The Deepwater Gas route to India

1. Abstract

High pressure trunk lines have proved to be the safest and cheapest way of transporting gas to market for short to medium distances up to 2,500 kilometers, making the proposed SAGE Middle East to India Deepwater Pipeline the optimal solution for gas delivery to the Indian Subcontinent. Linking the Middle East gas fields with India across the Arabian Sea for an offshore distance of 1300 kilometers, the SAGE gas transmission pipeline is designed to transport up to 1.1BSCFD gas into the Indian energy markets.

This paper will present details of recent studies that have enhanced the technical and commercial feasibility of the SAGE system, which will reach a record water depth of 3400m, cross two continental slopes, an earthquake subduction zone (deepsea trench) and outfall debris of the river Indus fan.

The economic and socio-political drivers for such a project will be presented together with future schedule for First Gas. The current design status will be reviewed and the challenges faced by the project from both a design and installation perspective will be presented. As a project that builds from the Oman-India project of the 1990's, the changes in risk profile, in terms of industry and vessel readiness, will be reviewed and the status of the next generation of installation vessels to install such a pipeline will be presented.

2. Introduction

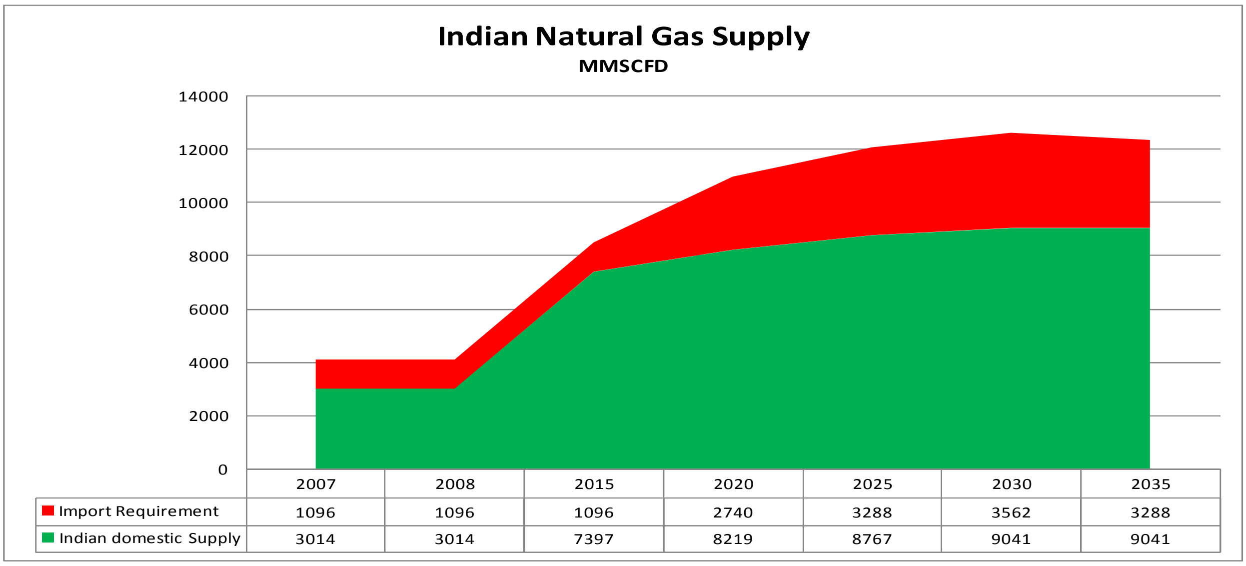
South Asia Gas Enterprise Pvt Ltd (SAGE), a joint venture between the Indian Siddhomal group and UK based deepwater technology companies, is actively considering building a deepwater, transnational, natural gas pipeline system from the Middle East to India. Over 2,000 TCF of natural gas reserves are held by countries with which India has a traditional trading relationship, including Qatar, Iran and Turkmenistan. The deepwater route across the Arabian Sea is the shortest secure distance between these huge reserves and the rapidly developing industrial heartland of India in Gujarat, and is too short for LNG to be an economic transportation option. The current work builds on the extensive study of the deepwater route of the Oman to India Pipeline that was carried out in the early 1990's. The case for this route has been strengthened by recent development work undertaken by SAGE and by the major body of deepwater design and pipelay experience accumulated over the last decade. The pipeline is to be developed by a global consortium of design and construction contractors.

3. Project Overview

Peritus International Ltd has been retained by SAGE to act as overall project management and pipeline design consultants for the planned Middle East to India Deepwater Pipeline (MEIDP). The pipeline is anticipated to be the first of many in a corridor of pipelines that will form the final leg of a major energy supply route linking the Middle East with India. The MEIDP 610 mm ID pipeline has been sized to facilitate the delivery of 1.1 BSCFD of sales quality natural gas to India. The base case, originates in Oman at the Middle East

Compression Station (MECS) and terminates in India at the Gujarat Pipeline Receiving Terminal (GPRT). Crossing the Arabian Sea, the pipeline will reach water depths of around 3,400m and will be circa 1,300km in length. An Offshore Gas Compression Station (OGCS) may be placed some 300km from the Omani coast on top of the Qualhat Seamount (Murray Ridge) where the water depth reduces to about 400m.

Imported gas will play a major role in bridging the demand-supply gap in the Indian market. India already imports around 1.1BSCFD in the form of LNG to meet its current shortfall. Based on EIA reference case (ref 1) this shortfall is expected to rise dramatically by 2020, and continue rising through to 2030 when it will peak at 3.56BSCFD, Figure 1.



	2007	2008	2015	2020	2025	2030	2035
🟥 Import Requirement	1096	1096	1096	2740	3288	3562	3288
🟩 Indian domestic Supply	3014	3014	7397	8219	8767	9041	9041

Figure 1 Indian Natural Gas Supply (Ref 1)

This need for imported gas is recognized by earlier proposals to build land gas pipelines from Iran through Pakistan to India (IPI) or from Turkmenistan through Afghanistan and Pakistan to India (TAPI). The IPI pipeline, despite years of discussion, has not been implemented. The TAPI pipeline proposal continues to move forward slowly: an intergovernmental agreement on the pipeline was finally signed on 11 December 2010 (Ref.3) after 15 years of discussion. Security during construction and subsequent operation will however probably continue to cast a shadow over these overland routes. Supply of gas from the Middle East to India via the deep sea route by comparison is far less exposed to risk of interruption.

The possibility of having an alternative supply of natural gas into the Indian market will also add competition and remove the potential for upset that a single supply route overland could be subject to. The deep ocean route also provides the easiest option for expansion into a corridor of supply pipelines in the future. The potential regional gas sources of Middle Eastern gas and pipeline route scenarios are presented in Figure 2.

