amec foster wheeler

ReCAP Project

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

Description of Reference Plants

Doc No.: BD0839A-PR-0000-RE-001

F02	20/04/2017	Revised where indicated	L.Boschetti	C.Gilardi	M.Castellano
F01	16/09/2016	Including comments	L.Boschetti	C.Gilardi	M.Castellano
C00	13/11/2015	First Issue	L.Boschetti	C.Gilardi	M.Castellano
REV.	ISSUE DATE	DESCRIPTION	PREPARED BY	CHECKED BY	APPROVED BY

Table of contents

Page

List of figures

List of tables

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.
- Develop a case study evaluating the constructability of retrofitting CO_2 capture in a complex oil refinery providing key information on the following (but not limited to): plant layout, space requirement, safety, pipeline network modification, access route for equipment, modular construction vs. stick-built fabrication, and others.

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.

Executive Summary

Scope of the present report is to provide a description of the four different oil refineries identified as Base Cases:

- Base Case 1) Simple refinery with a nominal capacity of 100,000 bbl/d.
- Base Case 2 and 3) Medium to highly complex refineries with nominal capacity of 220,000 bbl/d.
- Base Case 4) Highly complex refinery with a nominal capacity of 350,000 bbl/d.

The performance, in terms of mass and energy balances, and CO_2 emissions of the REFERENCE Plants (Base Cases) is the basis for comparison of the effectiveness and cost of the Oil Refinery with CO_2 capture.

In particular, the following figures show the performance, in terms of specific energy consumptions and CO_2 emissions, of the four Base Case Refineries:

Figure 0-1 shows the product slates' of the four Base Cases, reflecting the increasing complexity of the processing scheme from Base Case 1 to 4.

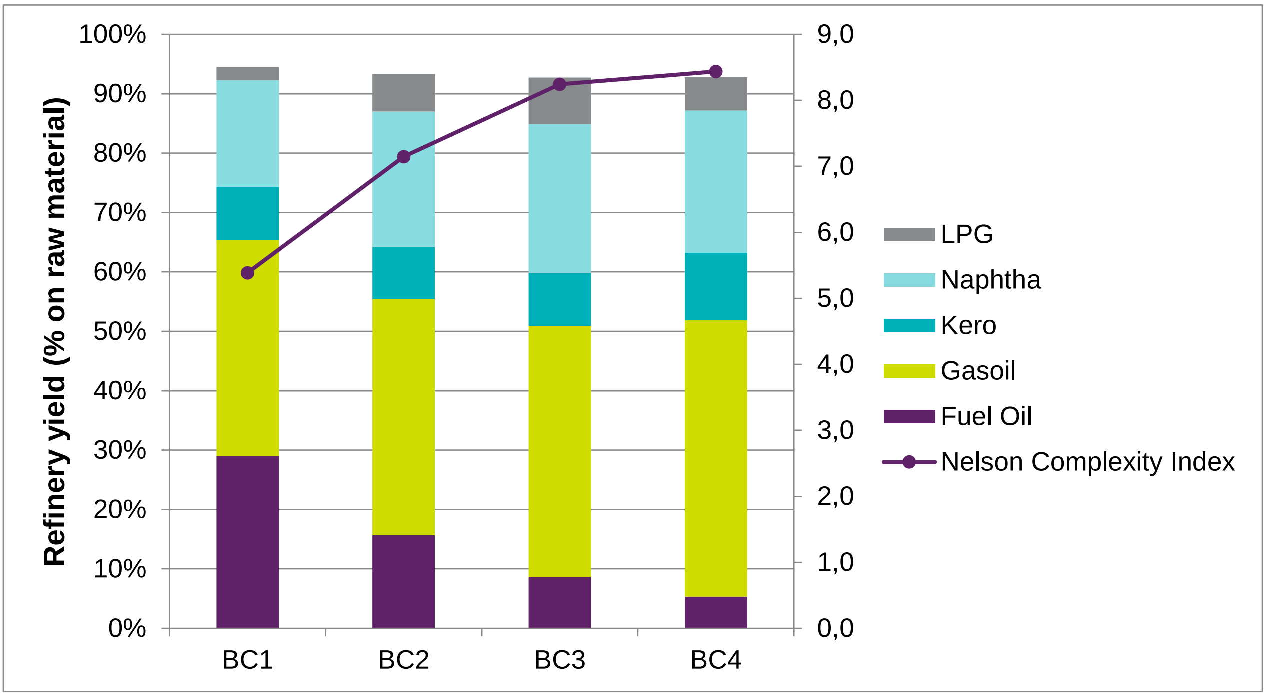


Figure 0-1: Refinery yields in different base case configurations

It is worth to highlight that from Base Case 1 to 4 the yield in black products (fuel oil, bitumen, coke and sulphur) decreases while the naphtha and gasoil fractions increase; this is fully in line with refinery configurations, since the more is the complexity (in particular the presence of Fluid Catalytic Cracking, Delayed Coking and Vacuum Gasoil Hydrocraking), the more is the conversion of heavy cuts to lighter and more valuable products.

The market conditions in the past periods have pushed the refineries to upgrade their configuration to process heavier crudes, cheaper than the lighter ones, and to re-process heavy distillate products to obtain more valuable fractions. These energy intensive units, however, demand a greater amount of fuel and, in turn, increase the amount of CO_2 emitted.

Figure 0-2 includes a comparison of specific fuel consumptions and CO_2 emission of the four cases, while Figure 0-3 reports the different fuel mix compositions.

It can be noted that the fuel demand in Base Case 4 is indeed more than 50% bigger than the consumption in Base Case 1, and this trend can be identified in CO_2 emission too.

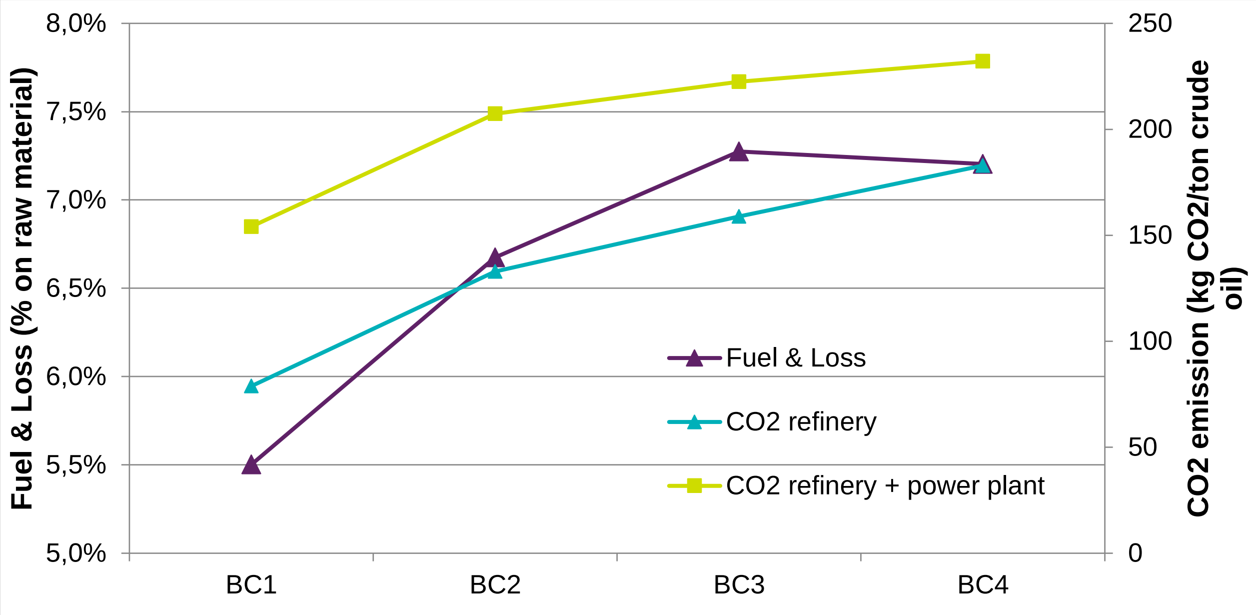


Figure 0-2: Fuel demand and CO_2 emission in different base case configurations

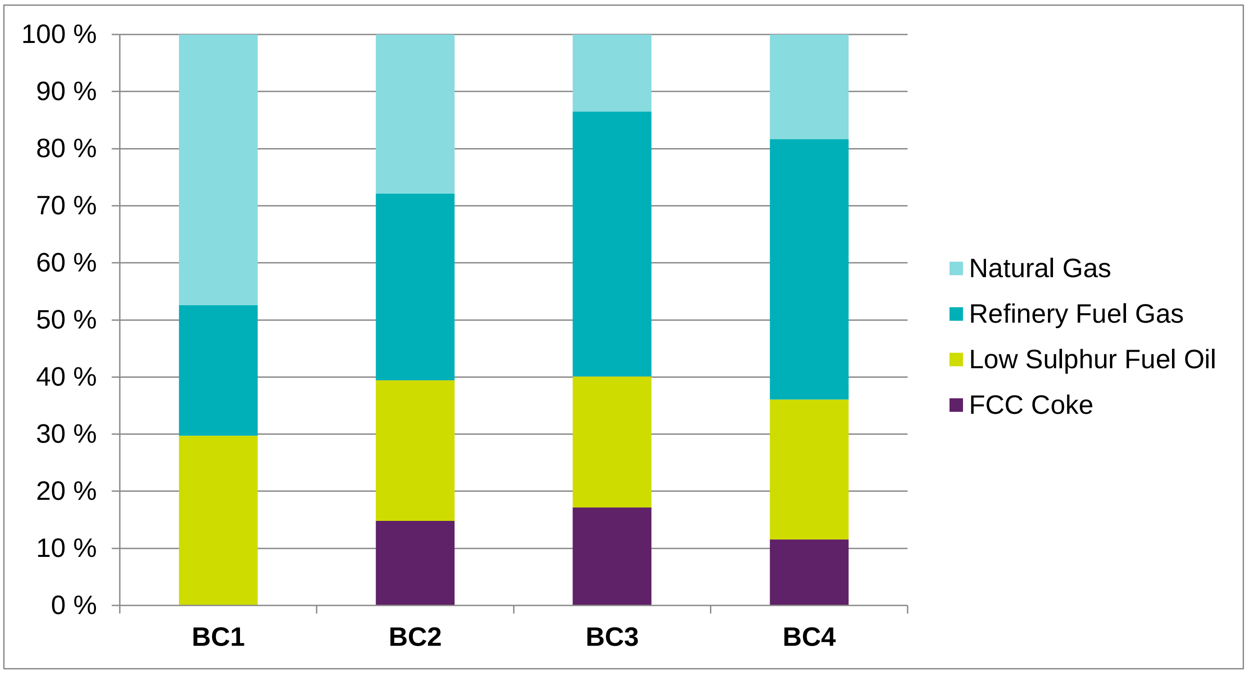


Figure 0-3: Fuel mix composition in different base case configurations

As a conclusion, the four identified base cases can be regarded as a good starting point for evaluating the effects of retrofitting CO_2 capture facilities in existing refineries, different per size and complexity.

The following charts summarize the main CO2 emission sources of the four base case refineries.

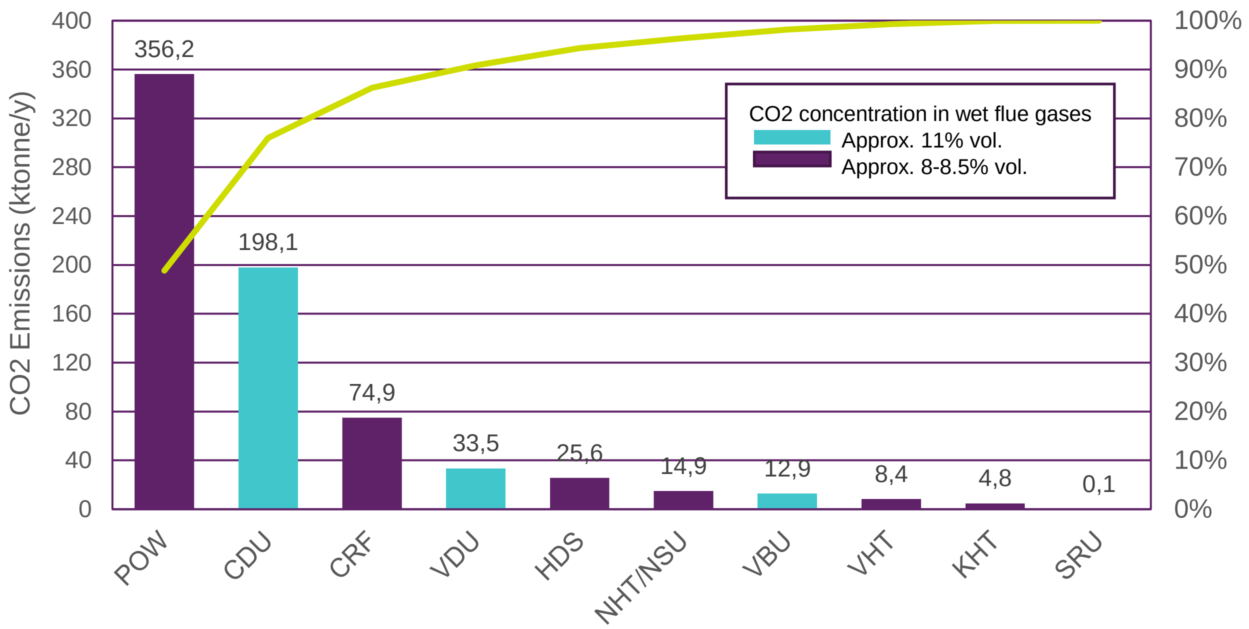


Figure 0-4) Main CO2 emission sources in Base Case 1 refinery

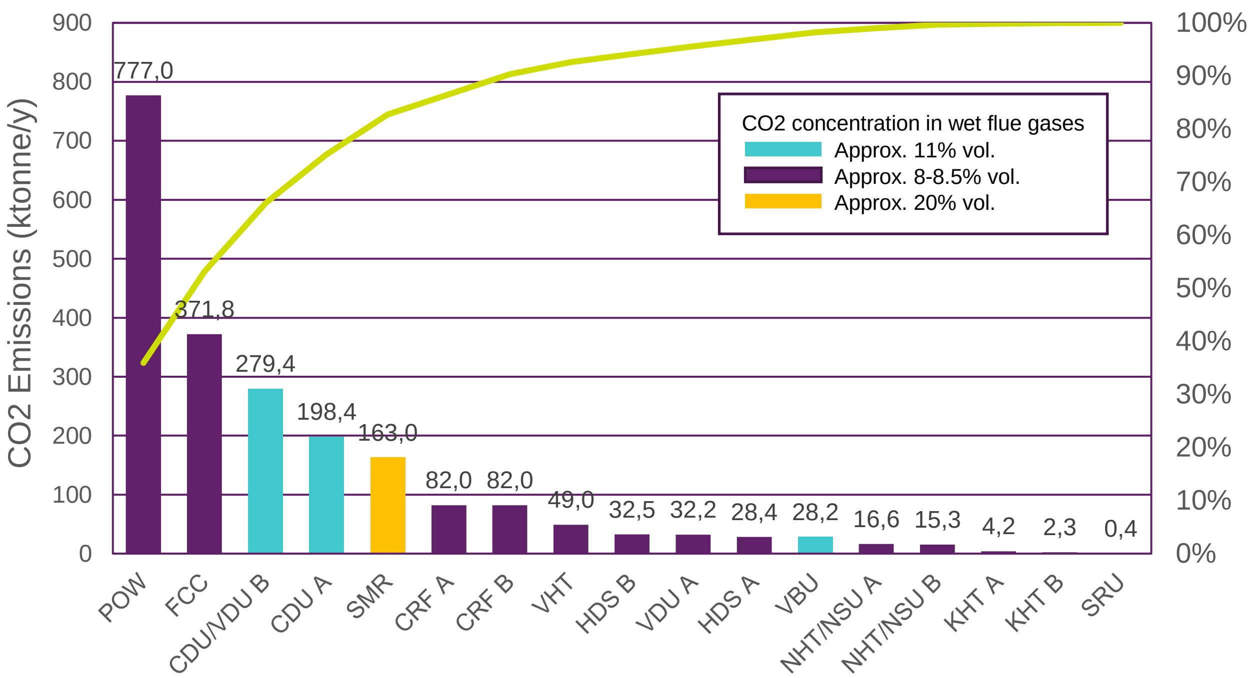


Figure 0-5) Main CO2 emission sources in Base Case 2 refinery

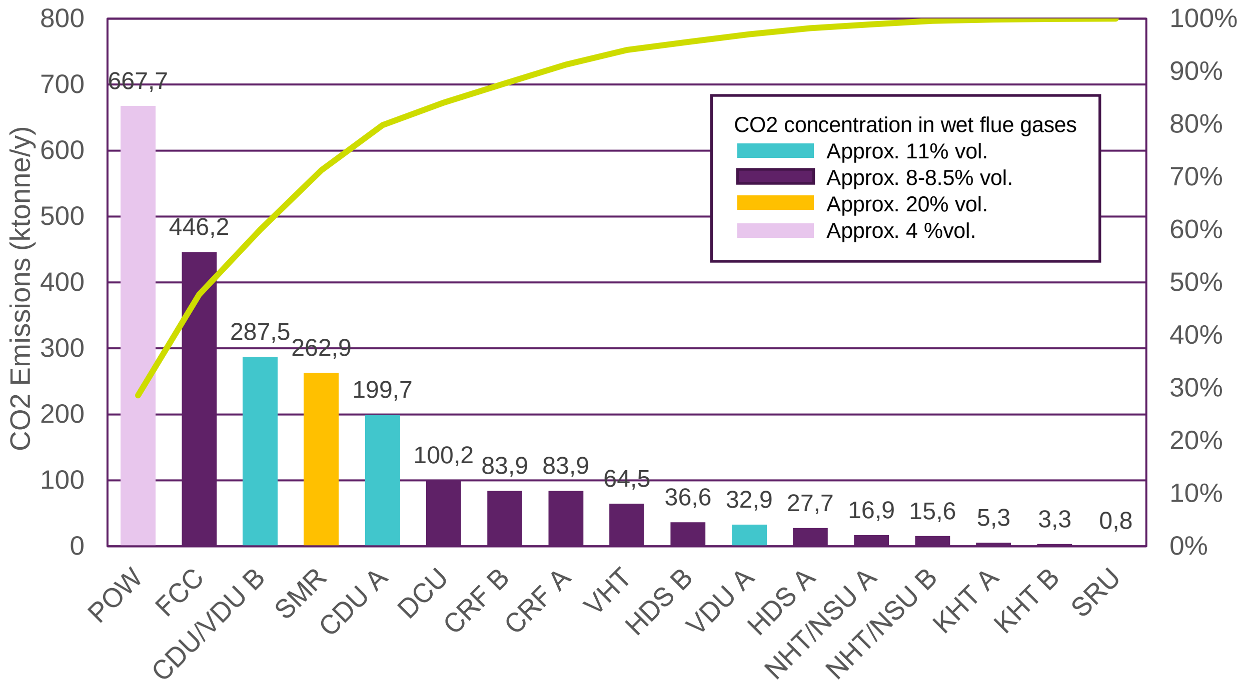


Figure 0-6) Main CO2 emission sources in Base Case 3 refinery

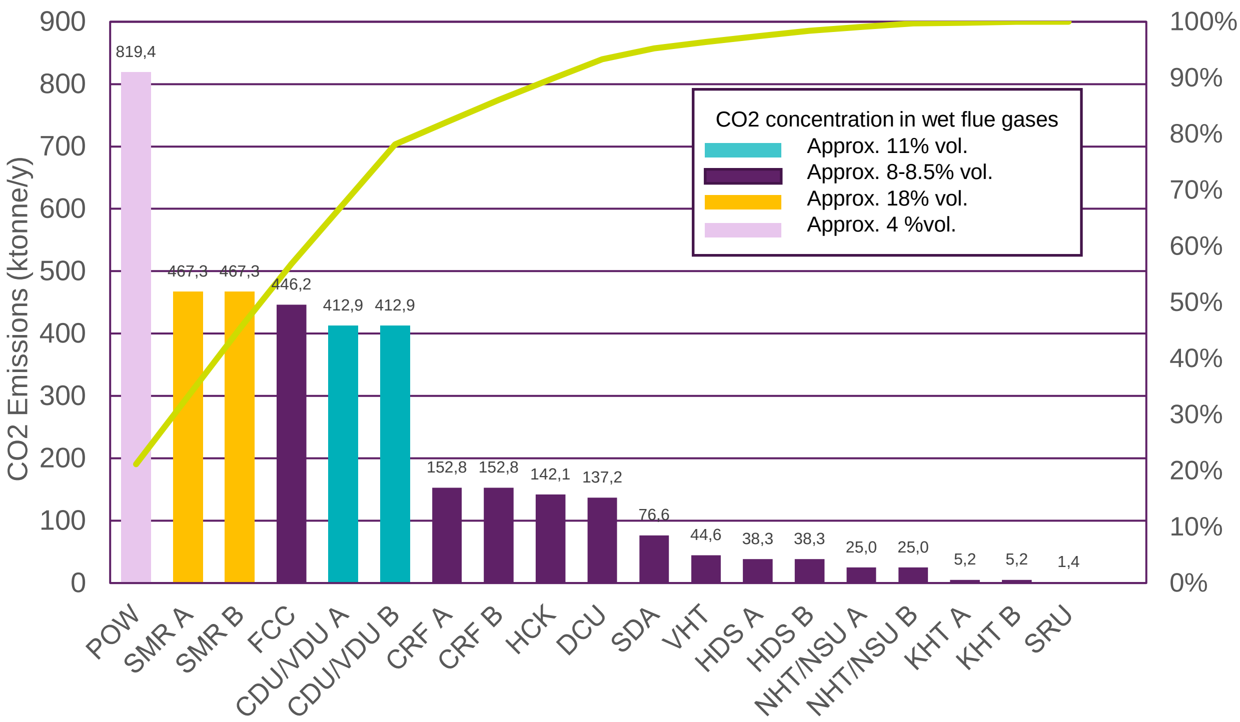


Figure 0-7) Main CO2 emission sources in Base Case 4 refinery

1. Introduction

The performance, in terms of mass and energy balances, and CO_2 emissions of the REFERENCE Plants (Base Cases) are the basis for comparison of the effectiveness and cost of the Oil Refinery with CO_2 capture.

Scope of the present report is to provide a description of the four different oil refineries identified as Base Cases, including the following main information:

- Refinery Block Flow Diagram showing the major processes of the refinery, including the overall mass balance,
- Overall plant layout,
- Refinery fuel balance,
- Hydrogen balance,
- Breakdown of the utilities consumptions (water, electricity and steam) for each major process,
- Summary of CO_2 emissions/concentrations from individual processes.

It must be emphasised that the base case refinery configurations, capacities and economics are values arrived at by consensus among project partners to provide an "average representation" for the wide array of existing European refineries. These do not represent any specific refinery (or refineries) in operation.

1.1 List of Base Cases

Four Base Cases have been considered which differ in terms of capacity and complexity, so providing a representative sample of most of the existing refineries in Europe.

All the assumptions made to build the base cases have been shared among the members of the consortium in order to reflect as much as possible the typical range of configurations, units' capacities, product slates, energy efficiencies, etc. of European refineries.

1.1.1 Base Case 1: Simple Hydro-skimming Refinery

- Capacity: 100,000 bbl/d
- Major Processes:
  - Unit 100: Crude Distillation Unit (CDU)
  - Unit 200: Saturated Gas Plant (SGP)
  - Unit 250: LPG Sweetening (LSW)
  - Unit 280: Kerosene Sweetening (KSW)
  - Unit 300: Naphtha Hydrotreater (NHT)
  - Unit 350: Naphtha Splitter (NSU)

- Unit 400: Isomerization Unit (ISO)
- Unit 500: Catalytic Reformer (CRF)
- Unit 550: Reformate Splitter (RSU)
- Unit 600: Kerosene Hydrotreater (KHT)
- Unit 700: Diesel Hydro-desulphurisation Unit (HDS)
- Unit 1100: Vacuum Distillation Unit (VDU)
- Unit 1500: Visbreaker Unit (VBU)
- Unit 2000: Amine Regeneration Unit (ARU)
- Unit 2100: Sour Water Stripper Unit (SWS)
- Unit 2200: Sulphur Recovery Unit (SRU)
- Unit 2300: Waste Water Treatment (WWT)
- Unit 2500: Power Plant (Electricity and Steam Production)
- Unit 3000: Utilities
- Unit 4000: Off-sites Unit

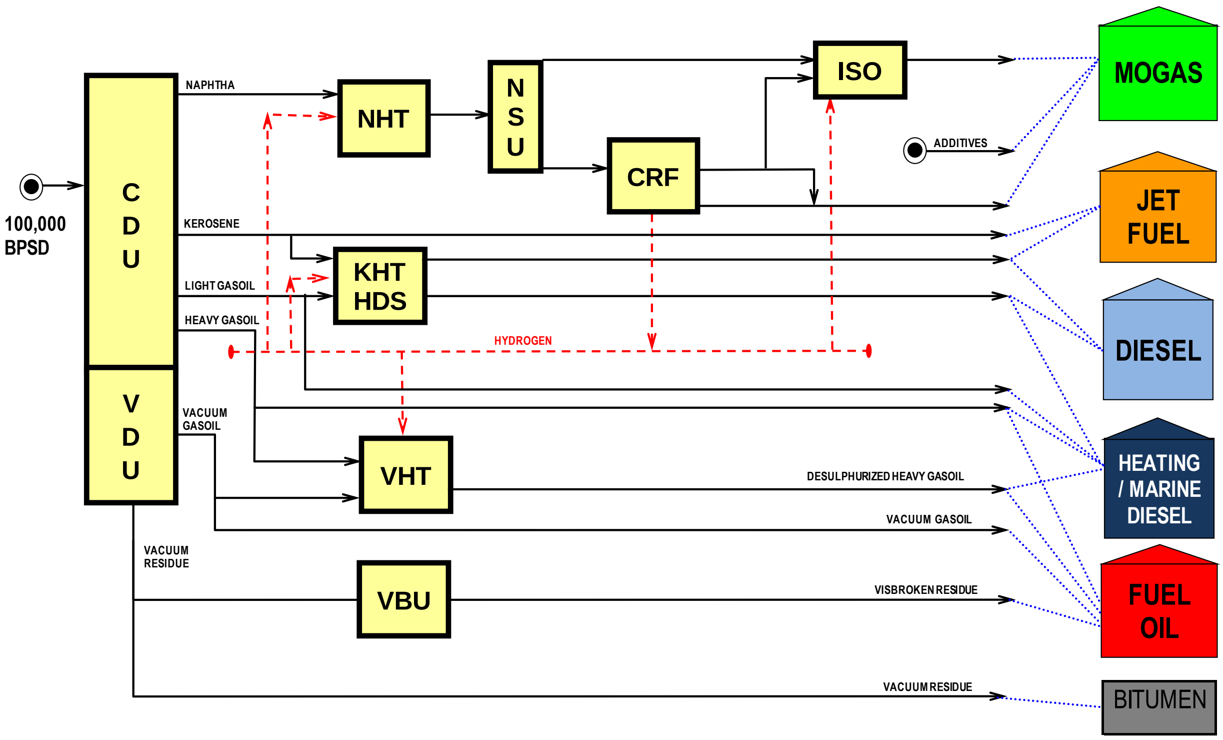


Figure 1-1: Simplified flow diagram for Base Case 1

1.1.2 Base Case 2: Medium Conversion Refinery

- Capacity: 220,000 bbl/d
- Major Processes:
  - Unit 100: Crude Distillation Unit (CDU)
  - Unit 200: Saturated Gas Plant (SGP)
  - Unit 250: LPG Sweetening (LSW)
  - Unit 280: Kerosene Sweetening (KSW)
  - Unit 300: Naphtha Hydrotreater (NHT)
  - Unit 350: Naphtha Splitter (NSU)
  - Unit 400: Isomerization Unit (ISO)
  - Unit 500: Catalytic Reformer (CRF)
  - Unit 550: Reformate Splitter (RSU)
  - Unit 600: Kerosene Hydrotreater (KHT)
  - Unit 700: Diesel Hydro-desulphurisation Unit (HDS)
  - Unit 800: Vacuum Gasoil Hydrotreater (VHT)
  - Unit 1000: Fluid Catalytic Cracker (FCC)
  - Unit 1050: FCC Gasoline Post-Treatment Unit (PTU)
  - Unit 1100: Vacuum Distillation Unit (VDU)
  - Unit 1200: Steam Methane Reformer (SMR)
  - Unit 1500: Visbreaker Unit (VBU)
  - Unit 2000: Amine Regeneration Unit (ARU)
  - Unit 2100: Sour Water Stripper Unit (SWS)
  - Unit 2200: Sulphur Recovery Unit (SRU)
  - Unit 2300: Waste Water Treatment (WWT)
  - Unit 2500: Power Plant (POW)
  - Unit 3000: Utilities
  - Unit 4000: Off-sites

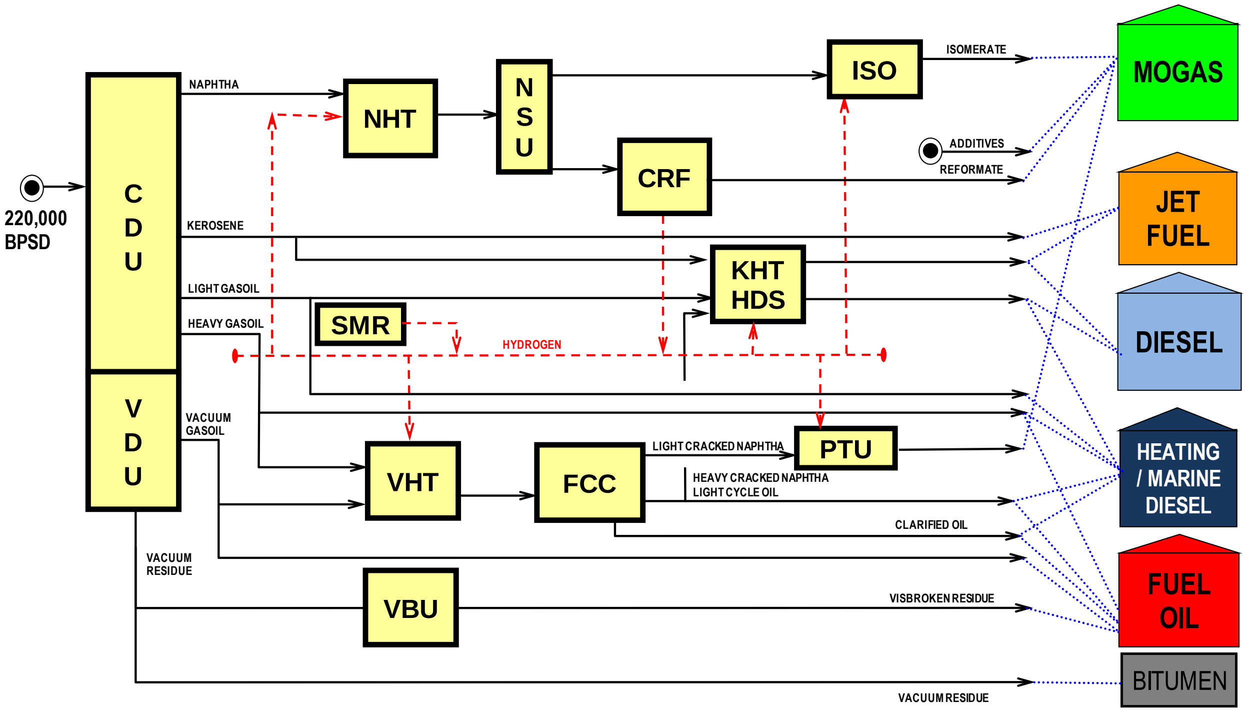


Figure 1-2: Simplified flow diagram for Base Case 2

1.1.3 Base Case 3: High Conversion Refinery

- Capacity: 220,000 bbl/d
- Major Processes:
  - Unit 100: Crude Distillation Unit (CDU)
  - Unit 200: Saturated Gas Plant (SGP)
  - Unit 250: LPG Sweetening (LSW)
  - Unit 280: Kerosene Sweetening (KSW)
  - Unit 300: Naphtha Hydrotreater (NHT)
  - Unit 350: Naphtha Splitter (NSU)
  - Unit 400: Isomerization Unit (ISO)
  - Unit 500: Catalytic Reformer (CRF)
  - Unit 550: Reformate Splitter (RSU)
  - Unit 600: Kerosene Hydrotreater (KHT)
  - Unit 700: Diesel Hydro-desulphurisation Unit (HDS)
  - Unit 800: Vacuum Gasoil Hydrotreater (VHT)

- Unit 1000: Fluid Catalytic Cracker (FCC)
- Unit 1050: FCC Gasoline Post-Treatment Unit (PTU)
- Unit 1100: Vacuum Distillation Unit (VDU)
- Unit 1200: Steam Methane Reformer (SMR)
- Unit 1400: Delayed Coker Unit (DCU)
- Unit 2000: Amine Regeneration Unit (ARU)
- Unit 2100: Sour Water Stripper Unit (SWS)
- Unit 2200: Sulphur Recovery Unit (SRU)
- Unit 2300: Waste Water Treatment (WWT)
- Unit 2500: Power Plant (POW)
- Unit 3000: Utilities
- Unit 4000: Off-sites

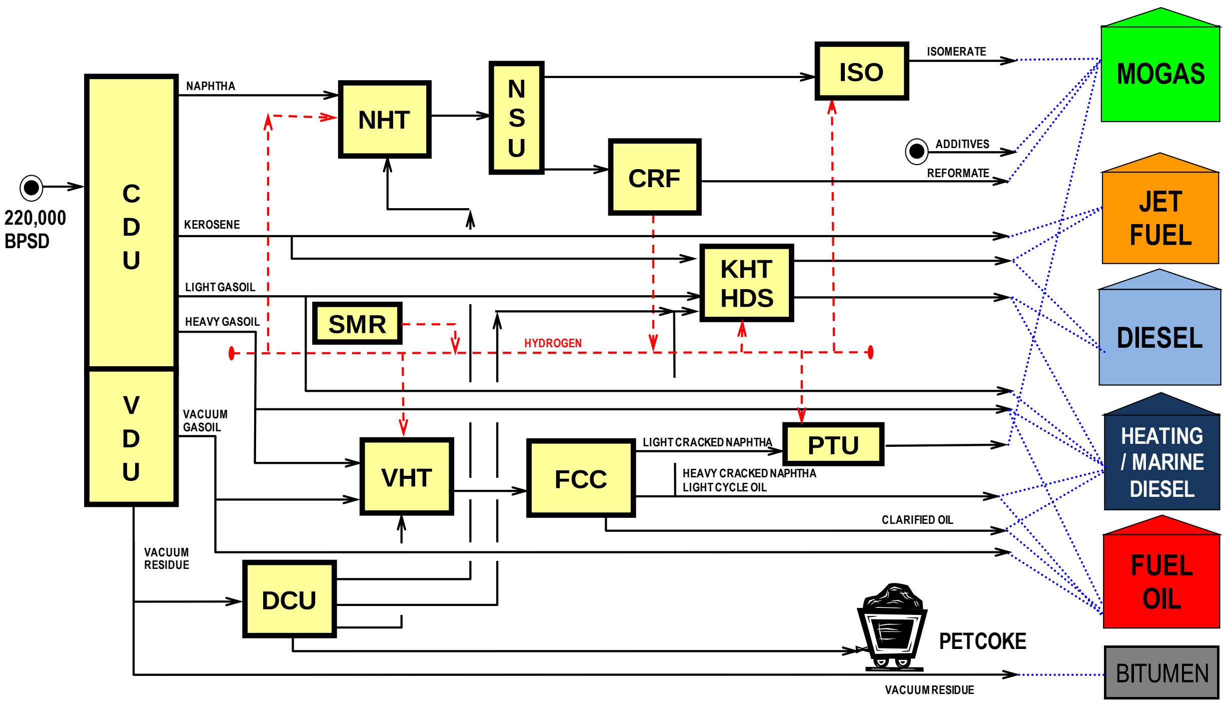


Figure 1-3: Simplified flow diagram for Base Case 3

1.1.4 Base Case 4: High Conversion Refinery

- Capacity: 350,000 bbl/d
- Major Processes:
  - Unit 100: Crude Distillation Unit (CDU)
  - Unit 200: Saturated Gas Plant (SGP)
  - Unit 250: LPG Sweetening (LSW)
  - Unit 280: Kerosene Sweetening (KSW)
  - Unit 300: Naphtha Hydrotreater (NHT)
  - Unit 350: Naphtha Splitter (NSU)
  - Unit 400: Isomerization Unit (ISO)
  - Unit 500: Catalytic Reformer (CRF)
  - Unit 550: Reformate Splitter (RSU)
  - Unit 600: Kerosene Hydrotreater (KHT)
  - Unit 700: Gasoil Hydro-desulphurisation Unit (HDS)
  - Unit 800: Vacuum Gasoil Hydrotreater (VHT)
  - Unit 900: Hydrocracker Unit (HCK)
  - Unit 1000: Fluid Catalytic Cracker (FCC)
  - Unit 1050: FCC Gasoline Post-Treatment Unit (PTU)
  - Unit 1100: Vacuum Distillation Unit (VDU)
  - Unit 1200: Steam Methane Reformer (SMR)
  - Unit 1300: Solvent Deasphalting Unit (SDA)
  - Unit 1400: Delayed Coker Unit (DCU)
  - Unit 2000: Amine Regeneration Unit (ARU)
  - Unit 2100: Sour Water Stripper Unit (SWS)
  - Unit 2200: Sulphur Recovery Unit (SRU)
  - Unit 2300: Waste Water Treatment (WWT)
  - Unit 2500: Power Plant (POW)
  - Unit 3000: Utilities
  - Unit 4000: Off-sites

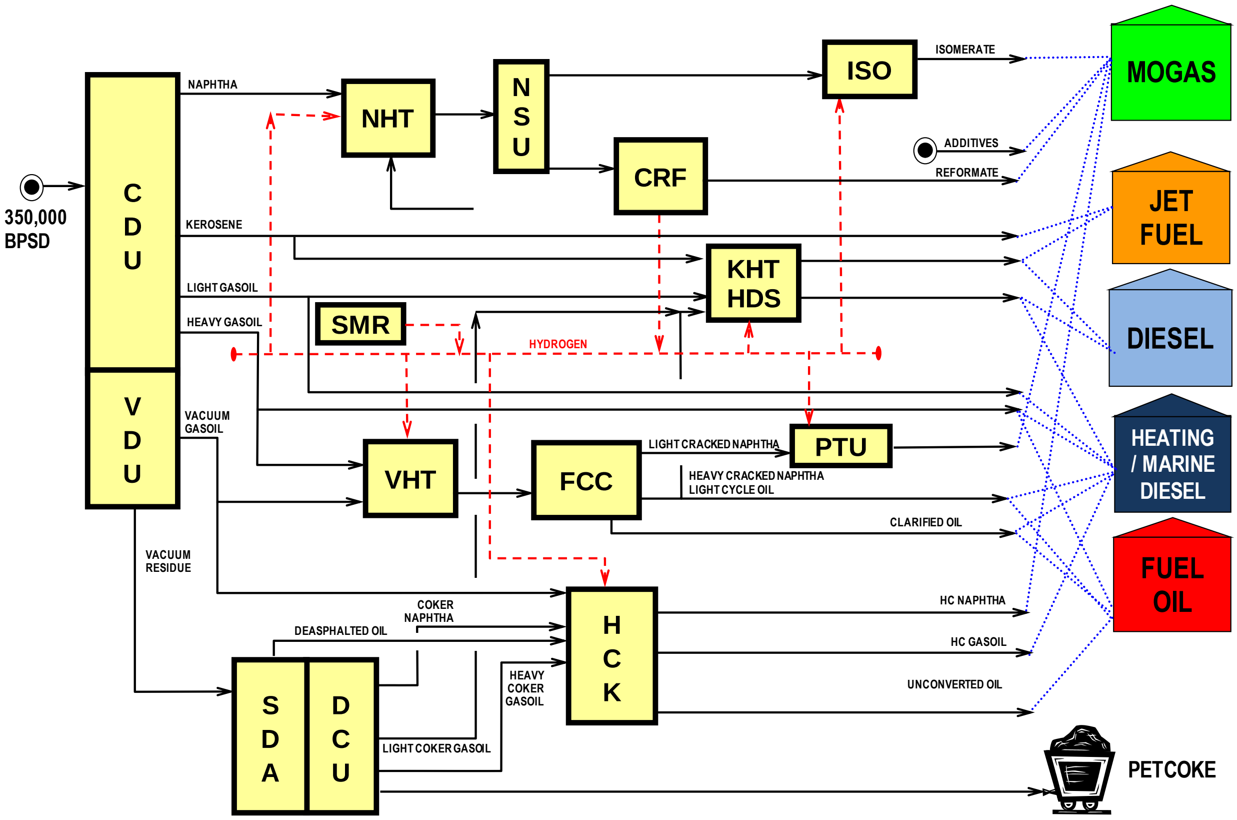


Figure 1-4: Simplified flow diagram for Base Case 4

2. Methodology

2.1 Refinery balances

A linear programming model has been built for each one of the four Base Cases, in order to produce consistent and realistic refinery balances.

Linear programming (LP) is an optimisation technique widely used in petroleum refineries.

LP models of refineries are used for capital investment decisions, the evaluation of term contracts for crude oil, spot crude oil purchases, production planning and scheduling, and supply chain optimisation.

Haverly Systems GRTMPS software (v. 5.0) has been used to build the refinery LP models.

