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End users process characteristics and requirements

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End-User Requirements fOr industrial Process heat Applications with Innovative nuclear Reactors for Sustainable energy supply

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Summary

Heat is used in industry for several reasons. The EUROPAIRS partners, who work in very different industrial sectors, were asked to provide their heat requirements (temperature levels and thermal power).
To develop a general description of the thermal energy need in the industry, three process classes were then defined.

- The first is called “the steam class” because heat is transport via steam media or heat is used to remove water. The temperature is between 150°C and 600°C.
- The second is called “the chemical class” because heat is the driver of chemical reactions and is consumed as reaction enthalpy generally at constant temperature. The temperature is between 600°C and 900°C. Heat is supply by fossil fuel burners and marginally by electrical heating.
- The third is called “the mineral class” because heat is used to melt solid or to drive reactions between solids. The temperature is in general above 1000°C.

These classes were described and illustrated by examples in the following report. As a conclusion “the steam class” and “the chemical class” appear as the more promising candidate for a coupling with High Temperature Reactor.

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1 Introduction

Industrial activities transform raw materials into more valuable products. During these transformations energy is consumed. According to the first law of thermodynamics, energy is the sum of work and heat. Industries consume then power (e.g. electricity) and heat. Since the industrial revolution, fossil fuel has been the principal energy source. With the global warming issue, reducing the consumption of fossil fuel and developing alternative energies is one of the objectives of European industry.

The following study will sum up the heat requirements of several processes in terms of temperature and thermal power. This document describes three heat consumer families and evaluates the potential near and long term opportunities for a non fossil thermal energy source.

2 Glossary

Work: *a manifestation of energy; the transfer of energy from one physical system to another expressed as the product of a force and the distance through which it moves a body in the direction of that force.*
Heat: *a form of energy that is transferred by a difference in temperature.*
Sensible heat: *heat absorbed or radiated with a temperature increase or decrease.*
Latent heat: *heat absorbed or radiated during a change of phase at a constant temperature and pressure.*
End users: *industrial heat consumer.*
Medium: *a way to transport heat from source to consumer.*
Reactants: *substances that are consumed in the course of a chemical reaction.*
Products: *substances that are produced in the course of a chemical reaction.*

3 Heat requirements in the industry

Industrial activities present very different processes which can be very simple or very complex. To evaluate this diversity, EUROPAIRS project regroups 13 different end users coming from 9 countries. The Table 1 presents these different industrial partners.

Table 1: EUROPAIRS End users list

Partner name	Country	Industrial sector
AMEC	United Kingdom	Oil sands engineering Cement engineering Paper engineering
Air liquide	France	Industrial gases company
Arcelor-Mittal	France	Steel producer
Fortum	Finland	Utilities (District heating)
FZJ	Germany	Coal gasification Steam methane reforming
GDF Suez - Tractebel	Belgium	Engineering
NWU/PBMR	South Africa	Synthesis fuel production Hydrogen production
PROCHEM	Poland	Refinery engineering
SAIPEM SA	France	Oil & Gas engineering
SOLVAY	Belgium	Soda ash
TECHNIP KTI	Italy	Refinery engineering
USG/BEC	Netherlands	Petro chemistry Utilities
ZAK	Poland	Ammonia – Fertilizers

Each partner was asked to fill a questionnaire (see Annex 1) in which they have to describe their process, the heat requirements (temperature and power) and the heat producer specifications (type, consumption, and operating temperature).

According to these data, three process families are proposed. The objective of this classification is to have a general view of heat utilization in the industry and to be able to use it for other purposes than the one studied in EUROPAIRS.

The three process classes were defined as follow:

- The first is called "**the steam class**" because heat is transport via steam media. The temperature is between 150°C and 600°C.
- The second is called "**the chemical class**" because heat is the driver of chemical reactions and is consumed as reaction enthalpy at constant temperature. The temperature is between 600°C and 900°C. Heat is supply by combustion reaction in burners and marginally by electrical heating.
- The third is called "**the mineral class**" because heat is used to melt solid or to drive reactions between solids. The temperature is in general above 1000°C.

The table 2 presents a summary of the different process unit's heat requirements. Detailed information is given in Annex 2.

Table 2: Heat requirements (temperature and power) synthesis

<table>
<tr><th>TEMPERATURE\POWER</th><th>10 -150 MWth</th><th>150 - 500 MWth</th><th>500 - 1000 MWth</th><th>> 1000 MWth</th></tr>
<tr><td rowspan="3">100-600 °C</td><td>Refinery Distillation
Steam
(heating, process, electricity)</td><td>Paper
Steam (drying)</td><td></td><td></td></tr>
<tr><td>Steel degassing
(process, electricity)</td><td>Water desalination
Steam (drying)</td><td></td><td></td></tr>
<tr><td>Refinery Distillation
Superheated Steam
(heating, process)</td><td>Soda ash
Steam (drying)</td><td>Steam as utility
for indutrial complex</td><td>Steam Assisted Gravity Drainage
Steam (process, electricity)</td></tr>
<tr><td rowspan="3">600-700°C</td><td>Petrochemicals (styrene...)
Reaction enthalpy</td><td></td><td></td><td></td></tr>
<tr><td>Hydrogen
Membrane steam reforming</td><td></td><td></td><td></td></tr>
<tr><td>Hydrogen
High temperature electrolysis</td><td></td><td></td><td></td></tr>
<tr><td rowspan="5">700-1000 °C</td><td>Olefine products
Reaction enthalpy</td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Methane Steam reforming (syngas)
Reaction enthalpy</td><td></td><td></td></tr>
<tr><td colspan="2">Coal gasification (syngas)
Reaction enthalpy</td><td></td><td></td></tr>
<tr><td>Oxygen
Membrane gas separation</td><td>Carbon monoxyde production</td><td></td><td></td></tr>
<tr><td>Hydrogen
Very High temperature electrolysis</td><td>Hydrogen
Chemical water splitting</td><td></td><td></td></tr>
<tr><td rowspan="3">> 1000 °C</td><td>Lime Kiln production</td><td>Cement production</td><td></td><td></td></tr>
<tr><td></td><td>Ore sintering</td><td></td><td></td></tr>
<tr><td></td><td>Coke making</td><td colspan="2">Metallurgical processes</td></tr>
</table>

4 « The steam class » (150 – 600°C)

4.1 Generalities on steam

Steam loops are used in several industries. On several industrial sites, steam is generated by a cogeneration unit which will provide electricity and heat to several end-users. In such unit, steam is generated in a boiler which is heated by a flame.

- In a topping cycle (see Figure 1), steam is used to generate electricity and after for heating.
- In a bottoming cycle (see Figure 2), steam is used for heating and after to generate electricity. In this case the maximum temperature for heating purpose can be higher but the efficiency of electricity generation is lower. At the end of the cycle, the condensate is treated and returned to the boiler.

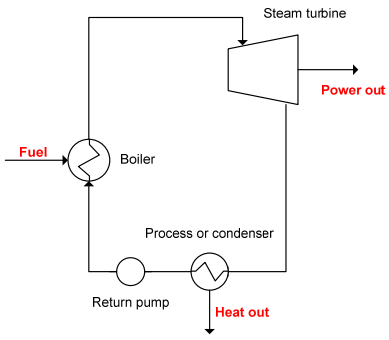


Figure 1: cogeneration cycle (topping)

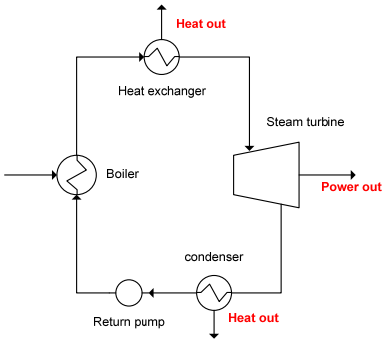


Figure 2: cogeneration cycle (bottoming)

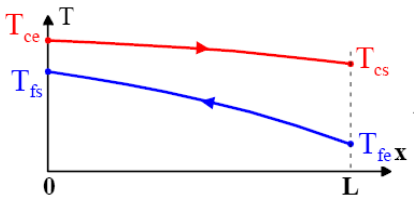
4.2 Use of steam in the industry

The steam is used for different purposes which are heating, drying, cooling, and process duty. This section describes these different uses.

4.2.1 Steam as heating media

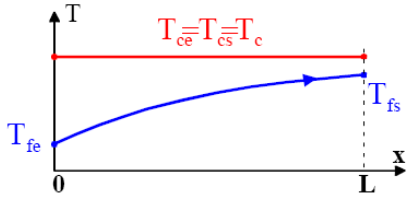
Steam is mostly used as heating media in a heat exchanger. Two situations are encountered:

- superheated steam which will exchange sensible heat to the fluid to be heated as described on Figure 3,
- Or steam that condenses at a constant temperature and that exchanges latent heat as described on Figure 4. Latent heat is preferred whenever possible because it requires lower steam quantities and enables to control heating temperature especially when the product can be damaged by high temperature.



Tce= Inlet hot fluid temperature
Tcs= outlet hot fluid temperature
Tfe= Inlet cold fluid temperature
Tfs= outlet cold fluid temperature

Figure 3: Sensible heat exchange



Tce= Inlet hot fluid temperature
Tcs= outlet hot fluid temperature
Tfe= Inlet cold fluid temperature
Tfs= outlet cold fluid temperature

Figure 4: Latent heat exchange

The limit for the use of saturated steam for latent heat purpose is the temperature and pressure of the water critical point (Temperature: 374°C, Pressure: 221 bar).

In practice as latent heat decreases with temperature increase (see the water T-H diagram given in Figure 5) the use of saturated steam is limited to a temperature well below 374°C.

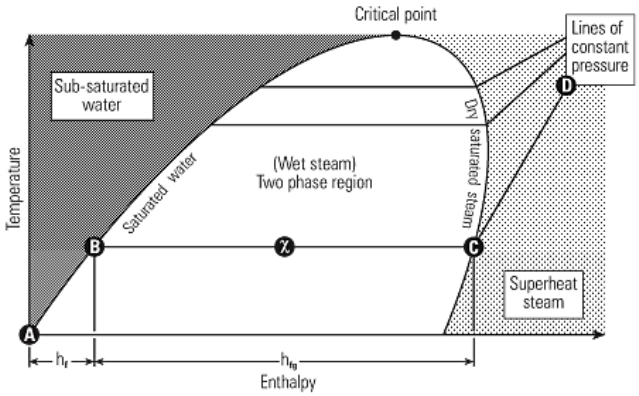


Figure 5: T-H diagram of steam

To explain this heat consumption mode, two examples are described hereafter according to the data provided by EUROPAIRS Partners.

The first example is a distillation unit in a refinery. According to PROCHEM data, steam is generated in the refinery at a temperature between 150 and 500°C. Steam is used as heating media in the distillation reboilers. The objective is to maintain the feedstock at a temperature near its evaporation temperature to separate the different hydrocarbons contained in the crude oil (see Figure 6).

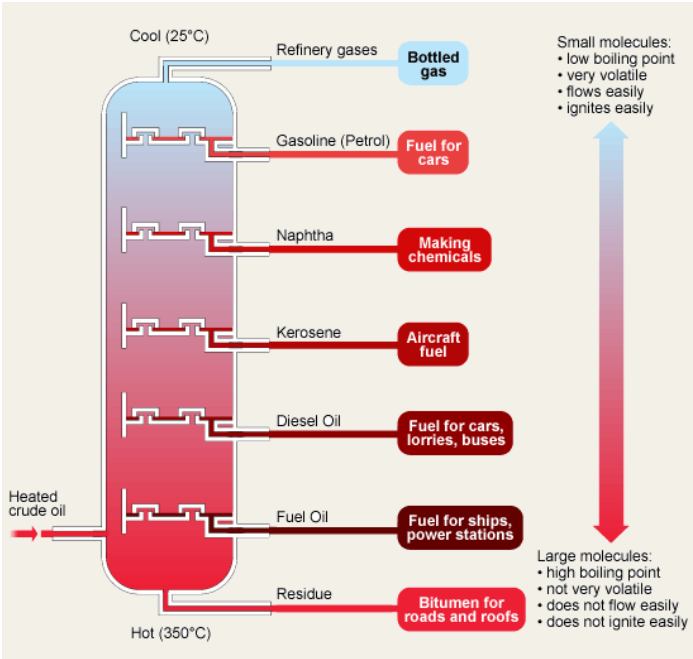
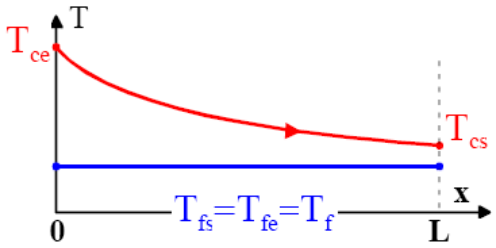


Figure 6: Refinery distillation column (source: website bbc.co.uk)

The second example is the district heating. According to FORTUM data, steam at the outlet of the steam turbine of a cogeneration plant is at a temperature between 100 and 130°C. This steam is used to heat water at 120°C. This warm water is then used to heat houses and cities.

4.2.2 Steam generation for drying

Another type of unit which consumes heat in the “steam class” temperature range is the drying operation. In this case heat is consumed to eliminate water from feedstock by evaporation.
The basic principle (see Figure 7) is to transfer heat from a fluid (which can be steam) at a temperature above the water evaporation temperature at the considered pressure.



Tce= Inlet hot fluid temperature
Tcs= outlet hot fluid temperature
Tfe= Inlet cold fluid temperature
Tfs= outlet cold fluid temperature

Figure 7: Heat exchange to evaporate a fluid

4.2.3 Water desalination

A very similar process is the production of fresh water by seawater distillation (see Figure 8).

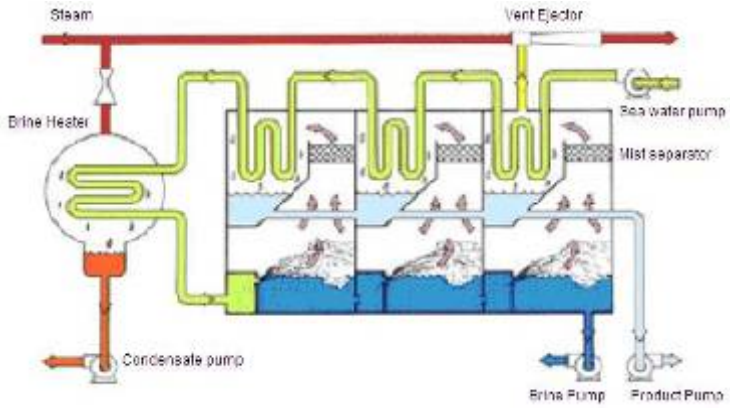


Figure 8: Multi-stage flash evaporation (source: website www.acwasakura.com)

The multistage flash evaporation process uses steam to heat seawater at a temperature of 100°C. Under low pressure, the warm seawater evaporates and generates steam that condensates to produce fresh water. In the same time the steam condensation preheats the seawater feed stream.

4.2.4 Steam generated in cooling system

Some chemical plants, in which exothermic reactions occur, use water as cooling media. Steam generation is used to evacuate heat from the reactor to control the temperature. The steam can then be used as heating media or process steam in another part of the plant. This type of process is detailed in section 5 of this document.

4.2.5 Process steam

Steam can be injected directly in the process equipment.

- In a refinery for example, it is injected in the stripping columns. In this column, the flux of steam carries away light molecules, helping the distillation process (see Figure 9).
- In the steel industry or in a refinery for example, it is used to put equipment under vacuum thanks to steam ejectors (see Figure 10).
- In a refinery the steam is also used to control temperature to avoid coke formation when crude oil is heated in the furnace.

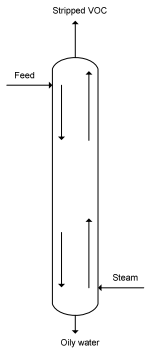


Figure 9: stripping column

Figure 10: steam ejector

In such processes, the important point to keep in mind is that steam comes in contact with the products. Furthermore the steam is 'consumed' in the process and can not be recovered.

4.3 Conclusion on the "steam class"

According to the data received, when the steam is used for heating purposes only, the temperature level is generally below 374°C. The latent heat of condensation makes steam a very efficient media in such cases.

When steam is produced at a higher temperature this is because:

1) a topping steam turbine produces energy,
2) Hot steam is required for process reasons (stripping or process reactants).

According to this investigation, it appears that the use of steam is limited to temperature levels under 600°C. This limit is in fact a technological barrier linked to the resistance of material to steam corrosion. However, new materials are developed to accept 700°C in supercritical steam power stations.

5 « The chemical class » (600 – 1000°C)

5.1 Generalities on chemical reactions

A chemical reaction transforms reactants into products.
If the energy level of reactants is higher than the products one, the reaction produces energy that shall be evacuated during the transformation. Heat is then produced and the reaction is exothermic (see Figure 12).
In contrary some reactions consume heat and are endothermic (see Figure 11).

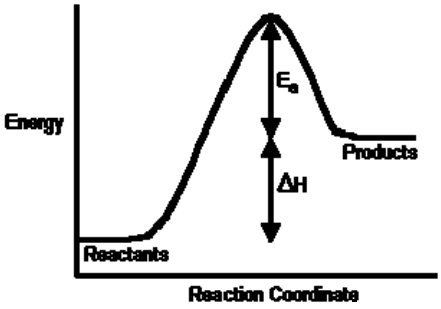


Figure 11: Endothermic reaction

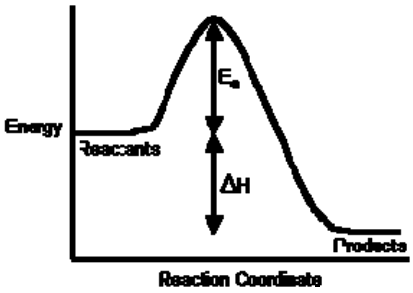


Figure 12: Exothermic reaction

The products composition depends on the reactants composition and on the reactor temperature and pressure. For a given reactants and products composition, temperature and pressure of the reactor are kept constant.
For an endothermic reaction, heat drives the reaction as the quantity of products is proportional to the quantity of heat received. Heat is exchanged via a media, its inlet temperature shall be above the reaction temperature and the quantity of heat exchange will be equal to the flow rate multiplied by the heat capacity multiplied by the temperature difference between inlet temperature and reaction temperature. The Figure 13 describes the energy profile of an endothermic chemical reaction and of the heating media.

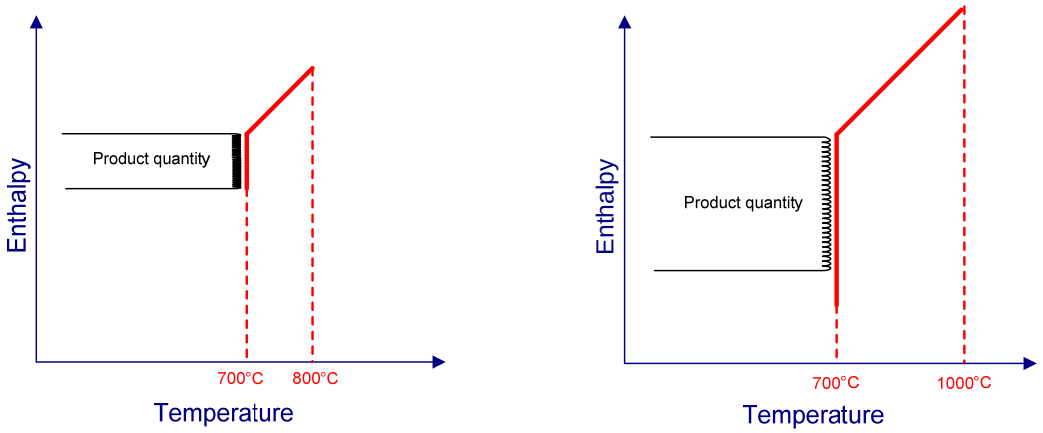


Figure 13: Energy profile of a chemical reaction for an inlet heating media temperature of 800°C and 1000°C

As the reaction temperature is fixed, two parameters for the heating media can be adapted: the inlet temperature and the flow rate. For the same quantity of products, decreasing the flow rate requires a temperature increase.

In the industry, heat for chemical reaction is produced thanks to burners where the combustion between air and fossil fuel produces exhaust gases at high temperature.

In the chemical industry where, on the same site, exothermic reactions occur at higher temperature than endothermic ones, heat can be reused. This thermal integration allows optimized energy consumption in the plant.

5.2 Oil derivatives

In a refinery, distillation products are upgraded and transformed.
Upgrading transforms low value products (such as heavy or high sulfur content components) into high quality products (i.e. fuels) by a reaction with hydrogen.
Transformation reactions produce petrochemicals base materials (i.e. olefins).

The Figure 14 presents the process flow diagram of a complex refinery.

