

GTL FPSO—An Alternative Solution to Offshore Stranded Gas

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Summary

Sustained and increasing world energy demands have led to very high oil prices. In parallel, there has been a significant increase in interest in economic and environmentally sensitive solutions for the monetization of remote, stranded gas offshore. Current global natural-gas reserves total approximately 6,100 Tcf, according to US Energy Information Administration estimates. Roughly one-half of these reserves are considered to be stranded gas that is uneconomical for market delivery because of the remote location of potential markets, the lack of economic transportation and infrastructure, or the lack of conversion technology. Such regions with significant stranded-gas reserves include Northern Australia, Vietnam, and Indonesia.

Gas-to-liquids (GTL) floating production, storage, and offloading (FPSO) offers an attractive new solution to monetize these remote, offshore stranded-gas fields. Products of the GTL process are clean transportation fuels ranging from diesel to jet fuel that can be readily used in the existing energy infrastructure. Although this option was considered in the past by Syntroleum and Statoil in mid-2000, a subsequent examination of this option is warranted because of recent advances in both GTL and FPSO technology. New GTL commercial plants have recently begun production in Qatar, using technologies by Sasol and Shell with the latest advances in process technologies and catalysts. Membrane- and process-intensification technologies show considerable promise in making GTL an attractive option in the future. The newly built oil-FPSO units (at Pazflor and Agbami) instill confidence that large oil- and gas-processing operations can be performed safely and economically on an FPSO unit.

A feasibility study has been completed recently as part of a multi-year development program to acquire the basic technology and engineering for GTL FPSO. An assessment was made on the technical feasibility of commercial-scale and near-commercial-scale technologies, and a preliminary design concept of the GTL process was produced for the topside. This study used technologies that best met the needs of the FPSO application and the corresponding preliminary design concept of the hull to support the topside GTL process. Additionally, preliminary market analysis was performed to better define the scope of GTL products to be produced. Economic analysis was performed to identify the major cost factors and understand their sensitivity on project economics.

The results of this feasibility study to date suggest that this GTL-FPSO design concept is technically feasible. Its clean fuel and chemical feedstock would be attractive to the market, and the design concept is economically competitive within the range of

the current project-cost factors. Future work will be directed at developing a more-definitive process, hull design, and project economics, and will bring commercial realization of this innovative approach to monetizing offshore stranded-gas fields.

Background

GTL-Production Technology. Fig. 1 summarizes the different options in monetizing natural gas with approximate, corresponding amounts of product produced per 100 MMscf/D of natural-gas feed (JDF 2007). The chemical-conversion options [methanol, dimethyl ether (DME), or GTL] all produce synthesis gas (syngas) in the intermediate step; however, each option produces the specific ratio of hydrogen to carbon monoxide (H_2/CO) required by its respective synthesis section.

Fig. 2 shows a schematic of the three main steps in the GTL process (Djakovic 2011). The products range from naphtha hydrocarbons (used as feedstock in the chemical industry and in refineries) to medium distillate hydrocarbons suitable for jet fuel and diesel to heavier hydrocarbons, such as wax, which may be further converted to produce more of the lighter products. Water is a major by-product in GTL production, in which approximately 1 bbl of water is produced per barrel of product. This water must be treated to remove hydrocarbon contaminants before discharge.

There are three commercial-scale GTL plants in production today: (1) Bintulu plant in Malaysia began in 1993 and was rebuilt in 2003 with a capacity of 14,700 B/D by Shell; (2) Pearl plant (Phase 1) in Qatar started up in 2011 with a 70,000-B/D capacity, and another 70,000 B/D is planned for Phase 2 by Shell; and (3) Oryx plant in Qatar, with a 34,000-B/D capacity, reached 90% nameplate capacity in 2012 by Sasol. These commercial-GTL technologies are assessed in this study for FPSO application.

Advances in FPSO. Rapid advances in FPSO have occurred in recent years, both in the sophistication of its processing function and the capacity of the ship. The Pazflor FPSO is 325 m in length, is 61 m in breadth, will produce 220,000 B/D of crude oil, and will store up to 1.9 million bbl in volume (Fig. 3). The Agbami FPSO unit is 320 m in length, is 59 m in breadth, will produce 250,000 B/D of crude oil and 450 MMscf/D of gas, and has a storage capacity of 2.3 million bbl in volume. Both FPSO units possess a large number of processing units on the topside and hull, including the inlet-gas treatment and stabilization, the power plant, and the desalination unit. These advances will serve as an important technology and engineering base for the envisioned GTL-FPSO project.

Past GTL-FPSO Works. The prospect of monetizing stranded-gas fields to produce premium-grade liquid products has made GTL FPSO attractive in the past. Syntroleum has pursued the development of its own GTL technology on an FPSO unit (Van Loenhout et al. 2006). Syntroleum's oil GTL-FPSO unit was designed to produce 40,000 B/D of oil and 16,300 B/D of GTL products

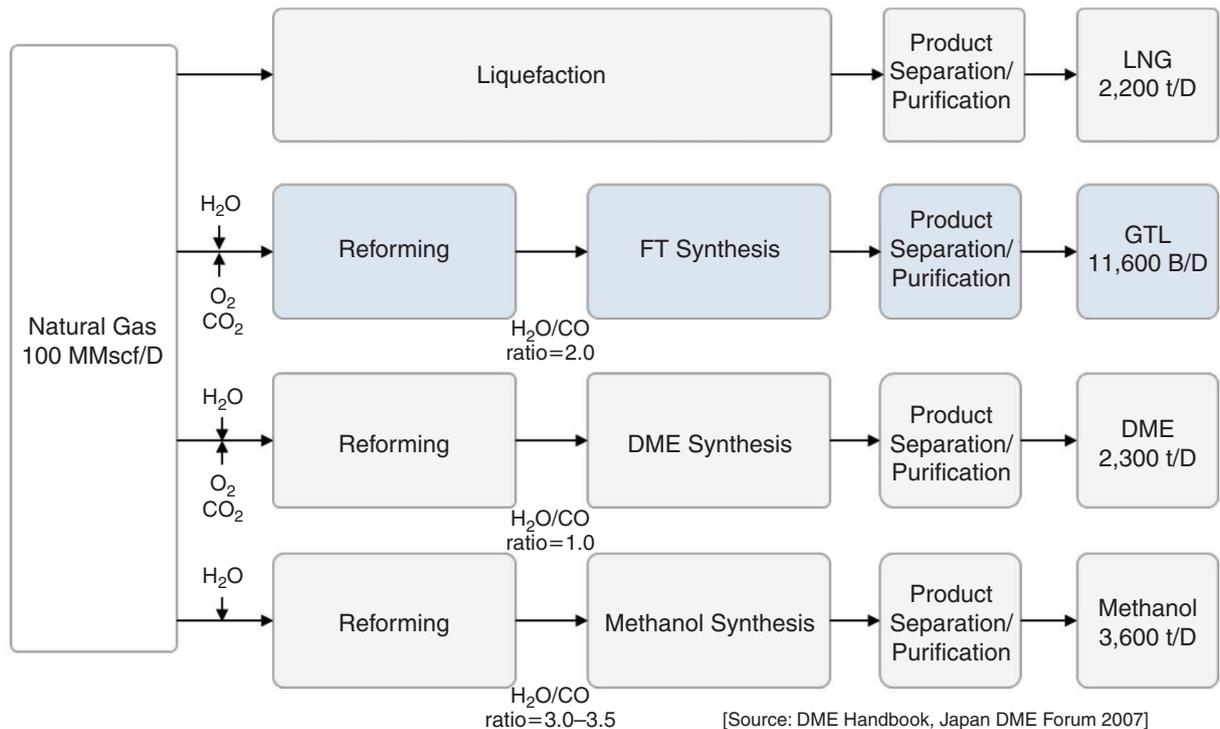


Fig. 1—Natural-gas monetization options. (LNG=liquefied natural gas.)

