ReCAP Project

Evaluating the Cost of Retrofitting CO_2 Capture in an Integrated Oil Refinery

Constructability Assessment

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Background of the Project

In the past years, IEA Greenhouse Gas R&D Programme (IEAGHG) has undertaken a series of projects evaluating the performance and cost of deploying CO_2 capture technologies in energy intensive industries such as the cement, iron and steel, hydrogen, pulp and paper, and others.

In line with these activities, IEAGHG has initiated this project in collaboration with CONCAWE, GASSNOVA and SINTEF Energy Research, to evaluate the performance and cost of retrofitting CO_2 capture in an integrated oil refinery.

The project consortium has selected Amec Foster Wheeler as the engineering contractor to work with SINTEF in performing the basic engineering and cost estimation for the reference cases.

The main purpose of this study is to evaluate the cost of retrofitting CO_2 capture in simple to high complexity refineries covering typical European refinery capacities from 100,000 to 350,000 bbl/d. Specifically, the study will aim to:

- Formulate a reference document providing the different design basis and key assumptions to be used in the study.
- Define 4 different oil refineries as Base Cases. This covers the following:
  - Simple refinery with a nominal capacity of 100,000 bbl/d.
  - Medium to highly complex refineries with nominal capacity of 220,000 bbl/d.
  - Highly complex refinery with a nominal capacity of 350,000 bbl/d.
- Define a list of emission sources for each reference case and agreed on CO_2 capture priorities.
- Investigate the techno-economics performance of the integrated oil refinery (covering simple to complex refineries, with 100,000 to 350,000 bbl/d capacity) capturing CO_2 emissions:
  - From various sources using post-combustion CO_2 capture technology based on standard MEA solvent.
  - From hydrogen production facilities using pre-combustion CO_2 capture technology.
  - Using oxyfuel combustion technology applied the Fluid Catalytic Cracker.
- Perform a preliminary constructability assessment, analyzing the main areas of attention related to the execution phase of a case study that considers the implementation of retrofitting CO_2 capture in a complex oil refinery.

This project will deliver “REFERENCE Documents” providing detailed information about the mass and energy balances, carbon balance, techno-economic assumptions, data evaluation and CO_2 avoidance cost, that could be adapted and used for future economic assessment of CCS deployment in the oil refining industry.

1. Introduction

The Construction Industry Institute defines Constructability as "the optimum use of construction knowledge and experience in planning, design, procurement, and field operations to achieve overall project objectives."

Specific studies demonstrate that, when methodically implemented, front-end constructability efforts are an investment that results in a substantial return. Documentation of constructability efforts showed that owners accrued an average reduction in total project cost and schedule of 4.3 percent and 7.5 percent, respectively. These savings represented a 10 to 1 return on the owner's investment in the constructability effort.

Especially in a retrofitting Project, an accurate constructability study in parallel to the engineering activities is essential, since during the construction of the new units/portions, the refinery operation shall not be disrupted.

In particular, when looking at constructability issues in an existing site, the following main aspects are crucial:

- Access route for large or heavy equipment
- Location of temporary facilities
- Interference of the construction works with the routine operation/maintenance activities in the Refinery
- Safety
- Security
- Plant start-up considerations (impacting on the sequence of erection/completion of the new portions)

This report provides a high-level guidance in implementing projects of retrofitting CO_2 capture facilities in a complex industrial site like an operating refinery.

1.1 Reference Case

Post-combustion capture case 04-03 has been selected as the reference case for the high-level constructability study.

This is the most complex case considered in the ReCAP Study, with CO_2 captured from the 5 main emitters of Base Case 4 refinery (see summary in Table 1-1).

Table 1-1: Summary of main CO_2 emission sources in Base Case 4

		CO_2 [t/h] @ operating point	**% of total CO_2 emissions**	**CO_2 %vol**	**CO_2 %wt**	**Flue gas [t/h]** @ operating point
D1	POW	76.0	20.9%	4.23	6.6	1160.5
		21.4		8.1	12.9	165.5
D2	FCC	53.1	11.4%	16.6	24.6	215.9
D3	CDU-A/VDU-A	49.2	10.5%	11.3	17.2	286.5
D4	CDU-B/VDU-B	49.2	10.5%	11.3	17.2	286.5
D5	SMR	19.8	25.1%	17.7	26.7	438.6
		97.5				

Note: Reference should be made to report "Performance analysis – Refinery reference plants for explanation of abbreviations POW, FCC, CDU, VDU, SMR".

For ease of reference, the following key documents are enclosed:

- Schematic process flow diagram representing the CO_2 capture plants, see Figure 1-1.
- General plot plan of the Base Case 4 refinery (highly complex refinery with a nominal crude capacity of 350,000 bbl/d), see Figure 1-2
- Marked-up layout showing the location of the new CO_2 capture plants plus new utility systems, see Figure 1-3.

In addition, when addressing high level constructability issues for the main pieces of equipment, reference has been made to the sized equipment lists prepared for the CO_2 capture plants, the new utility systems and the interconnecting facilities for Case 04-03 (attached to report *"Cost estimation and economic evaluation of CO_2 capture options for refineries"*).

