PUBLIC LEILAC FEED SUMMARY REPORT

Version 1.00

July 2017

Project LEILAC | Low Emission Intensity Lime and Cement project

Public LEILAC FEED Summary Report

Project partners:

- Calix (Europe) Limited
- HeidelbergCement AG
- CEMEX Research Group AG
- Tarmac Trading Limited
- Lhoist Recherche et Developpement SA
- AMEC FOSTER WHEELER ENERGY LIMITED
- Calix Limited
- Stichting Energieonderzoek Centrum Nederland (ECN)
- Imperial College of Science Technology and Medicine
- Process Systems Enterprise Limited (PSE)
- Quantis Sàrl
- The Carbon Trust

LEILAC is supported by

- The European Cement Association (CEMBUREAU),
- The European Cement Research Academy (ECRA), and
- The European Lime Association (EuLA).

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CONTENTS

1. EXECUTIVE SUMMARY

The LEILAC Front End Engineering and Design (FEED) study was intended to provide a final design and cost for an optimal pilot Direct Separation plant configuration, completed to a point such that no material variations are required following the Financial Investment Decision (FID). As such, this FEED report summarises the main engineering actions of this critical development phase of the project, contributing to the final formal project stage-gate. It covers the period from October 2016 to the Final Investment Decision (FID) in June 2017.

Throughout the FEED a number of critical steps have been taken to ensure that the proposed pilot plant operates as expected, is safe, and that its cost and schedule estimate are refined to the point where the project's governing body can take a final investment decision. As such, this FEED report contains summaries (as far as possible) of the engineering and design activities that have been undertaken – building on, and agreeing with, the Basis of Design and pre-FEED report (D3.2). Covering all the critical engineering elements that will be required to construct the pilot (process descriptions, equipment lists, engineering by discipline, construction plan, etc.) this design has been developed in compliance with Amec Foster Wheeler's corporate procedures and standards, and regulatory requirements.

Core to the LEILAC project is health and safety, and this FEED report provides and overview of how this is being comprehensively and successfully addressed. Key elements of the H&S Management Study Report that has been developed include the Scope and Responsibilities document, Health and Safety Plan, and the Environmental Plan.

A final critical element of the FEED has been the development of the Cost and Schedule Estimates for the pilot. Building on the extensive pre-work undertaken in the initial part of the project, procurement preparation has continued, including the issuing of formal competitive requests for quotation (RFQ) for the major item and equipment packages. For each package a Competitive Tender enquiry was issued to no less than three vendors, with fixed lump sum prices with pricing breakdowns being requested.

The resulting design option, project schedule and project cost was accepted by the project's governing bodies in June 2017. The project will now enter the next stage of development. During the Engineering, Procurement and Construction phase, the pilot and its equipment will be built and integrated into the HeidelbergCement cement plant at Lixhe, Belgium. It is anticipated that the pilot plant will commence operations in early 2019.