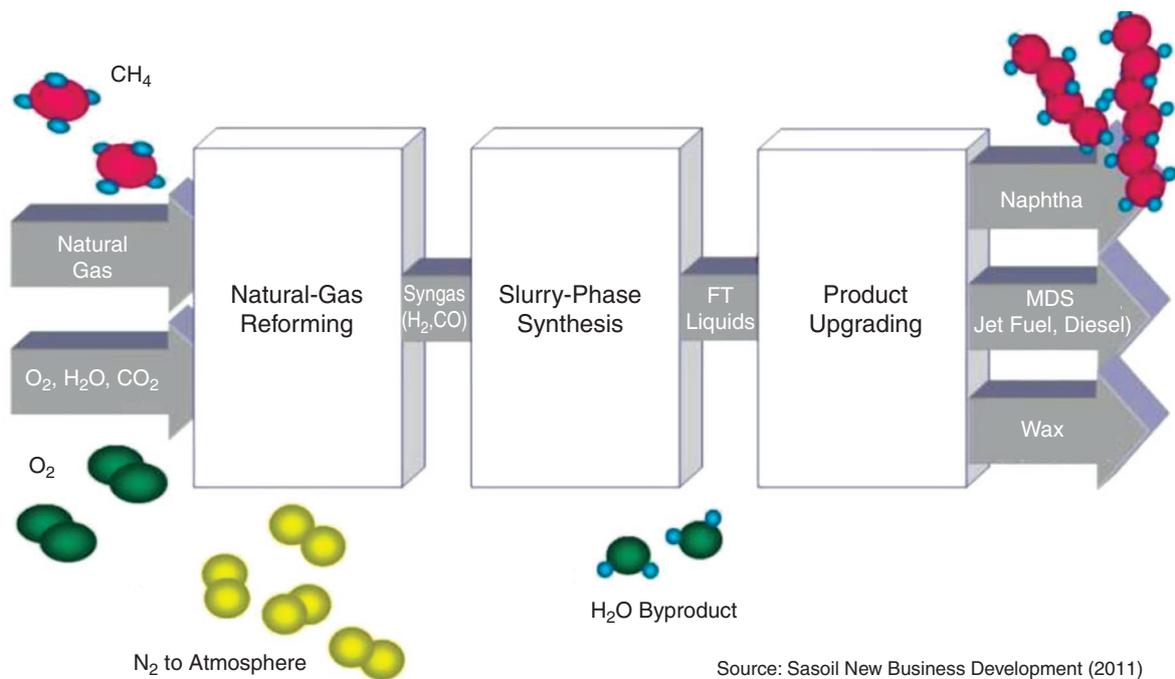


Fig. 2—Schematic of the GTL process. (MDS = middle distillate synthesis.)

on an FPSO unit with an estimated topside area of 310×65 m (length×breadth). The airblown-reformer technology used in the design resulted in very large equipment throughout the process. For example, the Fischer-Tropsch (FT) reactors were 10 m in diameter and required 84-in. pipes. This would present serious challenges in the space-restricted FPSO environment. The fact that this GTL technology had not been proved on the commercial scale onshore would have also been a concern in moving to offshore application.

Statoil's FPSO concept uses an autothermal reformer and a slurry FT reactor with a targeted production of 14,500 B/D of liquid

fuel (Osvik 2005). This concept uses pure oxygen and thus requires an air-separation unit onboard. In addition to the high cost and large footprint of the air-separation unit, the use of pure oxygen poses challenging safety concerns, particularly in the FPSO environment.

GTL-FPSO Development

GTL-FPSO-Development Approach. Fig. 4 illustrates the overall development plan of the GTL FPSO. The approach is to first assess and select the best GTL technology for each of the major steps in the process that best meet the key FPSO requirements, such



Dimensions: 325-m length×61-m breadth×32-m depth

Stabilized Oil: 232,000 BOPD
 Produced Water: 312,000 BWPD
 Produced Gas: 155 MMscf/D



Fig. 3—Oil FPSO unit at Pazflor in 2012.

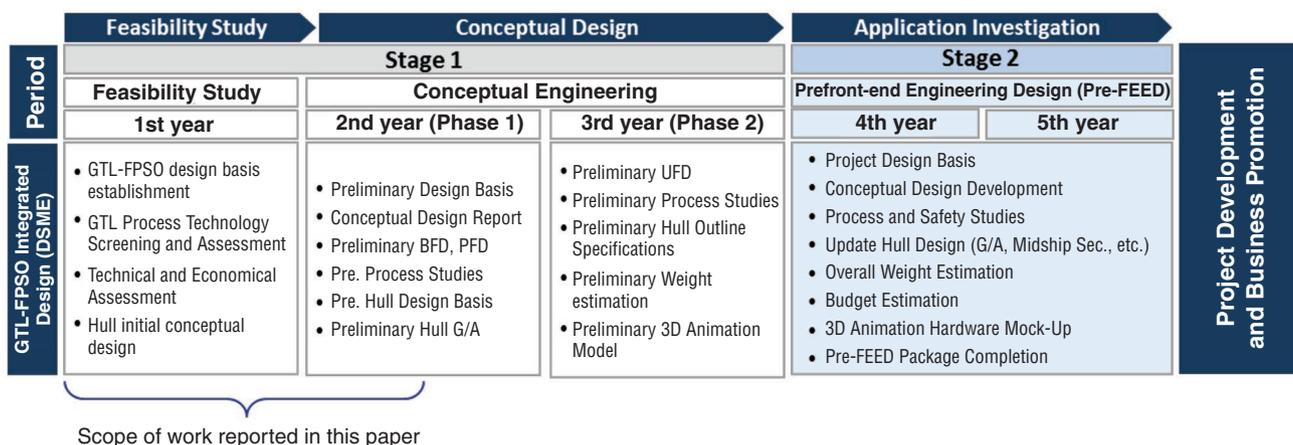


Fig. 4—Approach to GTL-FPSO development. (BFD = block flow diagram, PFD=process flow diagram, G/A=general arrangement, and UFD=utility flow diagram.)

as safety, sea worthiness, and having been commercially proved. The selected technologies will then be integrated to develop a process and hull-design concept, followed by conceptual engineering. The economic feasibility will be assessed at the end of each de-

sign stage. Daewoo Shipbuilding & Marine Engineering (DSME) is currently at the halfway mark of a 3-year Stage 1 plan that encompasses feasibility study and conceptual design. This paper describes the key results of the work completed to date.