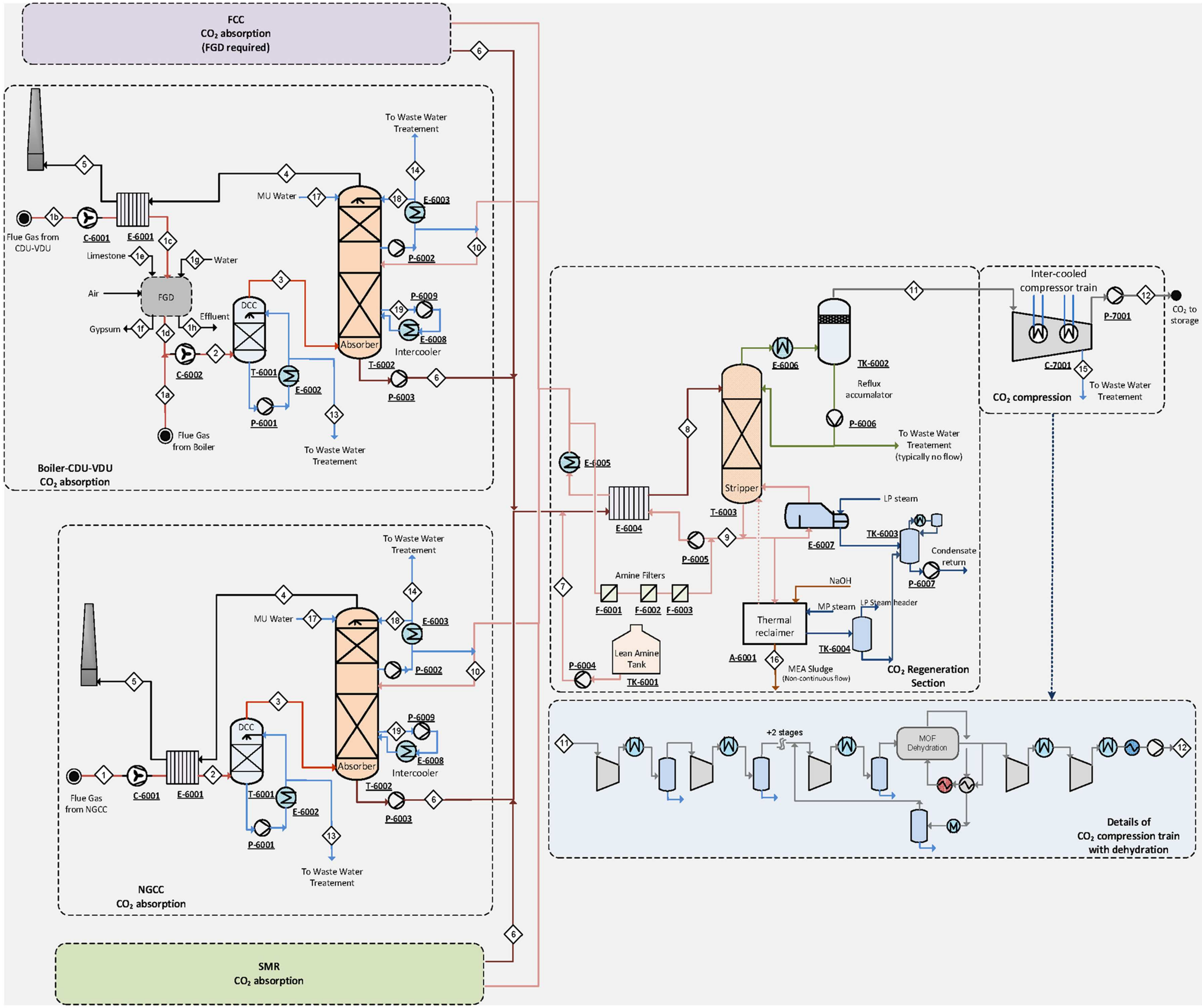


Figure 1-1: Post-combustion case 04-03) Process flow diagram

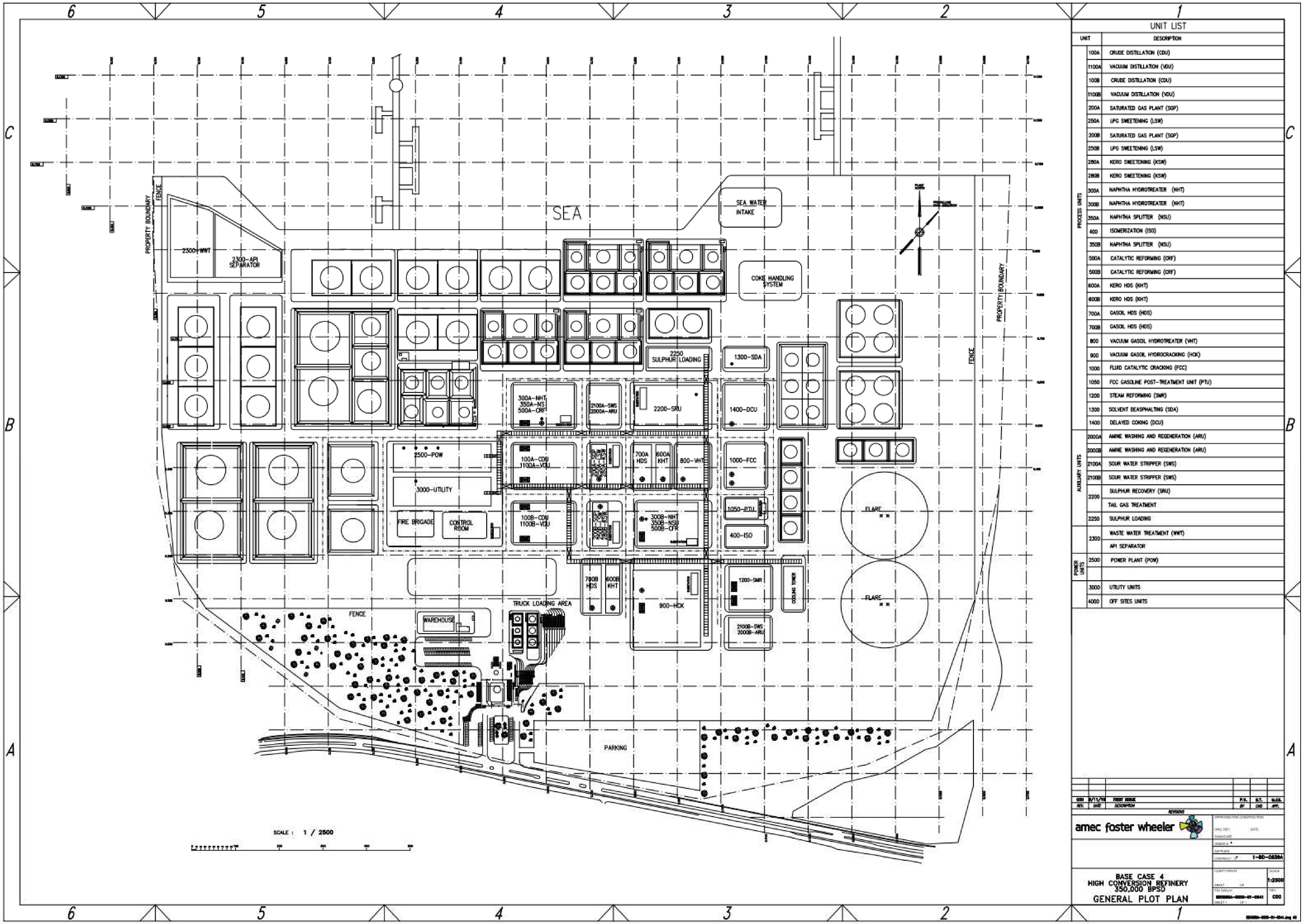


Figure 1-2: Base Case 4) Refinery layout

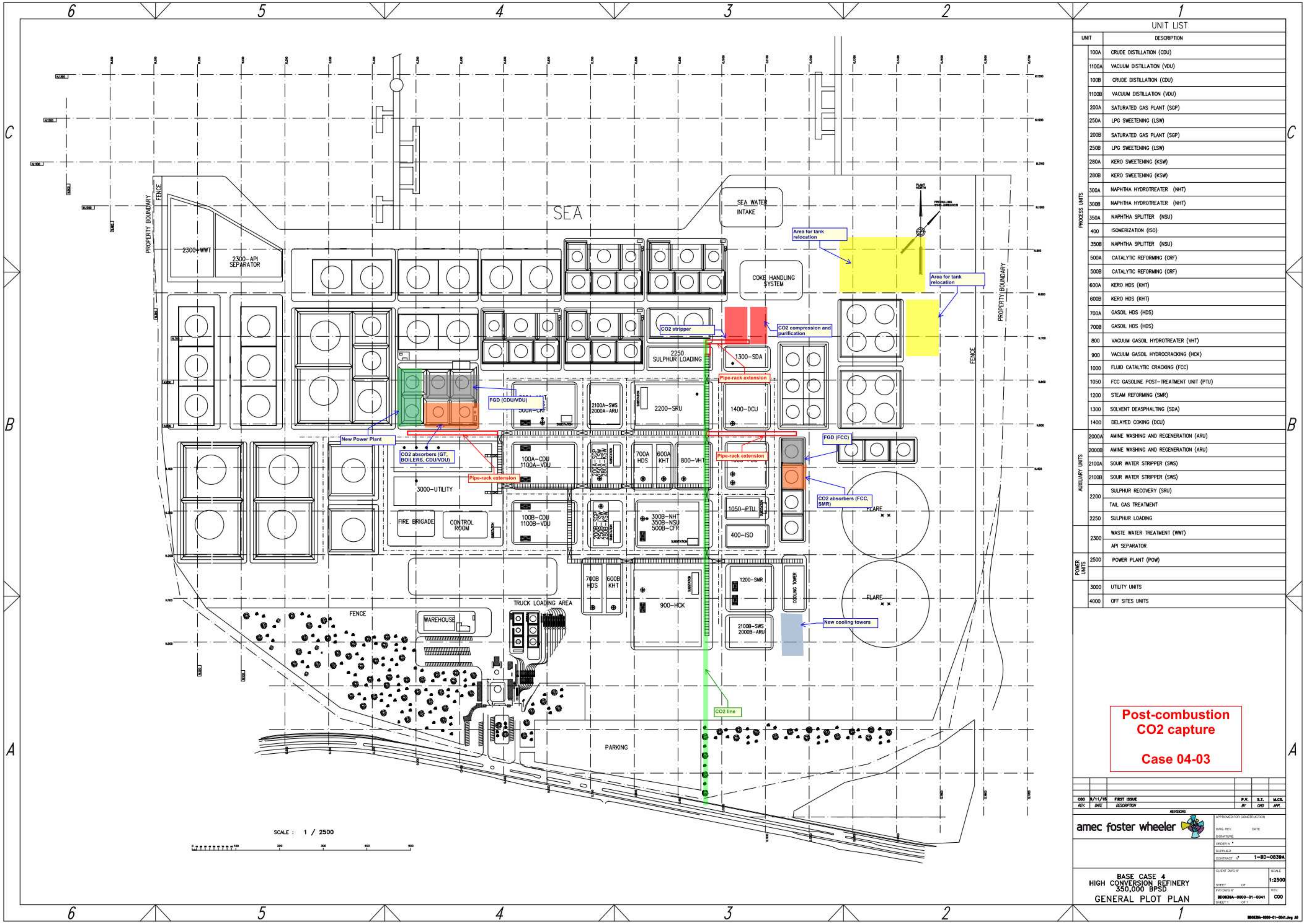


Figure 1-3: Post-combustion case 04-03) Refinery layout with location of the new plants

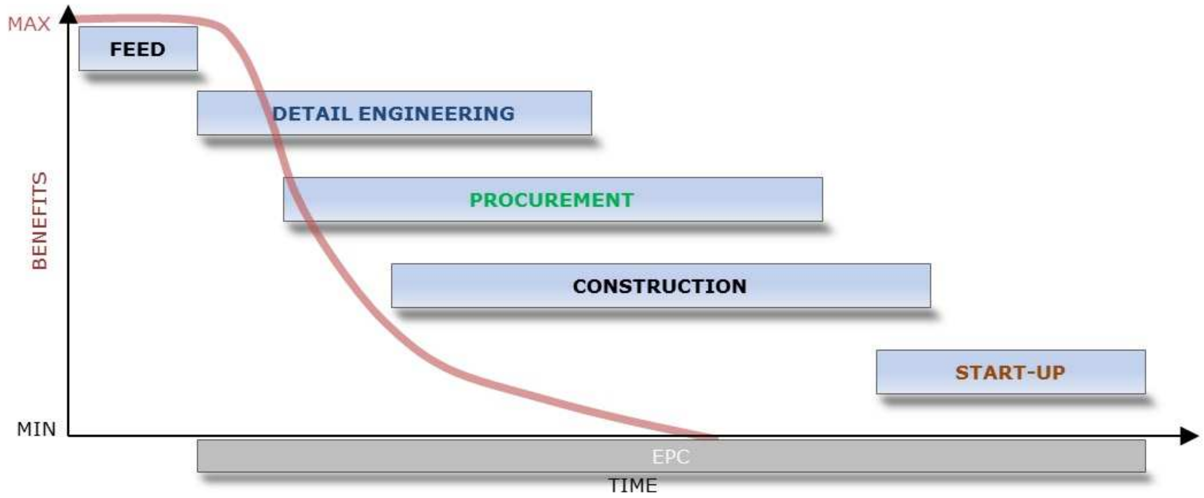
2. Constructability - Introduction

Constructability is considered as the anticipation of construction constraints and opportunities in order to improve the efficiency and effectiveness of the project, since they may influence the decisions taken by the various functions involved during the project life cycle. The Constructability process is aimed at taking benefit of the feedback and experience of the stakeholders involved in a project.

Once defined, the Constructability process ensures that those who have construction knowledge of the execution of the work are able to effectively provide input to the engineering, planning and procurement activities.

For these reasons, Constructability should foster project integration and not only the optimization of individual parts, encouraging teamwork, creativity, new ideas and new approaches.

Constructability is an integral part of all phases of the entire life project, focusing on the practicality of design, timeliness of procurement, efficiency in construction, ease of access for future maintenance, and reliability in operation. The constructability approach shall be transformed into effective actions strictly interfacing the engineering and the construction team, since the early stages of the Project development. Feedbacks form all the industry confirm that implementation of Constructability concept is very successful when applied in the early phase of the project, and decrease effectiveness in line with project progress.



