3 ALTERNATIVES

3.1 Introduction

This section summarises the process undertaken during pre-front-end engineering design (design process before FEED) and FEED to evaluate the technically and financially feasible alternatives for the Tilenga feeder pipeline while taking into account environmental and social impacts. The alternatives have been broadly categorised as follows:

- project zero alternative
- pipeline routing
- facility siting
- technology
- construction techniques.

3.2 Overview

The project alternatives considered and the decisions taken during the pre-FEED and FEED phases have led to the validation of the project base case as it is described in Section 2 Project Description. The objective of this section is to document how the pipeline design was optimised to reduce environmental and social impacts while being technically and financially feasible. This is based on assessment of the alternatives for each of the key strategic alternative themes, i.e., the “zero” project alternative and the main alternative areas mentioned in Section 3.1.

While the base case concept for technology was defined during pre-FEED phase, routing and siting alternatives have been analysed progressively in the context of the engineering, environmental, socio-economic and cultural heritage constraints identified during baseline surveys undertaken as part of the environmental and social impact assessment (ESIA) process. It should be noted that there is a requirement to provide flexibility for construction contractors that will develop the most efficient and cost-effective construction techniques while ensuring compliance with project standards. As mentioned in Section 2.1.1, refinements to design may be made during the detailed engineering and pre-construction phases influenced by site-specific conditions.

3.3 Approach to Alternatives Assessment

The environmental impact assessment (EIA) regulations for Uganda require an examination of feasible project alternatives and an explanation of the rationale for selecting the proposed project scheme. The specific requirements are detailed below:

In Uganda, The National Environment (Environmental Impact Assessment) Regulations SI 153-1 require the EIA to provide:

- a description of the proposed site and reasons for rejecting alternative sites
- the technology and processes that shall be used, and a description of alternative technologies and processes, and the reasons for not selecting them
- the environmental effects of the project including the direct, indirect, cumulative, short-term and long-term effects and possible alternatives
- an indication of whether the environment of any other State is likely to be affected and the available alternatives and mitigating measures.

In addition, the International Finance Corporation (IFC) Performance Standards Guidance Note 1: Assessment and Management of Environmental and Social Risks and Impacts (Ref. 4.4), requires:

> "…an examination of technically and financially feasible alternatives to the source of such impacts, and documentation of the rationale for selecting the particular course of action proposed."

An example of the alternatives assessment process is shown in Figure 3.3-1.

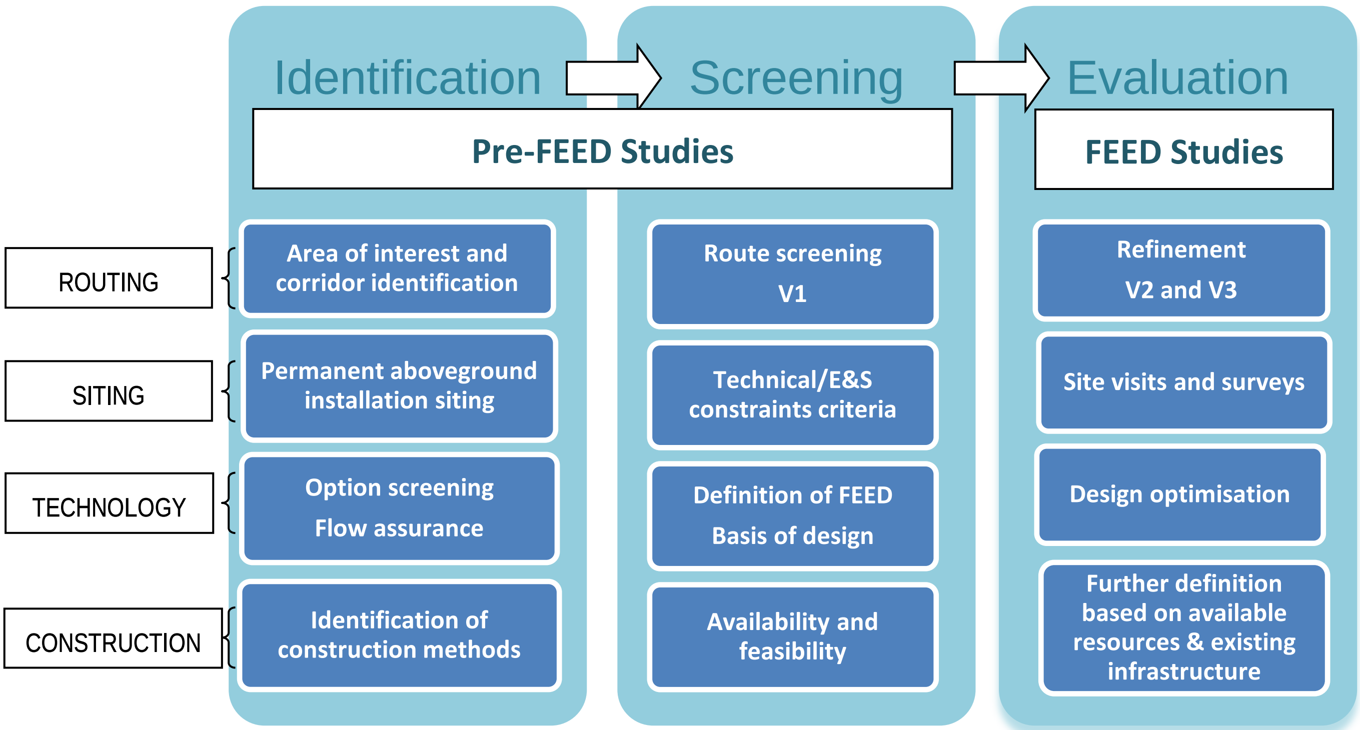


Figure 3.3-1 Alternatives Assessment Process

3.4 Zero Project Alternative

The "Zero Project Alternative" for the purposes of this alternatives assessment is the situation where the project, i.e., the Tilenga feeder pipeline, does not proceed. The development of oil pipelines are large-scale projects and under the zero project alternative there would be no environmental or social impacts, on land or in associated waters because no construction nor operation activities would occur. However, the discovery of oil in the Albertine Graben area of Uganda and the opportunity to access global markets, provide a new resource revenue stream for

Uganda and employment opportunities for local communities. A decision not to proceed with the project would result in the absence of revenue from crude oil production, crude oil export sales and associated economic development. Furthermore, benefits would not materialise from the opportunities that the project would provide such as employment, skills development, technology transfer and growth in other business sectors such as fabrication, construction and waste management.

A pipeline provides a well-established, comparatively safe system for the long-term delivery of oil. In addition, design specifications for pipeline systems are supported by robust international standards. Construction of a pipeline can be completed in a relatively short time. Once operational, pipelines have limited impacts that are localised and can be managed. A buried pipeline system provides the most efficient and dependable method of transport while minimising environmental and social impacts during operational phase. Consequently, the decision was made by the project to progress the oil transportation project as a buried pipeline (see Section 3.7.2 for consideration of above-ground versus buried pipeline).

