Frontier Deepwater Appraisal Solutions LLC

The Next Step in Deepwater – Proven Solutions with Innovation

Developing the GoM Lower Tertiary
An Innovative Solution to a New Set of Deepwater Challenges

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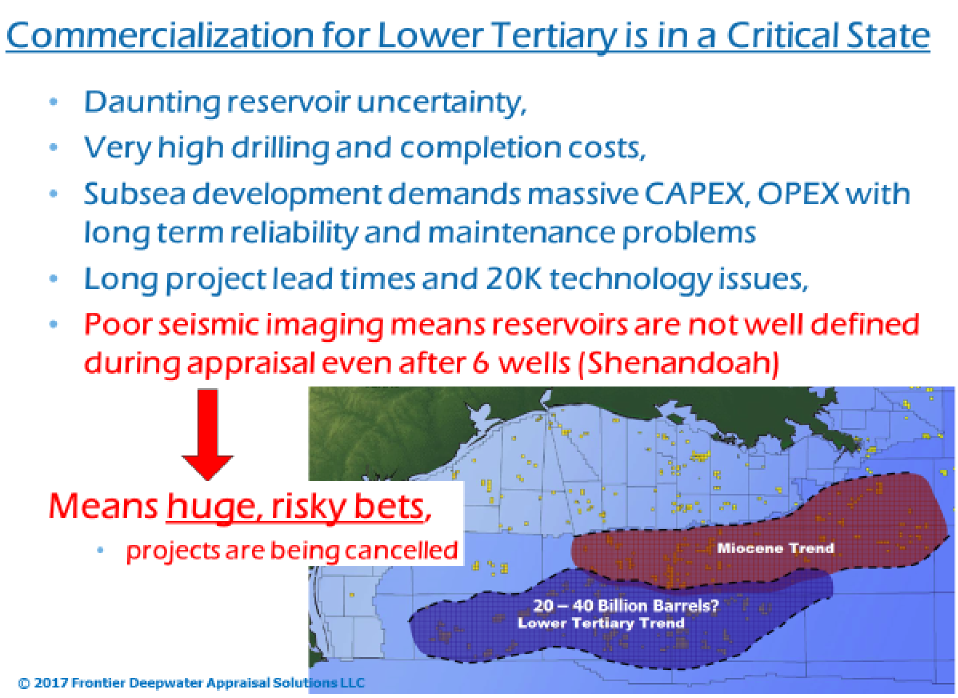
For nearly two decades, operators in the Gulf of Mexico have met with little success in their efforts to develop the massive reserves of ultra deepwater Lower Tertiary projects in the Gulf of Mexico. That is because their attempts to build subsea systems to develop these deepwater reserves have been thwarted by technology challenges, marginal economics and an often-unacceptable level of risk.

Lower Tertiary wells are the deepest, most complex and highest-pressure wells in the Gulf of Mexico. High-pressure Paleogene reservoirs are in extreme water depths and exhibit mudline pressures that can approach and exceed 15,000 psi. Wells drilled into these formations may reach total measured depths of up to 40,000 ft. Further complicating efforts to development projects in this extreme environment are significant reservoir uncertainties that stem from a lack of production history and overhanging salt canopies that make seismic imaging difficult (Figure 1).

Figure 1 - The Lower Tertiary is characterized by water depths that range from about 5,000 to 10,000 feet and reservoir depts of more than 30,000 ft. These extreme conditions create challenges that are pushing the limits of curent exploration, drilling, formation evaluation, well testing and completions technologies.



After drilling numerous appraisal wells to gather static information from electric logs and cores, the industry has been unable to define basic but critical factors about the Lower Tertiary, including:

- Faulting and connectivity
- Depletion drive mechanism
- Sand control needs
- Intervention requirements
- Reserve recovery per well
- Optimal well number per development.

Without dynamic reservoir information, these questions remain, making it difficult for operators to take on the expensive and high-risk investments to exploit this deepwater resource. As a result, despite estimates of 40 billion boe reserves in place, the Lower Tertiary remains essentially undeveloped.