Constructability reviews are to be intended as an on-going activity, carried out throughout the development of the Project, particularly intense and effective during the engineering phase. In fact, involved personnel pro-actively apply constructability techniques throughout all phases of the project. The responsibility for instigating constructability initiatives lies with the Construction Department. However, constructability issues are under the responsibility of the entire Project team and therefore shall be fully supported by the Project Director/Project Manager.

Constructability leaders are senior construction staff personnel, with sound experience in construction of similar plants/activities. Construction experts shall gather together with the personnel involved in the design, project control and supply chain management for verifying the practical, economical project strategies and aspects, in terms of schedule, time, assessing the risks related with the plant construction.

A dedicated team shall also follow-up the implementation of the decisions taken with a set of regular review meetings. The reviews will be planned to be kept in a structured manner and coincident with the key phases of the design

2.1 Operating method

The constructability engagement review process shall be conducted in a structured manner under the leadership of the facilitator and includes, but it is not limited to, the following phases:

- Preparation and issue of the Project Constructability Plan.
- Preparation and issue of the Constructability Checklist.
- Constructability Review meetings: Kick-off and follow-up sessions.
- Issue of the Constructability Action lists.
- Verification and implementation of the Constructability Action lists items and achievement of the established objectives.
- Preparation of the Constructability Report.

2.2 Areas of attention

Constructability analysis may focus on several topics; the assessment performed for the project identified the following areas of attention, on which the document has been focused:

- HSE management.
- Accessibility requirements for construction activities.
- Site preparation and enabling works.
- Sequential construction planning efforts.
- Critical lifting, access routes and planning area requirements for heavy lifts.
- Sewage and Waste Management.
- Temporary Construction Facilities.

Outcomes of the analysis done shall be considered as indicative, developed only at conceptual level, since a detailed study could be performed only on “real” sites, by considering all the relevant constraints (procedures, accesses, available areas, etc.).

The outcomes of the assessment performed are resumed in the following sections of the document.

3. Accessibility requirements

Logistic aspects play a crucial role while defining the project construction strategy. Existing space and dimensional limitations, and consequent implications on engineering and items dimensioning, may represent the rationale for leaning towards a modular approach or a stick built one.

The case study covers the implementation of the retrofitting CO2 capture inside an existing European refinery, that could made the logistic challenges even more complex. In fact the assessment of maximum size and weight of the transportable cargo shall take into consideration all the limitations posed by the surrounding environment.

In order to assure that logistic aspects are correctly taken into consideration, it is recommended, to engage a specialized contractor to perform a logistic study tailored on the specific cases, with the scope to investigate the following aspects:

- Define detailed transportation routes studies, providing suitable alternatives, remarking pro and cons of each alternatives.
- Verification of existing logistic facilities: jetty characteristics.
- Determine maximum transportable dimensions (size and weight) of equipment and modules.
- Definition of any temporary work that may be required to overcome the constraints given by existing operating facilities (e.g. pipe racks, etc.), up to a maximum reasonable extent.

With reference to the case study in subject, the proposed refinery presents two clear alternatives in terms of accessibility: via maritime transport from the seaside and via inland transportation from the existing road network.

Road transportation limits are imposed by the characteristics of the existing infrastructure, such as bridges, tunnels, etc. Obstacles and interferences shall be assessed not only from the origin of the cargos to the refinery but also inside the refinery boundaries. These limitations, in fact, could impose restrictions even to the items that could be shipped through sea transportation.

The proposed layout (reference is made to para. 1.1) has been studied and divided in two main areas of intervention:

- In a brown field area (i.e. construction activities foreseen in an area already occupied by existing facilities), requiring the relocation of some existing tanks: new power plant, CO2 absorber area and FGD for CDU/VDU).
- In a peripheral green field area (i.e. an area ideally free from existing facilities): CO2 compression and purification, stripper, new and relocated tanks.

Access to the two areas shall be studied independently, considering also the potential limitations imposed by the new installations. Result of the assessment would potentially suggest to adopt two different strategies for the two areas, ideally a more modularized driven approach for the green field area and a stick built one for the brown field one.

Appling ideally the proposed approach to the case study, it has been assumed that handling of oversized equipment could be handled though a dedicated existing offloading point: preliminary definition of these items can be found included in the assessment of the critical lift (section 7.1). After offload, the oversized cargos could be transported from that offloading point to the final location.

Differently, delivery of standardized cargo should be managed though road transport and initially delivered at the project warehouse (for warehouse and storage areas refer also to section 12).

Figure 3-1 shows the assumed routings of the two alternative logistic approaches..

Figure 3-1: Conceptual logistic assessment

4. Modular vs stick-built approach

The construction activities approach is a key decision that shall be assessed during the very preliminary phases of the project. A structured assessment for the modularization-stick built decision could be performed following the Construction Industry Institute (CII) guidelines on the topic, considering either qualitative and semi-quantitative analysis.

A first level assessment shall be performed as a gate to access to a more detailed analysis. Basically, an evaluation relevant to main criteria may lead to take the orientation for construction approach. In this step it is required only to define if those preliminary criteria considered, are pro stick-built or pro modularization approach. The table below summaries all benefits for each type of design and construction approach. As shown on the table there are several factors that drive the decision and therefore the contribute of all project parties is required.

Table 4-1: Modularized vs Stick built assessment criteria

Key considerations for selecting an appropriate Construction Execution Strategy		Modularized	Stick built
Schedule	Possibility to carry out parallel work, possibility to resequencing site work activities.	✓	
	Relaxed schedule – traditional construction work, proceeding in series, with seasonal disruption, is acceptable.		✓
Logistics	Challenges to access for material supply, high cost of maintaining large workforce at site.	✓	
	Easy access, can deliver materials at any time: cheap and easy to maintain large workforce at site		✓
Labour	Lack of readily available local skilled labour.	✓	
	Abundant labor available locally.		✓
Weather	Extreme cold, high winds – high probability of impact on site activities.	✓	
	Benign weather – low impact on site activities.		✓
Safety and Environmental	Site conditions challenging to achieving safety and environmental norms	✓	
	Easy site conditions, few challenges to achieving HSE norms.		✓
Special/Authority permit required	Yes – before site activities can begin – need to start work offsite to compress overall schedule.	✓	
	No – work can go ahead on site at any time.		✓
Plant Suitability for Modularization	Greenfield site, no SIMOPS complications. Repetitive elements (e.g. 3 trains).	✓	

	Brownfield site, few repetitive items, difficulty in coping with long lead equipment.		✓
Quality	Higher quality required – can be achieved in “factory” conditions of specialized fabricators	✓	
	Site quality under the expected harsh conditions will be good enough.		✓
Local content	Local content decidable but not mandatory.	✓	
	Local content.		✓

A second level assessment instead shall consist in an evaluation that allow to get into the details of each criteria. A “Criteria weight” table shall be agreed in order to better determinate an accurate weight (in %) of each criteria and then all criteria shall be discussed inside the constructability team in order to give a score for each of them (e.g. from 1, totally pro-stick built, to 4, totally pro-Modularization, or 2.5 when it was considered as neutral.