For each process unit, typical yields' structure, products' qualities and specific utility consumptions have been input, based on Amec Foster Wheeler in-house database.

In particular, as far as the primary distillation units are concerned (i.e. Crude Atmospheric and Vacuum Units), some process simulation models have been run in order to evaluate the distillates' yields and main qualities.

The model has been run based on:

- a consistent set of crude, natural gas and products' prices,
- a typical (average) crude diet,
- typical (average) units' sizes and utilization factors,
- European products' specifications,
- typical products' slates, reflecting the average proportions among gasoline markets (i.e. EU/US Export), middle distillates grades (jet fuel/automotive diesel/marine diesel/heating oil) and fuel oil/bitumen productions.

Moreover, in the LP model, an internal production of power and steam to satisfy the refinery needs has been considered.

In the following sections, more details are provided to describe the main input data and constraints of the linear programming models.

Reference is also made to the Reference Document – Technical Basis, including most of the basic assumptions made to develop the refinery balances.

2.2 Refinery layouts

The refinery layouts for the four Base Cases have been developed based on the processing schemes and units' capacities defined as a result of the modelling optimisation.

The layouts have been conceived starting from real examples (real sites) in Amec Foster Wheeler in-house database, to reflect as a much as possible the typical arrangement of European refineries. The intent of presenting typical layouts for the Base Cases is to create a reasonable background for evaluating, in a second phase of this Study, the impact of retrofitting CO_2 capture facilities in an existing site with the relevant constraints (e.g. the limitations in the available plot area, the need for long interconnecting ducts between the existing and the new plants, etc.)

The following notes apply to the Base Case layouts:

- Process units' block is normally located in a central area of the plot;
- Utility block is located in a lateral position with respect of process units;
- Storage tank areas are all around the units' block. Different tank sizes are shown for crude, finished products, intermediate products;
- Main pipe-racks connecting the various process units and utility blocks are shown;
- Jetties and truck loading facilities for sending/receiving products are shown;
- Flare and Waste Water Treatment facilities, which are very demanding in terms of plot area, are shown;
- The main gaseous emission points (e.g. fired heaters stacks) are shown.

3. Design Basis

3.1 Crudes

In order to develop the refinery balances, the following crudes have been considered:

- Ekofisk (Norway), 42.4° API, Sulphur content 0.17% wt.
- Bonny Light (Nigeria), 35.0° API, Sulphur content 0.13% wt.
- Arabian Light (Saudi Arabia), 33.9° API, Sulphur content 1.77% wt.
- Urals Medium (Russia), 32.0° API, Sulphur content 1.46% wt.
- Arabian Heavy (Saudi Arabia), 28.1° API, Sulphur content 2.85% wt.
- Maya (Mexico), 21.7°API, Sulphur content 3.18% wt.

The crude basket has been selected as representative of different supply regions, products' yields and qualities, and it is deemed to reflect with a fair representation the "average" operation of the four European refineries identified as Base Cases.

As far as Maya crude is concerned, it has been considered to be processed only in mixture with Arabian Light, in the proportion 50/50% wt. This to consider the fact that the typical crude distillation units in Europe were not originally designed for extra-heavy crudes and can accommodate them only in blended mode.

The chart in Figure 3-1 shows the distillation curves of the six crudes considered in the Study.

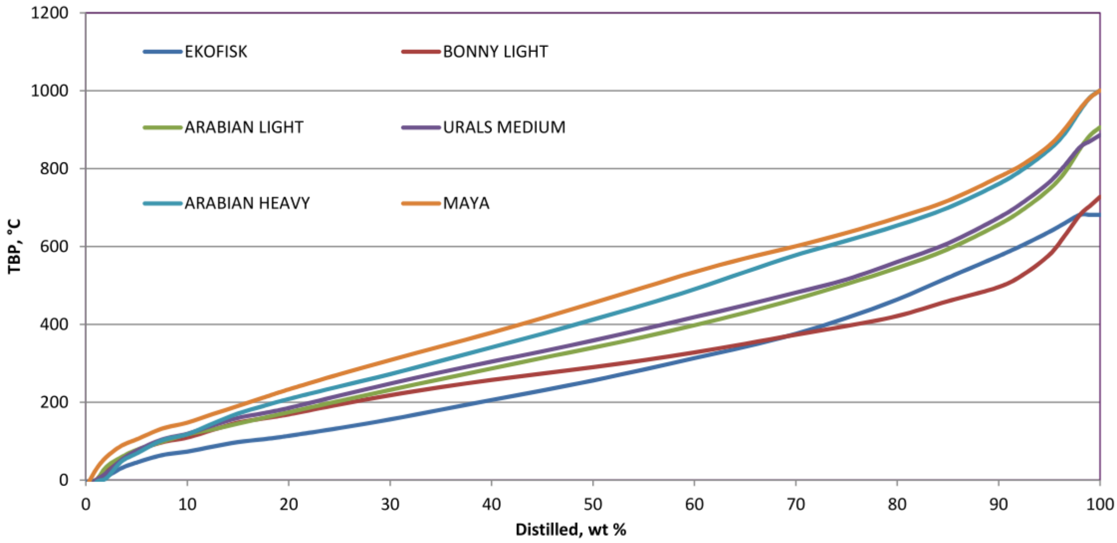


Figure 3-1: Crude Distillation Curves

The crude data grids, reporting the main properties of each crude oil and relevant cut fractions (theoretical, see also paragraph 4.1), are enclosed in the Reference Document – Technical Basis - Annex B.

As far as the proportions among the different crudes are considered, the following have been forced into the LP models to produce the optimised refinery balances:

- Maya Blend: 4% minimum.
- Arabian Heavy: 3% minimum (*)
- Arabian Light: 10% minimum.
- Urals: 30% minimum.
- Bonny Light: 30% maximum (*).
- Ekofisk: no limit. Balancing crude.

(*) Arabian Heavy increased to 10% minimum and Bonny Light decreased to 23% maximum in Base Case 3 and Base Case 4.

3.2 Product Specifications

The refinery product specifications considered in this Study are reported in the Reference Document – Technical Basis - Annex C.

No seasonal variations are considered.

3.3 Market Constraints

Products' market constraints have been input in the LP model in order to "drive" the model solution to reflect the typical products' slates of the European refineries.

3.3.1 Gasoline

Gasoline Export to US is 30 to 40% wt. of the total gasoline production. The rest of gasoline production is sold in Europe.

3.3.2 Jet fuel

Sales of Jet Fuel represent approx. 10% wt. of the total crude intake for Base Case 1 to Base Case 3.

Jet Fuel production is increased to 13% wt. of total crude intake for Base Case 4.

3.3.3 Gasoils

Automotive Diesel is minimum 75% wt. of the total gasoil production.

Marine Diesel is maximum 10% wt. of the total gasoil production.

3.3.4 Bitumen

Bitumen sold in Base Case 1, 2 and 3 is approx. 2.5% wt. of the total crude intake.

Bitumen is not produced in Base Case 4, since in such a deep conversion refinery it is considered to maximise the distillates' production.

3.4 Raw Material and Product Prices

The sets of prices considered in the LP models have been agreed among the members of the Consortium. They have been provided to Amec Foster Wheeler only for the purpose of calculations and they do not represent prices for any specific refinery.

3.5 Utility Conditions

In the LP models, the utility conditions have been considered as per Reference Document – Technical Basis - Paragraph 7.4.

3.6 On-stream Factor

350 operating days per year have been considered to develop the overall material balances of the four Base Case refineries, reflecting as an average:

- 1 week shutdown per year for unplanned shutdowns/catalyst replacements/minor repairs, plus
- 4 weeks general planned turnaround every 4 years for maintenance/major repairs.

3.7 Imported Vacuum Gasoil

Vacuum Gasoil is imported in some Base Cases in order to saturate the capacity of the heavy gasoil conversion units (e.g. Fluid Catalytic Cracking). The quality of imported Vacuum Gasoil is assumed equal to the quality of Heavy Vacuum Gasoil (nominal TBP cut range 420÷530°C) obtained by distillation of the Urals crude.

3.8 Refinery Fuel Oil

Low Sulphur Fuel Oil with 0.5% wt. Sulphur content is burnt in some of the refinery heaters.

Reference is made to Reference Document – Technical Basis - Paragraph 5.1 for the main properties of Low Sulphur Fuel Oil.

The heaters in the following process units have been considered 100% fuel oil fired:

- Unit 100: Crude Distillation Unit (CDU)
- Unit 1100: Vacuum Distillation Unit (VDU)
- Unit 1500: Visbreaker Unit (VBU) (*)

(*) VBU is present only in Base Case 1 and Base Case 2.

3.9 Refinery Fuel Gas

With the exception of the fired heaters burning fuel oil listed in the previous paragraph 3.8, the other refinery heaters and the Power Plant are 100% gas fired.

The off-gases produced in the various process units, after removal of H_2S in amine absorbers (to achieve a residual H_2S content of 50 ppm vol. max.), are collected into a Refinery Fuel Gas system to constitute the primary fuel of the refinery. Imported natural gas is mixed with refinery off-gases to saturate the fuel demand.

Reference is made to Reference Document – Technical Basis - Paragraph 4.2 and 5.2, respectively for the quality of natural gas and refinery off-gases (average) used for combustion calculations.

3.10 Bio-additives

Bio-ethanol is an additive to European Gasoline, while Bio-diesel is an additive to Automotive Gas Oil (Diesel).

To produce the typical refinery balances, the quantity of bio-additives in each finished product has been set/limited to the values reflecting the average European qualities:

- bio-ethanol blended into European Gasoline has been limited to 5% vol. max (despite the "official" specification is limiting the bio-ethanol content to 10% vol. max.);
- bio-diesel has been fixed in the range 6÷7% vol. on Diesel.

4. General data and assumptions

This chapter includes the sets of data and assumptions, common to all the Base Cases, used to build the refinery LP models.

The methodology normally used for refinery configuration studies has been adopted, trying however to:

- remove all the site-specific constraints coming from Amec Foster Wheeler past projects;
- obtain generic but realistic balances, with the level of accuracy needed for the purposes of ReCAP Project.

The valuable input from the members of the Consortium, has been used to optimise the refinery LP model calibration.

For the purpose of this study the capacity of the majority of the units has been adjusted to provide a utilisation rate over 90%. Exceptions to this are the sulphur recovery units and the steam reformers.

4.1 Primary Distillation Units

In order to produce the refinery balances, process simulation models have been created for Crude Distillation Unit (CDU) and Vacuum Distillation Unit (VDU).

Aspentech Hysys v.7.3 is the software used for process simulation.

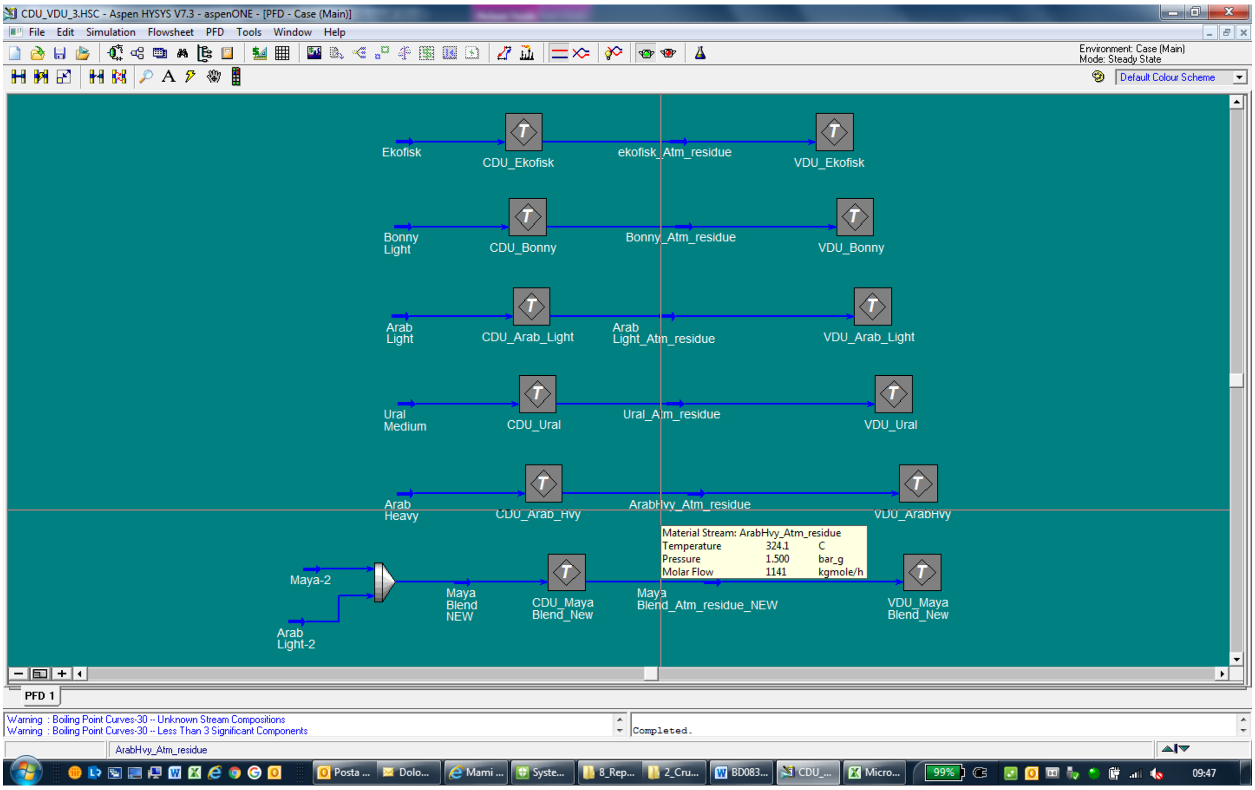


Figure 4-1: Main flowsheet of CDU/VDU simulation

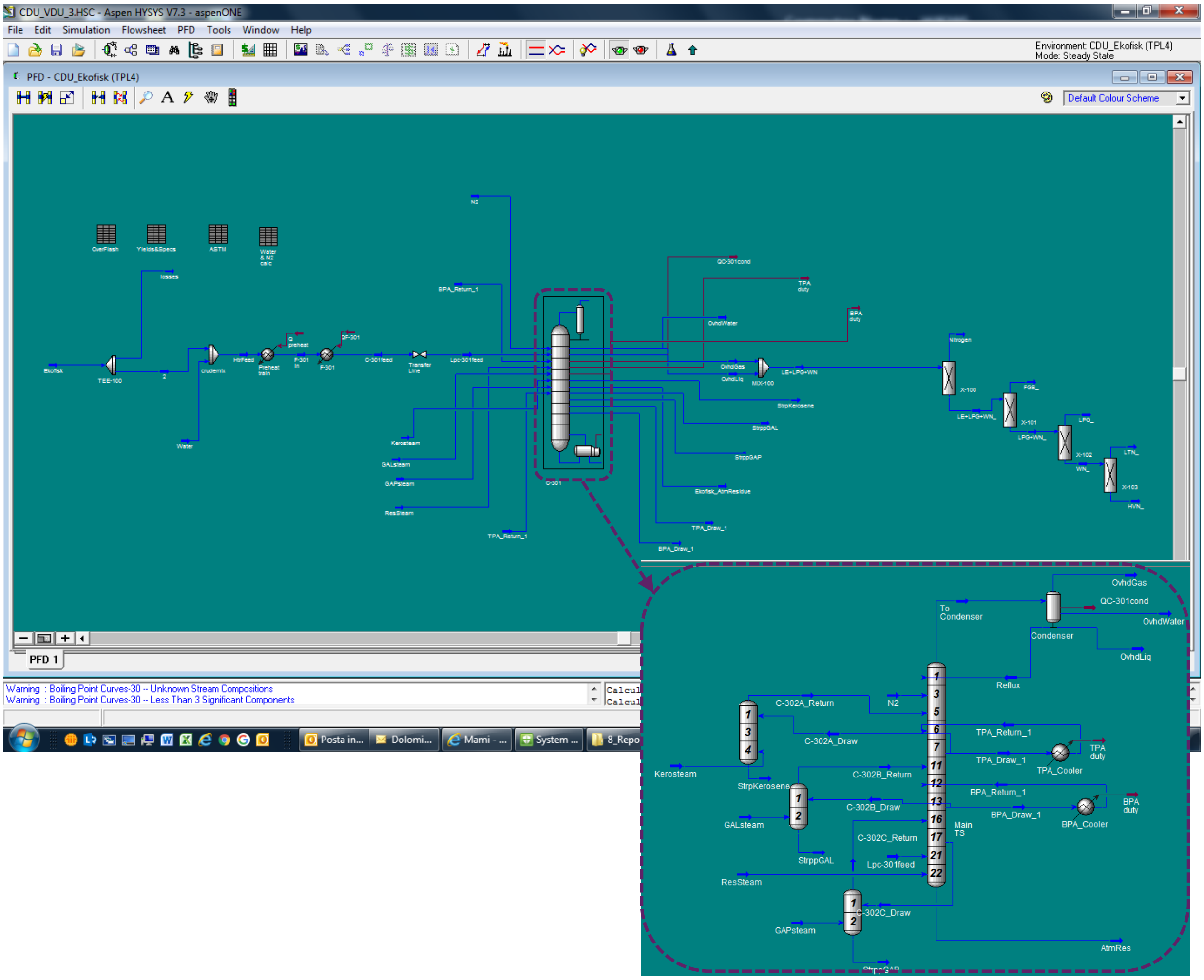


Figure 4-2: Flowsheet of CDU simulation model

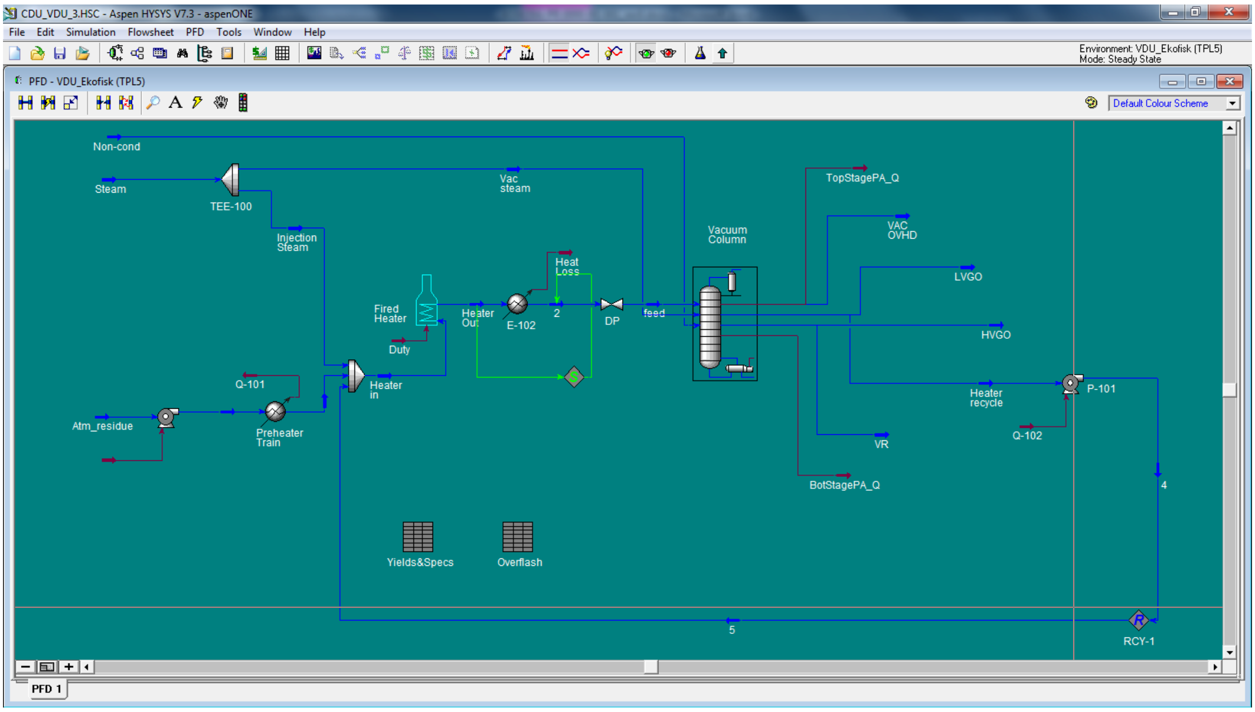


Figure 4-3: Flowsheet of VDU simulation model

The aim of simulation activity is to obtain crude cuts' yields and properties more realistic than the theoretical ones directly retrievable from the crude assay. As a matter of fact, by building a simulation model, the effect of distillation real efficiencies can be properly taken into account, with the consequent impacts on the size and duty of the downstream treating/cracking units.

Table 4-1, Table 4-2, Table 4-3 and Table 4-4 include the sets of yields and main qualities of the straight-run distillation cuts as resulting from the simulation activity.

Table 4-1: Yields of crude distillation cuts

Crude cuts	Yields on crude, wt%					
	EKOFISK	BONNY	ARAB LT	URALS	ARAB HY	MAYA BL
Offgas + LPG	1.65%	1.31%	0.89%	1.55%	2.03%	0.79%
Light Naphtha	10.57%	4.44%	3.70%	3.90%	4.04%	3.12%
Heavy Naphtha	19.30%	10.31%	11.17%	8.23%	6.93%	9.04%
Full Range Naphtha	29.87%	14.75%	14.87%	12.13%	10.97%	12.16%
Kero	18.21%	20.29%	15.70%	15.09%	11.95%	13.10%
Light Gasoil (LGO)	18.30%	29.79%	22.09%	21.49%	17.85%	19.50%
Heavy Gasoil (HGO)	4.54%	5.30%	3.50%	3.40%	2.84%	3.20%
Atmospheric Residue	27.43%	28.56%	42.95%	46.34%	54.36%	51.25%
Light Vacuum Gasoil (LVGO)	3.13%	9.43%	7.19%	6.86%	5.55%	6.00%
Heavy Vacuum Gasoil (HVGO)	12.21%	11.63%	13.97%	16.19%	13.31%	14.06%
Vacuum Residue	12.09%	7.50%	21.79%	23.29%	35.50%	31.19%

Table 4-2: Specific gravity (SG) of crude distillation cuts

Crude cuts	SG					
	EKOFISK	BONNY	ARAB LT	URALS	ARAB HY	MAYA BL
Light Naphtha	0.712	0.702	0.675	0.701	0.640	0.674
Heavy Naphtha	0.768	0.772	0.746	0.742	0.733	0.738
Full Range Naphtha	0.747	0.749	0.727	0.728	0.696	0.721
Kero	0.801	0.828	0.802	0.799	0.800	0.798
Light Gasoil (LGO)	0.849	0.871	0.853	0.858	0.866	0.858
Heavy Gasoil (HGO)	0.879	0.910	0.898	0.893	0.903	0.906
Atmospheric Residue	0.915	0.953	0.948	0.960	0.984	0.990
Light Vacuum Gasoil (LVGO)	0.884	0.900	0.901	0.896	0.908	0.908
Heavy Vacuum Gasoil (HVGO)	0.906	0.928	0.930	0.930	0.939	0.939
Vacuum Residue	0.938	1.019	0.977	1.002	1.015	1.033

Table 4-3: Sulphur content of crude distillation cuts

Crude cuts	Sulphur, wt%					
	EKOFISK	BONNY	ARAB LT	URALS	ARAB HY	MAYA BL
Light Naphtha	0.00007	0.00232	0.06510	0.00085	0.00706	0.05547
Heavy Naphtha	0.00257	0.00786	0.03610	0.01310	0.01320	0.07052
Full Range Naphtha	0.00168	0.00619	0.04331	0.00916	0.01094	0.06660
Kero	0.018	0.027	0.086	0.183	0.280	0.268
Light Gasoil (LGO)	0.111	0.097	0.981	1.011	1.530	1.362
Heavy Gasoil (HGO)	0.242	0.201	2.175	1.590	2.385	2.366
Atmospheric Residue	0.481	0.298	3.399	2.451	4.440	3.990
Light Vacuum Gasoil (LVGO)	0.258	0.215	2.216	1.627	2.426	2.386
Heavy Vacuum Gasoil (HVGO)	0.379	0.280	2.764	2.010	2.768	2.866
Vacuum Residue	0.642	0.430	4.201	3.000	5.386	4.809

Table 4-4: Main properties (other than Sulphur and SG) of Atmospheric and Vacuum Residue

Crude cuts	Conradson Carbon Residue (CCR), wt%					
	EKOFISK	BONNY	ARAB LT	URALS	ARAB HY	MAYA BL
Atmospheric Residue	4.8	3.3	10.5	7.4	14.5	14.8
Vacuum Residue	11.0	13.6	20.6	15.0	22.8	24.9

Crude cuts	Kinematic viscosity at 50°C, cSt					
	EKOFISK	BONNY	ARAB LT	URALS	ARAB HY	MAYA BL
Atmospheric Residue	213	178	434	560	2270	5215
Vacuum Residue	7147	13644	36679	68038	343155	2158606

Only Vacuum Residue from heavy crudes, i.e. Arabian Heavy and Maya Blend, is considered suitable for Bitumen production.

4.2 Specific Hydrogen Consumptions

Hydrogen balances have been developed by considering the units' specific hydrogen demands reported in Table 4-5.

The following notes apply:

- Specific consumptions are dependent on feed quality;
- Specific consumptions include chemical consumptions, solution losses and mechanical losses.

The hydrogen balances are reported in the block flow diagrams developed for each Base Case (reference is made to Figure 5-1, Figure 6-1, Figure 7-1 and Figure 8-1).

Table 4-5: Specific hydrogen consumptions of process units

Unit			Feed	H_2 consumption (wt% on feed)
0300	NHT	Naphtha Hydrotreater	Straight-run Naphtha	0.12
			VB Naphtha/Coker Naphtha	0.15
0400	ISO	Isomerization	Hydrotreated Light Naphtha	0.085
0600A	KHT	Kero HDS	Straight-run Kerosene	0.2
0700A	HDS	Gasoil HDS	Straight-run Light Gasoil	0.7
			VB Gasoil	0.8
			Light Coker Gasoil	0.8
			Light Cycle Oil	0.8
			Heavy Cracked Naphtha	0.25
0800	VHT	Vacuum Gasoil Hydrotreater	Straight-run Heavy Gasoil	1.2
			Light Vacuum Gasoil	1.2
			Heavy Vacuum Gasoil	1.5
			Heavy Coker Gasoil	1.5
			Deasphalted OIl	1.57
0900	HCK	Vacuum Gasoil Hydrocracker	Straight-run Heavy Gasoil	2.0
			Light Vacuum Gasoil	2.0
			Heavy Vacuum Gasoil	2.9
			Heavy Coker Gasoil	4.0

4.3 Sulphur Recovery

The H_2S produced in the desulphurization units will be recovered by means of Amine Washing and Regeneration Unit (Unit 2000 – ARU) and Sour Water Stripper (Unit 2100 – SWS). The acid gases recovered from the top of Amine Regenerator and the Sour gases from the top of the SWS column are then sent to Sulphur Recovery Unit (Unit 2200 – SRU). An overall sulphur recovery of 99.5% has been considered, assuming that a Tail Gas Treatment section is installed downstream the SRU Claus section.

4.4 Utility Consumptions

The following main utility balances have been developed:

- Fuel Gas
- Fuel Oil
- Electric Power
- Steam (High Pressure, Medium Pressure, Low Pressure)
- Cooling Water

The specific utility consumptions of the main process units have been retrieved from Amec Foster Wheeler in-house database, which has been populated with data of past Projects. Reference is made to Table 4-7 for the values considered in the LP models.

On top of the demand of the main process units, a refinery base load of power and steam is considered, to take into account all the remaining users (e.g. minor process units, utility and offsite units, buildings, etc.). Refinery base load is different for the various cases, depending on the size/complexity of the refinery. Reference is made to Table 4-6 for the base loads accounted for in the overall utility balances.

Table 4-6: Refinery base loads of power and steam

CASE	REFINERY BASE LOAD			
	EL. POWER MW	LPS t/h	MPS t/h	HPS t/h
BASE CASE 1	15	20	20	10
BASE CASE 2	22.5	30	30	15
BASE CASE 3	22.5	30	30	15
BASE CASE 4	30	40	40	20

Table 4-7: Specific utility consumptions for main process units

				ReCAP Project - Refinery Balances						
				SPECIFIC UTILITY CONSUMPTIONS						
CUSTOMER:				**SELECTED SPECIFIC CONSUMPTIONS**						
UNIT:										
JOB NO:		1-BD-0839A		**FOR LP MODELS**						
LOCATION:		The Netherlands								
			Capacity expressed as	EL. POWER	FIRED	COOLING W.		LPS	MPS	HPS
				Rated	FUEL	Flow	DT			
				kWh/unit	Gcal/unit	m3/unit	°C	t/unit	t/unit	t/unit
PROCESS UNITS										
100	CDU	Crude Distillation Unit	t feed	5.8	0.128	1.2	10	0.065	0.018	0.004
200	SGP	Saturated Gas Plant		included in CDU						
300	NHT	Naphtha HDT	t feed	3.6	0.033	2.2	10	-0.006	0.000	0.110
350	NSU	Naphtha Splitter	t feed	2.7	0.040	0.2	10	0.000	0.000	0.000
400	ISO	Isomerization	t feed	19.8	0.000	2.2	10	0.500	0.069	0.257
500	CRF	Catalytic Reforming	t feed	33.5	0.561	10.3	10	0.000	0.000	-0.134
600	KHT	Kero HDS	t feed	6.1	0.034	2.8	10	0.000	0.059	0.000
700	HDS	Gasoil HDS	t feed	13.2	0.093	1.3	10	0.000	0.018	0.000
800	VGO HDT	VGO Hydrotreating	t feed	34.9	0.124	0.03	10	0.021	0.020	0.000
900	HCK	HP Hydrocracking	t feed	68.6	0.214	0.9	10	-0.096	0.000	0.000
1000	FCC	Fluid Catalytic Cracking	t feed	5.0	0.376	48.3	10	0.000	0.133	0.085
1100	VDU	Vacuum Distillation Unit	t feed	4.7	0.059	10.9	10	0.016	0.063	0.000
1200	SMR	Steam Reforming & PSA	t feed	75.8	2.689	11.6	10	0.000	0.000	-3.032
1300	SDA	Solvent Deasphalting	t feed	20.5	0.225	0.2	10	0.000	0.081	0.000
1400	DCU	Delayed Coking	t feed	0.0	0.000	0.0	10	0.000	-0.044	0.040
1500	VBU	Visbreaker Unit	t feed	4.7	0.059	10.9	10	0.016	0.063	0.000
AUXILIARY UNITS										
2000	ARU	Amine Washing and Regeneration	t feed (H2S)	7.458	0.000	1.1	10	0.532	0.000	0.000
2100	SWS	Sour Water Stripper		included in BASE LOAD						
2200	SRU	Sulphur Recovery Unit	t feed (H2S)	5.364	0.036	3.5	10	0.000	-0.140	0.000
2250	TGT	Tail Gas Treatment		included in SRU						
2300	WWT	Waste Water Treatment		included in BASE LOAD						
POWER UNITS										
2500	CPP	Power Plant								
UTILITY UNITS										
3000	SWI	Sea Water Intake	m3	0.2						
3100	CWS	Cooling Water System	m3	0.2						
3200	SRW	Service and Raw Water		included in BASE LOAD						
3300	DEW	Demi Water								
3350	BFW	Boiler Feed Water								
3400	FFW	Fire Water and Fire Fighting								
3450	STS	Steam System								
3500	CON	Condensate Recovery System								
3600	AIR	Plant and Instrument Air								
3700	FGS	Fuel and Natural Gas System								
3750	FOS	Fuel Oil System								
3800	NGU	Nitrogen Generation and Distribution								
3900	CHE	Chemicals								
OFF-SITES										
4000	FLA	Flare System		included in BASE LOAD						
4100	TAN	Tankage and Pumping System								
4200	INT	Interconnecting System								
4300	COH	Coke Handling System								
4400	SEW	Sewer Systems								
4500	TLA	Trucks Loading Area								
	BUI	Buildings, DCS, S/S								

4.5 Power Plant

A simplified power plant is included in the LP models of the 4 refineries, to internally close the steam and power balances, without import/export, as requested in the Reference Document Technical Basis.

The power and steam generation is modelled as boiler(s) producing high pressure steam (HPS at 46 barg, 440°C) followed by condensation steam turbine(s). Part of the HPS steam generated in the boiler(s) is exported to the refinery, while the remaining portion is admitted to steam turbine(s) for power generation. From the turbine, part of the steam is extracted at medium and low pressure levels (HP, MP and LP) to feed the steam networks of the refinery.

The configuration of the simplified power plant is shown in Figure 4-4.

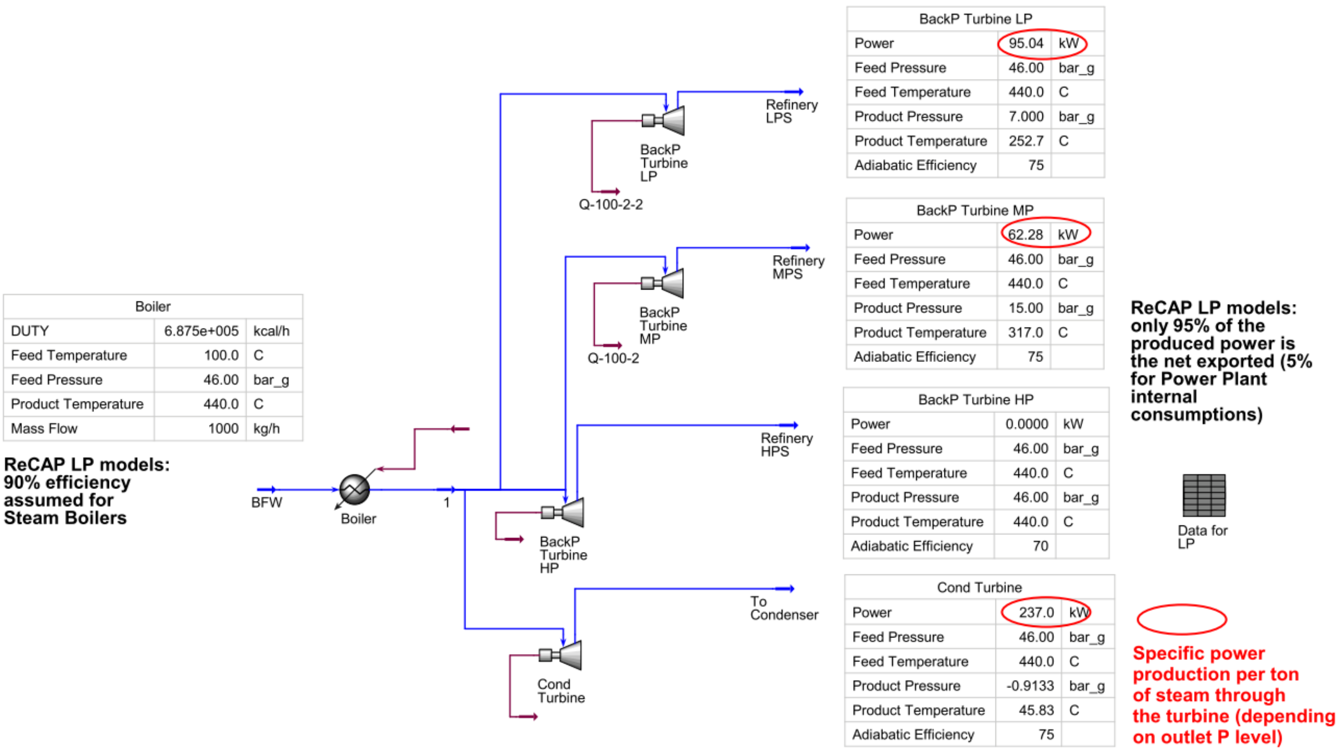


Figure 4-4: Simplified Power Plant configuration considered in the LP models

Moreover, the following assumptions have been made:

- Boiler(s): 90% efficiency,
- Steam Turbines: 75% efficiency (*),
- Net Power Export: 95% of the total generated power (**)

(*) A relatively low adiabatic efficiency is considered for steam turbines, to take into account some performance worsening due to ageing (efficiency is based on available data for relatively old machines).

(**) The remaining 5% is to satisfy the internal consumptions.

Once the refinery balances have been obtained (through the LP models), the configurations of the Power Plant for all the Base Cases have been defined in more detail, as described in the following paragraphs 5.4, 6.4, 7.4 and 8.4. The addition of CO_2 capture plants would have in fact an impact on the refinery steam/power balances, with consequent impacts on the operation/configuration of the power generation unit that need to be addressed as a part of this Study.

In particular, for Base Case 3 and Base Case 4, the Power Plant configuration includes gas turbine(s) in addition to the steam boilers/turbines. Therefore, the LP models relevant to these two cases have been updated to implement the configuration with gas turbine in parallel to steam turbine, in order to calculate more precisely the fuel demand (and consequently the emissions' data) of the Power Plant. Reference is made to paragraphs 7.4 and 8.4 for more details.

4.6 Rate and composition of Flue gases from Fired Heaters

The composition of flue gases from the various fired heaters of the refinery has been calculated depending on the fuel type.

They are reported in the following Table 4-8, Table 4-9 and Table 4-10 respectively for natural gas, sweet refinery offgas and fuel oil.

In all the tables, the combustion of 1 ton of fuel is considered.

It has to be remarked that, in all the refinery balances, the internally produced offgas is not sufficient to satisfy the gaseous fuel demand of the Plant. Therefore, natural gas is imported as a supplementary fuel. The offgas and the natural gas are assumed to be mixed in a centralized refinery fuel gas system and then distributed to all the users of gaseous fuel.

The relative weight of natural gas versus the offgas is dependent on the refinery configuration and it is therefore different in the four Base Cases.

The flowrates of the offgas and natural gas used as refinery fuel are reported in the section "FUEL MIX COMPOSITION" in Table 5-6 (Base Case 1), Table 5-6 (Base Case 2), Table 7-6 (Base Case 3), Table 8-6 (Base Case 4).

For each Base Case, the composition of flue gas from refinery heaters could be calculated as a linear combination of the flue gases generated by the combustion of 1 ton of natural gas (Table 4-8) and by the combustion of 1 ton of sweet refinery offgas (Table 4-9). The flue gas rate from each source could be then calculated from the refinery fuel gas rates reported in Table 5-7, Table 6-7, Table 7-7 and Table 8-7, respectively for Base Case 1 to 4.

In the same tables, the typical temperature levels of flue gases to the stacks are reported for each source. Temperatures are depending on the process service, the presence of heat recovery coils in the convective section (e.g. for steam generation and/or superheating), the presence of air preheating facilities (APH).

In particular, the presence of APH systems is considered typical for heaters designed for a fired duty higher than 20 MMkcal/h (because the payback period for the APH is relatively lower than for small heaters), so resulting in a lower temperature level for the relevant flue gases.