<u>An innovative solution</u>

In response to the hurdles that have so far stalled development of the Lower Tertiary, Frontier Deepwater Appraisal Solutions LLC (FDAS) has designed a simpler, adaptive and standardized system that allows operators to capture critical dynamic reservoir data with a phased development strategy. The FrPS is a converted 6th generation MODU capable of drilling Paleogene wells from top to bottom. Because the drilling systems are unmodified, the operator retains full access to all drilling and completion equipment. The conversion includes removing the marine drilling riser, subsea BOP and DP system which frees up ample space and weight to install a production module and moveable wellbay, Figure 2. As such, the new system incorporates a full 2.5MM lb. drilling, completion, intervention, workover, sidetrack rig on a 60K bpd production platform.

The deepwater Frontier Production System (FrPS) reduces risk and costs and builds on the precepts that worked so successfully for the onshore "Shale Revolution," including:

- Use of simple, reliable completions and technology
- Provide inexpensive drilling, completion. long-term maintenance and intervention.
- Use of the "pad" concept to drill and develop a 'cube', which in this case is more reservoir acreage than is contained in one on OCS block.

Extensive studies performed for various operators like BP, Anadarko and others have demonstrated that 20K subsea developments are not economic and that a very different solution will be required to develop the Lower Tertiary. The patented FrPS meets that challenge by creating billions of dollars in economic advantages over more expensive and less reliable 20K subsea developments. The FrPS can be delivered and installed in about half the time and cost of a purpose-built subsea "hub" system and, because it is a phased approach, operators can confidently and profitably sanction initial field developments with just a few wells and subsequently add future phases faster and at less cost than is possible with other approaches.

Further, the FrPS is a dry tree solution; dry tree completions have historically delivered about 25% higher reserve recovery than have wet trees. For a 400-million bbl resource, this advantage may mean as much as 100 million barrels of added production, which, at $50 per bbl is equivalent to more than $5 billion in added revenue compared with a subsea system. Due to the speed at which first and peak production can be achieved by implementing the FrPS development scheme, this revenue "bonus" comes at the front end of the project, doubling the value of early adoption.

Because dry trees allow surface access to wells, they are the preferred option for deepwater well intervention and maintenance. In the Lower Tertiary, where drilling and completion costs account for 70% of total expense, developments are not as much about the facility cost as they are about well construction, well intervention operating costs, and increasing recovery per well (artificial lift). This is a paradigm shift that has yet to be recognized by many operators seeking to deliver a commercial 20K subsea development. Frontier's solution addresses these cost challenges, while providing a phased entry strategy.

The FrPS provides this solution using:

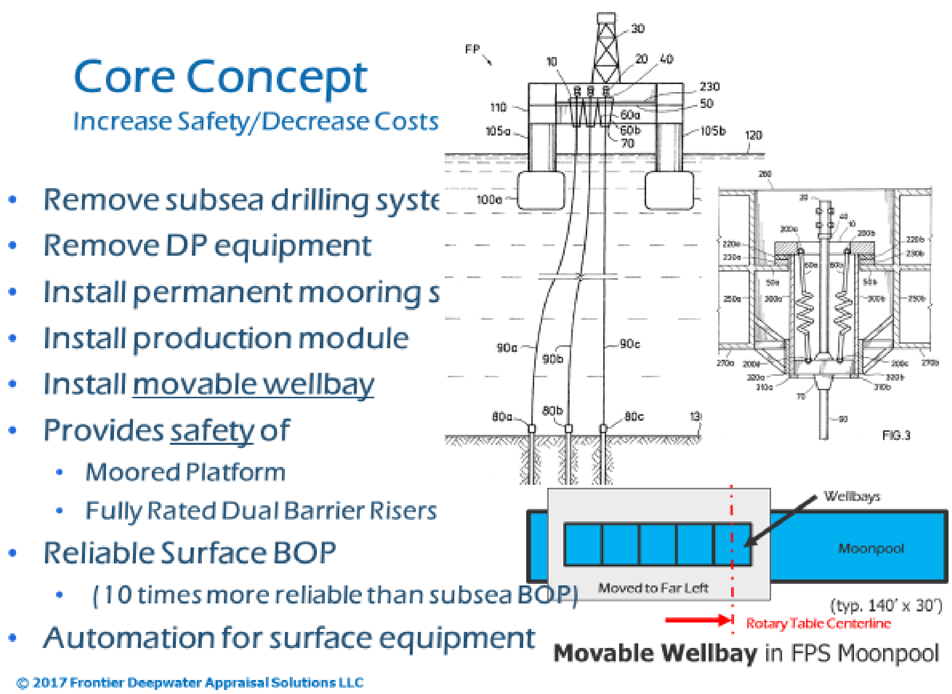
- A purpose-built or converted 6th generation semi-submersible
- A 60,000 bopd production module
- A moveable wellbay structure supporting five or more dry tree wells
- A permanent taut-leg mooring system
- Oil and gas export risers with pipeline tie-ins to regional infrastructure