4.1 Road map decision process

The decision-making process required in the development of a modularisation of a plant, aligned with typical project phases and typical cost estimate accuracies shall be summarized in six key steps:

- Step 1: key investigation / constraints.
- Step 2: module screening study
- Step 3: module quantification study
- Step 4: module proving study
- Step 5: module definition phase
- Step 6: module execution phase.

Even if it will be decided not to implement any pre-fabrication, it is advised to maximize the preassembly/pre-dressing of equipment at ground level, in order to reduce safety risks and having at the same time a positive impact on work efficiency.

5. Site preparation and enabling works

Enabling works are defined as the activities required to allow the start of the construction phase of the new installations.

A clear and careful definition of these works will enhance the possibility of a quick execution phase. With reference to the case study, the attention shall be principally paid to the following activities:

- Existing tanks relocation.

  Definition of sequences of relocation activities, such as, tie-ins execution, tanks empting and dismantling activities shall be carefully defined with the involvement of the operation and production of the refinery.

- Soil remediation activities inside existing tanks area.
- Soil preparation and structural soil improvement inside existing tanks area and new project areas. Geotechnical, geological and environmental aspects shall not be underestimated, since the time impact is usually remarkable. It is recommended to organize a soil investigation campaign in a very early phase of the project.
- Preparation activities for civil works in brown field areas (e.g. erection of new piperack foundations, see also section 6.3).
  Trial excavation and definition of actual underground installations is a time consuming activity, but it is fundamental in order to prevent clashes and future delays due to unfeasible design solutions.
- Preparation activities for mechanical works in brown field area (e.g. tie-ins preparation, see also para. 6.4.1). In order to minimize the amount of activities that require a shut down of the operating installation, the activities that require connections with existing installation shall be duly planned in detail since the initial execution phase. The advance effort will be beneficial, since it should reduce to a minimum the existing installation shut down time required.

6. Main construction works

6.1 Main Equipment

Equipment will be preferably delivered to site in one piece; depending on the outcomes of the logistic study, it will be evaluated the necessity to deliver equipment in two or more pieces, performing final assembly on site, in dedicated workshops or directly on the foundations.

Tanks are expected to be delivered in pieces and finally assembled at respective final location.

6.2 Pre-Assembly

6.2.1 Structural Steel Sections/Modules

Offsite Modularization will be determined pending on the viability and cost effectiveness of shipping and/or road transport to site. Where practicable, modules will include structural steel members, handrails and grid mesh, walkways, mechanical items, electrical cabling and any other Items deemed feasible for installation at the pre-assembly stage. These modules will be erected on 'skid' type steel members which will only be removed on site at final installation time. Progressive survey, dimensional checks, relevant QC sign off, punch list Items etc. will be recorded. Transportation bracing will be fabricated and installed on all relevant Items/Modules to be shipped and/or transported by road.

6.3 Piperacks

For the new racks, it has been considered to take advantage of existing piperack routings, but designing them so to be independent from a structural point of view. In fact it has been proposed to run the new pipe over the existing rack, but supported by new steel structure frames, installed on new concrete foundations.

The activities relevant to the new rack will be particularly critical, since the overall length of the new installation will exceed 2500 linear meters and the main part will be erected inside an area occupied by existing facilities.

Therefore it is recommended to proceed duly in advance with specific activities deemed fundamental to assure a smooth execution phase:

- Execution of trial excavations to define the actual status of the underground network, so to be in position to correctly define location and size of the new foundations.
- Design the foundation, considering the implementation of a solution that include as much as possible precast elements, so to reduce the installation phase and consequently the time during which there will be open excavation spot inside existing areas.
- Standardize the steel structure frame, so to ease and speed up the procurement and installation phase.
- Evaluate the possibility of pre-assembling part of the steel structure at ground.

6.4 Piping

Piping and supports major fabrication activities are planned to be done at site, in dedicated workshops.

6.4.1 Tie-ins

Tie-ins represent the interface between the new and existing facilities. As such, they shall be installed in a logical sequence. Considerations for tie-in timing and design shall include:

- Ability to isolate the existing line at tie-in location.
- Construction access to the tie point for installation.
- Piping configuration from routing and stress point of view.
- Minimize overall count and maximizing the pre turn-around count.
- Minimizing / eliminating the need of any hot tap *(*)*.

(*) Method of making a connection to existing piping or pressure vessels without the interrupting or emptying that section of pipe or vessel.

A project tie-in strategy should take into utmost considerations the safety aspects, but shall additionally include:

- Tie-in package content
- Tagging, walk-down, inspection and sign-off requirements
- Hot tap procedure.
- Air testing restrictions / procedure.

Generally, more tie-ins will be made during the turn-around (TA) than in pre-TA due to unavailability of existing lines and equipment; differently, in case a significant amount of re-commissioned, out-of-service equipment is available, higher percentages could be considered for pre-TA activities.

Further valid considerations, resulting from the long experience in turn around execution, are:

- Tie-ins are more effectively executed when they are walked down in the field during the design phase by the designer and the operator.
- Making tie-in packages is a significant, time-consuming activity. Plan allocation of resources based on tie-in count and the tie-in packages content requirements.
- Show tie in on an actualized plot plan (e.g. issued for construction).

In our case study, there will be a very limited integration between the new CO2 capture plants and the existing refinery units, especially when looking at the relevant utility systems. As a matter of fact, no capacity margins have been considered in the refinery utility systems to fulfil the demand of the new CO2 capture plants, but instead completely new – parallel- utility systems have been considered. As a result, the existing refinery block (with relevant utility units) and the new CO2 capture plants (with relevant new utility units) can be regarded as “independent”, interconnected only on the flue gas side. No many tie-ins will be therefore needed.

However, in other Projects, a deeper integration of the CO2 capture plants with the refinery could be realised (e.g. to take advantage of some capacity margins in the existing utility systems). In that case an accurate tie-ins study is recommended not to jeopardise the normal operation of the Refinery when connecting the new CO2 capture facilities.