Syncrude Properties	Naphtha	Syncrude
Amount (%)	23	77
Density (kg/m ³)	688	903
Viscosity (cSt)	2 (25°C)	15 (40°C)
Olefins (%)	< 1%	< 1%
Naphtha (wt%)	> 98%	< 5%
Middle distillates (wt%)	< 5%	30
Wax (~VGO+VR, wt%)	0	70

VGO = vacuum gas/oil.
 VR = vacuum residue.

Potential Field- and Target-Production Capacity. The potential locations of the envisioned GTL FPSO are stranded-gas fields off the coast of northwest Australia and Southeast Asia. A more specific location and its gasfield information will be incorporated into the project-design basis in the future. The offshore plant will produce 20,000 B/D of naphtha and synthetic crude (syncrude), and the design will consider the possibility of upgrading the syncrude to diesel and jet fuel. **Table 1** provides the product specifications for the envisioned products.

Key Design Considerations in FPSO Application. The key design considerations in assessing onshore-GTL technology for FPSO application are as follows:

- Robustness to marine motion: The process equipment must operate under vessel motion (acceleration caused by ship mo-

TABLE 2—COMMERCIAL GTL PLANTS IN PRODUCTION TODAY

	Project		
	Bintulu	Pearl	Oryx
Owners	Shell, Mitsubishi, Petronas, Sarawak State	100% Shell funded	Qatar Petroleum (51%) Sasol (49%)
Location	Bintulu, Malaysia	Qatar, Persian Gulf	Qatar, Persian Gulf
Plant capacity (B/D)	14,700 (2003)	140,000 (70,000 B/D for Phase 1 and 70,000 B/D for Phase 2)	34,000
Estimated invested capital (USD million)	850 (1993) 50 (2003 revamp)	18,000–19,000 including offshore	900–1,500
Startup	1993	March 2011 (Phase 1)	June 2006 March 2012 (90% nameplate)
Reforming technology	Partial oxidation	Partial oxidation	Prereformer and Haldor Topsoe Autothermal Reformer
FT reactor technology	Low-temperature mixed-tubular fixed-bed (cobased catalyst)	Low-temperature mixed-tubular fixed-bed (Co-based catalyst)	LT Sasol Slurry Phase (Co-based catalyst)
Product-upgrading technology	Heavy paraffin conversion	Heavy-paraffin conversion	Hydroprocessing

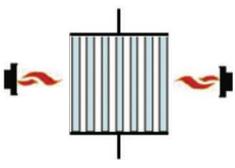
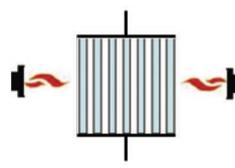
	SMR (Steam Methane Reforming)	POX (Partial Oxidation)	ATR (Autothermal Reforming)	SCR (Steam Carbon Reforming)
Reactor				
Reaction	$CH_4 + H_2O \rightarrow 3H_2 + CO$	$CH_4 + 1/2O_2 \rightarrow CO + 2H_2$	$CH_4 + 1/2O_2 \rightarrow CO + 2H_2$ $CH_4 + H_2O \rightarrow CO + 3H_2$	$CH_4 + H_2O \rightarrow 3H_2 + CO$ $CH_4 + CO_2 \rightarrow 2CO + 2H_2$
H ₂ /CO Ratio	>3	1.7–1.8	≈2.0	≈2.0 (adjustable by feed CO ₂)
Catalyst	Ni-Based	Noncatalytic	Ni-Based	Ni-Based

Fig. 5—Fundamental characteristics of reforming technologies.

tions such as pitch and roll). In particular, the columns and reactors having a liquid-free surface, such as the FT reactor, columns, and hydrocracker, can be influenced by inertia and inclination effects.

- Limited space (or available footprint): The compactness of design and suitability for multilayer arrangement are important. Process and utility facilities and equipment must fit into the overall topside and hull space.
- Weight and height: The total equipment weight, weight distribution, and center of gravity are important. Equipment height of less than 30 m is desirable.
- Need for self-sufficiency: All utilities (power, steam, water) must be supplied onboard. All maintenance and services must be performed while the vessel is on station.
- Safety: The confined spaces and compact process-plant layout for offshore applications increase the potential consequences and risk from fire and explosion. The location of hazardous

equipment on the topside and in the hull is constrained by the need to protect inhabited areas and to separate oxidants from combustible material.

- Additional considerations in constructability, fabrication, and certification requirement require attention, and these will be researched by experts at DSME.

Assessment of Commercial GTL Technologies. Reformer Reactor. Table 2 shows key project and technology aspects of the three commercial-scale GTL plants currently in operation. In consideration for FPSO application, both reforming technologies—partial oxidation and autothermal reformer—require pure oxygen. This presents considerable safety concerns for FPSO application; therefore, alternative reforming technologies were investigated.

Fig. 5 summarizes the fundamental characteristics of the major reforming technologies. Among these, the steam-carbon-reforming (SCR) technology has the potential to meet all of the key require-

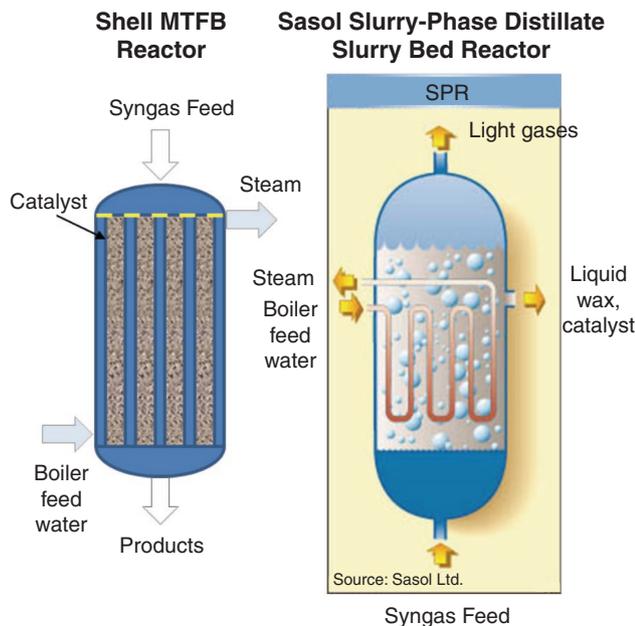


Fig. 6—Schematic of commercial FT reactors.

ments in this GTL-FPSO project. SCR technology may be viewed as a variation of traditional steam-methane-reforming (SMR) technology, but it is able to handle natural gas with high carbon dioxide (CO₂) content. The main characteristics of SCR technology relevant to FPSO are as follows:

- The externally provided heating eliminates the use of pure oxygen.
- This technology is able to tolerate feed gas with high CO₂ content; the high CO₂ content also serves to lower the H₂/CO ratio from the 3.0 or greater produced in conventional low-CO₂-feed SMR to 2.0 (the CO₂ reforming reaction gives an H₂/CO ratio of 1.0, while steam reforming gives an H₂/CO ratio of 3.0). These two reactions allow SCR to produce syngas with an H₂/CO ratio of approximately 2.0, as required by the FT reactor.
- The SCR technology is comparable to other reforming technologies in terms of tolerance to ship-motion effects and space requirements.