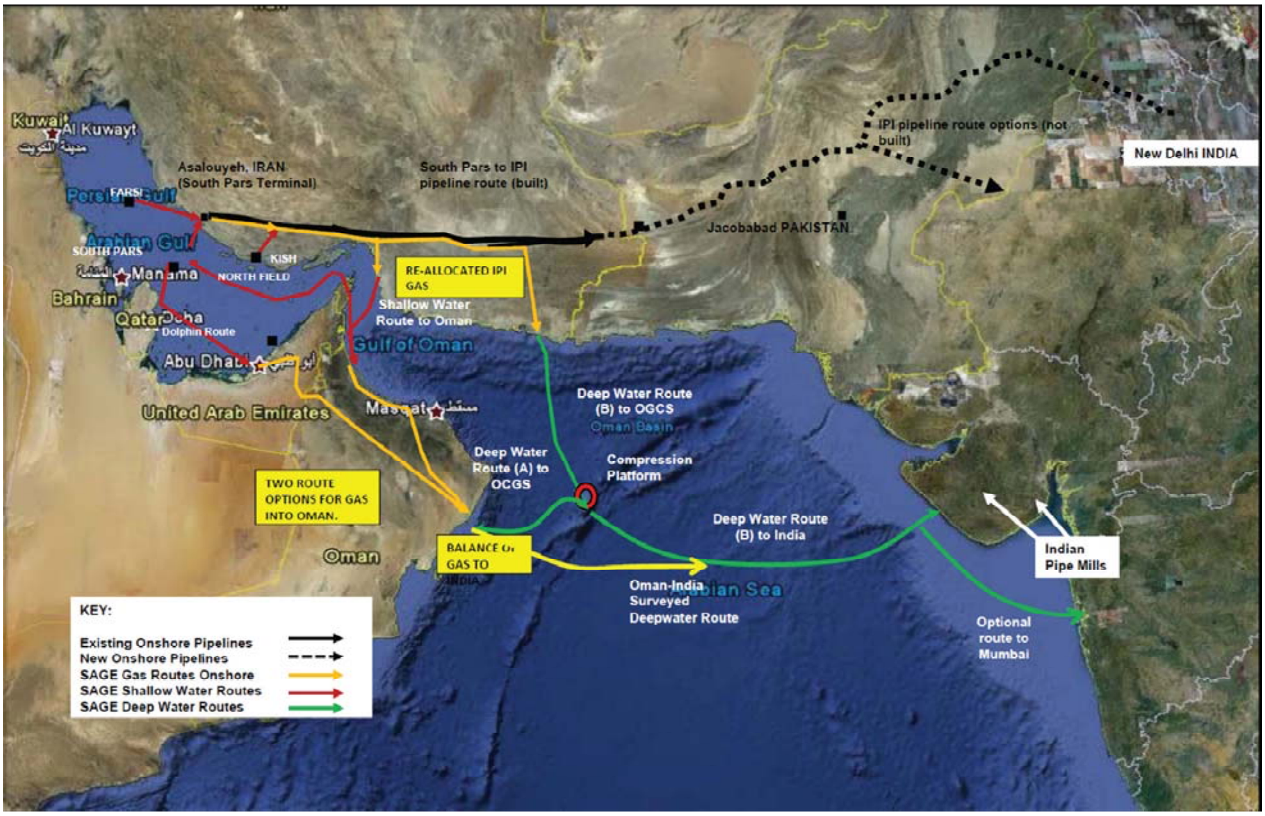


Figure 2 Potential regional gas sources and pipeline route scenarios

MOUs/Agreements to Co-operate with SAGE in developing MEIDP have been signed with:

- Indian Oil Corporation
- Oman Ministry of Oil and Gas
- GAIL
- NIGEC
- Peritus International Ltd.
- Engineers India Ltd.
- Saipem spa Milan
- Heerema Marine Contractors, Leiden.
- CORUS steel
- WELSPUN
- FUGRO GeoConsulting Ltd.
- INTECSEA (UK) Ltd.
- Det Norske Veritas

4. History

An offshore route to supply gas to India from the Middle East was first mooted in the mid 90’s when the Oman to India Pipeline project (OIP) investigated a deep sea route across the Arabian sea. In 2003 the deep sea route was again considered, this time from Iran to India, by a Joint venture between GAIL (India) and the NIOC.

The original Oman to India Pipeline project highlighted a number of technical challenges:

- No qualified deepwater pipeline repair system available
- Pipe mill upgrades would be required to manufacture the linepipe in the size needed and quality
- Lack of lay vessels with enough tension capability to lay pipes in 3,500 m water depth
- Incomplete understanding of seismic activities
- Lack of mitigation methods for mudflows, fault lines and slope failures
- Significant hydrotesting and drying concerns

The work carried out under OIP concluded that, these challenges were not insurmountable impediments by the industry. Three competitive pipelay bids were received and evaluated before the Omani-sourced gas was reassigned elsewhere.

The massive growth in the Indian economy and rising gas prices in the latter half of the last decade has reopened this supply route option across the Ariabian Sea. Supply of natural gas to India by pipeline across the short and geopolitically neutral direct offshore route is the obvious solution to India's energy demands. The OIP was held back 15 years ago mainly by concern over the depth of the Arabian Sea. The offshore oil and gas industry has moved on significantly since 1995 and numerous large diameter gas transmission pipelines such as Bluestream and Medgaz, have been installed in depths up to 2,200m and others such as Galsi are planned in circa 2,800m. An index of the difficulty of pipeline projects can be formulated by multiplying WD by diameter. The steady increase in difficulty expressed by this index is presented in Figure 3.

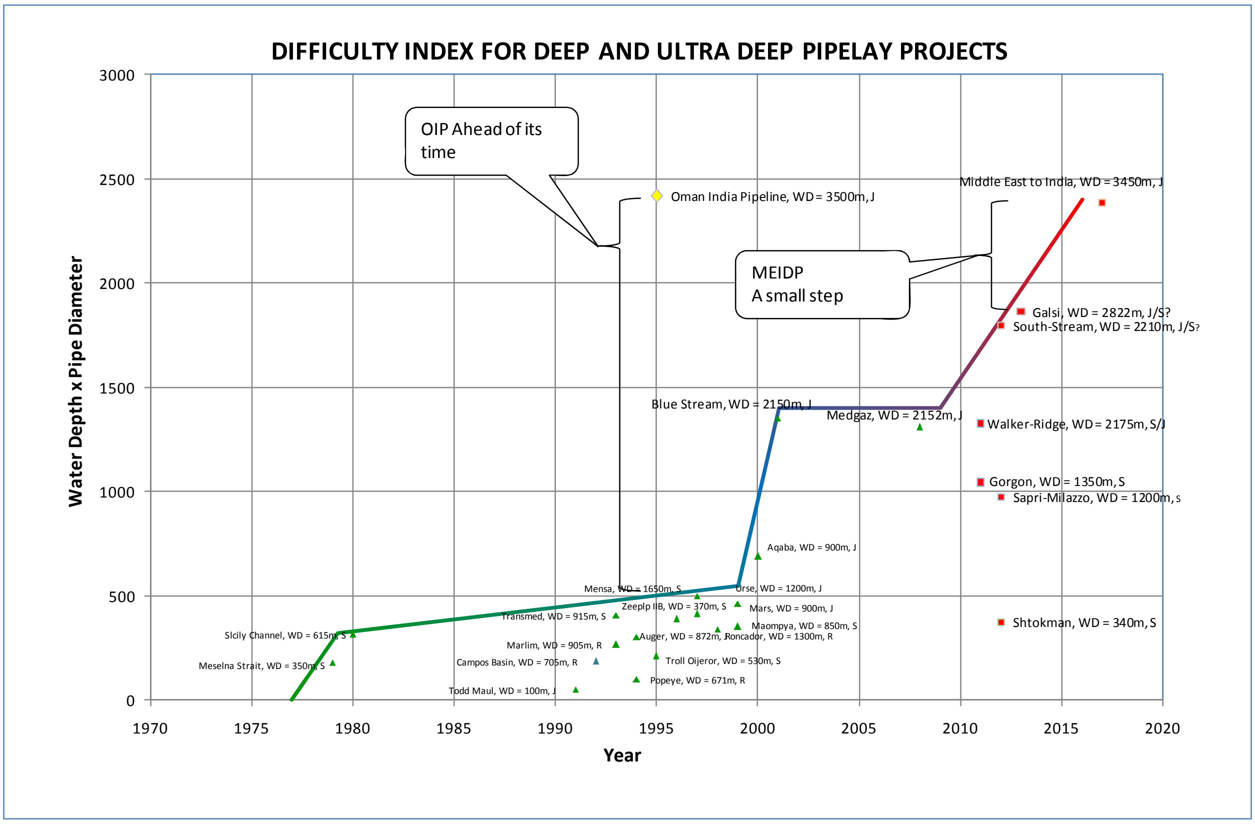


Figure 3 Difficulty Index for Ultra deep Pipelay Projects.

The advances in design tools, manufacturing facilities and installation vessels since 1995 means that SAGE's MEIDP has a substantially lower business risk profile, specifically:

- At least three new generation large lay vessels are being built that are potentially capable of installing pipelines in 3,500 m water depths. These include Saipem's CastorOne, which will be ready for work around the end of 2012 and has already been awarded work in the GOM on the Walker Ridge developments, Jack-St.Malo in 2,140m, 220km 24" pipeline, (Ref 2)
- Several mills (including India mills) can now manufacture pipe of sufficient size and quality to allow advanced design techniques to be adopted
- New and improved design/mitigation methods for free-spans and geohazards will allow larger spans to be accommodated and minimize the need for deepwater intervention
- Work class ROV systems are now rated at +4000m well beyond the need for MEIDP
- Rock dumping and seabed intervention vessels now currently rated for +2,000m water depths can be upgraded to 3,500m as and when the need arises
- Better survey and positioning capabilities during pipelay will accurately identify seabed hazards so that they may be avoided

- Deepwater repair systems have been developed and are available for deployment
- New testing and commissioning philosophies are being developed (SAGE with DNV) to permit the use of higher fabrication factors during design and to remove the need for hydrotesting

5. Progressing the MEIDP

Peritus international is performing project management services, pipeline systems design and supervising conceptual studies to move the project forward and take MEIDP into FEED in early 2012.

The project objective is to achieve first gas in 2017 to coincide with the forecast shortfall in India's natural gas needs. The project development schedule is:

- 2010-2011 Feasibility Studies
- 2011-2012 Reconnaisance Surveys
- 2012-2013 FEED Studies, Detailed Surveys
- 2013-2015 Detailed Design, Equipment Trials
- 2013-2015 Procurement of Long Lead Items
- 2015-2017 Installation

The execution schedule is shown below in Figure 4.

