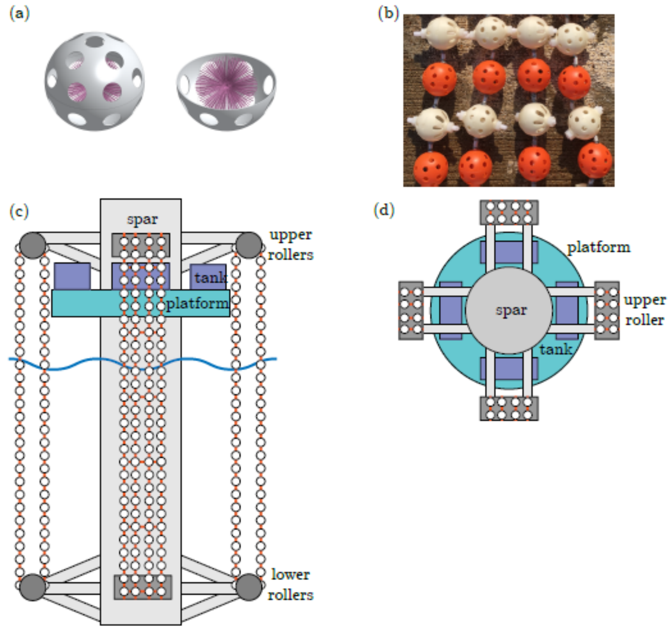


Figure 41 The Symbiotic Machine for Ocean uRanium Extraction (SMORE)

(Copyright 2018 by American Nuclear Society)

35 SEABED MINING

The International Seabed Authority (ISA) - a UN body that oversees the ocean floor and does not expect to until at least 2024. There currently is no approved permitting system though several companies filed a 2-year notice to proceed under a trigger clause in the Law of the Sea that states if the ISA is not responding in a timely manner the applicant can proceed, giving 2 years notice. The ISA has countered that the Rules are due to issue and were delayed by Covid impacts.

35.1 Seabed Manganese Nodules

While it can be supported it is not currently considered economically viable, and there are some environmental and regulatory concerns that are not yet resolved. Primarily around the role these nodules play in the deep ocean ecology, and the long-term impact of mining nodules given their low growth rate, estimated at less than a 0.1 mm per year. It is considered an industry to monitor for possible future inclusion but is not examined further at this time.

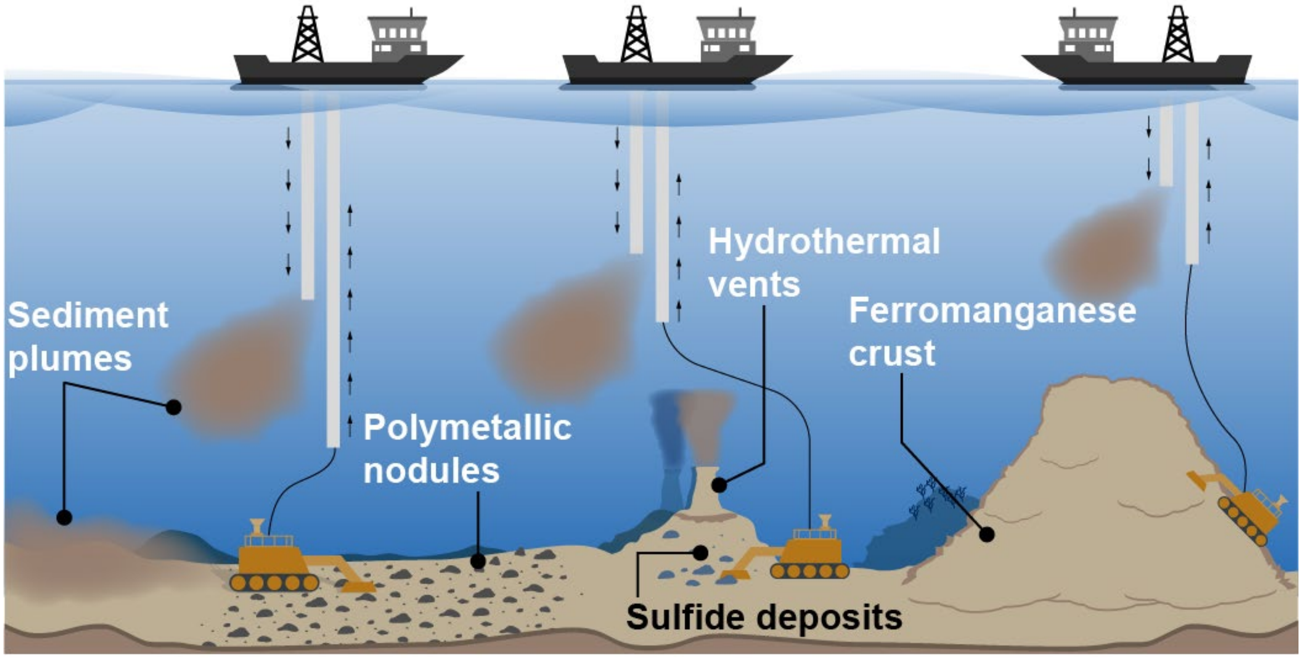


Figure 42 Ocean Mining Concerns

35.2 Seabed Mineral Excavation

There may be locations that minerals within seabed sediments are present in recoverable quantities, but any system used to extract the sediment will require careful review. Any area impacted by seabed mining will have an impact locally, but it is not likely to have a wider effect on the marine environment but locations like subsea vents must be protected. Unlike the surface the natural process of restoration takes place in geologic time.

An example of this can be found on the Newfoundland escarpment. Iceberg drag marks make it appear that building anything on the seabed is folly. The area is crisscrossed with thousands of iceberg drags clearly visible on surveys. However, these marks have accumulated of tens of thousands of years, and the annual chance and impact at any location is highly unlikely. This area is also a highly productive marine environment so while it has accumulated long lasting but localized disturbances to the seabed, they do not appear to have degraded the biosphere. This is likely to be similar to any subsea mining activity, the disturbance will be local and long lasting but not damaging to the overall ecosystem if done responsibly.

35.3 Equipment Testing

While no seabed mining is not included in the plans going forward the industry and technology will be monitored. As with most offshore technologies the Gulf and the legacy platforms are ideal locations to develop and test equipment. This may be an excellent area for the USGS and NOAA to apply research dollars, looking for methods of low to no disturbance seabed mining.

Topic X - Aquaculture, and algae, and seaweed farming

36 AQUACULTURE

36.1 Framing the Problem

The US leads the world in research and development spending on aquaculture but is ranked very low in terms of implementation. It is a 250 billion dollar a year industry that US has only 1% of, with China being the world leader with nearly 60% of the global production as shown in Figure 43. Effectively all of the US aquaculture is either onshore or in the coastal margins. To be useful as part of a platform repurposing requires an open water marine aquaculture system. A few of these systems do exist in the US but they make up less than 0.1% of the industry.