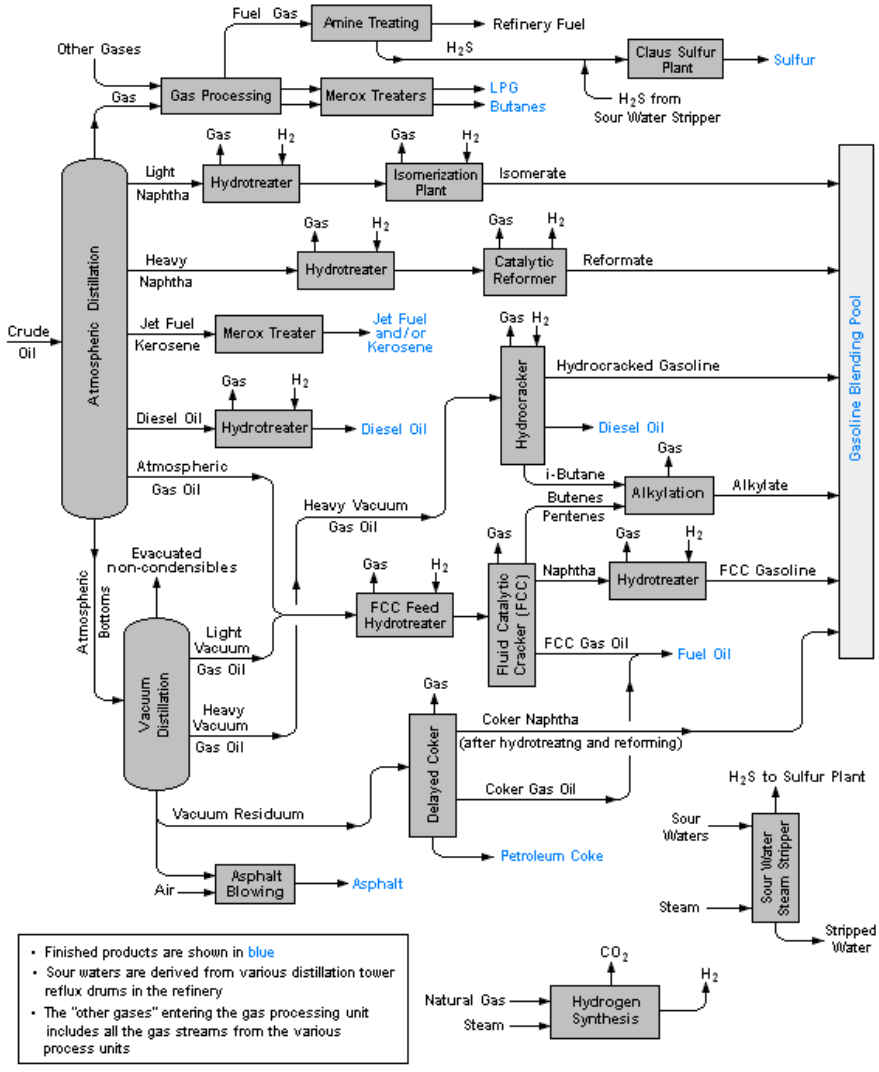


Figure 14: Complex refinery process flow diagram

5.2.1 Upgrading: hydrocracking, hydrotreatment

Upgrading is a hydro conversion of heavy oil distillates into light oil. This process unit consists of the hydrocracking of heavy oil and of the hydro treating of products. Hydro treating consists of several reactions between hydrogen and hydrocarbons. The result is the total saturation of olefins and the partial saturation of aromatics and the removal of undesired elements (e.g. sulfur). The reactions are exothermic at a temperature of 400-

420°C and generate heat which is transformed into steam for other uses (see chapter 4.2). In such units, heat at high temperature is only required to generate hydrogen via steam reforming process as described in chapter 5.3.1.

5.2.2 Endothermic transformations

Coking, cracking, dehydrogenation are endothermic reactions in a refinery. These process units transform distillates into more valuable products:

- Coking transforms heavy oil into petroleum coke and lighter oil products,
- catalytic cracking is used to produce gasoline,
- vapocracking is used to produce olefins from naphta and light alkanes (ethane, propane),
- And dehydrogenation is for example used in the production of styrene.

All these reactions consume heat at a temperature around 500 and 700°C and are typical examples of reactions of the “chemical class”.

5.2.3 Exothermic transformations

Etherification, alkylation, oxidation are exothermic reactions in a refinery. All these transformations occur in process reactors using some catalyst at a selected temperature which enables to control the formation of undesired by-products. These reactions require cooling as described in the chapter 4.2.4.
These process units are not potential consumers of high temperature heat. They shall be considered as heat generators which decrease the external need of “steam class” heat.

5.3 Methane, biomass and coal derivatives

Methane, biomass and coal can be transformed into syngas which is a mix of carbon monoxide and hydrogen. This syngas can be further processed to produce hydrogen or can be used as reactant in synthesis reactions as described in chapter 5.4.

5.3.1 Steam methane reforming

The main usual way to produce syngas is steam methane reforming. The process description is given on the Figure 15.

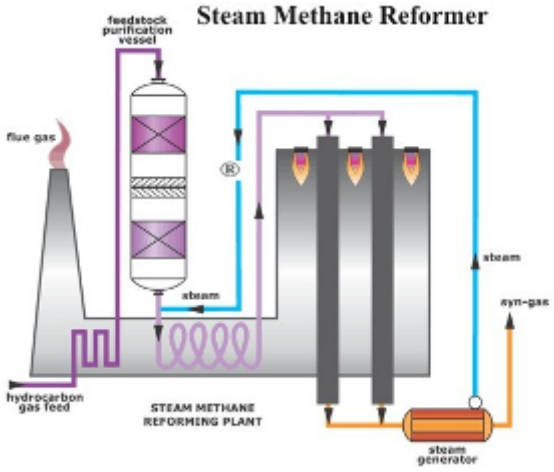


Figure 15: steam methane reforming process description

Treated gas is mixed with steam, the mix is preheated and enters the reformer tubes which contain nickel based catalyst and which are heated by an external burner.

Methane and steam react to form syngas according to the following endothermic reaction:

$$CH_4 + H_2O \xrightarrow[\text{Heat}]{\text{Nickel Catalyst}} CO + 3H_2$$

Syngas composition is dependant of the temperature and the pressure of the reformer as described in Figure 16.

Figure 16: syngas composition vs. temperature at 1bar and 40bar

In theory, high purity syngas can be obtained at low pressure and at very high temperature (above 1000°C). In the industry, steam methane reformers work between 700 and 900°C. This reaction consumes heat at a temperature around 700 and 900°C and is a typical consumer of "chemical class" heat.

New process using membranes enables to decrease slightly the reaction temperature to 600°C. This is the case in the steam methane reforming technology which is described in appendix 2.

5.3.2 Coal and biomass gasification

Syngas can be produced by coal or biomass gasification. This process unit is described in Figure 17 and is very similar to a steam reformer.

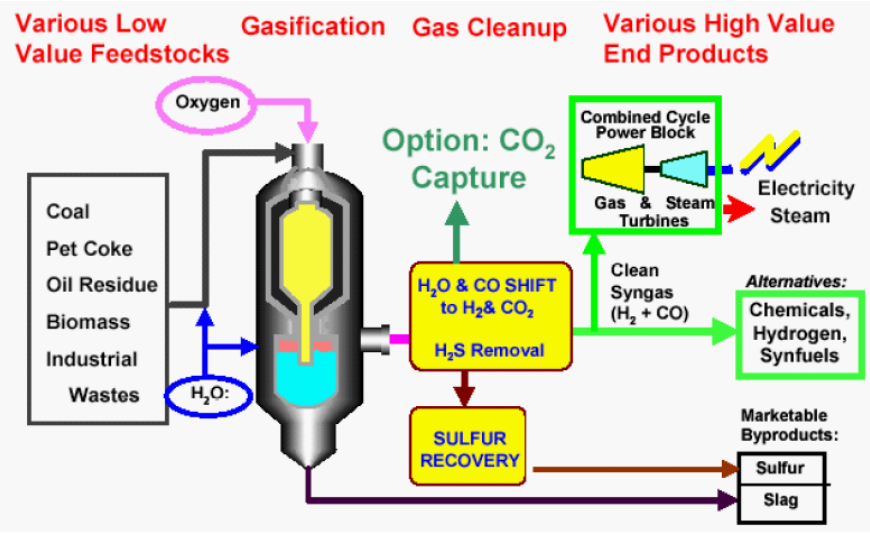


Figure 17: coal and biomass gasification process description

The heat required for the gasification reaction is produced by the combustion of coal in presence of oxygen (auto-thermal reactors). The different gasification technologies work at different temperature levels ranging from 370° to 1600°C as described in Figure 18.

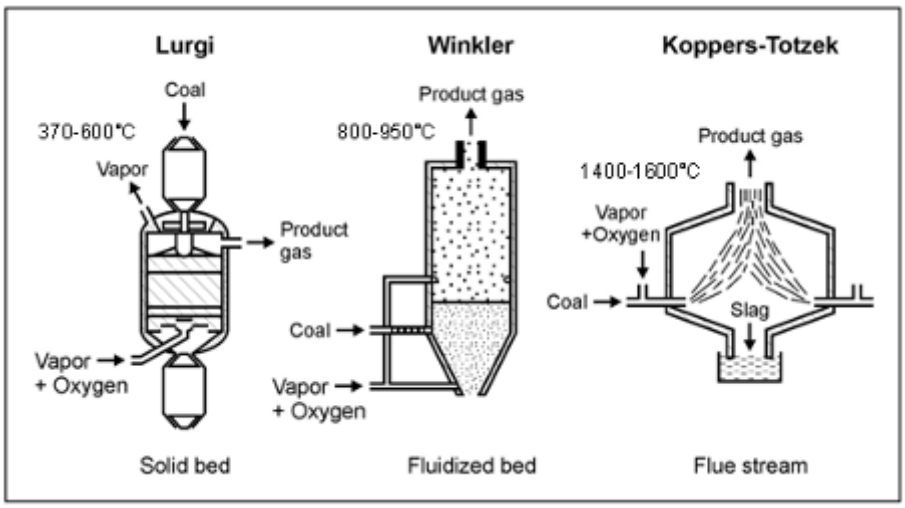


Figure 18: coal and biomass gasification technology

This reaction consumes heat at a temperature around 370 and 1600°C and is then a typical consumer of “chemical class” heat or “mineral class” (see chapter 6) heat.

Another way to gasify biomass is the pyrolysis as described on the Figure 19. Biomass is heated at a temperature around 700°C without oxygen. This reaction is then a consumer of “chemical class” heat.

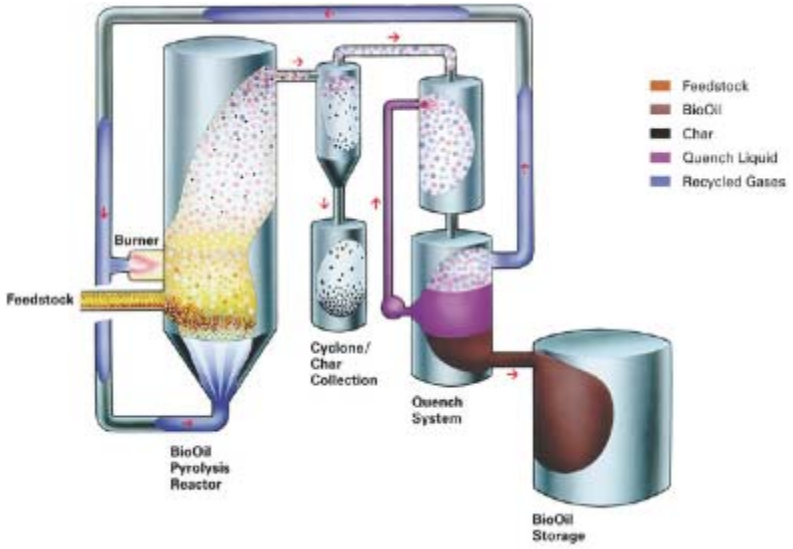


Figure 19: Flow diagram for the production of BioOil by pyrolysis process (Dynamotive corporation)

5.3.3 Hydrogen

Syngas produced by steam methane reforming or gasification can be processed to produce hydrogen. Water shift reaction and gas separation operations are required.

- The water shift reaction is an exothermic reaction which transforms carbon monoxide into carbon dioxide and hydrogen.
- The gas separation is a physical process which extracts hydrogen from the gas stream.

These reactions do not consume heat. Hydrogen production from methane, coal, and biomass consumes heat only for the steam methane reforming and for gasification as described in chapters 5.3.1 and 5.3.2.

5.3.4 CO

The reforming of methane with carbon dioxide (or dry reforming) produces synthesis gas with higher purity and lower H2/CO ratio than either partial oxidation or steam reforming. With appropriated gas treatment, this process produces high quantity of CO which can be used in chemical industries. This conversion is endothermic and favoured at higher temperature.

5.4 Synthetic products

The petrochemical industry uses derivates from oil or methane to produce synthetic products. Petrochemical plants are usually organized in industrial complex to gain benefit from synergies between different process units. Intermediate products and heat are exchanged between the different units.
For such reason, it can be difficult to introduce a new heat source because this would impact several units and the energy balance of the overall complex. The following chapter presents some petro chemistry applications and evaluates the possibility to introduce new heat sources.

5.4.1 Synthetic fuel

The Fisher Tropsch process uses syngas to produce synthetic hydrocarbons and water. This reaction is exothermic and the temperature of reaction is between 150 and 300°C. This reaction produces steam that can be used to heat other process units or to produce electricity (see chapter 4).
On the same site there generally is a gas treatment plant which requires heat at low temperature (<200°C), a steam methane reformer which consumes heat at a temperature above 700°C and the Fischer Tropsch reactor which generates heat at 300°C. The steam produces by the Fisher Tropsch reactor can then be used for the gas pre-treatment.

In such plant, the “chemical class” heat is then only required for syngas production and the need of “steam class” heat is reduced because the reaction provides energy for the gas pre-treatment.

5.4.2 Methanol

Methanol is produced by the reaction between carbon monoxide and hydrogen or carbon dioxide and hydrogen as described hereafter:

$$CO + 2H_2 \quad CH_3OH$$
$$CO_2 + 3H_2 \quad CH_3OH + H_2O$$

These two reactions are exothermic and require cooling which produces heat which can be reused in the plant.
The only endothermic reaction is the production of syngas. According to the size of the plant, different technologies are used.

- For a plant producing up to 2000 Million Ton Per Day, the single step reforming technology is used and syngas is produced as per chapter 5.3.1 at a temperature of 900°C.
- For a plant producing from 2000 to 7000 MTPD, the two steps reforming technology is used: classical steam methane reforming at 800°C and oxygen fired

secondary reforming at 1000°C to produce a syngas with a composition suitable for methanol synthesis.

- For a plant producing more than 7000 MTPD, the auto-thermal reformer technology is used.

In such plant, the “chemical class” heat is only required for syngas production and the need of “steam class” heat is reduced because the reactions provide energy.

5.4.3 Ammonia and fertilizers

Ammonia is industrially produced by the Haber Bosch process described on the Figure 20.

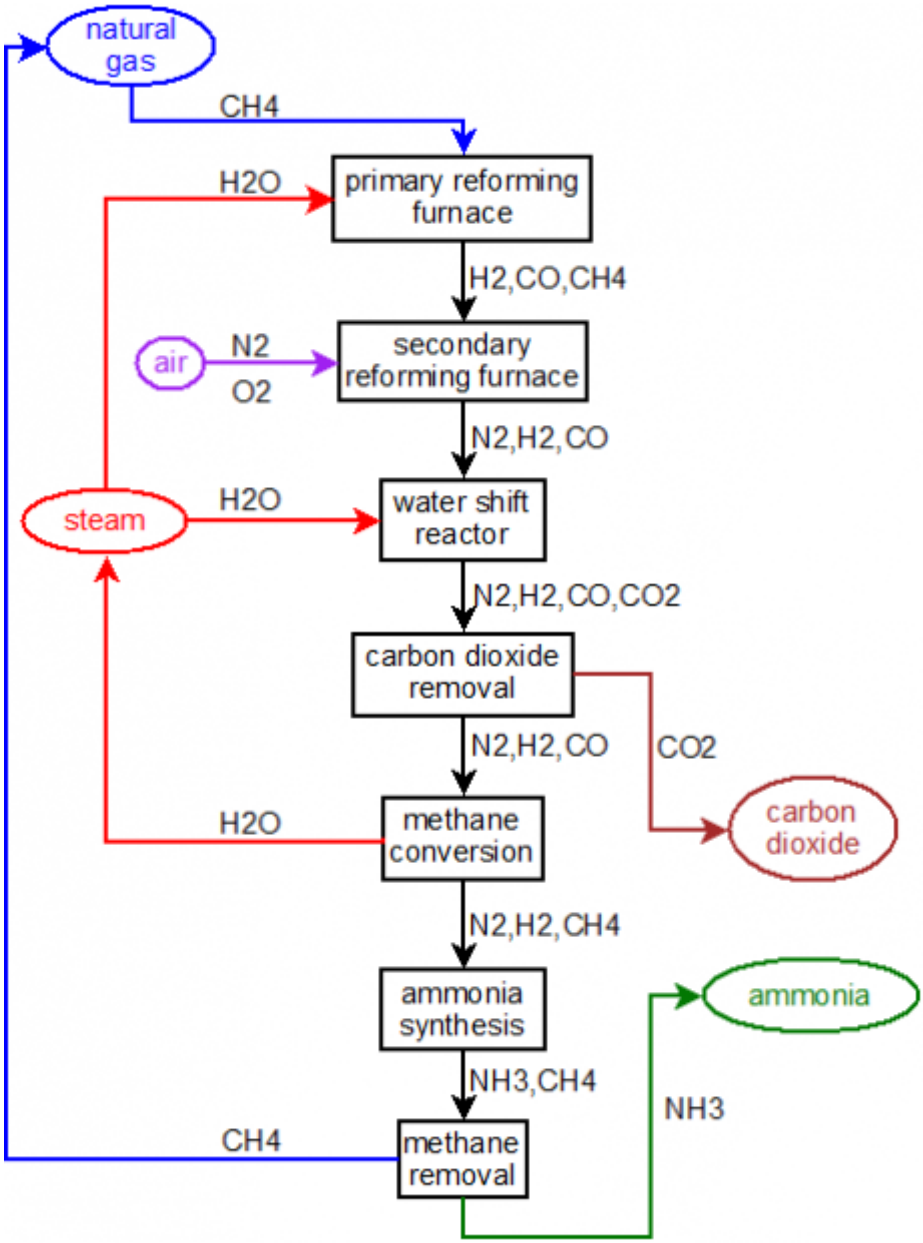


Figure 20: Haber Bosch process description

Primary and secondary reforming and carbon dioxide removal are endothermic reactions. Heat is also required to treat methane before reforming. The situation is similar to methanol for methane reforming: small plants use primary and secondary reformers and require heat from 750 to 1000°C, larger plants use auto thermal reformer.

On the same site ammonia can be transformed into urea, nitric acid and ammonium nitrate which is a base material of fertilizers.

- Urea is produced by reaction between CO_2 and ammonia. Carbon dioxide produced by the ammonia synthesis is then valorized. The reaction is globally exothermic at a temperature of 150-200°C. Steam is used for vacuum and heating purposes.
- Nitric acid is produced by oxidation of ammonia which occurs at 900°C and is very exothermic. Nitrogen dioxide is then absorbed by water to produce nitric acid. Acid is then concentrated to the required strength by water evaporation. Heat is required for water evaporation and vacuum. It is included in the "steam heat class".
- Ammonium nitrate is produced by the reaction between nitric acid and ammonia. This reaction is very exothermic. Heat is used for water evaporation and drying of ammonium nitrate. It is classified in the "steam heat class".

In such plant, the "chemical class" heat is only required for syngas production and carbon dioxide removal. The need of "steam class" heat is reduced because the reactions provide energy.

5.5 New processes for industrial gases production

Hydrogen and oxygen are industrial gases used in several industries. Several research programs are in progress to produce these gases via more efficient processes:

- For dioxygen the objective is to replace cryogenic separation by a high temperature membrane process (see chapter 5.5.1) ,
- For hydrogen produced from fossil energy, the objective is to decrease reaction temperature to reduce energy consumption and CO_2 emission.
- for hydrogen another objective is to use water as raw material (see chapter 5.5.3 & 5.5.4) instead of fossil material such as methane, coal or biomass (see chapter 5.3.3)

5.5.1 Ion transport membrane for oxygen production

Oxygen can be separated from air at high temperature thanks to ion transport membrane technology. The membranes are based on mixed-conducting ceramic materials that have both electronic and oxygen ionic conductivity at high temperatures. This technology requires heat to activate membrane and to heat the air stream. The required temperature is about 800°C. Even if the temperature is in the chemical heat class range, the heat consumed is not chemical enthalpy but sensible heat.

5.5.2 Reforming and Membrane Module (RMM) for hydrogen production

In Reforming and Membrane Module process, hydrogen selective membrane is assembled in separation modules applied downstream to reforming reactors. This configuration is composed by a series of reaction-separation modules: the reformer feed is sent to a convective steam reformer where it is partially converted into hydrogen; then hydrogen is recovered through a Pd alloy membrane separation module, while the retentate is sent to the next step or recycled to the first module.

Figure 21 reports a conceptual layout of the process scheme.

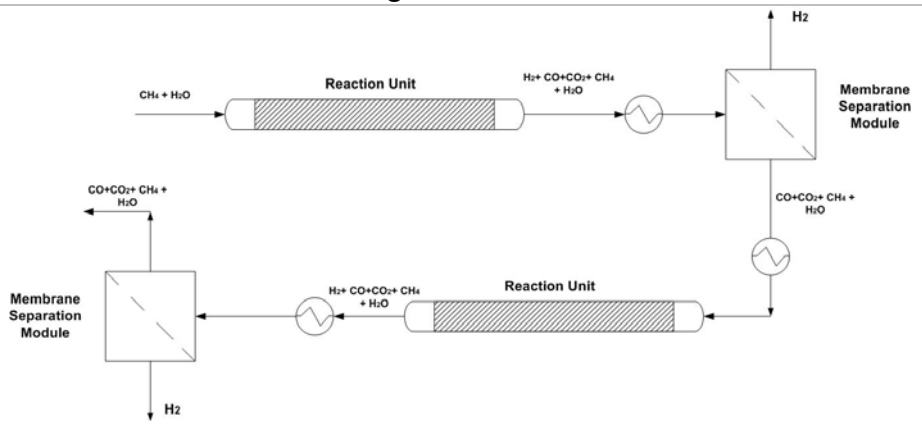


Figure 21: RMM conceptual lay out

The operating temperature can then be reduced thanks to the high temperature (450°C about) hydrogen separation between reaction steps, and it is possible to replicate the RMM until the desired natural gas conversion is achieved.