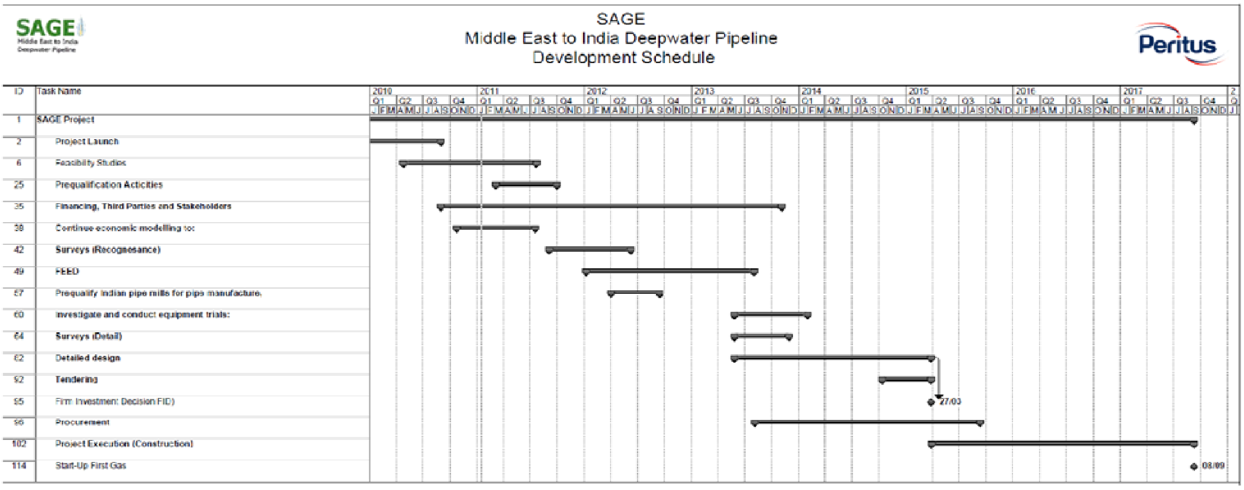


Figure 4 Project Development Schedule for 2017 first gas (Ref 10)

6. Feasibility and Development Studies

The program for the 2010 feasibility studies has concentrated on ensuring that a consistent design basis has been developed that can be used to guide all studies to confirm the MEIDP can be installed within an acceptable risk profile and that areas of uncertainty or gaps in understanding are acknowledged and a plan put in place to mitigate them. 2010 feasibility activities included:

- Design Basis definition
- Pipeline route definition
- Flow Assurance
- Mechanical Design

- Onshore Terminal Concept definition
- Offshore Compression Station definition
- Quantified Risk Assessment
- Geohazard, metocean and geotechnical desk study
- GIS Database development

6.1. Design Basis Memorandum

The Design Basis Memorandum (Ref **6** and Ref **7**) provides the outline framework for the preliminary development studies based on SAGE requirements and a review of available data. Two options exist for the transportation of gas through the MEIDP system:

- A single uniformly sized pipeline from the Oman coast near Ra's Al Jifan to the Indian coast at Gujarat
- A dual sized, single, pipeline from the Oman coast near Ra's Al Jifan to the Indian coast at Gujarat via a midline recompression station situated on the Murray ridge

The battery limits for these options are presented schematically in Figure 5. A number of options are examined. These options consider at varying amounts of offshore recompression with the resulting requirements for pipeline sizing and material/installation costs.

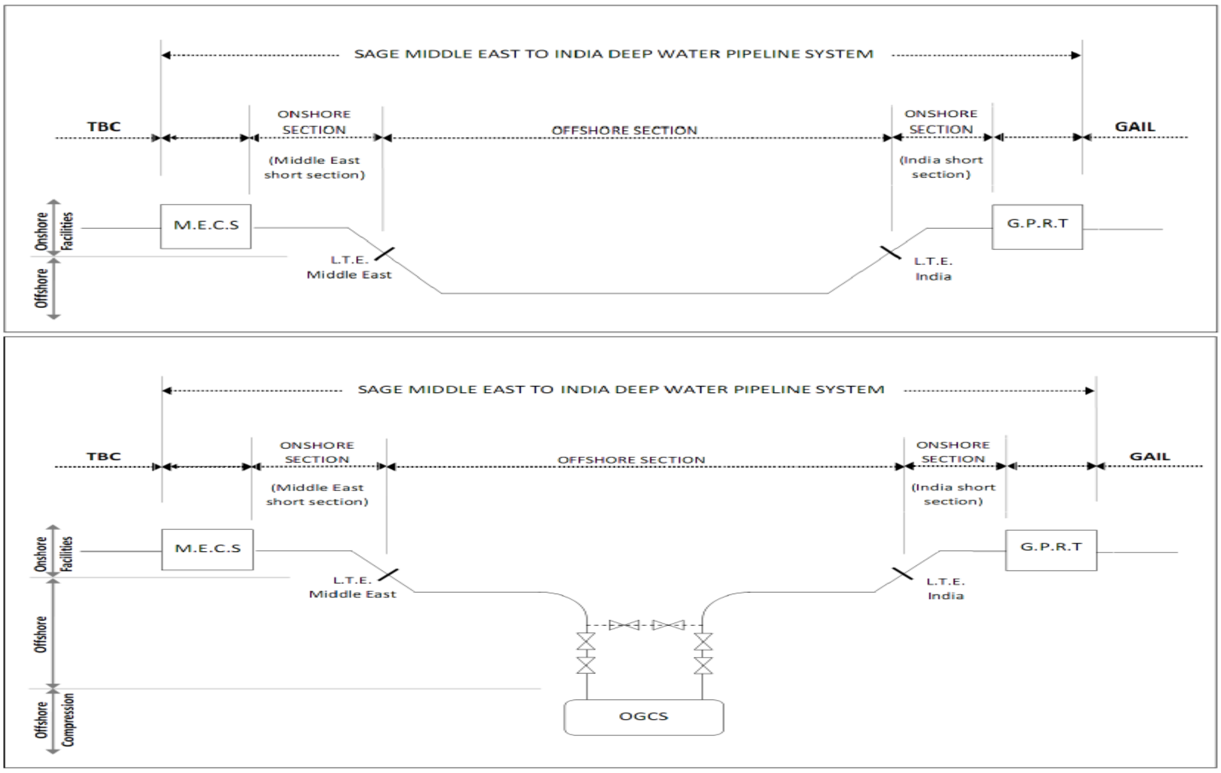


Figure 5 MEIDP Studies Battery Limits (Ref 6)

6.2. Pipeline Route

Based on satellite information, a number of route options have been considered. One option is shown in Figure 6. This route initiates at the Middle East Compression Station (MECS) near Ra's Al Jifan in Oman. The route crosses the Gulf of Oman and the Arabian Sea to terminate at the Gujarat Pipeline Receiving Terminal (GPRT) near Porbandar in India, a total distance of about 1,300km. Approximately 300km along the route is the Qualhat Seamount. This dramatic feature rises almost 3,000m from the seafloor to within 400m of the surface. An option exists to construct an Offshore Gas Compression Station (OGCS) on the Qualhat Seamount.

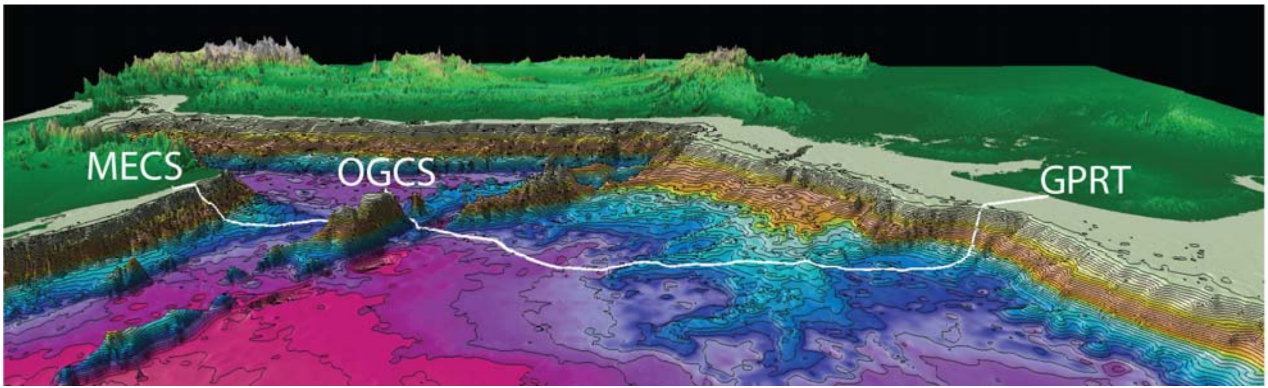


Figure 6. Pipeline route from MECS to GPRT via OGCS on Qualhat Seamount

This route crosses the gently sloping Oman Shelf and then descends the relatively steep and fractured Oman Slope to the Oman Abyssal Plain. The Oman Slope is characterized by a stepping topography caused by faulting and it is incised by deep erosive submarine canyons and channels with steep walls. The Oman Abyssal Plain is generally flat, smooth and featureless. After crossing the Oman Abyssal Plain, the route will ascends the north western slope of the Qualhat Seamount if the option to build the OGCS is selected. The route will either descend the Qualhat Seamount to the seafloor following broadly the same route as for the ascent or descend on a shorter route on the north eastern slope, Figure 7.