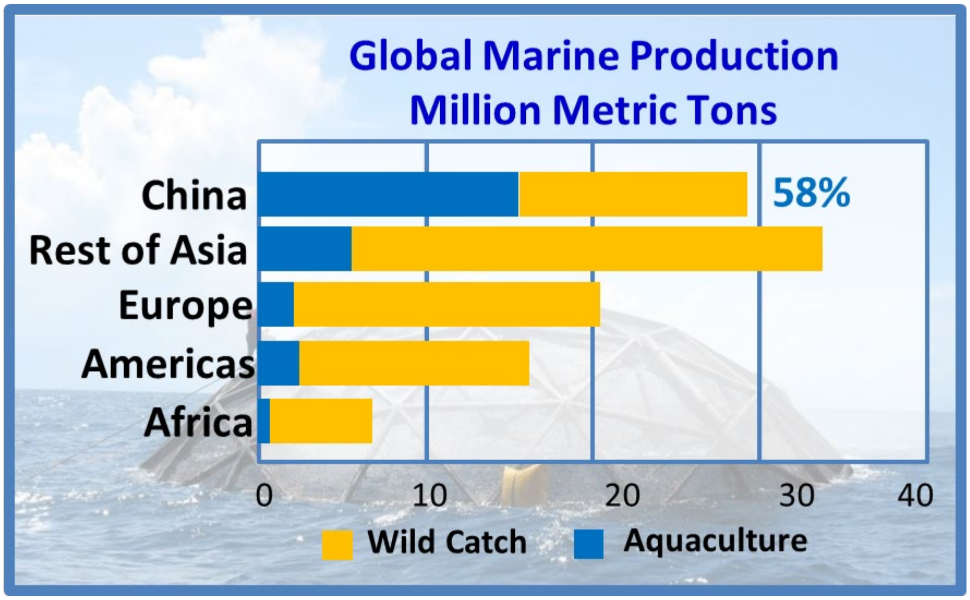
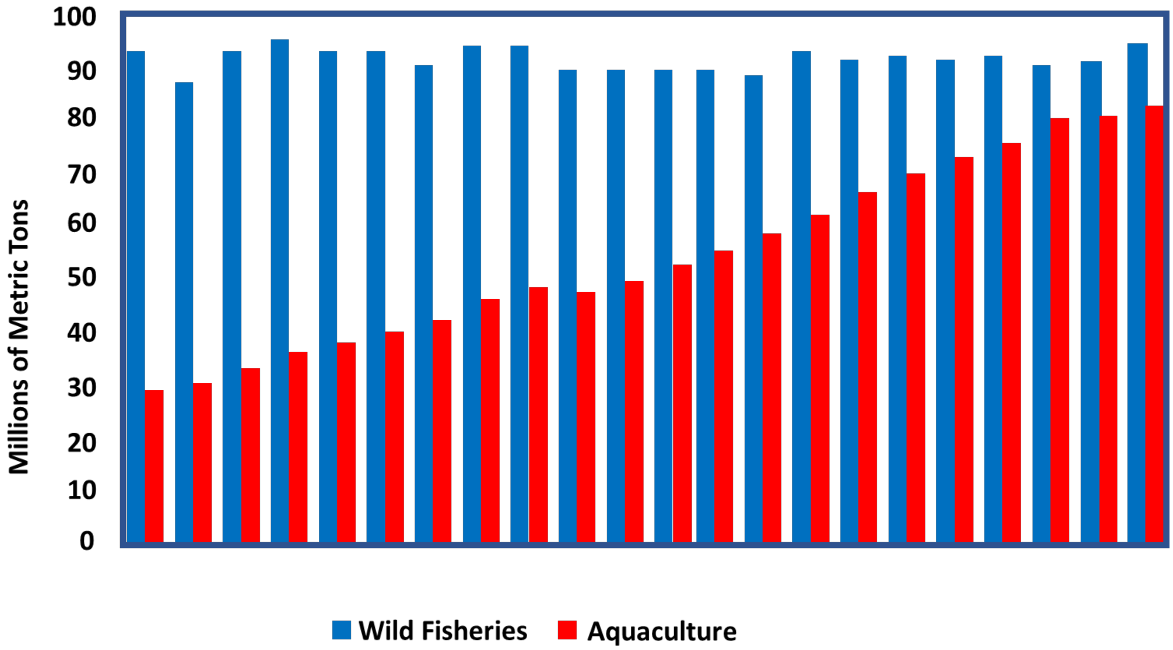


Figure 43 Global Share of Marine Aquaculture

A combination of some early failures in pioneering projects in Europe, irresponsible development in some less developed countries, resistance to any permeant offshore developments by fisherman on the east and west coasts, and in some cases misinformation campaigns have kept the aquaculture industry primarily onshore in the US. This is important because for many years the amount of wild harvested seafood has been stagnate, with half of all seafood now raised as shown in Figure 44. What we do have that most other countries don't are 600 unused offshore structures, any one of which can become a center supporting aquaculture. The term aquaculture, while often used to mean fish farming as it does in Figure 38, but actually covers a broad range of marine activities listed below:

- Multi-Trophic Aquaculture (Fish Farming)
- Algae & Macroalgae (Seaweed) Cultivation
- Molluscan Shellfish Aquaculture (Oysters and Clams)
- Crustaceans (Crab, Shrimp, And Lobster)



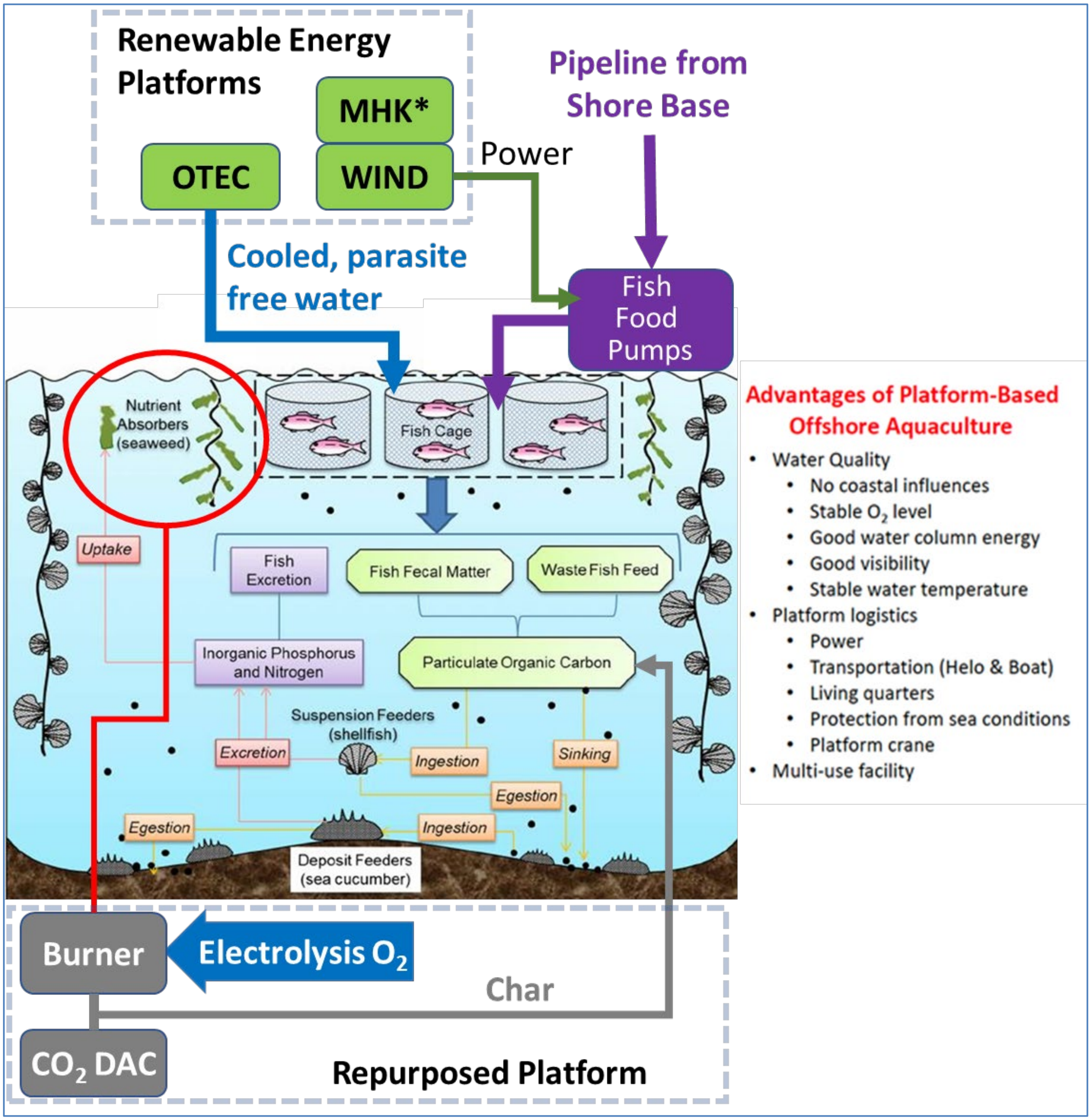
Source: Food and Agriculture Organization of the United Nations (FAO).

Figure 44 Global Wild Fisheries and Aquaculture Productions

Figure 45 Composite photo and drawing of an Aquapod net pen in open water.

36.2 The Possible Benefits of Co-development

As with the renewable energy systems there may be benefits to achieved by combining the various forms of aquaculture together. There is surprisingly little cooperative development of fin fish, algae, mollusks and crustaceans. One possibility could be vertically integrated aquaculture towers where a microenvironment could be established which would have benefits such as reduced risk of disease, less demand for outside food supply, better water quality, faster growth, and perhaps even improved taste and aspect. This is a recommended course of action in the ODE report and is illustrated below in Figure 46.