Innovation using proven technology

Rather than continuing to drill many appraisal wells (for example, Anadarko drilled six appraisal wells on its Shenandoah prospect with multiple sidetracks) and spending billions of dollars obtaining static information that is not sufficient to make the most informed decisions on a Lower Tertiary development, the FrPS provides operators with the means to move forward much more quickly with fewer appraisal wells while obtaining the dynamic reservoir information profitably at oil prices of less than $50 per bbl.

The core of the FrPS is the patented movable wellbay that can to support five dry trees atop dual barrier fully rated dry tree riser systems (Figure 2). To convert an existing rig to an FrPS, all subsea drilling and dynamic positioning systems are removed, which creates space and payload capacity for prefabricated 60,000 bopd production modules and the moveable wellbay.

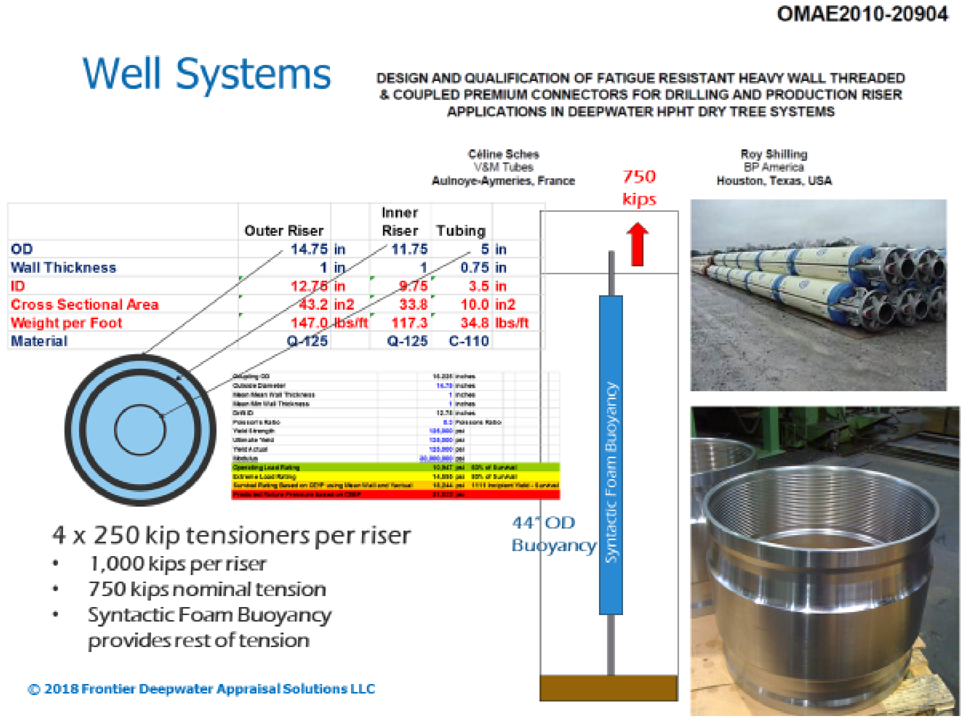
Figure 2 - The core of the FrPS is the movable wellbay installed in place of the standard subsea drilling and dynamic positioning systems of converted sixth generation MODUs.