Table 4-8: Flue gas data from natural gas combustion

COMBUSTION AND EMISSIONS CALCULATION
NATURAL GAS

INPUT DATA

FUEL GAS COMPOSITION, %WT			
H2	0	H2S, PPMV	5
CH4	79.22	FIRED DUTY, MMKCAL/H	11.103
C2H4	0		
C2H6	11.68	EXCESS AIR, %	15.0%
C3H6	0	WATER IN AIR, KG/KG	0.012300
C3H8	2.45		
C4H8	0	NOX (NO2), MG/NM3 DRY	150
C4H10	0.32	CO, MG/NM3 DRY	50
C5H12	0.04	SO2 CONVERTED INTO SO3, %WT	5.0%
N2	1.39		
CO	0		
CO2	4.9		

FUEL GAS CALCULATIONS

MOLECULAR WEIGHT	17.97	FLOWRATE, KG/H	1000.0
NHV, KCAL/KG	11103		

AIR CALCULATIONS

FLOWRATE DRY, KG/H	18294.89	FLOWRATE WET, KG/H	18519.92
FLOWRATE DRY, NM3/H	14218.50	FLOWRATE WET, NM3/H	14498.71
FLOWRATE DRY/FUEL, KG/KG	18.29	ARIA WET/FUEL, KG/KG	18.52
HUMIDITY, KG/H	225		

WET FLUE GAS CALCULATIONS

	KG/H	%WT	NM3/H	%VOL		MG/NM3	PPMW	PPMV
N2	14045	71.95%	11243	71.14%	CO	41.1	33.3	32.9
H2O	2263	11.60%	2818	17.83%	NOX	123.3	99.8	60.1
O2	555	2.84%	389	2.46%	SOX	1.1	0.9	0.4
CO2	2654	13.59%	1352	8.55%				
CO	0.65	0.0033%	0.52	0.0033%				
NO2	1.95	0.0100%	0.95	0.0060%				
SO2	0.02	0.0001%	0.01	0.0000%				
SO3	0.00	0.0000%	0.00	0.0000%				

WET FLUE GAS FLOWRATE	19520	KG/H	15804	NM3/H

DRY FLUE GAS CALCULATIONS

	KG/H	%WT	NM3/H	%VOL		MG/NM3	PPMW	PPMV
N2	14045	81.39%	11243	86.58%	CO	50.0	37.6	40.0
O2	555	3.22%	389	2.99%	NOX	150.0	112.9	73.1
CO2	2654	15.38%	1352	10.41%	SOX	1.4	1.0	0.5
CO	0.65	0.0038%	0.52	0.0040%	@ O2 EXCESS=3%V			
NO2	1.95	0.0113%	0.95	0.0073%	CO	50.0		
SO2	0.02	0.0001%	0.01	0.0000%	NOX	150.0		
SO3	0.00	0.0000%	0.00	0.0000%	SOX	1.4		

DRY FLUE GAS FLOWRATE	17257	KG/H	12985	NM3/H

Table 4-9: Flue gas from refinery offgas combustion

COMBUSTION AND EMISSIONS CALCULATION
SWEET REFINERY OFFGAS (AVERAGE COMPOSITION)

INPUT DATA

FUEL GAS COMPOSITION, %WT			
H2	8	H2S, PPMV	50
CH4	12	FIRED DUTY, MMKCAL/H	12.579
C2H4	0		
C2H6	18	EXCESS AIR, %	15.0%
C3H6	0	WATER IN AIR, KG/KG	0.0123
C3H8	24		
C4H8	0	NOX (NO2), MG/NM3 DRY	150
C4H10	38	CO, MG/NM3 DRY	50
C5H12	0	SO2 CONVERTED INTO SO3, %WT	5.0%
N2	0		
CO	0		
CO2	0		

FUEL GAS CALCULATIONS

MOLECULAR WEIGHT	15.27	FLOWRATE, KG/H	1000.0
NHV, KCAL/KG	12579		

AIR CALCULATIONS

FLOWRATE DRY, KG/H	19875.88	FLOWRATE WET, KG/H	20120.36
FLOWRATE DRY, NM3/H	15447.23	FLOWRATE WET, NM3/H	15751.65
FLOWRATE DRY/FUEL, KG/KG	19.88	ARIA WET/FUEL, KG/KG	20.12
HUMIDITY, KG/H	244		

WET FLUE GAS CALCULATIONS

	KG/H	%WT	NM3/H	%VOL		MG/NM3	PPMW	PPMV
N2	15244	72.18%	12203	71.02%	CO	40.8	33.2	32.7
H2O	2541	12.03%	3164	18.41%	NOX	122.4	99.6	59.6
O2	603	2.86%	422	2.46%	SOX	12.3	10.0	4.3
CO2	2730	12.92%	1391	8.09%				
CO	0.70	0.0033%	0.56	0.0033%				
NO2	2.10	0.0100%	1.02	0.0060%				
SO2	0.20	0.0010%	0.07	0.0004%				
SO3	0.01	0.0000%	0.00	0.0000%				
WET FLUE GAS FLOWRATE	21120	KG/H	17181	NM3/H				

DRY FLUE GAS CALCULATIONS

	KG/H	%WT	NM3/H	%VOL		MG/NM3	PPMW	PPMV
N2	15244	82.05%	12203	87.05%	CO	50.0	37.7	40.0
O2	603	3.25%	422	3.01%	NOX	150.0	113.2	73.1
CO2	2730	14.69%	1391	9.92%	SOX	15.1	11.4	5.2
CO	0.70	0.0038%	0.56	0.0040%	@ O2 EXCESS=3%V			
NO2	2.10	0.0113%	1.02	0.0073%	CO	50.0		
SO2	0.20	0.0011%	0.07	0.0005%	NOX	150.1		
SO3	0.01	0.0001%	0.00	0.0000%	SOX	15.1		
DRY FLUE GAS FLOWRATE	18580	KG/H	14017	NM3/H				

Table 4-10: Flue gas from fuel oil combustion

COMBUSTION AND EMISSIONS CALCULATION
LOW SULPHUR FUEL OIL

INPUT DATA

FIRED DUTY, MMKCAL/H	9.782
EXCESS AIR, %	25.0%
WATER IN AIR, KG/KG	0.012300
NOX (NO2), MG/NM3 DRY	450
CO, MG/NM3 DRY	100
SO2 CONVERTED INTO SO3, %WT	3.0%

FUEL OIL DATA

API GRAVITY	17.40	FLOWRATE, KG/H	1000.0
NHV, KCAL/KG	9782	SULPHUR, %WT	0.5

AIR CALCULATIONS

FLOWRATE DRY, KG/H	17411	FLOWRATE WET, KG/H	17628
FLOWRATE DRY, NM3/H	13531	FLOWRATE WET, NM3/H	13800
FLOWRATE DRY/FUEL, KG/KG	17.41	ARIA WET/FUEL, KG/KG	17.63
HUMIDITY, KG/H	217		

WET FLUE GAS CALCULATIONS

	KG/H	%WT	NM3/H	%VOL		MG/NM3	PPMW	PPMV
N2	13369.3	71.77%	10702.1	74.10%	CO	82.5	63.9	66.0
H2O	1234.7	6.63%	1537.5	10.65%	NOX	371.1	287.7	180.8
O2	808.8	4.34%	566.5	3.92%	SOX	691.7	536.3	240.8
CO2	3198.4	17.17%	1629.3	11.28%				
CO	1.2	0.01%	1.0	0.01%				
NO2	5.4	0.03%	2.6	0.02%				
SO2	9.7	0.05%	3.4	0.0235%				
SO3	0.3	0.00%	0.1	0.0006%				

WET FLUE GAS FLOWRATE 18628 KG/H 14442 NM3/H

DRY FLUE GAS CALCULATIONS

	KG/H	%WT	NM3/H	%VOL		MG/NM3	PPMW	PPMV
N2	13369.3	76.87%	10702.1	82.93%	CO	92.3	68.5	73.9
O2	808.8	4.65%	566.5	4.39%	NOX	415.3	308.1	202.3
CO2	3198.4	18.39%	1629.3	12.63%	SOX	774.2	574.4	269.5
CO	1.2	0.01%	1.0	0.01%		@ O2 EXCESS=3%V		
NO2	5.4	0.03%	2.6	0.02%	CO	100.0		
SO2	9.7	0.06%	3.4	0.03%	NOX	450.0		
SO3	0.3	0.00%	0.1	0.00%	SOX	840.1		

DRY FLUE GAS FLOWRATE 17393 KG/H 12905 NM3/H

4.7 Syngas and Flue Gas from Steam Methane Reformer

A Steam Methane Reformer unit (Unit 1200 – SMR) is present in 3 out of 4 refinery Base Cases, to satisfy the hydrogen demand of several process units.

Typical heat and material balances have been developed by Amec Foster Wheeler for a SMR operating to produce 20,000 Nm^3/h hydrogen (design capacity 30,000 Nm^3/h), in line with the capacity of SMR of Base Case 2 (see also paragraph 6.1).

Table 4-11 includes flowrate, conditions and composition of the Syngas upstream the Pressure Swing Absorption (PSA). Reference is made to the sketch in Figure 4-5.

Since this Syngas stream is relatively rich in CO_2 and at a relatively high pressure, it could be attractive to capture CO_2 from it. Syngas flowrates in Base Case 3 and Base Case 4 could be calculated on a pro-rate basis for the higher capacities.

Table 4-11: Syngas data for Steam Methane Reformer (20,000 Nm^3/h operating capacity)

Stream		**3**
Description		**PSA Inlet (Syngas)**
Temperature	*°C*	35
Pressure	*MPa*	2.67
Molar Flow	*kmol/h*	1349.57
Mass Flow	*kg/h*	14261.17
Composition		
CO2	*mol/mol*	0.1627
CO	*mol/mol*	0.0464
Hydrogen	*mol/mol*	0.7563
H2S	*mol/mol*	0.0000
Ammonia	*mol/mol*	0.0000
Nitrogen	*mol/mol*	0.0024
Oxygen	*mol/mol*	0.0020
Methane	*mol/mol*	0.0000
Ethane	*mol/mol*	0.0302
Propane	*mol/mol*	0.0000
n-Butane	*mol/mol*	0.0000
i-Butane	*mol/mol*	0.0000
i-Butene	*mol/mol*	0.0000
n-Pentane	*mol/mol*	0.0000
i-Pentane	*mol/mol*	0.0000
n-Hexane	*mol/mol*	0.1627
C6+	*mol/mol*	0.0464
H2O	*mol/mol*	0.7563
Contaminants:		
NOx	*mg/Nm3*	

(*) 30 mg/Nm^3 max

As an alternative, for the application of the post-combustion CO_2 capture cases, Table 4-12 includes rate and composition of the flue gases generated by the combustion of 2.32 tons of tail gas, which correspond to the tail gas rate generated by 1 ton of natural gas used as feed to SMR.

Total rate and average composition of the flue gas sent to SMR stack could be then calculated as a linear combination of the flue gases generated by 1 ton of feed and 1 ton of fuel, using the rates of feed and fuel to SMR reported in Table 5-7, Table 6-7, Table 7-7 and Table 8-7, respectively for Base Case 1 to 4.

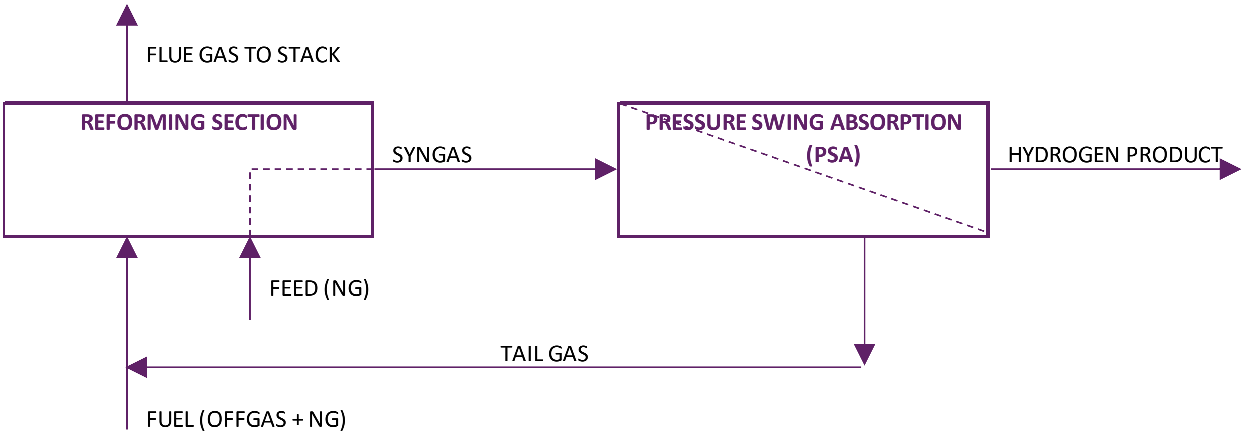


Figure 4-5: Steam Methane Reformer simplified representation

Table 4-12: Flue gas from PSA tail gas combustion

COMBUSTION AND EMISSIONS CALCULATION
PSA TAIL GAS

INPUT DATA

FUEL GAS COMPOSITION, %WT			
H2	2.0	H2S, PPMV	50
CH4	5.2	FIRED DUTY, MMKCAL/H	3.576
C2H4	0		
C2H6	0	EXCESS AIR, %	15.0%
C3H6	0	WATER IN AIR, KG/KG	0.0123
C3H8	0		
C4H8	0	NOX (NO2), MG/NM3 DRY	150
C4H10	0	CO, MG/NM3 DRY	50
C5H12	0	SO2 CONVERTED INTO SO3, %WT	5.0%
N2	0.6		
CO	14.1		
CO2	77.6		
H2O	0.5		

FUEL GAS CALCULATIONS

MOLECULAR WEIGHT	27.59	FLOWRATE, KG/H	2320.1
NHV, KCAL/KG	1541		

AIR CALCULATIONS

FLOWRATE DRY, KG/H	5162.00	FLOWRATE WET, KG/H	5225.49
FLOWRATE DRY, NM3/H	4011.83	FLOWRATE WET, NM3/H	4090.89
FLOWRATE DRY/FUEL, KG/KG	2.22	ARIA WET/FUEL, KG/KG	2.25
HUMIDITY, KG/H	63		

WET FLUE GAS CALCULATIONS

	KG/H	%WT	NM3/H	%VOL		MG/NM3	PPMW	PPMV
N2	3973	52.58%	3180	56.80%	CO	41.5	30.7	33.2
H2O	765	10.13%	953	17.02%	NOX	124.5	92.2	60.7
O2	157	2.07%	110	1.96%	SOX	48.5	36.0	16.8
CO2	2661	35.21%	1355	24.21%				
CO	0.23	0.0031%	0.19	0.0033%				
NO2	0.70	0.0092%	0.34	0.0061%				
SO2	0.26	0.0034%	0.09	0.0016%				
SO3	0.01	0.0002%	0.00	0.0001%				

WET FLUE GAS FLOWRATE	7557	KG/H	5599	NM3/H

DRY FLUE GAS CALCULATIONS

	KG/H	%WT	NM3/H	%VOL		MG/NM3	PPMW	PPMV
N2	3973	58.50%	3180	68.45%	CO	50.0	34.2	40.0
O2	157	2.30%	110	2.36%	NOX	150.0	102.6	73.1
CO2	2661	39.18%	1355	29.17%	SOX	58.5	40.0	20.3
CO	0.23	0.0034%	0.19	0.0040%	@ O2 EXCESS=3%V			
NO2	0.70	0.0103%	0.34	0.0073%	CO	48.3		
SO2	0.26	0.0038%	0.09	0.0019%	NOX	144.9		
SO3	0.01	0.0002%	0.00	0.0001%	SOX	56.5		

DRY FLUE GAS FLOWRATE	6791	KG/H	4646	NM3/H

4.8 Flue Gas from Fluid Catalytic Cracking (FCC) unit

A Fluid Catalyitc Cracking unit (Unit 1000 – FCC) is present in 3 out of 4 refinery Base Cases, to convert into valuable distillate (LPG, gasoline and diesel) the Vacuum Gasoil.

In the FCC, the circulating catalyst is continuously regenerated by burning the coke on it. This happens in the Regeneration section, where air is injected to achieve total oxidation of the coke.

The following Table 4-13 shows the compositions of the flue gas leaving the FCC Regenerator.

Table 4-13: Flue gas from FCC coke combustion

COMBUSTION AND EMISSIONS CALCULATION									
FCC COKE									**REV.1**
COKE									
	NHV, KCAL/KG	9200				**FLOWRATE, KG/H**	1000		
WET FLUE GAS CALCULATIONS									
	KG/H	**%WT**	**NM3/H**	**%VOL**		**MG/NM3**	**PPMW**	**PPMV**	
N2	9995	66.95%	8001	71.08%	**CO**	0.0	0.0	0.0	
H2O	889	5.95%	1126	10.00%	**NOX**	0.0	0.0	0.0	
O2	370	2.48%	259	2.30%	**SOX**	741.2	558.9	256.5	
CO2	3667	24.56%	1868	16.59%					
CO	0.0	0.00%	0.0	0.00%					
NO2	0.0	0.00%	0.0	0.00%					
SO2	7.9	0.05%	2.8	0.02%					
SO3	0.5	0.00%	0.1	0.00%					
WET FLUE GAS FLOWRATE		14929	**KG/H**		11256	**NM3/H**			
DRY FLUE GAS CALCULATIONS									
	KG/H	**%WT**	**NM3/H**	**%VOL**		**MG/NM3**	**PPMW**	**PPMV**	
N2	9995	71.19%	8001	78.98%	**CO**	0.0	0.0	0.0	
O2	370	2.63%	259	2.56%	**NOX**	0.0	0.0	0.0	
CO2	3667	26.12%	1868	18.44%	**SOX**	823.5	594.3	285.0	
CO	0.0	0.00%	0.0	0.00%		**@ O2 EXCESS=3%V**			
NO2	0.0	0.00%	0.0	0.00%	**CO**	0.0			
SO2	7.9	0.06%	2.8	0.03%	**NOX**	0.0			
SO3	0.5	0.00%	0.1	0.00%	**SOX**	803.7			
DRY FLUE GAS FLOWRATE		14039	**KG/H**		10131	**NM3/H**			

4.9 Flue Gas from Gas Turbine (GT) and Heat Recovery Steam Generators (HRSG)

As described in the following paragraphs 7.4 and 8.4, the Power Plant in Base Case 3 and Base Case 4 includes Gas Turbine(s) and relevant Het Recovery Steam Generator(s).

The specific rate (per ton of natural gas fed to the gas turbine) and composition of flue gases from the GT+HRSG is reported in the following tables. SOx concentration in the flue gas is not reported, being it far below 5 ppm wt.

from GT

	%vol	MW	%wt
		kg/kmol	
CH4	0%	16	0%
C2H6	0%	30	0%
C3H8	0%	44	0%
C4H10	0%	58	0%
C5H12	0%	72	0%
CO2	3.20%	44	5.00%
N2	76.40%	28	74.94%
SO2	0%	32	0%
O2	13.40%	32	15.00%
H2	0%	2	0%
H2O	6.10%	18	3.84%
Ar	0.90%	40	1.22%
Total	**1**	**28.6**	**100%**

From HRSG

	%vol	MW	%wt
		kg/kmol	
CH4	0%	16	0%
C2H6	0%	30	0%
C3H8	0%	44	0%
C4H10	0%	58	0%
C5H12	0%	72	0%
CO2	4.87%	44	7.55%
N2	75.10%	28	74.22%
SO2	0%	32	0%
O2	9.78%	32	11.04%
H2	0%	2	0%
H2O	9.40%	18	5.98%
Ar	0.86%	40	1.21%
Total	**1**	**28.3**	**100%**

Spec flue gas flowrate [t/t NG to GT] **53.0** t/t NG to GT

5. Base Case 1

Hydro-skimming Refinery - 100,000 BPSD Crude Capacity

The Hydro-skimming refinery is essentially composed of primary distillation units (Atmospheric and Vacuum), a gasoline block (Naphtha Hydrotreater, Splitter, Isomerization and Catalytic Reformer) for the production of on-spec gasolines, a Kerosene Sweetening unit for jet fuel production and middle-distillates Hydro-desulphurization units for the production of automotive diesel, marine diesel and heating oil. The residue from Vacuum distillation unit is partially sold as bitumen and partially sent to Visbreaking Unit, for partial conversion into distillates and viscosity reduction of the residue to comply with fuel oils' specifications.

The Hydrogen Rich Gas from the Heavy Naphtha Catalytic Reformer is compressed, sent to a Pressure Swing Absorber (PSA) module to increase the hydrogen concentration, and finally used for the desulphurization of products. No Steam Methane Reformer is included in the process scheme.

Crude Atmospheric Distillation and Vacuum Distillation are not thermally integrated, since they are considered being built in different phases (i.e. Vacuum Distillation, Vacuum Gasoil Hydrotreater and Visbreaking added in a second phase).

Sea Water is used for condensation and cooling purposes. No cooling towers are installed.

5.1 Refinery Balances

The balances developed for Base Case 1 are reported in the following tables and figures:

- Table 5-1: Base Case 1) Overall material balance
- Table 5-2: Base Case 1) Process units operating and design capacity
- Table 5-3: Base Case 1) Gasoline qualities
- Table 5-4: Base Case 1) Distillate qualities
- Table 5-5: Base Case 1) Fuel oil and bitumen qualities
- Table 5-6: Base Case 1) Main utility balance, fuel mix composition, CO2 emissions
- Figure 5-1: Base Case 1) Block flow diagrams with main material streams
- Table 5-7: Base Case 1) CO2 emissions per unit

Table 5-1: Base Case 1) Overall material balance

REV.7
12/05/2016

ReCAP Project
Refinery Balances

BASE CASE 1
Hydroskimming refinery, 100,000 BPSD

OVERALL MATERIAL BALANCE

PRODUCTS	Annual Production, kt/y
LPG	110.7
Petrochemical Naphtha	24.2
Gasoline U95 Europe	614.6
Gasoline U92 USA Export	263.4
Jet fuel	450.0
Road Diesel	1372.9
Marine Diesel	183.0
Heating Oil	274.6
Low Sulphur Fuel Oil	806.2
Medium Sulphur Fuel Oil	0.0
High Sulphur Fuel Oil	518.0
Bitumen	125.0
Sulphur	13.5
Subtotal	**4756.1**
RAW MATERIALS	Consumptions, kt/y
Ekofisk	1272.8
Bonny Light	1226.9
Arabian Light	460.0
Urals Medium	1390.0
Arabian Heavy	139.0
Maya Blend (1)	244.0
MTBE	59.8
Natural Gas	121.8
Biodiesel	86.7
Ethanol	31.9
Subtotal	**5033.0**
	kt/y
Fuels and Losses	**276.9**

Notes

1) Maya Blend consists of 50% wt. Maya crude oil + 50% wt.

Table 5-2: Base Case 1) Process units operating and design capacity

REV.7
12/05/2016

ReCAP Project
Refinery Balances

BASE CASE 1
Hydroskimming refinery, 100,000 BPSD

PROCESS UNITS OPERATING AND DESIGN CAPACITY

UNIT	Unit of measure	Design Capacity	Operating Capacity	Average Utilization
Crude Distillation Unit	BPSD	100000	100000	100%
Vacuum Distillation Unit	BPSD	35000	32805	94%
Naphtha Hydrotreater	BPSD	23000	21434	93%
Light Naphtha Isomerization	BPSD	8000	7292	91%
Heavy Naphtha Catalytic Reforming	BPSD	15000	13778	92%
Kero Sweetening	BPSD	5000	5000	100%
Kerosene Hydrotreater	BPSD	14000	13594	97%
Diesel Hydrotreater	BPSD	26000	24480	94%
Heavy Gasoil Hydrotreater	BPSD	6000	5610	94%
Visbreaking	BPSD	13000	11997	92%
Sulphur Recovery Unit	t/d Sulphur	55	38	70%

Table 5-3: Base Case 1) Gasoline qualities

REV.7
12/05/2016

ReCAP Project
Refinery Balances

BASE CASE 1
Hydroskimming refinery, 100,000 BPSD

GASOLINE QUALITIES

EXCESS NAPHTHA

Component		Weight Quantity	Weight Percent	Volume Quantity	Volume Percent
NAH	HT HEAVY NAPHTHA	14,449.82	59.680%	19,369.73	58.000%
NSCR5	STAB NAPHTHA ARAB.HEAVY	9,762.35	40.320%	14,026.36	42.000%
	Total	24,212.17	100.000%	33,396.09	100.000%

Quality		Blending Basis	Value	Min	Max
RHO	DENSITY, KG/M3	VL	725.00		725.00
SPM	SULFUR, PPMW	WT	144.36		500.00
VPR	VAPOR PRESSURE, KPA	VL	28.61		69.00

Unl. Premium (95) EU

Component		Weight Quantity	Weight Percent	Volume Quantity	Volume Percent
BU#	C4 TO MOGAS/LPG	1,823.33	0.297%	3,151.28	0.393%
HRF	HEAVY REFORMATE	318.85	0.052%	376.45	0.047%
R10	REFORMATE 100	355,242.13	57.803%	428,518.85	53.378%
ISO	ISOMERATE	165,472.91	26.925%	250,337.24	31.183%
MTB	PURCHASED MTBE	59,808.93	9.732%	80,280.45	10.000%
EOH	ETHANOL	31,911.48	5.192%	40,140.22	5.000%
	Total	614,577.63	100.000%	802,804.49	100.000%

Quality		Blending Basis	Value	Min	Max
RHO	DENSITY, KG/M3	VL	765.54	720.00	775.00
SPM	SULFUR, PPMW	WT	1.96		10.00
VPR	VAPOR PRESSURE, KPA	VL	60.00		60.00
BEN	BENZENE, %V	VL	0.87		1.00
ARO	AROMATICS, %V	VL	35.00		35.00
E50	D86 @ 150°C, %V	VL	88.24	75.00	
OXY	OXYGENATES, %V	VL	15.00		15.00
OLE	OLEFINS, %V	VL	0.10		18.00
EOH	ETHANOL, VOl%	VL	5.00		5.00
RON	Research	VL	97.08	95.00	
MON	Motor	VL	88.21	85.00	

Table 5-3bis: Base Case 1) Gasoline qualities

REV.7
12/05/2016

ReCAP Project
Refinery Balances

BASE CASE 1
Hydroskimming refinery, 100,000 BPSD

GASOLINE QUALITIES

Unl. Premium (92)

Component		Weight Quantity	Weight Percent	Volume Quantity	Volume Percent
BU#	C4 TO MOGAS/LPG	2,319.90	0.881%	4,009.52	1.141%
R10	REFORMATE 100	155,585.29	59.070%	187,678.28	53.428%
ISO	ISOMERATE	105,485.22	40.049%	159,584.29	45.430%
	Total	263,390.41	100.000%	351,272.09	100.000%

Quality		Blending Basis	Value	Min	Max
RHO	DENSITY, KG/M3	VL	749.82	720.00	775.00
SPM	SULFUR, PPMW	WT	0.04		10.00
VPR	VAPOR PRESSURE, KPA	VL	60.00		60.00
BEN	BENZENE, %V	VL	0.87		1.00
ARO	AROMATICS, %V	VL	35.00		35.00
E50	D86 @ 150°C, %V	VL	88.25	75.00	
OXY	OXYGENATES, %V	VL	0.00		15.00
OLE	OLEFINS, %V	VL	0.15		18.00
EOH	ETHANOL, Vol%	VL	0.00		10.00
RON	Research	VL	92.23	92.00	
MON	Motor	VL	85.29	84.00	

Table 5-4: Base Case 1) Distillate qualities

REV.7
12/05/2016

ReCAP Project
Refinery Balances

BASE CASE 1
Hydroskimming refinery, 100,000 BPSD

DISTILLATE QUALITIES

LPG PRODUCT

Component		Weight Quantity	Weight Percent	Volume Quantity	Volume Percent
LG#	LPG POOL	110,702.16	100.000%	197,532.72	100.000%
	Total	110,702.16	100.000%	197,532.72	100.000%

Quality		Blending Basis	Value	Min	Max
SPM	SULFUR, PPMW	WT	5.00		140.00
VPR	VAPOR PRESSURE, KPA	VL	666.23	632.40	887.60
OLW	OLEFINS, %W	WT	0.66		30.00

Jet Fuel EU

Component		Weight Quantity	Weight Percent	Volume Quantity	Volume Percent
KED	HT KERO	227,714.60	50.603%	286,974.92	50.774%
KMCR4	KERO FROM MEROX URALS	173,927.93	38.651%	217,682.01	38.514%
KMCR5	KERO FROM MEROX AR.HVY	16,541.00	3.676%	20,676.25	3.658%
KMCR6	KERO FROM MEROX MAYA	31,816.48	7.070%	39,870.27	7.054%
	Total	450,000.00	100.000%	565,203.45	100.000%

Quality		Blending Basis	Value	Min	Max
RHO	DENSITY, KG/M3	VL	796.17	775.00	840.00
SUL	SULFUR, %W	WT	0.10		0.30
FLC	FLASH POINT, °C (PM, D93)	VL	40.00	38.00	

Diesel EU

Component		Weight Quantity	Weight Percent	Volume Quantity	Volume Percent
KED	HT KERO	252,101.78	18.363%	317,708.61	19.339%
DLG	DESULF LGO	1,034,021.97	75.318%	1,226,597.83	74.661%
FAM	BIODIESEL	86,744.02	6.318%	98,572.75	6.000%
	Total	1,372,867.78	100.000%	1,642,879.20	100.000%

Quality		Blending Basis	Value	Min	Max
RHO	DENSITY, KG/M3	VL	835.65	820.00	845.00
SPM	SULFUR, PPMW	WT	9.00		10.00
FLC	FLASH POINT, °C (PM, D93)	VL	57.30	55.00	
CIN	CETANE INDEX D4737	VL	49.84	46.00	
V04	VISCOSITY @ 40°C, CST	WT	2.69	2.00	4.50
E36	D86 @360°C, %V	VL	97.39	95.00	
FAM	BIODIESEL CONTENT, %VOL	VL	6.00	6.00	7.00

Table 5-4bis: Base Case 1) Distillate qualities

REV.7
12/05/2016

ReCAP Project
Refinery Balances

BASE CASE 1
Hydroskimming refinery, 100,000 BPSD

DISTILLATE QUALITIES

Heating Oil

Component		Weight Quantity	Weight Percent	Volume Quantity	Volume Percent
KED	HT KERO	79,786.98	29.059%	100,550.70	31.115%
H1CR1	HGO EKOFISK	31,094.56	11.325%	35,374.92	10.946%
DLG	DESULF LGO	53,592.25	19.518%	63,573.25	19.672%
VLG	DESULF LGO ex VHT	18,870.38	6.873%	22,331.81	6.910%
LVCR2	LVGO BONNY	91,229.39	33.226%	101,332.22	31.356%
	Total	274,573.56	100.000%	323,162.89	100.000%

Quality		Blending Basis	Value	Min	Max
RHO	DENSITY, KG/M3	VL	849.64	815.00	860.00
SPM	SULFUR, PPMW	WT	1,000.00		1,000.00
FLC	FLASH POINT, °C (PM, D93)	VL	55.00	55.00	
CIN	CETANE INDEX D4737	VL	46.59	40.00	
V04	VISCOSITY @ 40°C, CST	WT	3.88	2.00	6.00

MARINE DIESEL

Component		Weight Quantity	Weight Percent	Volume Quantity	Volume Percent
KED	HT KERO	33,234.02	18.156%	41,882.83	19.747%
H1CR2	HGO BONNY	64,781.73	35.390%	71,165.25	33.553%
DLG	DESULF LGO	60,886.90	33.263%	72,226.45	34.054%
LVCR2	LVGO BONNY	24,146.39	13.191%	26,820.38	12.645%
	Total	183,049.04	100.000%	212,094.91	100.000%

Quality		Blending Basis	Value	Min	Max
RHO	DENSITY, KG/M3	VL	863.05		890.00
SPM	SULFUR, PPMW	WT	1,000.00		1,000.00
FLC	FLASH POINT, °C (PM, D93)	VL	60.00	60.00	
CIN	CETANE INDEX D4737	VL	47.04	35.00	
V04	VISCOSITY @ 40°C, CST	WT	4.56		6.00

Table 5-5: Base Case 1) Fuel oil and bitumen qualities

REV.7
12/05/2016

ReCAP Project
Refinery Balances

BASE CASE 1
Hydroskimming refinery, 100,000 BPSD

amec foster wheeler

FUEL OIL / BITUMEN QUALITIES

Low Sulphur Fuel

Component		Weight Quantity	Weight Percent	Volume Quantity	Volume Percent
H1CR1	HGO EKOFISK	26,437.65	2.995%	30,076.96	3.241%
VRCR1	VBRES MIX1	115,004.56	13.030%	120,046.52	12.936%
VRCR2	VBRES MIX2	68,795.82	7.794%	66,213.50	7.135%
VGCR1	HVGO EKOFISK	154,870.03	17.546%	171,032.61	18.430%
VGCR4	HVGO URALS	74,361.17	8.425%	79,958.25	8.616%
VGCR2	HVGO BONNY	142,237.41	16.115%	153,223.54	16.511%
VHR	RESIDUE ex VHT	261,282.19	29.602%	262,595.16	28.297%
LVCR1	LVGO EKOFISK	39,656.75	4.493%	44,860.57	4.834%
	Total	882,645.59	100.000%	928,007.12	100.000%

Quality		Blending Basis	Value	Min	Max
RHO	DENSITY, KG/M3	VL	951.12		991.00
SUL	SULFUR, %W	WT	0.50		0.50
FLC	FLASH POINT, °C (PM, D93)	VL	156.24	66.00	
V05	VISCOSITY @ 50°C, CST	WT	86.81		380.00
CCR	CONRADSON CARBON RES, %W	WT	3.33		15.00

High Sulphur Fuel

Component		Weight Quantity	Weight Percent	Volume Quantity	Volume Percent
H1CR3	HGO ARB. LIGHT	16,008.00	3.090%	17,826.28	3.327%
H1CR4	HGO URALS	23,094.34	4.458%	25,861.53	4.827%
H1CR5	HGO ARB.HEAVY	3,933.70	0.759%	4,356.26	0.813%
H1CR6	HGO MAYA	7,783.33	1.503%	8,595.61	1.604%
VRCR3	VBRES MIX3	74,922.68	14.464%	75,148.13	14.026%
VRCR4	VBRES MIX4	241,964.96	46.712%	236,756.32	44.189%
LVCR3	LVGO ARAB.LIGHT	32,957.71	6.363%	36,566.86	6.825%
LVCR4	LVGO URALS	95,065.69	18.353%	106,147.48	19.812%
LVCR5	LVGO ARB.HEAVY	7,678.80	1.482%	8,454.04	1.578%
LVCR6	LVGO MAYA	14,588.55	2.816%	16,070.23	2.999%
	Total	517,997.77	100.000%	535,782.74	100.000%

Quality		Blending Basis	Value	Min	Max
RHO	DENSITY, KG/M3	VL	966.81		991.00
SUL	SULFUR, %W	WT	3.15	1.00	3.50
FLC	FLASH POINT, °C (PM, D93)	VL	158.79	60.00	
V05	VISCOSITY @ 50°C, CST	WT	380.00		380.00
CCR	CONRADSON CARBON RES, %W	WT	12.51		18.00

BITUMEN

Component		Weight Quantity	Weight Percent	Volume Quantity	Volume Percent
VDCR5	VDU RES MIX5	49,166.94	39.334%	48,440.33	39.754%
VDCR6	VDU RES MIX6	75,833.06	60.666%	73,410.52	60.246%
	Total	125,000.00	100.000%	121,850.85	100.000%

Table 5-6: Base Case 1) Main utility balance, fuel mix composition, CO_2 emissions

REV.7
12/05/2016

ReCAP Project
Refinery Balances

BASE CASE 1
Hydroskimming refinery, 100,000 BPSD

MAIN UTILITY BALANCE

	FUEL Gcal/h	**POWER** kW	**HP STEAM** tons/h	**MP STEAM** tons/h	**LP STEAM** tons/h	**COOLING WATER** (2) m3/h	**RAW WATER** m3/h
MAIN PROCESS UNITS	155	11800	13	38	59	4920	
BASE LOAD		15000	10	20	20		
POWER PLANT	183	-28345	-23	-58	-79	4106	
SEA WATER SYSTEM		1545				-9026	
TOTAL	**338**	**0**	**0**	**0**	**0**	**0**	**100**

FUEL MIX COMPOSITION

	t/h	kt/y	wt%		
REFINERY FUEL GAS	7.0	58.8	23%		
LOW SULPHUR FUEL OIL (3)	9.1	76.4	30%		
NATURAL GAS	14.5	121.8	47%		
TOTAL	**30.6**	**256.9**			

CO2 EMISSIONS

	t/h
From FG/NG combustion	57.7
From FO combustion	29.1
TOTAL	**86.8**

corresponding to ***729.3*** *kt/y*
154.1 *kg CO2 / t crude*

Notes
1) (-) indicates productions
2) 10°C temperature increase has been considered
3) LSFO is burnt in CDU, VDU and VBU heaters

REV.7
12/05/2016

ReCAP Project

Overall Refinery Balance

BASE CASE 1

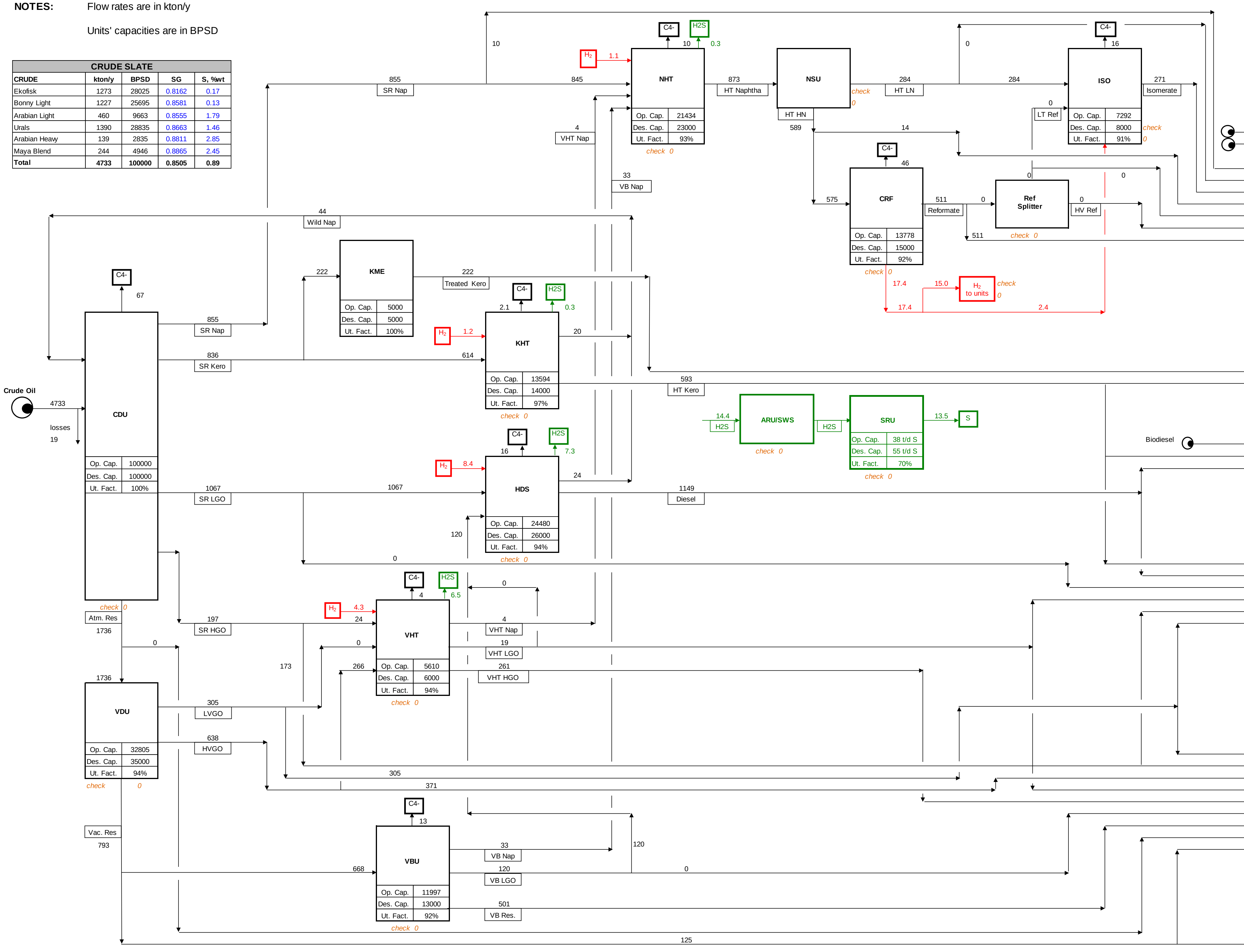
Hydroskimming Refinery, 100,000 BPSD

BLOCK FLOW DIAGRAM

NOTES: Flow rates are in kton/y

Units' capacities are in BPSD

CRUDE SLATE				
CRUDE	**kton/y**	**BPSD**	**SG**	**S, %wt**
Ekofisk	1273	28025	0.8162	0.17
Bonny Light	1227	25695	0.8581	0.13
Arabian Light	460	9663	0.8555	1.79
Urals	1390	28835	0.8663	1.46
Arabian Heavy	139	2835	0.8811	2.85
Maya Blend	244	4946	0.8865	2.45
Total	**4733**	**100000**	**0.8505**	**0.89**



	LPG
Propane	25
Butane	85
Total prod.	**111**
To fuel	*0*
Sales	**111**

	U 95-EU	U 92-US	Excess Naph.	TOT
MTBE	60	0	0	**60**
Ethanol	32	0	0	**32**
Butanes	2	2	0	**4**
SR Naphtha	0	0	10	**10**
HT Light Naphtha	0	0	0	**0**
Isomerate	165	105	0	**271**
HT Heavy Naphtha	0	0	14	**14**
LT Reformate	0	0	0	**0**
HV Reformate	0	0	0	**0**
Reformate	355	156	0	**511**
Sales	**615**	**263**	**24**	**902**

	Jet Fuel
Treated Kero	222
HT Kero	228
Sales	**450**

	Diesel
Biodiesel	87
HT Kero	252
Diesel	1034
Sales	**1373**

	Heating Oil	Mar. Dies.	TOT
HT Kero	80	33	**113**
Diesel	54	61	**114**
SR LGO	0	0	**0**
VHT LGO	19	0	**19**
SR HGO	31	65	**96**
SR LVGO	91	24	**115**
Sales	**275**	**183**	**458**

	LSFO	MSFO	HSFO	TOT
SR LVGO	40	0	150	**190**
SR HGO	26	0	51	**77**
SR HVGO	371	0	0	**371**
VHT LGO	0	0	0	**0**
VHT HGO	261	0	0	**261**
VB LGO	0	0	0	**0**
VB Residue	184	0	317	**501**
Atm. Residue	0	0	0	**0**
Vac. Residue	0	0	0	**0**
Total prod.	**883**	**0**	**518**	**1401**
To RFO	*76*	*-*	*-*	*76*
Sales	**806**	**0**	**518**	**1324**

	Bitumen
Vac. Res.	**125**
Sales	**125**

	Sulphur
Sulphur	**13**
Sales	**13**

Figure 5-1: Base Case 1) Block flow diagrams with main material streams

Table 5-7: Base Case 1) CO_2 emissions per unit

REV.7
12/05/2016

ReCAP Project
1-BD-0839A

CO_2 EMISSIONS PER UNIT - BASE CASE 1

UNIT			Unit of measure	Design Capacity	Operating Fuel Consumption [t/h]			Operating CO_2 Emission [t/h]			% on Total CO_2 Emission	CO_2 concentr. in flue gases, vol %	Operating Temperature [°C]	Notes
					Fuel Gas	Fuel Oil	Coke	Fuel Gas	Fuel Oil	Coke				(1)
PROCESS UNITS														
0100	CDU	Crude Distillation Unit	BPSD	100000	-	7.4	-	-	23.6	-	27.2%	11.3%	200 ÷ 220	
0300	NHT	Naphtha Hydrotreater	BPSD	23000	0.3	-	-	0.8	-	-	0.9%	8.4%	420 ÷ 450	(2)
0350	NSU	Naphtha Splitter Unit	BPSD	23000	0.4	-	-	1.0	-	-	1.1%	8.4%		
0500	CRF	Catalytic Reforming	BPSD	15000	3.3	-	-	8.9	-	-	10.3%	8.4%	180 ÷ 190	
0600	KHT	Kero HDS	BPSD	14000	0.2	-	-	0.6	-	-	0.7%	8.4%	420 ÷ 450	
0700	HDS	Gasoil HDS	BPSD	26000	1.1	-	-	3.0	-	-	3.5%	8.4%	420 ÷ 450	
0800	VHT	Vacuum Gasoil Hydrotreater	BPSD	6000	0.4	-	-	1.0	-	-	1.1%	8.4%	420 ÷ 450	
1100	VDU	Vacuum Distillation Unit	BPSD	35000	-	1.2	-	-	4.0	-	4.6%	11.3%	380 ÷ 400	
1500	VBU	Visbreaking Unit	BPSD	13000	-	0.5	-	-	1.5	-	1.8%	11.3%	380 ÷ 400	
							Sub Total Process Units		44.4		51.1%			
AUXILIARY UNITS														
2200	SRU	Sulphur Recovery & Tail Gas Treatment	t/d Sulphur	55	0.005	-	-	0.0	-	-	0.0%	< 8%	380 ÷ 400	
							Sub Total Auxiliary Units		0.01		0.0%			
POWER UNITS														
2500	POW	Power Plant	kW	40000	15.8	-	-	42.4	-	-	48.8%	8.4%	130 ÷ 140	
							Sub Total Power Units		42.4		48.8%			
							TOTAL CO_2 EMISSION		**86.8**		**100%**			
								66%	**34%**	**0%**				

Notes

(1) Fuel gas is a mixture of refinery fuel gas (33%) and imported natural gas (67%).