Source: Antigua & Grenada Sustainable Aquaculture

Figure 46 Benefits of Joint Renewable Energy/Aquaculture Development

GORI has found that the platforms can be used as hubs for multi-trophic offshore aquaculture (fish farming). See the figure below. The pristine Gulf waters surrounding the platforms are ideal for farming fish with minimal environmental impacts. This can not only provide fresh fish year-round to the Gulf coast but can create an industry which can compete globally. Instead of the US importing 85% of its seafood, Louisiana and Texas can lead the way in making the US a net exporter. With offshore renewable energy from wind, solar, and waves; the whole operation can run on renewable energy. Offshore farming can also mitigate the risk of extremely low temperatures that can impact onshore fish farming operations.

GORI and its research partners were awarded a grant in the amount of $100k at the end of 2021 from the Gulf States Marine Fisheries Commission to prepare a grid design for offshore net pens adjacent to an offshore platform – in this case, PN 975. The platform will be used for logistical support and surveillance, including feeding operations.

36.3 Sustainable Farmed Seafood

The U.S. is faced with rising indebtedness due in part to the impact of COVID 19 on the nation's economy, concerns over climate change, and supply chain vulnerabilities. At the same time, the U.S. has unprecedented opportunity in growing its marine "blue economy" to strengthen its gross domestic product; produce a new, storable, carbon-neutral energy source; and create a new, high-quality, sustainable farmed seafood. Additionally, we have the opportunity to repurpose our aging offshore infrastructure in a way that brings significant ecosystem benefits and provides marine monitoring and ocean observing capabilities.

A 2016 U.S. GAO study reported an estimated $38 billion in future decommissioning costs for the Gulf of Mexico (Gulf of Mexico) region alone. The Gulf of Mexico currently has about 1,600 offshore platforms, down from about 3,000 as recently as 2012; and, they are being shut down and removed at a rate of approximately 175/year. These offshore platforms can be re-purposed in accordance with the Energy Policy Act of 2005 and regulations at 30 CFR 585 Subpart J for scientific research, marine and atmospheric monitoring, science education, ecotourism, offshore (or ocean) renewable energy, and offshore aquaculture to provide environmental, recreational, and economic benefits to the Gulf of Mexico region and the Nation.

The COVID 19 pandemic has revealed vulnerabilities in the global supply chain in numerous areas, including protein food sources. Climate change concerns have caused governments to set policies to reduce greenhouse gas (GHG) emissions and promote low-carbon renewable energy. Ocean farming and the development of ocean renewable energy using the idle offshore platforms will reduce the need for terrestrial protein sources and imports, reduce global GHG emissions, and enable marine data collection. The platforms in their natural state also have a significant ecosystem role in the Gulf of Mexico, including essential habitat for many species of commercially important fish.

The Federal Rigs to Reefs (RTR) Program, administered by the Bureau of Safety and Environmental Enforcement (BSEE) of the Department of Interior, and the individual Gulf states which have a complementary RTR plan has provided beneficial reuse for many of these structures as artificial reefs. This is a voluntary program whereby oil and gas operators must make decommissioning decisions based on many variables, including economics, water depth, distances to approved reef sites, etc.

The conversion of standing platforms into artificial reefs results in a structure with a lower vertical relief, and no physical connection to the upper water column. As decommissioned standing platforms are increasingly converted into artificial reefs, it is important to evaluate the ecological effects of this physical transformation on platform-associated communities.

Furthermore, the number of standing platforms in the northern Gulf of Mexico continues to rapidly decline as removals through the decommissioning process exceed new installations. Thus, there is a central need for science-based decision making on the proper use of these structures and to establish the best management practices to maximize RTR programmatic goals.

The Gulf Offshore Research Institute (GORI) in partnership with Harte Research Institute (HRI) through a grant from Hess Energy reviewed the current state of scientific knowledge comparing the ecological function and habitat value of standing and reefed platforms in the northern Gulf of Mexico and identify critical information gaps in need of future research with special emphasis on the ecological functionality of standing platforms and performance related to upper-water column benefits. Studies evaluating how standing and reefed platforms function to support fish populations in the Gulf of Mexico have primarily focused on the biological characteristics of the economically important red snapper (*Lutjanus ampechanus*) given this species iconic status and importance as the most valuable reef fish in the Gulf of Mexico. As a demersal species, both standing and reefed platforms appear to provide suitable habitat with sufficient resources to support its biological needs. Though, the lack of similar trends among artificial and natural habitats in the northwestern and north-central Gulf of Mexico highlights the complex nature of habitat- and region-specific contributions to the Gulf of Mexico red snapper stock and warrants further investigation, especially into the loss of structure and function of habitat as well as loss of species in the upper water column. Nevertheless, increased emphasis on a wider range of species, including other broadly distributed fisheries species of commercial and/or recreational value (e.g., greater amberjack, *Seriola dumerili*), and on whole-community and functional approaches will build towards a more mechanistic understanding of the broader ecosystem values provided by both standing and reefed platforms. (Stunz et al. 2020)

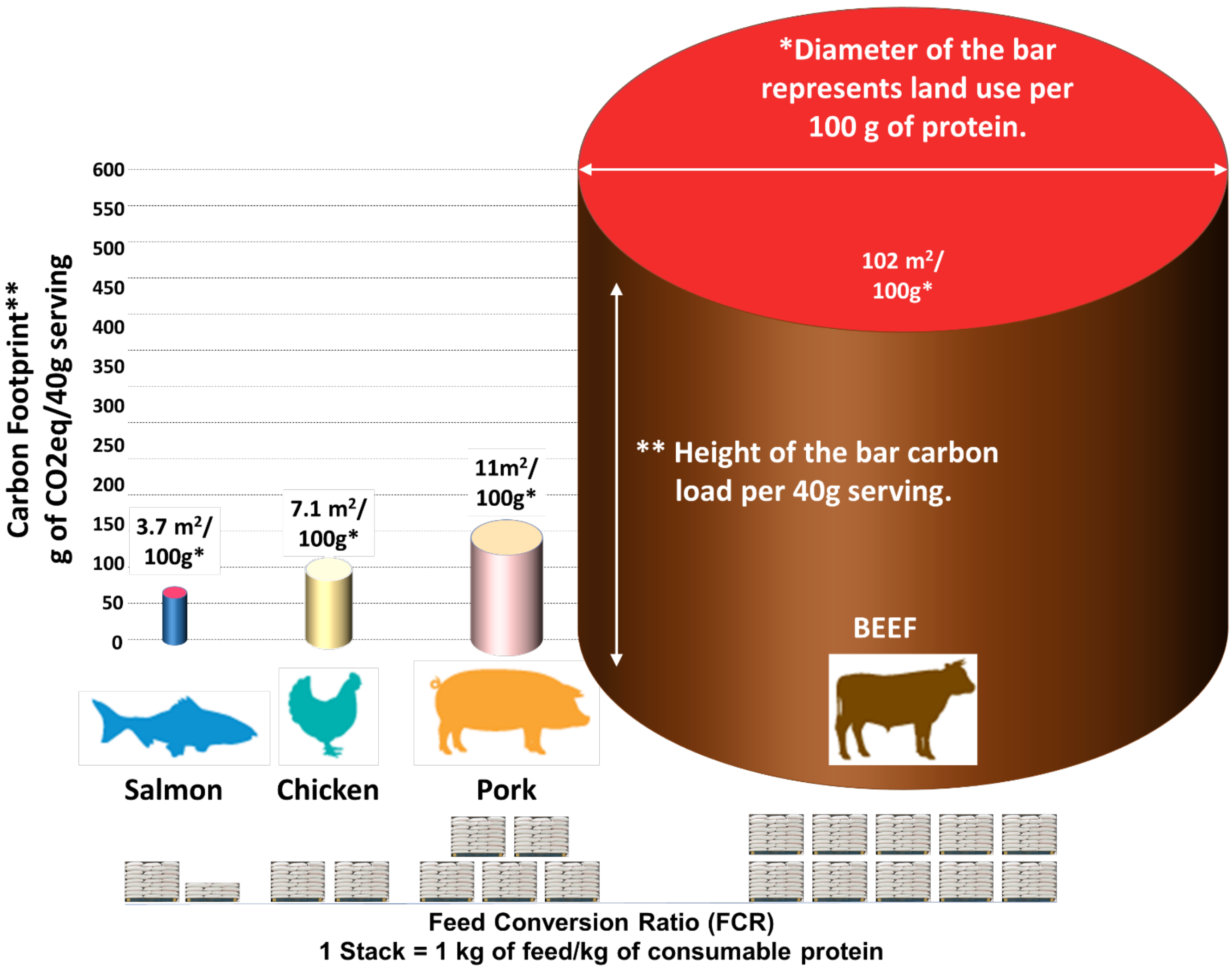
The extensive variability in marine life and environmental conditions such as water depth, distance from shore, size, and many other characteristics associated with existing standing platforms makes it difficult to establish a generic set of predictions regarding the ecological consequences of different decommissioning alternatives. Further research is needed understand the ecosystem benefits of offshore platforms and decommissioning and repurposing options.