The closest equivalent to SCR that has been demonstrated at significant scale is the Davy Process Technology (DPT) compact reformer. It is an SMR system that uses catalyst capable of handling high CO₂ natural gas and which is designed to maximize heat re-

covery from both flue gas and syngas product with minimum footprint (Gamlin 2010). As an externally fired reformer, it does not need pure oxygen, which eliminates the need for an air-separation unit.

The compact reformer has been tested in the 300-B/D GTL-demonstration plant operated by BP in Nikiski, Alaska, from 2003 to 2009. The resulting product, FT diesel, underwent extensive testing to assess its blending qualities and end-product performance characteristics. In engine trials, the Nikiski FT diesel successfully passed all standard industry tests, such as those for chemical fuel properties, emissions, and performance by use of a range of different fuel mixtures.

The compact reformer is believed to be capable of handling high CO₂ content in natural gas and is able to produce syngas with an H₂/CO ratio close to 2.0 with 20% CO₂. The membrane technology for hydrogen removal has also been used to offer further control of the H₂/CO ratio.

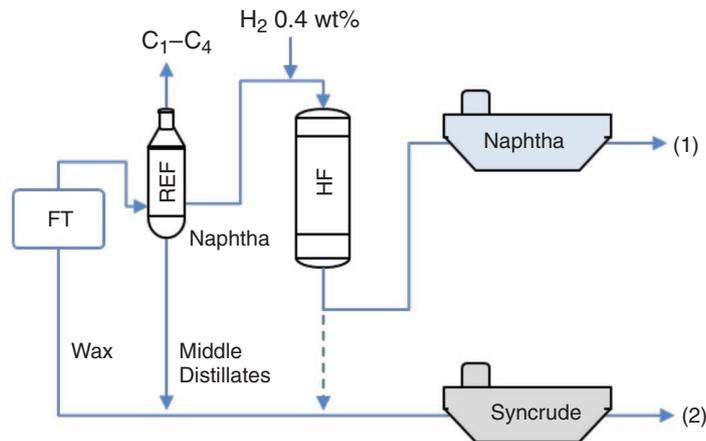
Additional merits of the DPT compact reformer for the envisioned FPSO project include a high thermal efficiency of 90% compared with approximately 50% for conventional SMR. This increased thermal efficiency is achieved by maximizing the heat transfer between the fuel gas and the process; firing is countercurrent to process flow, and smaller, more-tightly-packed tubes are used than in conventional SMR.

FT Reactor. Fig. 6 shows a schematic of a multitubular fixed bed (MTFB) and a slurry phase reactor (SPR). Both technologies share similar characteristics in fundamental reaction chemistry.

- These technologies share similar feed-gas-composition requirements, with an H₂/CO ratio of approximately 2.0.
- On the basis of a similar catalyst, the cobalt-based catalyst operates under the low-temperature-range FT reaction of approximately 230°C.
- These technologies share similar product compositions, consisting of mostly naphtha, middle distillates, and wax.

The two technologies, however, are quite different in their reactor mixing and mechanical characteristics:

- The reactant in the MTFB flows through the reactor in a plug-flow mode. The flow is close to a complete mixed mode in the SPR.
- The SPR is smaller and lighter than the MTFB, although inertia and inclination effects may have a greater influence on its free-liquid surface.
- The SPR allows the addition and replacement of catalyst without shutdown, while MTFB does not.
- The SPR reactor will have a lower pressure drop with no possibility of plugging or pressure drop increase during operation. The MTFB reactor will have a higher pressure



Syncrude Properties	(1)	(2)
Amount (%)	23	77
Density (kg/m ³)	688	903
Viscosity (cSt)	2 (25°C)	15 (40°C)
Olefins (%)	<1%	<1%
Naphtha (wt%)	>98	>5%
Middle Distillates (wt%)	<5%	<30
Wax (≈VGO+VR) (wt%)	0	70

Fig. 7—Product-stabilization process and properties of the final product from the GTL-FPSO process. (REF=reformer and HF=hydrofinish.)

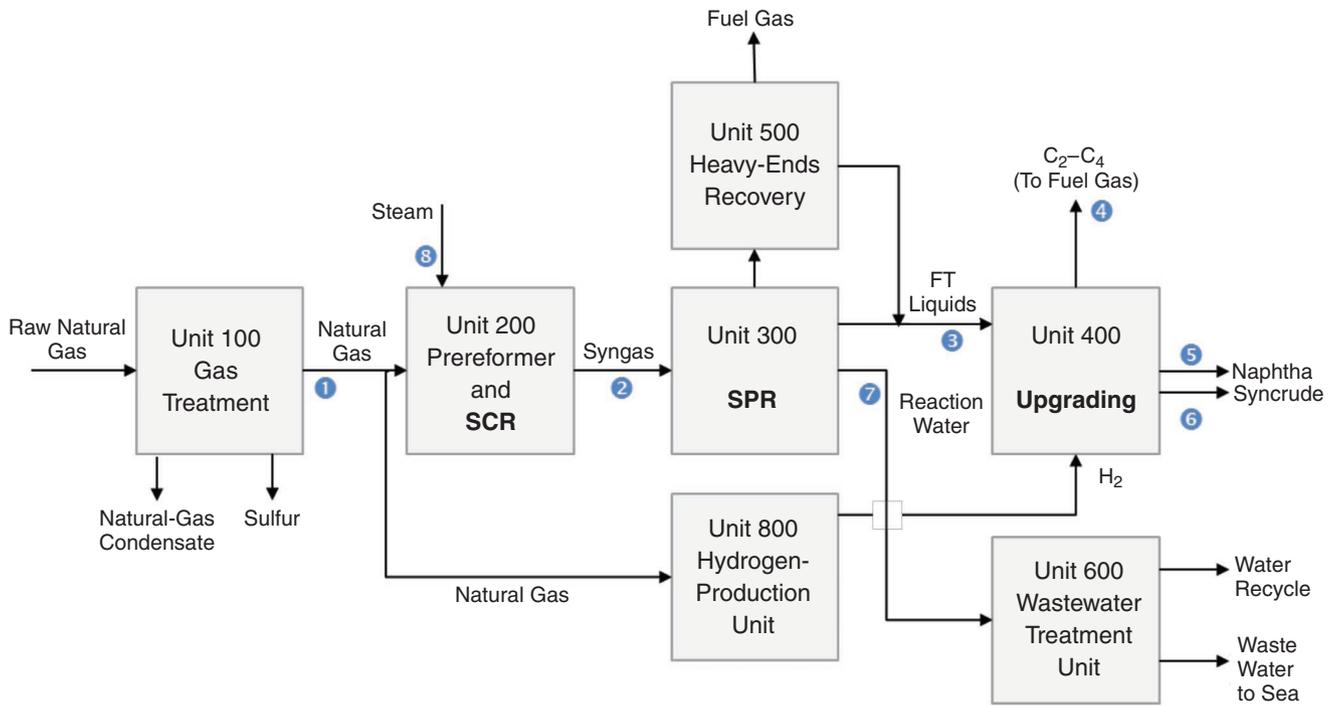


Fig. 8—Simplified block diagram of the GTL-FPSO process.