The main and lower decks support the movable wellbay, which is restrained from vertical movement but may be moved laterally to position each well slot under the rotary table. The wellbay includes a slot structure that extends downward to accommodate the stroke of the risers. Tension rings are guided and remain within the slot structure. A flexible production jumper is attached to each tree and to a manifold built onto the movable wellbay. Chokes produce a pressure break at the moveable wellbay production manifold so that low-pressure jumpers may be attached to the manifold on the rig.

High-pressure dual-barrier riser systems are installed with syntactic foam buoyancy to reduce the top tension requirements to about 750 kips in 6,000-ft water depth, allowing the use of four standard 250-kip tensioners (with one spare tensioner), Figure 3. The dry tree configuration takes advantage of the water depth that reduces the surface pressure below that at the mudline, thus allowing the operator to use proven surface well control and production components.

Figure 3 – The FrPS movable well bay includes high-pressure dual-barrier riser systems installed with syntactic foam buoyancy to reduce the top tension.



The FrPS uses existing technology and equipment that is available from multiple equipment suppliers today. The moveable wellbay is a novel solution for development of the Lower Tertiary because installation of a 2.5-million-pound drilling unit on a spar requires a platform larger than that at the BP Holstein development. Because dry trees offer numerous advantages over subsea completions for well surveillance and interventions, they allow operators to gain critical data necessary to evaluate well performance and maximize recovery from new geologic horizons, particularly in complex stratified reservoirs like the Lower Tertiary.

A study performed by Statoil and the Norwegian Petroleum Directorate (NPD) showed that in relatively homogeneous reservoirs, the recovery factor from subsea wells is 15% to 20% lower than from wells with direct vertical access. This lower recovery factor is magnified in reservoirs like the Lower Tertiary. Accessing subsea completed wells is more difficult and incurs significantly larger costs than do wells drilled from a dry tree installation. Typically, even for minor intervention operations, a MODU mobilization is the only practical option and because this is often an uneconomic solution, recoverable reserves are left behind.

As a consequence, the NPD study concluded, production from dry tree wells is typically 20% to 25% better than from subsea wells drilled in the same geologic environment; the primary cause of this difference is easy well access, which facilitates significantly less costly light interventions and wireline work in dry tree wells than in subsea wells. In addition, the ease of surveillance operations such as production logging, production inflow, and multi-rate production logging of individual reservoir layers, significantly contributes to better data gathering, which results in increased production performance of dry tree wells.

Dry trees and permanent moorings are safer

Dry tree development is strongly aligned with the principles for maintaining simplicity, reliability and safety. The use of permanent mooring systems rather than dynamic positioning (DP) vessels eliminates the need for emergency disconnection of the drilling riser, the risk of loss of position due to drive-off or drift-off, and the need to retrieve risers, which can result in weeks of hurricane and loop current abandonment in the Gulf of

Mexico. Another study conducted as part of the NPD program indicated that position excursions that are likely to lead to physical damage are about two orders of magnitude less likely on moored versus DP rigs.

Further, the FrPS dry trees are designed to handle the full wellbore pressure and eliminate the need for complicated subsea high integrity pressure protection systems (HIPPS). In addition, a surface BOP is much simpler and more reliable than a subsea BOP. The surface BOP uses simple, reliable hydraulic controls, while the subsea BOP requires electronic controls and large high-pressure subsea accumulators to function the system. The surface BOP is readily accessible for maintenance and in many cases can be repaired in place. This eliminates the expensive and risky task of pulling a MODU marine riser and subsea BOP back to the surface for repair and testing—an operation that requires weeks and cost tens of millions of dollars.

Dry tree developments have two other important safety advantages compared with purpose-built 20K subsea developments. Dry trees require significantly fewer manhours offshore and for delivery and installation of equipment and have much lower exposure to loss of well control. In an Exprosoft 2017 report, "Loss of Well Control Occurrence and Size Estimators," for the BSEE, the well integrity, data modelling and simulation company said the frequency of loss of well control (LOWC) for dry tree wells is slightly less than for subsea wells.