3.5 Pipeline Routing

3.5.1 Overview

Alternative routing options were considered for the Tilenga feeder pipeline during pre-FEED. However, because the start point (at Tilenga Project central processing facility [CPF]) and the end point (at Kabaale Industrial Park) are defined, the routing opportunities were restricted. The routing process began with the identification of an area of interest which was then followed by numerous screening studies. Using higher-resolution satellite imagery, two corridors were identified and further refined using several constraints criteria including environmental and social, geo-hazards, constructability and terrain (river crossings and slopes).

Further to consideration of the two identified corridors, the Government of Uganda announced the selected Uganda–Tanzania route on 23 April 2016, of which the Tilenga feeder pipeline will connect to, and is shown in Figure 2.3-1.

3.5.1.1 Corridor Options Screening

Eastern and western routes were considered for the Tilenga feeder pipeline as shown in Figure 3.5-1.

Eastern Route (FEED V2)

The eastern route starts at the CPF in Buliisa and runs east through Ngwedo, Kijumbya and Kichoke Bugana villages avoiding Masege Forest Reserve and continues along the western edge of the Bugungu Wildlife Reserve. The route ascends the escarpment near Biso and continues in a south-westerly direction through Kyamukwenda, Kiryawanga and Kigorobya villages, through Bujawe Forest and ending at Kabaale Industrial Park.

Western Route (FEED V6)

The western route starts at the CPF in Buliisa and runs west through Bukongolo, Kigoya and Kabwola avoiding Masege Forest Reserve and continuing along the western edge of the Bugungu Wildlife Reserve. At KP40 (Kisinja village), the route turns west, close to the shores of Lake Albert, passing through Walukuba, Booma and Runga B villages after which it ascends the escarpment in a south-westerly direction through Kabatindure and Kayakaboga avoiding Bujawe Forest and ending at Kabaale Industrial Park.

The routes were identified using a geographic information system, statistical analysis, least risk and cost potential. The two corridors were screened applying biological, geological, physical and socio-economic criteria and using a range of secondary data. The screening assessment considered physical factors including topography, climate, hydrology, hydrogeology, geology, geohazards and soils. Feasibility studies highlighted the potential benefits of pipeline corridor options to:

- be closer to existing infrastructure (roads)
- reduce the number of river crossings
- provide a more suitable elevation profile for pipeline hydraulic design.

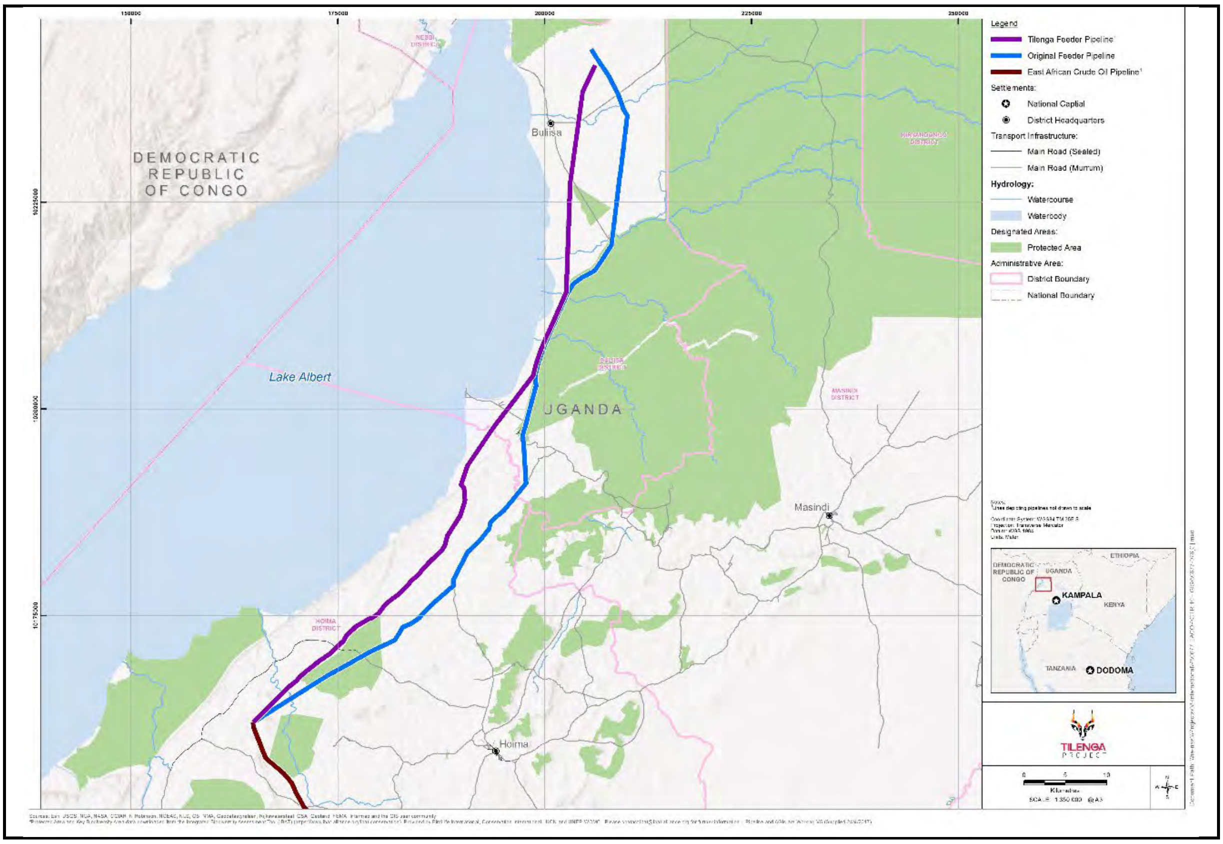


Figure 3.5-1 Tilenga Feeder Pipeline Route Options

3.5.1.2 Route Refinement

Using higher resolution satellite imagery, the identified routes were then subject to refinement including technical, environmental, socio-economic, cultural heritage, economic, geohazards, constructability and terrain constraints. The specific criteria are shown in Table 3.5-1.

Table 3.5-1 Route Refinement Criteria

Technical Criteria	Environmental Criteria	Socio-economic and Cultural Heritage Criteria
Route length Lateral slope (>10° Avoid unless very short distance or single instance) Front slope (>20° Avoid unless very short distance or single instance) Number of cold bends and tie-ins due to terrain undulations Shallow bedrock (granite, gneiss – Avoid) Wetlands (permanent and seasonal) River and stream crossing Road and track or rail crossing Fault crossing Other types of crossings Flooding hazard Landslide hazard Karsts, tunnels and mines (settlement hazard) Seismic zone with liquefaction risk (Avoid) Earthquake zone Geological features Infill land and waste disposal sites, including those contaminated by disease, radioactivity or chemicals	Internationally Protected Areas (Ramsar sites, UNESCO World Heritage Sites) (Avoid) Nationally Protected Areas (national park, wildlife reserve, wildlife sanctuary, forest reserve, community wildlife management area, high biodiversity wilderness area) Waterbodies (lake, reservoir) (Avoid) Internationally Designated Protected Areas (IUCN Category Ia, Ib and II) Internationally and Nationally Designated Protected Areas (IUCN III, IV, V and VI) Critical habitats[1] Natural habitats,[2] e.g., shrub land Other notable biodiversity areas	Industrial areas (mines, factories, power plants) (Avoid) Social and community infrastructure (including places of worship) Right-of-way (RoW) of existing or planned linear facilities Transport infrastructure Settlements (urban area, town, village) Structures within 50 m of corridor centreline Trees and timber forest Cash crop (e.g., tea, coffee plantation, sisal, sugar cane, banana) Water points, sources and wells Cultural heritage sites Tourism facilities and sites

Application of the criteria highlighted key routing constraints which included routing between protected areas and through hilly terrain. For the sections of the Tilenga feeder pipeline route external to these constraints, further optimisation was implemented with the aim to balance pipeline length, proximity to existing roads and the length of new access roads required. The route that best met the criteria was

[1] Critical habitats are areas with high biodiversity value, including (i) habitat of significant importance to Critically Endangered and Endangered species; (ii) habitat of significant importance to endemic or restricted-range species; (iii) habitat supporting globally significant concentrations of migratory species or congregatory species; (iv) highly threatened or unique ecosystems; or (v) areas associated with key evolutionary processes (IFC PS6, 2012).