(2) Naphtha Hydrotreater and Naphtha Splitter heaters (units 0300 and 0350) have a common stack.

5.2 Refinery Layout

The layout of the hydro-skimming refinery has been developed in analogy with some real plants of similar size and complexity.

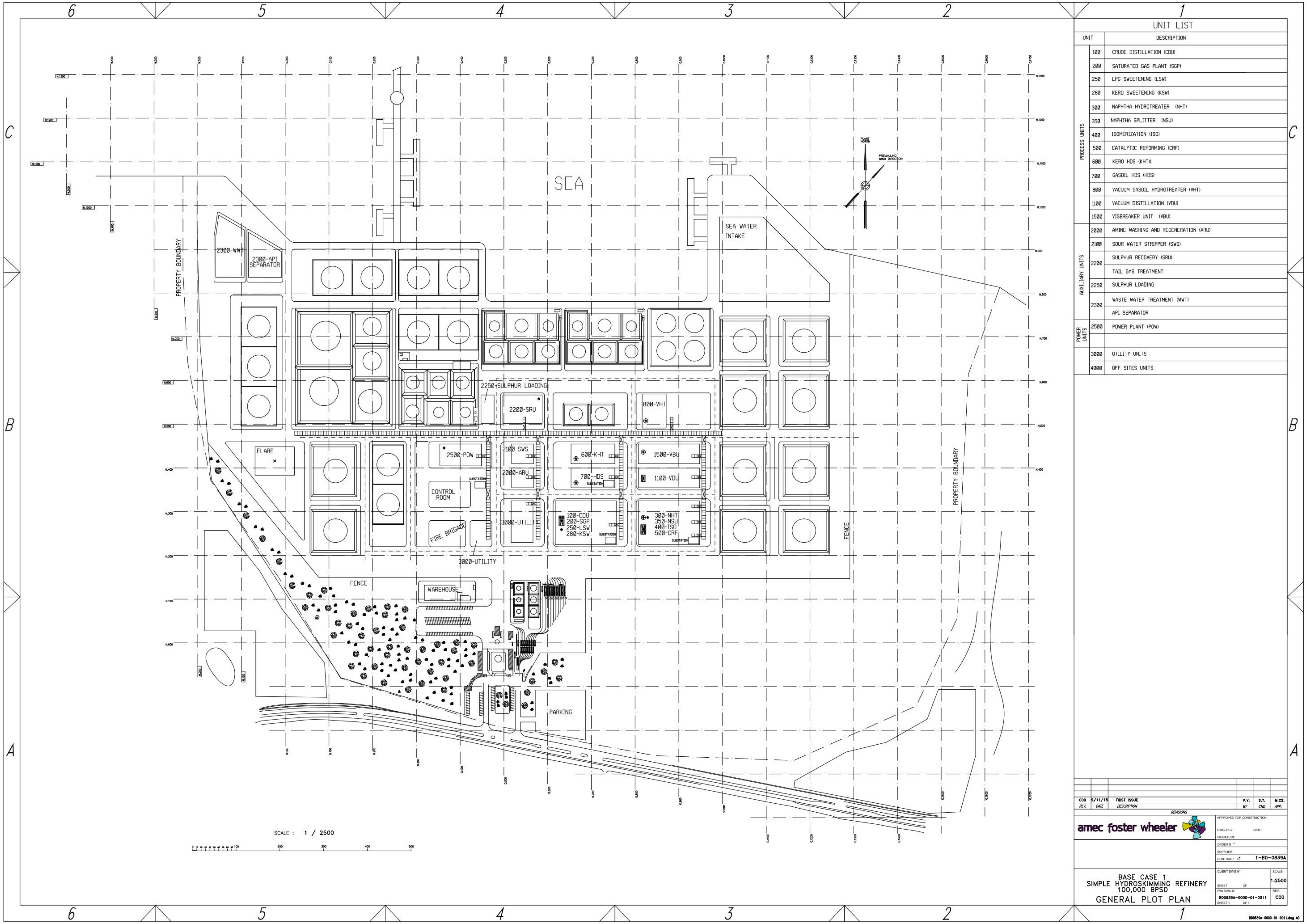


Figure 5-2: Base Case 1) Refinery layout

5.3 Main Utility Networks

The main utility balances have been reported on block flow diagrams, reflecting the planimetric arrangement of the process units and utility blocks.

In particular, the following networks' sketches have been developed:

- Figure 5-3: Base Case 1) Electricity network
- Figure 5-4: Base Case 1) Steam networks
- Figure 5-5: Base Case 1) Cooling water network
- Figure 5-6: Base Case 1) Fuel Gas/Offgas networks
- Figure 5-7: Base Case 1) Fuel oil network

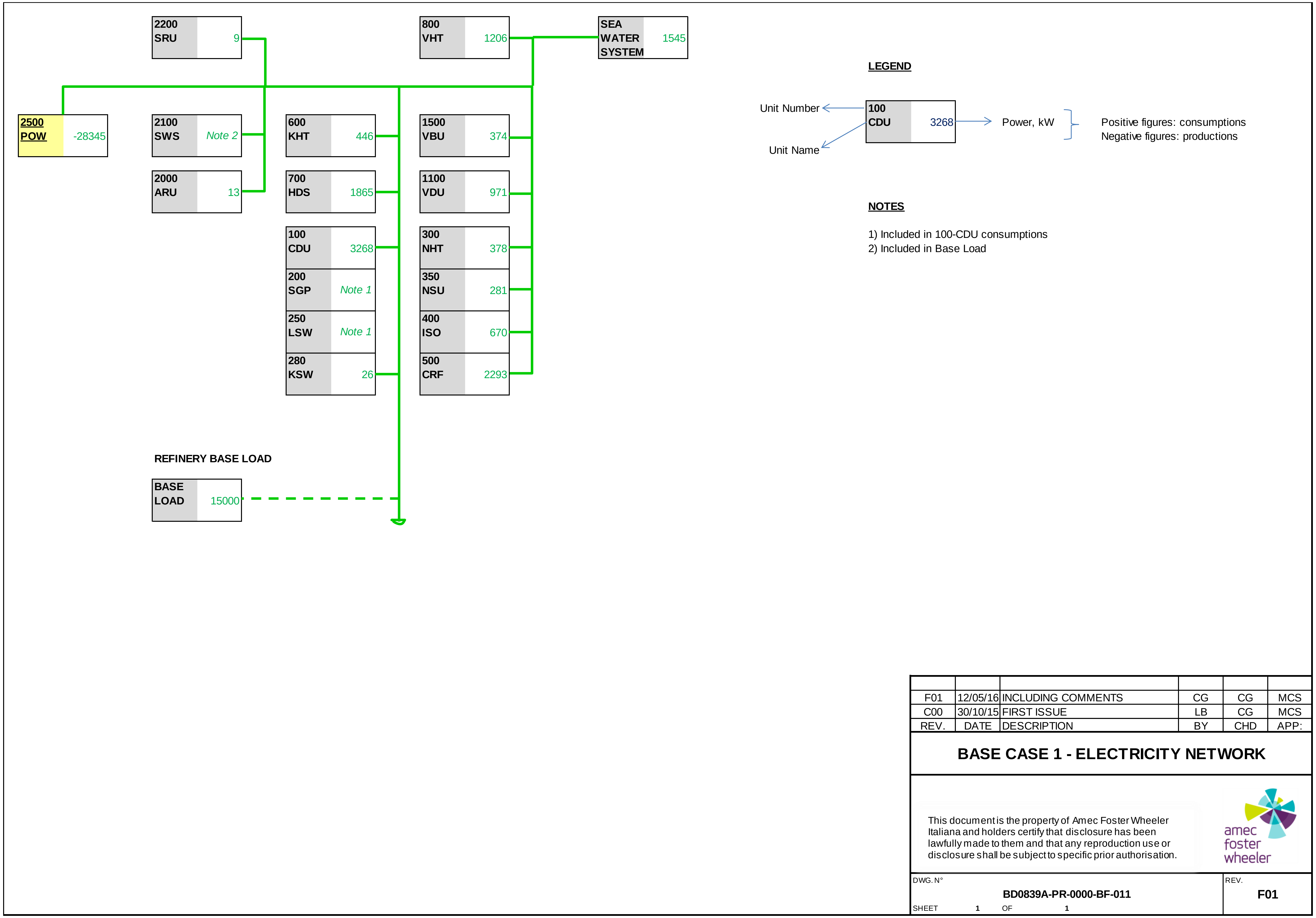


Figure 5-3: Base Case 1) Electricity network

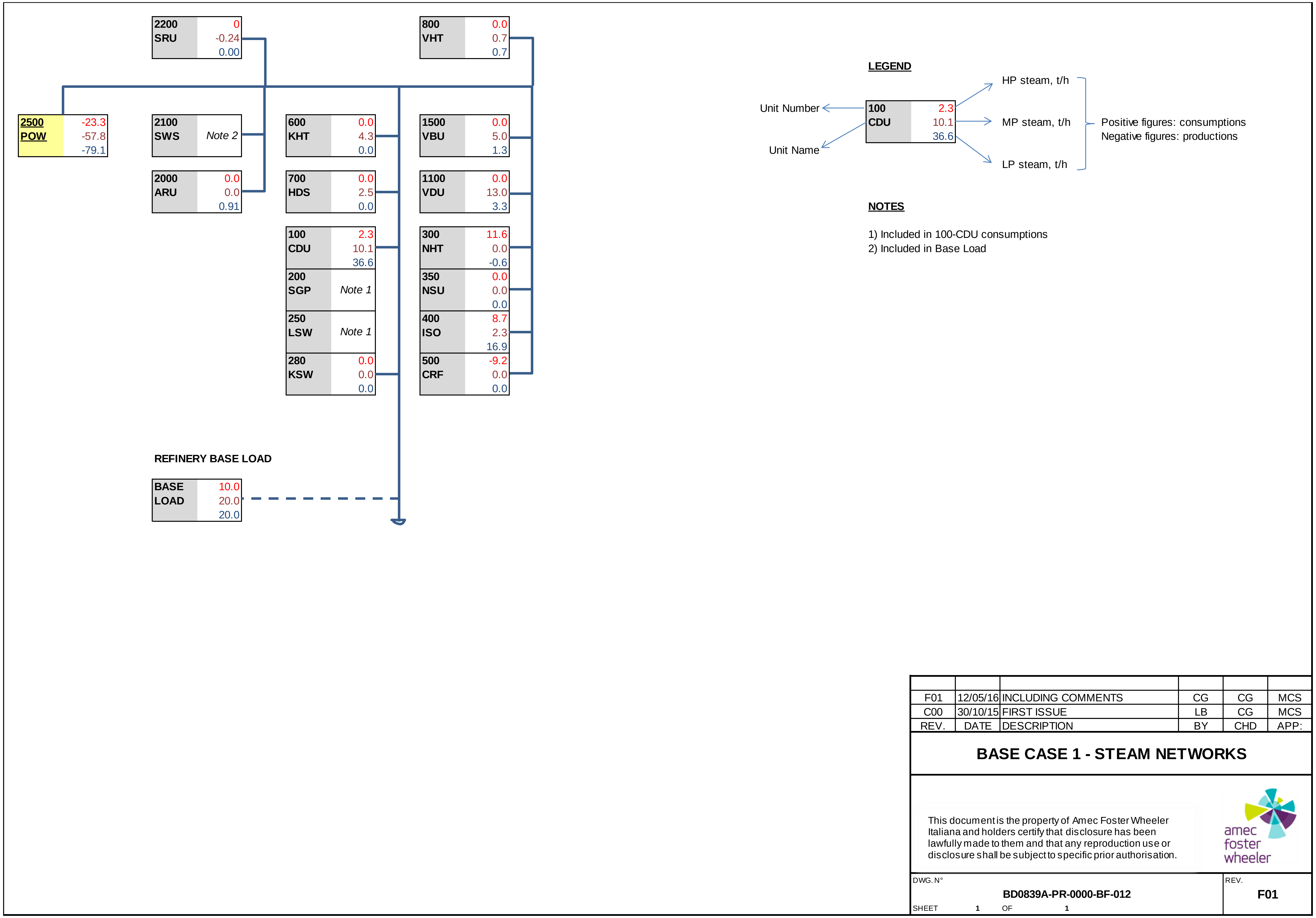


Figure 5-4: Base Case 1) Steam networks

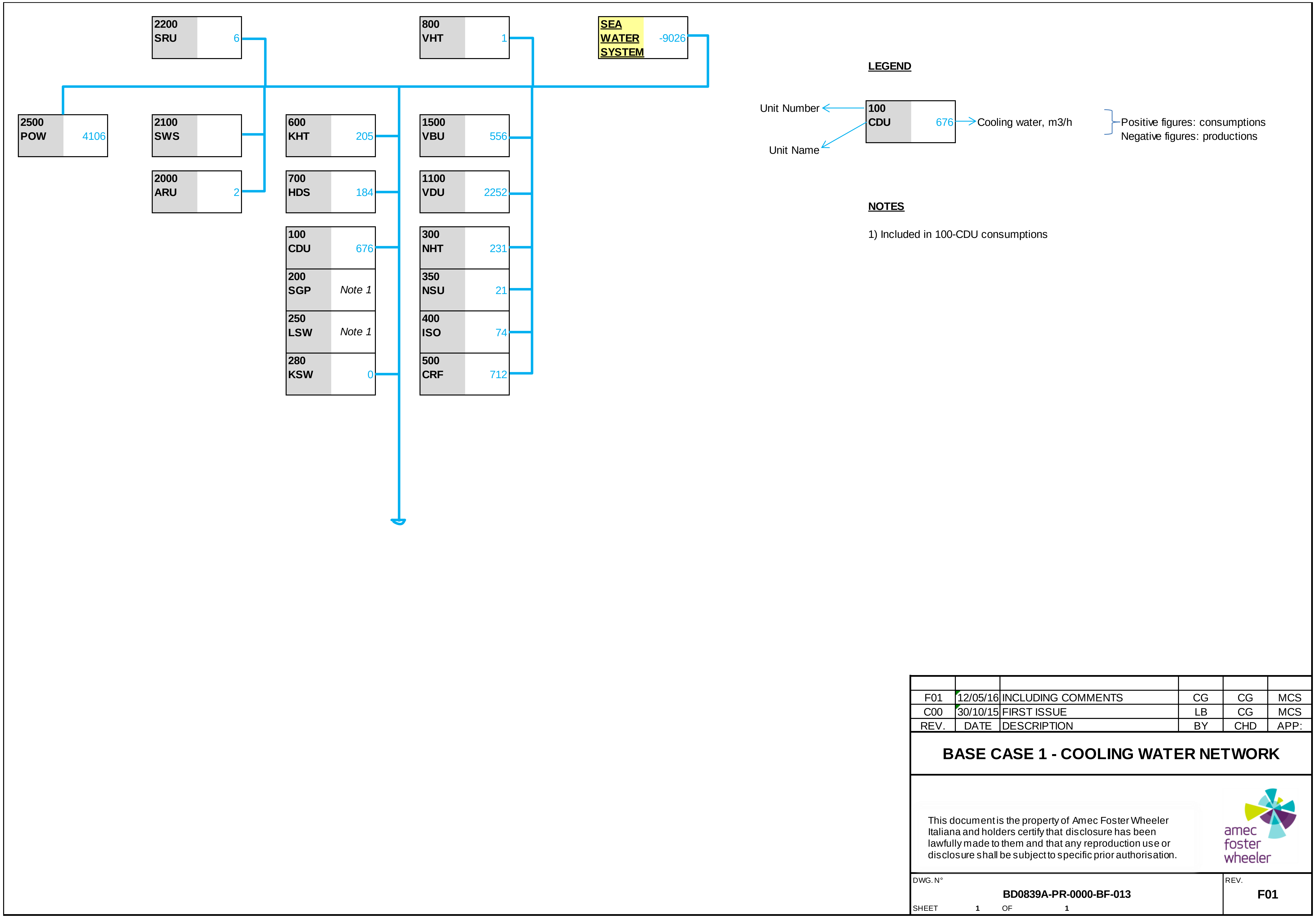


Figure 5-5: Base Case 1) Cooling water network

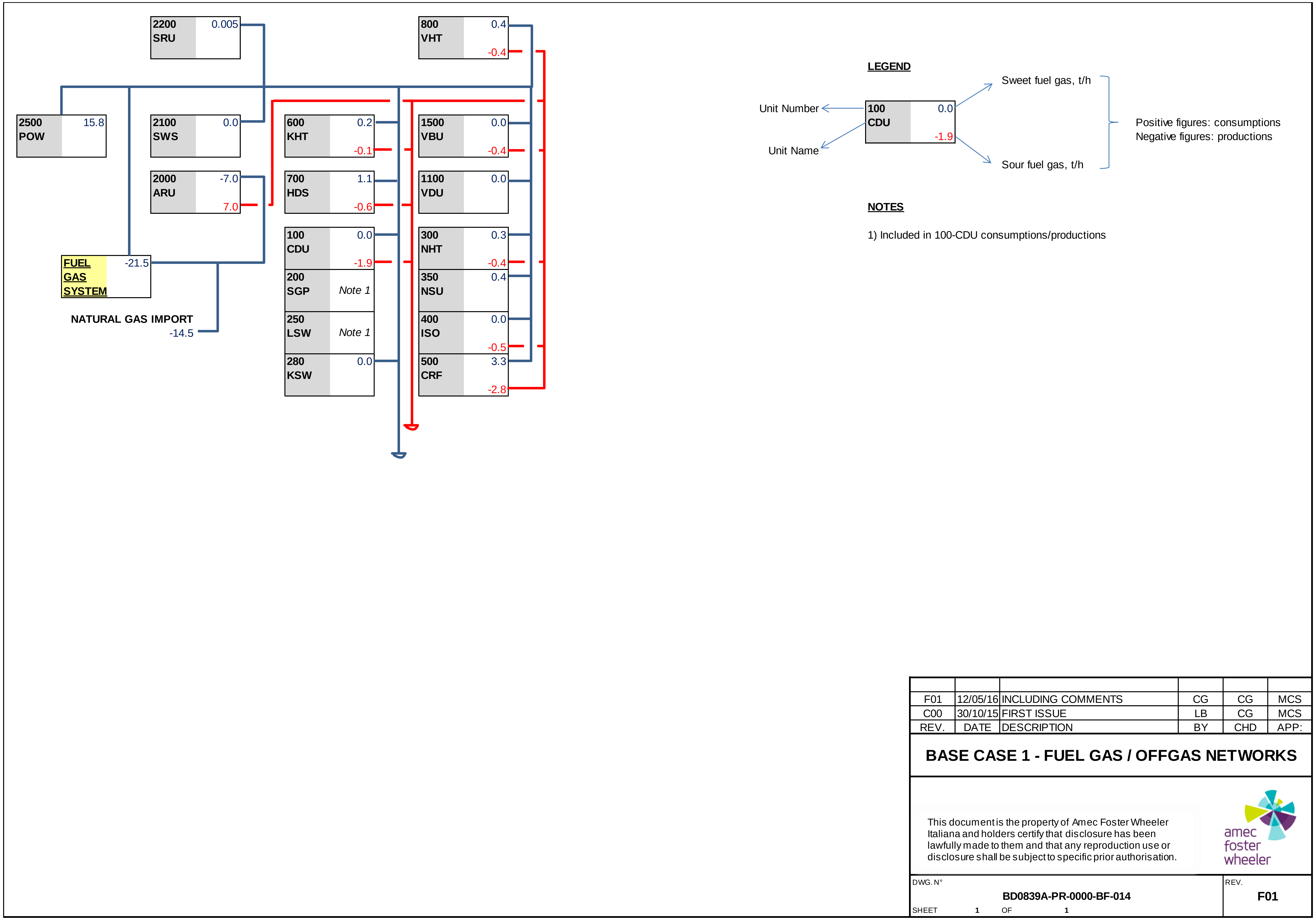
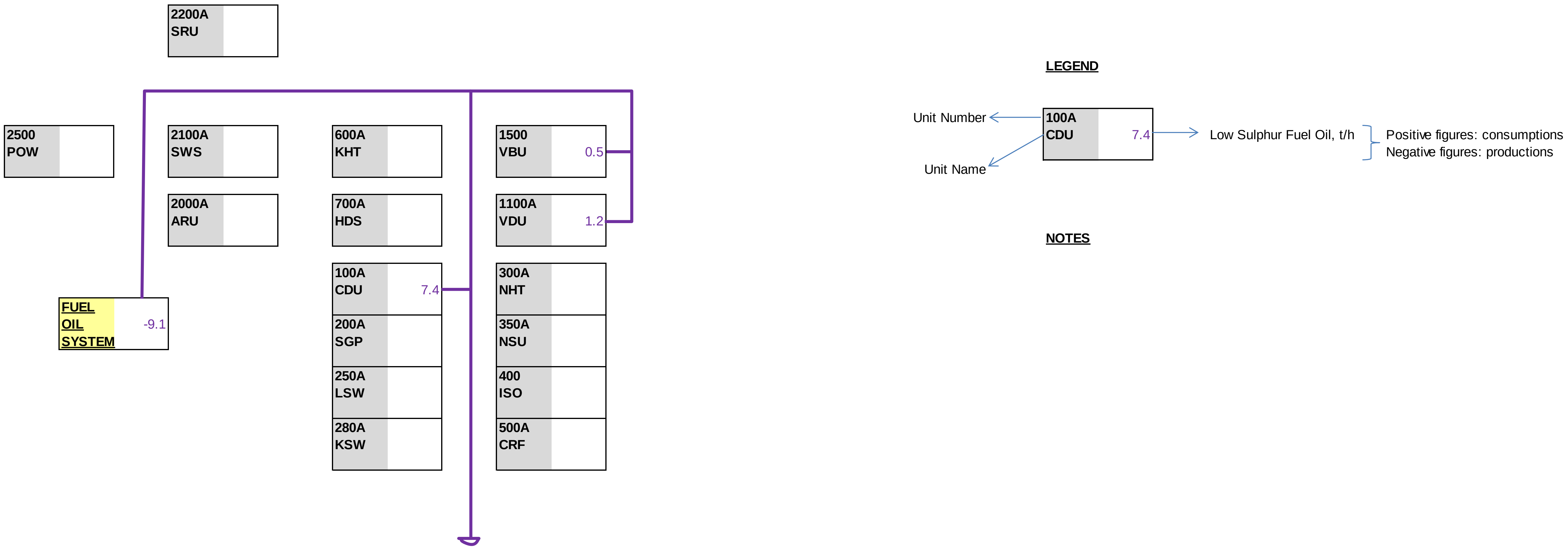


Figure 5-6: Base Case 1) Fuel Gas/Offgas networks



F01	12/05/16	INCLUDING COMMENTS	CG	CG	MCS
C00	30/10/15	FIRST ISSUE	LB	CG	MCS
REV.	DATE	DESCRIPTION	BY	CHD	APP:

BASE CASE 1 - FUEL OIL NETWORK

amec foster wheeler

DWG. N° BD0839A-PR-0000-BF-015 | REV. F01

SHEET 1 OF 1

Figure 5-7: Base Case 1) Fuel oil network

5.4 Configuration of Power Plant

A dedicated study has been carried out to define the most suitable power plant configuration to satisfy the power/steam demand from the refinery for Base Case 1.

A key aspect for the development of the study and for the definition of the power plant configuration has been the age of the refinery: for the design it has been considered the best available technologies at the time of construction of the refinery and the calculated power plant performances take into account the obsolescence of the machines.

For Base Case 1, the power and steam demand are summarized in the main utility balance in Table 5-6.

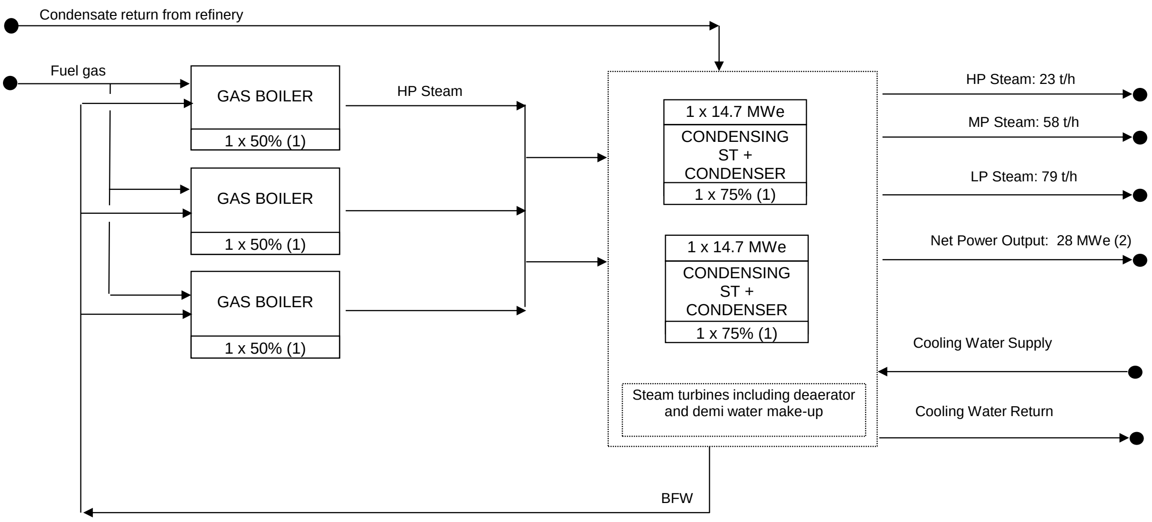
The power plant has been designed to be normally operated synchronized and in balance with the grid and with the refinery and such that no import/export of steam is required during normal operation. However, steam demand has higher priority over electricity demand, since refinery electrical demand can be provided by HV grid connection back-up.

Power Plant configuration for Base Case 1 is a steam cycle. High pressure steam is generated at the pressure level required by the refinery in a conventional gas boiler: HP steam generated is partially routed to the refinery, to satisfy the HP steam demand, and partially sent to extracting steam turbines for power and MP/LP steam generation. MP and LP steam are generated through two different extraction stages at the pressure required by the users. Steam turbines are condensing type: exhaust steam from the steam turbine is condensed into a condenser, which operates under vacuum, and pumped, together with a demi-water make up, to deaerator for BFW generation.

It is assumed that 50% of steam exported to refinery returns as atmospheric condensate while the rest is made up with demineralised water.

Power plant configuration proposed for Base Case 1 is summarized in the following sketch.

BASE CASE 1



Note: 1. Refers to total installed capacity
2. Net with respect to intenral power island consumptions

Figure 5-8: Base Case 1) Power Plant simplified Block Flow Diagram

Major equipment number and sizes are summarized hereinafter:

- 3 x 115 t/h Gas Boilers, normally operated at 69% of their design load (corresponding to 79.3 t/h each)
- 2 x 20 MWe Condensing Steam Turbines, normally operated at 74% of their design load (corresponding to 14.7 MWe each)

The system has been conceived to have such an installed spare capacity both for power and steam generation to handle possible oscillations in power/steam demand from refinery users and to avoid refinery shutdown in case one equipment (boiler or turbine) trips.

In case one of the steam turbines trips, however, only 68% of the total power demand is guaranteed: in this scenario, a load shedding is necessary unless there is the possibility to import the remaining electrical demand from the HV grid.

Total installed spare capacity is summarized hereinafter:

- Gas Boilers (Steam) **+45%**
- Steam Turbines (Electric Energy) **+37%**

6. Base Case 2

Medium Conversion Refinery - 220,000 BPSD Crude Capacity

The Medium Conversion Refinery, with respect of the Hydro-skimming Refinery described at paragraph 5, includes additional process units for the conversion of the Vacuum Gasoil (VGO) into more valuable distillates (essentially gasoline and automotive diesel).

In Europe, the most wide-spread VGO conversion unit is the Fluid Catalytic Cracking (FCC) and so this unit is included in Base Case 2.

Upstream of the FCC, a Vacuum Gasoil Hydrotreating (VHT) unit is present to decrease the sulphur content of FCC feedstock, in order to respect SO_x limits at FCC stack.

The hydrogen from the Heavy Naphtha Catalytic Reformer is not enough to cover the overall hydrogen demand of the refinery. Therefore, a Steam Methane Reformer (SMR) is also foreseen to close the hydrogen balance.

The FCC products are sent to finishing units to comply with the 10 ppm wt. sulphur specification for the automotive fuels.

The overall configuration of Base Case 2 is considered as a step-up evolution of Base Case 1, both in terms of capacity and complexity increase. In other words, it is considered that, in a simple hydro-skimming refinery (as the one depicted as Base Case 1), a second crude distillation train (Atmospheric and Vacuum Distillation Units) and FCC block (VHT+FCC+SMR) are built in a second phase. The consequent capacity increase of the gasoline block and the hydrotreating units is considered achieved by adding a second train in parallel to the original one.

The above assumption reflects the typical “life” of the European refineries, which have gradually expanded starting from an original nucleus. This results in the following main effects:

- Several units of the same type are running in parallel, resulting in a relatively good flexibility of the processing scheme (e.g. different feedstocks could be fed to each train) but also, on the other hand, in some inefficiencies (e.g. higher maintenance costs, lower energy efficiencies, etc.).
- Also the Power Plant in Base Case 2 is considered as an expansion of the facilities foreseen in Base Case 1, reflecting the “modular” expansion of the original refinery into a bigger, more complex and more demanding site.
- The increased demand of cooling water –with respect of cooling water consumption in Base Case 1- is considered to be satisfied by a closed loop circuit with cooling towers, working in parallel to the original open circuit of sea cooling water. As a matter of fact, for the upgrading of the refinery, it is assumed that more stringent environmental regulations have been met.
- Finally, also the layout of the Base Case 2 refinery reflects two main areas of units’ allocation: beside the original nucleus of the older units (unit numbers identified with suffix –A), a second block of units is present and clearly identifiable (unit numbers identified with suffix –B). The FCC block is included in this newer portion of the refinery.

6.1 Refinery Balances

The balances developed for Base Case 2 are reported in the following tables and figures:

- Table 6-1: Base Case 2) Overall material balance
- Table 6-2: Base Case 2) Process units operating and design capacity

- Table 6-3: Base Case 2) Gasoline qualities
- Table 6-4: Base Case 2) Distillate qualities
- Table 6-5: Base Case 2) Fuel oil and bitumen qualities
- Table 6-6: Base Case 2) Main utility balance, fuel mix composition, CO_2 emissions
- Figure 6-1: Base Case 2) Block flow diagrams with main material streams
- Table 6-7: Base Case 2) CO2 emissions per unit

Table 6-1: Base Case 2) Overall material balance

REV.8
12/05/2016

ReCAP Project
Preliminary Refinery Balances

BASE CASE 2
Medium Conversion Refinery, 220,000 BPSD

OVERALL MATERIAL BALANCE

PRODUCTS	Annual Production, kt/y
LPG	559.8
Propylene	164.3
Petrochemical Naphtha	108.4
Gasoline U95 Europe	1753.1
Gasoline U92 USA Export	751.3
Jet fuel	1000.0
Road Diesel	3411.8
Marine Diesel	87.2
Heating Oil	1050.1
Low Sulphur Fuel Oil	149.1
Medium Sulphur Fuel Oil	405.6
High Sulphur Fuel Oil	933.7
Bitumen	260.0
Sulphur	49.2
Subtotal	**10683.5**
RAW MATERIALS	Consumptions, kt/y
Ekofisk	2515.6
Bonny Light	3050.0
Arabian Light	1015.0
Urals Medium	3050.0
Arabian Heavy	305.0
Maya Blend (1)	489.4
Imported Vacuum Gasoil	476.6
MTBE	0.0
Natural Gas	240.2
Biodiesel	213.4
Ethanol	92.3
Subtotal	**11447.6**
	kt/y
Fuels and Losses	**764.1**

Notes
1) Maya Blend consists of 50% wt. Maya crude oil + 50% wt. Arabian Light Crude Oil

Table 6-2: Base Case 2) Process units operating and design capacity

REV.8
12/05/2016

ReCAP Project
Preliminary Refinery Balances

BASE CASE 2
Medium Conversion Refinery, 220,000 BPSD

amec foster wheeler

PROCESS UNITS OPERATING AND DESIGN CAPACITY

UNIT	Unit of measure	Design Capacity	Operating Capacity	Average Utilization
Crude Distillation Unit	BPSD	220000 (1)	220000 (1)	100%
Vacuum Distillation Unit	BPSD	80000 (1)	72034 (1)	90%
Naphtha Hydrotreater	BPSD	50000 (1)	46195	92%
Light Naphtha Isomerization	BPSD	15000	13988	93%
Heavy Naphtha Catalytic Reforming	BPSD	33000 (1)	30301	92%
Kero Sweetening	BPSD	15000 (1)	15000	100%
Kerosene Hydrotreater	BPSD	19000 (1)	18174	96%
Diesel Hydrotreater	BPSD	60000 (1)	60000	100%
Heavy Gasoil Hydrotreater	BPSD	35000	33308	95%
Fluid Catalytic Cracking	BPSD	50000	50000	100%
FCC Gasoline Hydrotreater	BPSD	20000	19273	96%
Visbreaking	BPSD	28000	26228	94%
Sulphur Recovery Unit	t/d Sulphur	220 (1)	141	64%
Steam Reformer	Nm^3/h Hydrogen	22500	19724	88%

Notes

1) Multiple units in parallel to be considered.

Table 6-3: Base Case 2) Gasoline qualities

REV.8
12/05/2016

ReCAP Project
Preliminary Refinery Balances

BASE CASE 2
Medium Conversion Refinery, 220,000 BPSD

GASOLINE QUALITIES

EXCESS NAPHTHA

Component		Weight Quantity	Weight Percent	Volume Quantity	Volume Percent
NAH	HT HEAVY NAPHTHA	8,782.63	8.103%	11,772.96	7.611%
NAL	HT LIGHT NAPHTHA	64,337.19	59.358%	92,305.86	59.676%
LCN	FCC LIGHT NAPHTHA treated	1,963.13	1.811%	2,745.64	1.775%
NSCR5	STAB NAPHTHA ARAB.HEAVY	33,306.00	30.728%	47,853.45	30.937%
	Total	108,388.95	100.000%	154,677.91	100.000%

Quality		Blending Basis	Value	Min	Max
RHO	DENSITY, KG/M3	VL	700.74		725.00
SPM	SULFUR, PPMW	WT	62.24		500.00
VPR	VAPOR PRESSURE, KPA	VL	69.00		69.00

Unl. Premium (95) EU

Component		Weight Quantity	Weight Percent	Volume Quantity	Volume Percent
BU#	C4 TO MOGAS/LPG	12,656.60	0.722%	21,700.02	0.934%
R10	REFORMATE 100	785,262.42	44.794%	947,240.55	40.772%
ISO	ISOMERATE	275,236.94	15.700%	416,394.76	17.923%
LCN	FCC LIGHT NAPHTHA treated	587,550.95	33.516%	821,749.57	35.371%
EOH	ETHANOL	92,349.08	5.268%	116,162.36	5.000%
	Total	1,753,055.99	100.000%	2,323,247.27	100.000%

Quality		Blending Basis	Value	Min	Max
RHO	DENSITY, KG/M3	VL	754.57	720.00	775.00
SPM	SULFUR, PPMW	WT	3.39		10.00
VPR	VAPOR PRESSURE, KPA	VL	60.00		60.00
BEN	BENZENE, %V	VL	0.71		1.00
ARO	AROMATICS, %V	VL	32.01		35.00
E50	D86 @ 150°C, %V	VL	91.03	75.00	
OXY	OXYGENATES, %V	VL	5.00		15.00
OLE	OLEFINS, %V	VL	14.53		18.00
EOH	ETHANOL, Vol%	VL	5.00		5.00
RON	Research	VL	95.00	95.00	
MON	Motor	VL	85.00	85.00	

Table 6-3bis: Base Case 2) Gasoline qualities

REV.8
12/05/2016

ReCAP Project
Preliminary Refinery Balances

BASE CASE 2
Medium Conversion Refinery, 220,000 BPSD

GASOLINE QUALITIES

Unl. Premium (92)

Component		Weight Quantity	Weight Percent	Volume Quantity	Volume Percent
BU#	C4 TO MOGAS/LPG	6,180.30	0.823%	10,596.27	1.043%
R10	REFORMATE 100	338,954.93	45.115%	408,872.05	40.264%
ISO	ISOMERATE	244,508.13	32.544%	369,906.40	36.427%
LCN	FCC LIGHT NAPHTHA treated	161,666.35	21.518%	226,106.78	22.266%
	Total	751,309.71	100.000%	1,015,481.49	100.000%

Quality		Blending Basis	Value	Min	Max
RHO	DENSITY, KG/M3	VL	739.86	720.00	775.00
SPM	SULFUR, PPMW	WT	2.19		10.00
VPR	VAPOR PRESSURE, KPA	VL	60.00		60.00
BEN	BENZENE, %V	VL	0.68		1.00
ARO	AROMATICS, %V	VL	29.72		35.00
E50	D86 @ 150°C, %V	VL	91.14	75.00	
OXY	OXYGENATES, %V	VL	0.00		15.00
OLE	OLEFINS, %V	VL	9.39		18.00
EOH	ETHANOL, Vol%	VL	0.00		10.00
RON	Research	VL	92.00	92.00	
MON	Motor	VL	84.00	84.00	

Table 6-4: Base Case 2) Distillate qualities

REV.8
12/05/2016

ReCAP Project
Preliminary Refinery Balances

BASE CASE 2
Medium Conversion Refinery, 220,000 BPSD

DISTILLATE QUALITIES

LPG PRODUCT

Component		Weight Quantity	Weight Percent	Volume Quantity	Volume Percent
LG#	LPG POOL	559,790.66	100.000%	984,736.23	100.000%
	Total	559,790.66	100.000%	984,736.23	100.000%

Quality		Blending Basis	Value	Min	Max
SPM	SULFUR, PPMW	WT	5.00		140.00
VPR	VAPOR PRESSURE, KPA	VL	622.89		887.60
OLW	OLEFINS, %W	WT	0.78		30.00

Jet Fuel EU

Component		Weight Quantity	Weight Percent	Volume Quantity	Volume Percent
KED	HT KERO	332,718.22	33.272%	419,304.62	33.438%
KMCR3	KERO FROM MEROX AR.LIGHT	108,750.20	10.875%	135,598.75	10.813%
KMCR4	KERO FROM MEROX URALS	458,415.00	45.842%	573,735.92	45.753%
KMCR5	KERO FROM MEROX AR.HVY	36,295.00	3.630%	45,368.75	3.618%
KMCR6	KERO FROM MEROX MAYA	63,821.58	6.382%	79,976.92	6.378%
	Total	1,000,000.00	100.000%	1,253,984.97	100.000%

Quality		Blending Basis	Value	Min	Max
RHO	DENSITY, KG/M3	VL	797.46	775.00	840.00
SUL	SULFUR, %W	WT	0.12		0.30
FLC	FLASH POINT, °C (PM, D93)	VL	40.00	38.00	

Diesel EU

Component		Weight Quantity	Weight Percent	Volume Quantity	Volume Percent
LCO	LIGHT CYCLE OIL treated	193,322.80	5.666%	203,497.69	5.035%
HCN	FCC HEAVY NAPHTHA	375,590.21	11.009%	441,870.84	10.933%
KED	HT KERO	469,302.16	13.755%	591,433.10	14.633%
DLG	DESULF LGO	2,160,135.16	63.314%	2,562,437.92	63.399%
FAM	BIODIESEL	213,404.09	6.255%	242,504.65	6.000%
	Total	3,411,754.44	100.000%	4,041,744.19	100.000%

Quality		Blending Basis	Value	Min	Max
RHO	DENSITY, KG/M3	VL	844.13	820.00	845.00
SPM	SULFUR, PPMW	WT	9.10		10.00
FLC	FLASH POINT, °C (PM, D93)	VL	55.00	55.00	
CIN	CETANE INDEX D4737	VL	48.16	46.00	
V04	VISCOSITY @ 40°C, CST	WT	2.45	2.00	4.50
E36	D86 @360°C, %V	VL	97.53	95.00	
FAM	BIODIESEL CONTENT, %VOL	VL	6.00	6.00	7.00