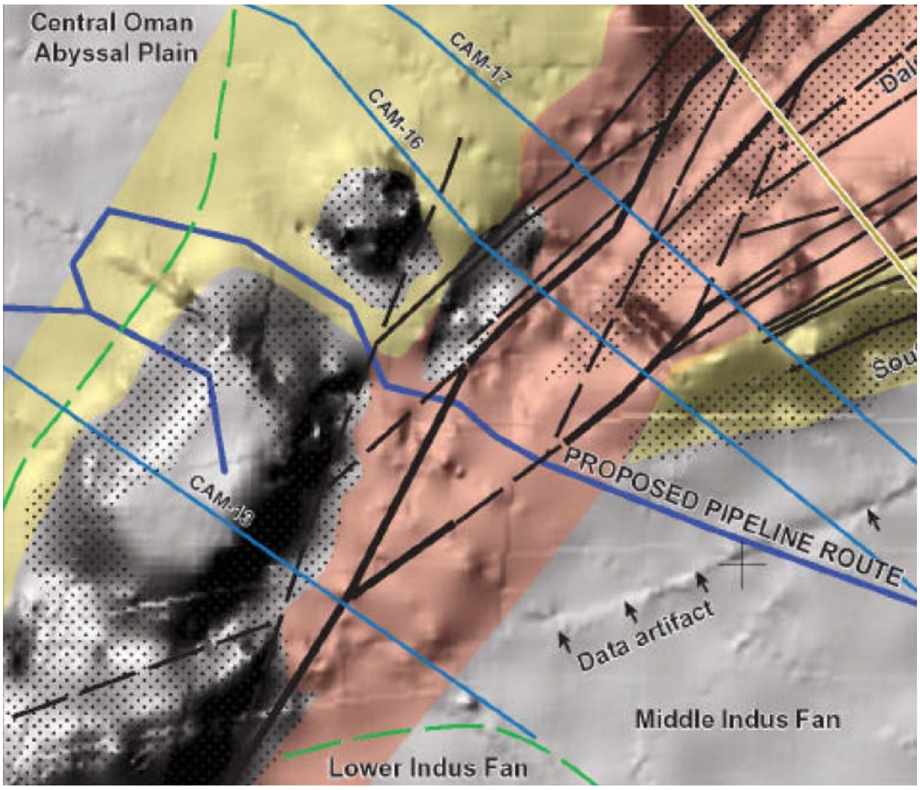


Figure 7. Pipeline routes for the Qualhat Seamount OGCS Option

On reaching the seafloor, the route turns and passes through a corridor between the Qualhat Seamount and a smaller seamount before crossing the tectonic plate boundary to enter the Arabian Abyssal Plain. The route through the Arabian Abyssal Plain is generally flat, smooth and featureless except where it encounters the meandering channels and levees of the Indus fan. Finally, the route will climb the relatively steep Indian Slope and cross the Indian Shelf to the GPRT. The profile for the pipeline route via the seamount is presented in Figure 8.

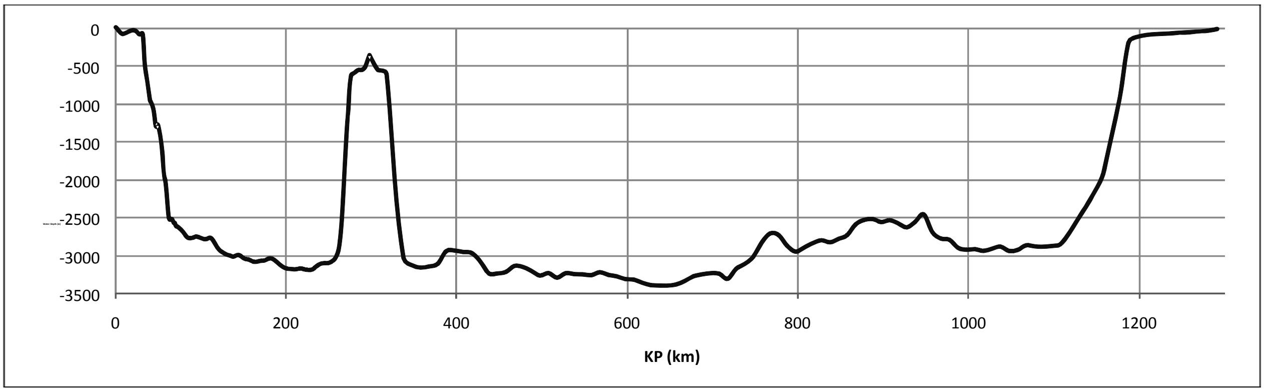


Figure 8. Pipeline profile from MECS to GPRT via OGCS on Qualhat Seamount

The route crosses 10 telecoms cables, all located in water depths in excess of 2000m. These crossings are detailed in Table 1

Table 1 Telecoms Cable Crossings along Pipeline Route

Crossing No.	Telecoms Cable Crossings
1	SALALAH-MUSCAT
2	SMW3 S.5.4
3	FLAG Segment H
4	SEA-ME-WE-4
5	MUSCAT-MUMBAI
6	UAE INDIA
7	MUSCAT-MUMBAI
8	MUSCAT-MUMBAI
9	UAE INDIA
10	SEA-ME-WE-4

6.3. Geological and Geohazard Route Assessment

A preliminary geological and geohazard route assessment of the proposed MEIDP pipeline between Oman and India has been performed by Fugro (Ref 4 and Ref 5) at a screening level. This assessment identifies expected hazards and forms part of the scoping work to define subsequent geophysical and geotechnical reconnaissance surveys. Identification and assessment of geohazards and engineering geological conditions is based on publically available data and previous Fugro experience.

Morphological analyses of the seafloor along the pipeline route are limited to one kilometre grid resolution of the digital elevation model available for the studies. A Morpho-Tectonic map has been prepared for the MEIDP route see Figure 9. Small seafloor features, such as fault scarps, small channels and pockmarks are not visible in the gridded bathymetric dataset. Larger hazards identified are presented in Table 2.

Table 2 Identified Risks along Pipeline Route

Geohazard	Location
Tsunami	Oman and Indian coastline
Steep slopes	Oman and Indian continental slopes and the Qualhat Seamount
Seismic activity	Northern Oman, Kathiawar Peninsula (Gujarat, India) and along the Owen Fracture Zone
Fault displacements	Faults of the Owen Fracture Zone and the Indian shelf and slope
Liquefaction	Oman and Indian (inner) shelf
Slope failures	Oman and Indian Continental slope, Qualhat Seamount, channels of the Indus Fan
Turbidity currents	Indus Fan

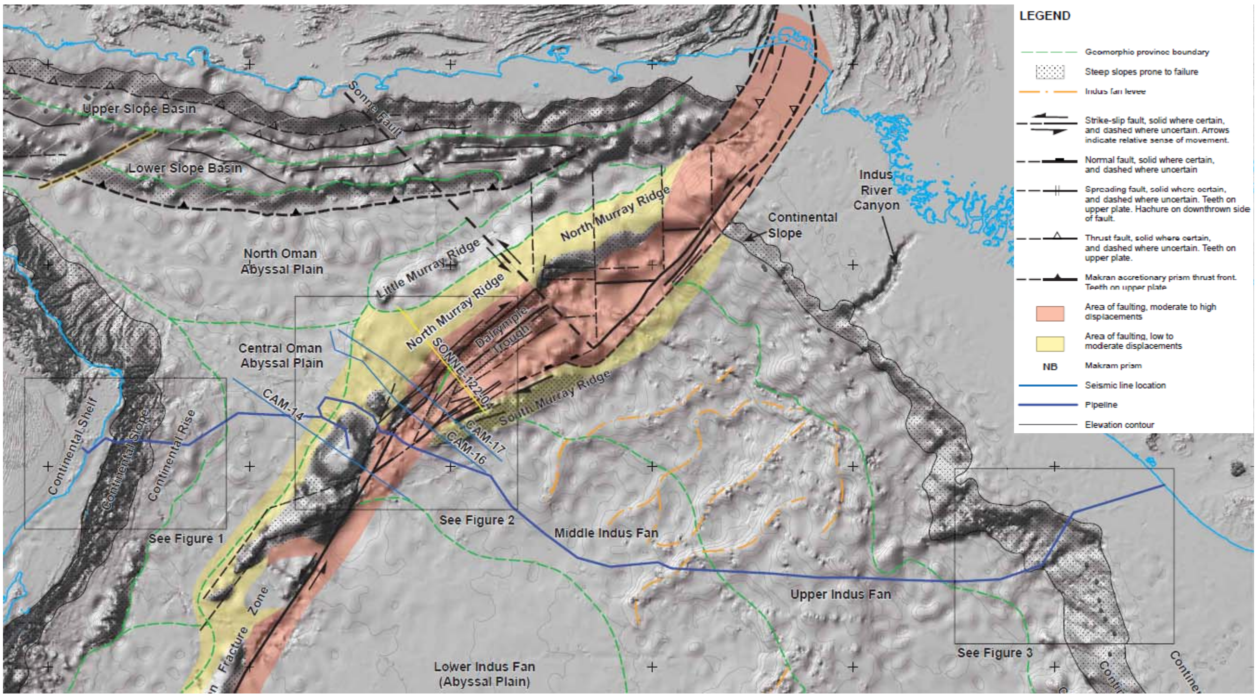


Figure 9 Morpho-Techtonic Map (Ref 14)