[2] Natural habitats are defined as areas composed of viable assemblages of plant and animal species of largely native origin, or where human activity has not essentially modified an area's primary ecological functions and species composition (IFC PS6, 2012).

selected as the base case and was identified as shown in Figure 3.5-1. The pipeline routing (pre-FEED and FEED) went through six version alterations, i.e., V1 to V6 after which the western route (FEED V6) was selected.

3.5.1.3 Route Optimisation

During pre-FEED the focus and effort to optimise the routes were intended to improve the side and front slopes, avoid nationally protected areas, reduce impacts to perennial rivers and wetlands, and where possible, reduce the overall length. Improvement of the side and front slopes along the route is important for several reasons:

- Elevation difference is important as it affects system hydraulics.
- During construction, the rate of elevation change (i.e., front slope) can increase the pipeline’s cost and create challenges for accessibility to the RoW.
- Side slopes require side cuts and fills necessary for construction equipment to safely manoeuvre and install the pipeline. During operation, the RoW will tend to retain water which can destabilise the ground supporting the pipeline.

Route optimisation also identified pinch points where routing options are restricted. The route restrictions are shown in green on Figure 3.5-2 and include:

- Maseege Forest Reserve
- Bugungu Wildlife Reserve
- Bujawe Forest Reserve
- major faults
- five permanent watercourses (Waiga, Waisoke, Sonse, Waki and Wambabya Rivers) and an ephemeral watercourse (Sambiye River)
- cultural heritage sites
- social Infrastructure
- tourism sites.

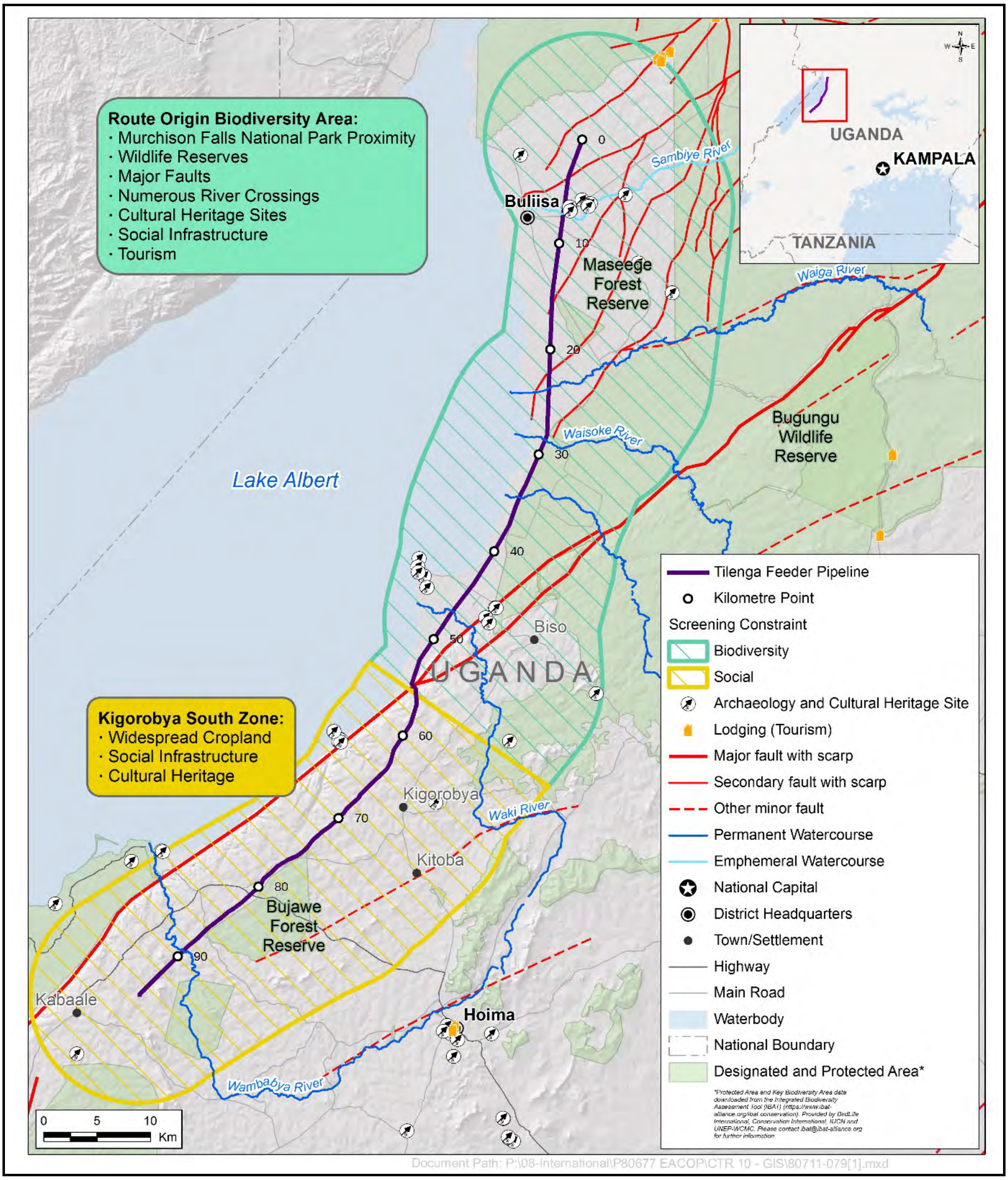


Figure 3.5-2 Pre-Front-End Engineering and Design Corridor Summary Constraint Zones

3.5.2 Front-End Engineering and Design

3.5.2.1 Routing Refinements

At the commencement of FEED, a 2000-m-wide corridor was used as the basis for the light detection and ranging (LIDAR)[3] survey for the Tilenga feeder pipeline. The LIDAR survey data produced a digital elevation model which was used along other routing tools to refine the route. The corridor was then mapped with a 100-m-wide corridor, suitable for technical verification during engineering site visits.

Data collected and ground truthing performed during an engineering site visit (April 2017) were used to establish a centreline within the 100-m-wide corridor and to advance the route:

- to produce route maps with a 100-m-wide corridor and a centreline
- as a basis for engineering i.e., procurement of essential materials and long lead items, such as pipe, heat tracing, valves and hot bends
- to prepare the scoping report.