Blue Silo Aquaculture LLC is working with GORI to identify and study offshore platforms in the Gulf of Mexico that can be used to culture finfish, shellfish, and macroalgae. The Gulf of Mexico has been designated by NOAA as one of the two aquaculture opportunity areas in U.S. offshore waters. Offshore aquaculture operations in the Gulf of Mexico, with its sometimes-harsh environment because of tropical storms and hurricanes, will be technically and operationally challenging and can be informed by offshore oil and gas experience. In particular, the offshore platforms, designed and built to withstand hurricane conditions can function as hubs for offshore aquaculture and ocean renewable energy (ORE).

The FAO estimates the 20-year average annual growth rate of aquaculture to be 8% globally compared with 1% for the U.S. In 2020, President Trump signed the Executive Order on Promoting American Seafood Competitiveness and Economic Growth (E.O. 13921) which states that NOAA will serve as the lead agency for National Environmental Policy Act (NEPA) review for offshore aquaculture projects. NOAA has ramped up its activity to promote offshore aquaculture, including the designation of two offshore areas for priority study. The Gulf of Mexico is one of these areas and may prove to be a high growth area because of its existing offshore platform and marine infrastructure.

According to USDA, our terrestrial protein food sources (beef, chicken, pork, and turkey) are 90-100% domestically produced compared to seafood which is about 15% domestically produced, and only a small portion of that amount is farmed. This presents a food supply vulnerability for U.S. consumers especially when we experience supply chain disruptions as we did with the COVID 19 pandemic, which continue to persist into 2022. Additionally, seafood has inherent health and environmental benefits that terrestrial protein sources lack, including a much smaller carbon footprint and land use requirements. See the figure below. This points to a significant opportunity for the health and welfare of Americans and as a growth initiative for the domestic economy.

Feed conversion ratio (FCR) is the conventional measure of livestock production efficiency: the weight of feed intake divided by weight gained by the animal. Lower FCR values indicate higher efficiency. Figure 47 shows the comparison of fish farming to other common meats.



Data Source: Lazard's Asset Management, Salmon for the Future as of 31 December 2017

Figure 47 Sustainability of Fish Farming Compared to Terrestrial Farming

GORI received a grant from the Gulf States Marine Fisheries Commission in 2020 to perform a feasibility study for offshore aquaculture located at two offshore platforms located about 30 nautical miles off south Texas (North Padre Island OCS area). Our work looked at environmental conditions at the location, such as wave and current data, geo-spatial baseline data, and economic analysis. We found that offshore aquaculture at this location is feasible and has a positive cash flow. (Satterlee et al. 2021)

NOAA traditionally has had the mission and responsibility of ocean monitoring and observing; however, the U.S. Navy also plays a key role for the military. As an agency within the Department of Commerce, NOAA is well positioned to collect and distribute ocean observing data and end products for the national commerce and the ocean economy. According to a NOAA 2020 report, the Marine-related gross domestic product grew 5.8% from 2017 to 2018, faster than the 5.4% growth of the total U.S. gross domestic product as measured in current dollars; consequently, the ocean observing data and its technical innovation is critically important to support the continued expansion of the blue economy while avoiding user conflicts and impacts to the ecosystem. The goal should be sustainability, i.e., to produce more goods and services from the ocean with a smaller environmental footprint. Blue technologies being developed today will enable that, and we believe the offshore oil and gas platforms have an important role to play. A variety of methods and platforms are used in ocean monitoring and observing, including aerial, satellite, ship, buoy, sea bottom, water column, etc.

36.4 Aquaculture Legal & Regulatory Considerations

The Gulf Offshore Research Institute (GORI) was founded in 2017 to research the ecological and beneficial uses of the Gulf of Mexico offshore oil and gas platforms beyond their days of oil and gas production. The research has shown that the offshore platforms provide critical habitat for a variety of marine species, including commercially and recreationally important species like Red Snapper. The platforms function as artificial reefs and provide significant ecosystem benefits to the Gulf and the Gulf states.

Through its research, GORI has found many potential uses for these legacy platforms. They can be used to meet the Nation’s energy and climate goals to generate offshore renewable energy and convert that energy into hydrogen through a process called electrolysis. The platforms and their depleted subsurface reservoirs can also be used to store carbon dioxide through a process called Carbon Capture and Sequestration (CCS). The figure below shows climate mitigation opportunities. They can be also used for scientific research and environmental restoration purposes to mitigate the impact of the Deepwater Horizon oil spill that occurred in 2010 through RESTORE Act funding.

37 MULTI-TROPHIC AQUACULTURE (FISH FARMS)

Platforms can be used as hubs for multi-trophic offshore aquaculture (fish farming). The pristine Gulf of Mexico waters surrounding the platforms are ideal for farming fish with minimal environmental impacts. This can not only provide fresh fish year-round to the Gulf coast but can create an industry which can compete globally. Instead of the US importing 85% of its seafood, Louisiana and Texas can lead the way in making the US a net exporter. With offshore renewable energy from wind, solar, and waves; the whole operation can run on renewable energy. Offshore farming also mitigates the risk of temperature extremes that can impact onshore fish farming operations. In the US there is no danger of releasing invasive species as any fish raised must be native to the local waters. For purposes of this study two species Cobia and Red Drum were considered as viable candidates. The initial start-up of a commercial shellfish aquaculture farm in the United States is subject to multiple regulatory requirements under federal, state, tribal, and local authorities. And like all offshore activities permitting can be an arduous process. The wording in 30CFR 585J however allows for its use for more than just renewable energy.

*"Establish procedures for issuance and administration of leases, right-of way (ROW) grants, and right-of-use and easement (ARUE) grants for renewable energy production on the Outer Continental Shelf (OCS) and ARUE's for the alternate use of OCS facilities for energy or **marine-related purposes**;"* (emphasis by author)

This does not mean that the 8 federal agencies and 16 separate offices typically involved in permitting a fish farm will not be involved. It does mean that unlike other areas there is an established acceptable use and a single agency (BOEM) that all the others must work through.

As was previously stated the pipelines can be used to support these fish farms, delivering fingerlings and fish feed.

38 FINFISH FEED DELIVERY SYSTEM REVIEW

Finfish feed delivery systems are typically designed for an onshore or a near shore farm setting. These delivery systems can be classified into 4 categories: Inertial, mechanical, pneumatic or hydraulic. Each of these systems have their particular strengths and weaknesses.

38.1 Inertial feeding system

Inertial feeding systems apply an initial force to the feed pellets that propel them from the distribution equipment. The feed pellets fly through the air and land on the surface within the netpen. An example would be a broadcast feeder (think deer feeder) or an air cannon.

38.2 Mechanical feeding system

Mechanical feeding systems use belt conveyors or screw conveyors with or without a rotational mechanism for spreading feed across a large area of the surface of the netpen.

38.3 Pneumatic feeding system

Pneumatic feeding systems use air to convey feed from the storage silo to the netpens through flexible tuning or piping. An air blower and rotary valve control the flow of feed through a hose to each netpen. While it could be possible to adjust the feed delivery point to anywhere in the netpen, from a practical standpoint, the feed is normally delivered to the surface within the netpen. If the feed were to be delivered subsurface, air would cause the hoses to be buoyant and would release large amounts of air into the netpen which would be stressful to the fish.

38.4 Hydraulic feeding systems

Hydraulic feeding systems are similar to the pneumatic systems, but instead of air as the transport medium, water is used. The advantage of this system is that it is not limited to delivering feed to the surface of the netpens. Feed pellets can be manufactured such that the pellets are positively buoyant, neutrally buoyant or negatively buoyant for the water density that the finfish are raised.

38.5 General Discussion

Gulf Offshore Research Institute's (GORI) overarching business plan is to utilize existing Gulf of Mexico hydrocarbon platforms for a wide variety of alternative purposes. Offshore open ocean aquaculture is but one of these alternative uses.