6.4. Metocean Data Definition

A metocean study has been performed by Fugro GEOS to determine environmental parameters for subsequent phases of the MEIDP to include:

- Wind and Wave data
- Surface and Seabed current data
- Water temperature data

Operational wind and wave statistics have been derived from the analysis of data taken from the Fugro GEOS WorldWaves database. The data for the study is based on a 0.5° grid at 6-hourly intervals for the period January 1997 to December 2006.

Current data were derived from the HYCOM, a global ocean current model developed as part of the U. S. Global Ocean Data Assimilation Experiment (GODAE) with an uplift factor of 2. The average spacing between grid points is approximately 7 km. Hindcast data were taken for 1 January 2004 to 15 September 2010.

Example plots of wave and current data during the 2 monsoon seasons (SW and NW) are presented in Figure 10 and Figure 11

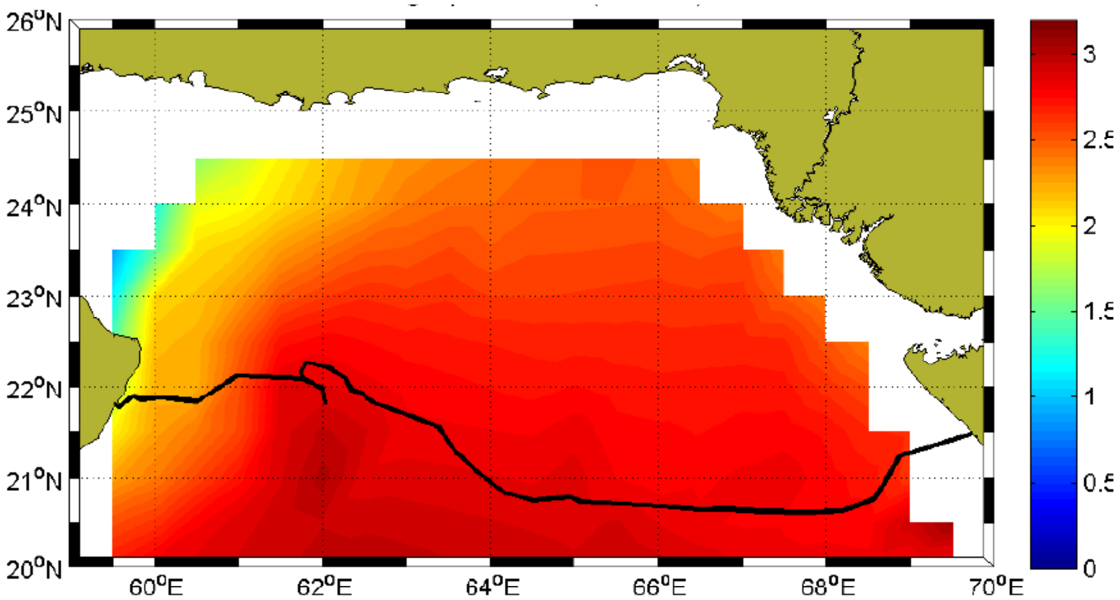


Figure 10 Mean Significant Wave Height, Hs (m) SW Monsoon (Ref 15)

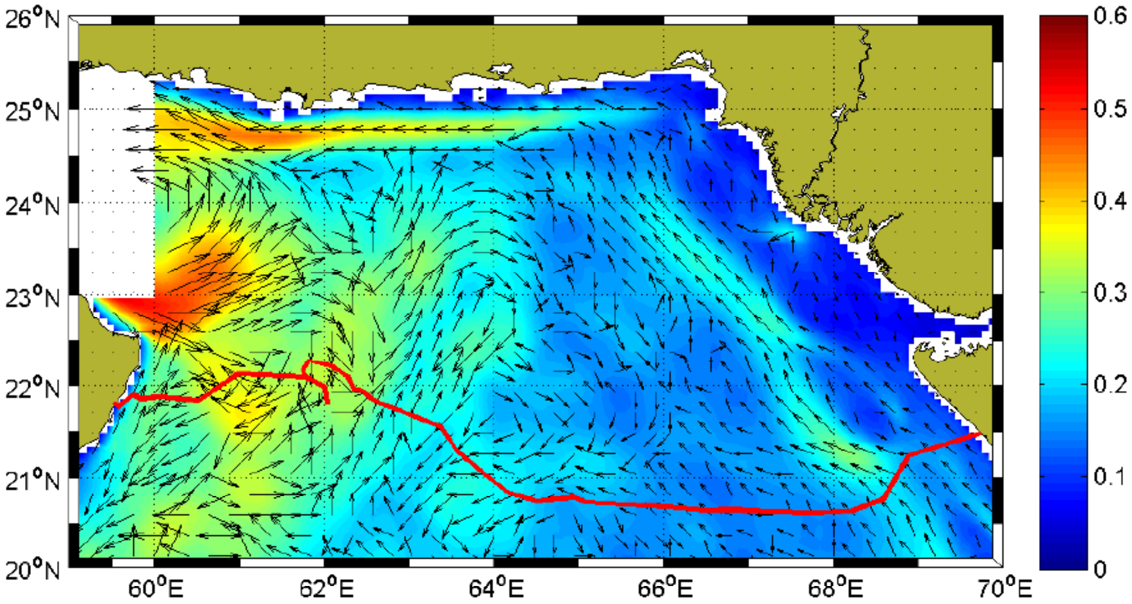


Figure 11Mean Surface Current Speed (m/s) NE Monsoon (Ref 15)

6.5. Flow Assurance Studies

The pipeline will carry sales quality dry natural gas. Initial steady state thermal hydraulic studies (Ref 8) have been carried out to confirm the pipeline sizes for the two export options.

Export Option 1 assumes an intermediate pressure boosting station (OGCS) to be located at 340m water depth above the Qualhat seamount approximately 300 km from Oman. Two arrival pressure conditions at the station have been considered i.e. LP arrival at 50 barg or HP arrival at 200 barg. The export pipeline from downstream of the OGCS to the receiving terminal at Gujarat (GPRT) assumes an available supply pressure of 400 barg and a final destination pressure of 50 barg.

Export Option 2 represents the direct transmission of gas from MECS to its final destination at GPRT without any intermediate pressure boosting i.e. in ‘free flow’ mode.

The selected pipeline sizes for an export (sizing case) flowrate of 1100 MMscfd or 31.1 MMSCMD are:

- 487 mm Pipe ID from MECS to OGCS (50 barg Arrival)
- 530 mm Pipe ID from MECS to OGCS (200 barg Arrival)
- 579 mm Pipe ID from OGCS to GPRT (50 barg Arrival)
- 610 mm Pipe ID from MECS to GPRT (50 barg Arrival)

Of the two OGCS arrival pressures considered, the 50 barg arrival pressure case is not feasible because the pipeline peak gas velocity arriving at the OGCS is excessive (28 m/s) and the greater gas expansion cooling accompanied by high velocity gas flow is predicted to generate unacceptably low arrival gas temperatures (between -9°C to -18C) at the OGCS. The 200 barg arrival pressure case is the preferred option for the following reasons:

- The velocities in the pipeline are considerably lower (6 m/s) and the gas arrival temperature at the offshore station is warmer (between 4°C to 7°C depending on the thickness of the anti-corrosion coating)
- With HP operation in the pipeline arrival at OGCS, the offshore compression train duty, utilities and power requirement and subsequently facility costs will be lower

In the event of an unplanned shutdown at the OGCS, the available capacity of the export pipeline (in free-flow operation) from CCS to GPRT via a 20” ID subsea bypass line at the OGCS is estimated to be 77% based on the selected pipeline sizes.