According to 2000 to 2015 data in the report, one can estimate an average dry tree LWOC release of about 4,000 bbls, while using the same methodology for subsea results in about 400,000 bbls (including Maconodo). Using an average damage cost of about $15,000 per bbl calculated from the BP Macondo incident, the expected damage loss associated with a 10-well Frontier FrPS full field development would be about $3.6 million. By contrast, for a 10-well 20K subsea development, the risk is more than $360 million, or a factor of 10 higher cost exposure than when using the FrPS. Much of this increased risk stems from the reliability issues associated with the subsea BOP and from the fact that thousands of feet of marine drilling riser extending from the BOP to the MODU is not fully pressure rated as it is with dry trees. As previously mentioned loss of position and dropped objects on high pressure subsea infrastructure is also a factor that disproportionately increases subsea risk.

In planning 20K purpose built subsea developments, operators must ensure access to two 20K MODU's throughout the course of the project. The MODUs must be newbuilds, meaning the operator not only must build the floating production system, but also must fabricate and deliver the 20K MODUs for the project. Both units are staffed with 150 to 200 personnel. In addition, installation vessels are required to install subsea equipment such as manifolds, flowlines, control umbilicals, HIPPS, etc. By comparison, the FrPS requires only one unit vs three for a 20K subsea solution. The drilling crew on the Frontier FrPS can run the production risers, which eliminates extra vessels and crew to install subsea infrastructure. Considering all manpower resource requirements over the life of a 20-year project, the FrPS requires less than 50% of the man-years associated with a purpose built 20K subsea system, which greatly reduces the risk of injury to personnel.

Phased development

To more clearly illustrate the commercial case for the FrPS, Decision Frameworks LP was commissioned to perform several case studies. The study compared Lower Tertiary development economics using the FrPS with those of a purpose built semi-submersible and 20K subsea wells option with various numbers of wells and initial well rates. Both concepts were evaluated at $50/bbl and $75/bbl flat oil prices, with no inflation or oil price escalation.

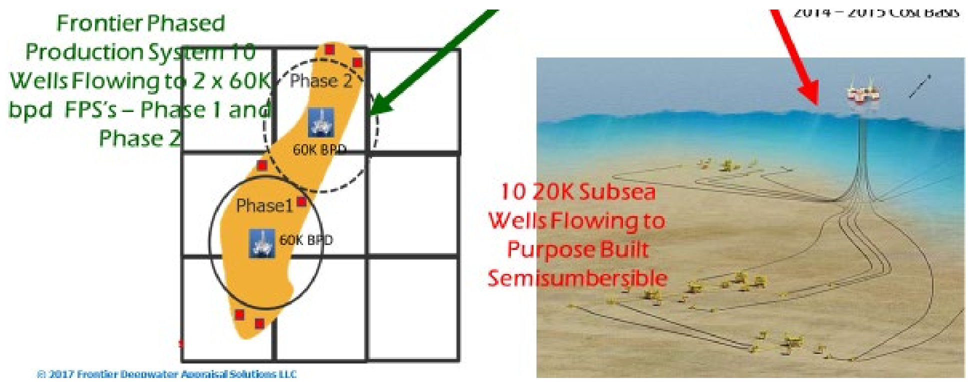
The studies focused on a project schedule comparison of the two concepts in which an initial discovery well and second appraisal wells are drilled with a commodity 15K MODU. In the case of the 20K subsea approach, FEED and 20K engineering begins with the third appraisal well and carried through the fourth and fifth appraisal wells, which are drilled as keepers (Figure 4).

The subsea hub project sanction and detailed engineering and procurement start after the fourth well results have been analyzed, resulting in the facility and equipment being delivered about 40 months later.

The facility is installed and commissioned with first oil for the 20K wells about one year after facility installation. The subsea wells are completed using the new 20K MODU.

