DESIGN SELECTION OF THE CAMEROON LNG PROJECT

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ABSTRACT

Cameroon LNG is a midstream project, encompassing an offshore gathering pipeline and an LNG production plant. The development is based on an export capacity up to 3.5 Mtpa of LNG based on gas reserves of about 3 Tcf.

In 2009, a feasibility study was launched to evaluate different development configurations for the offshore and onshore developments, which included liquefaction on floating facilities. Different locations for the onshore facilities were also assessed. The preferred development scheme, as a result of the screening of 25 cases, was to establish a 270 km national gas shallow-water transportation network linking Cameroon's offshore gas production facilities with onshore liquefaction facilities located near Kribi city on the southern coastline of Cameroon.

Based on this preferred development scheme, pre-FEED studies were launched in 2010 to select the design case for both onshore facilities and offshore pipeline. A coordinated approach, based on a reference case, was carried out to evaluate and select the most appropriate technologies and designs taking into account the following criteria:

- Robust operation,
- Low CAPEX and
- Value creation.

The selected Design Case was further optimised and engineered generating PFDs and plant layouts. Value engineering reviews, based on PFDs, improved the design and identified additional studies to be carried out during FEED phase.

Finally a class 3 cost estimate was developed, as defined by AACE international recommended practice, to assess the Project economics.

TABLE OF CONTENTS

1 Cameroon LNG Project development background 2
2 Cameroon Gas reserves 2
3 Project export feasibility study 3
4 Preliminary engineering studies (pre-Front End Engineering and Design) 7
  4.1 Site selection 7
  4.2 PreFEED execution plan and objectives 7
  4.3 Phase 1: Screening criteria 8
  4.4 Phase 1: Offshore Pipeline system design selection 9
  4.5 Phase 1: LNG Plant/Marine Facilities design selection 10
  4.6 Phase 2: Pipeline system design definition 13
  4.7 Phase 2: LNG Plant design definition 15
  4.8 Cost estimates 17
5 Conclusions 17
1. CAMEROON LNG PROJECT DEVELOPMENT BACKGROUND
As a long established oil producer, Cameroon is currently seeking to develop its gas potential through Liquefied Natural Gas (LNG) production.

The estimated discovered gas resources amount to approximately 4 Tcf which are spread over a number of gas fields operated by independent upstream companies. The exploration potential would be 5 times higher according to National Oil Company (NOC), but until today there has not been a gas monetizing scheme enabling commercial production thus no gas exploration campaign launched in the country.

In 2006, the Cameroonian State decided to monetize its gas reserves by allocating a significant portion of the existing gas discoveries to a single LNG export project with GDF SUEZ SA as the selected strategic partner to jointly work with its NOC, Société Nationale des Hydrocarbures, “SNH”, as the Project Partners.

In December 2010, the State signed a Framework Agreement for the Cameroon LNG Project (“CLNG”) with GDF SUEZ, confirming favourable fiscal, financial and commercial terms for CLNG and reaffirming the State’s strong support to gas development. SNH also developed a favourable fiscal package for gas production tied to supplying the LNG Project.

In the second quarter of 2010, the State granted a 470 hectares site to the Project. In 2011, the Project Partners positively concluded a Pre-Front End Engineering and Design (pre-FEED) study with Foster-Wheeler Energy Ltd. (UK) and a bankability study with Société Générale SA. The Project Partners also signed preliminary commercial agreements with the relevant upstream operators in the country.

In April 2012, H.E. Mr Paul BIYA, President of the Republic of Cameroon, enacted a new Gas Code following resolution by the National Assembly, to promote the development of the gas sector and to enable the negotiation of conventions with State, such as the one required by Cameroon LNG Project.

2. CAMEROON GAS RESERVES
The gas fields discovered in Cameroon are spread along the Cameroon shoreline (Figure 1). The estimated discovered resources proven and probable are about 4 Tcf, of which 3 Tcf are dedicated to the LNG export project. The discovered gas fields are operated by a number of Exploration and Production companies which signed pre commercial agreements with CLNG to deliver gas. No operator can on its own supply enough gas for the LNG project, and gas resources have to be aggregated.
3. PROJECT EXPORT FEASIBILITY STUDY

In 2009, a feasibility study was launched to define the Project development framework.