This technology seems promising and studies were performed to realize the coupling with nuclear or solar heat source.

The studied basic plant configuration is shown in Figure 22.

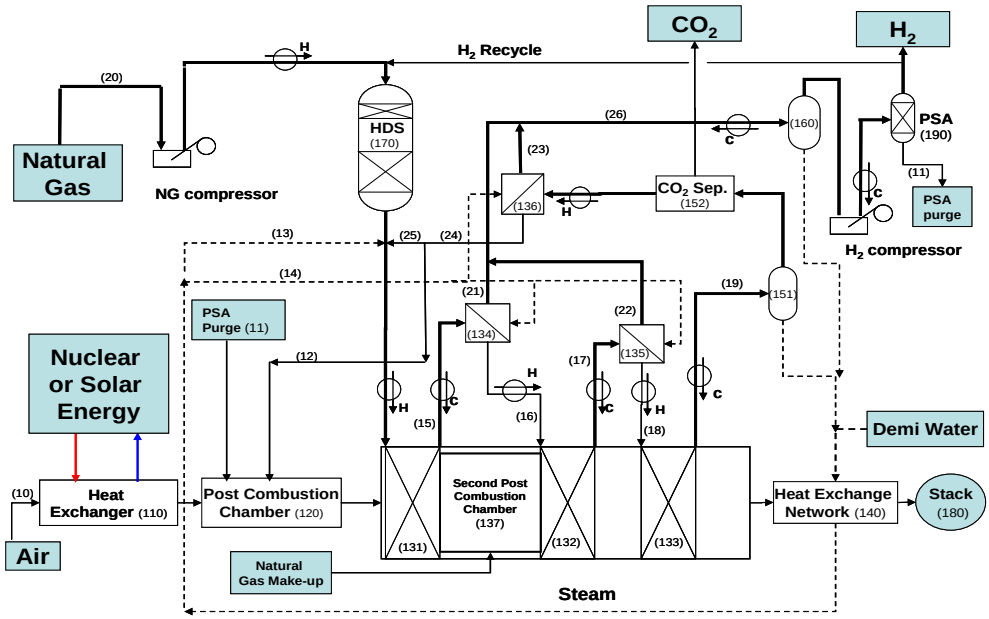


Figure 22: Basic plant configuration

Natural gas is compressed, heated and mixed with hydrogen recycle before entering the HDS reactor, where sulphur compounds are hydro-desulfurized to form H_2S which is removed by adsorption with ZnO.

The desulfurized feed is mixed with recycle process stream and then with steam in order to achieve a ratio ranging from 2.5 to 4 mol H_2O / mol C. The steam to carbon ratio (S/C) used to reform the hydrocarbon feed depends on the type and quantity of the hydrocarbons present in the natural feed.

The feed gas enters the first reforming step at a temperature around 580°C and exits at 650 °C. The reformed gas, before entering the first separation module, is cooled down to 450°C. Such a temperature allows a proper operation of Pd-based composite membranes. Pd-alloy

membranes are characterized by a very high selectivity towards hydrogen; therefore it can be assumed that the permeate side stream is composed by H_2 and the sweeping gas (water steam), used to remove the hydrogen permeated; such a mixture is cooled and water steam is condensed and separated. The retentate from the membrane unit moves to the second reforming step.

In the second and third reforming steps residual methane is reformed up to 90%. Before entering the third separation module, CO_2 is removed from such reformed streams. A part of the retentate is recycled to the feed entering the first reforming step.

The hydrogen permeated is separated from water steam by condensation and routed to a compression section and to a PSA unit where the final purification is carried out. A portion of the H_2 produced is recycled to the feed where it is needed to keep in the reduced (active) state the catalyst in the early part of the reformer.

Reforming reactors are heated by hot air which is preheated up to 550°C in a heat exchanger by a heating media coming from the nuclear reactor. The temperature of the preheated air is further increased in a post-combustion chamber where all the purge gas from the PSA unit together with some of natural gas and the not recycled retentate are burned to achieve a proper temperature.

This scheme seems to be a viable medium term nuclear cogeneration solution.

5.5.3 High temperature water electrolysis

Hydrogen can be produced from water by high temperature electrolysis (see Figure 23).

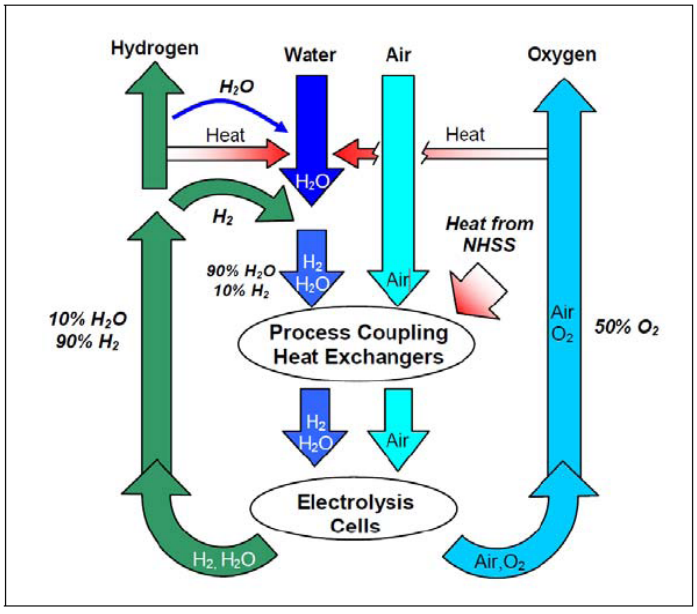


Figure 23: High temperature water electrolysis process description

This process can be designed to operate at different temperature levels from 100°C to 850°C (Alkaline water electrolysis (AWE) around 80°C, Protonic Ceramic Electrolyser Cell (PCEC) from 500°C to 800°C, Solid Oxide Electrolyser Cell (SOEC) from 800 to 1000°C).
The advantage of high temperature is to reduce electricity consumption and improve efficiency. The higher the temperature is, the lower the electricity consumption is and the higher the heat requirement is. High temperature nuclear reactor (HTR) is then a good option as the nuclear plant will provide electricity and heat without CO2 emission. It is important to note that this process can be designed according to the current HTR specifications.

5.5.4 High temperature chemical water splitting

Hydrogen can be produced by chemical water splitting at high temperature.
Two different cycles are studied both based on the sulfuric acid (H_2SO_4) chemistry. Two cycles were studied:

- Hybrid sulfur process described in Figure 24,
- Sulfur iodine process described in Figure 25.

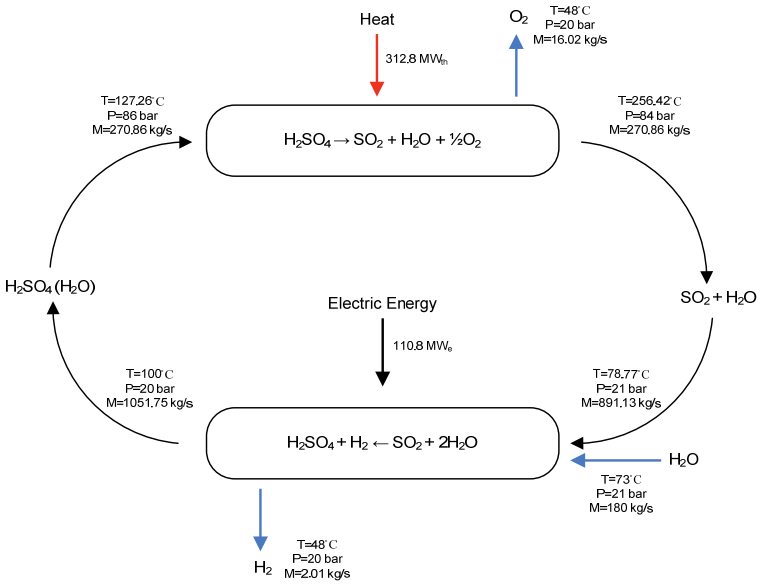


Figure 24: Hybrid sulfur process description

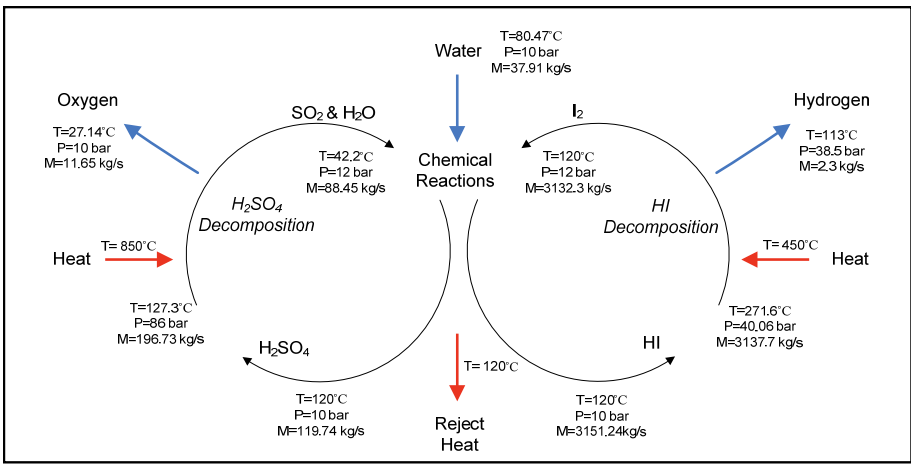


Figure 25: Sulfur iodine process description

The hybrid sulfur process requires heat to split sulfuric acid into water, sulfur oxide and oxygen. This reaction is endothermic at a reaction temperature of 522°C. To drive the reaction, heat shall be introduced at higher temperature.

The Sulfur iodine process requires heat to split sulfuric acid into water, sulfide oxide and oxygen and to split hydroiodic acid into hydrogen and iodine. These reactions are endothermic. The first, as described above, consumes heat at a temperature of 850°C and the second consumes heat at 450°C.

These two cycles are typical examples of new processes which require heat from the "chemical class".

5.6 Conclusion on the chemical heat class

The chemical heat class family is complex for several reasons:

- The first reason is the way in which heat is consumed. As heat drives the reaction, the temperature of the heat source shall be higher than the reaction temperature. To have a good efficiency, the temperature shall be as high as possible. For the moment the only way to produce a heat at a temperature from 600°C to 1000°C is fossil energy which produces greenhouse effect gas.
- The second reason is the plant organization in this sector. For the moment, the chemical industry is organized in industrial complexes which benefit from synergies between the different process units. These synergies are based on energy and materials exchanges. In this situation introducing a new heat source could impact not only one process unit but several ones. One way to facilitate change can be to produce with heat, intermediate materials such as syngas, hydrogen, oxygen that can be easily exchanged / transported within the complex.
- The third reason is the economical factor that impacts the use of one technology instead of another one. The economical benefits of the new heat source are then a key point that shall be taken into consideration.
- The fourth reason is the constant development of new technologies in this sector. This last point is an opportunity because new technologies can require new heat source.

According to all these points, the chemical heat class should be considered as a medium term opportunity for nuclear heat cogeneration.

6 « The mineral class » (> 1000°C)

6.1 Description

This class includes processes using reactions between solids which occur at temperature above 1000°C. Solid reactions are chemical reactions which consume heat as described in the chapter 5.1. The only difference with the "chemical class" is the temperature of the heat source which is above 1000°C.

6.2 Heat consumers description

The major industrial sectors are: metallurgy, ceramics, cement, glass…. In this chapter, two examples are presented: steel making and cement.

6.2.1 Steel making

The iron work is the first stage in the manufacture of steel from coal and iron ore.
It is articulated around the blast furnace and the ancillary reactors designed to prepare the burden materials. These include:

- the coke ovens which convert the coal to coke,
- the sintering plant which physically and chemically pre-treats the ore,
- the Cowper stoves for preheating the combustion air,
- And the preparation plant for the powdered coal injected in the twyers (Figure 26:).

Iron production in the blast furnace has now achieved a high level state of maturity. Modern integrated steelworks are all designed on the same model, in terms of both technical solutions and production capacities.

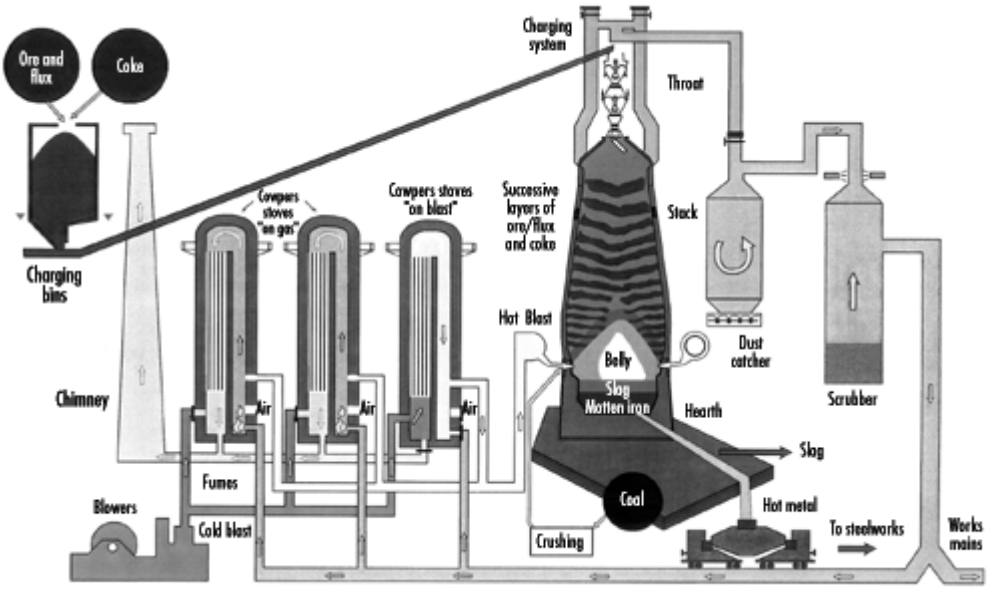


Figure 26: Schematic layout of a blast furnace and ancillary equipment

The different steps of the process require very high temperature as shown in Table 3.

Table 3: Temperature of the different process units in steel making industry.

Process unit	Temperature
Ore sintering	1000-1250°C
Coke making	1200-1350°C
Blast furnace	1300°C

After the blast furnace, hot metal is converted into liquid steel by elimination of excess carbon and impurities by oxidation. This reaction is very exothermic and occurs at a temperature of 1600°C.

Steel semis are transformed into finished products (bars and sheets) by hot rolling which requires to heat steel at a temperature of 1250°C.

All the iron and steel making operations require very high temperature and generate a lot of gas. This off gas is burnt in the blast furnace cowpers and in a power plant to produce electricity and steam that is then used for process duty such as vacuum degassing.

To decrease the temperature of the steel making process, other ways of iron reduction are possible such as direct iron reduction which requires hydrogen produced via steam methane reforming as described in chapter 5.3.1.

6.2.2 Cement

Cement is produced according to a process named pyroprocessing (see Figure 27)

Figure 27: Cement process description

This process requires heat at different temperature levels:

- Preheater / precalciner works at 900°C,
- Rotary kiln works at 1450°C.

Heat is produced by burner and by heated air recovered from the cooler. Exhaust gases at 350°C and air at 200°C are used to generate steam and produce electricity.

6.3 Conclusion on the mineral heat class

The mineral heat class processes work at very high temperatures (above 1000°C). Such temperature level is not achievable now with (very) high temperature reactors.
In order to have economical interest to use nuclear heat for such sector, other solutions have to be imagined to realize the coupling.
This coupling shall then be considered as a long term opportunity which shall require R&D work. This R&D program could include research to increase nuclear heat temperature, to decrease process heat temperature to a level achievable by nuclear reactor or to pump the heat to the required temperature.

7 Conclusion

The study of industrial heat requirements leads to identify three classes. The “steam class” and the “chemical class” represent the most interesting candidate for a coupling with a high temperature reactor. These solutions could have a positive impact by reducing the greenhouse gas emission and by limiting the fossil energy consumption.
Nevertheless, the development of such system requires to asses the economical viability in comparison to the “business as usual” and to evaluate the potential market of these solutions.

8 Annexes

Annex 1 – End User Heat requirements questionnaire

Annex 2 – End user answers

8.1 Annex 1:End user heat requirements questionnaire

EUROPAIRS - Task 1.1: End-User Processes
Inventory of data

Please fill this cover sheet for the identification of the document. The list of industries and processes in given in Sheet 6 for reference.

File	PARTNER_INDUSTRY_PROCESS_revA.xls

Partner	
Industry	
Plant / Process Unit	

Objectives of the document:

This document aims at gathering efficiently relevant data related to the end-user processes.
Each partner is asked to fill one FORM for each plant or process unit (existing & future).
This collection of data is the core of Task 1.1 and will be consolidated in order to de used as base information for Task 1.3.

A notice to correctly fill this FORM is given in a dedicated sheet.

Status of the document

Rev. A	29/09/2009	First issue by SSA of the document for comments from the partners of Task 1.1, 1.2 & 1.3

End-User Requirements fOr industrial Process heat Applications with Innovative nuclear Reactors for Sustainable energy supply

How to use this FORM?

This FORM is divided into 5 sheets:

Sheet 1	**HOME.** This is the cover sheet of the file. Before anything else, please make sure that you have filled the requested information: name of the partner and of the contact - name of the industry and of the described plant / process unit (in accordance with the list given in annex (sheet 6)).
Sheet 2	**NOTICE.** A notice is included in the FORM. It includes the description of the various sheets and a quick definition of the requested parameters.
Sheet 3	**PLANT/PROCESS DESCRIPTION.** In this sheet, the partner shall give a simplified flow scheme of the process with basic information such as the name of the process units included in the overall process (/plant) and the name and main characteristics (pressure, temperature, flowrate) of the fluids/products circulating between the units. You are free to use the proposed draft scheme or to include an existing flow scheme (as a jpeg image or as an attached pdf file). You can add any identified safety issues related to this process in this sheet.
Sheet 4	**CONSUMER DUTY.** This sheet focuses, within the process described in sheet 3, on the identification of the heating needs (independently from how heat is generated). Definition and examples of the data requested are given here below. They aim at characterizing the need in terms of physical conditions, operational philosophy, reliability, flexibility and safety.
Sheet 5	**PRODUCER SPECIFICATIONS.** In a second time, this sheet focuses on the existing systems implemented for heat generation. This information will be valuable in order to study the technical and economical impact of the use of HTR as an alternate for generation of High Temperature heat. Two sets of data are asked for: definition of the heat producer and characterization of the heat transportation media. Definition and examples of the data requested are given here below.
Sheet 6	**ANNEX.** Reminder of the list of partners and the related industries and plants / processes.