The following environmental and social constraints were considered during FEED to refine the pipeline corridor further:

- avoid:
  - physical resettlement of local population to the greatest extent possible
  - creation of access roads to otherwise inaccessible areas
  - cultural heritage and archaeological sites to the greatest extent possible
- reduce:
  - economic resettlement, disruption to livelihood of local population
  - project footprint (including the RoW, aboveground installations [AGIs], work sites, access roads)
  - land take; habitat and agricultural land lost
  - project disturbances (such as noise, light, vibration, dust)
  - groundwater abstraction sources and waste discharge locations
- restore habitats and hydrogeological regimes after construction.

Consistent application of these criteria has been of paramount importance while narrowing the study corridor from 2000 m down to a 30-m RoW with pipeline centreline.

Further refinements during FEED have also included:

- co-location of the pipeline with the road and adjacent powerline running along the western boundary of the Bugungu Wildlife Reserve to avoid routing through the reserve area, see Figure 3.5-3
- where the pipeline crosses the Albertine Rift (steep increase in elevation). Desktop analysis determined that the best option is to route straight up the hill from KP54.7. This also allowed the pipeline to avoid a village and road

[3] LIDAR is a remote sensing method that uses pulsed laser to measure ranges (variable distances) to the Earth, generating precise, three-dimensional information about the shape of the Earth and its surface characteristics (https://oceanservice.noaa.gov/facts/lidar.html).

crossing, while following the gentlest climb up the escarpment, see Figure 3.5-4.

- bypassing some hilly areas and routing around a village between KP75 and KP82, see Figure 3.5-5.