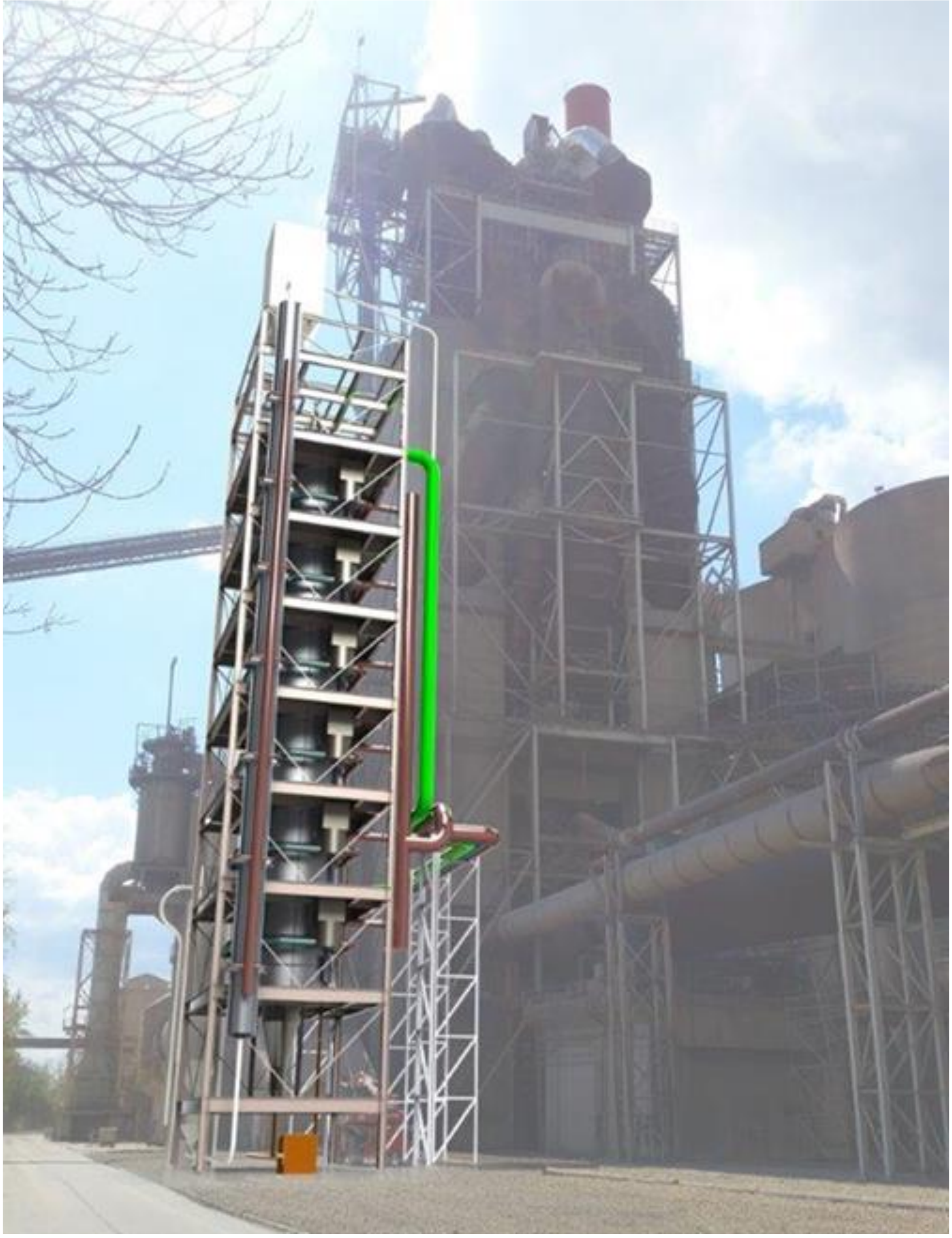
2. PROJECT BACKGROUND

LEILAC (Low Emissions Intensity Lime And Cement) will pilot a breakthrough technology that aims to enable both Europe's cement and lime industries to capture their unavoidable process carbon dioxide (CO_2) emissions for no energy penalty (other than compression) and at comparable capital costs to conventional equipment.

Calix's Direct Separation technology re-engineers the existing process flows by indirectly heating the limestone. This unique system enables pure CO_2 to be captured as it is released from the limestone. This elegant solution requires no additional chemicals or processes. This innovation requires minimal changes to the conventional processes for cement, and simply replaces the calciner.

LEILAC will develop, build, operate and test a 240 tonne per day pilot plant next to the HeidelbergCement's plant at Lixhe, Belgium, demonstrating that over 95% of the process CO2 emissions could be captured (60 % of total CO_2 emissions) from cement production (or lime) without significant energy or capital penalty. LEILAC will deliver a techno-economic roadmap for the technology's scale up and deployment. Comprehensive knowledge sharing activities are currently taking place, including a visitor centre at the pilot site near Brussels.

The international and EU community recognises that CO_2 emissions contribute to climate change. 80% emissions reductions are required by 2050, and LEILAC is uniquely placed to enable European cement and lime industries to contribute towards these targets in a timely, effective and efficient manner.



An impression of the LEILAC pilot from ground level

3. PROJECT PARTNERS

The consortium is led by technology provider Calix, and comprises HeidelbergCement, CEMEX, Tarmac, Lhoist, Amec Foster Wheeler, ECN, Imperial College, PSE, Quantis and the Carbon Trust.

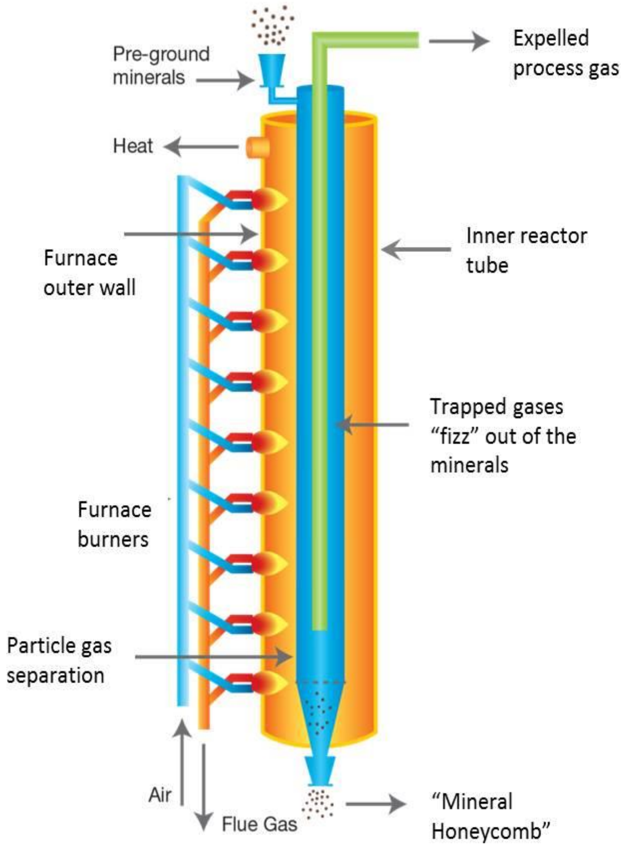
The project is supported by The European Cement Association (CEMBUREAU), The European Cement Research Academy (ECRA), and the European Lime Association (EuLA).

This project has received €12m of funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 654465.

4. TECHNICAL OVERVIEW

The LEILAC project aims to enable the efficient capture of the unavoidable process emissions from lime and cement production.

Calix's technology re-engineers the existing process flows of a traditional calciner, indirectly heating the limestone via a special steel vessel. This unique system enables pure CO2 to be captured as it is released from the limestone, as the furnace exhaust gases are kept separate. It is also a solution which requires no additional chemicals or processes, and requires minimal changes to the conventional processes for cement as it simply replaces the calciner. As two-thirds of CO_2 emission from cement production is generated from the limestone itself, this technology offers a unique opportunity as it can capture these emissions without significant energy or capital penalty. The energy losses associated with Direct Separation technology are primarily heat losses in the equipment, and CO_2 compression (for transport and storage).



It also enables the use of carbon capture techniques, which have been already developed by the power sector to be applied to the heating emissions.

In conjunction with research on key issues for building and scaling up the technology, the project, starting in 2016, will focus on the development, construction and extensive testing of the technology. Following a stage-gate feasibility, front-end engineering, and then design phase - construction should commence during late 2017. The pilot plant should be ready for operation during 2019 and will be test run for up to 2 years to demonstrate the technology. The verified results will be used to create a techno-economic roadmap.

5. BASIS OF DESIGN

The LEILAC Basis of Design document served as the design basis for the LEILAC pilot plant pre-FEED and FEED studies. It establishes the design criteria and assumptions for the main systems involved in the pilot plant. At the commencement of the project, over 40 process flow options were tabled. Through detailed assessment of these options, shaped by the initial results of the investigations and experimental work discussed above and building on the experience gained by Calix through the development of the CFC850 pilot plant and the CFC15000 production demonstration plant, a single primary design basis was proposed and approved. The Basis of Design (BOD) used mass and energy balances to determine and size the pilot plant, addresses the primary risks identified, with significant input from all of the project partners, and enabled preliminary engineering work and costing to commence.