To be filled in priority

Can be filled in a second time

REFERENCES & GLOSSARY

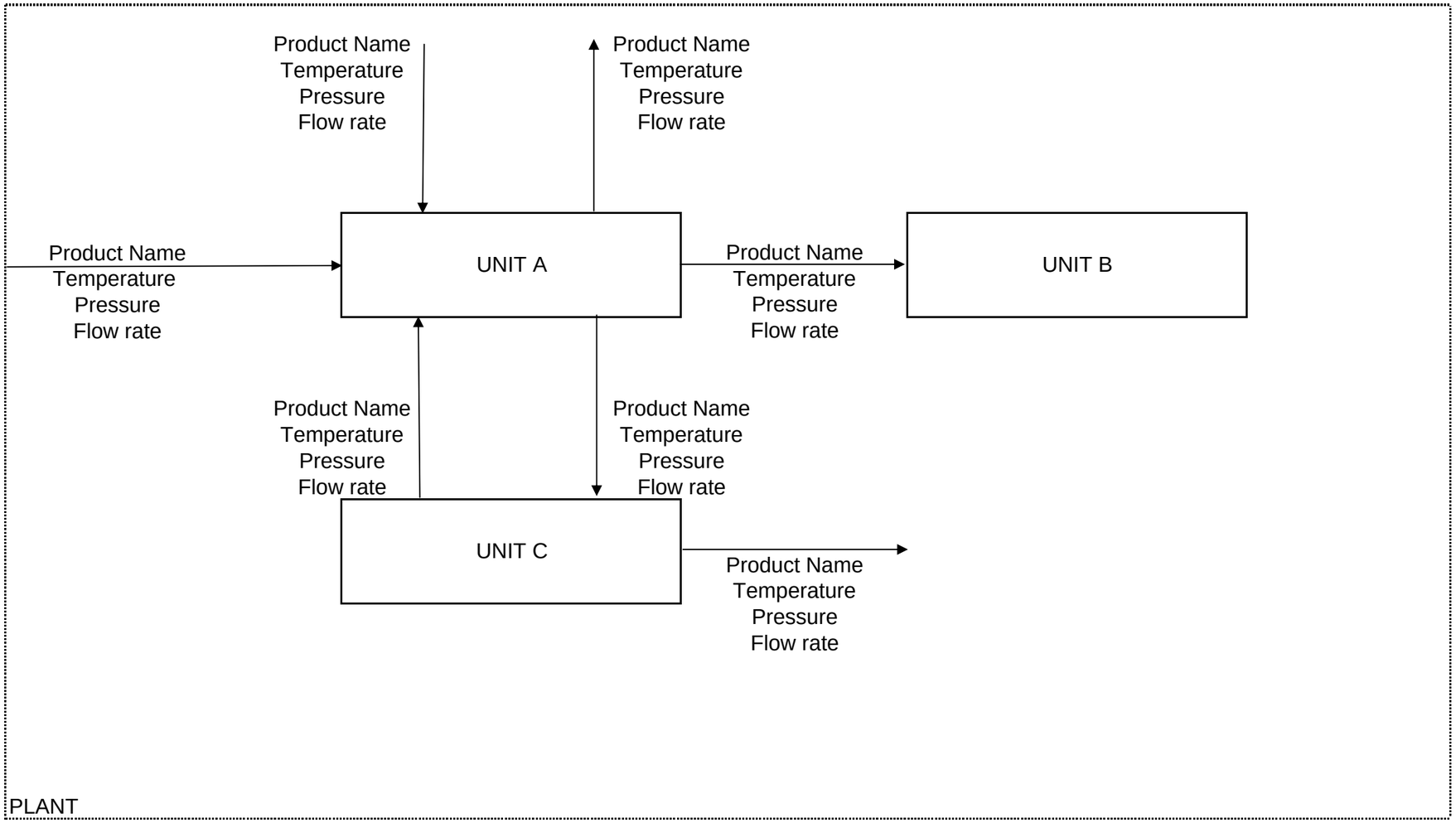
Ref.	*Parameter Name*	*Definition*	*Unit or Example*
		Process Description	
	Plant	An ensemble of process units	
	Process Unit	One elementary process unit that can be included in a plant or several plants	
(1)	Consumer Description	Name of the unit within the process (identical in sheet 3 and sheet 4)	steam reformming, hydrocracking…
		Consumer Duty - NEED	
(2)	Heating Loop N°	To number the heating loops properly allow to navigate easily in the file and to link heat production and heat consumption.	
(3)	Temperature	Temperature of the heating fluid at the inlet and the outlet **of the unit**.	K, °C, °F
(4)	Allowable Temperature Range	Min. & Max. temperatures at which the process takes place at full efficiency and without material damages.	K, °C, °F
(5)	Typical ramp up & down	Typical temperature gradient to be observed during transients (heating up & cool down).	K/min, K/s, K/h…
(6)	Continuous / Intermittent	Need for continuous heat supply (continuous process) or intermittent heat supply (batch process).	C or I (batch duration, number per year…)
(7)	Effect of heat supply disruption	What happens if case of heat supply disruption? Characterize the criticality of the heat supply.	shutdown of the process, degraded performances..
(8)	Consumption Leveling	Is there a possibility of leveling between the various heat loops in the process? Characterize the flexibility.	YES or NO
		Heat Producer Specifications - EXISTING	
(9)	Heat Generator Description	Name of the heat supply utility	
(10)	Fuel Type	Description of the fuel needed for heat generation	gas, coal, offgas (from unit X), electricity…
(11)	Fuel Consumption / External	Periodic consumption of external fuel	tpy, tph, Sm3/y…
(12)	Fuel Consumption / Offgases	Periodic consumption of internal fuel (offgases from another unit)	tpy, Sm^3/y…
(13)	Power	at least nominal power is required	MWh…
(14)	Back-up in case of shutdown	what is the planned back-up in case of the disruption og the normal heat supply?	
(15)	Media Type	Description of the media used for heat transportation between heat generation and consumption.	steam, oil, molten salt…
(16)	Temperature	Temperature of the medium at the inlet and at the outlet of the heat generation system	K, °C, °F
(17)	Pressure	Pressure of the medium at the inlet and at the outlet of the heat generation system	bar, psi…
(18)	Mass Flow	Mass flow rate of the heat transportation medium	tpy, Sm3/y…

Simplified Plant & Units flow scheme (1/2)

Objectives of the scheme

This simplified scheme aims at providing an easy understanding of the overall considered process.
You can add as many units as you think necessary.
In addition, please list at the bottom the safety concerns linked to the plant described here below.

❷ *Replace the example here below bythe flow scheme of the considered plant / process unit*



Simplified Plant & Units flow scheme (2/2)

❸ *Summarize here the name of the units*

	Consumer Description (1)
Unit A	
Unit B	
Unit C	
Unit D	
Unit E	
Unit F	
Unit G	
Unit H	
…	

❹*Please detail here below the identified safety concerns related to the process.*

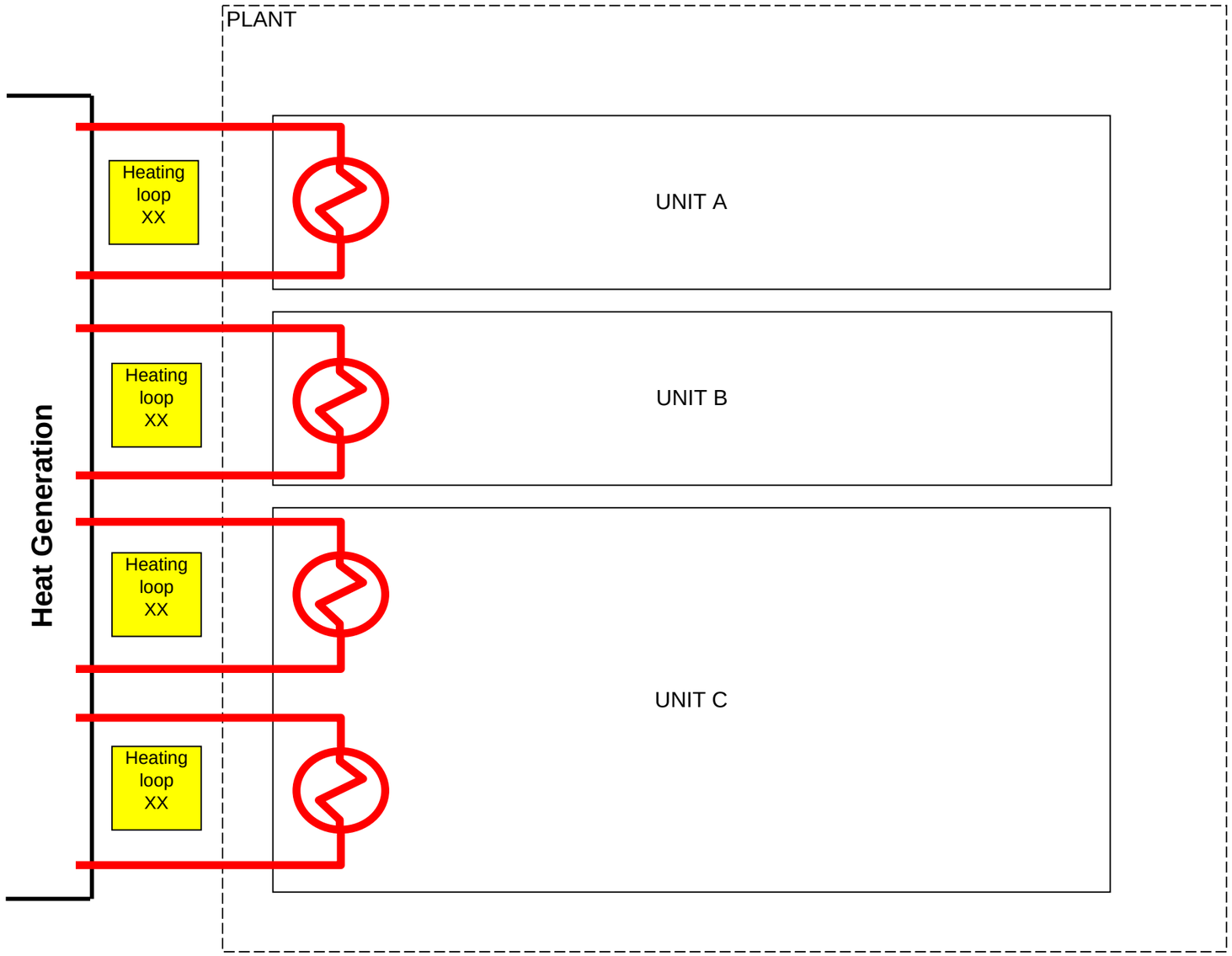
SAFETY CONCERNS.
-
-
-
-
-
-
-
-
-
-
-
-
-
-
-

Characterization of the heating needs (1/2)

Objectives of the sheet

This sheet gathers the information related to the needs for heat in the plant or process unit.

❺ *Replacet the example here below by the heating needs of the process units described in Sheet 3*



Characterization of the heating needs (2/2)

❻ *Fill the table here in accordance with the units described in Sheet 3 and with the scheme here above.Definitions of the parameters are given in Sheet 2.*

Consumer duty

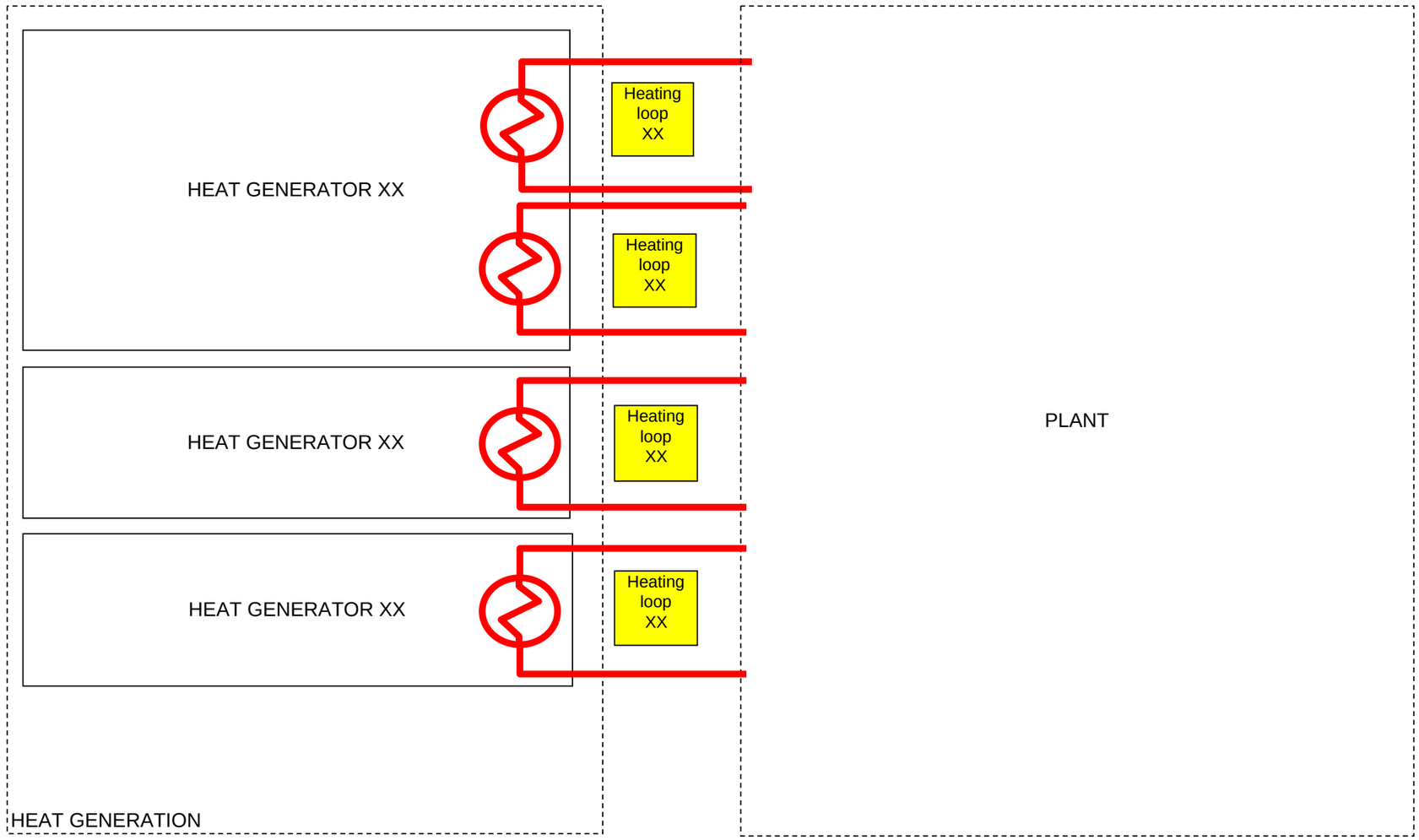
Consumer Description (1)		Heating Loop N° (2)	Temperature (3)		Allowable Temperature Range (4)		Typical ramp up and down (5)	Continuous OR Intermittent (6)	Effect of heat supply disruption (7)	Consumption leveling (8)	Comments
			inlet	outlet	T_{min}	T_{max}					
Unit A											
Unit B											
Unit C											
Unit D											
Unit E											
Unit F											
Unit G											
Unit H											
Unit I											
Unit K											
Unit L											
…											

Characterization of the existing heat generators (1/2)

Objectives of the sheet

This sheet gathers data on the existing heat generation systems.

❼ *Replace the example here below by the existing heat generation systems for the considered plant / process units. Heating LoopNumbers shall be in accordance with Sheet 4.*



Characterization of the existing heat generators (2/2)

Fill both table shere in accordance with the heating loops described in Sheet 4 and with the scheme here above. Definitions of the parameters are given in Sheet 2.

HEAT GENERATORS

Heating loop N° (2)	Heat generator description (9)	Fuel type (10)	Fuel Consumption		Power (kWth) (13)			Backup in case of shutdown (14)	Comments
			External (11)	Offgases (12)	Min.	Nominal	Max.		

MEDIA TABLE

Heating loop N° (2)	Media type (15)	Temperature (16)		Pressure (17)		Mass flow (18)			Comments
		inlet	outlet	inlet	outlet	Min.	Normal	Max.	
0									
0									
0									
0									
0									
0									
0									
0									
0									
0									
0									
0									

Industries & Processes

	Partners	Contact	Industries	Plant / Process Units
1	AMEC	Derek BUCKTHORPE derek.buckthorpe@amec.com	Oil sands	Steam Assisted Gravity Drainage
				Cyclic Steam Stimulation
			Petrochemicals	
			Ciment	Pyro processing
			Paper and Pulp	Kraft process
2	Air Liquide	Claire WEBER claire.weber@airliquide.com	Industrial Gas production	Oxygen Production - Ceramic membrane
				CO Production - dry reforming
3	Arcelor Mittal	Gerard Griffay gerard.griffay@arcelormittal.com	Steel Making	Coke Making
				SteelMaking
				Hot Rolling
				Direct Reduced Iron (DRI)
				Power Plant
				Lime plant
				Sintering
				Blast Furnace
4	Fortum	Harri Tuomisto harri.tuomisto@fortum.com	Paper and Pulp	
			Oil refinery	
			Co-generation	
			District Heating	
5	FZJ	Werner von Lensa w.von.lensa@fz-juelich.de	Coal	Coal Gasification
				Steam Methane Reforming
6	GDF Suez - Tractebel	Carmen Angulo carmen.angulo@gdfsuez.com	Co-Generation	-
7	NWU/PBMR	Gideon Greyvenstein	Petroleum Products	Fischer-Tropsch
				Steam Methane Reforming
		gideon.greyvenstein@pbmr.co.za	Oil Sands	
8	NWU	Frik van Niekerk frik.vanniekerk@nwu.ac.za	Hydrogen Production	Thermochemical water splitting
				Hybrid Sulfur
				Sulfur Iodine
				High Temperature Electrolysis
9	PROCHEM	Marek Tarka mtarka@prochem.com.pl	Refinery	Aromatics Extractive Distillation
				Crude Oil Distillates Hydrotreatment
				Crude Oil Distillation
10	SAIPEM	Jacques RUER jacques.ruer@saipem-sa.com	Energy Storage	Pumped Heat Electricity storage
11	Technip	Gaetano Iaquaniello iaquaniello.g@ktispa.it	Refinery	
			Hydrogen production	Steam Reforming
				Membranes Steam Reforming
12	USG (DSM) / BEC	Anton Baaten anton.baaten@me.com	Wide Range (Petro)chemicals incl. Urea & Ethylene	Utilities supply
13	ZAK	Marek Zuber marek.zuber@zak.com.pl	Nitrogen Fertilizers	Syngas production
				Hydrogen production
				Nitric acid synthesis
				Ammonia synthesis
				Urea production
			Organic Synthesis	Oxo processes
				Alcohol synthesis
				Phthalate plasticizers synthesis
				Phtalic and maleic anhydride

8.2 Annex 2: End user answers

EUROPAIRS - Task 1.1: End-User Processes
Inventory of data

Please fill this cover sheet for the identification of the document. The list of industries and processes in given in Sheet 6 for reference.

File	PARTNER_INDUSTRY_PROCESS_revA.xls

Partner	AMEC
Industry	Cement
Plant / Process Unit	Cement Pyroprocessing Plant

Objectives of the document:

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Each partner is asked to fill one FORM for each plant or process unit (existing & future).
This collection of data is the core of Task 1.1 and will be consolidated in order to de used as base information for Task 1.3.

A notice to correctly fill this FORM is given in a dedicated sheet.

Status of the document

Rev. A	29/09/2009	First issue by SSA of the document for comments from the partners of Task 1.1, 1.2 & 1.3

End-User Requirements fOr industrial Process heat Applications with Innovative nuclear Reactors for Sustainable energy supply

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This FORM is divided into 5 sheets:

Sheet 1	**HOME.** This is the cover sheet of the file. Before anything else, please make sure that you have filled the requested information: name of the partner and of the contact - name of the industry and of the described plant / process unit (in accordance with the list given in annex (sheet 6)).
Sheet 2	**NOTICE.** A notice is included in the FORM. It includes the description of the various sheets and a quick definition of the requested parameters.
Sheet 3	**PLANT/PROCESS DESCRIPTION.** In this sheet, the partner shall give a simplified flow scheme of the process with basic information such as the name of the process units included in the overall process (/plant) and the name and main characteristics (pressure, temperature, flowrate) of the fluids/products circulating between the units. You are free to use the proposed draft scheme or to include an existing flow scheme (as a jpeg image or as an attached pdf file). You can add any identified safety issues related to this process in this sheet.
Sheet 4	**CONSUMER DUTY.** This sheet focuses, within the process described in sheet 3, on the identification of the heating needs (independently from how heat is generated). Definition and examples of the data requested are given here below. They aim at characterizing the need in terms of physical conditions, operational philosophy, reliability, flexibility and safety.
Sheet 5	**PRODUCER SPECIFICATIONS.** In a second time, this sheet focuses on the existing systems implemented for heat generation. This information will be valuable in order to study the technical and economical impact of the use of HTR as an alternate for generation of High Temperature heat. Two sets of data are asked for: definition of the heat producer and characterization of the heat transportation media. Definition and examples of the data requested are given here below.
Sheet 6	**ANNEX.** Reminder of the list of partners and the related industries and plants / processes.