The study considered:

- Four different development options for natural gas liquefaction (LNG) facilities (refer to Figure 3 to 6) including floating LNG and onshore liquefaction plant

- Onshore facilities located at Limbe and/or Kribi areas

- Three LNG production capacities of 1.5, 2.5 and 3.5 Mtpa

- Feed gas produced from one or more different Cameroon offshore gas field zones. In the feasibility study, 3 Areas were considered (refer to Figure 2).
Figure 2: 3 Groups (by Colour) of Feed Gas Production Fields Considered for the Feasibility

In all the 25 cases, it was assumed that the gas dehydration facility, within the offshore gas production facilities, would remove free-water from the produced gas to acceptable levels necessary to protect the transmission lines from corrosion.

The study included heat and material balances up to the battery limits of the Project for each case with simplified Process flow Diagrams (PFDs) and plot plans. Figure 3 to Figure 6 illustrate the main options considered.

Finally Capital (CAPEX) and Operating expenditures (OPEX) for each option were defined for economic comparisons.

Figure 3: Option A: All Offshore, LPG Extraction and Liquefaction on Floating Facilities
The 25 cases were reviewed by CLNG combining the different options, production rates, LPG/LNG production locations (offshore and/or onshore) and gas field Areas. Each case was evaluated taking into account the following criteria:
The different configurations were ranked considering the above criteria and were referenced against the best case (with a 100% scoring), refer to Figure 7.

The top three scores per gas field Area were represented using the following colour code:
- Green - Highest score,
- Yellow - 2nd highest score
- Orange – 3rd highest score.

The highest score was obtained, considering the offshore gas fields in Area 1, with the option of an onshore Liquefaction plant solution of 3.5 Mtpa capacity located in Kribi. Unsurprisingly, the higher the gas reserves committed to the Project, the more favourable the configuration. With fixed reserves, the larger the plant the better the economics thanks to increased yearly revenue which outweight the marginal increase in cost.

For all other gas field Areas, an onshore Liquefaction plant in Kribi was deemed the most favourable option. An onshore plant located in Limbe had a lower score due to the high risks of a close proximity to the Volcanic Mount Cameroon.

An independent LPG production plant was deemed less valuable than a combined LPG and LNG onshore plant.

Finally, the floating options (combined LNG and LPG or with onshore independent LPG facilities) had the lowest scoring for all field areas. These options were less valuable considering that:
There will always be a need for offshore pipeline  
No possibility for future extension, hence reducing future exploration incentives  
Reduced local content  
Less references

As a conclusion of the feasibility study, the preferred scheme for monetising gas in Cameroon is to develop an onshore LNG plant located in Kribi. Plant capacity will depend on the gas reserves dedicated to LNG export Project.

After consultation with the stakeholders, CLNG decided to launch preliminary studies for defining the design of the Project in form of a pre-Front End Engineering and Design (pre-FEED).

4. PRELIMINARY ENGINEERING STUDIES (PRE-FRONT END ENGINEERING AND DESIGN)

4.1. Site Selection
Different sites for the LNG plant were assessed between Grand Batanga location, just south of Kribi, and Rocher du Loup. On 7 May 2010, the Cameroonian State, in consultation with the Project Partners, allocated an appropriate site located in the future industrial-port area surrounding the future Kribi deep sea port presently under construction in Mboro, refer to Figure 8.

![Figure 8: Kribi Master Plan Initial Phase](image-url)

**Figure 8: Kribi Master Plan Initial Phase**  
(Courtesy of the Industrial Port Development Committee)

4.2. PreFEED Execution Plan and Objectives
In May 2010, CLNG awarded Foster Wheeler Energy Ltd. (UK) a contract to carry out the pre-FEED for both the LNG plant and pipeline system. The marine facilities were subcontracted to HR Wallingford.

The main objectives of the pre-FEED were to:

- Optimise the design and facilities layout in order to increase the overall Project value
- Highlight show stoppers, if any
- Establish preliminary design of the offshore pipeline gathering system and the onshore liquefaction facilities
Determine the overall Project development schedule
Assess the Project economics
Prepare the FEED scope of work and design basis

The objectives were achieved in two phases. The first phase, Concept Selection, was to set the Design Case of the Project. The second phase, Concept Definition, was to develop the preliminary design of the different facilities of this Design Case for developing the FEED scope of work and basis of design.

Shortly after kick-off of the preFEED, a two day brainstorming session, attended by international experts, SNH and GDF SUEZ, was carried out to identify alternatives which should be screened and evaluated during this first phase.