In this scenario, the platform serves as the operational hub, providing living quarters and laboratory facilities for operational personnel as well as feed storage and delivery mechanisms. The installation of multiple netpens will be moored juxtaposed to the platform in an efficient grid layout. Because of the ever-present threat of hurricanes and storms, the design of the netpens and grid will be required to either withstand these weather events as is or be able to be submerged to avoid high energy waves resulting in destruction of the equipment and possible release of the finfish. Because these weather events can last for multiple days, and because the personnel will be evacuated during the most severe weather events, any feeding system that is utilized must have autonomous operation capability and be able to feed whether the netpens are in a surface or submerged position.

Finfish can be aggressive and finicky in their feeding behavior. For that reason, the feed delivery system should have the capability to adjust its feeding position within the netpen, delivering feed at the top, middle or bottom of the netpen.

38.6 Conclusion and Plans

At this point in the study, it appears that hydraulic conveyance provides the flexibility and attributes desired for an open ocean aquaculture project. Phase 2 of this grant will provide funding to investigate each of these feed storage and delivery system types, in depth, to verify initial impressions. We expect that at the end of phase 2, the field of options will be narrowed to no more than 3 systems for recommendation.

39 MACROALGAE AND SEAWEED

The Department of Energy also believes that macroalgae, or seaweed, which can be grown alongside the platforms might be able to produce up to 10% of the Nation's transportation fuels. GORI has completed a preliminary design for an offshore seaweed farming system adjacent to a platform.

We propose to study in the Phase 2 funding the feasibility of farming seaweed offshore from the platforms. This will include the harvesting of Sargassum which is indigenous to the Gulf of Mexico.

Another beneficial use is the prospect for science education and eco-tourism. The platforms can become offshore field laboratories and virtual classrooms. There are technologies now available that can operate an unmanned submarine that resides on an offshore platform. With a seabed docking station, an autonomous underwater vehicle (AUV) can be operated on a near- continuous basis. There are manned submarines that are commercially available that can be operated from the platforms. GORI plans to link these capabilities with the aquariums along the Gulf coast.

GORI is currently working with two offshore oil and gas operators to permit their platforms for alternate uses. See the figure below. Two of the platforms, North Padre Island (PN) 975 and 969 are located in the Western Gulf of Mexico in an area with good wind and wave resources. The PN platforms have large, depleted gas reservoirs and may be ideal for a CCS location. **We propose to study this in the Phase 2 funding. This study will include assessing the feasibility of utilizing the Transco pipeline to transport CO2 to the platform site**.

39.1 Algae & Seaweed Cultivation

Algae are photosynthetic, oxygen-exhaling, unicellular, or multicellular microorganisms with diverse characteristics such as consumption of carbon-dioxide, storage of essential nutrients, minerals, and vitamins in microorganisms. Seaweeds are the large plantlike macroalgae. Most seaweed is cultivated for direct food consumption, while algae is use is split between food and for use in biofuel.

The Department of Energy also believes that macroalgae, or seaweed, which can be grown alongside the platforms might be able to produce up to 10% of the Nation's transportation fuels.

As part of this study a preliminary design for an offshore seaweed farming system adjacent to a platform was produced.

The global Algae market was valued at USD 3.5 billion in 2020 and is expected to reach USD 4.5 billion by the end of 2030, with some projections as high as 11 billion, driven by increased biofuel needs. The US is a leading producer, but China has the fastest growing market.

The global commercial seaweed market is projected to grow from $15.01 billion in 2021 to $24.92 billion in 2028 at a CAGR of 7.51% during forecast period, but the US share of this market it low at $700 MM

Algae and seaweed cultivation can be used on those platforms where other forms of aquaculture may be impossible, such as the Dead Zone. The Dead Zone is an area the size of New Jersey in the northern Gulf of Mexico where agricultural runoff has contaminated the water with excess phosphates and nitrates. This leads to algae blooms, which then die, and their decomposition removes the oxygen from the water creating an anerobic environment. While this would make fish farming problematic, it would be a boon for algae cultivation. If done at a large enough scale this cultivation would result in better water quality, as well as being a source of biofuel, fish and livestock feed, and food additives.

40 MOLLUSCAN SHELLFISH AQUACULTURE

Molluscan Shellfish aquaculture is the raising of various local shellfish. Calms, mussels, oysters, scallops, and abalone all fall into this category. The specific species raised is dependent on the location, water depth, and available food sources. The eastern oyster and hard clams are cultured on the east coast of the United States and in the Gulf of Mexico. The main techniques for raising oysters are Intertidal, Rack & Bag, Longline, or Suspended Tray. Rack & Bag cultured oysters are grown in mesh cages or bags suspended about two feet off the bottom. Longline culture is where long ropes with seedling oysters attached are suspended vertically in deep water. Suspended Tray is a cross between the Rack and Bag and Longline methods with cages or trays suspended in deepwater. Mussels are farmed on lines in a similar manner to Longline oysters with the addition of a sock that covers the juvenile oysters. After one-year mussels are ready for harvest. Per NOAA a farm can produce as much as 15,000 pounds per line. Scallops can be raised in similar methods to oysters, with one added method being the Ear Hang method, which involves drilling a small hole in each Scallop shell. In general scallops are more complex to raise than oysters but can yield higher returns. Clams are not generally farmed in open water and were not considered.

Molluscan Shellfish aquaculture is estimated to have a global value $34 billion, of which the US has only a 1% share.

41 CRUSTACEANS (CRAB, SHRIMP, AND LOBSTER)

To date open water farming of crab, shrimp, and lobster is very limited. Nearly all framing is done onshore in ponds, or at best in sheltered waters nearshore. Shrimp are the most commonly cultivated, crab is next, with only small amounts of lobster (primarily from Vietnam and Indonesia) farmed. Both crabs and lobsters suffer from combinations of relatively long growth times and a propensity for cannibalistic behavior. Along the Gulf Coast shrimp are pond farmed, and Blue Crab larvae are raised and released. Some method of increasing or augmenting the wild stock crab and lobsters must be found. The existing fisheries are either stagnate or in decline, meanwhile demand for both crab and lobster increase year on year. Shrimp farming accounts for 55% of the global catch. While this relieves the stress on wild population it comes at a high environmental price in much of the world. In southeast Asia and

South America mangroves and other wetlands are often destroyed to make room for shrimp farms. Where the farms are located farther inland the runoff can also be an issue. Crustacean framing is considered as something to be monitored and perhaps as a focus for research in the Gulf of Mexico.

41.1 Offshore Transportation and Support

As we think about operating in an offshore environment, transport of personnel, equipment, supplies and material are an important aspect that must be addressed. There are only two options available: helicopters and boats. Traditionally, helicopters are used when time is of the essence and boats are used when large volumes of personnel, equipment, supplies and materials are needed and/or time is not critical. For this DOE study, a crew boat with a large open deck for carrying supplies would most likely work best.

There is a class of boat working in the Gulf of Mexico called a “work boat”. These are 110 to 200 foot class boats with a forward helm and large rear deck, similar to the photo in Figure 48.

Figure 48 Typical Offshore Workboat Planned for Aquaculture Support

Figure 49 Typical Offshore Workboat Deck Area

Since Gulf Offshore Research Institute (GORI) intends to reuse offshore platforms for multiple purposes, a crew boat such as this is very efficient at being used for many different purposes. To make it even more versatile, a variety of mission specific modules could be assembled to make it quick and easy to change missions and have all the equipment needed for that mission. Standard 20 ft long x 8.5 ft high x 8 ft wide intermodal shipping containers could be purchased. The containers can be modified easily, manipulated from shore to boat to platform and can be "cam-locked" into place on the deck of the boat so that they cannot shift during transport.