The direct export (free-flow) option from MECS to GPRT is also considered feasible from an operational standpoint as the normal operating velocity and temperature profiles in the pipeline are within acceptable limits.

There is no risk of condensed liquids in the export pipeline during normal operation for all export options considered based on a typical sales gas composition specification and water content used in the study. Based on an off-specification (‘rich’) gas composition assumed for this study, there is a potential for Hydrocarbon liquids condensation in the export pipeline.

6.6. Mechanical Design

Mechanical design studies determined wall thickness and material grade for the MEIDP for pipe sizes selected from the flow assurance studies, both with and without midline compression facilities. The pipeline will be fabricated from DSAW linepipe with a material of DNV 485 grade carbon steel (equivalent to API X70), fabricated to the requirements of DNV (Ref 18). The wall thickness design is performed in accordance with DNV-OS-F101.

In order to minimise the quantity of linepipe, wall thickness is based on Supplemental requirement U for improved quality control (QC). The DNV technical report (Ref 21) identifies a modest heat treatment during the pipe coating application can increase the fabrication factor for UOE from the default value of 0.85 to 1.0. This modified fabrication factor has been used. Specifically the following criteria are used:

- Supplementary requirement U material strength factor = 1.0
- Fabrication factor for UOE pipe (α_{fab}) = 1.0
- Ovality = 0.5%

Careful monitoring during the linepipe fabrication will be required to ensure the significant reduction in wall thickness can be realized.

Approximately 90% of pipeline route is situated in the deep water region between the CCS and GPRT. Within this section it is not economical to protect the pipeline from propagation buckling by increasing the wall thickness, therefore buckle arrestors will be required. A typical WT profile along the route is presented in Figure 12

The results show that the following wall thicknesses are suitable:

- MECS to GPRT, 610mm ID, WT - 30.2mm to 40.5mm depending on water depth, steel weight = 796,537tonnes
- MECS to OGCS, 530mm ID, WT – 28.7mm to 33.4mm depending on water depth, steel weight = 197,455tonnes
- OGCS to GPRT, 579mm ID, WT – 31.1mm to 38.4mm depending on water depth, steel weight = 537,803tonnes

The above identifies a potential saving of 61.3 thousand tonnes of steel, circa 8% if a midline compression station is adopted.

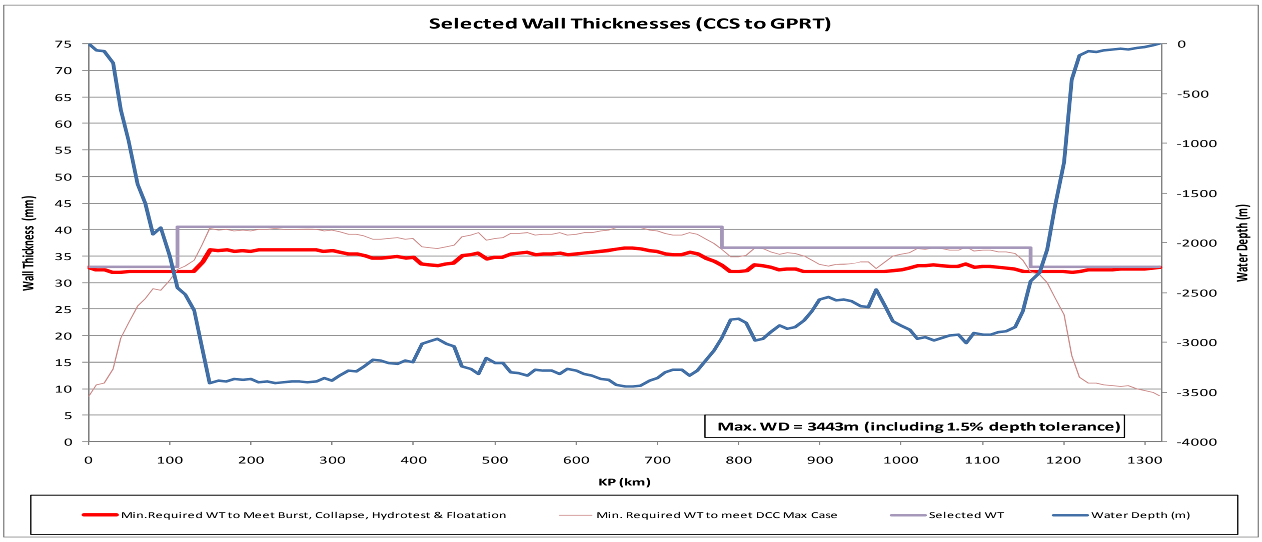


Figure 12 Wall Thickness Profile along MECS to GPRT Route (Ref 9)

6.7. Compression Facilities Studies

The pipeline transportation distance between the Middle East and India is such that intermediate gas compression between the source and the arrival point in India may be required or may provide a useful means of reducing pipe sizes and hence costs. Studies were undertaken by Intecsea and WorleyParsons and consider three building blocks for gas compression, one onshore and two offshore (Ref 12 and Ref 13).

The key objectives of the work were to perform Concept definition of the required Onshore (MECS) and Offshore (OGCS) Compression Facilities (two different compression scenarios were investigated) and develop suitable cost estimates. To achieve this, the following tasks were undertaken:

- Processing schemes for three compression station options (PFDs & Equipment Lists)
- Cost estimates to +40%/-30% accuracy for each option
- Weight estimates for all offshore options
- Block layouts for all processing plants
- High level plot plans / deck layouts
- Review and assess suitable platform support options for the Qualhat Seamount location

6.7.1. MECS Onshore Compression Facility Requirements

The onshore gas compression station comprises various process and utility units to carry out the gas compression process. The gas from the onshore pipeline is received in the Inlet Facilities, and routed further to the Gas Dehydration section. The dehydrated gas is further routed to the Gas Compression, for compression to the required pipeline delivery pressure. The compressed gas is then routed into the export pipeline. The total plant nominal capacity is 1,100 MMSCFD.

Two trains are considered for the gas compression unit, both identical and each capable of handling 50% of the plant throughput. Each compression train has two stages of compressors with a dedicated gas turbine for each compressor. In addition to the compressor turbines there will be gas turbines for generating power for the other electrical drives in the compression station. For each compression train, significant air coolers are required.

The findings of this study provide a basis for further investigation and optimisation in subsequent stages of project. There is scope for optimisation of the compressor train driver power in the context of train capacity, drive type selection and waste heat recovery from turbine exhausts.

6.7.2. OGCS Offshore Compression Facility Requirements

The OGCS study provides the conceptual evaluation of the facilities required for midline compression of the fluid stream.Two Offshore compression options are evaluated:

- OGCS capable of discharging 1,000 MMSCFD gas into the pipeline at 400 barg, with an inlet pressure set at 50
- OGCS capable of discharging 1,000 MMSCFD gas into the pipeline at 400 barg, with an inlet pressure set at 200 barg.

The studies concluded a single stage compression train required for the second option is suitable as the lower duty leads to lower power requirements and a reduced cooling medium system in conjunction with a smaller deck area. This results in a saving of circa £100 million. It is recognised that this lower duty option is likely to result in increased pipeline cost.

The total installed topsides weight for 350barg and 200barg offshore compression cases are 13,556 tonnes and 10,596 tonnes respectively.

6.7.3. OGCS Substructure Support Options

The most suitable Substructure candidate that fully satisfies all the technical drivers is a TLP. A semi-submersible platform is a potential candidate but requires suitable riser configuration to be developed. A fixed jacket, spar and compliant tower fail as these types of platform require offshore hull and topsides integration. Lastly a compliant tower is not satisfactory as this type of platform is unsuitable for the shallow water depth. Whilst a TLP sub-structure is considered the best technical fit for the OGCS, cost considerations and potential for future expansion mean that the jacket and semi-submersible platforms have not been excluded.

6.8. Quantitative Risk Assessment

The QRA performed by Peritus takes into consideration an earlier study prepared for the Oman-India Pipeline (OIP) in 1994. The major hazards, at the time, that cause loss of containment were identified by review of the 1994 risk report and on the basis of experience of conducting similar studies for other pipelines.

The following hazards have been quantified:

- Trawling
- Anchoring
- Objects dropped from ships
- Ship sinking
- Ship grounding
- Internal corrosion
- External corrosion
- Material and construction defects

It is not be possible to quantify the risks associated with geohazards until reconnaissance and detailed surveys are performed. These include: landslides; mass gravity flows; turbidity currents; fault movements. Although the above four hazards could not be quantified, a methodology for assessing them has been developed by Peritus. Several other hazards have been addressed qualitatively – spanning, third party construction hazards, sabotage and military action.