At the end of the Concept Selection phase, a peer assist was organised to validate the Design Case.

The Concept Selection defined:

- **The Pipeline system:**
  - Routing (including landfall)
  - Flow regime (single phase)
  - Materials of construction (considering CO₂)
  - Sizing (flow rates, pressures, compression, etc.)
  - Flow assurance
  - Pigging facilities (slug catcher, inhibitor system, etc.)
  - Upstream production facilities impact/requirements
  - Slug catcher requirements

- **The LNG Plant**
  - Gas Pre-Treatment
  - Liquefaction process configuration
  - Liquid handling
  - Refrigerant compressor drivers
  - Condensate stabilization
  - Utilities
  - Storage
  - Marine facilities

### 4.3. Phase 1: Screening Criteria

During the Concept Selection phase, in selecting the best Design Case, it was decided to arbitrarily set a reference case to be compared against the design alternatives. The design alternatives were weighted using the following criteria:

- Production Availability
- CAPEX/OPEX
- Economics (processing fee and upstream NPV)
- Operability- Maintainability
- Production and operation Flexibility
- Technology robustness and experience
- Environmental impact, based on CO₂ equivalent
- Local content
The intent of the screening study was that the Design Case will:

- Have robust operation
- Minimise CAPEX
- Create value

### 4.4. Phase 1: Offshore Pipeline System Design Selection

Different alternatives were assessed for:

- The Pipeline routing/landfall options
- Liquids Management
- Hydrate control
- Corrosion control (internal pipeline)

Twelve pipeline design alternatives were identified and studied. They are presented in Figure 9.

![Figure 9: Pipeline Design Alternatives Identified During Phase 1](image)

The comparison of the different alternatives for 3.5 Mtpa LNG production capacity are shown on Figure 10 with the reference case, scored at 100, and the highest score represents the most desirable option.
Case 2H was selected at the end of the Concept Selection phase as the best compromise with satisfactory flow assurance management, especially for the line from the North gas basin (Rio del Rey – RDR), in the increased operational flexibility (downturn) and allowing a 2 phase solution (gas with hydrocarbon liquid). Nevertheless, this configuration illustrated a slightly higher overall CAPEX and increased upstream facilities costs. Cases 2A to 2E were not taken into consideration due to hydrate and corrosion issues. The main advantages of the selected case were:

- Slugs can be controlled with pigging or a high gas velocity
- Velocity can be kept high with 24” trunkline and 18” spur line from RDR to the trunkline
- Slug Catcher volume is limited
- Corrosion can be controlled as the gas is dehydrated.

But

- Possibility of Limited capacity increase
- Requirement of higher upstream compression outlet pressure
- Requirement of water dehydration unit at upstream gas delivery tie-ins

The design of the pipeline system will be reassessed during FEED when all the upstream design definitions from the gas fields will be finalized, which will set the pipeline configuration. There is a possibility that the pre-FEED configuration could be changed.

4.5. Phase 1: LNG Plant/Marine Facilities Design Selection

Figure 11 summarises the main alternatives studied.

The design selection for the following systems resulted from specific studies:

- Construction facilities (e.g. materials offloading berth)
- Fire water (fresh water versus sea water)
- Breakwater for product jetty
- Permanent community

During the pre-FEED, only proven solutions were considered for the following systems:

- Acid Gas Removal Unit method/solvent
- Mercury removal adsorbent type and location
Liquefaction process, C3-MR but final liquefaction process will be selected during FEED phase

- Heating medium
- Marine facilities

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<th>Cooling media (3 Options)</th>
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<td>- Air coolers</td>
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<td>- Warm/cold seawater</td>
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<td>- Integrated turbo expanders</td>
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<td>- Upstream NGL extraction unit</td>
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<th>Train configuration (&gt;20 Options)</th>
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<td>- 4 Train configurations Single/multi strings</td>
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<tr>
<td>- Heavy/Light Industrial &amp; aeroderivative gas turbines</td>
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<td>- Electrical motors fixed /variable speed</td>
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<th>Storages Condensate, LPG/LNG (5 Options)</th>
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<td>- LNG Storage capacity</td>
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<td>- Type (atmospheric, pressurised, single /double/full containment or equivalent)</td>
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**Figure 11: Main Design Alternatives Assessed During PreFEED**

The concept options indicated in bold and red in Figure 11 highlight the selected options used for the Design Case and briefly explained below.