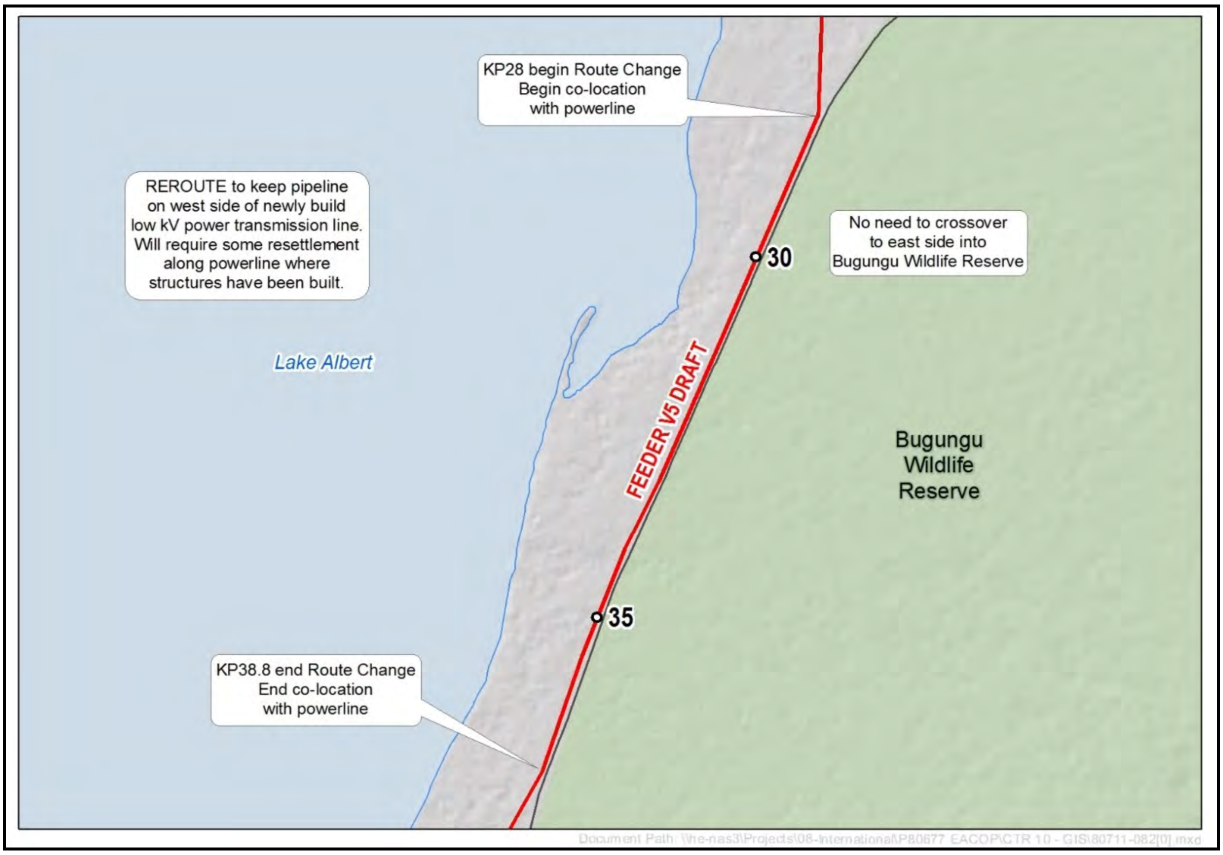


Figure 3.5-3 Route Refinement, Bugungu Wildlife Reserve

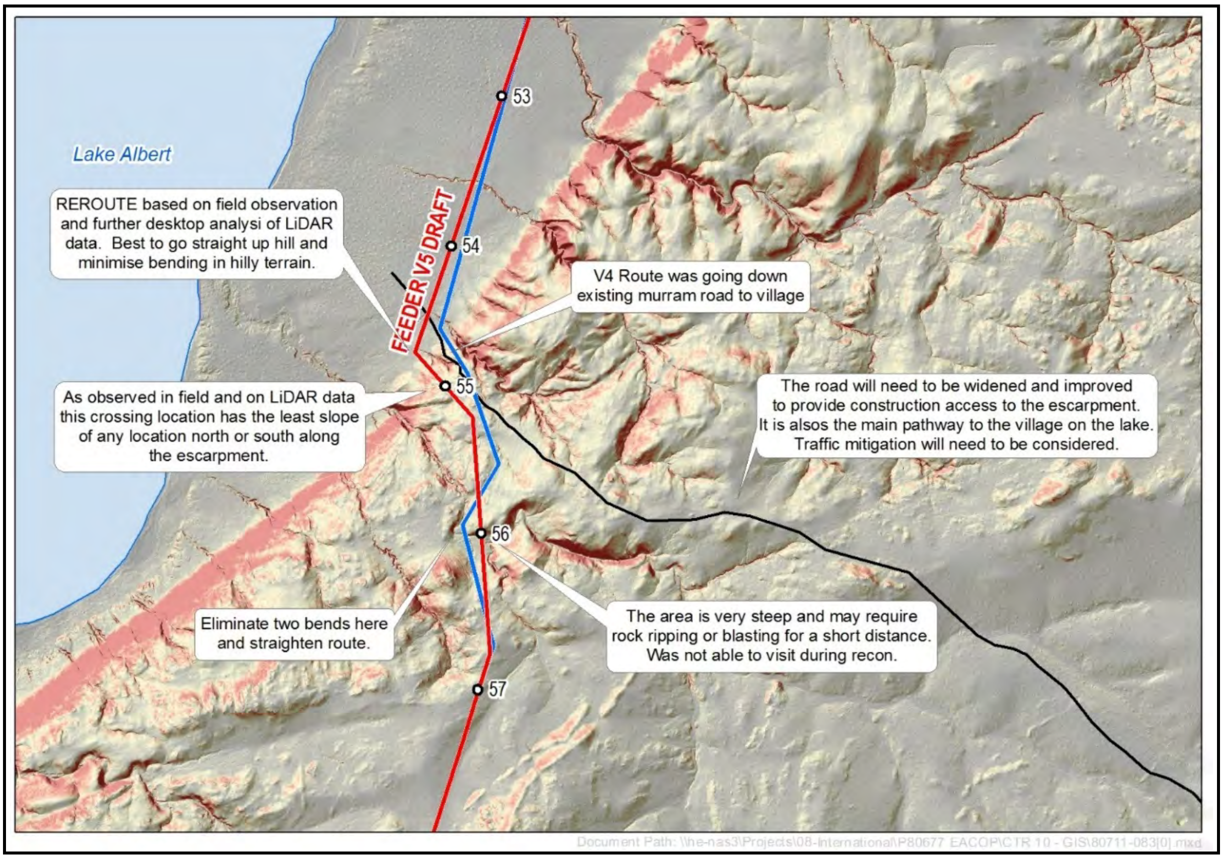


Figure 3.5-4 Route Refinement, KP53–57

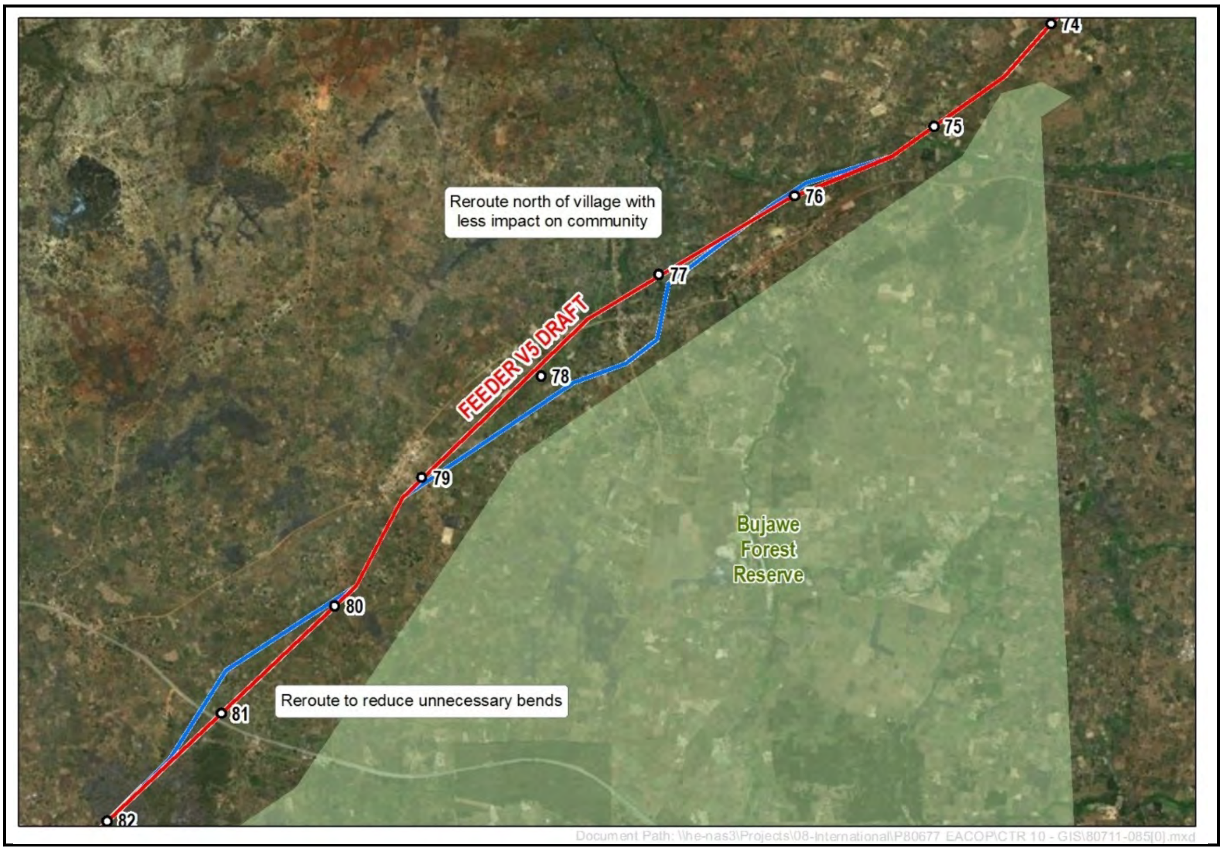


Figure 3.5-5 Route Refinement, KP75–82

A site visit was undertaken in April 2017 by a multi-disciplinary team including environmental and social specialists to confirm constraints along the routing. It was based primarily on the scoping baseline studies geotechnical and geophysical data. All refinements as a result of this work were minor, with most pertaining to constructability considerations and avoidance of structures, ecologically sensitive areas and watercourses including:

- location and size of AGIs
- locations of the main line block valves, one of them aligned with an intermediate electrical substation
- locations of a construction main camp and pipe yard.

3.5.2.2 Base Case Route

The base case route is shown in Figure 2.3-1. However, as investigations are on-going at the time of writing this ESIA, e.g., geophysical and geotechnical surveys, small-scale adjustments may still be made.

3.6 Facility Siting

3.6.1 Overview

This section describes the main alternatives assessed for the number, location, layout and footprint of the following facilities:

- AGIs
- construction facilities (MCPY).

The functional requirements of the surface facilities have been the main driver for the identification, screening and final location selection.

Additional imagery and site visits were used to establish suitable AGI and construction facility locations along the Tilenga feeder pipeline route during FEED. Siting of the electric substation (at one of the main block valves) was based on electrical studies, whereas the block valve locations have been defined based on detailed technological risk analysis.

The functional requirements vary for each type of facility and are described in this section. The selection process has also taken into account relevant safety, environmental and social constraints.

3.6.2 Aboveground Installations

The main driver for the type, number and location of the AGIs has been the technical specifications. The following criteria for AGI siting have been considered:

- thermal design requirements
- safety and environmental risk factors
- site physical conditions (topography, accessibility, proximity to existing infrastructure)
- environmental and social constraints.

3.6.2.1 Electric Substation

As described in Section 2.3.3.3, the electric substation houses transformers required for power transmission through the high voltage cable and step down transformers to provide the required voltage for the electrical heat tracing (EHT) system. The rationale for siting of the electric substation is based on the overall number of substations required by the trace heating system i.e., maximum cable length of 30 km and therefore, the maximum distance between power supplies required would be 60 km. As mentioned in Section 2.3.3.3, the Tilenga Project CPF will provide the power for EHT for the first segment of the pipeline.

During FEED, the siting of the electric substation was reviewed and the objective was to, if possible, combine it with a block valve location for the Tilenga feeder pipeline. The number of substation combinations with block valves, and the standalone substations, are shown in Table 3.6-1.