Table 6-4bis: Base Case 2) Distillate qualities

REV.8
12/05/2016

ReCAP Project
Preliminary Refinery Balances

BASE CASE 2
Medium Conversion Refinery, 220,000 BPSD

DISTILLATE QUALITIES

Heating Oil

Component		Weight Quantity	Weight Percent	Volume Quantity	Volume Percent
KSCR1	SR KERO EKOFISK	323,482.12	30.806%	403,847.84	32.904%
LGCR2	LGO BONNY	381,343.03	36.316%	437,822.08	35.672%
H1CR2	HGO BONNY	121,726.52	11.592%	133,721.33	10.895%
VLG	DESULF LGO ex VHT	50,926.81	4.850%	60,268.41	4.910%
LVCR2	LVGO BONNY	172,589.65	16.436%	191,702.38	15.619%
	Total	1,050,068.13	100.000%	1,227,362.03	100.000%

Quality		Blending Basis	Value	Min	Max
RHO	DENSITY, KG/M3	VL	855.55	815.00	860.00
SPM	SULFUR, PPMW	WT	1,000.00		1,000.00
FLC	FLASH POINT, °C (PM, D93)	VL	55.00	55.00	
CIN	CETANE INDEX D4737	VL	46.72	40.00	
V04	VISCOSITY @ 40°C, CST	WT	3.09	2.00	6.00

MARINE DIESEL

Component		Weight Quantity	Weight Percent	Volume Quantity	Volume Percent
KSCR1	SR KERO EKOFISK	18,873.59	21.648%	23,562.53	23.332%
LGCR2	LGO BONNY	2,140.36	2.455%	2,457.35	2.433%
H1CR2	HGO BONNY	39,313.48	45.093%	43,187.39	42.764%
VLG	DESULF LGO ex VHT	26,855.93	30.804%	31,782.17	31.471%
	Total	87,183.35	100.000%	100,989.44	100.000%

Quality		Blending Basis	Value	Min	Max
RHO	DENSITY, KG/M3	VL	863.29		890.00
SPM	SULFUR, PPMW	WT	1,000.00		1,000.00
FLC	FLASH POINT, °C (PM, D93)	VL	60.00	60.00	
CIN	CETANE INDEX D4737	VL	46.99	35.00	
V04	VISCOSITY @ 40°C, CST	WT	6.00		6.00

Table 6-5: Base Case 2) Fuel oil and bitumen qualities

REV.8
12/05/2016

ReCAP Project
Preliminary Refinery Balances

BASE CASE 2
Medium Conversion Refinery, 220,000 BPSD

FUEL OIL / BITUMEN QUALITIES

Low Sulphur Fuel

Component		Weight Quantity	Weight Percent	Volume Quantity	Volume Percent
SLU	FCC SLURRY OIL	25,340.95	7.986%	24,366.30	7.610%
lco	LIGHT CYCLE OIL untreated	22,066.39	6.954%	23,227.78	7.255%
LCO	LIGHT CYCLE OIL treated	15,040.81	4.740%	15,832.43	4.945%
VRCR1	VBRES MIX1	50,540.30	15.928%	52,756.05	16.477%
VRCR2	VBRES MIX2	171,018.58	53.898%	164,599.21	51.408%
VLG	DESULF LGO ex VHT	33,292.38	10.492%	39,399.26	12.305%
	Total	317,299.41	100.000%	320,181.04	100.000%

Quality		Blending Basis	Value	Min	Max
RHO	DENSITY, KG/M3	VL	991.00		991.00
SUL	SULFUR, %W	WT	0.50		0.50
FLC	FLASH POINT, °C (PM, D93)	VL	129.30	66.00	
V05	VISCOSITY @ 50°C, CST	WT	380.00		380.00
CCR	CONRADSON CARBON RES, %W	WT	11.36		15.00

Medium Sulphur Fuel

Component		Weight Quantity	Weight Percent	Volume Quantity	Volume Percent
SLU	FCC SLURRY OIL	167,462.02	41.287%	161,021.18	39.501%
lco	LIGHT CYCLE OIL untreated	27,663.62	6.820%	29,119.60	7.143%
VRCR1	VBRES MIX1	176,752.37	43.578%	184,501.43	45.261%
VRCR4	VBRES MIX4	33,725.32	8.315%	32,999.33	8.095%
	Total	405,603.33	100.000%	407,641.54	100.000%

Quality		Blending Basis	Value	Min	Max
RHO	DENSITY, KG/M3	VL	995.00		995.00
SUL	SULFUR, %W	WT	1.00		1.00
FLC	FLASH POINT, °C (PM, D93)	VL	156.64	66.00	
V05	VISCOSITY @ 50°C, CST	WT	380.00		380.00
CCR	CONRADSON CARBON RES, %W	WT	7.58		17.00

Table 6-5bis: Base Case 2) Fuel oil and bitumen qualities

REV.8
12/05/2016

ReCAP Project
Preliminary Refinery Balances

BASE CASE 2
Medium Conversion Refinery, 220,000 BPSD

FUEL OIL / BITUMEN QUALITIES

High Sulphur Fuel

Component		Weight Quantity	Weight Percent	Volume Quantity	Volume Percent
lco	LIGHT CYCLE OIL untreated	235,523.42	25.225%	247,919.39	26.314%
V1CR3	VBLGO MIX3	35,638.28	3.817%	41,927.39	4.450%
VRCR3	VBRES MIX3	165,318.53	17.706%	165,815.98	17.599%
VRCR4	VBRES MIX4	497,204.99	53.252%	486,501.95	51.637%
	Total	933,685.21	100.000%	942,164.70	100.000%

Quality		Blending Basis	Value	Min	Max
RHO	DENSITY, KG/M3	VL	991.00		991.00
SUL	SULFUR, %W	WT	3.00	1.00	3.50
FLC	FLASH POINT, °C (PM, D93)	VL	124.35	60.00	
V05	VISCOSITY @ 50°C, CST	WT	380.00		380.00
CCR	CONRADSON CARBON RES, %W	WT	14.58		18.00

BITUMEN

Component		Weight Quantity	Weight Percent	Volume Quantity	Volume Percent
VDCR5	VDU RES MIX5	107,884.28	41.494%	106,289.93	41.921%
VDCR6	VDU RES MIX6	152,115.72	58.506%	147,256.26	58.079%
	Total	260,000.00	100.000%	253,546.19	100.000%

Table 6-6: Base Case 2) Main utility balance, fuel mix composition, CO_2 emissions

REV.8
12/05/2016

ReCAP Project
Preliminary Refinery Balances

BASE CASE 2
Medium Conversion Refinery, 220,000 BPSD

MAIN UTILITY BALANCE

	FUEL Gcal/h	**POWER** kW	**HP STEAM** tons/h	**MP STEAM** tons/h	**LP STEAM** tons/h	**COOLING WATER** (2) m3/h	**RAW WATER** m3/h
MAIN PROCESS UNITS	485	32148	34	121	129	25122	
BASE LOAD		22500	15	30	30		
POWER PLANT	400	-60415	-49	-151	-159	8563	
SEA WATER SYSTEM		1712				-10000	
COOLING TOWER SYSTEM		4055				-23685	
TOTAL	**885**	**0**	**0**	**0**	**0**	**0**	**2590**

FUEL MIX COMPOSITION

	t/h	kt/y	wt%
REFINERY FUEL GAS	26.7	224.0	33%
LOW SULPHUR FUEL OIL (3)	20.0	168.2	25%
FCC COKE	12.1	101.4	15%
NATURAL GAS	22.7	190.5	28%
TOTAL	**81.4**	**684.1**	

CO2 EMISSIONS

	t/h
From Steam Reformer	15.7
From FG/NG combustion	133.4
From FO combustion	64.1
From FCC coke combustion	44.3
TOTAL	**257.4**

corresponding to ***2162.3*** *kt/y*
207.4 *kg CO2 / t crude*

Notes
1) (-) indicates productions
2) 10°C temperature increase has been considered
3) LSFO is burnt in CDU, VDU and VBU heaters

REV.8
12/05/2016

ReCAP Project

Overall Refinery Balance

BASE CASE 2

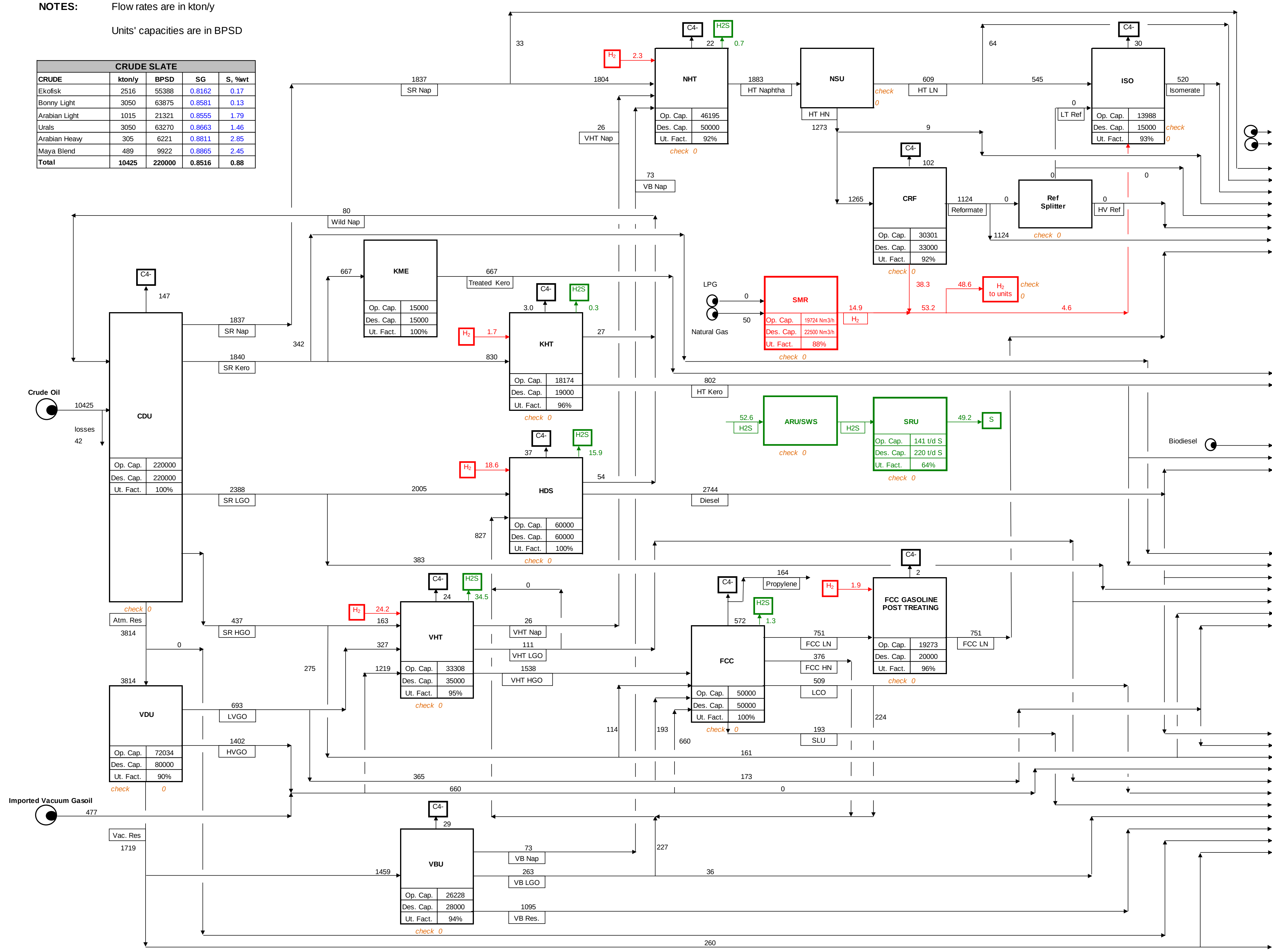
Medium Conversion Refinery, 220,000 BPSD

BLOCK FLOW DIAGRAM

NOTES: Flow rates are in kton/y

Units' capacities are in BPSD

CRUDE SLATE				
CRUDE	**kton/y**	**BPSD**	**SG**	**S, %wt**
Ekofisk	2516	55388	0.8162	0.17
Bonny Light	3050	63875	0.8581	0.13
Arabian Light	1015	21321	0.8555	1.79
Urals	3050	63270	0.8663	1.46
Arabian Heavy	305	6221	0.8811	2.85
Maya Blend	489	9922	0.8865	2.45
Total	**10425**	**220000**	**0.8516**	**0.88**



	LPG
Propane	94
Butane	465
Total prod.	**560**
To SMR	*0*
To fuel	*0*
Sales	**560**

	Propylene
Propylene	**164**
Sales	**164**

	U 95-EU	U 92-US	Excess Naph.	TOT
MTBE	0	0	0	**0**
Ethanol	92	0	0	**92**
Butanes	13	6	0	**19**
SR Naphtha	0	0	33	**33**
HT Light Naphtha	0	0	64	**64**
Isomerate	275	245	0	**520**
HT Heavy Naphtha	0	0	9	**9**
LT Reformate	0	0	0	**0**
HV Reformate	0	0	0	**0**
Reformate	785	339	0	**1124**
FCC LN	588	162	2	**751**
Sales	**1753**	**751**	**108**	**2613**

	Jet Fuel
Treated Kero	667
HT Kero	333
Sales	**1000**

	Diesel
Biodiesel	213
HT Kero	469
Diesel	2729
Sales	**3412**

	Heating Oil	Mar. Dies.	TOT
SR Kero	323	19	**342**
HT Kero	0	0	**0**
Diesel	0	0	**0**
SR LGO	381	2	**383**
VHT LGO	51	27	**78**
SR HGO	122	39	**161**
SR LVGO	173	0	**173**
Sales	**1050**	**87**	**1137**

	LSFO	MSFO	HSFO	TOT
Diesel	15	0	0	**15**
SR LVGO	0	0	0	**0**
SR HGO	0	0	0	**0**
SR HVGO	0	0	0	**0**
VHT LGO	33	0	0	**33**
LCO untreated	22	28	236	**285**
SLU	25	167	0	**193**
VB LGO	0	0	36	**36**
VB Residue	222	210	663	**1095**
Atm. Residue	0	0	0	**0**
Vac. Residue	0	0	0	**0**
Total prod.	**302**	**406**	**934**	**1642**
To RFO	*168*	-	-	*168*
Sales	**134**	**406**	**934**	**1473**

	Bitumen
Vac. Res.	**260**
Sales	**260**

	Sulphur
Sulphur	**49**
Sales	**49**

Figure 6-1: Base Case 2) Block flow diagrams with main material streams

Table 6-7: Base Case 2) CO_2 emissions per unit

REV.8
12/05/2016

ReCAP Project
1-BD-0839A

CO_2 EMISSION PER UNIT - BASE CASE 2

UNIT			Unit of measure	Design Capacity	Operating Fuel Consumption [t/h]			Operating CO_2 Emission [t/h]			% on Total CO_2 Emission	CO_2 concentr. in flue gases, vol %	Operating Temperature [°C]	Notes
					Fuel Gas	Fuel Oil	Coke	Fuel Gas	Fuel Oil	Coke				(1)
PROCESS UNITS														
0100A	CDU	Crude Distillation Unit	BPSD	100000	-	7.4	-	-	23.6	-	9.2%	11.3%	200 ÷ 220	
0100B	CDU	Crude Distillation Unit	BPSD	120000	-	8.9	-	-	28.3	-	11.0%	11.3%	200 ÷ 220	(2)
0300A	NHT	Naphtha Hydrotreater	BPSD	23000	0.3	-	-	0.9	-	-	0.3%	8.3%	420 ÷ 450	(3)
0350A	NSU	Naphtha Splitter Unit	BPSD	23000	0.4	-	-	1.1	-	-	0.4%	8.3%		
0300B	NHT	Naphtha Hydrotreater	BPSD	27000	0.3	-	-	0.8	-	-	0.3%	8.3%	420 ÷ 450	(3)
0350B	NSU	Naphtha Splitter Unit	BPSD	27000	0.4	-	-	1.0	-	-	0.4%	8.3%		
0500A	CRF	Catalytic Reforming	BPSD	15000	3.6	-	-	9.8	-	-	3.8%	8.3%	180 ÷ 190	
0500B	CRF	Catalytic Reforming	BPSD	18000	3.6	-	-	9.8	-	-	3.8%	8.3%	180 ÷ 190	
0600A	KHT	Kero HDS	BPSD	14000	0.2	-	-	0.5	-	-	0.2%	8.3%	420 ÷ 450	
0600B	KHT	Kero HDS	BPSD	5000	0.1	-	-	0.3	-	-	0.1%	8.3%	420 ÷ 450	
0700A	HDS	Gasoil HDS	BPSD	26000	1.3	-	-	3.4	-	-	1.3%	8.3%	420 ÷ 450	
0700B	HDS	Gasoil HDS	BPSD	34000	1.4	-	-	3.9	-	-	1.5%	8.3%	420 ÷ 450	
0800	VHT	Vacuum Gasoil Hydrotreater	BPSD	35000	2.2	-	-	5.8	-	-	2.3%	8.3%	200 ÷ 220	
1000	FCC	Fluid Catalytic Cracking	BPSD	50000	-	-	12.1	-	-	44.3	17.2%	16.6%	300 ÷ 320	
1100A	VDU	Vacuum Distillation Unit	BPSD	35000	-	1.2	-	-	3.8	-	1.5%	11.3%	380 ÷ 400	
1100B	VDU	Vacuum Distillation Unit	BPSD	45000	-	1.5	-	-	4.9	-	1.9%	11.3%	200 ÷ 220	(2)
1200	SMR	Steam Reformer	Nm^3/h Hydrogen	22500	1.4	-	-	3.7	-	-	1.4%	8.3%	135 ÷ 160	(4)
		Steam Reformer Feed			5.9	-	-	15.7	-	-	6.1%	24.2%		
1500	VBU	Visbreaking Unit	BPSD	28000	-	1.0	-	-	3.4	-	1.3%	8.3%	380 ÷ 400	
							Sub Total Process Units		164.9		64.1%			
AUXILIARY UNITS														
2200A	SRU	Sulphur Recovery & Tail Gas Treatment	t/d Sulphur	55	0.005	-	-	0.01	-	-	0.0%	< 8%	380 ÷ 400	
2200B	SRU	Sulphur Recovery & Tail Gas Treatment	t/d Sulphur	2 x 82.5	0.014	-	-	0.04	-	-	0.0%	< 8%	380 ÷ 400	
							Sub Total Auxiliary Units		0.05		0.0%			
POWER UNITS														
2500	POW	Power Plant	kW	80000	34.2	-	-	92.5	-	-	35.9%	8.3%	130 ÷ 140	
							Sub Total Power Units		92.5		35.9%			
							TOTAL CO_2 EMISSION		**257.5**		**100%**			
								58%	**25%**	**17%**				

Notes

(1) Fuel gas is a mixture of refinery fuel gas (54%) and imported natural gas (46%).
(2) In train B, Crude and Vacuum Distillation heaters (units 0100B and 1100B) have a common stack.
(3) Both in train A and B, Naphtha Hydrotreater and Naphtha Splitter heaters (units 0300A/0350A and 0300B/0350B) have a common stack.
(4) Only natural gas is used as feed to the Steam Reformer, unit 1200; after reaction and hydrogen purification, tail gas and fuel gas are burnt in the Steam Reformer furnace.

6.2 Refinery Layout

The layout of the medium conversion refinery has been developed starting from the plot plan of Base Case 1, essentially by adding a second block of process units beside the original nucleus of the refinery.

As already mentioned, this approach reflects the assumption of a refinery expanded, over its life, both in terms of capacity and complexity.

Also some auxiliary, utility and offsite systems, like for example the Waste Water Treatment (WWT) and the Flare, have been duplicated in the final configuration of the site.

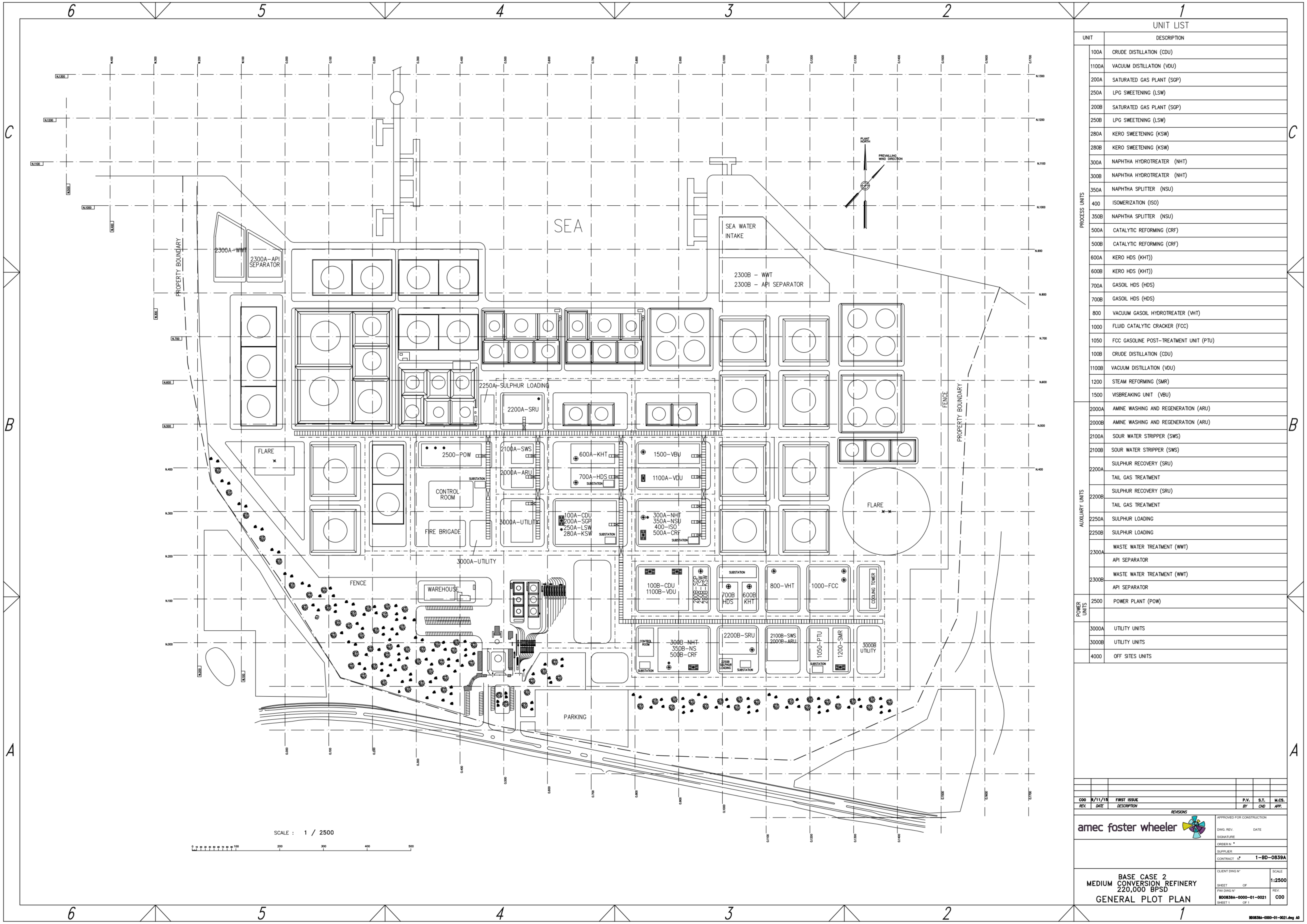


Figure 6-2: Base Case 2) Refinery layout

6.3 Main Utility Networks

The main utility balances have been reported on block flow diagrams, reflecting the planimetric arrangement of the process units and utility blocks.

In particular, the following networks' sketches have been developed:

- Figure 6-3: Base Case 2) Electricity network
- Figure 6-4: Base Case 2) Steam networks
- Figure 6-5: Base Case 2) Cooling water network
- Figure 6-6: Base Case 2) Fuel Gas/Offgas networks
- Figure 6-7: Base Case 2) Fuel oil network

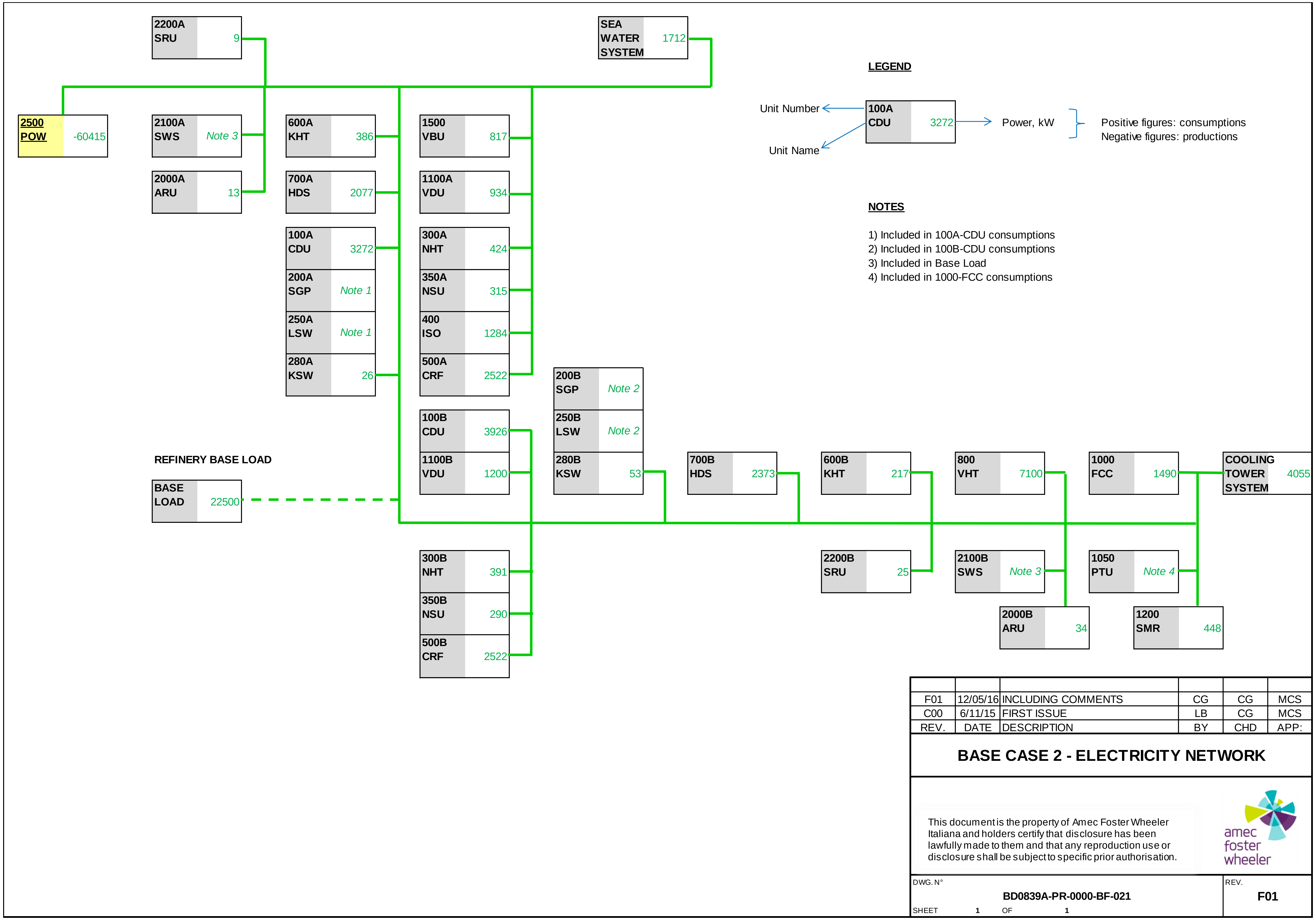


Figure 6-3: Base Case 2) Electricity network

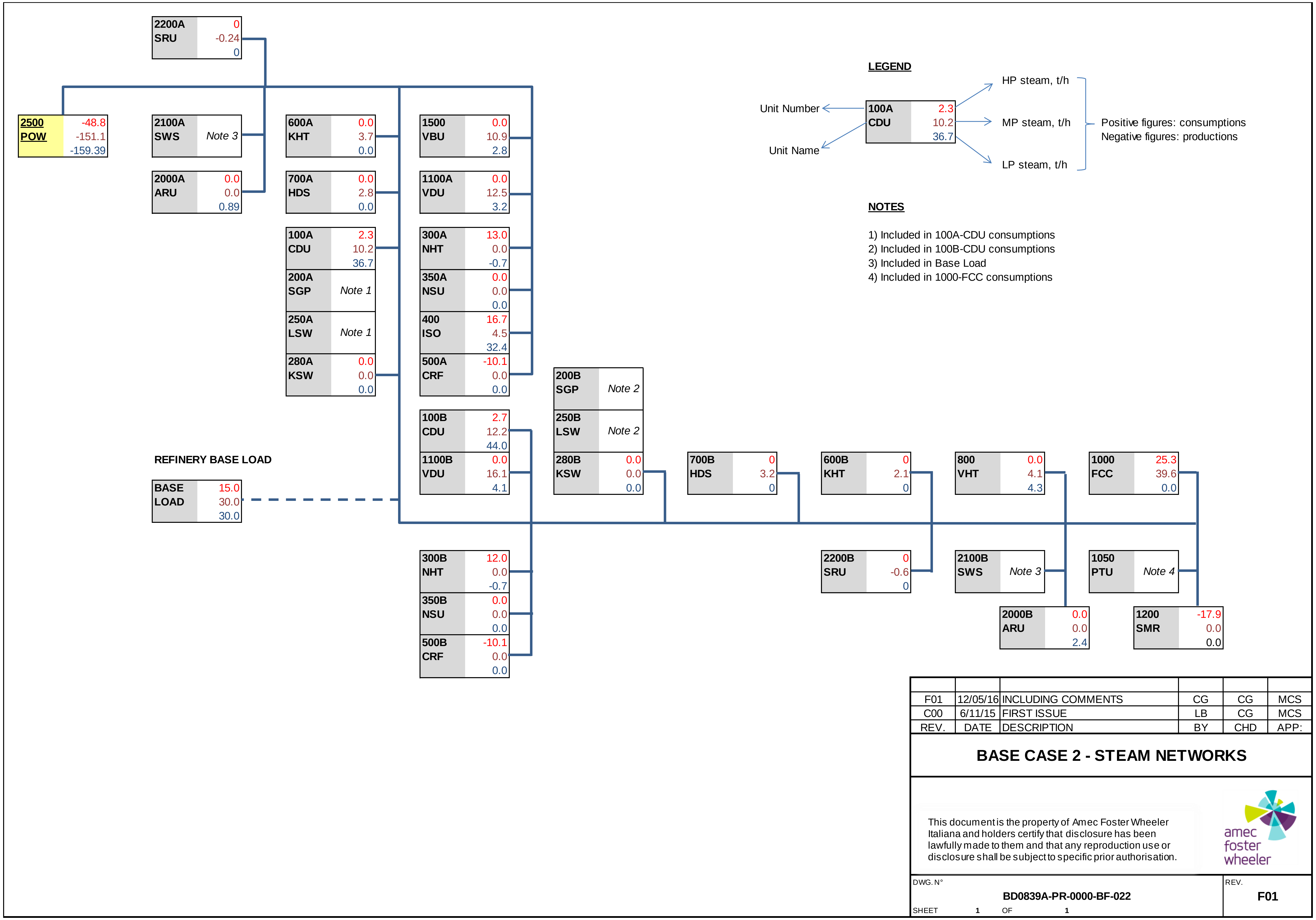


Figure 6-4: Base Case 2) Steam networks

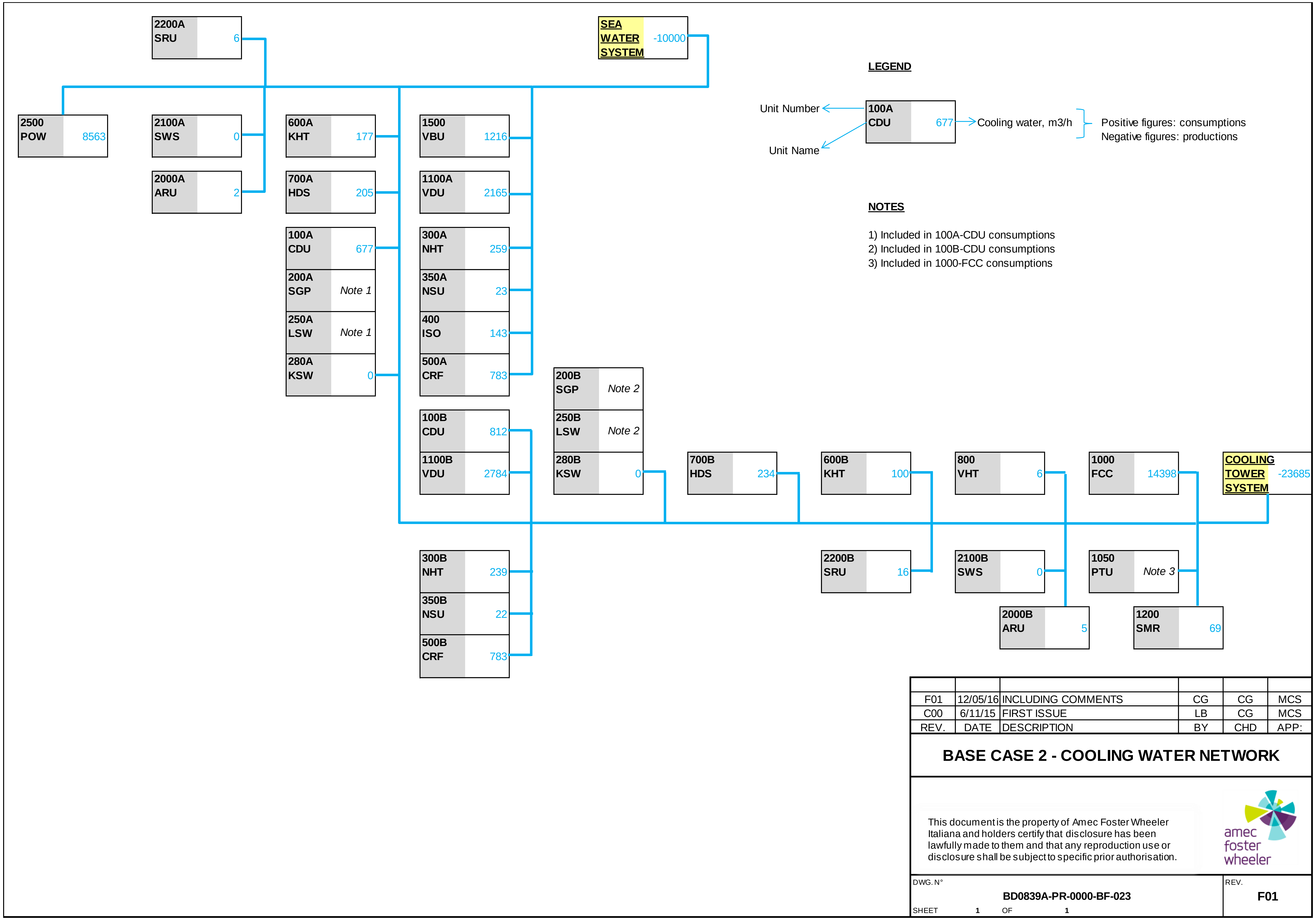


Figure 6-5: Base Case 2) Cooling water network

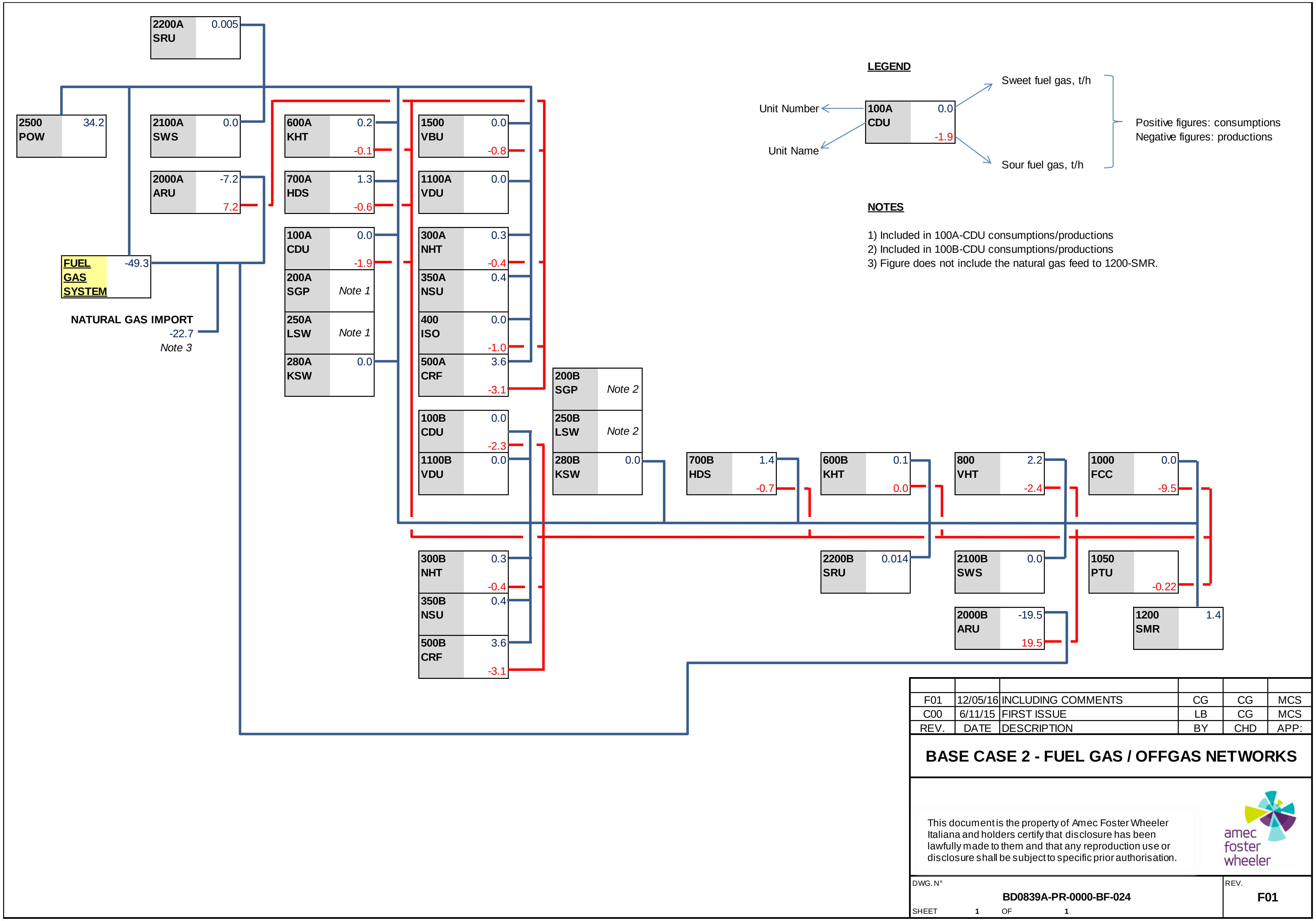


Figure 6-6: Base Case 2) Fuel Gas/Offgas networks

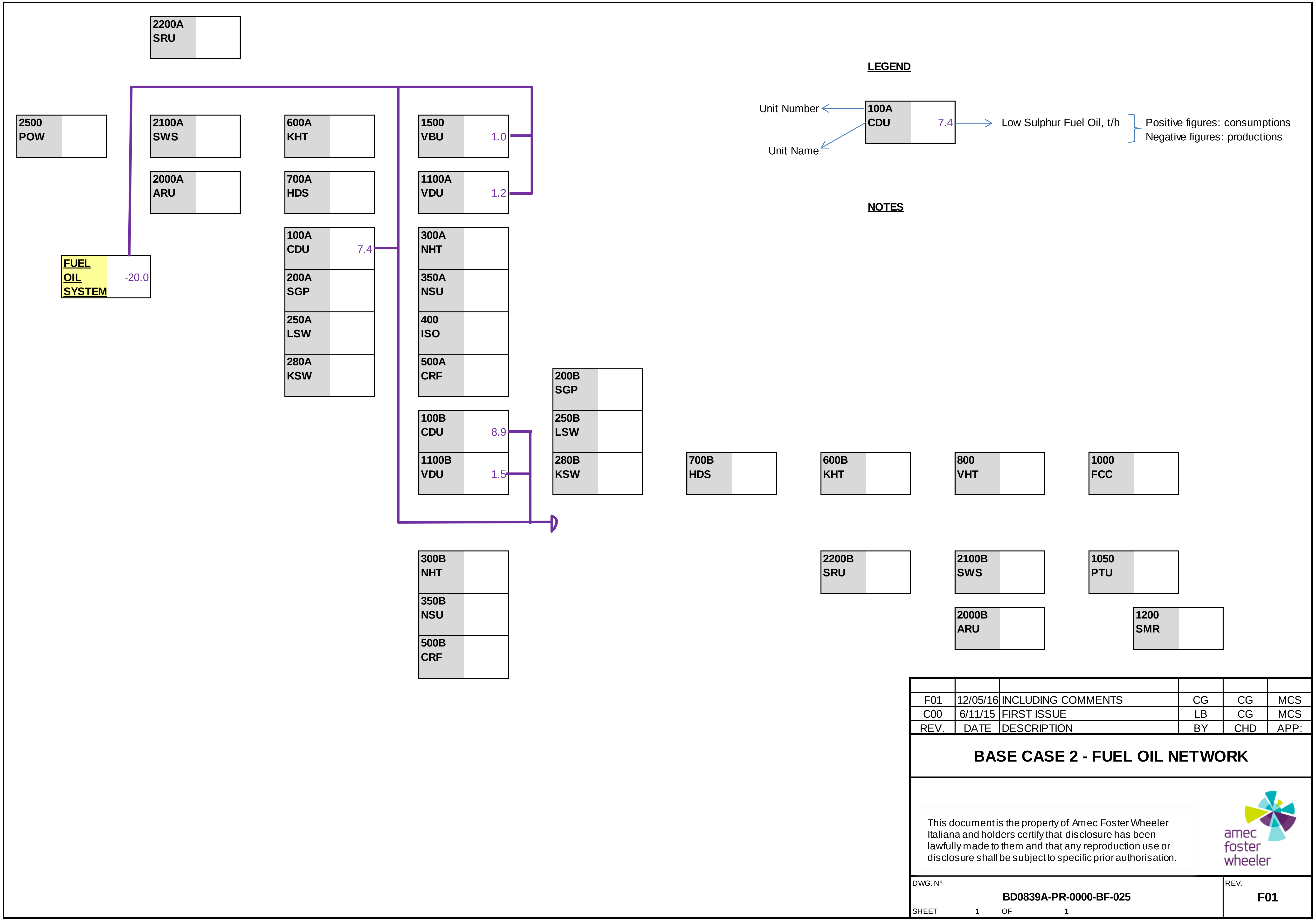


Figure 6-7: Base Case 2) Fuel oil network

6.4 Configuration of Power Plant

With respect of Base Case 1, the capacity and complexity increase of the refinery implies an increase in the steam and power demand, as shown in Table 6-6.