TABLE 3 — PRELIMINARY MASS BALANCE OF GTL-FPSO PROCESS

Description	Stream								
	1	2	3	4	5	6	7	8	9
	Natural-Gas Feed	Syngas	FT Liquids	C ₂ -C ₄	Naphtha	Syncrude	Rxn Water	Steam	Hydrogen
Standard volume flow (MMscf/D)	171	317							5
Standard volume flow (Nm ³ /h)	216 022	399 197							5500
Total mass flow (t/hr)	185	258	111	0.01	24.4	87.5	136	73.6	2.22
Total product flow (B/D)			22,398	600	5,356	14,626	20,600		

(Stream numbers correspond to those in Fig. 8.)

drop and some risk of plugging or increasing pressure drop during operation.

For the envisioned GTL-FPSO project, the SPR was selected because of its favorable size and weight and for its easier catalyst-handling ability onboard. Given that the feed input and product output are quite similar, it would be relatively straightforward to consider the MTFB option in future design works.

Product Upgrading. Both the Shell and the Sasol GTL plants in Qatar have full product-upgrading facilities that convert FT products into the maximum amount of naphtha, jet fuel, and diesel. To reduce the complexity in producing finished products, this project limits the product upgrading to separation and stabilization of FT products for storage and shipping. Fig. 7 provides a schematic of the product-stabilization steps and the product properties. The FT-reactor products are separated into gas, naphtha, and syncrude. The gas stream, consisting of mostly light olefins, is too small to be stored and shipped, and is therefore used as fuel gas. Naphtha is hydrofinished by means of olefin saturation for stability in storage and transportation. Condensates from the FT reactor and the product from the hydrofinish are shipped together as syncrude to the refinery for use as a feed. These product-upgrading steps are simple

and generic, and, hence, no technology assessment and selection are required at this conceptual design stage.

Utilities. The GTL-FPSO process will need to be entirely self-sufficient in utility requirements. The major utility units are described as the following:

- Hydrogen-production unit—used for supplying the hydrogen needed to stabilize the FT products. The amount of hydrogen required will be less than that required for full product upgrading provided to land-based GTL plants.
- Power plant—used for providing the electrical power needed by the process. The GTL process produces a considerable amount of steam from process heat recovery. This steam is used in steam-turbine generators to produce power. In addition, a combined-cycle system (gas-turbine generators/heat-recovery steam generation/steam-turbine generators) will provide the balance of the power required by the process and will provide initial power for startup.
- Wastewater-treatment unit—used to remove oxygenated hydrocarbons from the plant waste water to meet applicable standards for discharge.
- Desalination unit—will use reverse-osmosis membranes to produce all makeup freshwater from seawater.

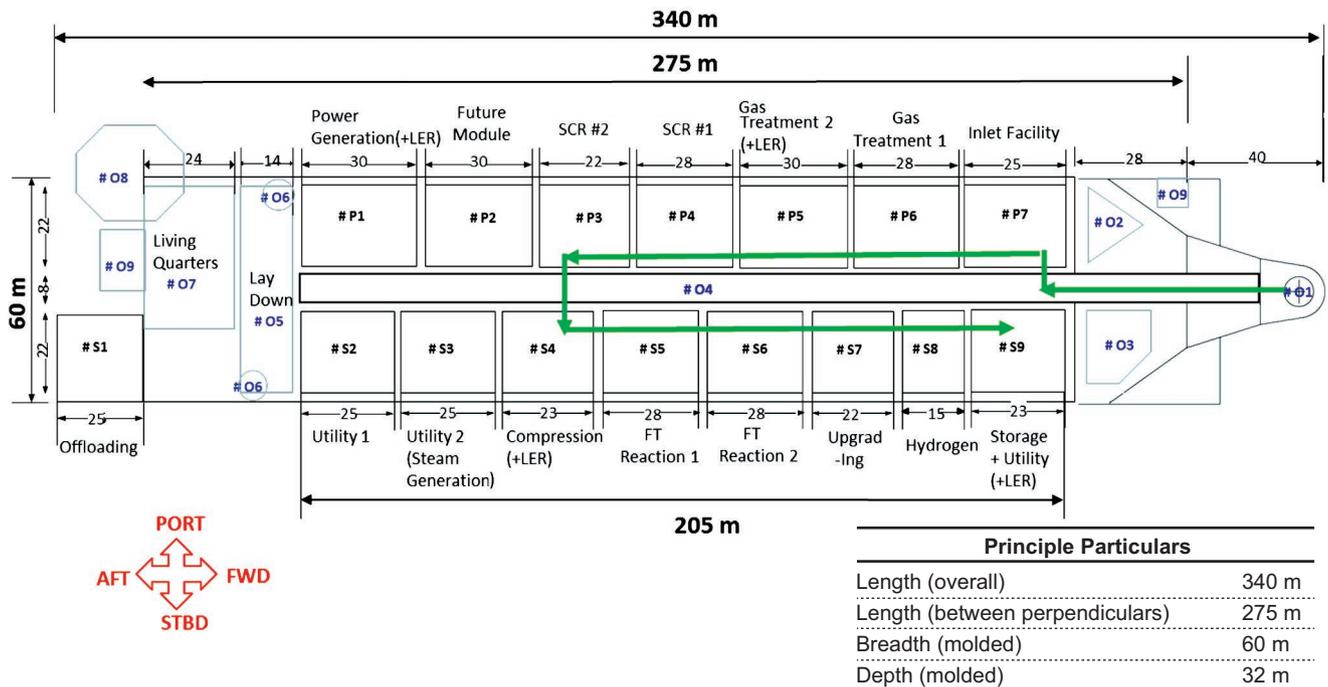


Fig. 9—Conceptual plot plan of the GTL-FPSO topside.