To be filled in priority

Can be filled in a second time

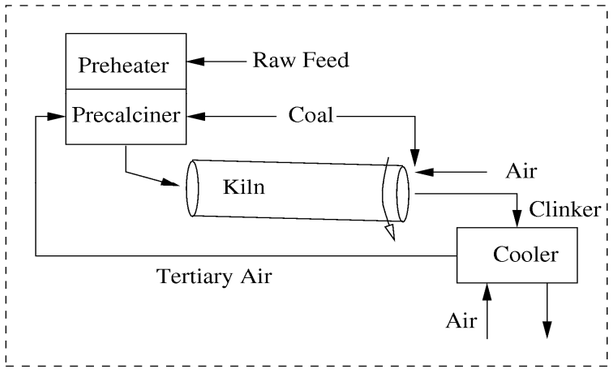
REFERENCES & GLOSSARY

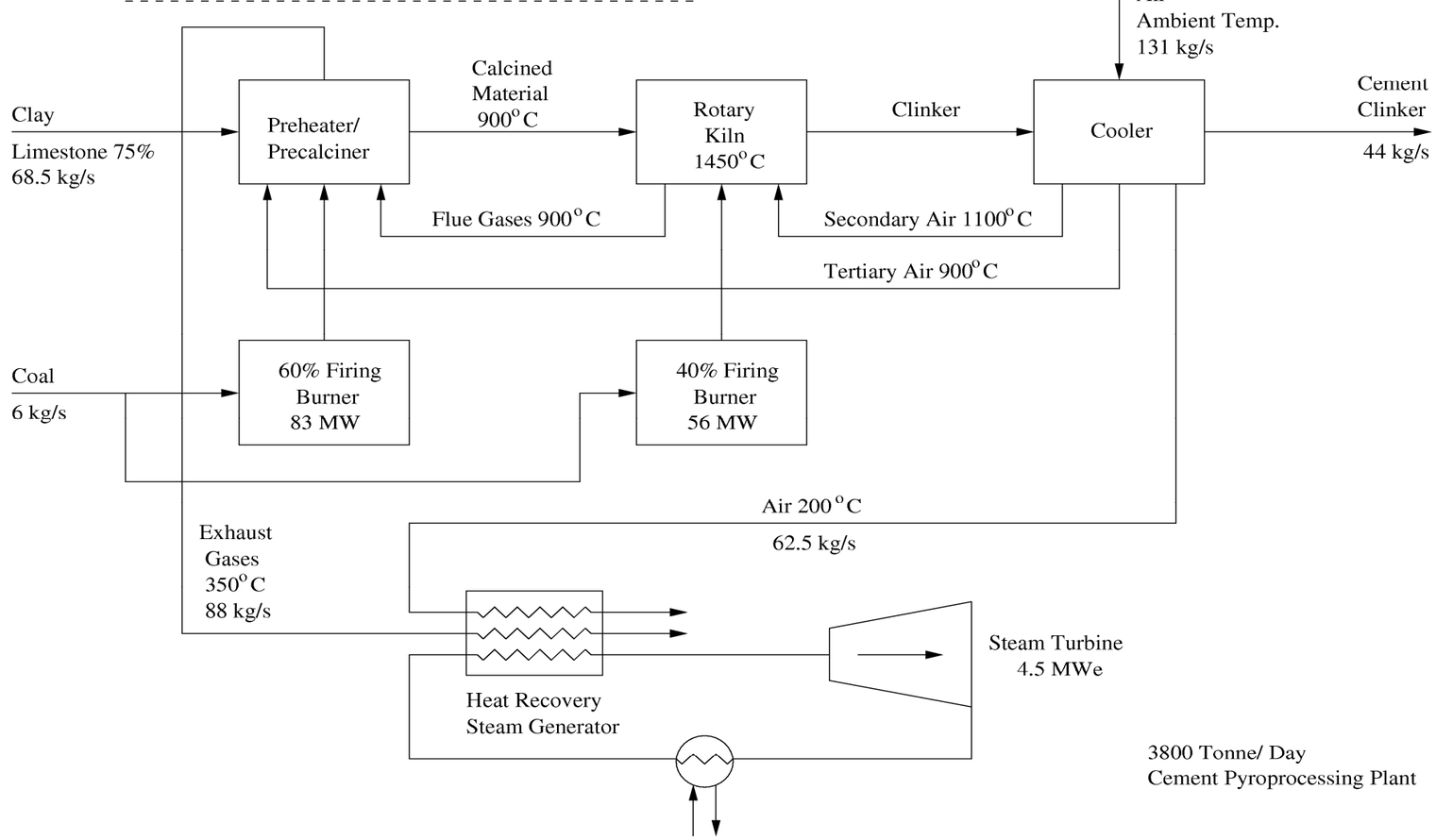
Ref.	*Parameter Name*	*Definition*	*Unit or Example*
		Process Description	
	Plant	An ensemble of process units	
	Process Unit	One elementary process unit that can be included in a plant or several plants	
(1)	Consumer Description	Name of the unit within the process (identical in sheet 3 and sheet 4)	steam reformming, hydrocracking…
		Consumer Duty - NEED	
(2)	Heating Loop N°	To number the heating loops properly allow to navigate easily in the file and to link heat production and heat consumption.	
(3)	Temperature	Temperature of the heating fluid at the inlet and the outlet **of the unit**.	K, °C, °F
(4)	Allowable Temperature Range	Min. & Max. temperatures at which the process takes place at full efficiency and without material damages.	K, °C, °F
(5)	Typical ramp up & down	Typical temperature gradient to be observed during transients (heating up & cool down).	K/min, K/s, K/h…
(6)	Continuous / Intermittent	Need for continuous heat supply (continuous process) or intermittent heat supply (batch process).	C or I (batch duration, number per year…)
(7)	Effect of heat supply disruption	What happens if case of heat supply disruption? Characterize the criticality of the heat supply.	shutdown of the process, degraded performances..
(8)	Consumption Leveling	Is there a possibility of leveling between the various heat loops in the process? Characterize the flexibility.	YES or NO
		Heat Producer Specifications - EXISTING	
(9)	Heat Generator Description	Name of the heat supply utility	
(10)	Fuel Type	Description of the fuel needed for heat generation	gas, coal, offgas (from unit X), electricity…
(11)	Fuel Consumption / External	Periodic consumption of external fuel	tpy, tph, Sm3/y…
(12)	Fuel Consumption / Offgases	Periodic consumption of internal fuel (offgases from another unit)	tpy, Sm^3/y…
(13)	Power	at least nominal power is required	MWh…
(14)	Back-up in case of shutdown	what is the planned back-up in case of the disruption og the normal heat supply?	
(15)	Media Type	Description of the media used for heat transportation between heat generation and consumption.	steam, oil, molten salt…
(16)	Temperature	Temperature of the medium at the inlet and at the outlet of the heat generation system	K, °C, °F
(17)	Pressure	Pressure of the medium at the inlet and at the outlet of the heat generation system	bar, psi…
(18)	Mass Flow	Mass flow rate of the heat transportation medium	tpy, Sm3/y…

Simplified Plant & Units flow scheme (1/2)

Objectives of the scheme

This simplified scheme aims at providing an easy understanding of the overall considered process.
You can add as many units as you think necessary.
In addition, please list at the bottom the safety concerns linked to the plant described here below.





Simplified Plant & Units flow scheme (2/2)

❸ *Summarize here the name of the units*

	Consumer Description (1)
Unit A	Preheater/ Precalciner
Unit B	Rotary Kiln
Unit C	Cooler
Unit D	
Unit E	
Unit F	
Unit G	
Unit H	
…	

❹ *Please detail here below the identified safety concerns related to the process.*

SAFETY CONCERNS.
Not necessarily safety concerns, but for optimal operation:
Monitoring of the circulating elements is necessary to avoid buildup in the preheater/ precalciner system.
The kiln has to be run with a relatively constant kiln feed and burn rate in order to achieve stable operation.
Kiln alignment and shell temperatures are required to be monitored frequently.
In addition, a reasonable O2 level has to be maintained to avoid excessive CO generation.
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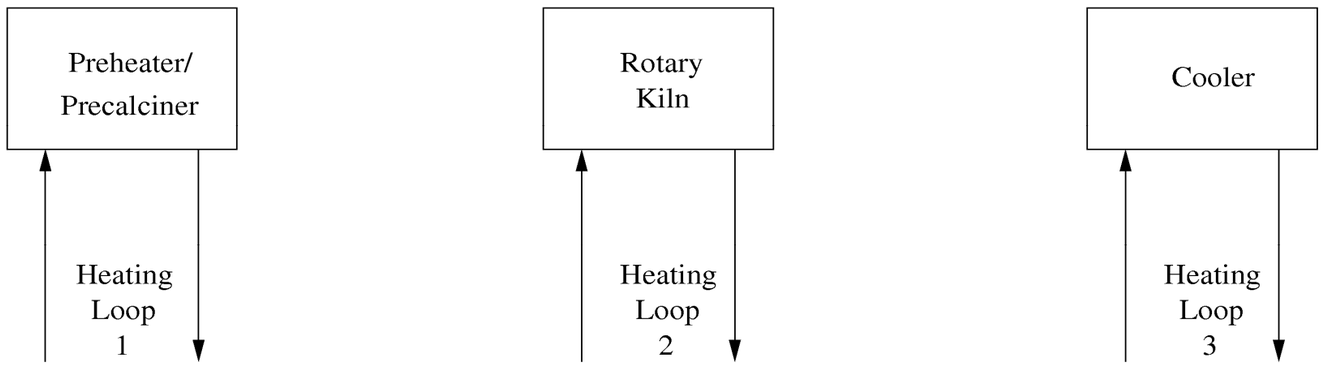
Characterization of the heating needs (1/2)

Objectives of the sheet

This sheet gathers the information related to the needs for heat in the plant or process unit.

❺ *Replacet the example here below by the heating needs of the process units described in Sheet 3*



Characterization of the heating needs (2/2)

❻ *Fill the table here in accordance with the units described in Sheet 3 and with the scheme here above.Definitions of the parameters are given in Sheet 2.*

Consumer duty

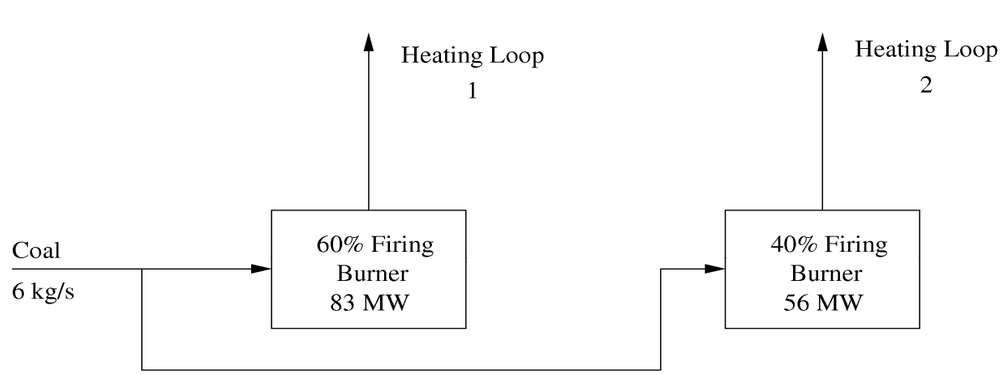
Consumer Description (1)		Heating Loop N° (2)	Temperature (3)		Allowable Temperature Range (4)		Typical ramp up and down (5)	Continuous OR Intermittent (6)	Effect of heat supply disruption (7)	Consumption leveling (8)	Comments
			inlet	outlet	T_{min}	T_{max}					
Unit A	Preheater/ Precalciner	1	900°C	350°C	800°C	1000°C	1K/min	Continuous		Yes	
Unit B	Rotary Kiln	2	1450°C	900°C	1300°C	1500°C	1K/min Preheating takes about 36 to 48 hr, for kiln repair, about 24 h. Full production possible in a few hours. With a proper shutdown procedure, the kiln can be stopped and cooled down for maintenance within 24 to 36 hours.	Continuous	Trip and run down the kiln, and trigger the emergency shutdown procedure. Slow the kiln fan to mininmum speed. Complete shutdown of the kiln system may be necessary.	Yes	
Unit C	Cooler	3	20°C	1100°C				Continuous		Yes	
Unit D											
Unit E											
Unit F											
Unit G											
Unit H											
Unit I											
Unit K											
Unit L											
…											

Characterization of the existing heat generators (1/2)

Objectives of the sheet

This sheet gathers data on the existing heat generation systems.

❼ *Replace the example here below by the existing heat generation systems for the considered plant / process units. Heating LoopNumbers shall be in accordance with Sheet 4.*



Characterization of the existing heat generators (2/2)

❽ *Fill both table shere in accordance with the heating loops described in Sheet 4 and with the scheme here above. Definitions of the parameters are given in Sheet 2.*

HEAT GENERATORS

Heating loop N° (2)	Heat generator description (9)	Fuel type (10)	Fuel Consumption		Power (kWth) (13)			Backup in case of shutdown (14)	Comments
			External (11)	Offgases (12)	Min.	Nominal	Max.		
1	Burner	Coal	3.5 kg/s		81MW	83 MW	85 MW	N/A	Fired at 60% for calcination of the meal to 95% in the calciner.
2	Burner	Coal	3 kg/s		54 MW	56 MW	58 MW	N/A	Fired at 40% for balance of heat in the kiln for clinkerization.

MEDIA TABLE

Heating loop N° (2)	Media type (15)	Temperature (16)		Pressure (17)		Mass flow (18)			Comments
		inlet	outlet	inlet	outlet	Min.	Normal	Max.	
1	Heating by radiative and conductive heat transfer from luminous flame and combustion gases.								
2	See above.								
0									
0									
0									
0									
0									
0									
0									
0									
0									
0									

Industries & Processes

	Partners	Contact	Industries	Plant / Process Units
1	AMEC	Derek BUCKTHORPE derek.buckthorpe@amec.com	Oil sands	Steam Assisted Gravity Drainage
				Cyclic Steam Stimulation
			Petrochemicals	
			Cement	Pyro processing
			Paper and Pulp	Kraft process
2	Air Liquide	Claire WEBER claire.weber@airliquide.com	Industrial Gas production	Oxygen Production - Ceramic membrane
				CO Production - dry reforming
3	Arcelor Mittal	Gerard Griffay gerard.griffay@arcelormittal.com	Steel Making	Coke Making
				SteelMaking
				Hot Rolling
				Direct Reduced Iron (DRI)
				Power Plant
				Lime plant
				Sintering
				Blast Furnace
4	Fortum	Harri Tuomisto harri.tuomisto@fortum.com	Paper and Pulp	
			Oil refinery	
			Co-generation	
			District Heating	
5	FZJ	Werner von Lensa w.von.lensa@fz-juelich.de	Coal	Coal Gasification
				Steam Methane Reforming
6	GDF Suez - Tractebel	Carmen Angulo carmen.angulo@gdfsuez.com	Co-Generation	-
7	NWU/PBMR	Gideon Greyvenstein	Petroleum Products	Fischer-Tropsch
				Steam Methane Reforming
		gideon.greyvenstein@pbmr.co.za	Oil Sands	
8	NWU	Frik van Niekerk frik.vanniekerk@nwu.ac.za	Hydrogen Production	Thermochemical water splitting
				Hybrid Sulfur
				Sulfur Iodine
				High Temperature Electrolysis
9	PROCHEM	Marek Tarka mtarka@prochem.com.pl	Refinery	Aromatics Extractive Distillation
				Crude Oil Distillates Hydrotreatment
				Crude Oil Distillation
10	SAIPEM	Jacques RUER jacques.ruer@saipem-sa.com	Energy Storage	Pumped Heat Electricity storage
11	Technip	Gaetano Iaquaniello iaquaniello.g@ktispa.it	Refinery	
			Hydrogen production	Steam Reforming
				Membranes Steam Reforming
12	USG (DSM) / BEC	Anton Baaten anton.baaten@me.com	Wide Range (Petro)chemicals incl. Urea & Ethylene	Utilities supply
13	ZAK	Marek Zuber marek.zuber@zak.com.pl	Nitrogen Fertilizers	Syngas production
				Hydrogen production
				Nitric acid synthesis
				Ammonia synthesis
				Urea production
			Organic Synthesis	Oxo processes
				Alcohol synthesis
				Phthalate plasticizers synthesis
				Phtalic and maleic anhydride

EUROPAIRS - Task 1.1: End-User Processes
Inventory of data

Please fill this cover sheet for the identification of the document. The list of industries and processes in given in Sheet 6 for reference.

File	PARTNER_INDUSTRY_PROCESS_revA.xls

Partner	AMEC
Industry	Paper and Pulp
Plant / Process Unit	Kraft Pulp Mill

Objectives of the document:

This document aims at gathering efficiently relevant data related to the end-user processes.
Each partner is asked to fill one FORM for each plant or process unit (existing & future).
This collection of data is the core of Task 1.1 and will be consolidated in order to de used as base information for Task 1.3.

A notice to correctly fill this FORM is given in a dedicated sheet.

Status of the document

Rev. A	29/09/2009	First issue by SSA of the document for comments from the partners of Task 1.1, 1.2 & 1.3

End-User Requirements fOr industrial Process heat Applications with Innovative nuclear Reactors for Sustainable energy supply

How to use this FORM?

This FORM is divided into 5 sheets:

Sheet 1	**HOME.** This is the cover sheet of the file. Before anything else, please make sure that you have filled the requested information: name of the partner and of the contact - name of the industry and of the described plant / process unit (in accordance with the list given in annex (sheet 6)).
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Sheet 4	**CONSUMER DUTY.** This sheet focuses, within the process described in sheet 3, on the identification of the heating needs (independently from how heat is generated). Definition and examples of the data requested are given here below. They aim at characterizing the need in terms of physical conditions, operational philosophy, reliability, flexibility and safety.
Sheet 5	**PRODUCER SPECIFICATIONS.** In a second time, this sheet focuses on the existing systems implemented for heat generation. This information will be valuable in order to study the technical and economical impact of the use of HTR as an alternate for generation of High Temperature heat. Two sets of data are asked for: definition of the heat producer and characterization of the heat transportation media. Definition and examples of the data requested are given here below.
Sheet 6	**ANNEX.** Reminder of the list of partners and the related industries and plants / processes.

To be filled in priority

Can be filled in a second time

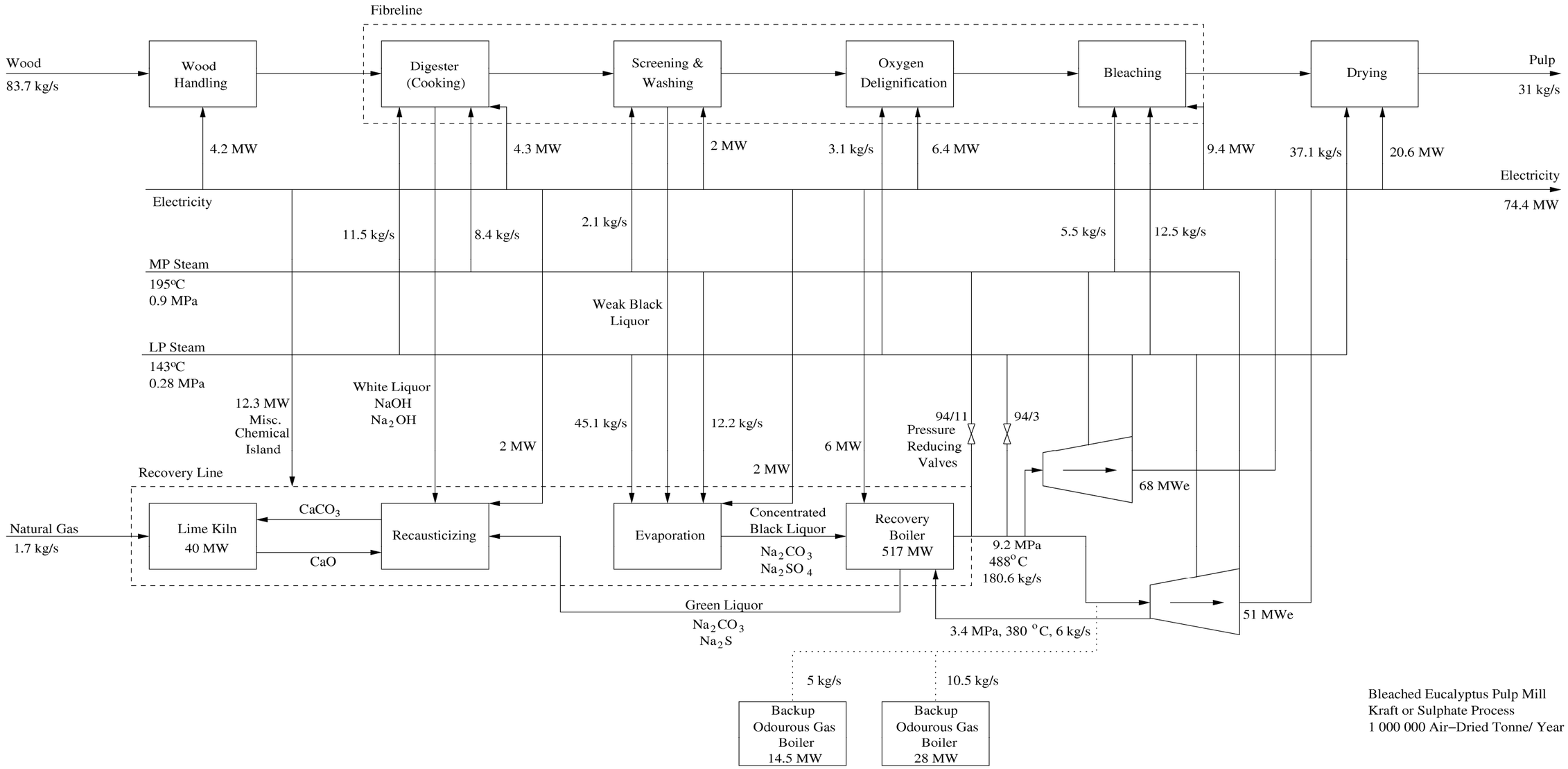
REFERENCES & GLOSSARY

Ref.	*Parameter Name*	*Definition*	*Unit or Example*
		Process Description	
	Plant	An ensemble of process units	
	Process Unit	One elementary process unit that can be included in a plant or several plants	
(1)	Consumer Description	Name of the unit within the process (identical in sheet 3 and sheet 4)	steam reformming, hydrocracking…
		Consumer Duty - NEED	
(2)	Heating Loop N°	To number the heating loops properly allow to navigate easily in the file and to link heat production and heat consumption.	
(3)	Temperature	Temperature of the heating fluid at the inlet and the outlet **of the unit**.	K, °C, °F
(4)	Allowable Temperature Range	Min. & Max. temperatures at which the process takes place at full efficiency and without material damages.	K, °C, °F
(5)	Typical ramp up & down	Typical temperature gradient to be observed during transients (heating up & cool down).	K/min, K/s, K/h…
(6)	Continuous / Intermittent	Need for continuous heat supply (continuous process) or intermittent heat supply (batch process).	C or I (batch duration, number per year…)
(7)	Effect of heat supply disruption	What happens if case of heat supply disruption? Characterize the criticality of the heat supply.	shutdown of the process, degraded performances..
(8)	Consumption Leveling	Is there a possibility of leveling between the various heat loops in the process? Characterize the flexibility.	YES or NO
		Heat Producer Specifications - EXISTING	
(9)	Heat Generator Description	Name of the heat supply utility	
(10)	Fuel Type	Description of the fuel needed for heat generation	gas, coal, offgas (from unit X), electricity…
(11)	Fuel Consumption / External	Periodic consumption of external fuel	tpy, tph, Sm3/y…
(12)	Fuel Consumption / Offgases	Periodic consumption of internal fuel (offgases from another unit)	tpy, Sm^3/y…
(13)	Power	at least nominal power is required	MWh…
(14)	Back-up in case of shutdown	what is the planned back-up in case of the disruption og the normal heat supply?	
(15)	Media Type	Description of the media used for heat transportation between heat generation and consumption.	steam, oil, molten salt…
(16)	Temperature	Temperature of the medium at the inlet and at the outlet of the heat generation system	K, °C, °F
(17)	Pressure	Pressure of the medium at the inlet and at the outlet of the heat generation system	bar, psi…
(18)	Mass Flow	Mass flow rate of the heat transportation medium	tpy, Sm3/y…

Simplified Plant & Units flow scheme (1/2)

Objectives of the scheme

This simplified scheme aims at providing an easy understanding of the overall considered process.
You can add as many units as you think necessary.
In addition, please list at the bottom the safety concerns linked to the plant described here below.