- **Cooling media:**
  Air cooling system selected. The alternative seawater cooling solution was discarded because its significantly increases CAPEX and creates marginal economic benefit. In addition, the seawater system has an impact on environmental and marine life. Maintenance of the seawater system presents crucial issues to the operator due to fouling and corrosion of the facilities.

- **LPG Extraction:**
  High Recovery Scrub Column with MR condenser configuration selected for LPG extraction. The alternative solutions did not meet LNG requirements (the Wobbe index), fuel gas specifications, commercial butane local market requirements thus higher CAPEX.

- **Train configuration selection:**
  - Resulting from the initial drivers screening, 6 concept configurations were assessed, setting the plant’s process scheme, Figure 12.
Each configuration was assessed and ranked using quantitative (CAPEX, OPEX, Availability and environmental impact based on CO₂ equivalent emissions) and qualitative criteria (Operability/maintainability, operation flexibility/capability of accommodating future additional options, technology industrial references). The results of the ranking are presented in Figure 13 with the highest score representing the most favourable option.

**Figure 12: Concept Configurations**

- Reference case (1)
  - 3.5 Mtpa LNG train, single MR & C3 compressor/driver strings, industrial GT drivers, air cooled, on site power generation

- Low case (2)
  - 2.5 Mtpa LNG train, single MR & C3 compressor/driver strings, industrial GT drivers, air cooled, on site power generation
  - This case allows the evaluation of the economy of scale

- Aero derivative drivers (3)
  - 3.5 Mtpa LNG train, 2 x 50% MR & C3 compressor/driver strings, aero-derivative GT drivers, air cooled, on site power generation

- Electric motor drivers (4)
  - 3.5 Mtpa LNG train, single MR & C3 compressor/driver strings, electric motor drivers, air cooled, on site power generation

- Lean feed gas (5)
  - 3.5 Mtpa LNG train, single MR & C3 compressor/driver strings, industrial GT drivers, air cooled, on site power generation, no LPG extraction facilities
  - This case evaluates the savings associated with a minimum scope

- Stand alone NGL recovery unit (6)
  - 3.5 Mtpa LNG train, single MR & C3 compressor/driver strings, industrial GT drivers, air cooled, on site power generation
  - Stand alone NGL extraction unit upstream liquefaction unit

**Figure 13: Configuration Ranking**

- Based on the ranking, the two most appealing configurations were the Reference and Lean gas (neither condensate, nor LPG extraction) cases. Both represented the lowest annual LNG production CAPEX/ton, higher operability and extensive technological references. Between the 2 cases, the lean gas case was deemed less favourable due to need for pretreatment of the feed gas either in an independent plant (overall economics is lower as indicated during the feasibility study) or at the various offshore gas production facilities (technically and economically too challenging).
Storages:

Assessment of the different tank technologies concluded in selecting full containment technology for LNG and LPG refrigerated tanks due to safety and site preparation costs. Larger site are required for other tankage technologies due to the greatly extended safety distances and more elaborate fire fighting facilities. During FEED phase, membrane technology having equivalent safety level should be considered. The condensate atmospheric single containment tank technology, with internal floating roof, presented the lowest CAPEX for an acceptable safety level.

4.6. Phase 2: Pipeline System Design Definition

The routing design highlighted possible options taking the coordinates of the existing offshore production facilities and the trunk/spur-lines length restrictions into consideration. Figure 14 shows the different obstacles (e.g. existing production platforms, subsea installations, telecom cables, Cameroon Volcanic Line or CVL) in or around the corridor. The basis for the routing selection is to minimise the challenges and limit the water depths.

![Figure 14: Constraints Mapping Along the Potential Pipeline Routes](image)

The selected route for preFEED and corresponding water depths are presented on Figure 15.
In the selected route, the pipeline preliminary design set the following:

- Pipeline metering, Corrosion Inhibitor injection skid, Emergency Shutdown Valves and control systems
- Pipeline platform risers, J tubes, and subsea connection spools to the subsea pipeline connections
- Permanent pig launcher at the upstream and trunkline platforms
- Subsea Isolation Valves integrated into piled subsea structures
- Subsea spurlines tie-ins along the trunkline

Figure 15: Pipeline Route and Corresponding Water Depths
Subsea shore approach to a landfall beach valve
Onshore pig reception facility
Slug catcher

Technical solutions were implemented for crossing the Cameroon Volcanic line and pipeline land fall. Figure 16 details the land fall.