6. ENVIRONMENT HEALTH AND SAFETY

6.1 Safety Studies

Planning

A series of health, safety and environment plans were generated for the FEED phase, to ensure appropriate adoption of EHS policy and health and safety regulation. These will be updated in the detailed design phase. The compliance was structured around EU Directives, but facilitation of local, Walloon region, requirements will need to be addressed in the next phase of the project.

HAZID

A Hazard Identification (HAZID) study was conducted during the feasibility phase, which was intended to identify safety and environmental impact hazards. Early identification of such hazards enables a lower cost for mitigation, and the study raised a number of actions. The majority of these actions were addressed in the feasibility and FEED phases, but some have been held open for detailed design.

The majority of hazards related to the use of natural gas to fire the preheater and reactor furnace, with the need to ensure appropriate controls within novel equipment. Other significant hazards included those related to a loss of containment of hot meal/cement and carbon dioxide.

HAZOP

A Hazard and Operability (HAZOP) study was conducted during the FEED phase, and the design was broken down into seven nodes, a report issued, and 88 actions raised.

No significant concerns were raised, but a revision to the study will be necessary in detailed design when actual vendor information will be provided for individual packages, as the study considered current Amec Foster Wheeler understanding of vendor provision.

The HAZOP raised a number of hazards that are planned to be mitigated by safety instrumented functions (SIF), and hence was used as the basis for a subsequent safety instrumented level (SIL) assignment.

SIL

The HAZOP study identified a number of hazards to be mitigated by safety instrumented functions, so a Safety Integrity Level (SIL) assignment study was carried out, to be compliant with IEC 61511, edition 2. A tolerability of risk was derived from the IEC standard, and agreed between Amec Foster Wheeler and Calix, based on a risk tolerance of one fatality or major environmental incident every 10,000 years. A Layers Of Protection Analysis was carried out, concluding that five hazards required SIF. Of these, two were assigned SIL 2.

BAT

A preliminary Best Available Technology (BAT) assessment was carried out, to try and identify environmental impacts on the plant design, recognising any environmental permit variation would be the responsibility of Heidelberg Cement. Given all continuous emissions would be routed back to the existing plant, no new emission points would be caused, but the impact of more combustion plant could lead to increased nitrogen oxide emissions, which would need to be controlled by judicious selection of burner type, to ensure best available technique had been incorporated.

ATEX Compliance

A short Explosive Atmospheres study was carried out to determine the extent of classified are around the gas handling systems.

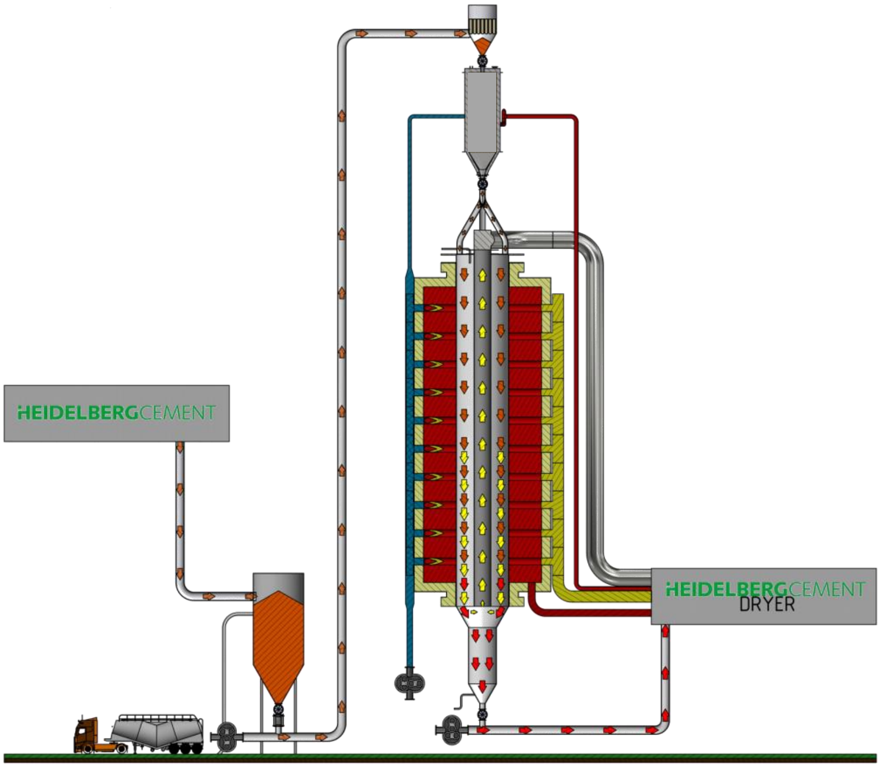
The study also considered the potential for confined space explosions, and the project adopted the provision of appropriate integrity burner management systems to mitigate the risk of continued gas supply into a hot furnace shell, in preference to explosion doors.

6.2 Project HSE Issues

A number of HSE issues will need to be progressed during detailed design:

- Local implementation of the Temporary or Mobile Construction Sites Directive, and determination of any Walloon design/construction interface regulations.
- Extent of package responsibility and provision by specialist vendors.
- Confirmation of SIL targets for remaining SIF, and confirmation of risk tolerances with all stakeholders
- Ensure burner technology is best available technique for NOx control.

7. PROCESS DESCRIPTION



Raw process material is sourced either from the HeibelbergCement plant or delivered via road tankers and stored in the Raw Feed Silo in preparation for being fed into the Direct Separation Reactor.

The raw material is pneumatically conveyed to the top of the reactor tower before being separated from the transport gas. The material is then metered through an indirect preheater increasing the material's temperature before being fed into the Direct Separation Reactor.