Bleached Eucalyptus Pulp Mill
Kraft or Sulphate Process
1 000 000 Air–Dried Tonne/ Year

Simplified Plant & Units flow scheme (2/2)

❸ *Summarize here the name of the units*

	Consumer Description (1)
Unit A	Digester
Unit B	Screening and Washing
Unit C	Oxygen Delignification
Unit D	Bleachers
Unit E	Dryers
Unit F	Recovery Boiler
Unit G	Evaporator
Unit H	Recausticizer
I	Lime Kiln
All	

❹*Please detail here below the identified safety concerns related to the process.*

SAFETY CONCERNS.
The main safety concerns for the evaporators and Digester is Non Condensable Gas release (Toxic and Noxious gases that are generated and normally burnt such as Hydrogen sulphide, di methyl sulphide and Di methyl disulphide), and in softwood mills turpentine systems. These gases are flammable, and require handling in special systems to avoid gas explosions, personal hazards and environmental discharges (that are oderous and annoying to neighbours).
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The main safety concern for the recovery boiler is prevention of a smelt-water explosion. These occasionally occur, if the water tubes or steam drum are/is perforated, and water flows onto the molten smelt bed. There are a number of specific procedures to avoid this, including drum level indication and alerting (including a video camera on manual level indicator on the actual drum, rapid drain procedures, and the use of blast reinforced stairwell, for personnel exit. Newer furnaces may also have smaller smelt beds.
See digester.
See general safety concerns below.
General safety concerns include personnel protection from handling or hot chemical streams and steam systems, corrosive chemical handling for acid and caustic streams, reactive chemical handling for chemicals such as hydrogen peroxide and chlorine dioxide, protection from rotating machine (pumps, paper machine drives), and protection for occupational exposure to excessive heat (paper machine dryers/penthouses in digesters, lime kiln area)
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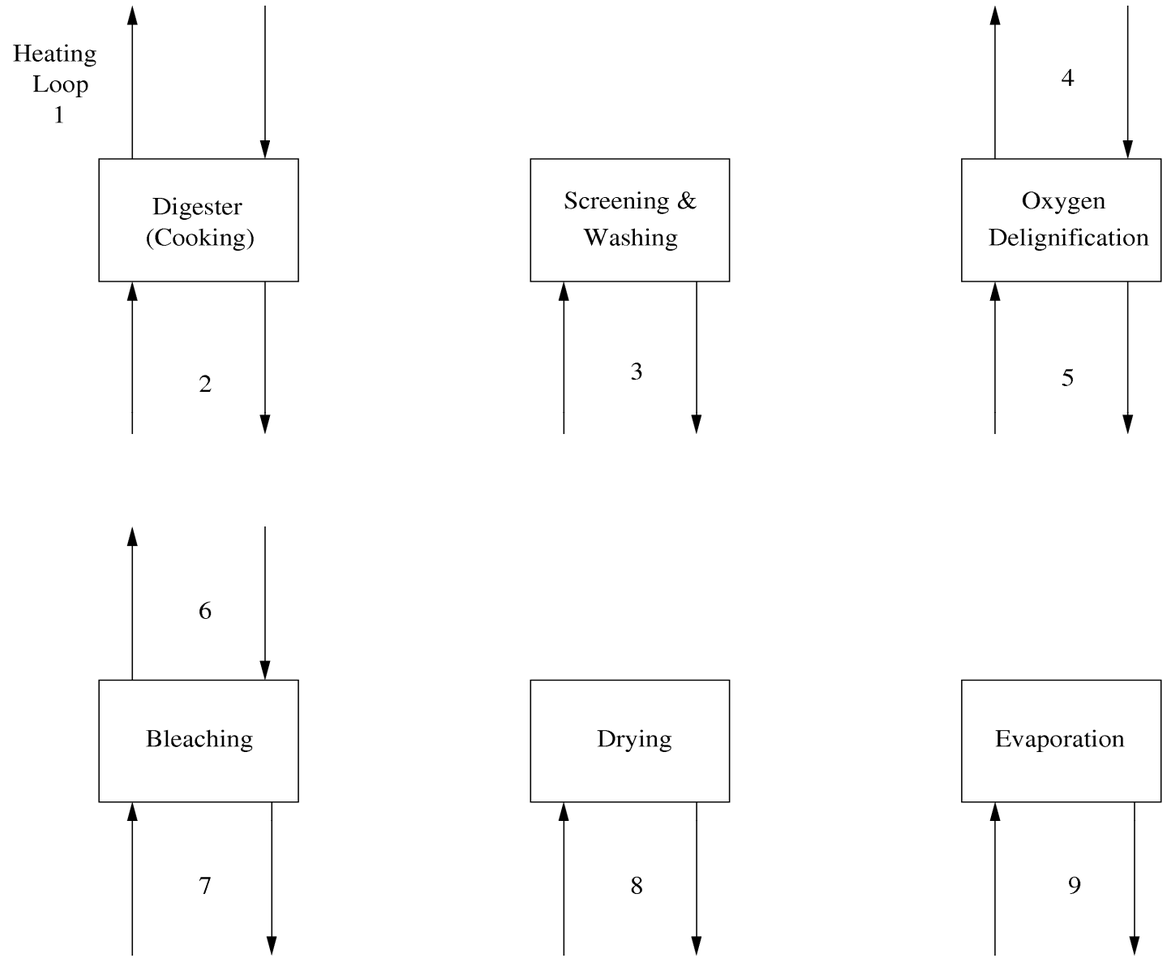
Characterization of the heating needs (1/2)

Objectives of the sheet

This sheet gathers the information related to the needs for heat in the plant or process unit.

❺ *Replacet the example here below by the heating needs of the process units described in Sheet 3*



Characterization of the heating needs (2/2)

❻ *Fill the table here in accordance with the units described in Sheet 3 and with the scheme here above.Definitions of the parameters are given in Sheet 2.*

Consumer duty

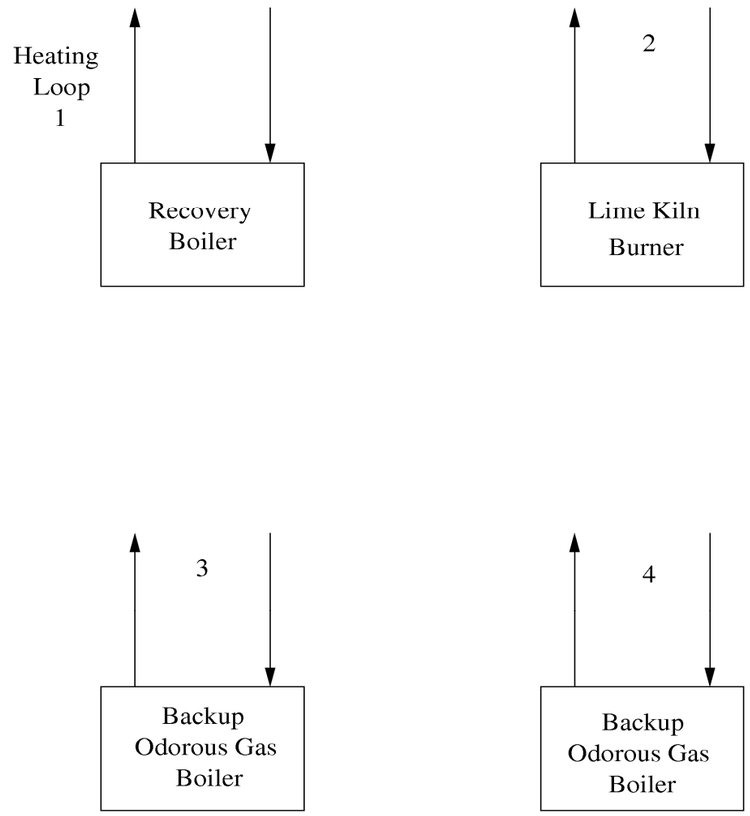
Consumer Description (1)		Heating Loop N° (2)	Temperature (3)		Allowable Temperature Range (4)		Typical ramp up and down (5)	Continuous OR Intermittent (6)	Effect of heat supply disruption (7)	Consumption leveling (8)	Comments
			inlet	outlet	T_{min}	T_{max}					
Unit A	Digester	1 2	195°C 143°C	70°C 70°C	Steam with a small amount of superheat of (5-10 °C) is generally sufficent.	200°C 150°C	Standard start-up for the majority of unit processes is 4-8 hr Occasionally one part of the process may go down – for say 6-8 hours, and interstage storage tanks may take some of this load. The mill normally has pressure reducing valves (and often back pressure turbines) to control the steam pressures, and also use a deaerator and	Continuous	If steam supply should fail, the evaporators and digesters are normally “shut or bottled in”, but with some non condensable gas venting, to avoid reactive pressure build-up (in the digesters some heat is evolved from chemical reactions). In an integrated pulp and paper plant, the paper machine will come to a crash stop (which is not preferred).	Yes	Storage is available between the Brown Fiberline and Bleach Plant, Bleach Plant and Paper machine (Stock or Pulp Storage Tanks) , Brown Fiberline and evaporators (weak black liquor), evaporator and recovery boiler (strong black liquor), Recovery and Recausticing (Green Liquor Storage), Recausticing and Brown Fiberline
Unit B	Screening & Washing	3	195°C	70°C	See above		See above	Continuous	See above	Yes	
Unit C	Oxygen Delig.	4 5	195°C 143°C	70°C 70°C	See above		See above	Continuous	See above	Yes	
Unit D	Bleacher	6 7	195°C 143°C	70°C	See above		See above	Continuous	See above	Yes	
Unit E	Dryer	8	143°C	70°C						Yes	
Unit F	Recovery Boiler										
Unit G	Evaporator	9	195°C 143°C	70°C	See above			Continuous		Yes	
Unit H	Recausticizer										
Unit I	Lime Kiln										

Characterization of the existing heat generators (1/2)

Objectives of the sheet

This sheet gathers data on the existing heat generation systems.

❼ *Replace the example here below by the existing heat generation systems for the considered plant / process units. Heating LoopNumbers shall be in accordance with Sheet 4.*



Characterization of the existing heat generators (2/2)

❽ *Fill both table shere in accordance with the heating loops described in Sheet 4 and with the scheme here above. Definitions of the parameters are given in Sheet 2.*

HEAT GENERATORS

Heating loop N° (2)	Heat generator description (9)	Fuel type (10)	Fuel Consumption		Power (kWth) (13)			Backup in case of shutdown (14)	Comments
			External (11)	Offgases (12)	Min.	Nominal	Max.		
1	Recovery Boiler	Black Liquor	300 kg/s			517 MW_{th}		Backup boilers (loops 3 and 4) typicallyprovide steam for restart and *essential* operations	The mill normally has pressure reducing valves (and often back pressure turbines) to control the steam pressures, and also use a deaerator and sometimes steam accumulators, to help control transients.
2	Lime Kiln Burner	Natural Gas	1.7 kg/s			40 MW			
3	Backup Odourous Gas Boiler	Odorous Gas From Process				14.5 MW			
4	Backup Odourous Gas Boiler	Odorous Gas From Process				28 MW			

MEDIA TABLE

Heating loop N° (2)	Media type (15)	Temperature (16)		Pressure (17)		Mass flow (18)			Comments
		inlet	outlet	inlet	outlet	Min.	Normal	Max.	
1	Steam	50°C							
2	Steam								
3	Steam								
4	Steam								
0									
0									
0									
0									
0									
0									
0									

Industries & Processes

	Partners	Contact	Industries	Plant / Process Units
1	AMEC	Derek BUCKTHORPE derek.buckthorpe@amec.com	Oil sands	Steam Assisted Gravity Drainage
				Cyclic Steam Stimulation
			Petrochemicals	
			Ciment	Pyro processing
			Paper and Pulp	Kraft process
2	Air Liquide	Claire WEBER claire.weber@airliquide.com	Industrial Gas production	Oxygen Production - Ceramic membrane
				CO Production - dry reforming
3	Arcelor Mittal	Gerard Griffay gerard.griffay@arcelormittal.com	Steel Making	Coke Making
				SteelMaking
				Hot Rolling
				Direct Reduced Iron (DRI)
				Power Plant
				Lime plant
				Sintering
				Blast Furnace
4	Fortum	Harri Tuomisto harri.tuomisto@fortum.com	Paper and Pulp	
			Oil refinery	
			Co-generation	
			District Heating	
5	FZJ	Werner von Lensa w.von.lensa@fz-juelich.de	Coal	Coal Gasification
				Steam Methane Reforming
6	GDF Suez - Tractebel	Carmen Angulo carmen.angulo@gdfsuez.com	Co-Generation	-
7	NWU/PBMR	Gideon Greyvenstein	Petroleum Products	Fischer-Tropsch
				Steam Methane Reforming
		gideon.greyvenstein@pbmr.co.za	Oil Sands	
8	NWU	Frik van Niekerk frik.vanniekerk@nwu.ac.za	Hydrogen Production	Thermochemical water splitting
				Hybrid Sulfur
				Sulfur Iodine
				High Temperature Electrolysis
9	PROCHEM	Marek Tarka mtarka@prochem.com.pl	Refinery	Aromatics Extractive Distillation
				Crude Oil Distillates Hydrotreatment
				Crude Oil Distillation
10	SAIPEM	Jacques RUER jacques.ruer@saipem-sa.com	Energy Storage	Pumped Heat Electricity storage
11	Technip	Gaetano Iaquaniello iaquaniello.g@ktispa.it	Refinery	
			Hydrogen production	Steam Reforming
				Membranes Steam Reforming
12	USG (DSM) / BEC	Anton Baaten anton.baaten@me.com	Wide Range (Petro)chemicals incl. Urea & Ethylene	Utilities supply
13	ZAK	Marek Zuber marek.zuber@zak.com.pl	Nitrogen Fertilizers	Syngas production
				Hydrogen production
				Nitric acid synthesis
				Ammonia synthesis
				Urea production
			Organic Synthesis	Oxo processes
				Alcohol synthesis
				Phthalate plasticizers synthesis
				Phtalic and maleic anhydride

EUROPAIRS - Task 1.1: End-User Processes
Inventory of data

Please fill this cover sheet for the identification of the document. The list of industries and processes in given in Sheet 6 for reference.

File	PARTNER_INDUSTRY_PROCESS_revA.xls

Partner	AMEC
Industry	Petroleum Industry
Plant / Process Unit	Steam Assisted Gravity Drainage (SAGD) Oil Sands Extraction Facility

Objectives of the document:

This document aims at gathering efficiently relevant data related to the end-user processes.
Each partner is asked to fill one FORM for each plant or process unit (existing & future).
This collection of data is the core of Task 1.1 and will be consolidated in order to de used as base information for Task 1.3.

A notice to correctly fill this FORM is given in a dedicated sheet.

Status of the document

Rev. A	29/09/2009	First issue by SSA of the document for comments from the partners of Task 1.1, 1.2 & 1.3

End-User Requirements fOr industrial Process heat Applications with Innovative nuclear Reactors for Sustainable energy supply

How to use this FORM?

This FORM is divided into 5 sheets:

Sheet 1	**HOME.** This is the cover sheet of the file. Before anything else, please make sure that you have filled the requested information: name of the partner and of the contact - name of the industry and of the described plant / process unit (in accordance with the list given in annex (sheet 6)).
Sheet 2	**NOTICE.** A notice is included in the FORM. It includes the description of the various sheets and a quick definition of the requested parameters.
Sheet 3	**PLANT/PROCESS DESCRIPTION.** In this sheet, the partner shall give a simplified flow scheme of the process with basic information such as the name of the process units included in the overall process (/plant) and the name and main characteristics (pressure, temperature, flowrate) of the fluids/products circulating between the units. You are free to use the proposed draft scheme or to include an existing flow scheme (as a jpeg image or as an attached pdf file). You can add any identified safety issues related to this process in this sheet.
Sheet 4	**CONSUMER DUTY.** This sheet focuses, within the process described in sheet 3, on the identification of the heating needs (independently from how heat is generated). Definition and examples of the data requested are given here below. They aim at characterizing the need in terms of physical conditions, operational philosophy, reliability, flexibility and safety.
Sheet 5	**PRODUCER SPECIFICATIONS.** In a second time, this sheet focuses on the existing systems implemented for heat generation. This information will be valuable in order to study the technical and economical impact of the use of HTR as an alternate for generation of High Temperature heat. Two sets of data are asked for: definition of the heat producer and characterization of the heat transportation media. Definition and examples of the data requested are given here below.
Sheet 6	**ANNEX.** Reminder of the list of partners and the related industries and plants / processes.

To be filled in priority

Can be filled in a second time

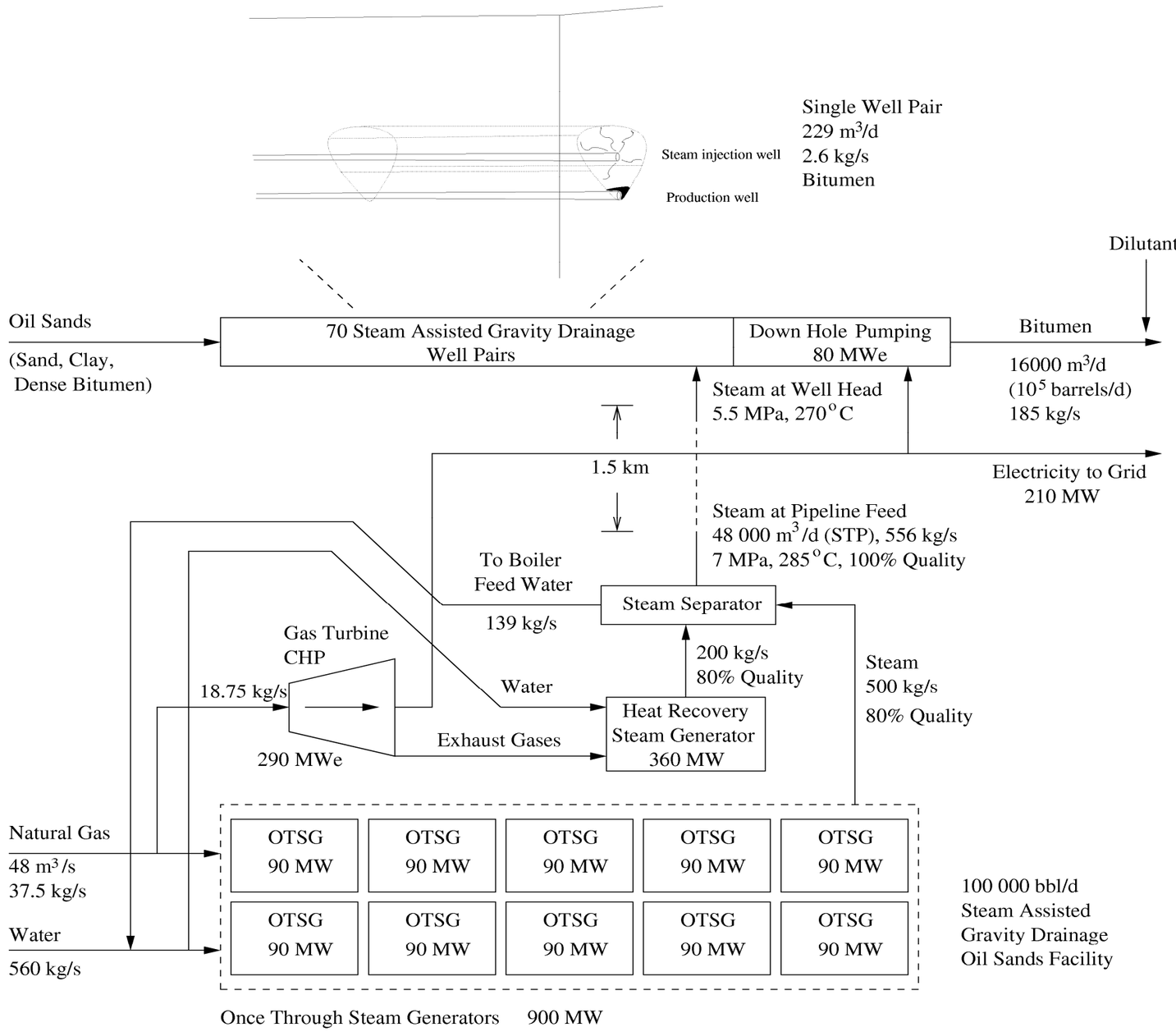
REFERENCES & GLOSSARY

Ref.	*Parameter Name*	*Definition*	*Unit or Example*
		Process Description	
	Plant	An ensemble of process units	
	Process Unit	One elementary process unit that can be included in a plant or several plants	
(1)	Consumer Description	Name of the unit within the process (identical in sheet 3 and sheet 4)	steam reformming, hydrocracking…
		Consumer Duty - NEED	
(2)	Heating Loop N°	To number the heating loops properly allow to navigate easily in the file and to link heat production and heat consumption.	
(3)	Temperature	Temperature of the heating fluid at the inlet and the outlet **of the unit**.	K, °C, °F
(4)	Allowable Temperature Range	Min. & Max. temperatures at which the process takes place at full efficiency and without material damages.	K, °C, °F
(5)	Typical ramp up & down	Typical temperature gradient to be observed during transients (heating up & cool down).	K/min, K/s, K/h…
(6)	Continuous / Intermittent	Need for continuous heat supply (continuous process) or intermittent heat supply (batch process).	C or I (batch duration, number per year…)
(7)	Effect of heat supply disruption	What happens if case of heat supply disruption? Characterize the criticality of the heat supply.	shutdown of the process, degraded performances..
(8)	Consumption Leveling	Is there a possibility of leveling between the various heat loops in the process? Characterize the flexibility.	YES or NO
		Heat Producer Specifications - EXISTING	
(9)	Heat Generator Description	Name of the heat supply utility	
(10)	Fuel Type	Description of the fuel needed for heat generation	gas, coal, offgas (from unit X), electricity…
(11)	Fuel Consumption / External	Periodic consumption of external fuel	tpy, tph, Sm3/y…
(12)	Fuel Consumption / Offgases	Periodic consumption of internal fuel (offgases from another unit)	tpy, Sm^3/y…
(13)	Power	at least nominal power is required	MWh…
(14)	Back-up in case of shutdown	what is the planned back-up in case of the disruption og the normal heat supply?	
(15)	Media Type	Description of the media used for heat transportation between heat generation and consumption.	steam, oil, molten salt…
(16)	Temperature	Temperature of the medium at the inlet and at the outlet of the heat generation system	K, °C, °F
(17)	Pressure	Pressure of the medium at the inlet and at the outlet of the heat generation system	bar, psi…
(18)	Mass Flow	Mass flow rate of the heat transportation medium	tpy, Sm3/y…

Simplified Plant & Units flow scheme (1/2)

Objectives of the scheme

This simplified scheme aims at providing an easy understanding of the overall considered process.
You can add as many units as you think necessary.
In addition, please list at the bottom the safety concerns linked to the plant described here below.