Table 3.6-1 Electric Substation Siting – Combined and Standalone

Siting Options	Number
Standalone electric substations	0
Electric substations combined with block valves	1
Total	1

3.6.3 Block Valves

The primary function of block valves is to isolate sections of the pipeline and the number and location of block valves is based on ASME B31.4 (434.15), which requires that block and isolating valves shall be installed to:

- limit hazard and damage from accidental discharge
- facilitate maintenance of the piping system.

The number and location of valves has also been informed by risk assessment based on safety and environmental risk considerations. Preferred locations include:

- upstream side of major river crossings and public water supply reservoirs
- at other locations appropriate for the terrain features
- at remotely controlled pipeline facilities to isolate segments of the pipeline
- on the inlet and outlet of pump stations whereby the pump station can be isolated from the pipeline
- in industrial, commercial, and residential areas where construction activities pose a risk of external damage to the pipeline.

Based on these preferences, block valves were sited at:

- long continuously ascending or descending elevation profile
- on each side of wetlands and major water crossings (> 30 m wide)
- at each river or stream < 30 m wide, where downstream impacts from a pipeline leak could impact populations, reservoirs, waterways and sensitive areas.

The Tilenga feeder pipeline design includes four block valves. Further evaluation and optimisation of block valve locations was undertaken when the number of electric substations, one, required for the Tilenga feeder pipeline heat tracing system became available. Additional work was then performed to combine the locations for block valves and the electric substation as much as possible to optimise facilities’ footprint and access requirements.

The optimisation for the Tilenga feeder pipeline resulted in:

- elimination of two block valves
- three standalone block valves within the pipeline RoW
- one block valve combined with an electric substation within the pipeline RoW.

3.6.4 Construction Facilities

The Tilenga feeder pipeline will have one main camp and pipe yard (MCPY) to support construction operations. The construction facilities site selection process has taken into consideration the requirement to:

- minimise land acquisition
- minimise distance from existing road networks
- avoid populated and protected areas
- take cognisance of the terrain type and topography suitability.
- have water availability.

In September 2016, a MCPY site review was undertaken to assess locations proposed for the V3 route. The locations were subject to preliminary assessment based on the criteria shown in Table 3.6-2.

Table 3.6-2 Construction Facility Location Selection Criteria

Technical	Environmental	Social
Facilitate access to RoW for the MCPY Facilitate access for pipes from main roads Availability of water Availability and capability of local contractors to undertake the required scopes. Location within 50 km of most remote work site	Limit footprint and impact by minimising requirements for temporary roads Avoid nationally protected sites and internationally recognised sites of conservation interest and critical habitats Topography Terrain type (avoiding wet areas) Potential geo-hazards (such as flood zones, faults)	Avoiding resettlements or limiting extent of resettlement Clear of villages and schools Social and community infrastructure (including places of worship) Settlements (urban area, town, village) Cash crop (e.g., tea, coffee plantation, sisal, sugar cane, banana) Water points, sources and wells Cultural heritage sites Tourism facilities and sites Land use Avoiding the clearance of trees/timber forests, existing crops and bush in dry areas (where crops would be easier to restore) Clear of military facilities

The criteria for construction facility location as shown above was applied in combination with the selection criteria for the pipeline route selection as shown in Table 3.5-1.

The three locations that were considered are shown in Figure 3.6-1. The emphasis is on utilisation of existing facilities that can be easily converted to a MCPY to minimise construction footprint and associated impacts.

Based on the requirements listed above, all the alternative locations considered for MCPY are around the middle section of the Feeder Pipeline (near KP45, Butiaba subcounty, Buliisa district) and near Butiaba road. This general location was selected to facilitate delivery of construction materials to worksites. The different alternative locations considered are discussed below.

3.6.4.1 Alternative 1

Alternative 1 is on relatively flat land on the shore of Lake Albert, near Butiaba landing site. The site contains structures of a defunct fish-processing facility that aimed at commercialising fish sourced from Lake Albert by the local communities. The location was classified as a floodplain, and stagnant water was observed onsite during field visits. Alternative 1 was therefore not selected owing to its proximity to Lake Albert (within 200 m of the lake's protection zone) and its location in a floodplain (environmental constraints).

3.6.4.2 Alternative 2

Alternative 2 was formerly used as a temporary campsite by Tullow Oil during the oil exploration phase. Although this site could minimise associated impacts on the landscape, it was not selected because of the requirement for the construction of a long access road from Butiaba road (technical constraint) and due to ongoing land ownership disputes (social constraint).

3.6.4.3 Alternative 3 (preferred option)

Alternative 3 is a former construction camp site owned by Mineral Services Limited. This site was selected as the preferred MCPY location owing to its proximity to Butiaba road, which is currently being upgraded to tarmac, thereby eliminating the requirement for the construction of an access road and making it ideal for delivering pipe and other construction materials to the pipeyard and pipeline RoW. In addition, selection of the site minimises the project footprint by eliminating further land take and resettlement.

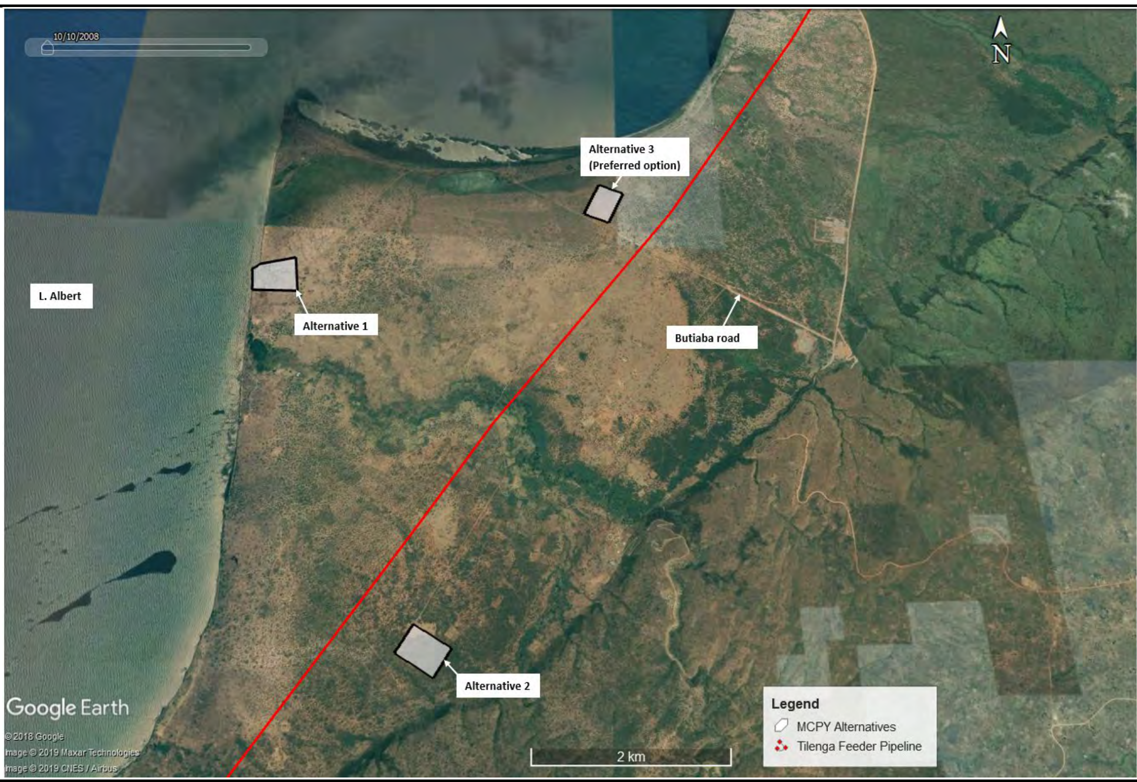


Figure 3.6-1 Tilenga Feeder Pipeline Main Camp and Pipe Yard Alternatives

3.7 Technology

3.7.1 Overview

This section describes the main design alternatives to the project base case as described within Section 2.3. The pre-FEED phase focused on the screening and option evaluation of the main technology alternatives while FEED has concentrated on further refinement. The process has focused on the following elements of the design:

- pipeline (diameter and wall thickness)
- thermal insulation
- heating.