7. Critical lifting activities

As soon as a preliminary sizing/design of the main equipment is available, it is advised to execute a heavy lifting optimization study with the aim to minimize the number of heavy lifting equipment.

Mentioned study shall include lifting feasibility evaluations, items delivery timing and construction schedule considerations. The lifting plans, tailored to every single critical lift, shall specify cranes and lifting equipment to be provided, crane's lifting locations and boom length to be used. The crane's out-rigger loading and special ground preparation requirements should also be specified.

Dedicated lifting drawings and plans shall be produced for review and approval for all heavy lifts deemed critical, usually meaning lifts meeting one or more of the following criteria:

- The load is heavier than 45 t (50 ton).
- The load is less than 45 t (50 ton) but a complex lifting sequence is required.
- The lift involves a complex rigging arrangement or that requires specialty rigging.
- The load is heavier than 18 t (20 ton) and it is also greater than 80 percent of the manufacturer's rated capacity.
- The load is being lifted over or near an occupied building, operating equipment, or electrical power-lines.
- Two or more pieces of lifting equipment are required to work in unison: this includes using a tailing crane.
- Special lifting equipment (e.g. hydraulic gantries) or non-standard crane configurations, is used.
- The load represents more than 90 percent of the manufacturer's rated capacity at the working radius.

The lifting studies shall provide as a minimum:

- Definition of special equipment and rigging needs.
- Development of a rigging plan for each heavy lift.
- Definition of type, rating, and anticipated duration for all lifting equipment.
- Incorporation of heavy lift equipment needs and durations into the overall project construction schedule.

All heavy lift cranes shall be utilized in the permitted configuration, rated and tested by the crane manufacturer. All cranes capacities shall be within the published equipment charts capacities, in the configuration being utilized for the lift and in compliance with applicable local codes. Any propose lifting frames shall be supported by structural calculation in compliance with all applicable codes, industry practice and local regulations. Whenever possible, the equipment delivered to site will be offloaded and erected immediately onto their foundations, to avoid double handling.

7.1 Critical items

A preliminary assessment has been performed on the basis of the data included in the available equipment lists: items that have been identified as critical from a lifting perspective have been reported below.

Table 7-1: Critical Lifting Table

Unit	Tag	Description	Dia [mm]	Length [mm]	Weight [t]
NGCC	T-6001	Direct Contact Cooler	12100	36500	430
NGCC	T-6002	Absorber	10200	48000	472
POW CDU VDU	T-6001	Direct Contact Cooler	10250	31000	293
POW CDU VDU	T-6002	Absorber	10600	48000	501
SMR	T-6001	Direct Contact Cooler	8000	24000	141
SMR	T-6002	Absorber	8850	44000	336
FCC	T-6001	Direct Contact Cooler	6000	18000	69
FCC	T-6002	Absorber	5850	36000	125
Regen	T-6003	Regenerator (stripper)	10200	38000	614

Table 7-1 includes the items that have been deemed critical assessing items dimensions and weight; selection of the lifting method for each items, shall take into consideration, from a technical point of view, the availability of areas for installing a heavy crane and the sequencing of the lifting activities.

Figure 7-1: Reactor installation with gantry crane (example)

Other packages that have evaluated as critical from an erection prospective are:

- Flue Gas Desulfurization unit.
- CO2 Compression package.

As of today it is not expected that these packages includes items with dimensions similar to the ones included in table 7-1, but the overall size of the packages and the technical complexity recommend to develop dedicated study to assess the installation sequence and optimize the duration of the construction activities.

It is recommended to execute during an early execution phase a heavy lifting optimization study with the aim of minimizing the number of heavy lifting equipment. Mentioned study shall include lifting feasibility evaluations, items delivery timing and construction schedule considerations. Considered installation methods may include the use of standard crawler and telescopic cranes or of other heavy lifting equipment, such gantry cranes, strand jacks, etc.

A gantry system is a side shift mechanism that allows to transverse the load giving the system the capacity to move the load in the 3 directions. It consist in 4 jacking units, supported on wheels or on rails, having one vertical lift cylinder and a vertical lift boom mounted on top; a lifting beam is installed on each two jacking units. According this scenario items shall be delivered on site, lifted by the gantry system, translated inside the shelter and afterwards laid on the foundations.

Installation method selection may have impacts on the design of surrounding structures. For example, in case of items to be installed inside sheltered structures, it is advised to do not link equipment installation to the erection of the structure, in order to avoid the risk of having the progress of the shelter blocked by any inconvenience related to a long delivery equipment.

On this basis, shelter/enclosures shall be designed in such a way to allow item installation with the structure almost completed or in an advanced status of progress.

In case of installation by crane, shelter roof shall be removable, considering a net opening over each item foundation of such dimensions to allow safe lifting operations. On the contrary, choosing a gantry system solution, roof can be completed, but shelter façade, shall present, on one side, in correspondence of each foundation, a net opening between the columns wider than the sum of the width of the concrete item pedestal and the installation device (i.e. width of a rail and a jack unit per side).

Figure 7-2: Installation with hydraulic gantry crane (example)

8. Systems turnover

To ensure that construction and pre-commissioning are performed in the sequence required for commissioning and start-up the following measures shall be taken and procedures followed:

- ► Required completion sequences of commissioning/start-up systems shall be identified in as “as early as possible” phase of the Project. Commissioning/start-up systems and required completion sequences should be defined during the P&ID development phase. Mark-up P&ID’s with commissioning system identification numbers to be provided.
- ► Hydro-test systems, loop tests and electrical continuity tests will be established in line with the commissioning systems.
- ► Dedicated system component lists shall be prepared identifying each hydro-test system, equipment tag, instrument loop and identification of MCC’s pertaining to a commissioning system. The lists shall be kept up-to-date for items completed.
- ► Pre-commissioning schedules shall be prepared in line with the commissioning system priority sequences.
- ► Installation activities shall be shifted from geographical oriented construction to system oriented construction at approx. 60-70% overall construction progress.
- ► Follow-up system progress and completion through periodical updates of the system component lists.

Dedicated Turnover and Commissioning procedures shall be prepared.

9. Site material management

A dedicated material management system has to be set up and afterwards implemented to control the flow of equipment and materials from material take off preparation through issue to construction contractors and final utilization.

The system shall register and monitor all materials to be delivered to the warehouse(s) and therefore issued to the construction contractors. At the same time the material management system shall offer an integrated handling of materials required for field changes, field purchased materials and production planning based on expected material availability and actual material availability.