Power plant size has been increased following a modular approach: since Base Case 2 represents a step-up evolution of Base Case 1, the configuration of power plant has been also developed starting from the one described in paragraph 5.4, by adding new boilers and steam turbines of the same size to meet the new refinery power and steam demand.

As per Base Case 1, the power plant has been designed to be normally operated in balance with the grid and the refinery and such that no import/export of steam is required in normal operation. Also in this case, steam demand has higher priority over electricity demand, since refinery electrical demand can be provided by HV grid connection back-up.

Power plant configuration developed for Base Case 2 is shown in the following sketch.

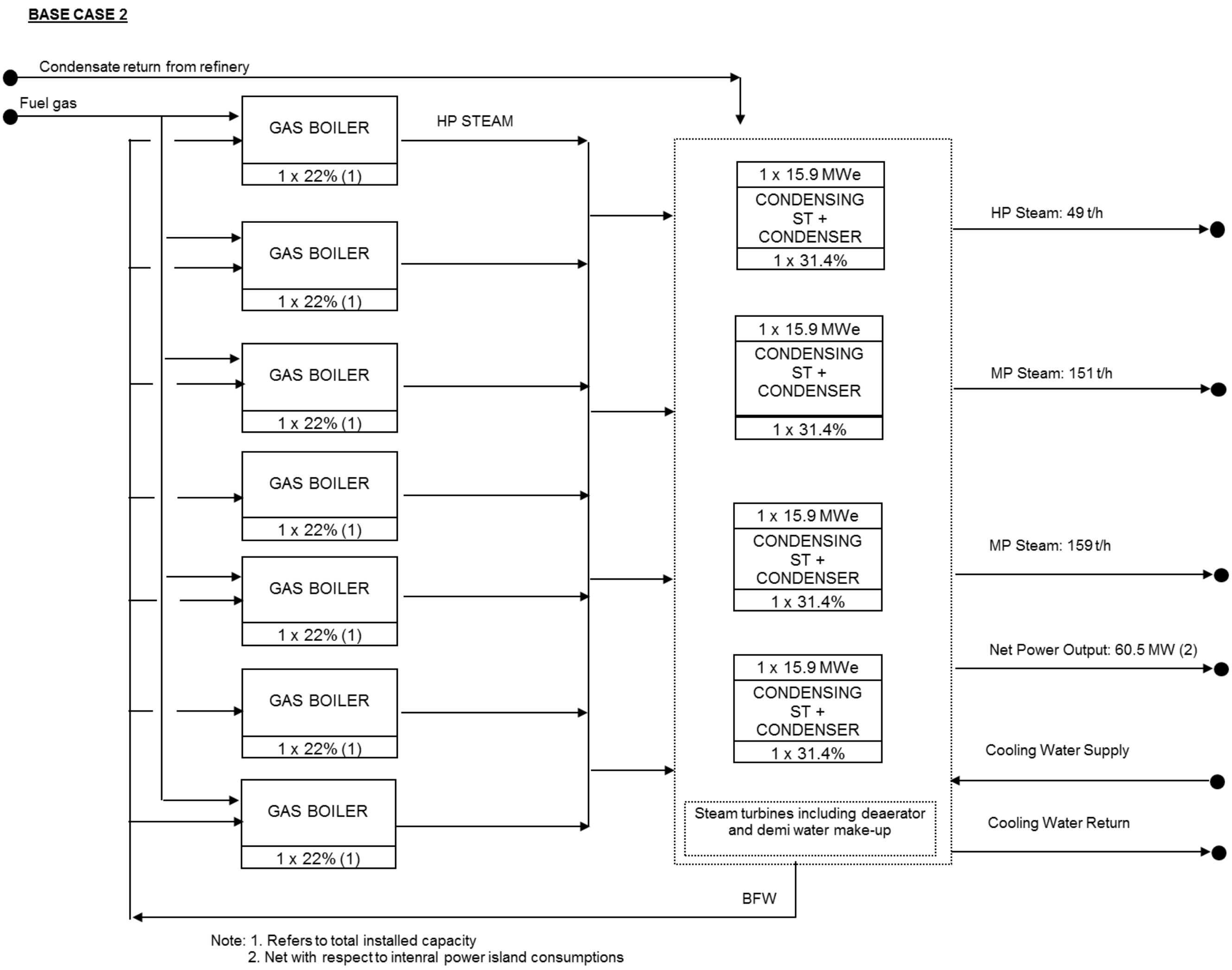


Figure 6-8: Base Case 2) Power Plant simplified Block Flow Diagram

Base Case 2 power plant major equipment number and size are summarized hereinafter:

- 7 x 115 t/h Gas Boilers normally operated at 65% of their design load (corresponding to 74.7 t/h each)
- 4 x 20 MWe Condensing Steam Turbines normally operated at 79.6% of their design load (corresponding to 15.9 MWe each)

Power plant configuration has been conceived to have such an installed spare capacity both for power and steam generation to handle possible oscillations in power/steam from the users and to avoid refinery shutdown in case of equipment (boiler or steam turbine) trip.

In case one steam turbine trips, 95% of the total power demand is guaranteed by the remaining three steam turbines in operation: only a small import from the grid or load shedding is required in this scenario in order not to compromise the refinery normal operation.

Total installed spare capacity is summarized hereinafter:

- Gas Boilers (Steam) **+54%**
- Steam Turbines (Electric Energy) **+26%**

7. Base Case 3

High Conversion Refinery - 220,000 BPSD Crude Capacity

The High Conversion Refinery, with respect of the Hydro-skimming Refinery described at paragraph 4.8, includes additional process units for the conversion of the Vacuum Gasoil (VGO) and of the Vacuum Residue into more valuable distillates (essentially gasoline and automotive diesel).

In Europe, the most wide-spread VGO conversion unit is the Fluid Catalytic Cracking (FCC) and so this unit is included in Base Case 3 (as in Base Case 2).

Upstream of the FCC, a Vacuum Gasoil Hydrotreating (VHT) unit is present to decrease the sulphur content of FCC feedstock, in order to respect SO_x limits at FCC stack.

For Vacuum Residue conversion, a Coker Unit is considered. It is considered to sell the fuel grade coke produced.

The FCC and Coker distillates are sent to finishing units to comply with the 10 ppm wt. sulphur specification for the automotive fuels.

The hydrogen from the Heavy Naphtha Catalytic Reformer is not enough to cover the overall hydrogen demand of the refinery. Therefore, a Steam Methane Reformer (SMR) is foreseen to close the hydrogen balance.

The overall configuration of Base Case 3 is considered as a step-up evolution of Base Case 1, both in terms of capacity and complexity increase. In other words, it is considered that, in a simple hydro-skimming refinery (as the one depicted as Base Case 1), a second crude distillation train (Atmospheric and Vacuum Distillation Units), FCC block (VHT+FCC+SMR) and DCU are built in a second phase. The consequent capacity increase of the gasoline block and the hydrotreating units is considered achieved by adding a second train in parallel to the original one.

The above assumption reflects the typical “life” of the European refineries, which have gradually expanded starting from an original nucleus. This results in the following main effects:

- Several units of the same type are running in parallel, resulting in a relatively good flexibility of the processing scheme (e.g. different feedstocks could be fed to each train) but also, on the other hand, in some inefficiencies (e.g. higher maintenance costs, lower energy efficiencies, etc.).
- Also the Power Plant in Base Case 3 is considered as an expansion of the facilities foreseen in Base Case 1, reflecting the “modular” expansion of the original refinery into a bigger, more complex and more demanding site.
- The increased demand of cooling water –with respect of cooling water consumption in Base Case 1- is considered to be satisfied by a closed loop circuit with cooling towers, working in parallel to the original open circuit of sea cooling water. As a matter of fact, for the upgrading of the refinery, it is assumed that more stringent environmental regulations have been met.
- Finally, also the layout of the Base Case 3 refinery reflects two main areas of units’ allocation: beside the original nucleus of the older units (unit numbers identified with suffix –A), a second block of units is present and clearly identifiable (unit numbers identified with suffix –B). The FCC block and DCU are included in this newer portion of the refinery.

7.1 Refinery Balances

The balances developed for Base Case 3 are reported in the following tables and figures:

- Table 7-1: Base Case 3) Overall material balance
- Table 7-2: Base Case 3) Process units operating and design capacity
- Table 7-3: Base Case 3) Gasoline qualities
- Table 7-4: Base Case 3) Distillate qualities
- Table 7-5: Base Case 3) Fuel oil and bitumen qualities
- Table 7-6: Base Case 3) Main utility balance, fuel mix composition, CO_2 emissions
- Figure 7-1: Base Case 3) Block flow diagrams with main material streams
- Table 7-7: Base Case 3) CO_2 emissions per unit

Table 7-1: Base Case 3) Overall material balance

REV.7
12/05/2016

ReCAP Project
Preliminary Refinery Balances

BASE CASE 3
High Conversion Refinery, 220,000 BPSD

OVERALL MATERIAL BALANCE

PRODUCTS	Annual Production, kt/y
LPG	680.6
Propylene	197.1
Petrochemical Naphtha	200.6
Gasoline U95 Europe	1824.8
Gasoline U92 USA Export	782.1
Jet fuel	1000.0
Road Diesel	3542.8
Marine Diesel	472.4
Heating Oil	708.6
Low Sulphur Fuel Oil	209.8
Medium Sulphur Fuel Oil	0.0
High Sulphur Fuel Oil	0.0
Bitumen	150.0
Coke Fuel Grade	522.6
Sulphur	89.3
Subtotal	**10380.7**
RAW MATERIALS	Consumptions, kt/y
Ekofisk	1648.8
Bonny Light	2350.0
Arabian Light	1015.0
Urals Medium	4060.0
Arabian Heavy	1015.0
Maya Blend (1)	406.0
Imported Vacuum Gasoil	206.7
MTBE	0.0
Natural Gas	176.1
Biodiesel	221.4
Ethanol	96.1
Subtotal	**11195.1**
	kt/y
Fuels and Losses	**814.4**

Notes
1) Maya Blend consists of 50% wt. Maya crude oil + 50% wt. Arabian Light Crude Oil

Table 7-2: Base Case 3) Process units operating and design capacity

REV.7
12/05/2016

ReCAP Project
Preliminary Refinery Balances

BASE CASE 3
High Conversion Refinery, 220,000 BPSD

PROCESS UNITS OPERATING AND DESIGN CAPACITY

UNIT	Unit of measure	Design Capacity	Operating Capacity	Average Utilization
Crude Distillation Unit	BPSD	220000 (1)	220000 (1)	100%
Vacuum Distillation Unit	BPSD	86000 (1)	78604 (1)	91%
Naphtha Hydrotreater	BPSD	50000 (1)	48797	98%
Light Naphtha Isomerization	BPSD	15000	13774	92%
Heavy Naphtha Catalytic Reforming	BPSD	33000 (1)	31589	96%
Kero Sweetening	BPSD	15000 (1)	15000	100%
Kerosene Hydrotreater	BPSD	26000 (1)	24673	95%
Diesel Hydrotreater	BPSD	65000 (1)	65000	100%
Heavy Gasoil Hydrotreater	BPSD	50000	45154	90%
Fluid Catalytic Cracking	BPSD	60000	60000	100%
FCC Gasoline Hydrotreater	BPSD	24000	23128	96%
Delayed Coker	BPSD	35000	33807	97%
Sulphur Recovery Unit	t/d Sulphur	450 (1)	255	57%
Steam Reformer	Nm^3/h Hydrogen	35000	31922	91%

Notes

1) Multiple units in parallel to be considered.

Table 7-3: Base Case 3) Gasoline qualities

REV.7
12/05/2016

ReCAP Project
Preliminary Refinery Balances

BASE CASE 3
High Conversion Refinery, 220,000 BPSD

GASOLINE QUALITIES

EXCESS NAPHTHA

Component		Weight Quantity	Weight Percent	Volume Quantity	Volume Percent
NAL	HT LIGHT NAPHTHA	104,352.21	52.031%	149,716.23	52.667%
LRF	LIGHT REFORMATE	31.15	0.016%	44.00	0.015%
LCN	FCC LIGHT NAPHTHA treated	96,172.85	47.953%	134,507.48	47.317%
	Total	200,556.21	100.000%	284,267.71	100.000%

Quality		Blending Basis	Value	Min	Max
RHO	DENSITY, KG/M3	VL	705.52		725.00
SPM	SULFUR, PPMW	WT	17.80		500.00
VPR	VAPOR PRESSURE, KPA	VL	69.00		69.00

Unl. Premium (95) EU

Component		Weight Quantity	Weight Percent	Volume Quantity	Volume Percent
BU#	C4 TO MOGAS/LPG	13,154.43	0.721%	22,519.42	0.931%
R10	REFORMATE 100	818,352.14	44.845%	987,155.78	40.821%
ISO	ISOMERATE	287,186.34	15.738%	434,472.52	17.966%
LCN	FCC LIGHT NAPHTHA treated	610,026.70	33.429%	853,184.19	35.281%
EOH	ETHANOL	96,125.20	5.268%	120,912.21	5.000%
	Total	1,824,844.80	100.000%	2,418,244.12	100.000%

Quality		Blending Basis	Value	Min	Max
RHO	DENSITY, KG/M3	VL	754.62	720.00	775.00
SPM	SULFUR, PPMW	WT	3.38		10.00
VPR	VAPOR PRESSURE, KPA	VL	60.00		60.00
BEN	BENZENE, %V	VL	0.71		1.00
ARO	AROMATICS, %V	VL	32.03		35.00
E50	D86 @ 150°C, %V	VL	91.02	75.00	
OXY	OXYGENATES, %V	VL	5.00		15.00
OLE	OLEFINS, %V	VL	14.53		18.00
EOH	ETHANOL, VOl%	VL	5.00		5.00
RON	Research	VL	95.00	95.00	
MON	Motor	VL	85.00	85.00	

Table 7-3bis: Base Case 3) Gasoline qualities

REV.7
12/05/2016

ReCAP Project
Preliminary Refinery Balances

BASE CASE 3
High Conversion Refinery, 220,000 BPSD

GASOLINE QUALITIES

Unl. Premium (92)

Component		Weight Quantity	Weight Percent	Volume Quantity	Volume Percent
BU#	C4 TO MOGAS/LPG	8,614.91	1.102%	14,748.10	1.399%
HRF	HEAVY REFORMATE	318.85	0.041%	376.45	0.036%
R10	REFORMATE 100	353,317.19	45.177%	426,196.85	40.430%
ISO	ISOMERATE	224,608.43	28.720%	339,800.95	32.234%
LCN	FCC LIGHT NAPHTHA treated	195,216.97	24.961%	273,030.72	25.900%
	Total	782,076.34	100.000%	1,054,153.07	100.000%

Quality		Blending Basis	Value	Min	Max
RHO	DENSITY, KG/M3	VL	741.90	720.00	775.00
SPM	SULFUR, PPMW	WT	2.55		10.00
VPR	VAPOR PRESSURE, KPA	VL	60.00		60.00
BEN	BENZENE, %V	VL	0.69		1.00
ARO	AROMATICS, %V	VL	30.40		35.00
E50	D86 @ 150°C, %V	VL	91.10	75.00	
OXY	OXYGENATES, %V	VL	0.00		15.00
OLE	OLEFINS, %V	VL	11.01		18.00
EOH	ETHANOL, VOl%	VL	0.00		10.00
RON	Research	VL	92.41	92.00	
MON	Motor	VL	84.00	84.00	

Table 7-4: Base Case 3) Distillate qualities

REV.7
12/05/2016

ReCAP Project
Preliminary Refinery Balances

BASE CASE 3
High Conversion Refinery, 220,000 BPSD

DISTILLATE QUALITIES

LPG PRODUCT

Component		Weight Quantity	Weight Percent	Volume Quantity	Volume Percent
LG#	LPG POOL	680,600.64	100.000%	1,202,764.04	100.000%
	Total	680,600.64	100.000%	1,202,764.04	100.000%

Quality		Blending Basis	Value	Min	Max
SPM	SULFUR, PPMW	WT	5.00		140.00
VPR	VAPOR PRESSURE, KPA	VL	671.77	632.40	887.60
OLW	OLEFINS, %W	WT	2.56		30.00

Jet Fuel EU

Component		Weight Quantity	Weight Percent	Volume Quantity	Volume Percent
KED	HT KERO	333,008.43	33.301%	419,670.36	33.457%
KMCR4	KERO FROM MEROX URALS	493,264.17	49.326%	617,351.90	49.217%
KMCR5	KERO FROM MEROX AR.HVY	120,785.00	12.079%	150,981.25	12.037%
KMCR6	KERO FROM MEROX MAYA	52,942.40	5.294%	66,343.86	5.289%
	Total	1,000,000.00	100.000%	1,254,347.37	100.000%

Quality		Blending Basis	Value	Min	Max
RHO	DENSITY, KG/M3	VL	797.23	775.00	840.00
SUL	SULFUR, %W	WT	0.14		0.30
FLC	FLASH POINT, °C (PM, D93)	VL	40.00	38.00	

Diesel EU

Component		Weight Quantity	Weight Percent	Volume Quantity	Volume Percent
LCO	LIGHT CYCLE OIL treated	394,124.38	11.125%	414,867.77	9.895%
HCN	FCC HEAVY NAPHTHA	134,746.57	3.803%	158,525.38	3.781%
KED	HT KERO	744,173.47	21.005%	937,836.76	22.368%
DLG	DESULF LGO	2,048,398.35	57.818%	2,429,891.28	57.956%
FAM	BIODIESEL	221,373.62	6.249%	251,560.93	6.000%
	Total	3,542,816.39	100.000%	4,192,682.11	100.000%

Quality		Blending Basis	Value	Min	Max
RHO	DENSITY, KG/M3	VL	845.00	820.00	845.00
SPM	SULFUR, PPMW	WT	8.96		10.00
FLC	FLASH POINT, °C (PM, D93)	VL	55.00	55.00	
CIN	CETANE INDEX D4737	VL	46.86	46.00	
V04	VISCOSITY @ 40°C, CST	WT	2.45	2.00	4.50
E36	D86 @360°C, %V	VL	97.48	95.00	
FAM	BIODIESEL CONTENT, %VOL	VL	6.00	6.00	7.00

Table 7-4bis: Base Case 3) Distillate qualities

REV.7
12/05/2016

ReCAP Project
Preliminary Refinery Balances

BASE CASE 3
High Conversion Refinery, 220,000 BPSD

DISTILLATE QUALITIES

Heating Oil

Component		Weight Quantity	Weight Percent	Volume Quantity	Volume Percent
HCN	FCC HEAVY NAPHTHA	229,656.16	32.412%	270,183.72	32.363%
LGCR3	LGO ARAB.LIGHT	36,429.59	5.141%	42,707.61	5.116%
LGCR1	LGO EKOFISK	300,582.21	42.421%	354,042.65	42.408%
VLG	DESULF LGO ex VHT	141,895.31	20.026%	167,923.45	20.114%
	Total	708,563.28	100.000%	834,857.43	100.000%

Quality		Blending Basis	Value	Min	Max
RHO	DENSITY, KG/M3	VL	848.72	815.00	860.00
SPM	SULFUR, PPMW	WT	1,000.00		1,000.00
FLC	FLASH POINT, °C (PM, D93)	VL	55.00	55.00	
CIN	CETANE INDEX D4737	VL	48.11	40.00	
V04	VISCOSITY @ 40°C, CST	WT	2.65	2.00	6.00

MARINE DIESEL

Component		Weight Quantity	Weight Percent	Volume Quantity	Volume Percent
LCO	LIGHT CYCLE OIL treated	43,142.22	9.133%	45,412.87	8.393%
HCN	FCC HEAVY NAPHTHA	86,305.52	18.271%	101,535.91	18.765%
LGCR2	LGO BONNY	325,872.15	68.986%	374,135.65	69.144%
LGCR3	LGO ARAB.LIGHT	15,725.09	3.329%	18,435.04	3.407%
VLG	DESULF LGO ex VHT	1,330.54	0.282%	1,574.60	0.291%
	Total	472,375.52	100.000%	541,094.06	100.000%

Quality		Blending Basis	Value	Min	Max
RHO	DENSITY, KG/M3	VL	873.00		890.00
SPM	SULFUR, PPMW	WT	1,000.00		1,000.00
FLC	FLASH POINT, °C (PM, D93)	VL	62.45	60.00	
CIN	CETANE INDEX D4737	VL	46.24	35.00	
V04	VISCOSITY @ 40°C, CST	WT	2.70		6.00

Table 7-5: Base Case 3) Fuel oil and bitumen qualities

REV.7
12/05/2016

ReCAP Project
Preliminary Refinery Balances

BASE CASE 3
High Conversion Refinery, 220,000 BPSD

FUEL OIL / BITUMEN QUALITIES

Low Sulphur Fuel

Component		Weight Quantity	Weight Percent	Volume Quantity	Volume Percent
SLU	FCC SLURRY OIL	231,363.57	62.137%	243,540.60	62.137%
lco	LIGHT CYCLE OIL untreated	140,981.25	37.863%	148,401.31	37.863%
	Total	372,344.82	100.000%	391,941.92	100.000%

Quality		Blending Basis	Value	Min	Max
RHO	DENSITY, KG/M3	VL	950.00		991.00
SUL	SULFUR, %W	WT	0.36		0.50
FLC	FLASH POINT, °C (PM, D93)	VL	119.54	66.00	
V05	VISCOSITY @ 50°C, CST	WT	17.10		380.00
CCR	CONRADSON CARBON RES, %W	WT	0.00		15.00

BITUMEN

Component		Weight Quantity	Weight Percent	Volume Quantity	Volume Percent
VDCR5	VDU RES MIX5	23,814.30	15.876%	23,462.36	16.112%
VDCR6	VDU RES MIX6	126,185.70	84.124%	122,154.60	83.888%
	Total	150,000.00	100.000%	145,616.96	100.000%

Table 7-6: Base Case 3) Main utility balance, fuel mix composition, CO_2 emissions

REV.7
12/05/2016

ReCAP Project
Preliminary Refinery Balances

BASE CASE 3
High Conversion Refinery, 220,000 BPSD

amec foster wheeler

MAIN UTILITY BALANCE

	FUEL Gcal/h	**POWER** kW	**HP STEAM** tons/h	**MP STEAM** tons/h	**LP STEAM** tons/h	**COOLING WATER** (2) m3/h	**RAW WATER** m3/h
MAIN PROCESS UNITS	580	40870	37	114	131	28362	
BASE LOAD		22500	15	30	30		
POWER PLANT	345	-68583	-52	-144	-161	2089	
SEA WATER SYSTEM		1712				-10000	
COOLING TOWER SYSTEM		3501				-20452	
TOTAL	**924**	**0**	**0**	**0**	**0**	**0**	**2260**

FUEL MIX COMPOSITION

	t/h	kt/y	wt%
REFINERY FUEL GAS	39.1	328.8	46%
LOW SULPHUR FUEL OIL (3)	19.3	162.5	23%
FCC COKE	14.5	121.7	17%
NATURAL GAS to fuel system	1.9	16.3	2%
NATURAL GAS to gas turbine	9.5	79.4	11%
TOTAL	**84.4**	**708.7**	

CO2 EMISSIONS

	t/h			
From Steam Reformer	25.5			
From FG/NG combustion	137.5			
From FO combustion	61.9			
From FCC coke combustion	53.1			
TOTAL	**278.0**	*corresponding to*	***2334.8***	*kt/y*
			222.5	*kg CO2 / t crude*

Notes
1) (-) indicates productions
2) 10°C temperature increase has been considered
3) LSFO is burnt in CDU and VDU heaters

REV.7
12/05/2016

ReCAP Project

Overall Refinery Balance

BASE CASE 3

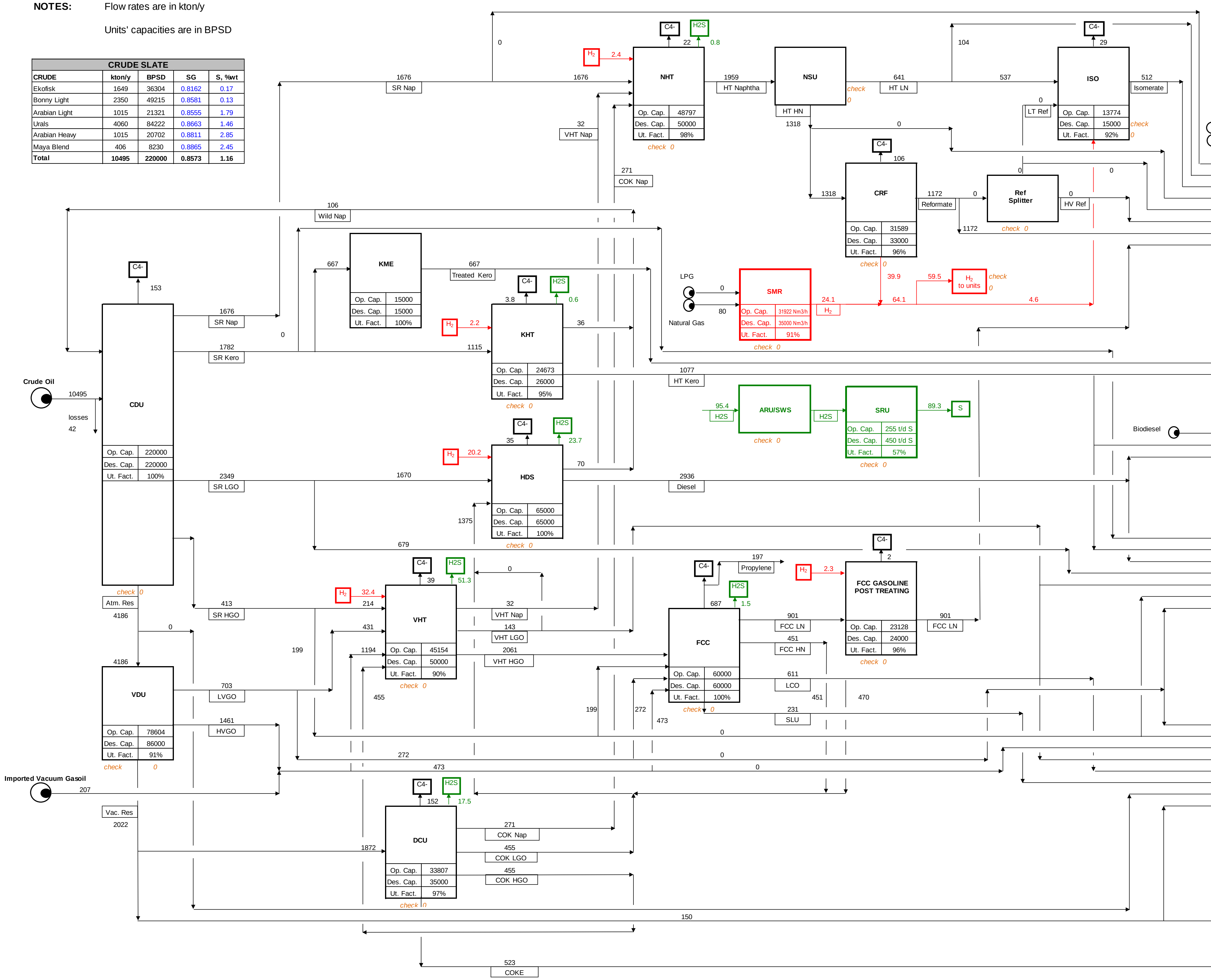
High Conversion Refinery, 220,000 BPSD

BLOCK FLOW DIAGRAM

NOTES: Flow rates are in kton/y

Units' capacities are in BPSD

CRUDE SLATE				
CRUDE	kton/y	BPSD	SG	S, %wt
Ekofisk	1649	36304	0.8162	0.17
Bonny Light	2350	49215	0.8581	0.13
Arabian Light	1015	21321	0.8555	1.79
Urals	4060	84222	0.8663	1.46
Arabian Heavy	1015	20702	0.8811	2.85
Maya Blend	406	8230	0.8865	2.45
Total	**10495**	**220000**	**0.8573**	**1.16**



	LPG
Propane	121
Butane	560
Total prod.	**681**
To SMR	*0*
To fuel	*0*
Sales	**681**

	Propylene
Propylene	**197**
Sales	**197**

	U 95-EU	U 92-US	Excess Naph.	TOT
MTBE	0	0	0	**0**
Ethanol	96	0	0	**96**
Butanes	13	9	0	**22**
SR Naphtha	0	0	0	**0**
HT Light Naphtha	0	0	104	**104**
Isomerate	287	225	0	**512**
HT Heavy Naphtha	0	0	0	**0**
LT Reformate	0	0	0	**0**
HV Reformate	0	0	0	**0**
Reformate	818	353	0	**1172**
FCC LN	610	195	96	**901**
Sales	**1825**	**782**	**201**	**2807**

	Jet Fuel
Treated Kero	667
HT Kero	333
Sales	**1000**

	Diesel
Biodiesel	221
HT Kero	744
Diesel	2577
Sales	**3543**

	Heating Oil	Mar. Dies.	TOT
SR Kero	0	0	**0**
HT Kero	0	0	**0**
Diesel	230	129	**359**
SR LGO	337	342	**679**
VHT LGO	142	1	**143**
SR HGO	0	0	**0**
SR LVGO	0	0	**0**
Sales	**709**	**472**	**1181**

	LSFO	MSFO	HSFO	TOT
SR LVGO	0	0	0	**0**
SR HGO	0	0	0	**0**
SR HVGO	0	0	0	**0**
VHT LGO	0	0	0	**0**
LCO untreated	141	0	0	**141**
SLU	231	0	0	**231**
Atm. Residue	0	0	0	**0**
Vac. Residue	0	0	0	**0**
Total prod.	**372**	**0**	**0**	**372**
To RFO	*163*	-	-	*163*
Sales	**210**	**0**	**0**	**210**

	Bitumen
Vac. Res.	**150**
Sales	**150**

	Sulphur
Sulphur	**89**
Sales	**89**

	Coke
Coke Fuel Grade	**523**
Sales	**523**

Figure 7-1: Base Case 3) Block flow diagrams with main material streams

REV.7
12/05/2016

ReCAP Project
1-BD-0839A

amec foster wheeler

CO_2 EMISSION PER UNIT - BASE CASE 3

UNIT			Unit of measure	Design Capacity	Operating Fuel Consumption [t/h]			Operating CO_2 Emission [t/h]			% on Total CO_2 Emission	CO_2 concentr. in flue gases, vol %	Operating Temperature [°C]	Notes
					Fuel Gas	Fuel Oil	Coke	Fuel Gas	Fuel Oil	Coke				(1)
PROCESS UNITS														
0100A	CDU	Crude Distillation Unit	BPSD	100000	-	7.4	-	-	23.8	-	8.5%	11.3%	200 ÷ 220	
0100B	CDU	Crude Distillation Unit	BPSD	120000	-	8.9	-	-	28.5	-	10.3%	11.3%	200 ÷ 220	(2)
0300A	NHT	Naphtha Hydrotreater	BPSD	23000	0.34	-	-	0.9	-	-	0.3%	8.1%	420 ÷ 450	(3)
0350A	NSU	Naphtha Splitter Unit	BPSD	23000	0.40	-	-	1.1	-	-	0.4%	8.1%		
0300B	NHT	Naphtha Hydrotreater	BPSD	27000	0.31	-	-	0.8	-	-	0.3%	8.1%	420 ÷ 450	(3)
0350B	NSU	Naphtha Splitter Unit	BPSD	27000	0.37	-	-	1.0	-	-	0.4%	8.1%		
0500A	CRF	Catalytic Reforming	BPSD	15000	3.6	-	-	10.0	-	-	3.6%	8.1%	180 ÷ 190	
0500B	CRF	Catalytic Reforming	BPSD	18000	3.6	-	-	10.0	-	-	3.6%	8.1%	180 ÷ 190	
0600A	KHT	Kero HDS	BPSD	14000	0.2	-	-	0.6	-	-	0.2%	8.1%	420 ÷ 450	
0600B	KHT	Kero HDS	BPSD	12000	0.1	-	-	0.4	-	-	0.1%	8.1%	420 ÷ 450	
0700A	HDS	Gasoil HDS	BPSD	26000	1.2	-	-	3.3	-	-	1.2%	8.1%	420 ÷ 450	
0700B	HDS	Gasoil HDS	BPSD	39000	1.6	-	-	4.4	-	-	1.6%	8.1%	420 ÷ 450	
0800	VHT	Vacuum Gasoil Hydrotreater	BPSD	50000	2.8	-	-	7.7	-	-	2.8%	8.1%	200 ÷ 220	
1000	FCC	Fluid Catalytic Cracking	BPSD	60000	-	-	14.5	-	-	53.1	19.1%	16.6%	300 ÷ 320	
1100A	VDU	Vacuum Distillation Unit	BPSD	35000	-	1.2	-	-	3.9	-	1.4%	11.3%	380 ÷ 400	
1100B	VDU	Vacuum Distillation Unit	BPSD	51000	-	1.8	-	-	5.7	-	2.1%	11.3%	200 ÷ 220	(2)
1200	SMR	Steam Reformer	Nm^3/h Hydrogen	35000	2.1	-	-	5.8	-	-	2.1%	8.1%	135 ÷ 160	(4)
		Steam Reformer Feed			9.6	-	-	25.5	-	-	9.2%	24.2%		
1400	DCU	Delayed Coking	BPSD	35000	4.4	-	-	11.9	-	-	4.3%	8.1%	200 ÷ 220	
							Sub Total Process Units		198.5		71.4%			
AUXILIARY UNITS														
2200A	SRU	Sulphur Recovery & Tail Gas Treatment	t/d Sulphur	55	0.005	-	-	0.01	-	-	0.0%	< 8%	380 ÷ 400	
2200B	SRU	Sulphur Recovery & Tail Gas Treatment	t/d Sulphur	2 x 197.5	0.030	-	-	0.08	-	-	0.0%	< 8%	380 ÷ 400	
							Sub Total Auxiliary Units		0.10		0.0%			
POWER UNITS														
2500	POW	Power Plant - Gas Turbine	kW	78000	9.5	-	-	25.1	-	-	9.0%	3.2%	115 ÷ 140	
		Power Plant - HRSG + Steam Boilers			19.9	-	-	54.3	-	-	19.5%	8.1%	115 ÷ 140	
							Sub Total Power Units		79.5		28.6%			
							TOTAL CO_2 EMISSION		**278.0**		**100%**			
								50%	**22%**	**19%**				

Notes

(1) Fuel gas is a mixture of refinery fuel gas (95%) and imported natural gas (5%).
(2) In train B, Crude and Vacuum Distillation heaters (units 0100B and 1100B) have a common stack.
(3) Both in train A and B, Naphtha Hydrotreater and Naphtha Splitter heaters (units 0300A/0350A and 0300B/0350B) have a common stack.
(4) Only natural gas is used as feed to the Steam Reformer, unit 1200; after reaction and hydrogen purification, tail gas and fuel gas are burnt in the Steam Reformer furnace.

7.2 Refinery Layout

The layout of the Base Case 3 refinery has been developed starting from the plot plan of Base Case 1, essentially by adding a second block of process units beside the original nucleus of the refinery.

As already mentioned, this approach reflects the assumption of a refinery expanded, over its life, both in terms of capacity and complexity.

Also some auxiliary, utility and offsite systems, like for example the Waste Water Treatment (WWT) and the Flare, have been duplicated in the final configuration of the site.

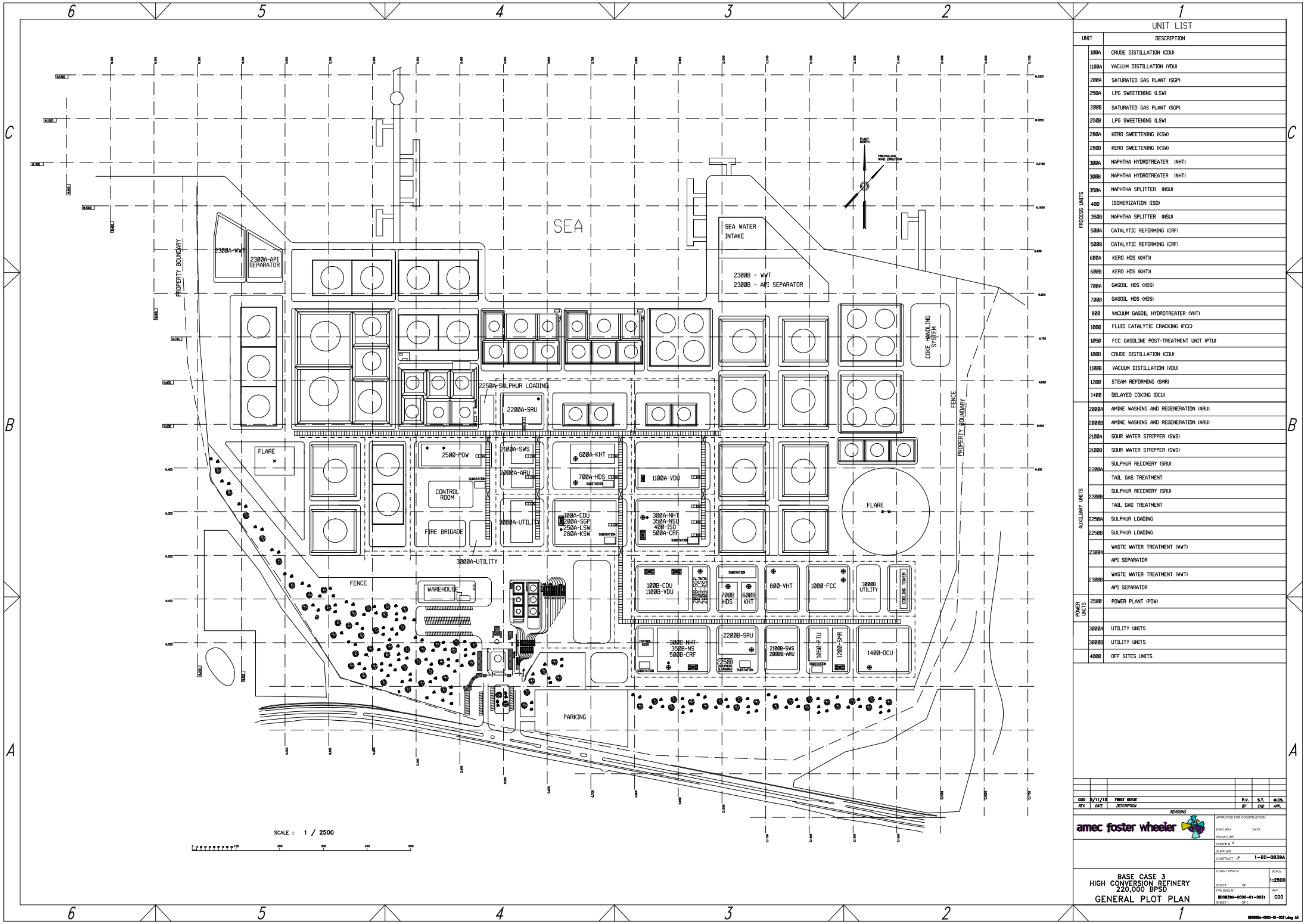


Figure 7-2: Base Case 3) Refinery layout

7.3 Main Utility Networks

The main utility balances have been reported on block flow diagrams, reflecting the planimetric arrangement of the process units and utility blocks.