The failure (loss of containment) frequencies for the hazards that were capable of quantification have been calculated (Ref 11) and are compared against the failure frequencies from the earlier OIP QRA. The total failure frequency for MEIDP is calculated to be 0.08 per 50 years compared to 0.21 per 40 years in the earlier OIP QRA. The studies identified it is the shallow waters of the Oman Shelf and Indian Shelf that present the highest risk areas. However these risks are no more or less of a concern than those for any shallow water pipeline exposed to shipping and fishing activities and are arguably considerably less than some of the long large diameter trunklines installed in the North Sea.

The dominant hazards are ship related and occur mainly in the shallow Oman and Indian shelf areas. Since no shipping data are available, conservative assumptions have been made in order to determine the shipping-related risks, which comprise grounding, sinking, dropped objects and anchoring. When data on shipping is available, it is anticipated that the shipping-related risks will reduce. The grounding risk can be substantially mitigated (approximately halved) by burying the pipeline from the landfall out to a water depth of 44m.

The next most significant hazards are material/construction defects and external corrosion. The assessment of both of these hazards was based on generic industry failure frequencies with adjustment for the specific attributes of the MEIDP such as its unusually heavy wall thicknesses. The failure frequencies are not high when expressed per kilometre per year. The overall failure frequencies are noteworthy, simply due to the length and long design life of the MEIDP. The analysis suggests that failure frequencies for the hazards of material/construction defects and corrosion do not scale in simple proportion to the pipeline length. However, the nature of the size effect cannot be determined from the available pipeline failure databases which are usually based on much shorter pipelines. It is possible that structural reliability modeling could be used to determine the size effects and hence to allow a less conservative estimate of the failure frequencies.

The predicted internal corrosion failure frequency in dry sales quality natural gas in pipeline transmission systems is very low and it has been assumed that the pipeline will be inspected with an intelligent pig at intervals not exceeding 5 years.

No data are available on fishing, so the trawling risk assessment was performed using very conservative assumptions. Even so, the risk is found to be insignificant due to the heavy wall thicknesses of the MEIDP, and the presence of concrete in the shallow water sections.

The sabotage risk, was addressed only qualitatively, and can be mitigated by pipeline burial in the shore approaches and by surveillance. Burial to 70m water depth will prevent access to the pipeline by compressed air diving. Until the risks from seismic fault displacements have been addressed, it would be premature to make definitive recommendations on burial since buried pipelines are more vulnerable to fault movement.

7. Development Studies for 2011

The program for 2011 feasibility studies will ensure that the project is well positioned to move into a full FEED phase in 2012 by closing gaps in understanding and finalizing the project design constraints. The 2011 activities planned by SAGE include:

- Vessel & Equipment Capabilities Review
- Pipeline Intervention Review
- Riser and Subsea By-Pass Definition
- Establish No Hydrotest Principle
- Reconnaissance Survey Definition and Scope of Work
- Onshore Receiving Terminal Definition
- Offshore Facilities Optimization.

- Insurance Risk Review
- Define Survey ITT and Tender
- Environmental Statement
- Emergency Repair Equipment Review
- Examine the effect of moderate heat treatment and recovery of compressive strength.

Work in these areas is currently ongoing by Peritus and others.

7.1. Pipelay Vessel Capabilities

Several major deepwater pipelay contactors have new build highly capable deepwater installation vessels in construction. Saipem has the *CastorOne* currently under construction at Raffles, Yantai Yard, Shandong, China and due for delivery by end 2011, Allseas has the *Pieter Schelte* under construction at Daewoo Shipbuilding in Korea and due for delivery end 2013, HMC has the *Aegir* under construction at Daewoo Shipbuilding in Korea and due for delivery mid 2013. These vessels are scheduled for availability well before they are required for MEIDP. These vessels are identified as having pipelay capabilities in 3500m water depths. The ability to accommodate the heavy wall MEIDP 610mm ID x 40.4mm WT pipeline in 3400m water depth will need to be established.

Work currently being performed by Peritus indicates that a normal static lay tension (demand) of 1060tonnes will be required to install the pipeline through the deepest route section, based on maintaining a strain level below 0.12% in the sag bend. It is recommended that a factor of 1.5 (DAF=1.3 x SF=1.15, Ref 25) is applied to tension requirement when determining tension capacity of vessels to account for dynamics in the system. The nominal normal lay capacity of a suitable J-Lay vessel will therefore be circa 1600 tonnes. Once the true dynamics of the candidate lay vessels are established it is possible to increase the nominal limiting strain value >0.12% and thereby reduce the top tension demand. An overview of the normal lay tension demand, based on J-Lay installation with a limiting strain under static empty conditions of ε_L=0.12% is shown in Figure 13. For a survival flooded case it will be necessary for the installation vessel to be able to hold and abandon the pipeline with a top tension of at least 2000 tonnes. In the flooded case the tension demand is the minimum required to keep below the DCC limit.

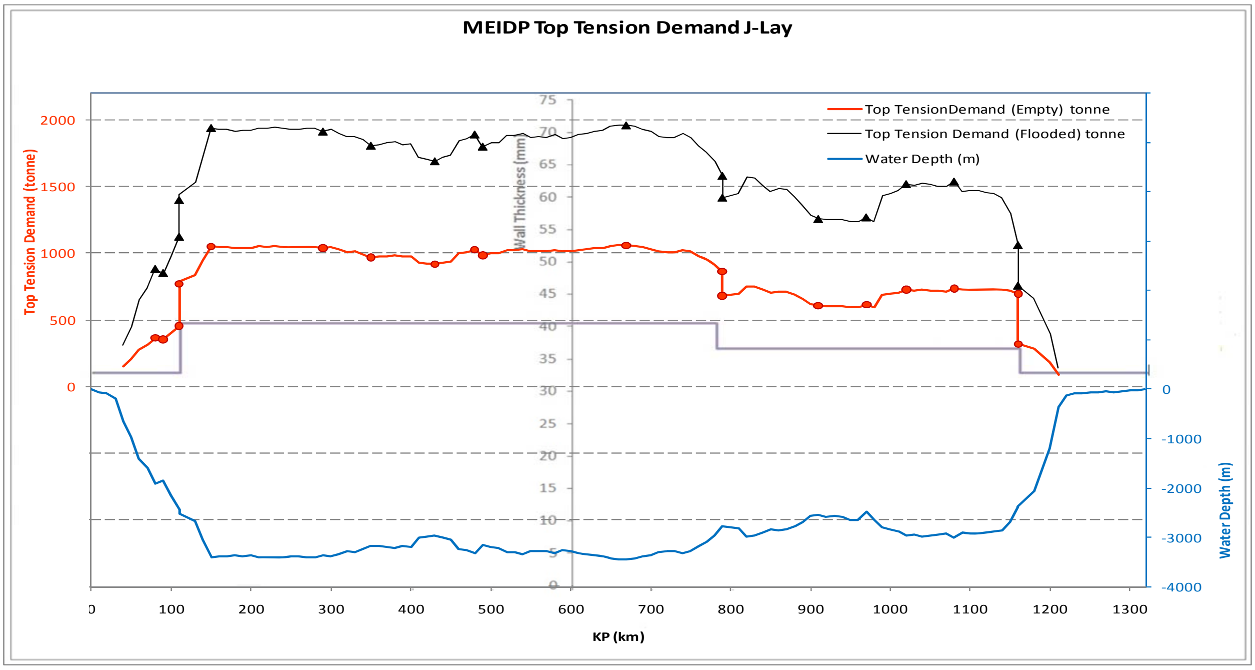


Figure 13 MEIDP Top Tension Demand J-Lay (Ref 11)

7.2. Intervention Vessels and Equipment Capabilities

It is anticipated that intervention will be required either pre-lay or post-lay in the following zones along the pipeline route:

1) Shallow Water Section (0 to 150m WD)
2) Oman and Indian Continental Slope Sections (150m to 2500m WD)
3) Deep Water Dalyrimple Trough/Owen Fracture zone Section (2500m to 3450m WD)
4) Qualhat Seamount Section (300m to 3000m WD)
5) Indus Fan Levees Section (2500m WD approximately)

Zones 2) to 5) are characterised by steep slopes and irregular seabeds where pipeline spanning and protection against geohazards such as debris and turbidity flows will need to be accommodated. Typically pre-lay and post lay intervention may take the forms detailed in Table 3. A review of new build and planned intervention vessels is underway, to determine suitability for use on MEIDP and highlight, where necessary, gaps in current vessel and equipment capabilities.

New build intervention vessels such as Tideway's *Flintstone* will be operational by mid 2011. Tideway have indicated that *Flintstone* (currently rated to 2,000m) is capable of being upgraded to be able to work up to 3,500m water depth. Jan De Nul's newly launched (2009) vessel, *Simon Stevin* is currently rated at 2,000m, Saipem's *Beluga*, mechanical trencher is currently rated to 2,250m water depth.