10. Construction quality control

A dedicated quality control plan has to be developed in order to agree the quality control system to be adopted to duly monitor the execution of the construction activities.

The quality control plan shall be organized at discipline level and shall consider the specific tasks belonging to each phase.

Every construction contractor shall issue a specific quality control plan in accordance to the minimum Project requirements. Any test, inspection and check shall be carried out in due time before moving to other activities.

Level of test and inspections required for all works in field and relevant inspecting personnel involvement shall be summarized in dedicated tables.

11. HSE management

Considering the complexity of the project and the large numbers of people that shall be engaged during the field activities, HSE require a detailed approach shared and considered as top priority by everyone involved in the Project. To achieve HSE excellence an intensive training program shall be organized to train all the manpower and employees before starting the work at site.

- General training

  The general HSE training will be conduct to all people before entering to site and will regards the following topics:

  - Behaviour

  Training will stress the behaviour that people shall maintain while working at field and in the office, about respect each other, ready to help the colleagues, not smoking unless in the denigrated area, housekeeping of the work areas including offices, work management, drink fluid to maintain the correct hydration.

  - Golden Rules

  To prevent occupational accidents:

    - Clear explain the Basic Rules that everyone should know and apply;
    - Risk identification and risk mitigation;
    - String then prevention by incomes people to step in whenever they see something being done wrong;
    - Stop work if the risk is not being properly managed.

  The Golden Rules must be fully understood and obeyed by everyone.

  Example of Golden Rules are: traffic, use of correct PPE, lifting operation, energized system, confined space, excavation work, work at high, management of change, simultaneous operation or co-activities.

  - Permit to work

  Basic understanding of the work permit process including the risk evaluation and mitigation.

  - House Keeping

  Basic explanation on how important is to maintain any work area tidies and clean to prevent accidents.

- Dedicate training for each trade

Training for each type of trade will be arranged with the aim to verify the real skill of the workers and to refresh their behaviour.

It will be important to ascertain the real capability and understanding of HSE rules of the foreman and supervisors and retrain them when their performance is not as for the required standard.

12. Interface management

A proper site interface management will reduce the risk of delay due to lack of permits and avoid any problems during the normal operation of the refinery. The interface management will follow up also the coordination with other contractors who can be present at Site during project activities construction period.

Usually the interface management is directly managed by a site technical manager, however in some cases (e.g. schedule analysis, request of work permits, etc.) he will be supported by his/her discipline co-operators (e.g. construction managers, planners).

The site technical manager shall organize regular meetings (on daily, weekly or monthly basis as per necessity) with the Owner responsible and operational management of the refinery to evaluate the schedule, organize the activities to be performed and request the necessary permits. In the above mentioned meeting shall be invited also the other Contractors present in the Terminal during the period of project scope of work.

12.1 Work permits

It is considered that all the activities inside the plant shall be done under work permits, managed directly by the Client. The type of Work Permit shall be different in relation to the area in which the activities shall be performed. For example, works in operation area should be managed by PTW released for task/working crew; differently, general work permit should be released for less risky activities in green field areas.

In order to regulate site activities and properly plan the duration of the works, a dedicated “Permit to Work (PTW)” procedure shall be developed and agreed with the refinery management in an early phase of the project.

12.2 Interface with Local Authorities

During the construction activities, some interfaces with the local authorities shall be faced; project strategy will define whether these interfaces will be managed directly by the refinery or delegated to a specific contractor. Typical activities that will require Local Authorities permission shall be:

- Dewatering;
- Erection of Temporary Site Facilities.
- Excavation and disposal of excavated soil.
- Certification of particular kind of scaffoldings.
- Waste disposal.

13. Site Security

Considered the project location and the fact that the intervention shall be executed inside an existing production facility, general plant security services are assumed to be already properly organized. Anyhow, a project dedicated security plan shall be developed in advance with respect to the execution phase, in order to define project related aspects and assess the management of interfaces with refinery activities. The project security plan shall cover, but not be limited to, the following topics:

- Security organization, responsibilities matrix and communications channels.
- Access and egress procedures to and from the area of operations, yards, offices and work areas including but not limited to, searches of people, luggage, vessels, vehicles, containers and equipment.
- Surveillance.
- Contingency plans and emergency response plans.
- Area of operations evacuation plan.
- Equipment requirements.
- Physical security measures (fencing, alarms, etc.).
- Security personnel requirements.
- Efficient and reliable communications equipment.
- Standard operating procedures.
- Transportation procedures of the personnel to and from area of operations, yards, work areas and offices.
- Reporting and investigation of security incidents.

Furthermore, project security plan shall delineate the roles and responsibilities of manager(s) and supervisors and require that their actions clearly demonstrate an understanding of their roles and responsibilities with regard to the security process.

14. Temporary Construction Facilities

The Temporary Construction Facilities (TCF) are intended as all the areas, the temporary buildings and structures, the temporary workshops and more generically all the temporary facilities required to support the construction activities and to sustain the execution of the planned works.

Correct, efficient and timely planning and execution of the TCF are important preplanning tasks that can either enhance or adversely affect construction productivity. A correct and efficient TCF can significantly reduce construction conflicts and improve project efficiency.

An overall conceptual layout of the TCF, including all the areas presented in the following subsections is shown in Figure 14-1.

14.1 Site offices

It is recommended to organize the site team in a unique building; in case free space should not be available inside permanent refinery facilities, a temporary site office shall be erected to accommodate the project site team.

The types and layouts of offices must be consistent with the level of organization envisaged. Preference must, however, be given to arrangements that allow for the expansion of spaces in the event of unforeseeable future circumstances.

Office space shall be fully equipped to support the functionality of the office; and shall be equipped with meeting rooms, it tools, document reproduction/file equipment, pc, fax machine, telecommunications, computers, toilets and washrooms. First-aid facilities shall be made available in the first aid room

Sufficient parking area will be arranged around the site office.

Furthermore, if a part of field engineering is done directly on site, a dedicated and suitably equipped space should be set aside for this. Special care should also be taken with the arrangement of controlled areas for the management and adequate space for the technical archive.

Office spaces must be made up of single rooms for the higher levels of management and of double, triple and multiple rooms for the rest of the organization and for secretarial and services staff as well open space. Spaces must be available for meeting rooms, conference room, document filing, changing rooms, kitchens and coffee bays men’s and women’s toilets, inclusive of showers.

All staff that require a computer (generally the majority) will be equipped with one, and a certain number of printers will be connected using the site LAN. Office equipment must include slide projectors, containers for files and drawings, white/blackboards and, lastly, infirmary equipment.