The challenges associated with flow assurance have been a key consideration throughout pre-FEED and FEED with respect to technology selection. Several design alternatives have been subject to screening and evaluation as described in the following sections.

3.7.2 Pipeline

A partially aboveground pipeline alternative was considered during early pre- FEED but was discounted for numerous reasons including concerns associated with security and safety, risk of interference by third parties, visual impacts and impacts to large wildlife movement. Furthermore, pipeline design codes that would later be adopted require pipelines to be buried. Therefore, the concept selected for study at pre-FEED was a trenched and buried pipeline.

Two strategies were considered to enhance oil flow required by the oil characteristics:

- a cold transport option requiring the partial removal of paraffinic components ensuring that gelling of the oil is prevented. This requires some oil processing and is extremely expensive. Consequently, this alternative was screened out.
- a hot transport option aimed at maintaining the fluid temperature above 50°C with the use of thermal insulation, and a combination of heating options. Hot transport was selected as the base case for further study.

Various studies considered the alternative pipeline options and recommended the most suitable and practical means to be taken forward for study during FEED. The key consideration at that stage was the hydraulic design concept, namely:

- Case 1 (Base Case): 24-in.
- Case 2 (Design Pressure Reduction): 26-in.
- Case 3 (PS Reduction): 24-26-24-in.

The main conclusions from the pre-FEED studies were that Case 1 (24-in.) should be taken forward as it is considered the most balanced option in terms of meeting technical and economic criteria.

3.7.3 Thermal Insulation

The pre-FEED assessed insulated and un-insulated pipeline options. The steady state analysis concluded that heat losses with the uninsulated case would require separate crude fired heating stations resulting in high crude consumption, larger project footprint, larger environmental impact and operational costs. Conversely, applying thermal insulation on the pipeline concluded that heating requirements could be optimised with lower crude consumption, lower project footprint, less requirement for facilities, higher initial cost, but more economical over the lifetime of the project. The decision was taken to service the power required for operation of the EHT for the Tilenga feeder pipeline from the Tilenga Project CPF resulting in only one intermediate electric substation required along the pipeline RoW.

Several existing pipe thermal insulation alternatives were screened in terms of thermal efficiency, availability and constructability as summarised in Table 3.7-1. The decision was taken to incorporate polyurethane foam (PUF) as the base as it offers the highest thermal efficiency with lowest Capex.

Table 3.7-1 Insulation Alternatives

Insulation Type	Characteristics		Conclusion
PUF	Lower thermal conductivity New coating plant required with high productivity Two methods possible for foam application: spray or moulding Excess foam material above heat tube or raceway is to be removed with spray process Polyethylene jacket added over foam to provide mechanical protection Many references of pipeline in service		Accepted as base case
Glass	Higher thermal conductivity makes it less efficient Conventional pipeline construction including bends Field applied in long lengths with glue or resin and external membrane High manpower requirement making it not suitable for long pipelines Very limited references essentially for piping in plants Pre-cut grooves fit over pipe or channel / heat tape		Not selected for main line because of lower thermal efficiency and lack of references – possible use at field cold bends

Pipe in Pipe (PiP)	High linear weight making it suitable for wetlands Water ingress risk very low due to welded construction Field bends possible with care External steel sleeve implies additional welding and coating		Not selected because of higher capital expenditure (CapEx)

3.7.4 Heating

The temperature management principles of the pipeline are to:

- maintain operating temperature above 50°C at all times during export conditions (normal, transient and degraded modes)
- ease commissioning and ramp-up phases by maintaining fluid temperature above 50°C
- under no flow condition, i.e., preservation, temperature shall be maintained by the EHT above 50°C
- allow a cold restart from minimum ambient temperature up to 50°C
- no bulk heating (BH) will be required, during production plateau, providing the fluid export temperature from Tilenga Project CPF is exported at 80°C
- Tilenga Project CPF will maintain the crude oil temperature above 50°C in flowing conditions. EHT will be required for cold restart.

Three heating configurations were considered to maintain the oil temperature above 50°C:

- Case 1 – EHT only case
- Case 2 – BH only
- Case 3 - EHT + BH (mixed heating architecture).

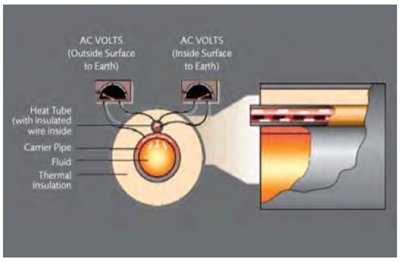
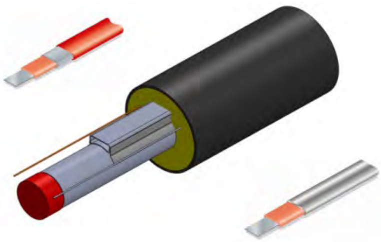
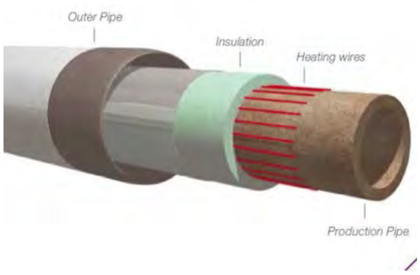
The thermal design concept selection for Tilenga feeder pipeline is Case 1, i.e., EHT only. Power shall be provided by the Tilenga Project CPF to maintain crude oil temperature with the export temperature from CPF at 80°C. This negates the requirement to have BH for the Tilenga feeder pipeline.

EHT is considered the optimal design case for the Tilenga feeder pipeline.

3.7.4.1 Electrical Heat Tracing System Types

Several EHT alternatives were screened during pre-FEED as both primary and secondary sources of heat input. Aspects of the screening study are shown in Table 3.7-2. The three systems reviewed were skin effect heat tracing (SEHT), long line heat tracing (LLHT) and pipe in pipe (PIP).