A sampling of mission specific modules are:

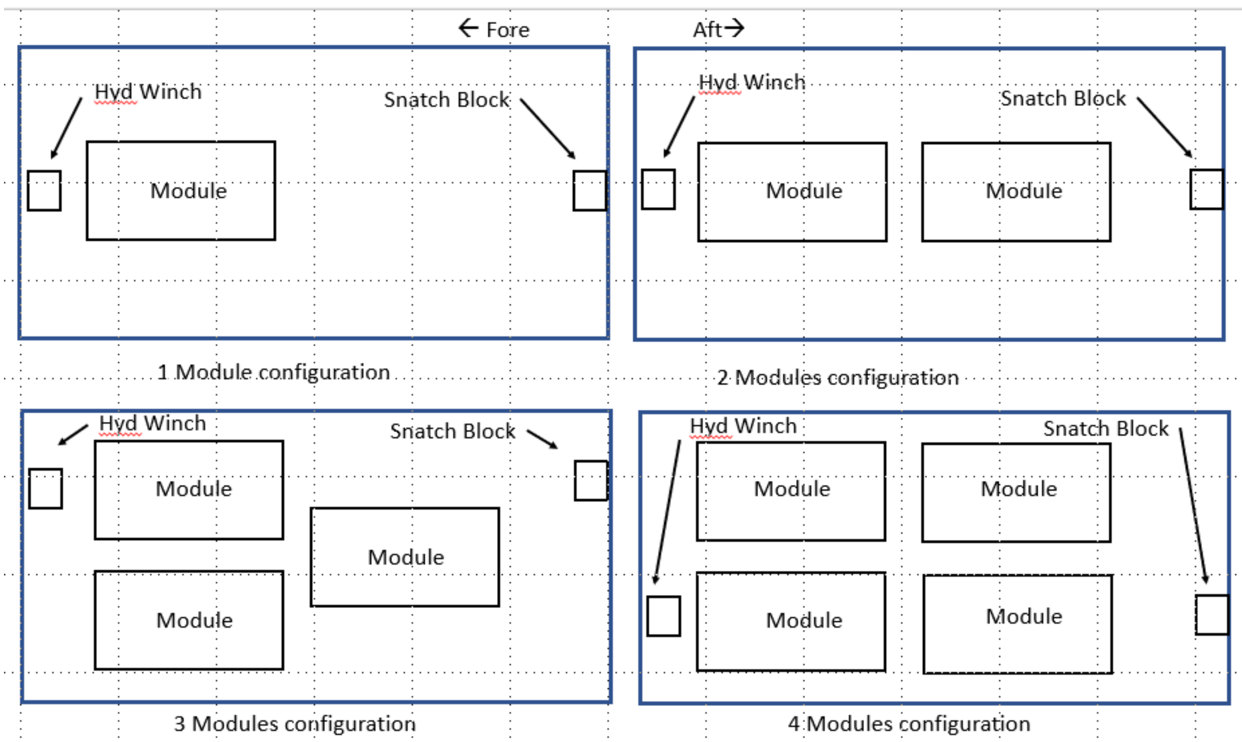
- Fingerling transport to the netpens
- Harvest from the platform to shore
- Eco-Tourism -Diving, fishing, submarining transport
- Subsurface archaeology
- Subsurface/seafloor mapping
- Temporary quartering to support offshore oil and gas operations – bunkrooms, galley, rec room,
- Academia expeditions
- Blue Tech research and development
- Air-conditioned transport of aquaculture feed

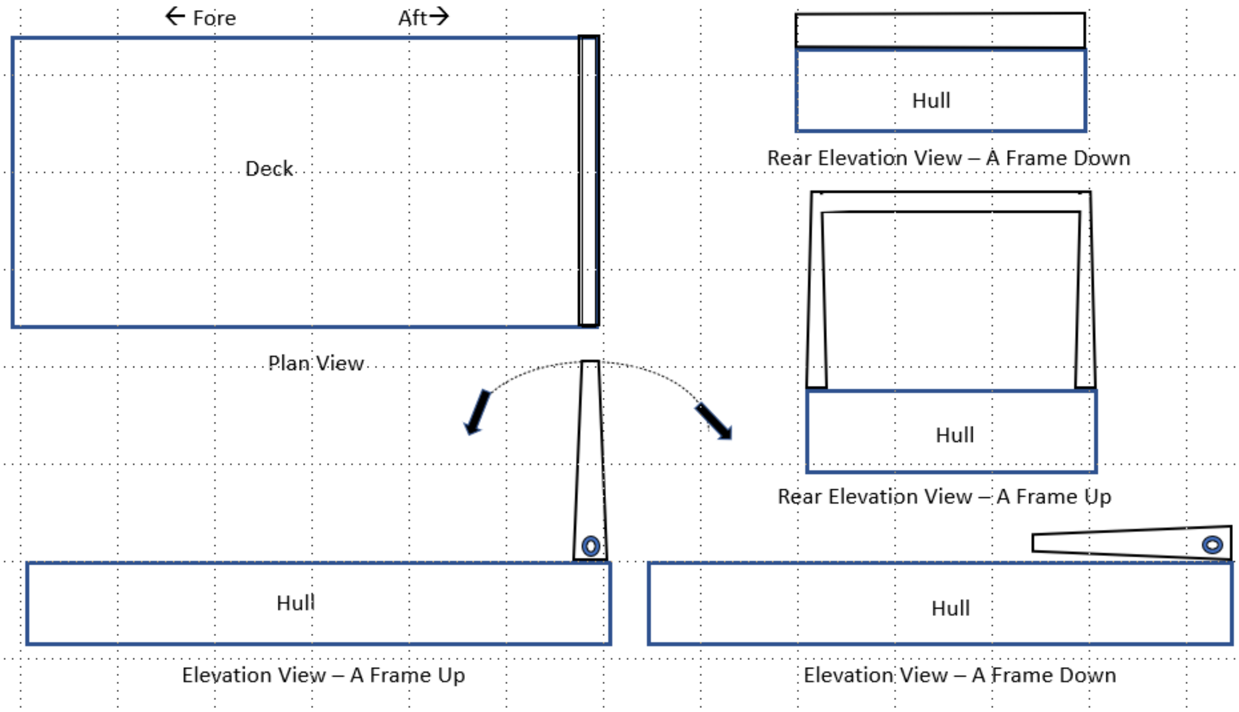
- An air compressor capable of both recharging dive tanks and aerating the fingerling module during transport

There are, currently, many crew boats available on the market due to the downturn in the oil and gas industry. Certain modifications to an available crew boat may be necessary to accommodate the desired outcome.

- Installation of a 50 kW 3 phase generator and wiring to power certain modules
- Increased capacity fuel storage.
- Strategically placed intermodal “cam-lock” devices in the boat deck
- Installation of a lifting device to lift the containers at the dock and place them on the deck
- Installation of a hydraulic winch and tackle block to move modules around on deck
- Installation of additional deck lighting
- Other potential modifications not yet envisioned

Conceptual sketches are below.





Phase 2 of this project will be to survey the market for potential crew boats and work with a naval architect to refine the concepts and prepare cost estimates for the boat and modifications.

Topic XI - Use for Monitoring, Security, and Test Facilities

42 MARINE MONITORING, SECURITY, AND SEARCH & RESCUE

The legacy platforms of the Gulf of Mexico can, at relatively low cost be used for monitoring ship, submarine, and aircraft traffic. Some of these platforms could host Coast Guard or Naval assets for these purposes. It would be expensive and not cost eff-ective to the taxpayer to completely assume responsibility for the platforms or to build bespoke ones, but if the services are co-hosted on platforms that have been repurposed for other Blue Economy or Renewable Energy uses these economics change. For example, of the Coast Guard's 11 statutory missions, listed below, at least 10 can be facilitated by building and interconnected network of stations in the Gulf of Mexico

The Coast Guard 11 statutory missions:

- Ports, Waterways, and Coastal Security
- Drug Interdiction
- Alien Migrant Interdiction Operations
- Defense Readiness
- Other Law Enforcement
- Marine Safety
- Search and Rescue (SAR)
- Aids to Navigation and Maritime Transportation System Management
- Living Marine Resources
- Marine Environmental Protection
- Ice Operations (Not applicable to the Gulf of Mexico)

These functions can co-exist with the other proposed uses in this study, and it is envisioned that they would contract space as tenants as needed.

43 OCEAN SCIENCE & EDUCATION STATIONS

There are more than 1000 colleges and universities in the US that offer marine related studies. Repurposed offshore oil and gas platforms can be made into working laboratories, offering professors students hands on access marine environments they might not otherwise have. These students will be able to see and participate in aquaculture, renewable energy, ocean mining, and ocean monitoring activities. This will be critical in the future as the Blue Economy grows and demand for talent increases. These at-sea classrooms will give the US a competitive advantage.

44 ECO-TOURISM

Another beneficial use is the prospect for science education and eco-tourism. The platforms can become offshore field laboratories and virtual classrooms. There are technologies now available that can operate an unmanned submarine that resides on an offshore platform. With a seabed docking station, an autonomous underwater vehicle (AUV) can be operated on a near- continuous basis. There are manned submarines that are commercially available that can be operated from the platforms. GORI plans to link these capabilities with the aquariums along the Gulf coast.