In any case, all localities must be equipped in such a way as to facilitate voice or data transmission services, both between themselves and with headquarters and the engineering offices (if engineering is not done centrally). These connections must be also provided for video conferences which are increasingly used on sites located at long distances from the main office.

14.2 Warehouse and storage areas

Part of the incoming materials must be protected while waiting to be installed. For this reason, roofed and indoor warehouses are prepared for those materials following the suppliers recommend. Other materials can simply be covered or left outdoors in fenced areas. Some materials (solvents, glues, paints, etc.) must be kept in well-aired environments and be separated from the rest of the materials, following the MDS specification.

The warehousing and delivery of materials is an extremely important activity for the success of the site. Alongside complete management of the process, the traceability and fabrication analysis for certain material (such as piping) based on inventories and pre-allocated stock should be stressed.

14.2.1 Warehouse

Site warehouses shall be composed by the following sections:

- Covered section for mechanical material to be assembled

  Covered warehouse building will be installed at Site, the warehouse may be constructed using a traditional structure with walls made of corrugated metal, pre-fabricated modular wooden elements, brick, etc. Material control staff will be located in a dedicated office space.

  Materials to be stored in this space are: gaskets, pipe fittings, flanges and valves, bolts, electrical item, instrument item, equipment, electronic components, switchgears, fuses, relays, instruments, control boards, analyzers, instrumentation fittings, pre- commissioning materials, spare parts, etc.

- Covered section for painting and chemicals

  For the storage of dangerous materials (toxic, corrosive, flammable, etc.) an isolated building with air conditioning must be provided. In addition to the above, all the requirements included in the MSDS (Material Safety Data Sheet) of the materials shall be followed during the design of the warehouse. Proper safety signs shall be applied at the entrance of the warehouse.

- Shed section for insulation material
- Marshalling yard for quarantine materials
- Shed Section for materials which can be exposed to the weather, but in their packaging

14.2.2 Storage areas

Storage areas are required lo laydown the construction material and shall include:

- Fenced areas

  The fenced area must be:

  - Placed adjacent of the warehouse;
  - Adequately lighting;
  - Flat and compacted to allow the circulation of vehicles such as fork-lift trucks, cranes.

Materials to be stored in this area are: pipes, flanges, fittings, filters, columns internals, steel plates, steel section bars, concrete steel bars, cable coils, packages, etc.

- Unfenced areas

  The unfenced area must be located as close as possible to the fenced area. For the storage of vessels, equipment, machinery, packages, steel structures, etc.

14.3 Construction contractors areas

Dedicated areas shall be assigned to Construction contractors for the installation of their Temporary Construction Facilities, that, depending on contractors' core activities, may include:

- Site offices
- Piping Fabrication, sandblasting and painting workshops
- Contractors equipment and material storage facilities.

Considering the location of the project, it is expected that some of the construction contractors TCF and material production facilities (e.g. concrete batching plant) shall be available on the local market and hence shall not be temporarily erected for project scope only.

14.4 Temporary utilities

Temporary utilities are required to support the execution of the construction works, and typically include:

- Industrial water
- Demi water
- Potable water
- Electrical power
- Sewage system
- Data system
- Steam
- Compressed air

Utilities shall be either sourced from refinery networks (e.g. industrial water) or generated on purpose (e.g. power diesel generators in case of unavailability of enough power through the existing grid).

Figure 14-1: Temporary Construction Facilities conceptual layout

15. Waste management

15.1 Waste water management

All sewage water, including the one derived from construction activities, shall be treated before disposal. Treatment could be done through the existing refinery water treatment plant. Alternatively, a new dedicated waste water treatment plant should be erected or, in case a treatment plant is available not too far from the site, transfer of the sewage shall be organized by appropriate means, of course by entering into an agreement with the owner of the Waste Water Treatment Plant and with the support of the client.

For the disposal of hydrotest water it could be considered, in accordance with refinery and local regulation, the use of a temporary evaporation pond.

Disposal of waste water could also be through vacuum tankers to a local waste water treatment plant.

15.2 Waste management

Solid waste shall be segregated by type directly at site and collected in dedicated skip's ready for collection and disposal in an approved dumping area for further process.

Construction contractors shall be responsible for managing and arranging disposal in an acceptable manner of the various types and categories of waste, which accrues throughout the execution of the Project.

All hauling and dumping operations shall be in accordance with refinery procedures and methods of disposing of waste and local regulation. Waste types shall include, but not be limited to, the following typologies:

- Chemicals and Oils:

  This includes any Chemicals and Oils, which constitute a high degree of hazard to public health and the environment, such as hydrocarbons (Oils, Lubricants etc.), corrosive, reactive and toxic Chemicals. These must be handled and disposed of in an approved area for further process.

- Construction debris and material unsuitable for fill

  These materials will be disposed of in the approved dump site; it includes material such as timber, steel, packaging material, concrete etc.

- Garbage Disposal

  Biodegradable, chemically decomposable and inert waste will be dumped in an approved dump site. This material includes non-hazardous solid waste and sludge that are biologically or chemically decomposable in the natural environment such as paper, digestive sewage, garbage or waste that is not biologically or chemically active in the natural environment such as glass, most plastics and rubber products.

16. Conclusions

Retrofitting CO2 capture plants in an existing refinery requires an accurate constructability study to be carried out at the very beginning of the design phase, to identify as soon as possible all the critical aspects that could have an impact on the construction duration, strategy, cost.

The new CO2 capture plants have relatively few interfaces, in terms of process, with the rest of the facility, but they are very demanding in terms of plot area requirements and interconnections between the different portions of the plant (e.g. Absorber, Stripper, Compression/Purification, Utility systems). This implies an accurate planning of the works required for the areas' preparation, as well as for the extension/revamping of main piperacks to connect all the portions.

Moreover, the size of the main columns (DCC, Absorber, Stripper) is large and requires dedicated studies for identifying the most suitable access/routing for the transportation and for defining a proper lifting strategy.

All the interfaces (physical, human, operational) between the new and the existing installations need to be taken into account.

In conclusion, for revamping even more than for grass-root projects, the constructability task is a very complex activity, driven by many key-factors like schedule, cost, impact on the existing facilities and routine operations, and, first of all, safety during all the phases of the project implementation.

Evaluating technology options to mitigate greenhouse gas emissions

IEA Greenhouse Gas R&D Programme

Pure Offices, Cheltenham Office Park, Hatherley Lane,
Cheltenham, Glos. GL51 6SH, UK

Tel: +44 1242 802911

mail@ieaghg.org
www.ieaghg.org