The Direct Separation Reactor uses external burners to indirectly heat the outer reactor wall to temperatures in excess of 1000°C.

As the material falls through the reactor, calcination occurs releasing pure CO_2. The Direct Separation Reactor separates the process solids from the CO_2. At a full scale plant the uncontaminated CO_2 will be either used or compressed and stored.

The separated solids and all other sources of waste gas are returned to the HeidelbergCement plant.

Site Location

The site is the located within the CBR Lixhe cement plant, located on the eastern border of Belgium.

- Address - Rue des Trois Fermes,
  4600 Lixhe-les-Visé
  Belgium
- Latitude - 50.762536°
- Longitude - 5.673225°

It will be located alongside the existing calciner tower of the cement plant.

8. PROCESS CONTROL STRATEGY

The operation of the plant is to be automated to a point that it may operate stably at steady state without operator intervention. The user will be able to enter set points which the control system must target or may be able to set variables directly within the system. Health, Safety or Environmental requirements, and equipment protection requirements, will dictate certain control measures to ensure a high level of safety is consistently maintained.

The plant's research nature has direct influences on the control system that would not typically be seen in day to day mass manufacture plant. The operators must have the ability to vary the operating conditions to test their influences on the process stream and resultant product while maintaining the same safety requirements of a typical plant. A control hierarchy is used to ensure a high level of safety is maintained through-out the varied operating conditions. SIL rated risk sensors hold the right of decision making in the control system, either bring the system back into a safe range or safely shutting down the plant down.

9. PRESSURE RELIEF

Due to the non-flammable/non-toxic nature of the solids, and the manner of the solids handling process, pressure relief from solids handling will discharge directly to atmosphere either upstream of the solids process, or downstream of filtration equipment to remove any solids from the streams. Process vents will also be in use during normal operation for the solids conveying operation.

Any potential for solids release to atmosphere as a result of pressure relief are strictly not allowed in the project. The Direct Separation Reactor (DSR) CO_2 offgas line will contain a pressure relief line so as to ensure no damage to equipment with low tolerance to high pressures.

It has been requested of vendors of pumps, blowers and fans to provide integral pressure relief for equipment to prevent overpressure cases from occurring. This was deemed sufficient for the pilot nature and the expected lifespan of the plant. The provision of this pressure relief is to be confirmed in the next phase.

Where it is stated to be in the project scope, the conditions of each potential relief scenario are to be evaluated and recorded in dedicated calculations for each relief valve in the next phase.

A summary of safety/relief valves in the project scope is as follows:

Relief Valve	P&ID	Protected Equipment
PSV-0003	29690-8111-3B4-25-0003	112-HE-01

10. EQUIPMENT LISTS

Preliminary equipment datasheets have been produced for all main equipment items. Vendor proposals have been consolidated and preliminary data has been updated in the project equipment list.

It should be noted that for some equipment listed, the vendor has not yet been selected, and hence design data and utility consumptions are subject to change during detailed engineering once vendor selection has been completed.

11. DISCIPLINE ENGINEERING OVERVIEW

11.1 PIPING

11.1.1 Introduction

This section describes the piping basis for the works required as part of the FEED Study for the Leilac project at Lixhe, Belgium.

11.1.2 Plot Plan (29690-8230-3B4-01-0001 and 0002)

The Plot Plan shows the extents of the main process area along with basic supply and return routes for the main pipework. The major process equipment along with supporting structure and civil requirements are also shown on this drawing. These items along with associated auxiliary equipment have been modelled in a 3D CAD package to ensure that the footprint shown in the plot plan is adequate and to identify the scope of the main civil works.

The Plot Plan was formally reviewed by Amec Foster Wheeler and Calix. Calix reviewed with Heidelberg Cement prior to the formal review.

The main items of equipment shown on the Plot Plan are:

- 111-FL-01 Feed Filter
- 112-HE-01 Pre-Heater

- 120-RE-01 DSR Reactor
- 111-HP-01 Ground Feed Storage Silo
- Also shown are the locations for the E&I rooms, the Control Room and the provisional tie-In points for supply of Meal, Natural Gas and Towns Water along with the tie-In point for product and Flue Gas return

11.1.3 Tie-in connections (TP-01, 02, 03 & 04)

Part of the design will be the requirement to connect to existing Lixhe pipework. This includes:

- TP-01 - Product / Meal supply from the spare connection on the existing Silo 360.1.021
- TP-02 - Potable Water supply
- TP-03 - Product return tie-in to the existing ductwork, including Flue Gas from the new plant and will be designed and located by Heidelberg Cement
- TP-04 - Natural Gas supply

11.1.4 Codes and Standards

All pipework is designed to the latest versions of ASME / ASTM standards as follows:

- ASME B31.3 - Code for Pressure Piping
- ASTM A312 - Stainless Steel Pipework
- ASTM A333 - Carbon Steel Pipework (including casing for Refractory Lined pipework)
- ASTM A213 - High Temp stainless steel pipework

The above materials were selected to comply with the PED.

11.1.5 Construction / Operating Hazards

The following risks have been identified as part of FEED:

- Working at height - during construction phase there will be the need to erect pipework at height. Although this cannot be completely eliminated the majority of the pipework will be dressed on the modules at grade with the use of Hook-up spools between modules.
- Attachment to existing buildings and steelwork - there will be the need to confirm that the attachment of pipe supports to existing steelwork and concrete will be suitable.
- Hot pipework - there is a large amount of hot pipework both on the structure and at grade ranging from 75 deg C up to 1150 deg C. Wherever it is possible for personnel to touch this pipework there will be either personnel protection applied direct to the pipework in the form of open mesh cage or the area will be barriered off to prevent personnel approaching that area.

- Attachment to existing Pipe and Ductwork - all new pipework will be designed and/or supported in such a way that there will be very little / no impact on the existing equipment and pipework.

11.2 CIVILS

11.2.1 Introduction

This section describes the Civil and Structural works required as part of the Leilac project at Lixhe, Belgium.