Figure 16: Offshore Pipeline Land Fall Details

4.7. Phase 2: LNG Plant Design Definition
The onshore plant was designed to accommodate different feed gas qualities due to the field production constraints and the gas fields production phasing. Feed gas composition is foreseen to fluctuate during the life cycle of the plant. Three representative design feed gas compositions were selected considering the wide gas quality spectrum potentially feeding the plant. Furthermore, design margins were defined to match the uncertainties in the feed gas quality, within conventional technologies to avoid extra expenditures and technology risks.

All other parts of the preliminary design are standard and no specific issues have been raised, except the site characteristics within the plant layout.

The layout was developed considering the European standard EN 1473 specifying main requirements for equipment safety distances. Safety distances have been verified through a preliminary hazard assessment. The layout also considered:

The Site boundary
Land fall and jetty location
Topography, hydrology
Prevailing wind conditions
Preliminary site geological and geophysical data

Preliminary data were made available by the local authorities who conducted preliminary site surveys for the deep sea port project development, making the basis of design for the pre-FEED more robust than usual.

Specific studies, in particular, site preparation cut and fill analysis, drainage study and foundation design for the heaviest components (product tanks, large static and rotating equipment) were conducted to optimize the layout. Figure 17 represents the pre-FEED preliminary layout. This layout would be readdressed during FEED phase with more elaborate geophysical and geotechnical data.
At the end of the preliminary studies, a Value Engineering workshop was held for reviewing and challenging the engineering design at the PFD level, to identify and implement actions for:

- Reducing CAPEX and OPEX
- Simplifying design

On review of the PFD, 20 items were identified in finalising the Pre-FEED and 21 items to be carried out in the FEED phase.

An overall cold eye review identified 22 additional studies to be considered during FEED for further improvement of the Project economics. Figure 18 shows the preliminary 3D design overview.

Preliminary Liquefaction plant main features are summarised below, they could be adjusted during next phase:

- 1 LNG train up to 3.5 Mtpa
- One onshore tank of 190 000 m³ (full containment or equivalent)
- Two LPG tanks of 44 000 m³ (full containment or equivalent)
- One Condensate tank 60 000 m³ (single containment with internal floating roof)
- Material offloading facilities for construction phase
- Product export jetty of 1650 m
4.8. Cost Estimates
The class 3 cost estimate was established in accordance with the Association for the Advancement of Cost Engineering, AACE recommendation 18R-97. Pipeline and Plant CAPEX were calculated based on the equipment list extracted from each system’s PFD and plant layout. The bulk estimate was calculated per type of system. Engineering Procurement Construction Commissioning (EPCC) contractor fees and contingencies were calculated and adjusted taking into account the site characteristics, country risk and market conditions.

Owner costs were established in a detailed manned based, in particular, on its organisation and maintenance costs. The contingencies were assessed to cover risks which were identified during specific workshops with the preFEED contractor and Project Partners. Finally a third party reviewed the cost estimate. At the end of the process, the cost estimate accuracy was estimated between -15% to +30%.

This cost estimate was used to fine-tuning the Project economics. Based on these results, pre commercial agreements were signed with gas producers which represent an important milestone for the Project development.

5. CONCLUSIONS
Cameroon LNG Project has achieved significant progress since the Project was launched.

The pre-FEED studies and initial Bankability study have demonstrated that a LNG export Project is economically viable in Cameroon.

The Project benefits of full Cameroonian State support as it is one of the largest projects that will contribute to the country’s ambitious development.

On site, early work activities have started. A meteorological station and three data buoys were installed to gather meteo data. Geophysical and geotechnical survey campaigns are soon to be launched on site. All collected data will be utilised to create a more robust basis of design thus minimising development risks.

Currently, the Cameroon LNG Project has completed its preliminary ESIA covering both the pipeline and onshore facilities. The first public information was delivered in 2012, while simultaneously, a comprehensive social acceptance programme was launched fully involving the local community.

The Project Partners have deliberately put a strong focus on proven technical choices, low CAPEX options, environmental concerns and local integration, which are key to the success of Cameroon LNG. Today we believe the Project has gained the right momentum for a successful development.