Topic XII – Target Platforms

45 PORT MANSFIELD DEVELOPMENT

Because of the proximity of the North Padre Island platforms to Port Mansfield, the potential for a comprehensive development at the port has been studied. Several meetings have been held with the Port Mansfield Port Director, Willacy County Officials, and the Texas General Land Office. The port has recently completed a $16 million dredging project that will allow oceangoing barges and oilfield vessels to enter the port. This opens up the opportunity to produce renewable energy at the port and in state territorial waters to supply the energy needs of the port and convert electricity and heat to store power in the form of hydrogen which can be transported by barge along the Intracoastal Waterway to users in the Corpus Christi, TX and Houston, TX markets.

GORI has held several meetings with the port director at Port Mansfield and with the Texas General Land Office about leasing state waters for wind and wave energy development.

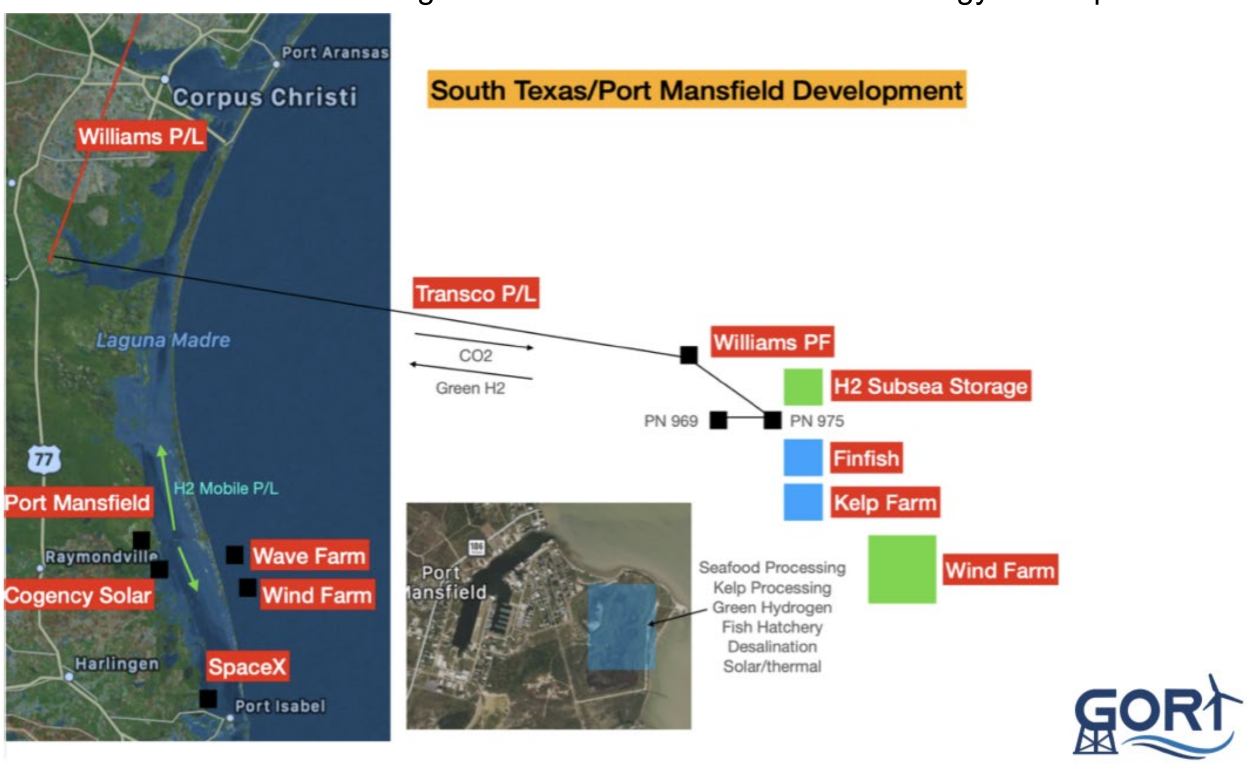


Figure 50 Port Mansfield Project

We propose to study in the Phase 2 funding the different technologies for blue and green hydrogen production at Port Mansfield and transportation by barge to markets along the Gulf Coast.

46 OTHER PLATFORMS

GORI is currently working with two offshore oil and gas operators to permit their platforms for alternate uses. See the figure below. Two of the platforms, North Padre Island (PN) 975 and 969 are located in the Western Gulf of Mexico in an area with good wind and wave resources. PN platforms have large depleted gas reservoirs and may be ideal for a CCS location.

We propose to study this in the Phase 2 funding. This study will include assessing the feasibility of utilizing the Transco pipeline to transport CO2 to the platform site.

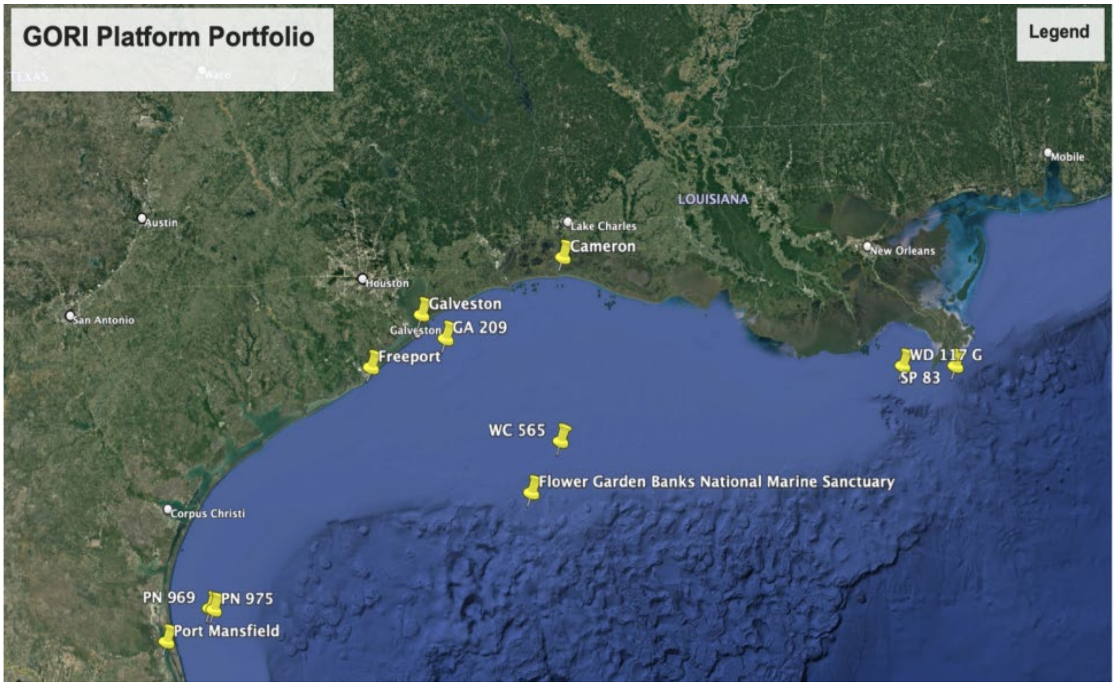


Figure 51 Typical Offshore Workboat Deck Area

The figure 45 below shows BOEM's 2020 GOM Renewable Energy Resources candidate sites. GORI envisions an offshore development tied to Port Mansfield, TX, where the port can house the necessary dock and support facilities for the offshore development.

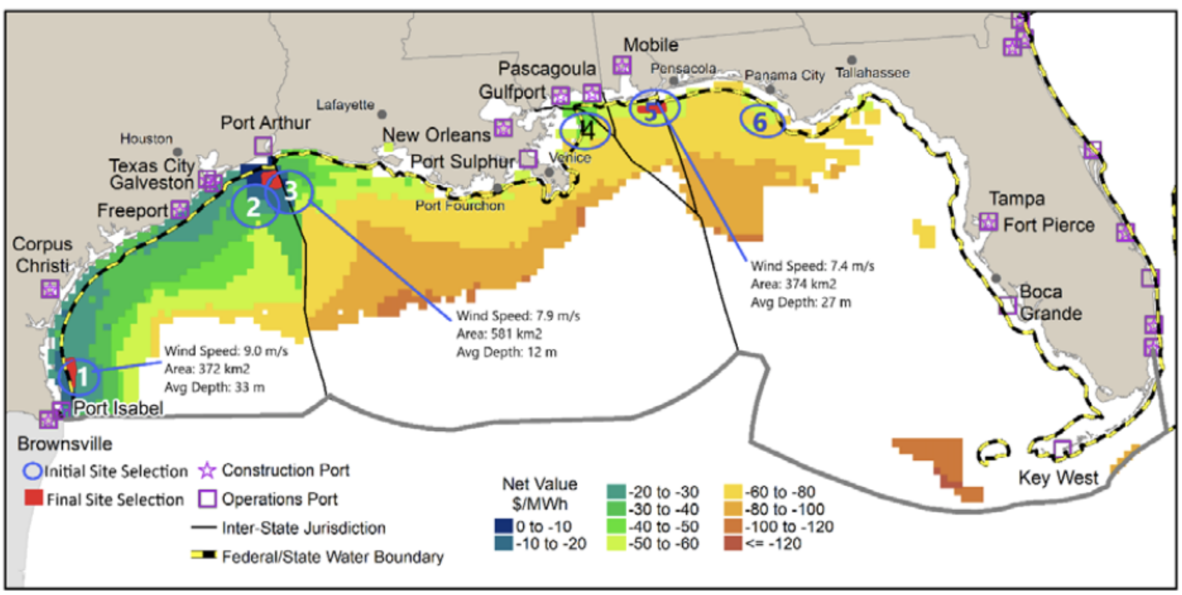


Figure 24. Estimated net value for Gulf of Mexico (2030 COD) with candidate sites.
Note: 2030 data were extrapolated from modeled data for 2015, 2022, and 2027 in Beiter et al. (2017).