In particular, the following networks' sketches have been developed:

- Figure 7-3: Base Case 3) Electricity network
- Figure 7-4: Base Case 3) Steam networks
- Figure 7-5: Base Case 3) Cooling water network
- Figure 7-6: Base Case 3) Fuel Gas/Offgas networks
- Figure 7-7: Base Case 3) Fuel oil network

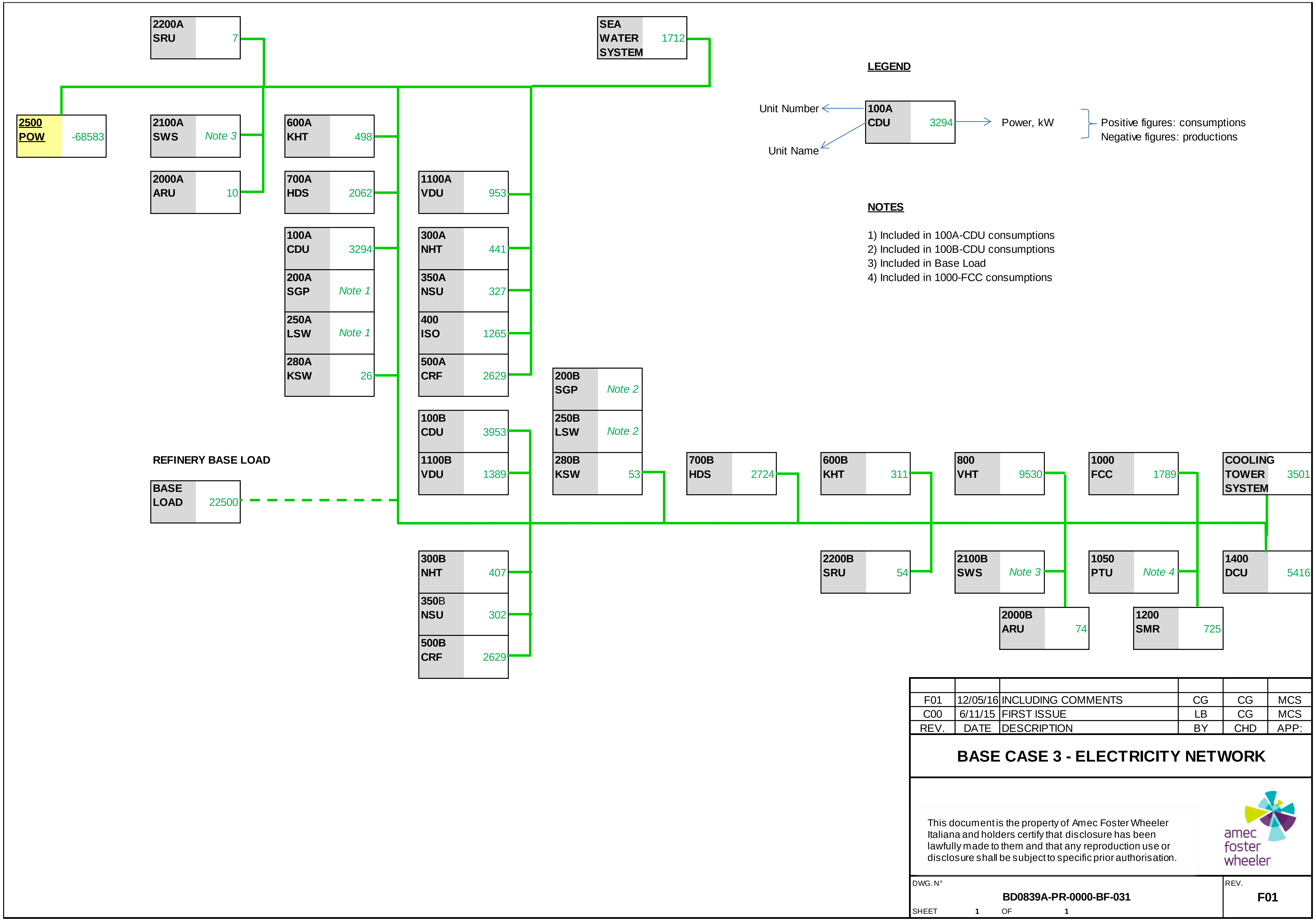


Figure 7-3: Base Case 3) Electricity network

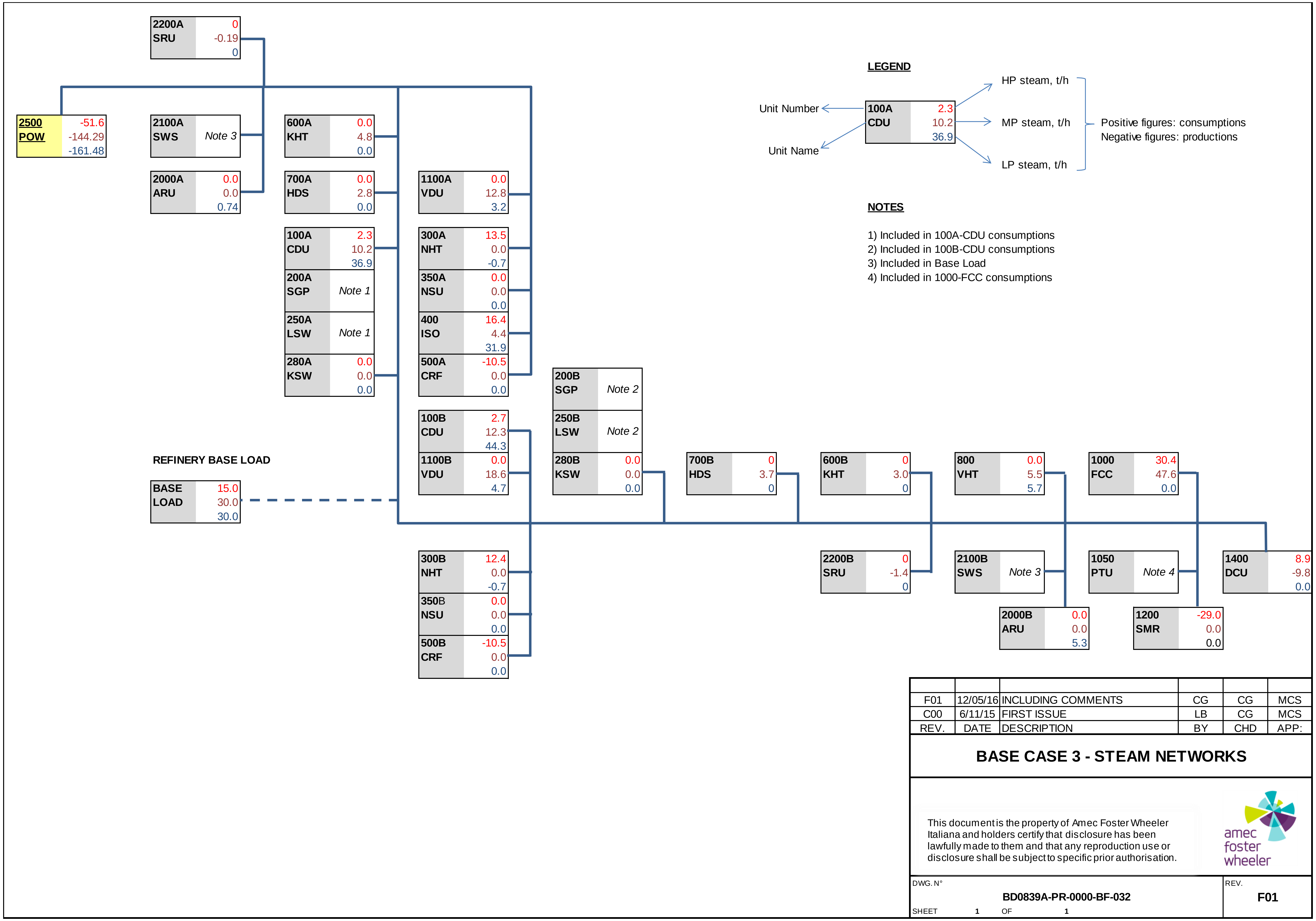


Figure 7-4: Base Case 3) Steam networks

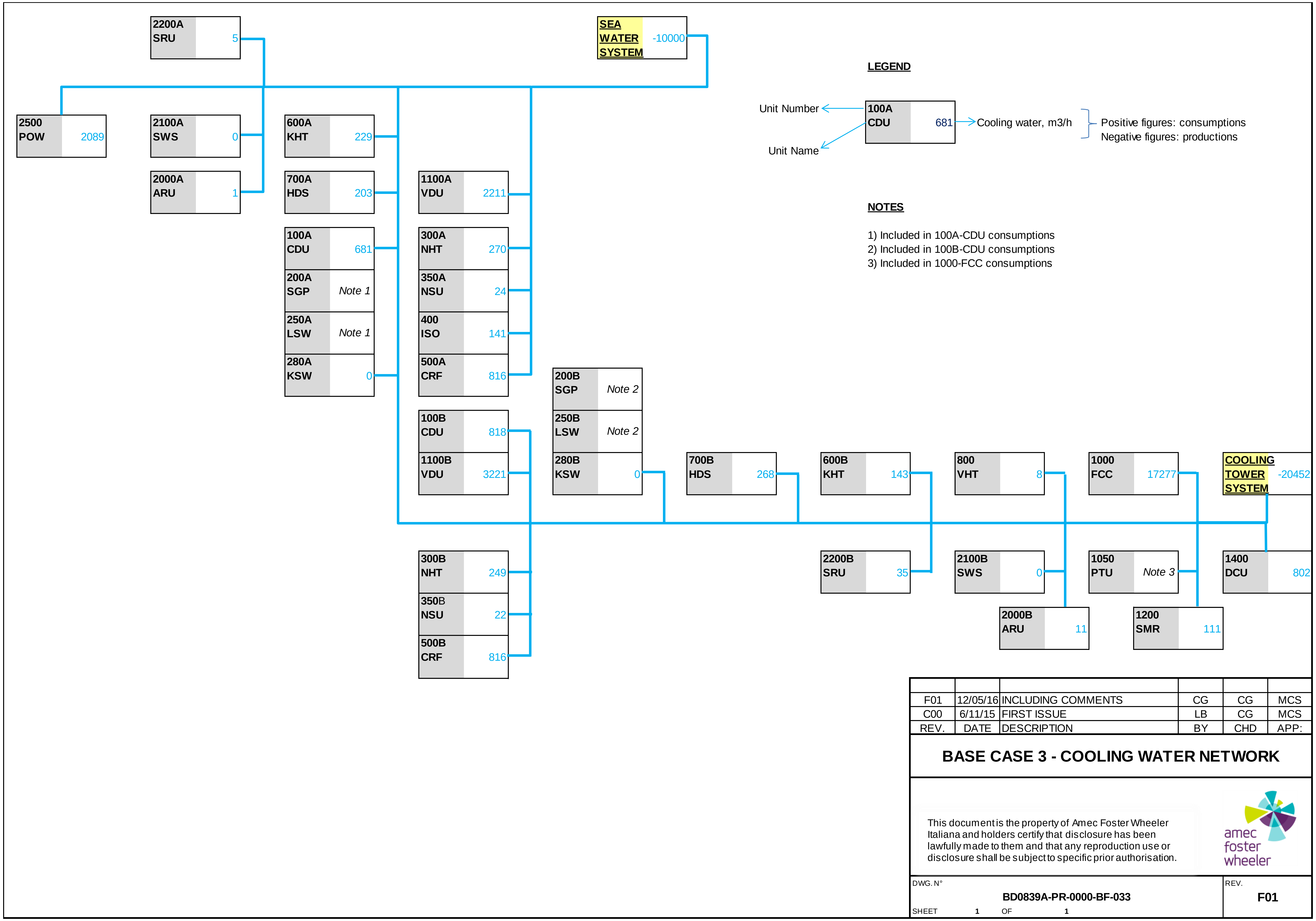


Figure 7-5: Base Case 3) Cooling water network

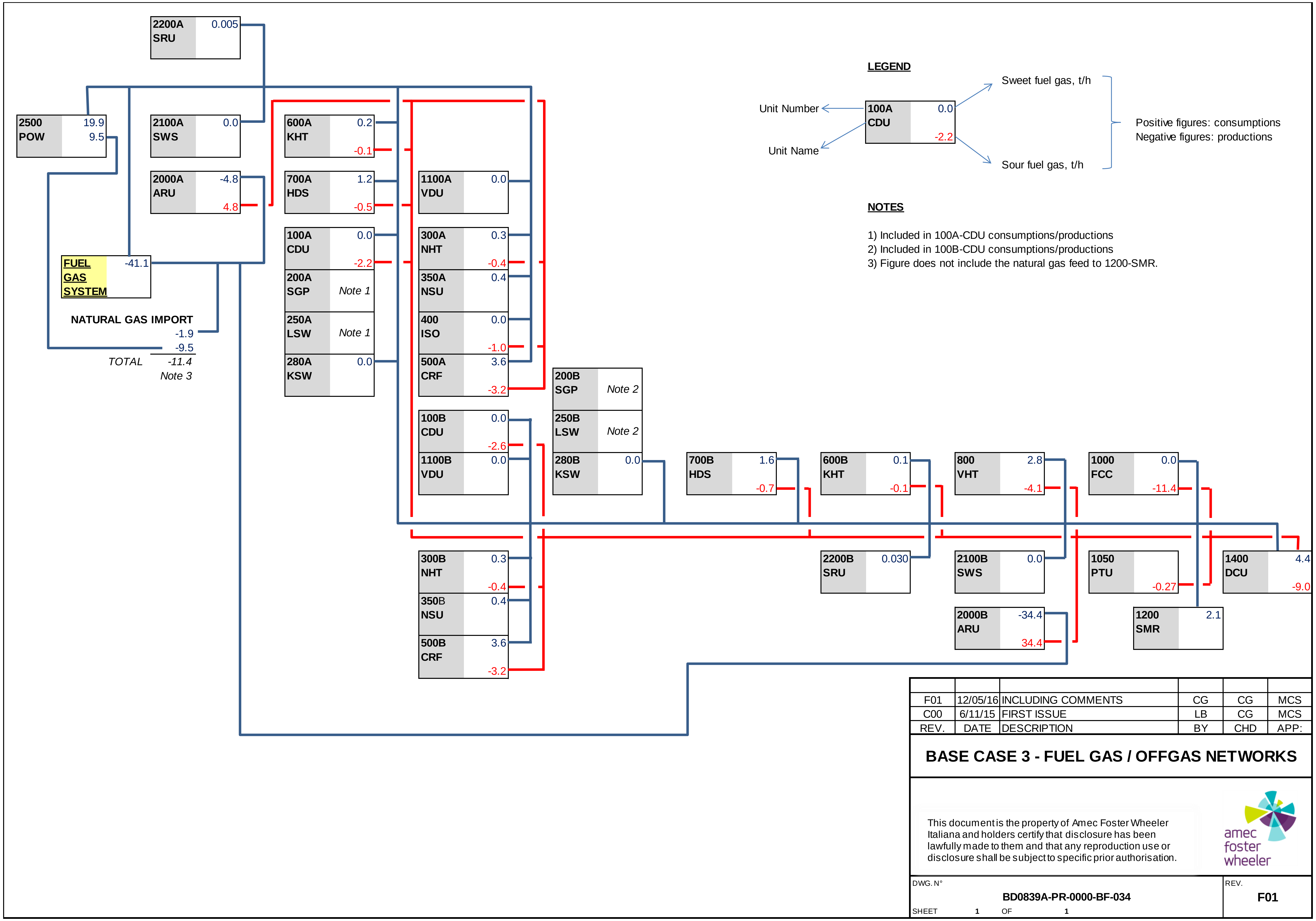


Figure 7-6: Base Case 3) Fuel Gas/Offgas networks

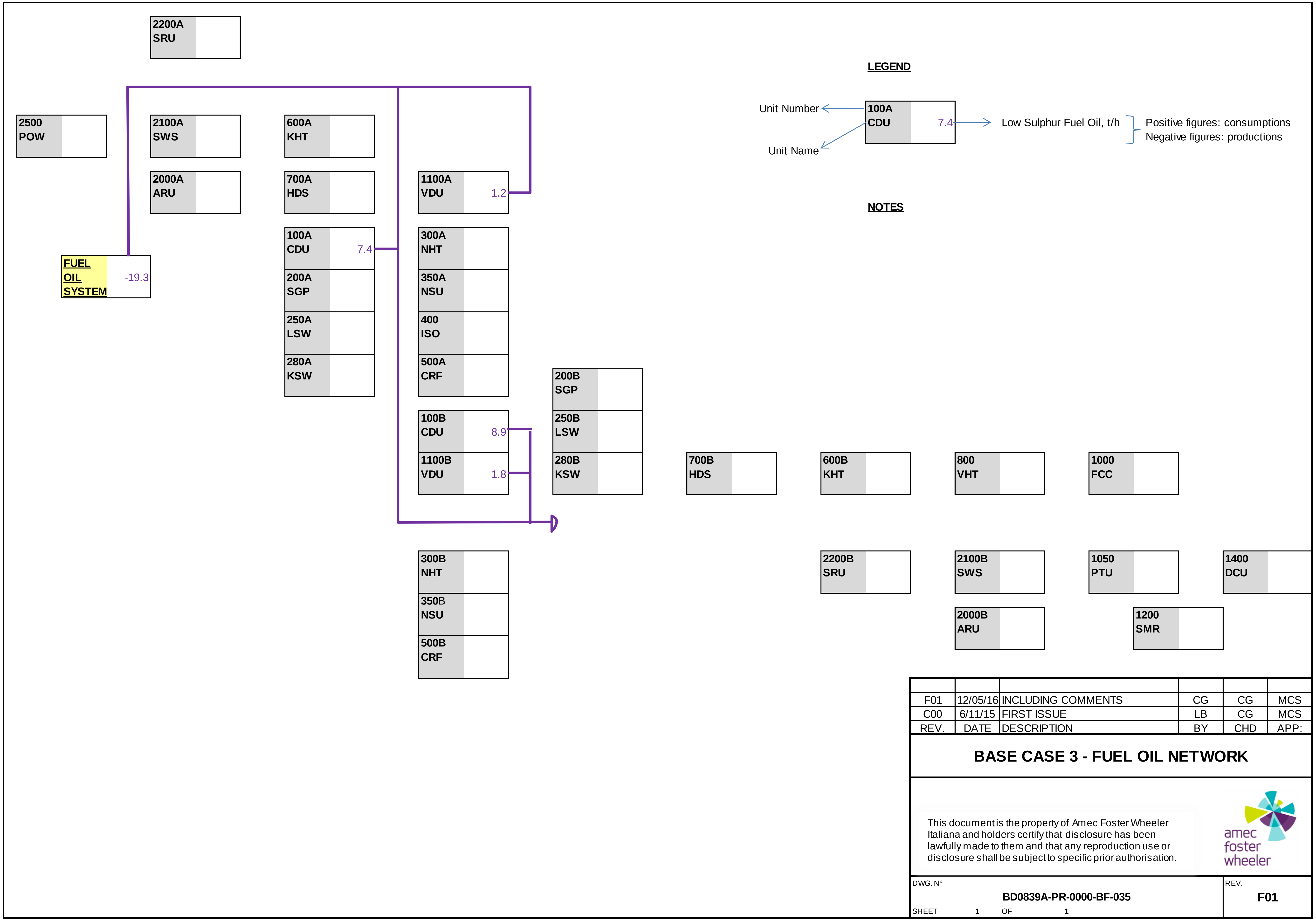


Figure 7-7: Base Case 3) Fuel oil network

7.4 Configuration of Power Plant

As already mentioned, Base Case 3 is considered a step-up evolution of Base Case 1: therefore, the power plant configuration nucleus of Base Case 1 (3 x 115 t/h Gas Boiler and 2 x 20 MW Steam Turbines) is kept also in Base Case 3.

In terms of power and steam demand, Base Case 3 differs from Base Case 2 only for the higher power requirement while the steam demand is nearly the same.

For Base Case 3 design, steam and power requirements are summarized in Table 7-6.

In addition to the Base Case 1 configuration (3 boilers and 2 Steam Turbine) power plant configuration for Base Case 3 is based on the addition of a Gas Turbine and an associated Heat Recovery Steam Generator (HRSG), equipped with supplementary firing.

Part of the power is produced by the Gas Turbine 38.3 MW frame, whose exhaust pass through a heat recovery steam generator generating superheated high pressure steam at the conditions required from the refinery. Natural gas only is fed to the Gas Turbine, while refinery fuel gas is fed to HRSG.

The post firing installed in the HRSG is operated at the 84% of its nominal load in order to meet the total steam requirement. In case of need, post firing load can be raised to 100% and the steam generation increased accordingly. As a matter of fact, in order to meet the HP/MP/LP steam and power requirements, it is necessary to produce an additional amount of steam with respect to what generated in the gas boilers, kept in operation as per Base Case 1.

Therefore, the HP steam generated from the HRSG is mixed with steam generated by boilers and then partially routed to the refinery users and partially sent to the Steam Turbines for power and MP/LP Steam generation. MP and LP Steam are produced through two different extraction stages at the pressure required by the users. Desuperheaters are installed both on MP and LP steam lines to bring the steam temperatures down to the values required by the refinery at power plant battery limits. Steam turbines are condensing type: exhaust steam from the steam turbines is condensed in a cooling water condenser, which operates under vacuum, and pumped, together with a demi water make up, to deaerators for BFW generation.

Also in Base Case 3 the power plant has been designed to be normally operated in balance with the grid and the refinery and such that no import/export of steam is required in normal operation. Also in this case, steam demand has higher priority over electricity demand, since refinery electrical demand can be provided by HV grid connection back-up.

A simplified scheme of power plant configuration in Base Case 3 is shown in Figure 7-8.

Base Case 3 power plant major equipment number and sizes are summarized hereinafter:

- 1 x 38.3 MWe Gas Turbine normally operating at 100% of the design load and 84% post fired plus 1 x HRSG producing 148.3 t/h HP Steam;
- 3 x 115 t/h normally operating at 66% of their design load (corresponding to 75.3 t/h HP Steam)
- 2 x 20 MWe Condensing Steam Turbines normally operating at 85% of their design load (corresponding to 17 MWe each)

Either in case a steam turbine or the gas turbine trips, it is necessary to import electrical power from the national grid or, as an alternative, to put in place a load shedding plan.

BASE CASE 3

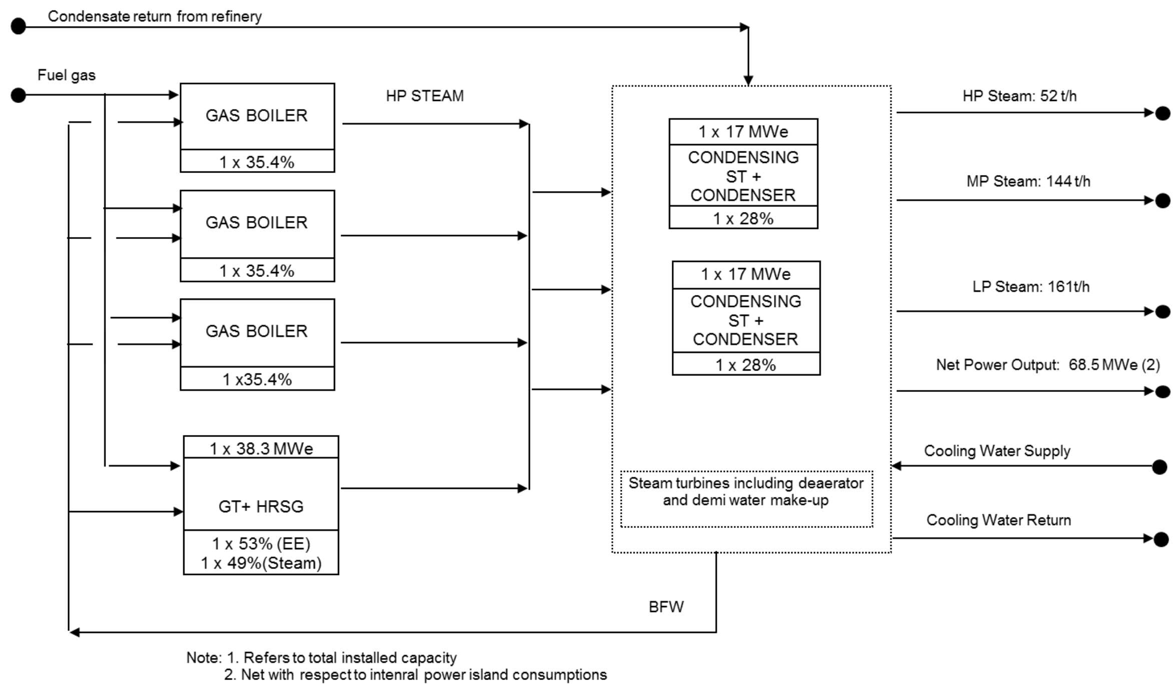


Figure 7-8: Base Case 3) Power Plant simplified Block Flow Diagram

Total installed spare capacity is summarized hereinafter:

- Gas Boilers + HRSG (Steam) **+55%**
- Steam Turbines + Gas Turbines (Electric Energy) **+10%**

The decision to expand the power plant of Base Case 1 by adding a gas turbine results in a final configuration which is different from the scheme proposed for Base Case 2; this is considered interesting for the purposes of the study, but on the other hand the discrete commercial sizes of the GT result in a lower spare capacity for the power generation. This limited margin is however deemed sufficient for a stable operation because a permanent connection to the electrical grid is typically present in European plants.

8. Base Case 4

High Conversion Refinery - 350,000 BPSD Crude Capacity

The High Conversion Refinery consists of two parallel crude distillation trains (Crude Atmospheric and Vacuum Distillation Units), followed by gasoline blocks for octane improvement, kerosene sweetening units, hydrotreating units for the middle-distillates.

Two different types of Vacuum Gasoil (VGO) conversion units are also included: i.e. the Fluid Catalytic Cracking (FCC) and the High Pressure Hydrocracking (HCK). These two units have the same design capacity of 60,000 BPSD each.

Upstream of the FCC, a Vacuum Gasoil Hydrotreating (VHT) unit is present to decrease the sulphur content of FCC feedstock, in order to respect SO_x limits at FCC stack.

For Vacuum Residue conversion, a Solvent Deasphalting Unit (SDA) followed by a Coker Unit (DCU) are considered. Solvent Deasphalting allows recovering from the Vacuum Residue the paraffinic material (DAO), which can be then fed to the VGO cracking units (essentially to HCK) for being converted into more valuable distillates.

The pitch from SDA is then sent to DCU. It is considered to sell the fuel grade coke produced in DCU.

The FCC and Coker distillates are sent to finishing units to comply with the 10 ppm wt. sulphur specification for the automotive fuels.

Two parallel Steam Methane Reformer (SMR) trains are foreseen to satisfy the hydrogen demand of this complex refinery.

Base Case 4 is conceived as representative of top-class refineries, which have achieved their final configuration and capacity in a more straight-forward way with respect of Base Case 2 and 3.

This results in a more organic layout, design with parallel symmetrical trains for process and utility units and a more efficient power plant.

8.1 Refinery Balances

The balances developed for Base Case 4 are reported in the following tables and figures:

- Table 8-1: Base Case 4) Overall material balance
- Table 8-2: Base Case 4) Process units operating and design capacity
- Table 8-3: Base Case 4) Gasoline qualities

- Table 8-4: Base Case 4) Distillate qualities
- Table 8-5: Base Case 4) Fuel oil and bitumen qualities
- Figure 8-1: Base Case 4) Block flow diagrams with main material streams
- Table 8-6: Base Case 4) Main utility balance, fuel mix composition, CO_2 emissions

Table 8-1: Base Case 4) Overall material balance

REV.5
12/05/2016

ReCAP Project
Preliminary Refinery Balances

BASE CASE 4
High Conversion Refinery, 350,000 BPSD

OVERALL MATERIAL BALANCE

PRODUCTS	Annual Production, kt/y
LPG	837.3
Propylene	197.1
Petrochemical Naphtha	157.3
Gasoline U95 Europe	2988.2
Gasoline U92 USA Export	1280.7
Jet fuel	2100.0
Road Diesel	6452.6
Marine Diesel	860.4
Heating Oil	1290.5
Low Sulphur Fuel Oil	0.0
Medium Sulphur Fuel Oil	0.0
High Sulphur Fuel Oil	0.0
Bitumen	0.0
Coke Fuel Grade	824.7
Sulphur	160.2
Subtotal	**17149.0**
RAW MATERIALS	Consumptions, kt/y
Ekofisk	2870.5
Bonny Light	3738.6
Arabian Light	1614.8
Urals Medium	6196.6
Arabian Heavy	1614.8
Maya Blend (1)	645.9
Imported Vacuum Gasoil	862.4
MTBE	0.0
Natural Gas	375.8
Biodiesel	404.0
Ethanol	156.9
Subtotal	**18480.3**
	kt/y
Fuels and Losses	**1331.3**

Notes
1) Maya Blend consists of 50% wt. Maya crude oil + 50% wt. Arabian Light Crude Oil

Table 8-2: Base Case 4) Process units operating and design capacity

REV.5
12/05/2016

ReCAP Project
Preliminary Refinery Balances

BASE CASE 4
High Conversion Refinery, 350,000 BPSD

PROCESS UNITS OPERATING AND DESIGN CAPACITY

UNIT	Unit of measure	Design Capacity	Operating Capacity	Average Utilization
Crude Distillation Unit	BPSD	350000 (1)	350000	100%
Vacuum Distillation Unit	BPSD	130000 (1)	124111	95%
Naphtha Hydrotreater	BPSD	80000 (1)	76154	95%
Light Naphtha Isomerization	BPSD	23000	23000	100%
Heavy Naphtha Catalytic Reforming	BPSD	60000 (1)	58635	98%
Kero Sweetening	BPSD	24000 (1)	24000	100%
Kerosene Hydrotreater	BPSD	30000	30000	100%
Diesel Hydrotreater	BPSD	85000 (1)	78570	92%
Heavy Gasoil Hydrotreater	BPSD	36000	31615	88%
Fluid Catalytic Cracking	BPSD	60000	60000	100%
FCC Gasoline Hydrotreater	BPSD	24000	23128	96%
Hydrocracker	BPSD	60000	57000	95%
Solvent Deasphalting	BPSD	30000	27727	92%
Delayed Coker	BPSD	50000	46000	92%
Sulphur Recovery Unit	t/d Sulphur	750 (1)	458	61%
Steam Reformer	Nm^3/h Hydrogen	130000 (1)	114653	88%

Notes

1) Multiple units in parallel to be considered.

Table 8-3: Base Case 4) Gasoline qualities

REV.5
12/05/2016

ReCAP Project
Preliminary Refinery Balances

BASE CASE 4
High Conversion Refinery, 350,000 BPSD

GASOLINE QUALITIES

EXCESS NAPHTHA

Component		Weight Quantity	Weight Percent	Volume Quantity	Volume Percent
NAH	HT HEAVY NAPHTHA	36,942.44	23.485%	49,520.70	22.197%
NAL	HT LIGHT NAPHTHA	104,554.84	66.467%	150,006.95	67.238%
LRF	LIGHT REFORMATE	31.15	0.020%	44.00	0.020%
HLN	LIGHT NAPHTHA ex HCU	15,775.79	10.029%	23,528.39	10.546%
	Total	157,304.22	100.000%	223,100.04	100.000%

Quality		Blending Basis	Value	Min	Max
RHO	DENSITY, KG/M3	VL	705.08		725.00
SPM	SULFUR, PPMW	WT	56.57		500.00
VPR	VAPOR PRESSURE, KPA	VL	69.00		69.00

Unl. Premium (95) EU

Component		Weight Quantity	Weight Percent	Volume Quantity	Volume Percent
BU#	C4 TO MOGAS/LPG	20,294.41	0.679%	34,843.25	0.883%
R10	REFORMATE 100	1,452,479.89	48.607%	1,752,086.72	44.388%
ISO	ISOMERATE	550,286.28	18.415%	832,505.72	21.091%
LCN	FCC LIGHT NAPHTHA treated	808,236.34	27.048%	1,130,400.47	28.638%
EOH	ETHANOL	156,901.04	5.251%	197,359.80	5.000%
	Total	2,988,197.97	100.000%	3,947,195.96	100.000%

Quality		Blending Basis	Value	Min	Max
RHO	DENSITY, KG/M3	VL	757.04	720.00	775.00
SPM	SULFUR, PPMW	WT	2.74		10.00
VPR	VAPOR PRESSURE, KPA	VL	60.00		60.00
BEN	BENZENE, %V	VL	0.76		1.00
ARO	AROMATICS, %V	VL	33.37		35.00
E50	D86 @ 150°C, %V	VL	90.23	75.00	
OXY	OXYGENATES, %V	VL	5.00		15.00
OLE	OLEFINS, %V	VL	11.79		18.00
EOH	ETHANOL, Vol%	VL	5.00		5.00
RON	Research	VL	95.00	95.00	
MON	Motor	VL	85.35	85.00	

Table 8-3bis: Base Case 4) Gasoline qualities

REV.5
12/05/2016

ReCAP Project
Preliminary Refinery Balances

BASE CASE 4
High Conversion Refinery, 350,000 BPSD

GASOLINE QUALITIES

Unl. Premium (92)

Component		Weight Quantity	Weight Percent	Volume Quantity	Volume Percent
BU#	C4 TO MOGAS/LPG	19,590.39	1.530%	33,634.51	1.971%
HRF	HEAVY REFORMATE	318.85	0.025%	376.45	0.022%
R10	REFORMATE 100	720,137.36	56.232%	868,681.97	50.894%
ISO	ISOMERATE	304,310.62	23.762%	460,379.15	26.973%
LCN	FCC LIGHT NAPHTHA treated	93,180.17	7.276%	130,321.92	7.635%
HLN	LIGHT NAPHTHA ex HCU	143,118.89	11.175%	213,450.99	12.506%
	Total	1,280,656.27	100.000%	1,706,844.99	100.000%

Quality		Blending Basis	Value	Min	Max
RHO	DENSITY, KG/M3	VL	750.31	720.00	775.00
SPM	SULFUR, PPMW	WT	1.36		10.00
VPR	VAPOR PRESSURE, KPA	VL	60.00		60.00
BEN	BENZENE, %V	VL	0.96		1.00
ARO	AROMATICS, %V	VL	35.00		35.00
E50	D86 @ 150°C, %V	VL	88.80	75.00	
OXY	OXYGENATES, %V	VL	0.00		15.00
OLE	OLEFINS, %V	VL	3.73		18.00
EOH	ETHANOL, VOI%	VL	0.00		10.00
RON	Research	VL	92.00	92.00	
MON	Motor	VL	84.56	84.00	

Table 8-4: Base Case 4) Distillate qualities

REV.5
12/05/2016

ReCAP Project
Preliminary Refinery Balances

BASE CASE 4
High Conversion Refinery, 350,000 BPSD

DISTILLATE QUALITIES

LPG PRODUCT

Component		Weight Quantity	Weight Percent	Volume Quantity	Volume Percent
LG#	LPG POOL	931,068.08	100.000%	1,656,084.90	100.000%
	Total	931,068.08	100.000%	1,656,084.90	100.000%

Quality		Blending Basis	Value	Min	Max
SPM	SULFUR, PPMW	WT	5.00		140.00
VPR	VAPOR PRESSURE, KPA	VL	698.51	632.40	887.60
OLW	OLEFINS, %W	WT	2.56		30.00

Jet Fuel EU

Component		Weight Quantity	Weight Percent	Volume Quantity	Volume Percent
KED	HT KERO	1,032,814.13	49.182%	1,301,593.11	49.357%
KMCR4	KERO FROM MEROX URALS	790,801.35	37.657%	989,738.86	37.532%
KMCR5	KERO FROM MEROX AR.HVY	192,157.99	9.150%	240,197.48	9.108%
KMCR6	KERO FROM MEROX MAYA	84,226.53	4.011%	105,547.03	4.002%
	Total	2,100,000.00	100.000%	2,637,076.49	100.000%

Quality		Blending Basis	Value	Min	Max
RHO	DENSITY, KG/M3	VL	796.34	775.00	840.00
SUL	SULFUR, %W	WT	0.11		0.30
FLC	FLASH POINT, °C (PM, D93)	VL	40.00	38.00	

Diesel EU

Component		Weight Quantity	Weight Percent	Volume Quantity	Volume Percent
LCO	LIGHT CYCLE OIL treated	568,379.17	8.808%	598,293.86	7.819%
HCN	FCC HEAVY NAPHTHA	450,708.26	6.985%	530,245.01	6.929%
KED	HT KERO	282,659.01	4.381%	356,218.03	4.655%
DLG	DESULF LGO	2,542,546.59	39.403%	3,016,069.50	39.414%
HKR	KERO ex HCU	716,644.14	11.106%	903,143.22	11.802%
HLG	DESULF LGO ex HCU	1,487,657.54	23.055%	1,789,125.12	23.380%
FAM	BIODIESEL	404,037.66	6.262%	459,133.71	6.000%
	Total	6,452,632.37	100.000%	7,652,228.45	100.000%

Quality		Blending Basis	Value	Min	Max
RHO	DENSITY, KG/M3	VL	843.24	820.00	845.00
SPM	SULFUR, PPMW	WT	8.05		10.00
FLC	FLASH POINT, °C (PM, D93)	VL	59.17	55.00	
CIN	CETANE INDEX D4737	VL	46.16	46.00	
V04	VISCOSITY @ 40°C, CST	WT	2.53	2.00	4.50
E36	D86 @360°C, %V	VL	98.23	95.00	
FAM	BIODIESEL CONTENT, %VOL	VL	6.00	6.00	7.00

Table 8-4bis: Base Case 4) Distillate qualities

REV.5
12/05/2016

ReCAP Project
Preliminary Refinery Balances

BASE CASE 4
High Conversion Refinery, 350,000 BPSD

DISTILLATE QUALITIES

Heating Oil

Component		Weight Quantity	Weight Percent	Volume Quantity	Volume Percent
KSCR1	SR KERO EKOFISK	206,736.19	16.020%	258,097.61	17.006%
LGCR2	LGO BONNY	552,293.87	42.796%	634,091.70	41.779%
LGCR1	LGO EKOFISK	523,288.62	40.548%	616,358.80	40.611%
LVCR4	LVGO URALS	8,207.79	0.636%	9,164.57	0.604%
	Total	1,290,526.47	100.000%	1,517,712.69	100.000%

Quality		Blending Basis	Value	Min	Max
RHO	DENSITY, KG/M3	VL	850.31	815.00	860.00
SPM	SULFUR, PPMW	WT	1,000.00		1,000.00
FLC	FLASH POINT, °C (PM, D93)	VL	63.80	55.00	
CIN	CETANE INDEX D4737	VL	48.30	40.00	
V04	VISCOSITY @ 40°C, CST	WT	2.81	2.00	6.00

MARINE DIESEL

Component		Weight Quantity	Weight Percent	Volume Quantity	Volume Percent
KSCR1	SR KERO EKOFISK	181,790.34	21.130%	226,954.23	22.489%
LGCR2	LGO BONNY	556,585.57	64.693%	639,019.02	63.320%
VLG	DESULF LGO ex VHT	105,003.52	12.205%	124,264.52	12.313%
LVCR4	LVGO URALS	16,971.55	1.973%	18,949.93	1.878%
	Total	860,350.98	100.000%	1,009,187.70	100.000%

Quality		Blending Basis	Value	Min	Max
RHO	DENSITY, KG/M3	VL	852.52		890.00
SPM	SULFUR, PPMW	WT	1,000.00		1,000.00
FLC	FLASH POINT, °C (PM, D93)	VL	60.00	60.00	
CIN	CETANE INDEX D4737	VL	48.27	35.00	
V04	VISCOSITY @ 40°C, CST	WT	2.97		6.00
V04	VISCOSITY @ 40°C, CST	WT	3.16		6.00

Table 8-5: Base Case 4) Fuel oil and bitumen qualities

REV.5
12/05/2016

ReCAP Project
Preliminary Refinery Balances

BASE CASE 4
High Conversion Refinery, 350,000 BPSD

FUEL OIL / BITUMEN QUALITIES

Low Sulphur Fuel

Component		Weight Quantity	Weight Percent	Volume Quantity	Volume Percent
SLU	FCC SLURRY OIL	231,363.57	89.661%	243,540.60	89.721%
HHR	RESIDUE ex HCU	6,809.62	2.639%	8,073.05	2.974%
VDCR4	VDU RES MIX4	19,868.83	7.700%	19,829.17	7.305%
	Total	258,042.02	100.000%	271,442.83	100.000%

Quality		Blending Basis	Value	Min	Max
RHO	DENSITY, KG/M3	VL	950.63		991.00
SUL	SULFUR, %W	WT	0.50		0.50
FLC	FLASH POINT, °C (PM, D93)	VL	197.68	66.00	
V05	VISCOSITY @ 50°C, CST	WT	131.16		380.00
CCR	CONRADSON CARBON RES, %W	WT	1.16		15.00

Table 8-6: Base Case 4) Main utility balance, fuel mix composition, CO_2 emissions

REV.6
19/04/2017

ReCAP Project
Preliminary Refinery Balances

BASE CASE 4
High Conversion Refinery, 350,000 BPSD

MAIN UTILITY BALANCE

	FUEL Gcal/h	**POWER** kW	**HP STEAM** tons/h	**MP STEAM** tons/h	**LP STEAM** tons/h	**COOLING WATER** (2) m3/h	**RAW WATER** m3/h
MAIN PROCESS UNITS	975	83180	-20	160	174	35364	
BASE LOAD		30000	20	40	40		
POWER PLANT	419	-119235	0	-200	-214		
SEA WATER SYSTEM		1712				-10000	
COOLING TOWER SYSTEM		4342				-25364	
TOTAL	**1393**	**0**	**0**	**0**	**0**	**0**	**2900**

FUEL MIX COMPOSITION

	t/h	kt/y	wt%
REFINERY FUEL GAS	57.2	480.1	46%
LOW SULPHUR FUEL OIL (3)	30.7	258.0	25%
FCC COKE	14.5	121.7	12%
NATURAL GAS to fuel system	0.1	1.1	0%
NATURAL GAS to gas turbine	22.9	192.2	18%
TOTAL	**125.4**	**1053.1**	

CO2 EMISSIONS

	t/h			
From Steam Reformer feed (4)	91.6			
From FG/NG combustion	217.8			
From FO combustion	98.3			
From FCC coke combustion	53.1			
TOTAL	**460.8**	*corresponding to*	***3871.0***	*kt/y*
			232.1	*kg CO2 / t crude*