Table 3 Intervention Zonation (Ref.24)

Zone	Intervention Required For	PRE-lay Intervention						Post-lay Intervention				
		Dredging	Trenching	Rock Dumping	Mattresses	Mechanical intervention	VIV Strakes	Backfilling	Trenching	Rock Dumping	VIV Strakes	Pipeline Repair System
1	Stability at Landfall	X						X				
1	Pipeline Stability								X			
1,4	Thermal Buckling					X				X		
1	Ship Anchor Damage								X			
1,4	Fishing Gears Interaction								X			
1,2,3,4,5	Free Spans		X	X			X		X	X	X	
1,2,3,4,5	Pipe Leaks or Local Buckle											X
2,3,4,5	Geohazards		X						X			
2,3,4,5	Pressure Buckling					X				X		
2,3	Crossings			X	X	X						

A summary of intervention equipment capabilities is presented in Figure 14

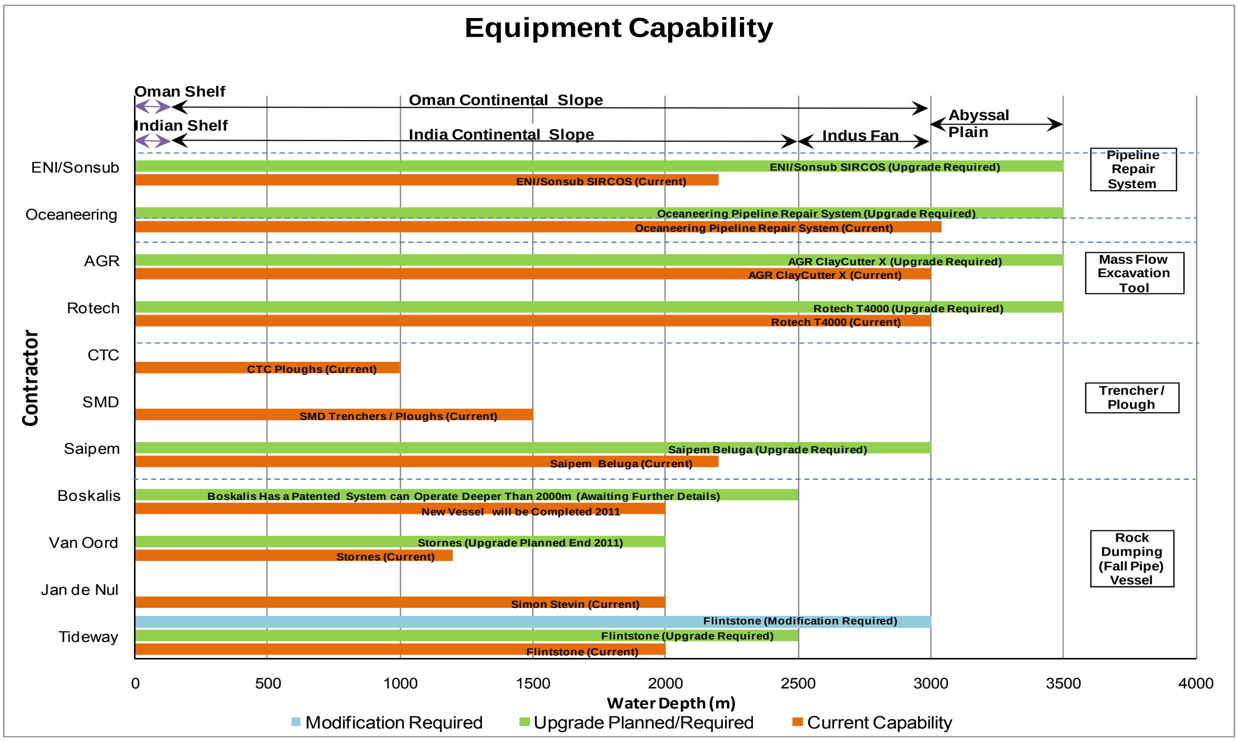


Figure 14 MEIDP Summary of Intervention Vessel & Equipment (Ref 24)

7.3. Alternative Integrity Verification (No Hydrotest)

Significant work has been performed in the industry to justify an alternative integrity verification (AIV) to the traditional hydrotest. Previous work including a JIP funded by the MMS Technology Assessment and Reasearch Program (Ref 17) concluded qualitatively that there is a case for not hydrotesting deepwater pipelines. Precedents for not hydrotesting are the Gulf of Aqaba (Red Sea 860m WD) 36" pipeline, the GulfTerra Phoenix Gas Gathering System (GOM 1615m WD), 36” pipeline. In addition, TransCanada has installed at least two land pipelines in Alberta, Canada in the period 2004-2006 without hydrotesting.

Subsequent phases of MEIDP will develop the case for AIV in association with DNV. Peritus is currently developing a program for the AIV activities to demonstrate that the same level of assurance of safety as a precommissioning hydrotest can be achieved.

7.4. Emergency Repair Equipment

Various emergency repair equipment systems exist. Examples include the SiRCoS system operated by Sonsub (Ref 16), currently rated to 2200m, but which can be upgraded to 3500m and the ROV’s that are required to operate this equipment are already available to 4000m rated water depth.

8. Summary and Conclusions

8.1. Technical summary

The progress into the water depths expected for MEIDP are no longer a giant leap forward, but rather the logical next step. The development of deepwater pipelay vessels capable of installing MEIDP and due for commissioning in 2013, mean that the industry will be ready with the necessary tools to take this step. Studies performed in 2009 and 2010 have proven that the feasibility of the MEIDP project to be designed in accordance with accepted deepwater codes such as DnV OS-F101 (Ref 18). Fabrication technologies exist to achieve pipe size/wall thickness combinations that are within current mill capacities. Preliminary routes have been established from Oman to India that give options for a midline compression station and avoid the worst features of the Indus Fan, minimising project technical risks. Subsequent phases of the project will utilize the latest multibeam survey equipment mounted on AUVs to allow very accurate definition of seabed features and obstructions. In-depth ‘baseline’ studies and proven environmental principles will be adopted to ensure environment-friendly project implementation.

8.2. Economic and commercial summary

The MEIDP pipeline provides the most economic method of gas supply to the Western coast of India and enhances the security of energy supply for Indian subcontinent. Unlike the current onshore projects such as TAPI pipeline (Turkmenistan Afghanistan Pakistan India) and the IPI pipeline (Iran Pakistan India), MEIDP provides a safe and economic route and promotes competition in the Indian energy markets. The MEIDP project will ensure minimum transport costs for the proposed new route of gas supply to the Indian Subcontinent. In addition, the MEIDP project will contribute significantly towards the implementation of sustainable development strategies of an integrated energy plan for the Indian Subcontinent.

Nomenclature & Abbreviations

AIV	*Alternative Integrity Verification*
AUV	*Autonomous Underwater Vehicle*
BSCFD	*Billion Standard Cubic Feet per Day* (10^9)
DCC	*Displacement Controlled Criteria*
DNV	*Det norske Veritas*
DSAW	*Double Submerged Arc Welded*
EIA	*Energy Information Agency*
FEED	*Front End Engineering Design*
GIS	*Geographical information systems*
GODAE	*Global Ocean Data Assimilation Experiment*
GOM	*Gulf of Mexico*
GPRT	*Gujurat Pipeline Receiving Terminal*
HMC	*Heerema Marine Contractors*
HYCOM	*Hybrid Coordinate Ocean Model*
ID	*Internal Diameter*
IPI	*Iran-Pakistan-India*
ITT	*Invitation to Tender*
JIP	*Joint Industry Project*
LNG	*Liquified Natural Gas*
MECS	*Middle East Compression Station*
MEIDP	*Middle East to India Deepwater Pipeline*
MMS	*Materials Management Service*
MMSCFD	*Million Standard Cubic Feet per Day* (10^6)
NIOC	*National Iranian Oil company*
NW	*Northwest*
OGCS	*Offshore Gas Compression Station*
OIP	*Oman India Pipeline*
PFD	*Process Flow Diagram*
QRA	*Quantified Risk Assessment*
ROV	*Remotely Operated Vehicle*
SAGE	*South Asia Gas Enterprise*
SiRCoS	*Sistema di Riparazione per Condotte Sottomarine (Subsea Pipelines Repair System)*
SW	*Southwest*
TAPI	*Turkmenistan-Afganistan-Pakistan-India*
TCF	*Trillion Cubic Feet* (10^{12})
TEG	*Triethylene Glycol*
TLP	*Tension Leg Platform*
WD	*Water Depth*
WT	*Wall Thickness*
α_{fab}	*Fabrication factor for UOE pipe*
ε_L	*Longitudinal Strain*

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