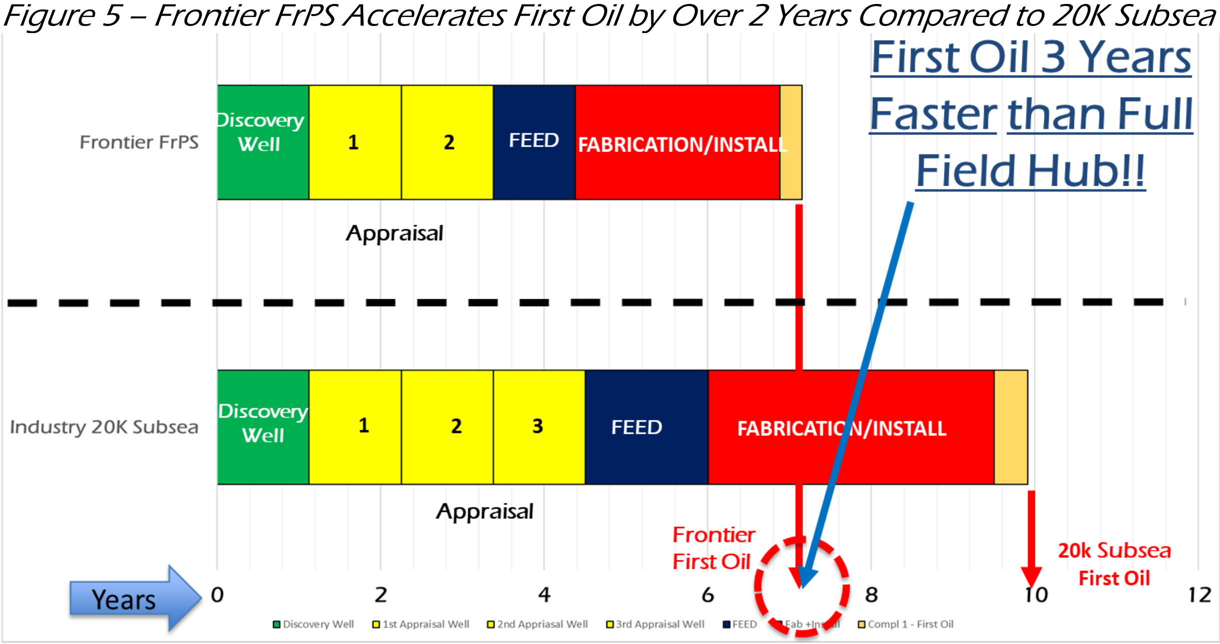
Figure 4 – Expenses for FrPS dry tree phased development are significantly less than those for subsea developments in comparable deepwater reservoirs based on 2018 cost data.

	Frontier FrPS - 5 Wells Phase 1	20K Subsea - 10 Wells	Frontier FrPS - 5 Wells Phase 1 + 2
Hull and Topsides Installed	$ 700,000,000	$ 800,000,000	$ 1,400,000,000
Dry Tree Risers and/or 20K SURF	$ 180,000,000	$ 1,250,000,000	$ 360,000,000
Drilling and Completion	$ 860,000,000	$ 3,440,000,000	$ 1,720,000,000
		$ -	
Total	**$ 1,740,000,000**	**$ 5,490,000,000**	**$ 3,480,000,000**



The FrPS scenario is similar except that a phased development scenario is employed in which the third appraisal well and all other wells are drilled as producers. The operator drills the first two well, which are actually the third and fourth appraisal wells, and cements production casing using a commodity 15K MODU. The 15K MODU then drills the remaining three wells to the 14-in casing cementing point and cements the casing, which is angled in the direction of the desired bottom hole locations. While these wells are being pre-drilled, an existing MODU is converted into the FrPS and then installed over the five pre-drilled wells. The operator then installs dual barrier production risers and completes the first two wells for first oil, resulting in an acceleration of first oil by more than 2 years, Figure 5. The remaining three wells can be directionally drilled and completed using the rig on the FrPS.