11.2.2 Ground Conditions

Currently the underlying ground conditions are to be determined by a site investigation study, including boreholes and trial excavations. A Site Investigation Specification has been completed in readiness for the investigation to be undertaken. There is evidence on adjacent sites of the shallow depth of overlying soil to the rock horizon (chalk deposits), though the exact depth to the outcrop at the site is unknown.

It is anticipated that, due to the height of the main structure, the main foundation will be piled. An assessment of the pile length shall be determined during the EPC, once the Site Investigation has been completed. The pile may be designed with a combination of resistance from end bearing in the rock and skin friction in the alluvium.

11.2.3 Topographic Survey

The site arrangement has been prepared in conjunction with the existing site drawings provided by the site owner and a site reconnaissance visit completed in June 2016.

At the commencement of the EPC stage a Topographic survey, will be required, to confirm locations and levels of the existing equipment, services and ground, adjacent to the proposed site. A specification has been prepared in preparation for completion of this work.

11.2.4 Process Equipment

All of the process equipment was detailed.

The arrangement of the process equipment is shown on the Plot Plans 29690-8230-3B4-01-0001 and 0002. The main pieces of equipment have been listed, and their locations identified.

11.2.5 Connections to Existing Services

There is a requirement to connect to the existing site infrastructure to feed into the main process. These services include the meal Feed, fuel provision, and product and gas offtake.

11.2.6 Existing Services

In the vicinity of the proposed site there are a number of existing services. During FEED, it was determined that they remain in their current location and are incorporated or protected within the proposed foundation arrangement.

11.2.7 Scope of Structural Work

The scope of the structural work developed during the FEED was detailed, and included both primary structures for the reactor, and secondary structures to support connections to existing infrastructure.

11.2.8 Scope of Civil Work

The scope of the civil work developed during the FEED was detailed. These include Further refinement will occur during the EPC stage, once further information is available. It is not anticipated there will be any modifications to the existing roads.

11.2.9 Design Life

The project is a development project and is to be designed with a 10 year design life. In accordance with Eurocode 1990 clause 2.3, the structure is classified as a temporary structure Category 1.

11.2.10 Applied Loadings

Dead Loads

The new works will be designed in accordance with the Eurocode requirements specified in BS EN1991-1-1.

Imposed Loads

The new works will be designed in accordance with the Eurocode requirements specified in BS EN 1991-1-1. The structure category is E2, industrial use.

Equipment Loads

Equipment and piping dead and imposed loads have been applied to the structure.

Wind Loads

The new works will be designed in accordance with the Eurocode requirements specified in BS EN 1991-1-4.

Load Factors

The structures and their foundations have been designed and detailed.

11.2.11 Codes and Standards

The codes applied to the design are the Eurocode suite of standards.

1991-1-1 Densities, Self Weight and Imposed Loads
1991-1-4 Wind Actions
1991-1-5 Thermal Actions
1991-1-6 Actions during execution
1992 - Design of Concrete Structures
1993 - Design of Steel Structures
1997 - Geotechnical Design

Material Specifications shall be:

BS EN 206 - Specification of Concrete
BS EN 10025 - Specification of Structural Steelwork
BS EN 14688 - Geotechnical Investigation and Testing - Identification and Classification of Soil
BS EN 22466 - Geotechnical Investigation and Testing - Field Testing
BS1377 - Soils for Civil Engineering Purposes
BS 5930 - Code of Practice for Site Investigations

11.2.12 Material Selection

The main Civil and Structural materials have been selected and detailed.

11.2.13 Construction Hazards

The construction risks have been identified as part of the FEED, itemised, and mitigation steps agreed upon.

11.3 INSTRUMENTS & CONTROL

11.3.1 General

This section describes the control & instrument work scope executed for FEED, the basis and method of execution and highlights any issues requiring further development in the EPC phase.

11.3.2 Buildings

There are two control & instrument buildings planned for the plot. The first is a combined electrical and instrument equipment room located adjacent to the structure. This building will house the instrument system cabinets, e.g. P.C.S. (Process Control System) & S.I.S. (Safety Instrumented System) along with the electrical cabinets and MCC.

The second is an instrument control room which is located east of site. This room will consist of a plant operator station and plant shutdown capability.

11.3.3 Process Control System (P.C.S.)

It is proposed that a Process Control System (P.C.S.) will provide the operator interface to monitor and control the LEILAC Plant. Process monitoring control, sequences and non-safety related process interlocks and logic functions shall generally be executed in the P.C.S.

11.3.4 Safety Instrumented System (S.I.S.)

Safety Instrumented Systems (S.I.S.) will provide both manual and automatic means of minimising any escalation risk to the facility, by isolating process systems and equipment, in the event of hazardous abnormal conditions.

11.3.5 Hazardous Area Protection

Hazardous areas have been identified, and area protection has been assigned.

11.4 ELECTRICAL

11.4.1 Scope of Supply

The aim of the electrical scope of work is to develop the electrical infrastructure requirements to support the construction of the new LEILAC (Low Emission Intensity Lime and Cement) Plant.

11.4.2 Electrical Scope of Work

The FEED electrical scope of work included the following:

- Assess load requirements for all new equipment and production of an Electrical Load Schedule
- Providing an assessment of underground cable routes and requirements
- Producing a detailed Bulk Material Take Off
- Producing a detailed Cable Schedule
- Producing detailed Cable Sizing Calculations
- Producing detailed lighting and small power layouts
- Producing detailed cable routing layouts
- Producing Block Cable Diagrams
- Producing Single Line Diagrams

11.4.3 Power Transmission/Distribution System

The power transmission/distribution systems were fully considered.

11.5 MECHANICAL

11.5.1 General

Formal material requisitions were developed and issued via procurement for all of the major equipment items, including:

- Burners for the DSR and Preheater
- DSR Furnace
- Preheater
- Reactor Tubes

11.5.2 Other Equipment

All other equipment was assessed against the Process Design to determine a suitably accurate estimate for price and sizing to feed into the FEED Estimate and FEED layout.