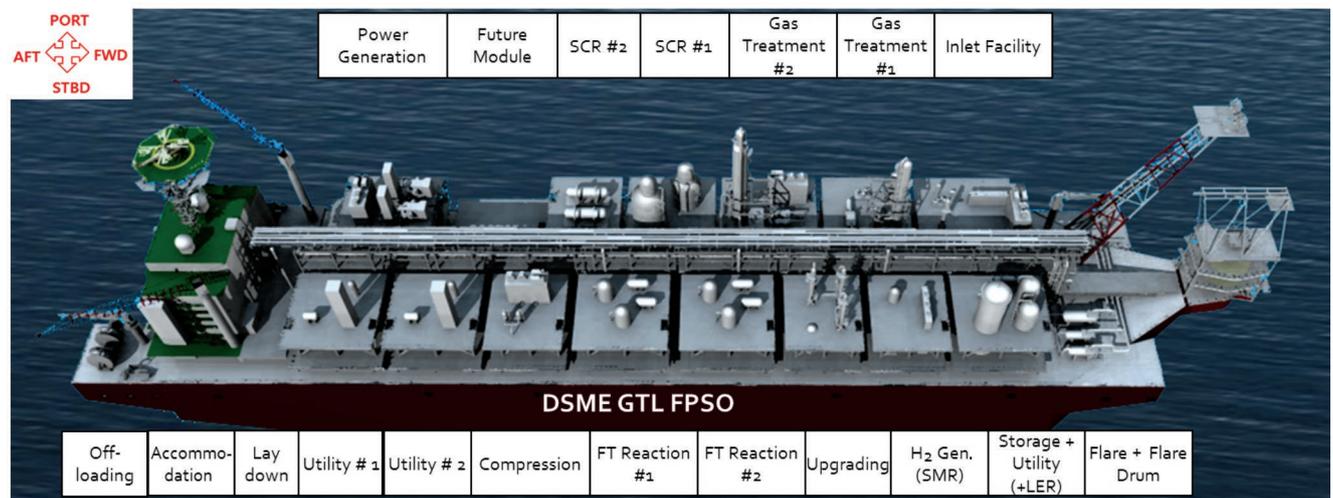


Fig. 10—3D image of the GTL-FPSO unit.

- Cooling-water unit—will exchange heat from a closed-loop freshwater cooling system that rejects heat to seawater.

Topside Process-Design Concept

Fig. 8 shows a simplified block diagram of the envisioned GTL-FPSO process that incorporates the technologies selected in the preceding sections.

Table 3 shows the preliminary mass balance corresponding to the block diagram. The following assumptions were made in the mass balance:

- The percentage of CO₂ in the raw feed gas was assumed to be 25%. This high CO₂ content is prevalent in the offshore gas fields that this project is targeting, such as those in Southeast Asia and northwest Australia.
- The liquefied petroleum gas (C₂–C₄) from the upgrading section can be used primarily in the fuel-gas system.
- The hydrogen required to stabilize products in the upgrading section is supplied by an SMR requiring approximately 6 t/h of pretreated natural gas.

- The overhead from the SPR will consist of unreacted syngas, C₂–C₃, and some lighter FT-product species. The heavy-ends recovery unit will recover the FT species (to be combined with the SPR reactor underflow), and the unreacted syngas will be recycled to the reforming section or SPR feed, while the C₂–C₃ material will be used as fuel gas.

On the basis of this preliminary block diagram and mass balance, a conceptual plot plan of the topside was arranged, as shown in Fig. 9. The topside area requirement of 340 m in length and 60 m in breadth is similar to the recently built oil FPSO units, such as that for Pazflor (325-m length×61-m breadth) and that for Agbami (320-m length×59-m breadth). The requirement of the storage facility in the hull will be similar to that of the oil FPSO units. The total storage capacity is estimated to be 240 000 m³, consisting of approximately 80 000 m³ of naphtha and 160 000 m³ of GTL syncrude.

Fig. 10 shows preliminary 3D images of this layout. This layout resembles that of the DME-FPSO project that was recently completed by DSME at the prefront-end engineering-design level. (The DME-FPSO unit was a collaborative effort between KOGAS and

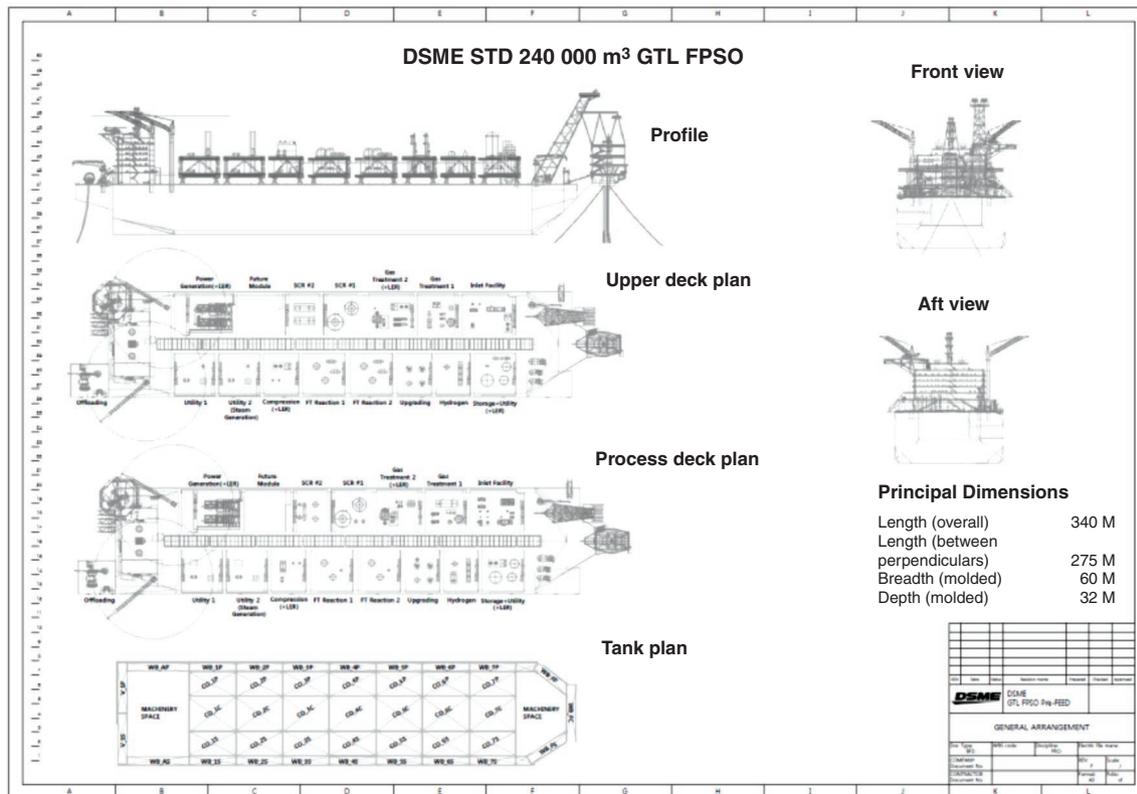


Fig. 11—Preliminary general arrangement.