Figure 5 – Frontier FrPS Accelerates First Oil by Over 2 Years Compared to 20K Subsea

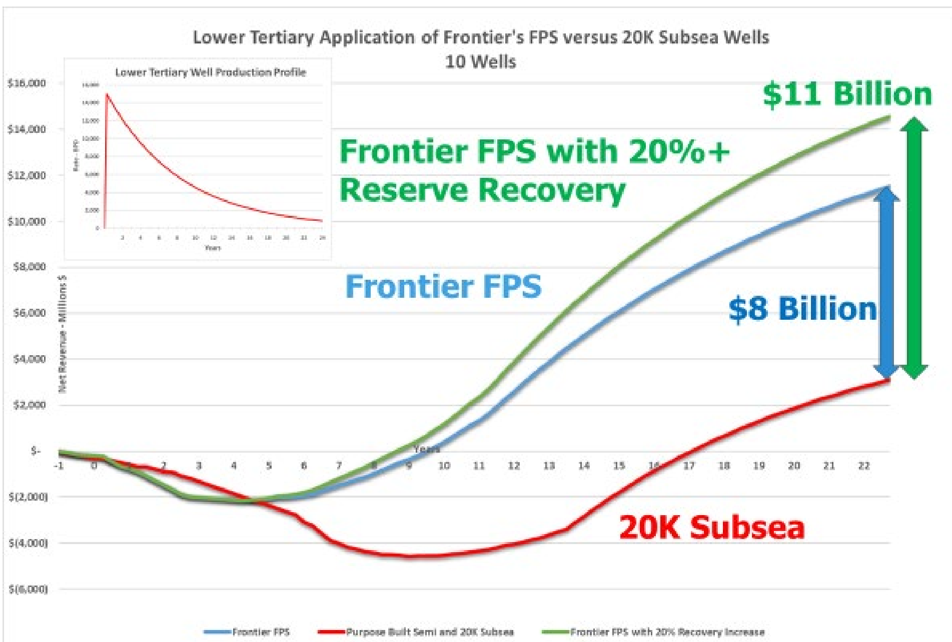


An initial well production rate of 15,000 bbls per day was selected for both the dry tree and subsea cases based on existing BSEE production data from Lower Tertiary production at Jack St. Malo, Julia, Cascade and Chinook. The analysis concluded that because of its significant cost savings and schedule improvements, the Frontier FrPS is a much more valuable development (Figure 6). Five specific aspects drove the value benefits, including:

- Lower capex— the FrPS is less expensive to design and build and enables use of dry trees
- Lower rig rates and operating costs
- Faster schedule delivery and earlier first oil because of shorter facility lead time
- Significantly reduced opex—lower workover costs because 20K MODU mob/demob cost is eliminated.
- Significantly improved reserve recovery using dry trees which afford direct, cheap reservoir access for intervention, monitoring and maintenance.

With dynamic reservoir information obtained in Phase 1, operators may proceed with additional phases in possession of a much higher degree of reservoir certainty. Frontier's phased approach provides operators about $8 billion more value than a traditional subsea development scenario. If the additional reserve recovery from dry trees, as referenced in industry studies, is considered the difference increases to more than $11 billion.

Figure 6 - Operators can realize first oil and positive cash flow far sooner through FrPS development methods than through traditional subsea developments.



Conclusion

For decades, as it moved to ever deeper water and more hostile and complex environments, the E&P gas industry has repeatedly turned to engineering innovation to meet evolving technological and economic challenges. To exploit the vast reserves of the Lower Tertiary, the industry must once again turn to engineering innovation rather than attempting to mutate a subsea supply chain solution built for other reservoirs in which drilling, completion and maintenance are not the cost drivers as in the Lower Tertiary. The FrPS is such an engineering innovation. This step change is centered on the realization that, unlike in the past, it is the cost of well construction as well as access to dynamic reservoir data, and not the production facility and supply chain, that must drive development decisions in the Lower Tertiary.

Although the initial driver was to create a technical and economic solution to unlock the deepwater Tertiary plays in the Gulf of Mexico, GoM, the FrPS is a viable solution for development opportunities in shallower water and normally pressured. That is because the FrPS dry trees offer higher reserve recoveries than subsea completions, which raise the economic limit and thwart late in life reserve recovery efforts. The operator also has the option to relocate the unit once the field reaches its economic life.

The moveable wellbay technology is also applicable to new construction TLPs and deep draft floaters, such as spars, because the rig may be built lower into the platform, eliminating the heavy and expensive rig skidding systems on the top deck. In doing so, the drilling systems and utilities become simpler and the overall platform size and complexity can be reduced.

As such, the FrPS has worldwide applications beyond the Gulf of Mexico.

MOVABLE WELLBAY