Simplified Plant & Units flow scheme (2/2)

❸ *Summarize here the name of the units*

	Consumer Description (1)
Unit A	SAGD Well Pairs
Unit B	
Unit C	
Unit D	
Unit E	
Unit F	
Unit G	
Unit H	
…	

❹*Please detail here below the identified safety concerns related to the process.*

SAFETY CONCERNS.
Process leaks (hot emulsion or steam, H2S) spraying onto operators, rotating equipment operation and boiler control. Water hammer, the pressure surge apparent during heating up of the steam lines can be dangerous if done improperly. In addition, some of the process chemicals used can be very hazardous.
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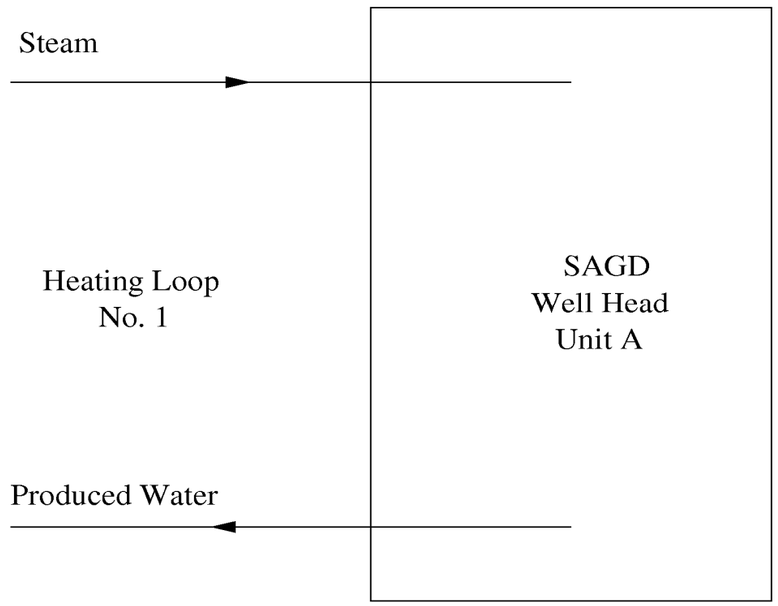
Characterization of the heating needs (1/2)

Objectives of the sheet

This sheet gathers the information related to the needs for heat in the plant or process unit.



Characterization of the heating needs (2/2)

❻ *Fill the table here in accordance with the units described in Sheet 3 and with the scheme here above.Definitions of the parameters are given in Sheet 2.*

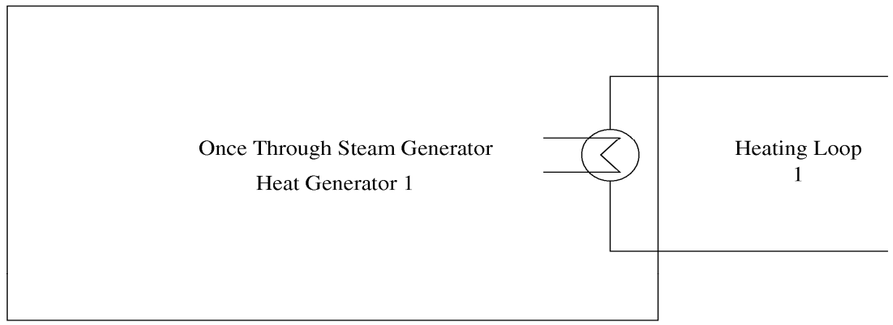
Consumer duty

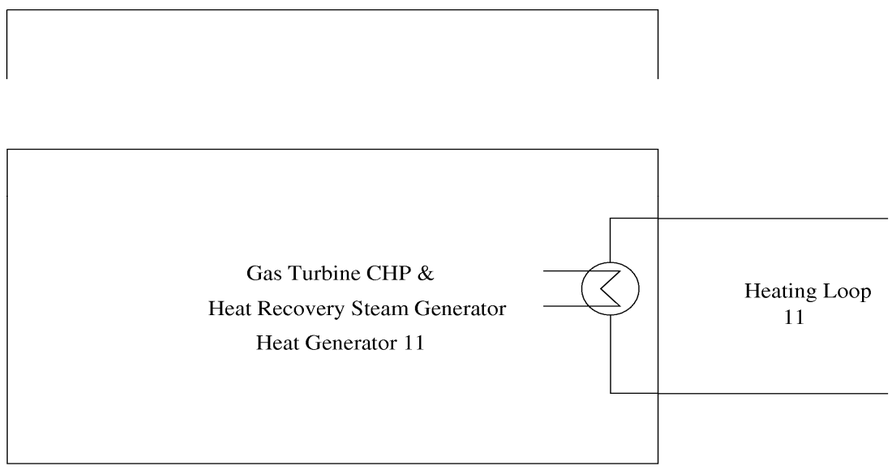
Consumer Description (1)		Heating Loop N° (2)	Temperature (3)		Allowable Temperature Range (4)		Typical ramp up and down (5)	Continuous OR Intermittent (6)	Effect of heat supply disruption (7)	Consumption leveling (8)	Comments
			inlet	outlet	T_{min}	T_{max}					
Unit A	SAGD Well Head	1	270°C	85°C	210	310	OTSG can warm up in a couple of hours. (1.5 K/min). The steam distribution pipelines might take 12 hrs to warm up. Killing the wells for equipment turnaround could take 24 hours.	Continuous	Steam disruptions if longer than a couple of days can cause damage to the underground horizontal steam chamber that is being developed. Long shutdowns can prevent the proper shape at full size from being developed. Also, long shutdowns on a partially developed well can create the need for production well and injection well circulation for days or weeks to reheat the well and reservoir to the proper temperature prior to resuming normal SAGD operation.	N/A	Hard stop of production may be necessary. A steam shut down over a couple of hours cause the steam pipelines to cool down and water condensate to form. A cold line could take up 12 hours to slowly heat up depending on length. A slow low pressure/temperature heat up is required to prevent water hammer.
Unit B											
Unit C											
Unit D											

Characterization of the existing heat generators (1/2)

Objectives of the sheet

This sheet gathers data on the existing heat generation systems.





Characterization of the existing heat generators (2/2)

❽ *Fill both table shere in accordance with the heating loops described in Sheet 4 and with the scheme here above. Definitions of the parameters are given in Sheet 2.*

HEAT GENERATORS

Heating loop N° (2)	Heat generator description (9)	Fuel type (10)	Fuel Consumption		Power (kWth) (13)			Backup in case of shutdown (14)	Comments
			External (11)	Offgases (12)	Min.	Nominal	Max.		
1	OSTG	Natural Gas	18.75 kg/s		Flexible so long as net steam production is maintained.	90 MW_{th}		Redundancy through provision of additional steam generators is common.	
9 Additional Steam Generators as above.									
11	HRSG	Natural Gas	18.75 kg/s		360 MW_{th}			See above.	

MEDIA TABLE

Heating loop N° (2)	Media type (15)	Temperature (16)		Pressure (17)		Mass flow (18)			Comments
		inlet	outlet	inlet	outlet	Min.	Normal	Max.	
1	Steam	170°C	304°C	9.6 Mpag	9.6 Mpag		50 kg/s		
11	Steam	170°C	304°C	9.6 Mpag	9.6 Mpag	200 kg/s			
0									
0									
0									
0									
0									
0									
0									

Industries & Processes

	Partners	Contact	Industries	Plant / Process Units
1	AMEC	Derek BUCKTHORPE derek.buckthorpe@amec.com	Oil sands	Steam Assisted Gravity Drainage
				Cyclic Steam Stimulation
			Petrochemicals	
			Cement	Pyro processing
			Paper and Pulp	Kraft process
2	Air Liquide	Claire WEBER claire.weber@airliquide.com	Industrial Gas production	Oxygen Production - Ceramic membrane
				CO Production - dry reforming
3	Arcelor Mittal	Gerard Griffay gerard.griffay@arcelormittal.com	Steel Making	Coke Making
				SteelMaking
				Hot Rolling
				Direct Reduced Iron (DRI)
				Power Plant
				Lime plant
				Sintering
				Blast Furnace
4	Fortum	Harri Tuomisto harri.tuomisto@fortum.com	Paper and Pulp	
			Oil refinery	
			Co-generation	
			District Heating	
5	FZJ	Werner von Lensa w.von.lensa@fz-juelich.de	Coal	Coal Gasification
				Steam Methane Reforming
6	GDF Suez - Tractebel	Carmen Angulo carmen.angulo@gdfsuez.com	Co-Generation	-
7	NWU/PBMR	Gideon Greyvenstein	Petroleum Products	Fischer-Tropsch
				Steam Methane Reforming
		gideon.greyvenstein@pbmr.co.za	Oil Sands	
8	NWU	Frik van Niekerk frik.vanniekerk@nwu.ac.za	Hydrogen Production	Thermochemical water splitting
				Hybrid Sulfur
				Sulfur Iodine
				High Temperature Electrolysis
9	PROCHEM	Marek Tarka mtarka@prochem.com.pl	Refinery	Aromatics Extractive Distillation
				Crude Oil Distillates Hydrotreatment
				Crude Oil Distillation
10	SAIPEM	Jacques RUER jacques.ruer@saipem-sa.com	Energy Storage	Pumped Heat Electricity storage
11	Technip	Gaetano Iaquaniello iaquaniello.g@ktispa.it	Refinery	
			Hydrogen production	Steam Reforming
				Membranes Steam Reforming
12	USG (DSM) / BEC	Anton Baaten anton.baaten@me.com	Wide Range (Petro)chemicals incl. Urea & Ethylene	Utilities supply
13	ZAK	Marek Zuber marek.zuber@zak.com.pl	Nitrogen Fertilizers	Syngas production
				Hydrogen production
				Nitric acid synthesis
				Ammonia synthesis
				Urea production
			Organic Synthesis	Oxo processes
				Alcohol synthesis
				Phthalate plasticizers synthesis
				Phtalic and maleic anhydride

EUROPAIRS - Task 1.1: End-User Processes
Inventory of data

Please fill this cover sheet for the identification of the document. The list of industries and processes in given in Sheet 6 for reference.

File	AL_IG_O2 Plant for oxycombustion_revA.xls

Partner	AL
Industry	Industiral Gas
Complex / Process Unit	ITM Oxygène plant for oxycombustion
Overall Electrical Power	71.6 MW

Objectives of the document:
This document aims at gathering efficiently relevant data related to the end-user processes.
Each partner is asked to fill one FORM for each complex or process unit (existing & future).
This collection of data is the core of Task 1.1 and will be consolidated in order to de used as base information for Task 1.3.

A notice to correctly fill this FORM is given in a dedicated sheet.

Status of the document

Rev. 0	29/09/2009	First issue by SSA of the document for comments from the partners of Task 1.1, 1.2 & 1.3
Rev. 1	21/10/2009	Issue by SSA of the finale FORM
Rev. A	02/11/2009	filled by AL - 1st draft

End-User Requirements fOr industrial Process heat Applications with Innovative nuclear Reactors for Sustainable energy supply

How to use this FORM?

This FORM is divided into 5 sheets:

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Sheet 4	**CONSUMER DUTY.** This sheet focuses, within the process described in sheet 3, on the identification of the heating needs (independently from how heat is generated). Definition and examples of the data requested are given here below. They aim at characterizing the need in terms of physical conditions, operational philosophy, reliability, flexibility and safety.
Sheet 5	**PRODUCER SPECIFICATIONS.** In a second time, this sheet focuses on the existing systems implemented for heat generation. This information will be valuable in order to study the technical and economical impact of the use of HTR as an alternate for generation of High Temperature heat. Two sets of data are asked for: definition of the heat producer and characterization of the heat transportation media. Definition and examples of the data requested are given here below.
Sheet 6	**ANNEX.** Reminder of the list of partners and the related industries and plants / processes.

To be filled in priority

Can be filled in a second time

REFERENCES & GLOSSARY

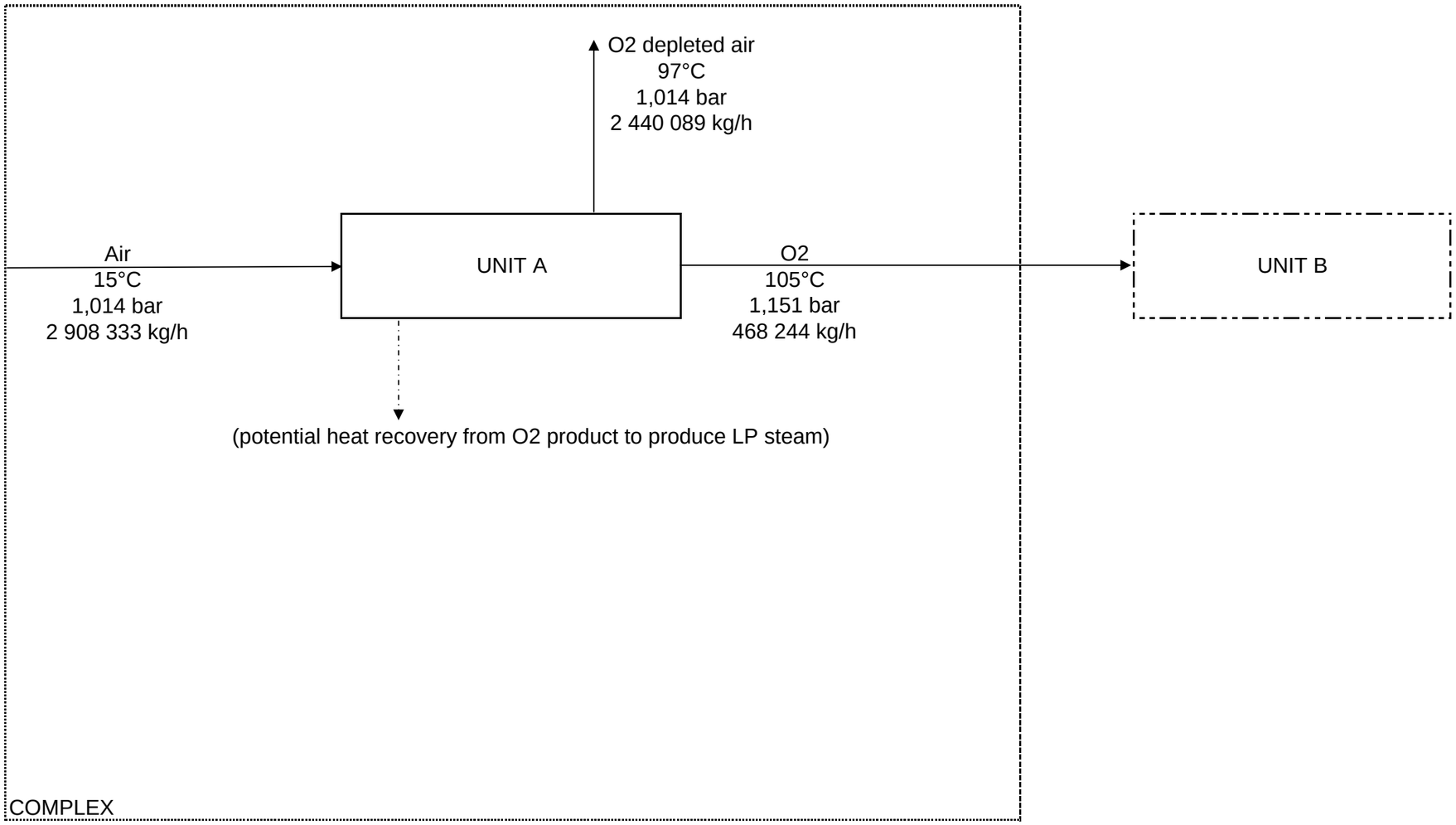
Ref.	*Parameter Name*	*Definition*	*Unit or Example*
		Process Description	
	complex	An ensemble of process units	
	Process Unit	One elementary process unit that can be included in a complex or several complexs	
(1)	Consumer Description	Name of the unit within the process (identical in sheet 3 and sheet 4)	steam reformming, hydrocracking…
		Consumer Duty - NEED	
(2)	Heating Loop N°	To number the heating loops properly allow to navigate easily in the file and to link heat production and heat consumption.	
(3)	Temperature	Temperature of the heating fluid at the inlet and the outlet **of the unit**.	K, °C, °F
(4)	Allowable Temperature Range	Min. & Max. temperatures at which the process takes place at full efficiency and without material damages.	K, °C, °F
(5)	Typical ramp up & down	Typical temperature gradient to be observed during transients (heating up & cool down).	K/min, K/s, K/h…
(6)	Continuous / Intermittent	Need for continuous heat supply (continuous process) or intermittent heat supply (batch process).	C or I (batch duration, number per year…)
(7)	Effect of heat supply disruption	What happens if case of heat supply disruption? Characterize the criticality of the heat supply.	shutdown of the process, degraded performances…
(8)	Consumption Leveling	Is there a possibility of leveling between the various heat loops in the process? Characterize the flexibility.	YES or NO
		Heat Producer Specifications - EXISTING	
(9)	Heat Generator Description	Name of the heat supply utility	
(10)	Fuel Type	Description of the fuel needed for heat generation	gas, coal, offgas (from unit X), electricity…
(11)	Fuel Consumption / External	Periodic consumption of external fuel	tpy, tph, Sm3/y…
(12)	Fuel Consumption / Offgases	Periodic consumption of internal fuel (offgases from another unit)	tpy, Sm^3/y…
(13)	Power	at least nominal power is required	MWh…
(14)	Back-up in case of shutdown	what is the planned back-up in case of the disruption og the normal heat supply?	
(15)	Media Type	Description of the media used for heat transportation between heat generation and consumption.	steam, oil, molten salt…
(16)	Temperature	Temperature of the medium at the inlet and at the outlet of the heat generation system	K, °C, °F
(17)	Pressure	Pressure of the medium at the inlet and at the outlet of the heat generation system	bar, psi…
(18)	Mass Flow	Mass flow rate of the heat transportation medium	tpy, Sm3/y…
(19)	Consumed in process ?	Indicate if the heat medium (for inst. STEAM) is recycled to heat generation OR consumpted afterwards in the process	YES or NO

Simplified Plant & Units flow scheme (1/2)

Objectives of the scheme

This simplified scheme aims at providing an easy understanding of the overall considered process.
You can add as many units as you think necessary.
In addition, please list at the bottom the safety concerns linked to the plant described here below.