Notes
1) (-) indicates productions
2) 10°C temperature increase has been considered
3) LSFO is burnt in CDU and VDU heaters
4) Composed of Natural Gas plus LPG

REV.5
12/05/2016

ReCAP Project

Overall Refinery Balance

BASE CASE 4

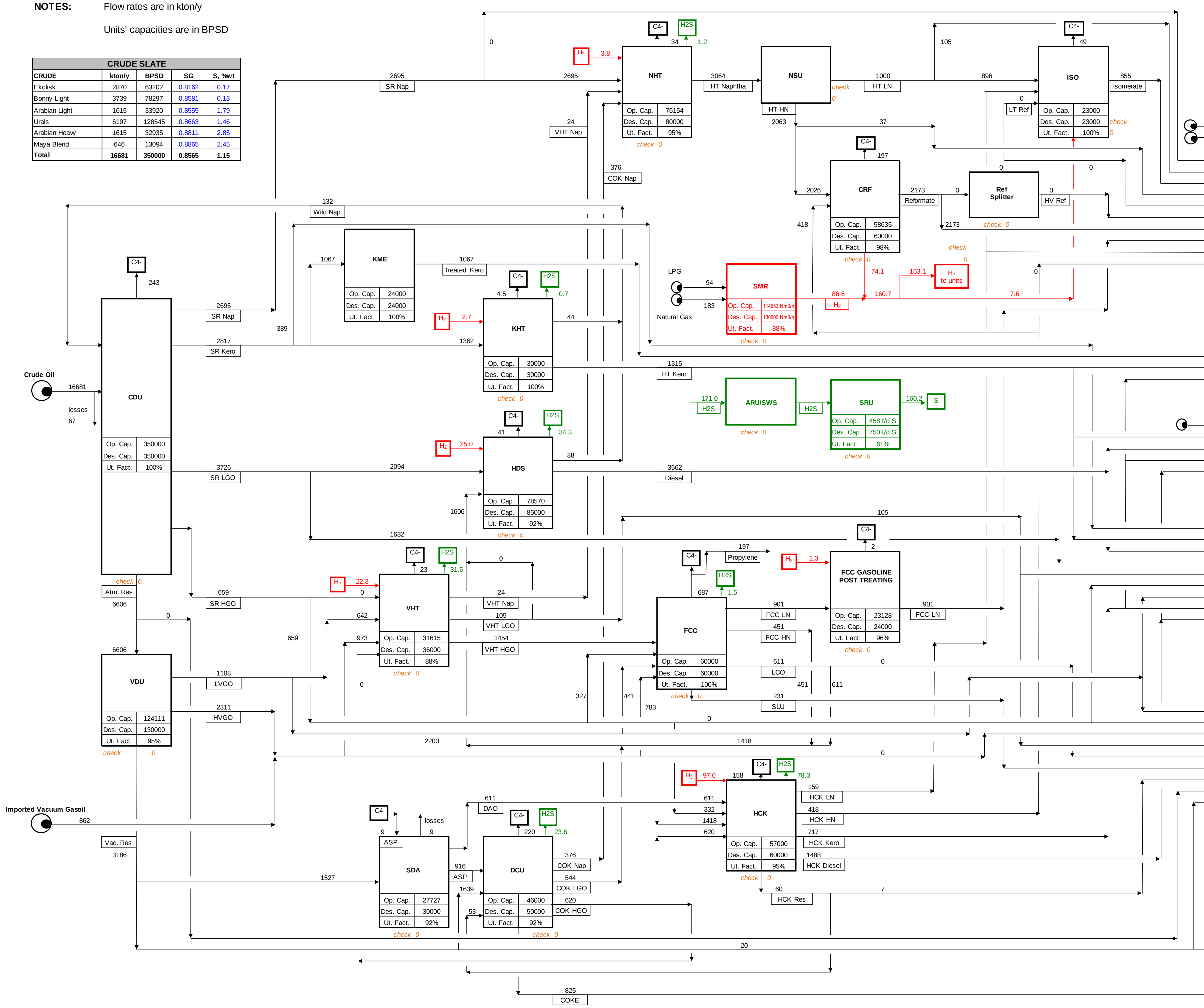
High Conversion Refinery, 350,000 BPSD

BLOCK FLOW DIAGRAM

NOTES: Flow rates are in kton/y

Units' capacities are in BPSD

CRUDE SLATE				
CRUDE	**kton/y**	**BPSD**	**SG**	**S, %wt**
Ekofisk	2870	63202	0.8162	0.17
Bonny Light	3739	78297	0.8581	0.13
Arabian Light	1615	33920	0.8555	1.79
Urals	6197	128545	0.8663	1.46
Arabian Heavy	1615	32935	0.8811	2.85
Maya Blend	646	13094	0.8865	2.45
Total	**16681**	**350000**	**0.8565**	**1.15**



	LPG
Propane	224
Butane	707
Total prod.	**931**
To SMR	*94*
To fuel	*0*
Sales	**837**

	Propylene
Propylene	**197**
Sales	**197**

	U 95-EU	U 92-US	Excess Naph.	TOT
MTBE	0	0	0	**0**
Ethanol	157	0	0	**157**
Butanes	20	20	0	**40**
SR Naphtha	0	0	0	**0**
HT Light Naphtha	0	0	105	**105**
Isomerate	550	304	0	**855**
HT Heavy Naphtha	0	0	37	**37**
LT Reformate	0	0	0	**0**
HV Reformate	0	0	0	**0**
Reformate	1452	720	0	**2173**
FCC LN	808	93	0	**901**
HCK LN	0	143	16	**159**
HCK HN	0	0	0	**0**
Sales	**2988**	**1281**	**157**	**4426**

	Jet Fuel
Treated Kero	1067
HT Kero	1033
HCK Kero	0
Sales	**2100**

	Diesel
Biodiesel	404
HT Kero	283
Diesel	3562
HCK Kero	717
HCK Diesel	1488
Sales	**6453**

	Heating Oil	Mar. Dies.	TOT
SR Kero	207	182	**389**
HT Kero	0	0	**0**
Diesel	0	0	**0**
SR LGO	1076	557	**1632**
VHT LGO	0	105	**105**
SR HGO	0	0	**0**
SR LVGO	8	17	**25**
HCK Kero	0	0	**0**
HCK Diesel	0	0	**0**
Sales	**1291**	**860**	**2151**

	LSFO	MSFO	HSFO	TOT
SR LVGO	0	0	0	**0**
SR HGO	0	0	0	**0**
SR HVGO	0	0	0	**0**
VHT LGO	0	0	0	**0**
LCO untreated	0	0	0	**0**
SLU	231	0	0	**231**
HCK Residue	7	0	0	**7**
Atm. Residue	0	0	0	**0**
Vac. Residue	20	0	0	**20**
Total prod.	**258**	**0**	**0**	**258**
To RFO	*258*	*-*	*-*	*258*
Sales	**0**	**0**	**0**	**0**

	Bitumen
Vac. Res.	**0**
Sales	**0**

	Sulphur
Sulphur	**160**
Sales	**160**

	Coke
Coke Fuel Grade	**825**
Sales	**825**

Figure 8-1: Base Case 4) Block flow diagrams with main material streams

REV.6
19/04/2017

ReCAP Project
1-BD-0839A

CO_2 EMISSION - PER UNIT BASE CASE 4

UNIT			Unit of measure	Design Capacity	Operating Fuel Consumption [t/h]			Operating CO_2 Emission [t/h]			% on Total CO_2 Emission	CO_2 concentr. in flue gases, vol %	Operating Temperature [°C]	Notes
					Fuel Gas	Fuel Oil	Coke	Fuel Gas	Fuel Oil	Coke				(1)
PROCESS UNITS														
0100A	CDU	Crude Distillation Unit	BPSD	175000	-	13.0	-	-	41.6	-	9.0%	11.3%	200 ÷ 220	(2)
0100B	CDU	Crude Distillation Unit	BPSD	175000	-	13.0	-	-	41.6	-	9.0%	11.3%	200 ÷ 220	(2)
0300A	NHT	Naphtha Hydrotreater	BPSD	40000	0.5	-	-	1.4	-	-	0.3%	8.1%	420 ÷ 450	(3)
0350A	NSU	Naphtha Splitter Unit	BPSD	40000	0.6	-	-	1.6	-	-	0.4%	8.1%		
0300B	NHT	Naphtha Hydrotreater	BPSD	40000	0.5	-	-	1.4	-	-	0.3%	8.1%	420 ÷ 450	(3)
0350B	NSU	Naphtha Splitter Unit	BPSD	40000	0.6	-	-	1.6	-	-	0.4%	8.1%		
0500A	CRF	Catalytic Reforming	BPSD	30000	6.6	-	-	18.2	-	-	3.9%	8.1%	180 ÷ 190	
0500B	CRF	Catalytic Reforming	BPSD	30000	6.6	-	-	18.2	-	-	3.9%	8.1%	180 ÷ 190	
0600A	KHT	Kero HDS	BPSD	15000	0.2	-	-	0.6	-	-	0.1%	8.1%	420 ÷ 450	
0600B	KHT	Kero HDS	BPSD	15000	0.2	-	-	0.6	-	-	0.1%	8.1%	420 ÷ 450	
0700A	HDS	Gasoil HDS	BPSD	42500	1.7	-	-	4.6	-	-	1.0%	8.1%	200 ÷ 220	
0700B	HDS	Gasoil HDS	BPSD	42500	1.7	-	-	4.6	-	-	1.0%	8.1%	200 ÷ 220	
0800	VHT	Vacuum Gasoil Hydrotreater	BPSD	36000	1.9	-	-	5.3	-	-	1.2%	8.1%	200 ÷ 220	
0900	HCK	Vacuum Gasoil Hydrocracker	BPSD	60000	6.2	-	-	16.9	-	-	3.7%	8.1%	200 ÷ 220	
1000	FCC	Fluid Catalytic Cracking	BPSD	60000	-	-	14.5	-	-	53.1	11.5%	16.6%	300 ÷ 320	
1100A	VDU	Vacuum Distillation Unit	BPSD	65000	-	2.4	-	-	7.6	-	1.6%	11.3%	200 ÷ 220	(2)
1100B	VDU	Vacuum Distillation Unit	BPSD	65000	-	2.4	-	-	7.6	-	1.6%	11.3%	200 ÷ 220	(2)
1200A	SMR	Steam Reformer	Nm^3/h Hydrogen	85000	3.6	-	-	9.9	-	-	2.1%	8.1%	135 ÷ 160	(4)
		Steam Reformer Feed			10.9 (5)	-	-	45.8	-	-	9.9%	24.2%		
1200B	SMR	Steam Reformer	Nm^3/h Hydrogen	85000	3.6	-	-	9.9	-	-	2.1%	8.1%	135 ÷ 160	(4)
		Steam Reformer Feed			10.9 (5)	-	-	45.8	-	-	9.9%	24.2%		
1300	SDA	Solvent Deasphalting	BPSD	35000	3.3	-	-	9.1	-	-	2.0%	8.1%		
1400	DCU	Delayed Coking	BPSD	46000	6.0	-	-	16.3	-	-	3.5%	8.1%	200 ÷ 220	
							Sub Total Process Units		363.1		78.8%			
AUXILIARY UNITS														
2200	SRU	Sulphur Recovery & Tail Gas Treatment	t/d Sulphur	3 x 250	0.06	-	-	0.16	-	-	0.0%	< 8%	380 ÷ 400	
							Sub Total Auxiliary Units		0.16		0.0%			
POWER UNITS														
2500	POW	Power Plant - Gas Turbine	kW	175000	22.9	-	-	60.8	-	-	13.2%	3.2%	115 ÷ 140	
		Power Plant - HRSG + Steam Boilers			13.4	-	-	36.7	-	-	8.0%	8.1%	115 ÷ 140	
							Sub Total Power Units		97.6		21.2%			
							TOTAL CO_2 EMISSION		**460.8**		**100%**			
								54%	**21%**	**12%**				

Notes

(1) Fuel gas is a mixture of refinery fuel gas (99.8%) and imported natural gas (0.2%).
(2) Both in train A and B, Crude and Vacuum Distillation heaters (units 0100A/1100A and 0100B/1100B) have a common stack.
(3) Both in train A and B, Naphtha Hydrotreater and Naphtha Splitter heaters (units 0300A/0350A and 0300B/0350B) have a common stack.
(4) Natural gas and LPG are used as feed to the Steam Reformer, units 1200A/B; after reaction and hydrogen purification, tail gas and fuel gas are burnt in the Steam Reformer furnaces.
(5) Plus 5.6 t/h LPG.

8.2 Refinery Layout

The layout of the Base Case 4 refinery is enclosed in Figure 8-2.

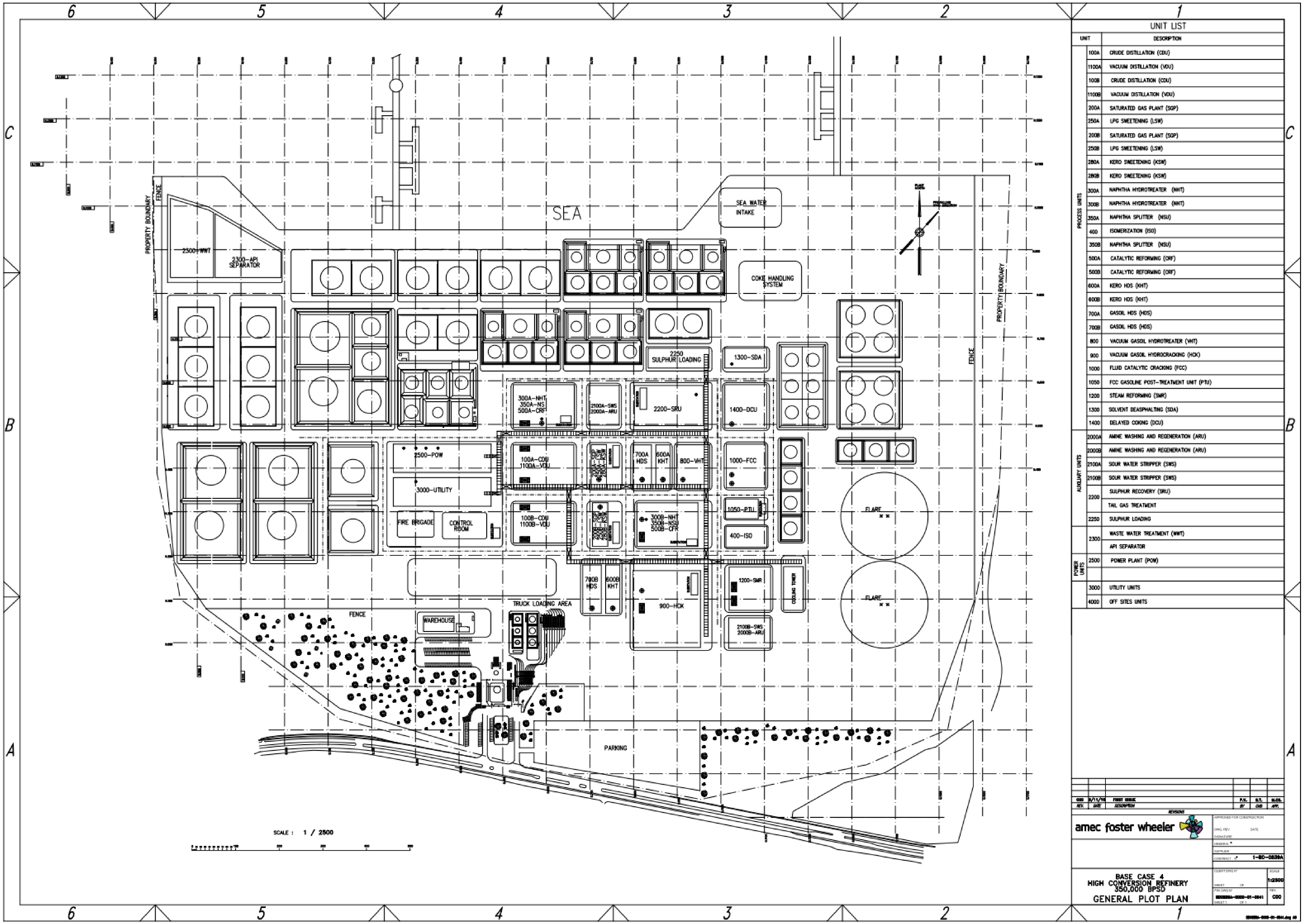


Figure 8-2: Base Case 4) Refinery layout

8.3 Main Utility Networks

The main utility balances have been reported on block flow diagrams, reflecting the planimetric arrangement of the process units and utility blocks.

In particular, the following networks' sketches have been developed:

- Figure 8-3: Base Case 4) Electricity network
- Figure 8-4: Base Case 4) Steam networks
- Figure 8-5: Base Case 4) Cooling water network
- Figure 8-6: Base Case 4) Fuel Gas/Offgas networks
- Figure 8-7: Base Case 4) Fuel oil network

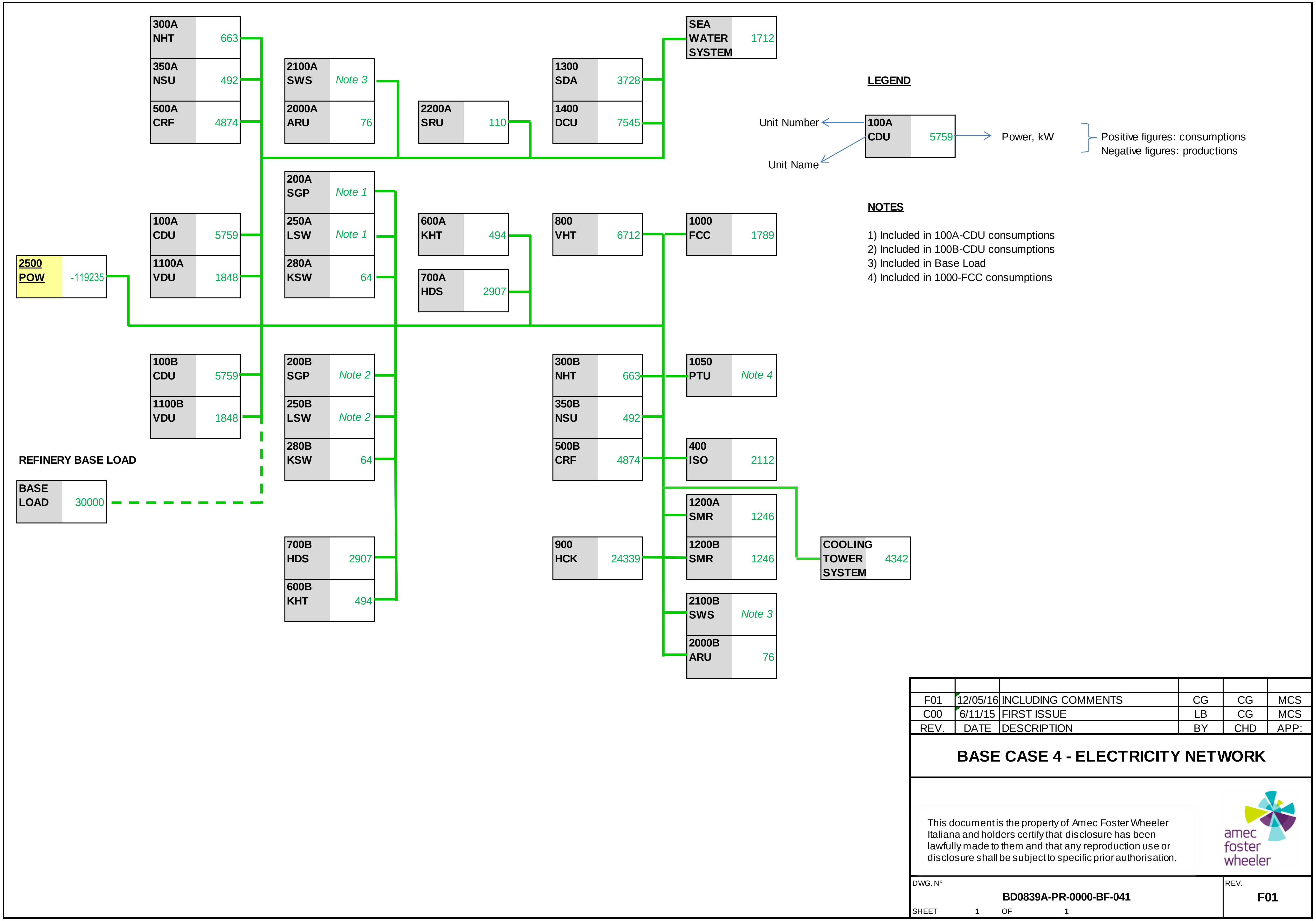


Figure 8-3: Base Case 4) Electricity network

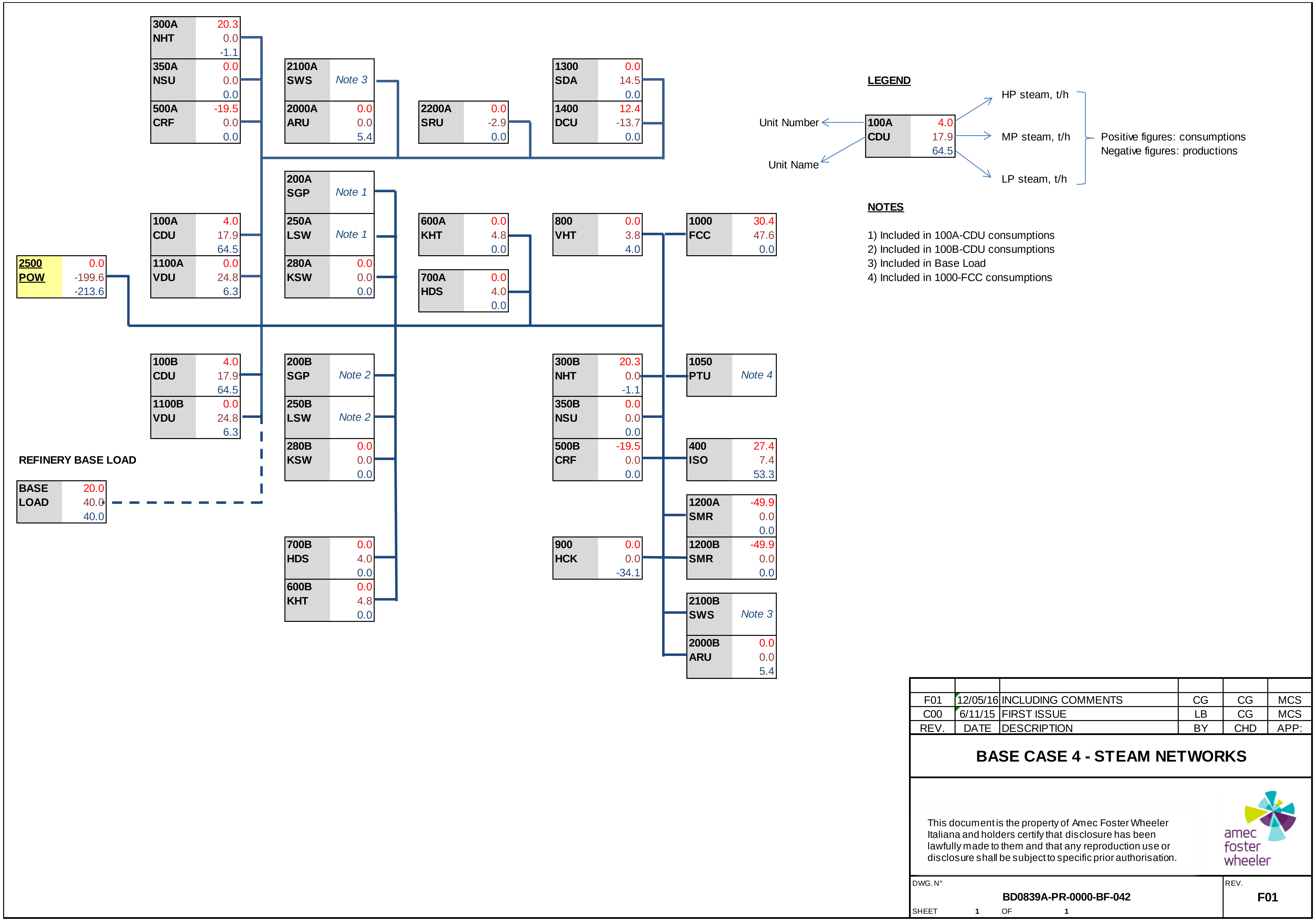


Figure 8-4: Base Case 4) Steam networks

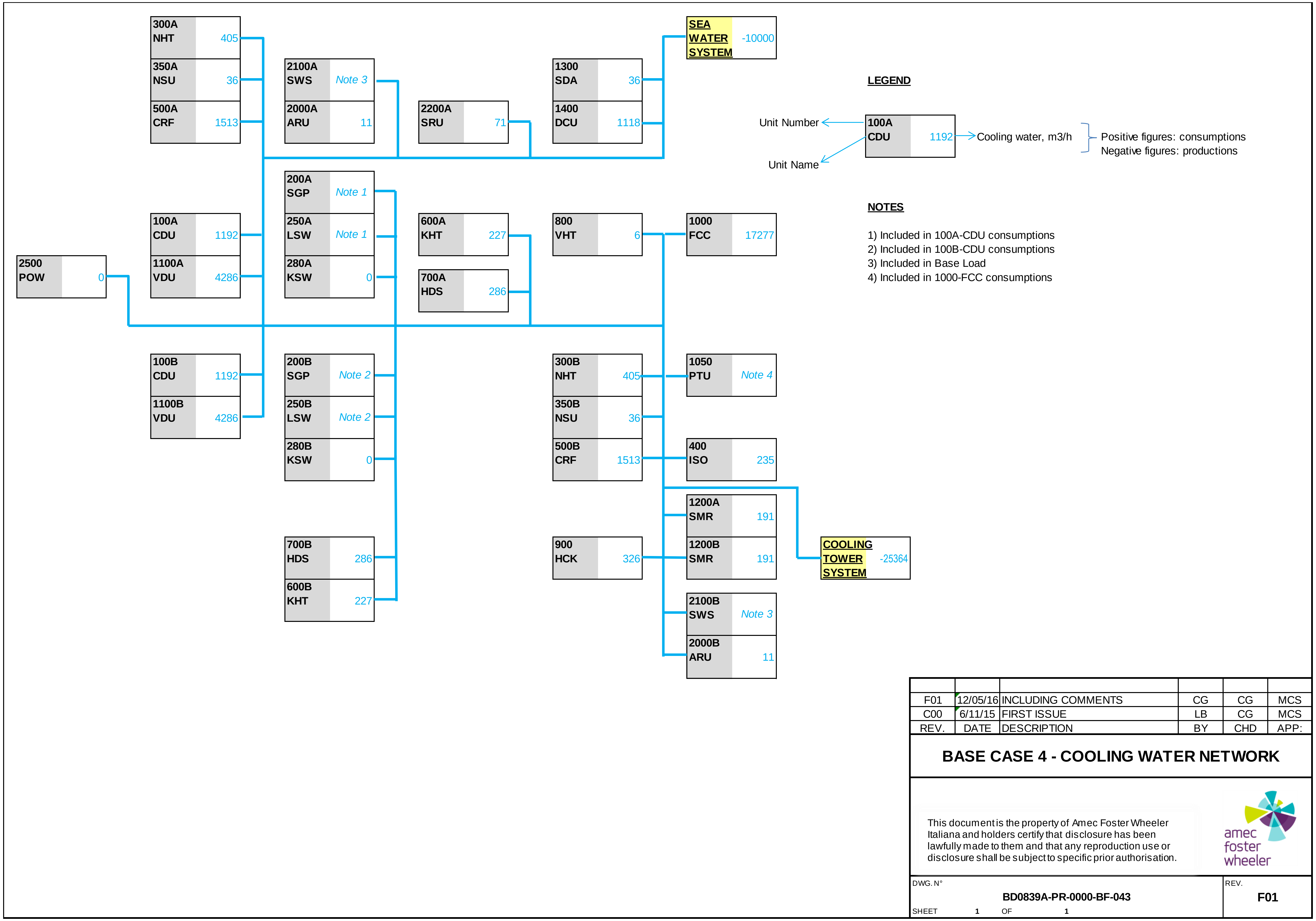
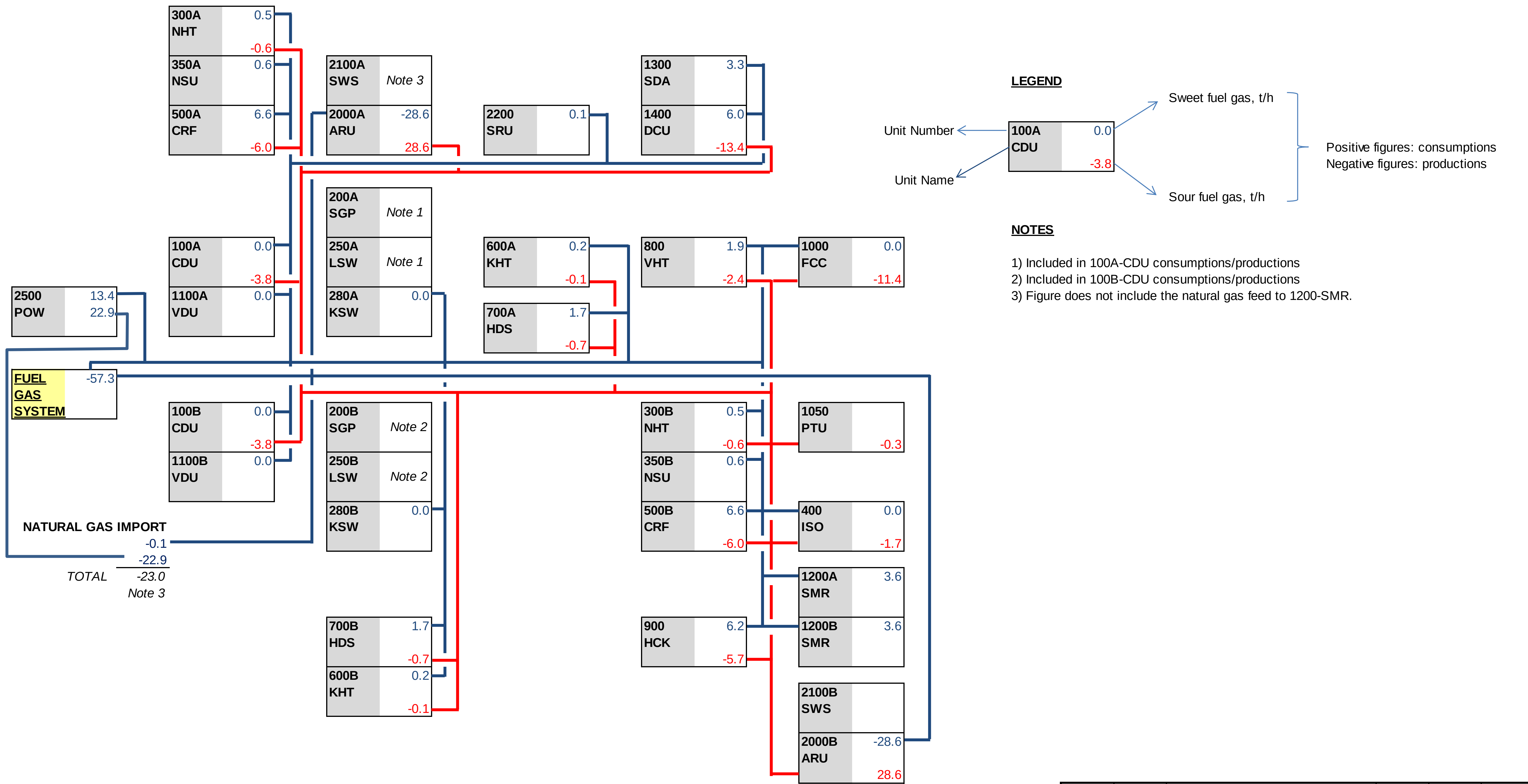


Figure 8-5: Base Case 4) Cooling water network



F01	12/05/16	INCLUDING COMMENTS	CG	CG	MCS
C00	6/11/15	FIRST ISSUE	LB	CG	MCS
REV.	DATE	DESCRIPTION	BY	CHD	APP:

BASE CASE 4 - FUEL GAS NETWORK

amec foster wheeler

DWG. N° BD0839A-PR-0000-BF-044 REV. F01

SHEET 1 OF 1

Figure 8-6: Base Case 4) Fuel Gas/Offgas networks

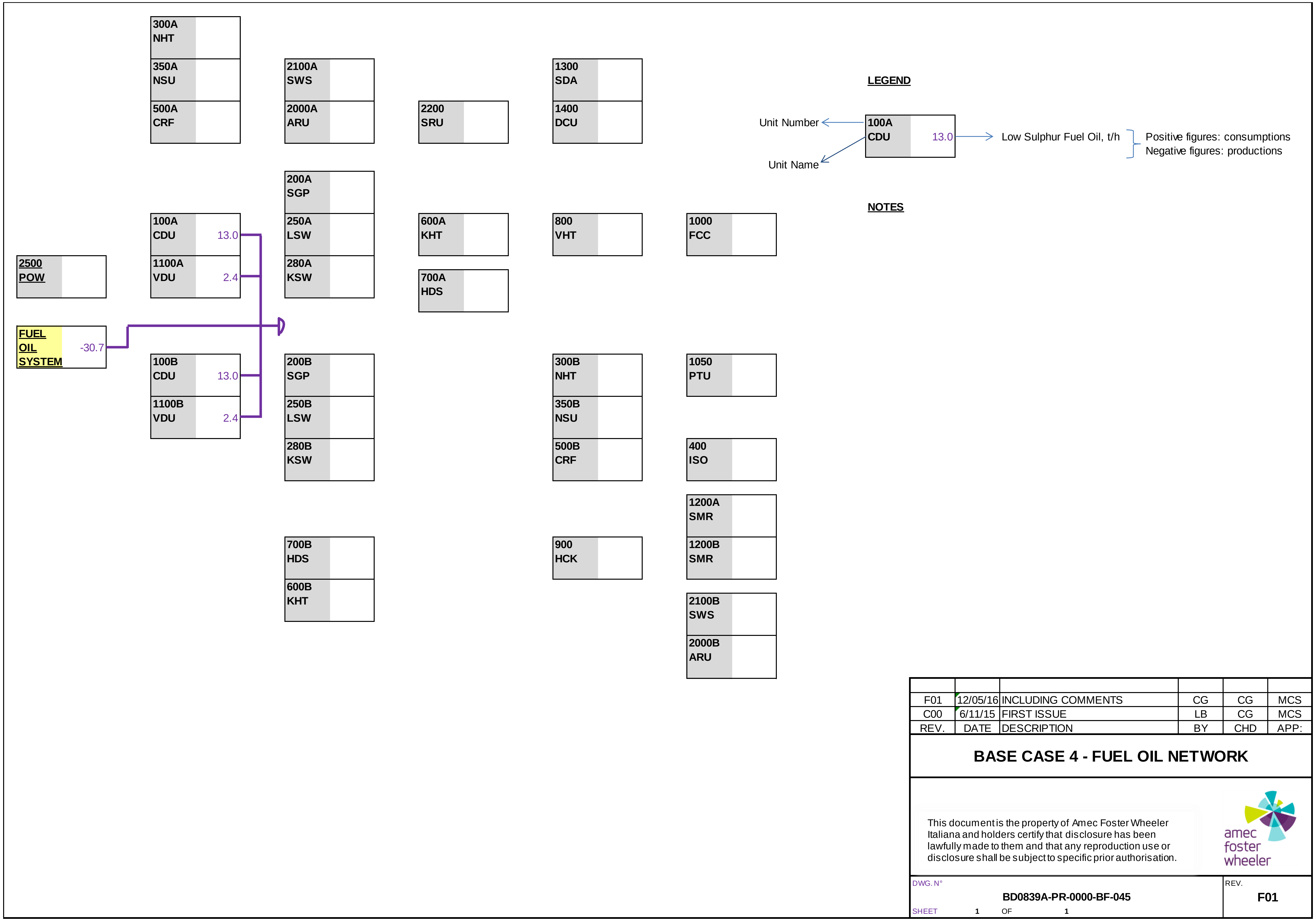


Figure 8-7: Base Case 4) Fuel oil network

8.4 Configuration of Power Plant

Base Case 4, representing a high capacity, high conversion refinery, is not considered as an evolution of a different scheme.

Following the same approach, also it has been defined an optimized power plant configuration, disregarding any constraints represented by existing equipment to be re-used, considering also the present best available technologies.

Power and steam demand shown in Table 8-6 have been taken as a basis.

The power plant has been designed to be normally operated synchronized and in balance with the grid and with the refinery and such that no import/export of steam is required during normal operation. However, steam demand has higher priority over electricity demand, since refinery electrical demand can be provided by HV grid connection back-up.

Power plant configuration for Base Case 4 is a combined cycle. The configuration of the gas cycle foresees three Gas Turbines 45 MWe frame (ISO conditions) operating at 69% load. Exhaust gases from the gas turbine are post fired to enhance the HP steam production in the Heat Recovery Steam Generators (HRSG). HP Steam leaves the HRSGs at the condition required by the refinery units. Natural gas only is fed to the Gas Turbines, while refinery fuel gas is fed to HRSG.

HP Steam produced by the HRSGs is routed to the Steam Turbines for power and MP/LP Steam generation. For Base Case 4, an auxiliary boiler normally operating at the minimum load has been foreseen to ensure that the steam supply to the refinery is not compromised when a gas turbine (and the corresponding HRSG) trips or is in maintenance. Steam generated by the Auxiliary boiler goes directly to the common HP header before being sent to the steam turbines.

In Base Case 4, Steam turbines are backpressure type. MP Steam is generated through a medium pressure extraction and desuperheated to the temperature required by the users. Exhaust steam from the steam turbine is almost completely sent to the battery limits as LP steam export to the refinery users, except the amount needed from the deaerator for BFW generation.

There is no cooling water consumption, since there is no steam condenser.

Power plant configuration considered for Base Case 4 is shown in Figure 8-8.

Base Case 4 power plant major equipment number and size are summarized hereinafter:

- 3 x 45 MWe GTs normally operating at 69% of their design load (corresponding to 31 MWe) plus 3xHRSGs normally producing 122.8 t/h HP Steam;
- 2 x 20 MWe Steam Turbines normally operating at 85% of their design load (corresponding to 17 MWe each)
- 1 x 130 t/h Auxiliary boiler normally operated at 30% of the design load (corresponding to 39 t/h), assumed to be its minimum stable load.

BASE CASE 4

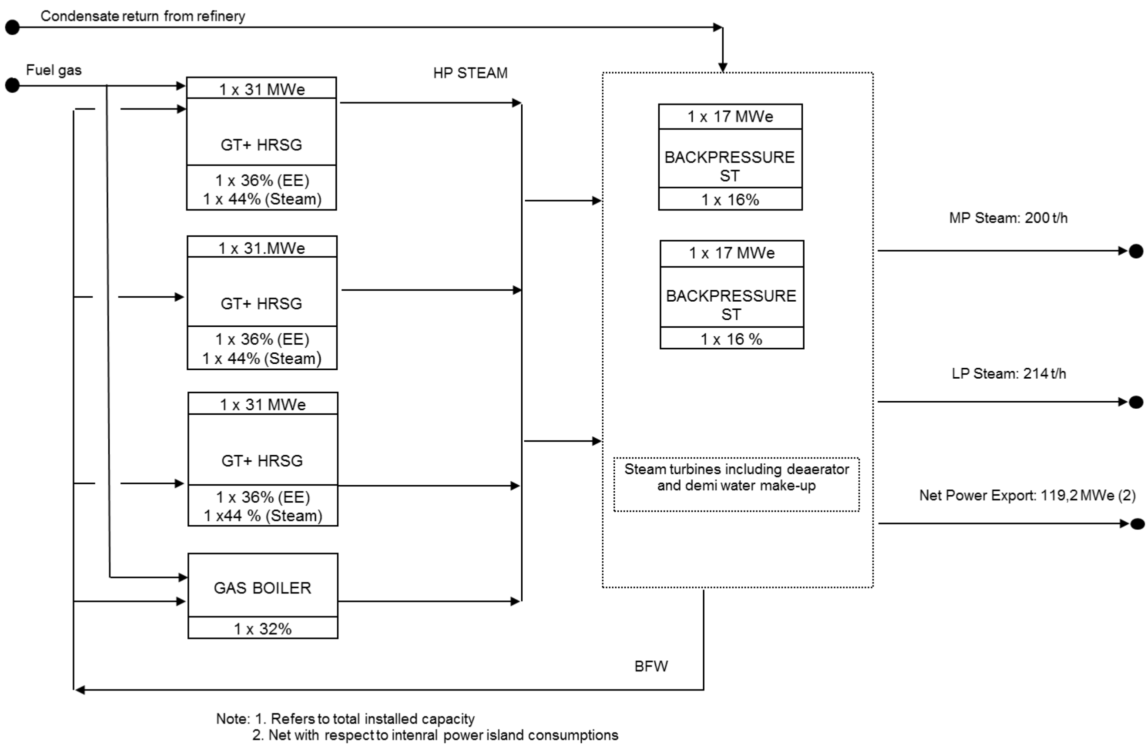


Figure 8-8: Base Case 4) Power Plant simplified Block Flow Diagram

The system has been conceived to have such an installed spare capacity both for power and steam generation to handle possible oscillations of power and steam demand from the refinery users and to avoid refinery units shutdown in case of one piece of equipment (gas/steam turbine or boiler) trips or is in maintenance.

Total installed spare capacity is summarized hereinafter:

- Gas Boilers + HRSG (Steam) **+64%**
- Steam Turbines + Gas Turbines (Electric Energy) **+40%**