Figure 52 BOEM's 2020 GOM Renewable Energy Resources candidate sites

The port and the Texas state territorial waters can also support renewable energy development. The Transco pipeline that previously was used to transport natural gas from the offshore platforms to shore may be able to be re-purposed to move CO2 offshore for CCS.

GORI entered into another agreement with an oil and gas operator to repurpose its platforms near the Mississippi River Delta (SP 83 and WD 117) and to perform a phase 1 feasibility study for CO2 storage on the GA 209 platform located off the coast of Galveston, TX. See Figure 44. GORI is assessing the SP 83 and WD 117 platforms to determine the alternate uses that will submitted to BOEM and BSEE in its permit applications – scheduled for April 2022.

Figure 53 SP 83 Water Depth 400ft 40km to Deepwater

SP 83 may be capable of supporting a novel energy generation system being developed by Excipio, will be ideal for testing the GTA electrolyzer. It is this location that comparison for the V3 turbine to a conventional turbine was made, indicating a 76% capacity factor for the V3.

47 CONCLUSIONS AND FOLLOW ON WORK

The legacy oil and gas facilities in the Gulf of Mexico hold the potential to unlock the Blue Economy and make the region the global leader in renewable energy, carbon sequestration, aquaculture, marine science, efuel and green hydrogen production, mineral extraction, and water treatment. For any platform, well, or pipeline that is structurally sound there are direct cost and environmental benefits to including them in a repurposing effort.

To fully realize the potential of the Blue Economy physical and economic models that integrate multiple systems and technologies need to be developed. Existing models mimic the industries they analyze by treating each as a discreet development. A systems model, possibly using control theory and an AI engine, would allow rapid and accurate evaluations of offshore locations for their full potential. Such a model could also be used for estimating the potential of new technologies as they arise, helping to de-risk them by accurately portraying their potential effects on the system.

While the study is focused on the Gulf of Mexico, the result cab be applied to other areas where there are extensive offshore oil and gas fields.

While not explicitly included in this DOE study, oil and gas companies can use the DOE study as a guide for what changes they may consider for greenfield developments such as:

- Wells designed for production and then evolution into geothermal use or for sequestration
- Export pipelines that can carry not just production fluids but pure H2, ammonia, and/or CO2.
- Platforms and field developments designed to support non-oil and gas activities either simultaneously or in the future when production ends.
- Include offshore renewable power as a minimum sounding new developments to replace gas fired turbines.

The technologies to build the Blue Economy are advanced enough that building offshore industrial complexes is technically feasible, the limitations are systemic. The main change that is required is to replace the pursuit of single commodity and single technology business models to more sustainable and more profitable multifaceted models that generate more value, with less waste, and make the environment around them richer and more diverse.

To advance this work further the focus for each area is as follows:

Topic I - Permitting of legacy oil and gas facilities.

BOEM and BSEE were shown to be resistant to allowing repurposing of platforms already slated for demolition, and operators are reluctant to submit active platforms for consideration because the specific criteria for approval is unknown, despite the CFR being clear on its purpose. Excipio has proposed to BSEE and BOEM, and several operators that as part of Phase II a decision tool be developed to provide a basis for submissions. It was supported and would take the form of a JIP.

Topic II - Legacy Facility Repurposing Options & Methodology

In Phase II a GoM wide assessment tool capable of combined wind, wave, and current prediction along with thermal gradients and geothermal potential will be further developed.

Topic III - Methods of Renewable Power Generation in the Gulf of Mexico

Existing studies of the renewable energy potential of the GoM were found to be overly conservative, underestimating the energy potential by at least 75%. In Phase II a GoM wide assessment tool capable of combined wind, wave, and current prediction along with thermal gradients and geothermal potential will be further developed.

Conventional wind turbines struggle to perform well in the relatively low average wind speeds in the Gulf of Mexico. In Phase II a new wind turbine design by V3 Technologies that is suited to the GoM will be further developed, with the objective of commercial deployment after the end of Phase II.

While the GoM does not have the wind and wave resources of the other coasts it does have OTEC potential. OTEC while proven technically, has struggled commercially. Phase II - Excipio intends to develop a design for a retrofit OTEC system that will extend the life of the GoM platforms. The system will, in keeping with Excipio's integrated approach feed into the hydrogen and CO2 capture systems in other areas of focus.

Topic IV - Greening of Oil and Gas Production

To decarbonize GoM oil production and aquaculture, supply vessels must be decarbonized. In Phase II methods of refueling and/or recharging support vessels with green energy/fuel will be identified.

Topic IV - Green Hydrogen & Ammonia Production, Topic VI - Synthetic or E-fuel Production, Topic VII - Carbon Capture, Utilization and Sequestration (CCUS)

A highly suitable technology for hydrogen production was identified. This will be paired with a novel CO2 capture method developed by Excipio. Phase II - the detailed design and cost of the green hydrogen and CO2 capture system will be developed. These systems are the building blocks required for power to fuel systems.

The result should yield a retrofit system that generate power, hydrogen, Caron dioxide, char, and inputs into the topi IX work below.

Topic VIII - Desalination and Water Treatment Options, Topic IX - Mineral Extraction

In the process of making green hydrogen brine is produced. There is a promising mineral recovery technique identified during the Phase I study that warrants development. Phase II – in conjunction with a university adsorption media and techniques to extract critical minerals from GoM brine will be tested.

Topic X - Aquaculture, and algae, and seaweed farming

There is potential for repurposing legacy assets for aquaculture and further study is warranted. Phase II the design of multi-modal (combined seaweed, finfish, mollusk) aquaculture will be developed. A mapping of the suitable indigenous species by area will be developed.

Topic XI - Use of existing platforms for Monitoring, Security, and Test Facilities

There are no plans to advance the further in the Initial Phase II. But once a platfrom is successfully permitted it will be re-introduced into the following Phases.

Topic XII – Target Platforms

Currently there are 4 platforms being actively permitted, though 3 have had their permits denied GORI are working with Shell to appeal BSEE's denial. The 4th is SP83 currently owned by Arena. The intent in Phase II is to include SP83 in the plans for both the new renewable energy technology testing and proposed aquaculture plans. Note that SP 83 is in the Dead Zone which may preclude fish farming but will actually benefit algae growth.

48 DISCLAIMER

49 ABBREVIATIONS

BOEM	Bureau of Ocean Energy Management
ARUE	Alternate Right of Use and Easement
DOE	US Department of Energy
NREL	US National Renewable Energy Laboratory
BSEE	Bureau of Safety Energy Management
OTEC	Ocean Thermal Energy Conversion
NOAA	National Oceanic and Atmospheric Administration
ORE	Offshore Renewable Energy
SAR	Search and Rescue
GW	Gigawatt
MW	Megawatt
LCOE	Levelized Cost of Energy ($/MWh)
KWh	Kilowatt-hour (kwh)
GORI	Gulf Offshore Research Institute
HACCP	Hazard Analysis Critical Control Point
FSMA	Food Safety Modernization Act
APHIS	Animal and Plant Health Inspection Service
BRS	Biotechnology Regulatory Services – an APHIS Agency
PPQ	Plant Protection and Quarantine – an APHIS Agency
AWG	Algae Interagency Working Group
ACOE	U.S. Army Corps of Engineers
BR&D	Biomass Research and Development Board
WTIV	Wind Turbine Installation Vessel

49.1 ACKNOWLEDGEMENTS

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