Table 3.7-2 Electrical Heat Tracing Alternatives

System	Characteristics		Conclusions
SEHT	Current flows through centre of insulated wire and returns though heat tube Requires special transformers Welding and coating for tubing increases cost and schedule Coverage 9–12 km maximum with one tube Field proven used for most of trace heating pipelines		Not selected on basis of less coverage over long distances, more cabling required and more electric substations required More power consumption (as one phase out of the three is not used) Higher CapEx than LLHT
LLHT	Experience of use on plants and some buried pipelines All three phases used Requires transformers Uses standard pipe Coverage up to 30–50 km		Selected as base case as greater coverage over long distances, less core cable quantities and less electrical substations required (lower overall project footprint)
PIP	Application for short subsea lines with steel pipe encased in large diameter steel pipe Multiple cables (24) provide redundancy Pre-constructed lengths welded and heating cables jointed on site. Includes insulation (needs to be dry)		Not selected because not considered suitable for length of line Will require an extra 1550 km of at least 28 in. steel pipe to serve as external jacket to 24 in. pipe Highest CapEx of the three options

3.8 Construction Techniques

3.8.1 Overview

This section describes the various construction techniques considered during pre-FEED and FEED phases. The most critical factors in defining the construction strategy are:

- route optimisation and siting
- logistics strategy (optimisation of road and rail networks)
- weather conditions and seasonal constraints
- biodiversity-related seasonal constraints
- availability and proximity of existing infrastructure for material transport and for siting of facilities

- sequencing of pipeline insulation and coating activities with pipelay
- availability of materials and labour
- trenchability, including blasting requirements.

This section identifies the main alternatives reviewed during pre-FEED that have culminated in the definition of the constructions strategy as detailed in Section 2.4.2.

3.8.2 Strategy and Logistics

A traditional "spread" construction approach is proposed. During FEED, numerous site visits and surveys along the pipeline route made important observations on the approach to construction and concluded that most of the pipeline is on relatively flat or rolling hill areas, which present few particular construction difficulties. However, several different options for scheduling were considered during an early constructability study during prior FEED where it was established that the Tilenga feeder pipeline construction can be achieved utilising one spread.

The study also concluded that owing to constraints on the sizes, length and particularly the type of thermal insulation, efficient coordination of insulation and coating activities with the pipelay schedule are the most critical factors for construction execution. In addition, the requirement to ensure fully free access to the RoW to prevent delays to mobilisation for construction was also identified. The conclusions from the study have been used to develop the base construction strategy, and schedule as presented in Section 2.4.2.

The logistics strategy has been developed during the prior FEED and FEED phases based on the following principles:

- achieve early enough, but not too early material delivery (knowledge of all material flows is the key to a smooth transportation plan)
- provide smooth equipment replenishment to avoid unnecessary costs as well as delays
- synchronise material supply with the construction schedule to make reliable estimation of material requirement and locations where the material is required
- Align the equipment resourcing and transportation plan with fuel supply strategy to minimise delay
- estimate the optimum storage capacity to minimise the cost of storage while maintaining reliability of timely material supply to the project
- eliminate or minimise potential unpredicted delays at border crossings, custom clearance and other logistics bottlenecks by making realistic predictions and observing local/country capacity and calendar
- ensure availability of trucks and site transportation and plan for importing or sourcing adequate equipment and vehicles to fulfil the project requirements
- determine the season dependency of the road conditions, availability of transportation vehicles and border crossing times, and prepare for it.

3.8.3 Pipeline Construction

3.8.3.1 Construction Techniques

The pipelay sequence is described in Section 2.4.2.2 and is comprised of three main aspects:

- open areas where the spread technique is utilised, i.e., pipe storage, RoW clearing and grading, stringing, bending, welding and trenching
- crossing locations where specialist crews and specific techniques are used e.g., auger boring
- special sections such as restricted working areas, difficult terrain and environmentally and socially sensitive areas.

During pre-FEED the spread technique was considered the most suitable for onshore pipe lay and therefore no other alternative construction strategies were considered during FEED.

3.8.3.2 Blasting and Micro-Blasting

In rocky sections of the pipeline route, where normal excavation is not possible, blasting may be required to fracture the rock and enable pipeline trench excavation.

Micro-blasting avoids rock projectiles and creates less noise and vibrations but can only be used under certain conditions. Sections suitable for micro-blasting will be identified during construction, based on geology, the proximity to infrastructure and environmentally sensitive features.

3.8.3.3 Crossings

The Tilenga feeder pipeline route crosses numerous watercourses and wetlands, some of which are permanent, and others are of a seasonal nature. In addition, the pipeline will cross existing infrastructure such as roads.

Several alternatives exist for the installation of the crossings for roads, streams, rivers and wetlands. Both open cut and trenchless techniques have been considered and the identification of appropriate technique has been based on a systematic assessment of the pipeline route using the following criteria:

- size and nature of the crossing (length, location, terrain, geotechnical constraints)
- nearby environmental and social features
- constructability (access restrictions, size of construction spread required).

The open-cut technique is the option selected for the crossings along the Tilenga feeder pipeline route owing to its simplicity and minimal construction footprint. Several trenchless construction alternatives were reviewed including, Auger boring, horizontal direction drilling (HDD) and micro-tunnelling. For tarmac roads, the Auger boring technique will be used to prevent disruption to services. Other techniques such as direct pipe and micro-tunnelling were discounted during FEED owing to requirement for a much larger construction footprint and increased Capex.

The methodology and rationale for selection of the appropriate crossing techniques is shown in Table 3.8-1. The finalised list of crossings for Tilenga feeder pipeline is shown in Table 2.4-2.

Table 3.8-1 Crossing Alternatives

Technique	Open Cut	HDD	Micro-tunnel	Auger Boring
Summary	Most efficient and simple technique involving excavation of a trench, pipe is laid and backfilled. For flowing watercourses, the crossing site is isolated to prevent construction materials from entering the watercourse	Drilling of a hole, along a pre-determined alignment, by pulling/pushing a drill string) and installing “stringing” the pipeline from the opposite side of the crossing back through the drilled hole. Used for crossings up to 1.5 km	Circular precast concrete pipe sections being pushed (jacked) through the ground along a predetermined alignment.	Well proven technique which requires excavation of pits on either side of the crossing to aid the installation of the pipeline. The depth of the pits depends on the nature of the crossing and the local ground conditions. Used for crossings up to 120 m
Cost	Lowest	Low (comparable with auger-boring)	Highest (expected to be 50% more than HDD)	Low (comparable with HDD)
Logistics	Simplest logistically requiring the least amount of equipment and plant	Logistically challenging requiring the mobilisation of drill rig, mud management and excavators and personnel	Logistically challenging based on required plant, equipment and personnel.	Logistically challenging requiring the mobilisation of drill rig, mud management and excavators and personnel
Environment	Risk of sedimentation but controlled with proper isolation techniques and avoid seasonal sensitivities	Lowest material required and spoil generated Larger construction footprint for spread	Highest spoil generated Larger construction footprint for spread	Mid spoil generated Minimal construction footprint required

3.8.3.4 Water Sourcing

Construction activities requiring water comprise mainly concrete mixing and dust suppression. These activities do not require potable water, although potable water must be available for consumption by construction workers (it is assumed bottled water will be provided).

To reduce water abstraction and discharge, the reuse of treated sewage effluent is a viable alternative for industrial water supply which is being evaluated.

In addition, potential sources of surface water abstraction for construction activities were identified using satellite imagery analysis. These are water bodies which appear to be perennially available and within approximately 10 km of truckable distance of the pipeline route (confirmation of those sources is subject to the water supply study).