12. CONSTRUCTION

12.1 Construction Documentation

A full set of construction documentation was developed during the FEED phase of the project.

12.2 Construction Execution Strategy

The purpose of the Construction Execution Strategy (CES) is to outline the construction execution approach established during the FEED and which will be further developed for the project during the EPC phase. The CES defines the extent of responsibilities and the methods by which the project shall be constructed and completed.

This document was the key construction deliverable created during the FEED phase of the project. The CES has brought together all the construction issues into one document and sets out how construction will be executed throughout the project. It includes:

- Path of Construction
- Lifting Operations
- Permit to Work Systems
- Hot Work Minimisation
- Pre-Assembly Strategy
- Plant Tie-Ins
- Worksite Organisation
- Fabrication & Installation Strategy
- Contracting Strategy

- Labour Recruitment
- Training
- IR Strategy and
- Material Control, Preservation & Maintenance.

Additional construction deliverables will be developed to support this document during the EPC phase of the project.

The CES is a 'live' document and shall be periodically reviewed and updated to reflect project development during the detailed design phase of the project.

12.3 Constructability Review

Constructability is the timely and effective application of engineering and construction knowledge, experience, and lessons learnt to improve construction performance and optimise safety, cost, schedule and quality.

Constructability Reviews were carried out during the Pre-FEED and FEED phases of the project, with key discipline members of the Amec Foster Wheeler and Calix project team.

The Constructability Review Report has been issued. This report provides details of actions raised during the reviews.

The review included:

- Constructability presentation covering key issues including:
  - Transportation and Lifting
  - Vehicle Routes
  - Permit to Work
  - Path of Construction
  - Temporary Facilities.
- Review of Amec Foster Wheeler standard constructability checklist and assignment of actions.

Subsequent actions derived from completion of the constructability checklist were either closed out during completion of the FEED or assigned to be completed during the EPC Phase of the project.

12.4 HAZCON 1 Review

The HAZCON 1 Review is the first HAZCON on the project. The process was used to identify and assess Construction Safety, Health and Environmental hazards that may occur during the execution of the project.

During the FEED Study a HAZCON 1 Safety Review was undertaken covering construction hazards relative to the works associated with the project. From this initial review, there were several actions generated which will be closed out during the EPC phase of the project.

Risks identified in the HAZCON review with a residual risk value of high or medium will be required to be actioned during the EPC phase to bring the residual value down to a low rating.

12.5 Temporary Facilities Plan

A Temporary Facilities Plan has been developed during the FEED. The purpose of this document is to provide a basis upon which temporary site facilities shall be specified, designed, priced and provided. The plan has been developed by the Amec Foster Wheeler and Calix project team.

Designated areas for temporary facilities have already been identified at site. The areas identified will be utilised to site following facilities:

- EPC and Contractor Welfare Facilities
- General, Material Storage, and Equipment Laydown Areas
- Pre-Assembly and Dressing Area.

At the commencement of the EPC phase, this plan shall require supplementary input, verification and revision to further validate:

- Walking/pedestrian access routes from the car parking area to the welfare facilities
- Disposal routes/strategy for the spoil generated from the piling operations
- Dewatering strategy
- Temporary power requirements
- General layout review of the facilities, crane berthing and lifting zones.

The Temporary Facilities will be utilised by the EPC Contractors and Construction Contractors for the duration of the project.

13. PROCUREMENT

13.1 FEED Stage Procurement Report 26/04/17

Non-Disclosure Agreements were signed and returned by vendors where appropriate. Relationships and contacts were developed with suppliers for correspondence, enquiries, technical clarifications, problem solving etc. Single vendor points of contact (commercial and technical) were requested and received.

The aim of the FEED stage procurement was to gain the most accurate costs for estimate, not to select final vendors.

Based on early and developing design enquiries were issued subject to the formal procurement enquiry process. These scopes of work were deemed to be the main critical packages of equipment/service.

Other budget costs included within the FEED estimate were requested and obtained directly by the discipline engineers, or estimated with in-house data).

The procurement strategy used for each formal enquiry was Competitive Bid followed by Technical Evaluation and Commercial Evaluation (partial). The details of the Commercial Bid Evaluations were completed based on the vendor's early, undeveloped responses.

Amec Foster Wheeler Standard Terms and Conditions of Purchase were issued as 'sample' terms at this FEED stage to gauge vendor opinion.

Each Competitive Tender enquiry was issued to no less than 3 vendors, with fixed lump sum prices with pricing breakdowns being requested. Where applicable a Schedule of Rates was requested for Site Services and Supervisory Assistance during commissioning/installation phase.

14. COST ESTIMATES

A +/- 15% cost estimate comprises an overall summary, followed by a breakdown of equipment costs and then backup sheets for the remaining cost items.

This cost estimate formed a major element of the project’s forward budget, which was provided to the General Assembly in June 2018 for a Final Investment Decision.

15. SCHEDULE

The overall engineering, procurement and construction schedule was assessed for Project LEILAC. This identified an 18 months duration for these works.

Critical path for the pilot’s construction and commissioning was identified. This schedule formed a major element of the project’s plan, which was provided to the General Assembly in June 2018 for a Final Investment Decision.

16. FINAL INVESTMENT DECISION

In June 2018, the General Assembly of the The Low Emissions Intensity Lime & Cement (LEILAC) project accepted the completion of the Front End Engineering Design (FEED) study for the pilot plant. This was completed successfully and on time. This also marked the passing of the Final Investment Decision (FID) for the project, based on the forward budget and schedule. The project will now enter an Engineering

Procurement and Construction phase. It is anticipated the pilot plant will commence operation in early 2019.