	Naphtha	Syncrude
Production rate	6,000 B/D	14,000 B/D
Cargo-storage capacity	500,000 bbl (80 000 m ³)	1,000,000 bbl (160 000 m ³)
Required production time for full storage	83 days	71 days
Export parcel	49,000 DWT (448,000 bbl)	115,500 DWT (804,000 bbl)
Production time for export parcel	75 days	57 days
Spare-production capacity	9 days	14 days
FPSO-unit total-storage capacity	1,500,000 bbl (240 000 m ³)	

DSME. The topside process engineering was completed by the RES Group in December 2012.) DME is an additional potential option to monetize stranded gas fields offshore. The process units for DME share many similarities to those in the GTL plant, especially in the gas-treatment and reforming sections.

Hull-Design Concept

FPSO-Hull Principal Dimensions. This section describes the principal dimensions of the hull section of the GTL FPSO. The preliminary estimated topside layout resulted in a requirement (module) size of 7800 m² and a cargo-storage capacity of 1.5 million bbl. The main hull dimensions are:

- Length overall: 340 m
- Length between perpendiculars: 275 m
- Breadth (molded): 60 m
- Depth (molded): 32 m

Fig. 11 shows the preliminary general arrangement of the GTL-FPSO unit. The dimensions shown in the figure are 340-m length×60-m breadth×32-m depth. After deducting the pipe rack, the intramodule clearance requirements—lay down,

accommodation—for the space available for topside process equipment is approximately 45% of the area calculated from the FPSO-unit beam and length.

Cargo-Storage Concept and Shuttle Tanker. Given the limited topside area available on the FPSO, the product-upgrading section will contain only the process equipment needed to stabilize the products from the FT reactor for storage onboard and shipment to a shore-based plant for further processing. The storage requirements of the stabilized products are as follows:

- Total storage capacity: 240 000 m³ (=1,500,000 bbl)
- Naphtha: 80 000 m³ (=50,000 bbl)
- Syncrude: 160 000 m³(=1,000,000 bbl)

The shuttle tankers for the GTL-FPSO unit are described in Table 4. The capacity and schedule of the shuttle tankers will need to be consistent with the FPSO onboard storage capacity (in both volume and days of production) and allow for possible delays in the shuttle schedule caused by bad weather or other issues. Shuttle tankers for naphtha and syncrude will be selected depending on the

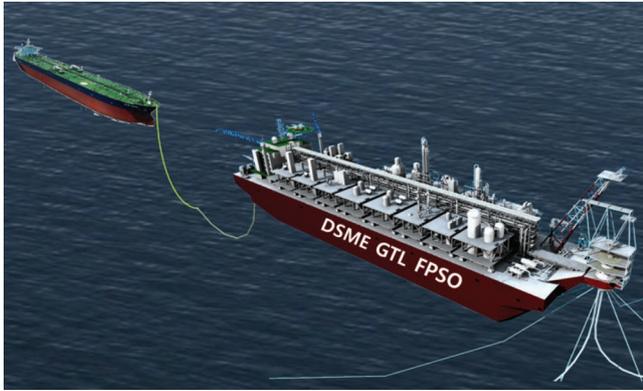


Fig. 12—Tandem offloading concept.

size of the export parcel. Aframax-sized conventional oil tankers [115,500 dry-weight tonnage (DWT)] with heating oil are suitable as shuttle carriers for the syncrude, and conventional product tankers (49,000 DWT) are suitable for the naphtha.

Turret and Mooring. Mooring is a vitally important system for seakeeping of the FPSO unit in variable weather conditions. The turret-and-riser mooring system shall be designed to withstand extremes of wave and wind, while taking into consideration the cost and installation period.

The external turret is preferred to the internal turret as a base case for the GTL-FPSO unit. The external turret is preferred in more moderate environmental conditions such as those targeted in this project (northwest Australia and Southeast Asia). See **Table 5**. In addition, the external turret is lower in cost and has a shorter construction period compared with the internal turret. However, the internal turret will be kept as an alternative option.

Offloading. **Fig. 12** shows the concept of the tandem offloading system envisioned for the GTL-FPSO unit. The tandem offloading system is an effective means of offloading naphtha and syncrude stored in the hull to shuttle tankers. The fea-

tures of tandem offloading for GTL-FPSO application are as follows:

- Tandem offloading with heating coil to tankers (approximately 50 to 80°C).
- Offloading time of approximately 26 hours (including ramp up, steady offloading, and ramp down).
- Major components include the hose system, mooring hawser system, and electrohydraulic control system.

Preliminary Economic Analysis

Fig. 13 shows the cases for the product marketing considered in this project. The cases differ by the extent of upgrading. The base case represents the simplest upgrading required to stabilize the FT liquid products for storage and shipping. The alternative case represents full upgrading, during which the wax from the FT reactor is fully converted to middle distillates and naphtha. Given the preliminary stage of the project, economic analysis is reported for the base case only. The alternative case(s) will be examined in a future study.

An economic model based on annual cash-flow analysis for the total duration of the project (start of basic engineering to the end of production after 25 years of service) was performed to understand the project economics and to identify dominant economic factors and their sensitivity. **Fig. 14** shows the sensitivity of crude oil, topside total installed cost (TIC), TIC, feed-gas price for GTL process and utilities, and product shipping costs on the internal rate of return (IRR). The ranges of these cost factors are chosen to cover the foreseeable cost scenarios. The crude-oil price is the most dominant cost factor in the project economics because the GTL-product price follows the crude-oil price closely. An increase of USD 10/bbl in crude price translates to an approximately 2.5% increase in the IRR. The feed-gas price, topside TIC, and the TIC have a moderate impact on the project economics.

In the next stage of the project, these major cost factors will be estimated more accurately on the basis of the conceptual design information, a better understanding of the potential gasfield source, and an updated projection on the crude-oil price in the lifespan of the project.