17. ABBREVIATIONS

ASME	-	American Society of Mechanical Engineers (international codes and standards)
ASTM	-	American Section of the International Association for Testing Materials (international codes and standards)
ATEX	-	Equipment for use in ATmosphères EXplosibles (EU Directives 2014/34/EU and 99/92/EC)
BAT	-	Best Available Technology
BOD	-	Basis of Design
BS	-	British Standards
CES	-	Construction Execution Strategy
CFD	-	Computational Fluid Dynamics
CO_2	-	Carbon dioxide
EC	-	European Commission
EN / Eurocode	-	European standard for structural design
ENVID	-	ENVironmental Impact IDentification
EPC	-	Engineering, procurement and construction
DSR	-	Direct Separation Reactor
FAD	-	Free Air Delivery
FEA	-	Finite Element Analysis
FEED	-	Front End Engineering Design
FID	-	Final Investment Decision
FSI	-	Fluid Solid Interaction
gPROMS	-	PSE's advanced process modelling product
H&MB	-	Heat and Mass Balance
HAZCON	-	HAZard in CONstruction (Safety, Health and Environmental)
HAZID	-	HAZard IDentification (Safety, Health and Environmental)

HAZOP	-	HAZard and Operability (Safety, Health and Environmental)
HSE	-	Health, Safety and Environment
LEILAC	-	Low Emissions Intensity Lime and Cement Project
LHV	-	Lower Heating Value
LPM	-	Litres per Minute
PCS	-	Process Control System
Pre-FEED	-	Preliminary Front End Engineering Design
RAS	-	Reverse Axial Separator
P&ID	-	Piping and Instrumentation Diagram
PFD	-	Process Flow Diagram
SI	-	International System of Units
SIL	-	Safety integrity level
SIS	-	Safety Instrument System
TBD	-	To Be Determined

18. LIST OF MAIN FEED DELIVERABLES PRODUCED

While the following appendices are unavailable in this public summary report, the list of the main associated deliverables has been reproduced to provide a sense of the scope and breadth of the work undertaken in support of this engineering activity.

APPENDIX A - HAZID/ENVID REVIEW REPORT

29690-8150-3B3-PR-0004	O1	HAZID/ENVID REVIEW - TERMS OF REFERENCE
29690-8150-3B3-RP-0001	A1	HAZID/ENVID REVIEW REPORT

APPENDIX B - HAZARD & OPERABILITY REPORT

29690-8150-3B4-HR-0001	O1	HAZOP TERMS OF REFERENCE
29690-8150-3B4-HR-0002	A1	HAZOP STUDY REPORT

APPENDIX C - HAZID AND HAZOP CLOSE OUT REPORT

29690-8150-3B4-RP-0004	O1	HAZID AND HAZOP CLOSE OUT REPORT

APPENDIX D - SIL REVIEW REPORT

29690-8150-3B4-RP-0002	O1	SIL ASSIGNMENT REPORT

APPENDIX E - HSE PLANS 1, 2, AND 4

29690-8150-3B3-PR-0001	A1	HSE PLAN DOCUMENT 1 - SCOPE AND RESPONSIBILITIES
29690-8150-3B3-PR-0002	A1	HSE PLAN DOCUMENT 2 - HEALTH AND SAFETY PLAN
29690-8150-3B3-PR-0003	A1	HSE PLAN DOCUMENT 4 - ENVIRONMENTAL PLAN

APPENDIX F - ATEX RISK ASSESSMENT

29690-8150-3B4-RP-0003	O1	ATEX RISK ASSESSMENT

APPENDIX G - PRELIMINARY BAT DEMONSTRATION

29690-8150-3B4-RP-0001	A1	PRELIMINARY BAT DEMONSTRATION

APPENDIX H - PLOT PLAN & MODEL REVIEW

29690-8310-RP-0001	O1	PLOT PLAN REVIEW
29690-8320-3B4-PR-0001	O1	PLANT LAYOUT BASIS QUESTIONAIRE

APPENDIX I - P&ID REVIEW

29690-8110-3B4-RP-0001	A1	P&ID REVIEW ACTION SUMMARY REPORT

APPENDIX K - CAUSE AND EFFECT MATRIX

29690-8120-3B4-24-0100	A1	CAUSE AND EFFECT DIAGRAM

APPENDIX L - PROCESS FLOW DIAGRAM

29690-8110-3B3-20-0001	F1	PROCESS FLOW DIAGRAM

APPENDIX M - PIPING AND INSTRUMENTATION DIAGRAMS

29690-8111-3B4-25-0000 SHT 1/2	A1	
29690-8111-3B4-25-0000 SHT 2/2	A1	

29690-8111-3B4-25-0001	A1	
29690-8111-3B4-25-0002	A1	
29690-8111-3B4-25-0003	A1	
29690-8111-3B4-25-0004	A1	
29690-8111-3B4-25-0005	A1	
29690-8111-3B4-25-0006	A1	
29690-8111-3B4-25-0007	A1	

APPENDIX N- EQUIPMENT LIST AND DATASHEETS

29690-8110-3B4-EL-0001	A2	EQUIPMENT LIST

APPENDIX O - PROCESS DRAWINGS & DOCUMENTS

29690-8110-3B4-PS-0001	O1	
29690-8110-3B4-PS-0002	O1	
29690-8110-3B4-PS-0003	A1	PROCESS SPECIFICATION
29690-8110-3B4-PS-0007 SHT 1/1	A1	
29690-8110-3B4-PS-0008	A1	
29690-8110-3B4-PS-0009	A1	
29690-8110-3B4-PS-0010	A1	
29690-8110-3B4-PS-0011	A1	
29690-8110-3B4-PS-0012	A1	
29690-8110-3B4-PS-0013	A1	
29690-8110-3B4-PS-0014	A1	
29690-8110-3B4-PS-0015	A1	
29690-8110-3B4-PS-0016	A1	
29690-8110-3B4-PS-0018	A1	
29690-8110-3B4-PS-0019	O1	
29690-8110-3B4-PS-0020	O1	
29690-8110-3B4-PS-0021	A1	
29690-8110-3B4-PS-0023	O1	
29690-8110-3B4-PS-0024	A1	
29690-8110-3B4-PS-0201	O1	
29690-8110-3B4-PS-0202	O1	
29690-8110-3B4-PS-0203	O1	
29690-8110-3B4-PS-0204	O1	
29690-8110-3B4-PS-0205	O1	
29690-8110-3B4-PS-0207	O1	
29690-8110-3B4-PS-0208	O1	
29690-8111-3B3-PD-0001	O2	LEILAC BASIS OF DESIGN