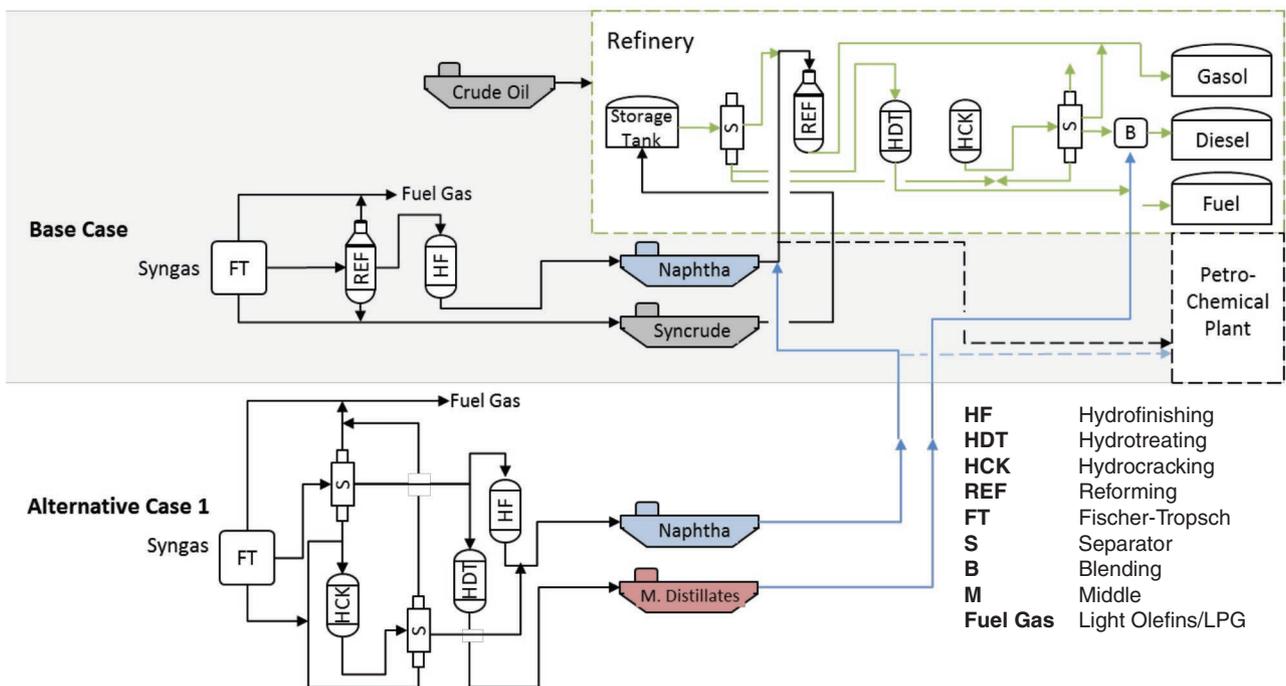


Fig. 13—Potential market scenarios considered in the GTL-FPSO project.

TABLE 5—FEATURES OF CONVENTIONAL EXTERNAL-TURRET MOORING AND INTERNAL-TURRET SYSTEM

	External-Turret Mooring	Internal-Turret Mooring
Type	Permanent and disconnectable type	
Environments	Mild to moderate	Moderate to harsh
Example	Africa, Southeast Asia, Middle East, South Pacific	Brazil, North Sea, North Atlantic, South China Sea, Gulf of Mexico
Number of risers	Small	Large
Water depth	Shallow to moderate water depth	Moderate to deep water
Figure		

Summary

- The GTL-FPSO design concept has been completed to produce a capacity of 20,000 B/D of GTL products (73% syncrude and 27% naphtha). The design requires the topside to be 340 m in length and 60 m in breadth, with a storage capacity totaling 240 000 m³ (80 000 and 160 000 m³ for naphtha and syncrude storage, respectively).
- The concept of shuttle tankers takes into account the FPSO-vessel cargo-storage capacity and the spare time needed to allow for possible tanker delay and bad weather. Aframax-sized conventional oil tankers (115,500 DWT) with heating oil are suitable as shuttle carriers for the syncrude, and conventional product tankers (49,000 DWT) are suitable shuttle carriers for the naphtha.
- The external turret was selected as a mooring system for the envisioned GTL-FPSO unit. The tandem offloading system is an effective means of offloading naphtha and syncrude from GTL-FPSO unit to shuttle tankers.
- The DPT compact reformer was selected as the best-suited technology for this GTL-FPSO unit. This technology meets all major requirements, including the capability to produce the required H₂/CO ratio of 2.0, the ability to tolerate feed gas with high CO₂ content, and the elimination of pure-oxygen use to alleviate a major safety concern. Although not in commercial operation, several years of successful testing at the demonstration scale provide confidence in the reliability required for commercial operation.
- SPR was selected as the FT reactor in this GTL-FPSO application because of its favorable size and weight, as well as its easier onboard catalyst-handling ability.
- The product upgrading, hydrogen-production, power-plant, and heavy-ends-recovery units do not present technological challenges or have been handled in previous oil-FPSO-unit designs.
- The FT-GTL process produces a large volume of water that is contaminated with water-soluble oxygenated hydrocarbons (alcohols, ketones, aldehydes, and carboxylic acids). These are different from the water-immiscible hydrocarbons typically encountered in conventional oil processing. For a land-based GTL process, the oxygenated hydrocarbons are removed with conventional industrial-wastewater-treatment technologies that have a very large footprint and liquid-holdup volumes.
- Because the traditional wastewater-treatment approach used on land will not be feasible for a GTL-FPSO process, the DSME GTL-FPSO conceptual-design project is examining an alternative approach that will directly recycle all of the FT reaction water and almost all of the oxygenated organic hydrocarbons back into the process, leaving only a small purge

stream containing primarily water and carboxylic acids that will require treatment before discharge. This approach is expected to require a much smaller footprint than the traditional wastewater-treatment-plant technologies, require no significant holdup volume, and will reduce the makeup flow required from the desalination unit substantially.

- On the basis of the preliminary economic analysis, the IRR of this project is within the economically competitive range. As expected, the crude-oil price was found to be the most dominant cost factor in the project economics given that the GTL product price closely follows the crude-oil price. An increase of USD 10/bbl in crude price translates to an approximately 2.5% increase in the IRR. The feed-gas price, topside TIC, and TIC have a moderate impact on the project economics. The economic feasibility will be updated in the next stage of the project, with a more accurate estimation of the cost factors, a better understanding of the potential gasfield source, and an updated projection on the crude-oil price in the lifespan of the project.

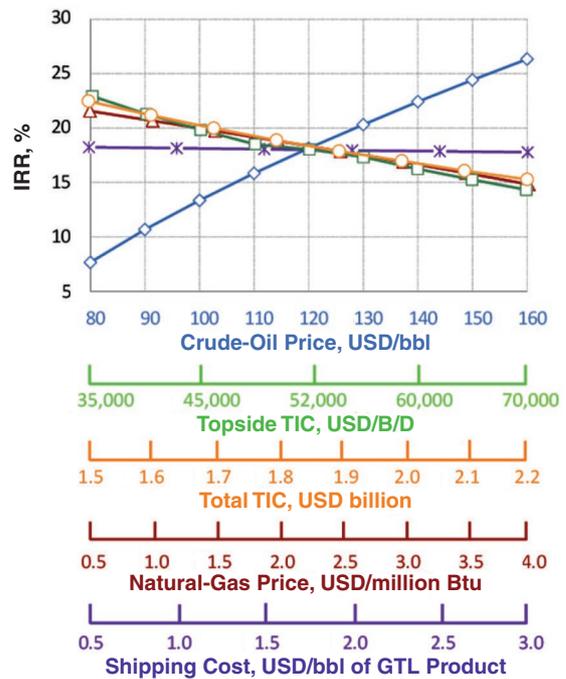


Fig.14—Sensitivity analysis of major cost factors in the GTL-FPSO project.

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