29690-8110-3B3-22-0001	O1	DESIGN PRESSURE AND TEMPERATURE DIAGRAM
29690-8110-3B3-23-0001	O1	MATERIAL SELECTION DIAGRAM
29690-8110-3B4-26-0001	A1	PROJECT LINE LIST
29690-8110-3B4-53-0001	O1	TIE- IN REGISTER
29690-8111-3B3-21-0001	O2	HEAT & MATERIAL BALANCE

APPENDIX P - PIPING DRAWINGS & DOCUMENTS

29690-8230-3B4-01-0001	A1	FEED PLOT PLAN
29690-8230-3B4-01-0002	A1	FEED PLOT PLAN

APPENDIX Q - ELECTRICAL DRAWINGS & DOCUMENTS

29690-8530-3B4-BM-0001	A1	BULK MATERIAL TAKE OFF
29690-8530-3B4-CA-0001	A1	LV CABLE SIZING CALCULATIONS
29690-8530-3B4-SH-0002	A1	ELECTRICAL LOAD SCHEDULE
29690-8530-3B4-SH-0003	A1	ELECTRICAL CABLE SCHEDULE
29690-8530-3B4-64-0001	A1	MOTOR CONTROL CENTRE
29690-8530-3B4-70-0001	A1	MOTOR CONTROL CENTRE
29690-8530-3B4-70-0002	A1	SITE LIGHTING
29690-8530-3B4-70-0003	A1	SMALL POWER
29690-8530-3B4-74-0001	A1	LIGHTING AND SMALL POWER LAYOUT
29690-8530-3B4-78-0001	A1	OVERALL CABLE ROUTING LAYOUT

APPENDIX R - CIVIL & STRUCTURAL DRAWINGS & DOCUMENTS

29690-8320-3B4-SP-0001	O1	SPECIFICATION FOR STEELWORK FABRICATION
29670-8320-3B4-46-0003	O1	MAIN STRUCTURE - STAIR TOWER
29690-8310-3B4-41-0001	O1	EXCAVATION TO LOCATE EXIST U/GROUND SERVICES
29690-8310-3B4-42-0001	O1	PILING GENERAL ARRANGEMENT AND DETAILS
29690-8310-3B4-43-0001	O1	FOUNDATION LAYOUT
29690-8310-3B4-43-0002	O1	BEAM ELEVATIONS ON GRID LINES
29690-8310-3B4-43-0003	O1	GROUND FLOOR SLAB LAYOUT
29690-8320-39-0001	O1	STRUCTURAL GENERAL NOTES
29690-8320-39-0002	O1	TYPICAL STEELWORK DETAILS -SHT 1
29690-8320-39-0003	O1	TYPICAL STEELWORK DTLS -SHT 2
29690-8320-39-0004	O1	TYPICAL STEELWORK DTLS-SHT 3
29690-8320-3B4-46-0001	O2	MAIN STRUCTURE - PLANS
29690-8320-3B4-46-0002	O2	MAIN STRUCTURE - SECTIONS

APPENDIX S - INSTRUMENT DRAWINGS & DOCUMENTS

29690-8550-3B4-BM-0001	O1	MATERIAL TAKE OFF SCHEDULE
29690-8550-3B4-DS-0001	O1	
29690-8550-3B4-DS-0002	O1	ON/OFF VALVES - DATASHEET

29690-8550-3B4-DS-0003	O1	WEIGH SYSTEM - DATASHEET
29690-8550-3B4-DS-0004	O1	
29690-8550-3B4-DS-0005	O1	CONTROL VALVES - DATASHEET
29690-8550-3B4-DS-0006	O1	
29690-8550-3B4-DS-0007	O1	
29690-8550-3B4-DS-0008	O1	
29690-8550-3B4-RP-0001	O1	AUTOMATION INTEGRATION STRATEGY
29690-8550-3B4-60-0001	O2	PROJECT INSTRUMENT LIST
29690-8550-3B4-64-0001	O1	INSTRUMENT CABLE BLOCK DIAGRAM
29690-8550-3B4-64-0002	O1	INSTRUMENT CABLE BLOCK DIAGRAM
29690-8550-3B4-64-0003	O1	INSTRUMENT CABLE BLOCK DIAGRAM
29690-8550-3B4-64-0004	O1	INSTRUMENT CABLE BLOCK DIAGRAM
29690-8550-3B4-64-0005	O1	INSTR CABLE BLOCK DIAGRAM
29690-8550-3B4-64-0006	O1	SYSTEM ARCHITECTURE
29690-8550-3B4-68-0001	O2	INSTRUMENT CABLE ROUTING DIAGRAM

APPENDIX U - CONSTRUCTION

29690-8710-3B3-RP-0002	O1	CONSTRUCTABILITY REVIEW
29690-8710-3B4-CS-0001		CONSTRUCTION EXECUTION STRATEGY
29690-8820-RP-0001	O1	SITE VISIT REPORT

APPENDIX V - PROCUREMENT DOCUMENTS

29675-1242A01	E1	MATERIAL REQUISITION
29690-2461-3B4-A	E1	STRUCTURAL STEEL FAB GALVANISING & DELIVERY.
29690-2461-3B4-B	E1	STRUCTURAL STEEL FAB GALVANISING & DELIVERY.
29695-1241A01	E1	MATERIAL REQUISITION
29695-1248A01	E1	MATERIAL REQUISITION
-		SUPPLIER SUMMARY

APPENDIX W - COST ESTIMATE

APPENDIX X - COST ESTIMATE NOTES