❷ *Replace the example here below bythe flow scheme of the considered complex / process unit*



Simplified Plant & Units flow scheme (2/2)

❸ *Summarize here the name of the units*

	Consumer Description (1)
Unit A	ITM Oxygen Plant
Unit B	coal Boiler
Unit C	
Unit D	
Unit E	
Unit F	
Unit G	
Unit H	
…	

❹ *Please detail here below the identified safety concerns related to the process.*

SAFETY CONCERNS.
- high temperature, O2 depleted air, O2 enriched air, ignition, pressurised equipments
-
-
-
-
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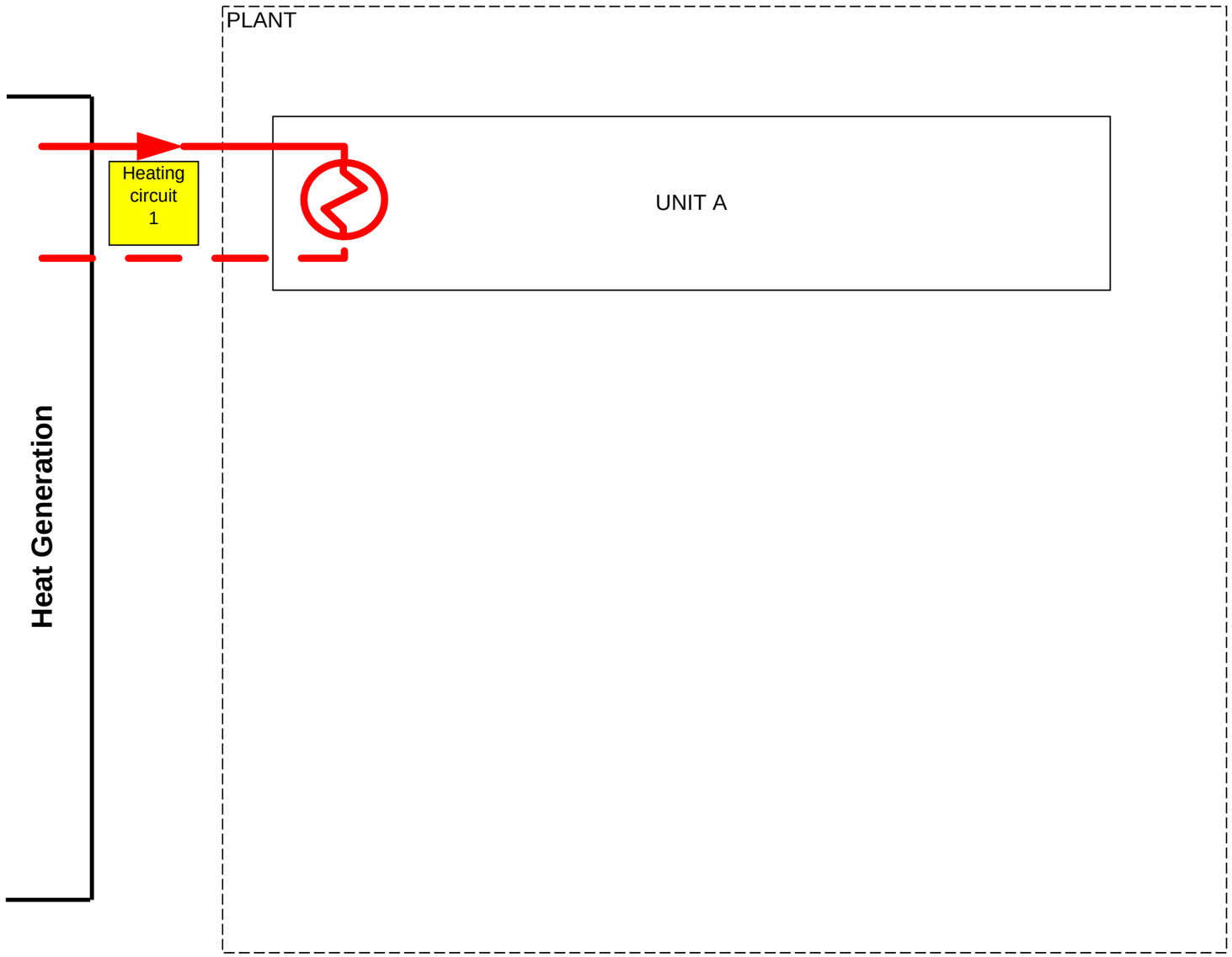
-
-

Characterization of the heating needs (1/2)

Objectives of the sheet

This sheet gathers the information related to the needs for heat in the plant or process unit.

❺ *Replacet the example here below by the heating needs of the process units described in Sheet 3*



Characterization of the heating needs (2/2)

❻ *Fill the table here in accordance with the units described in Sheet 3 and with the scheme here above.Definitions of the parameters are given in Sheet 2.*

Consumer duty

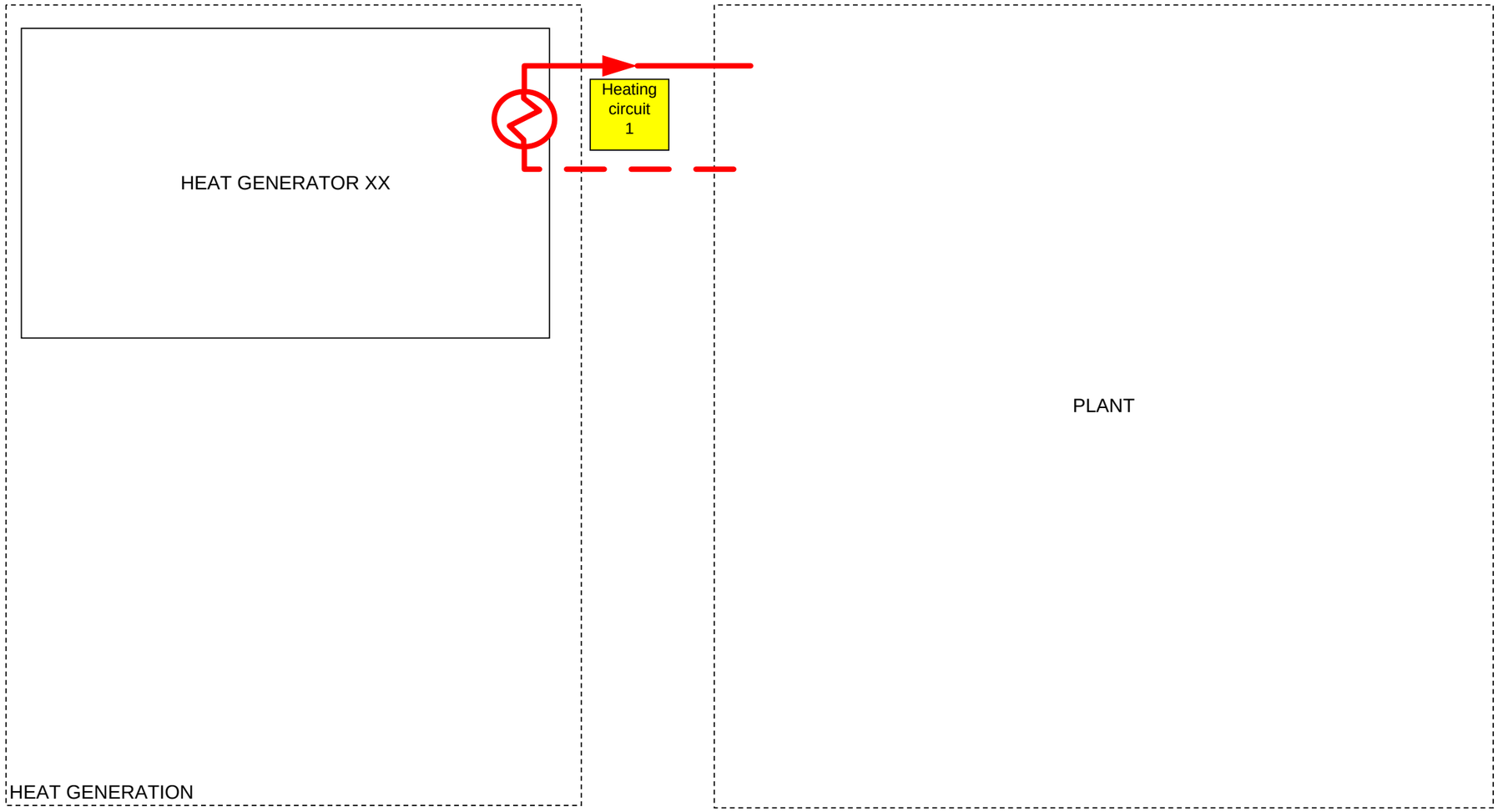
Consumer Description (1)		Heating Circuit N° (2)	Temperature (3)		Allowable Temperature Range (4)		Typical ramp up and down (5)	Continuous OR Intermittent (6)	Effect of heat supply disruption (7)	Consumption leveling (8)	Comments
			inlet	outlet	T_{min}	T_{max}					
Unit A	ITM O2 plant	1	=802°C +50°C	=695°C +50°C			10°/min transitoire phase problem is linked to the oxygen partial pressure control and its evolution at the two sides of membrane	Continuous	membrane no more permeable - membrane material degradation	no	+50°C = T heat - T fluid
Unit B											
Unit C											
Unit D											
Unit E											
Unit F											
Unit G											
Unit H											
Unit I											
Unit K											
Unit L											
…											

Characterization of the future heat generators (1/2)

Objectives of the sheet

This sheet gathers data on the existing heat generation systems.

❼ *Replace the example here below by the existing heat generation systems for the considered complex / process units. Heating Circuit Numbers shall be in accordance with Sheet 4.*



Characterization of the future heat generators (2/2)

❽ *Fill both table shere in accordance with the heating circuits described in Sheet 4 and with the scheme here above. Definitions of the parameters are given in Sheet 2.*

HEAT GENERATORS

Heating circuit N° (2)	Heat generator description (9)	Fuel type (10)	Fuel Consumption		Power (kWth) (13)			Backup in case of shutdown (14)	Comments
			External (11)	Offgases (12)	Min.	Nominal	Max.		
1	HTR	nuclear				99 043			IMT oxygen plants are futur process (R&D stage) - only nuclear heat is considered (at least, external very high temperature heat source)

MEDIA TABLE

Heating circuit N° (2)	Media type (15)	Temperature (16)		Pressure (17)		Mass flow (18)			Consumed in the process ? (19)	Comments
		inlet	outlet	inlet	outlet	Min.	Normal	Max.		
1	to be determined - depends on the high temperature heat exchanger and associated media fluid									
0										
0										
0										
0										
0										
0										
0										
0										
0										
0										

Industries & Processes

	Partners	Contact	Industries	Plant / Process Units
1	AMEC	Derek BUCKTHORPE derek.buckthorpe@amec.com	Oil sands	Steam Assisted Gravity Drainage
				Cyclic Steam Stimulation
			Petrochemicals	
			Ciment	Pyro processing
			Paper and Pulp	Kraft process
2	Air Liquide	Claire WEBER claire.weber@airliquide.com	Industrial Gas production	Oxygen Production - Ceramic membrane
				CO Production - dry reforming
3	Arcelor Mittal	Gerard Griffay gerard.griffay@arcelormittal.com	Steel Making	Coke Making
				SteelMaking
				Hot Rolling
				Direct Reduced Iron (DRI)
				Power complex
				Lime complex
				Sintering
				Blast Furnace
4	Fortum	Harri Tuomisto harri.tuomisto@fortum.com	Paper and Pulp	
			Oil refinery	
			Co-generation	
			District Heating	
5	FZJ	Werner von Lensa w.von.lensa@fz-juelich.de	Coal	Coal Gasification
				Steam Methane Reforming
6	GDF Suez - Tractebel	Carmen Angulo carmen.angulo@gdfsuez.com	Co-Generation	-
7	NWU/PBMR	Gideon Greyvenstein	Petroleum Products	Fischer-Tropsch
				Steam Methane Reforming
		gideon.greyvenstein@pbmr.co.za	Oil Sands	
8	NWU	Frik van Niekerk frik.vanniekerk@nwu.ac.za	Hydrogen Production	Thermochemical water splitting
				Hybrid Sulfur
				Sulfur Iodine
				High Temperature Electrolysis
9	PROCHEM	Marek Tarka mtarka@prochem.com.pl	Refinery	Aromatics Extractive Distillation
				Crude Oil Distillates Hydrotreatment
				Crude Oil Distillation
10	SAIPEM	Jacques RUER jacques.ruer@saipem-sa.com	Energy Storage	Pumped Heat Electricity storage
11	Technip	Gaetano Iaquaniello iaquaniello.g@ktispa.it	Refinery	
			Hydrogen production	Steam Reforming
				Membranes Steam Reforming
12	USG (DSM) / BEC	Anton Baaten anton.baaten@me.com	Wide Range (Petro)chemicals incl. Urea & Ethylene	Utilities supply
13	ZAK	Marek Zuber marek.zuber@zak.com.pl	Nitrogen Fertilizers	Syngas production
				Hydrogen production
				Nitric acid synthesis
				Ammonia synthesis
				Urea production
			Organic Synthesis	Oxo processes
				Alcohol synthesis
				Phthalate plasticizers synthesis
				Phtalic and maleic anhydride

EUROPAIRS - Task 1.1: End-User Processes
Inventory of data

Please fill this cover sheet for the identification of the document. The list of industries and processes in given in Sheet 6 for reference.

File	AL_IG_O2plant for pipeline_revA.xls

Partner	AL
Industry	Industiral Gas
Complex / Process Unit	ITM Oxygène plant
Overall Electrical Power	36.5 MW

Objectives of the document:
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Status of the document

Rev. 0	29/09/2009	First issue by SSA of the document for comments from the partners of Task 1.1, 1.2 & 1.3
Rev. 1	21/10/2009	Issue by SSA of the finale FORM
Rev. A	02/11/2009	filled by AL - 1st draft

End-User Requirements fOr industrial Process heat Applications with Innovative nuclear Reactors for Sustainable energy supply

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This FORM is divided into 5 sheets:

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Sheet 2	**NOTICE.** A notice is included in the FORM. It includes the description of the various sheets and a quick definition of the requested parameters.
Sheet 3	**COMPLEX/PROCESS DESCRIPTION.** In this sheet, the partner shall give a simplified flow scheme of the process with basic information such as the name of the process units included in the overall process (/complex) and the name and main characteristics (pressure, temperature, flowrate) of the fluids/products circulating between the units. You are free to use the proposed draft scheme or to include an existing flow scheme (as a jpeg image or as an attached pdf file). You can add any identified safety issues related to this process in this sheet.
Sheet 4	**CONSUMER DUTY.** This sheet focuses, within the process described in sheet 3, on the identification of the heating needs (independently from how heat is generated). Definition and examples of the data requested are given here below. They aim at characterizing the need in terms of physical conditions, operational philosophy, reliability, flexibility and safety.
Sheet 5	**PRODUCER SPECIFICATIONS.** In a second time, this sheet focuses on the existing systems implemented for heat generation. This information will be valuable in order to study the technical and economical impact of the use of HTR as an alternate for generation of High Temperature heat. Two sets of data are asked for: definition of the heat producer and characterization of the heat transportation media. Definition and examples of the data requested are given here below.
Sheet 6	**ANNEX.** Reminder of the list of partners and the related industries and plants / processes.

To be filled in priority

Can be filled in a second time

REFERENCES & GLOSSARY

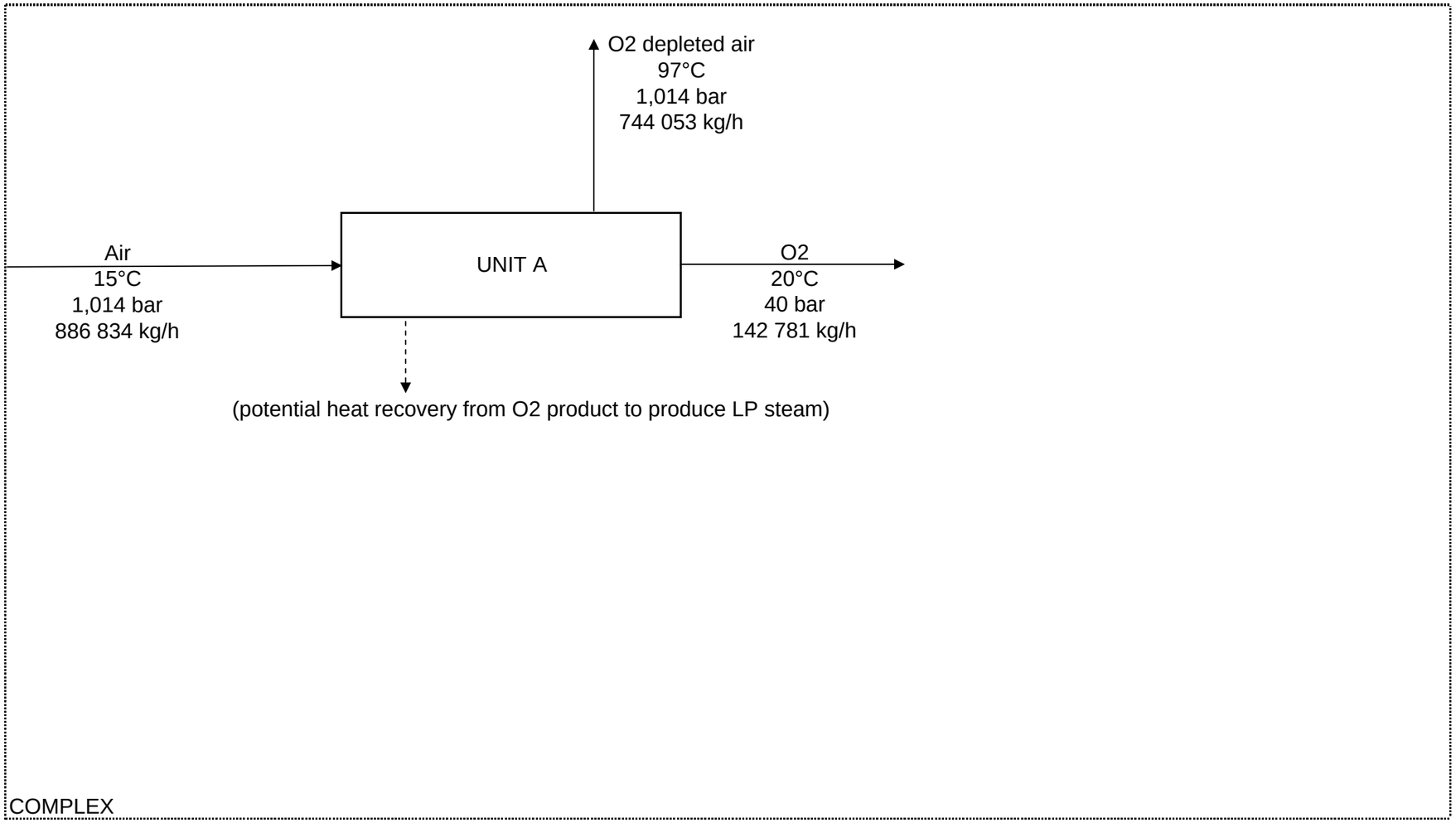
Ref.	*Parameter Name*	*Definition*	*Unit or Example*
		Process Description	
	complex	An ensemble of process units	
	Process Unit	One elementary process unit that can be included in a complex or several complexs	
(1)	Consumer Description	Name of the unit within the process (identical in sheet 3 and sheet 4)	steam reformming, hydrocracking…
		Consumer Duty - NEED	
(2)	Heating Loop N°	To number the heating loops properly allow to navigate easily in the file and to link heat production and heat consumption.	
(3)	Temperature	Temperature of the heating fluid at the inlet and the outlet **of the unit**.	K, °C, °F
(4)	Allowable Temperature Range	Min. & Max. temperatures at which the process takes place at full efficiency and without material damages.	K, °C, °F
(5)	Typical ramp up & down	Typical temperature gradient to be observed during transients (heating up & cool down).	K/min, K/s, K/h…
(6)	Continuous / Intermittent	Need for continuous heat supply (continuous process) or intermittent heat supply (batch process).	C or I (batch duration, number per year…)
(7)	Effect of heat supply disruption	What happens if case of heat supply disruption? Characterize the criticality of the heat supply.	shutdown of the process, degraded performances…
(8)	Consumption Leveling	Is there a possibility of leveling between the various heat loops in the process? Characterize the flexibility.	YES or NO
		Heat Producer Specifications - EXISTING	
(9)	Heat Generator Description	Name of the heat supply utility	
(10)	Fuel Type	Description of the fuel needed for heat generation	gas, coal, offgas (from unit X), electricity…
(11)	Fuel Consumption / External	Periodic consumption of external fuel	tpy, tph, Sm3/y…
(12)	Fuel Consumption / Offgases	Periodic consumption of internal fuel (offgases from another unit)	tpy, Sm^3/y…
(13)	Power	at least nominal power is required	MWh…
(14)	Back-up in case of shutdown	what is the planned back-up in case of the disruption og the normal heat supply?	
(15)	Media Type	Description of the media used for heat transportation between heat generation and consumption.	steam, oil, molten salt…
(16)	Temperature	Temperature of the medium at the inlet and at the outlet of the heat generation system	K, °C, °F
(17)	Pressure	Pressure of the medium at the inlet and at the outlet of the heat generation system	bar, psi…
(18)	Mass Flow	Mass flow rate of the heat transportation medium	tpy, Sm3/y…
(19)	Consumed in process ?	Indicate if the heat medium (for inst. STEAM) is recycled to heat generation OR consumpted afterwards in the process	YES or NO

Simplified Plant & Units flow scheme (1/2)

Objectives of the scheme

This simplified scheme aims at providing an easy understanding of the overall considered process.
You can add as many units as you think necessary.
In addition, please list at the bottom the safety concerns linked to the plant described here below.

❷ *Replace the example here below bythe flow scheme of the considered complex / process unit*



Simplified Plant & Units flow scheme (2/2)

❸ *Summarize here the name of the units*

	Consumer Description (1)
Unit A	ITM Oxygen Plant
Unit B	
Unit C	
Unit D	
Unit E	
Unit F	
Unit G	
Unit H	
…	

❹*Please detail here below the identified safety concerns related to the process.*

SAFETY CONCERNS.
- high temperature, O2 depleted air, O2 enriched air, ignition, pressurised equipments
-
-
-
-
-
-
-
-
-
-
-
-
-
-

Characterization of the heating needs (1/2)

Objectives of the sheet

This sheet gathers the information related to the needs for heat in the plant or process unit.

❺ *Replacet the example here below by the heating needs of the process units described in Sheet 3*

Characterization of the heating needs (2/2)

❻ *Fill the table here in accordance with the units described in Sheet 3 and with the scheme here above.Definitions of the parameters are given in Sheet 2.*

Consumer duty

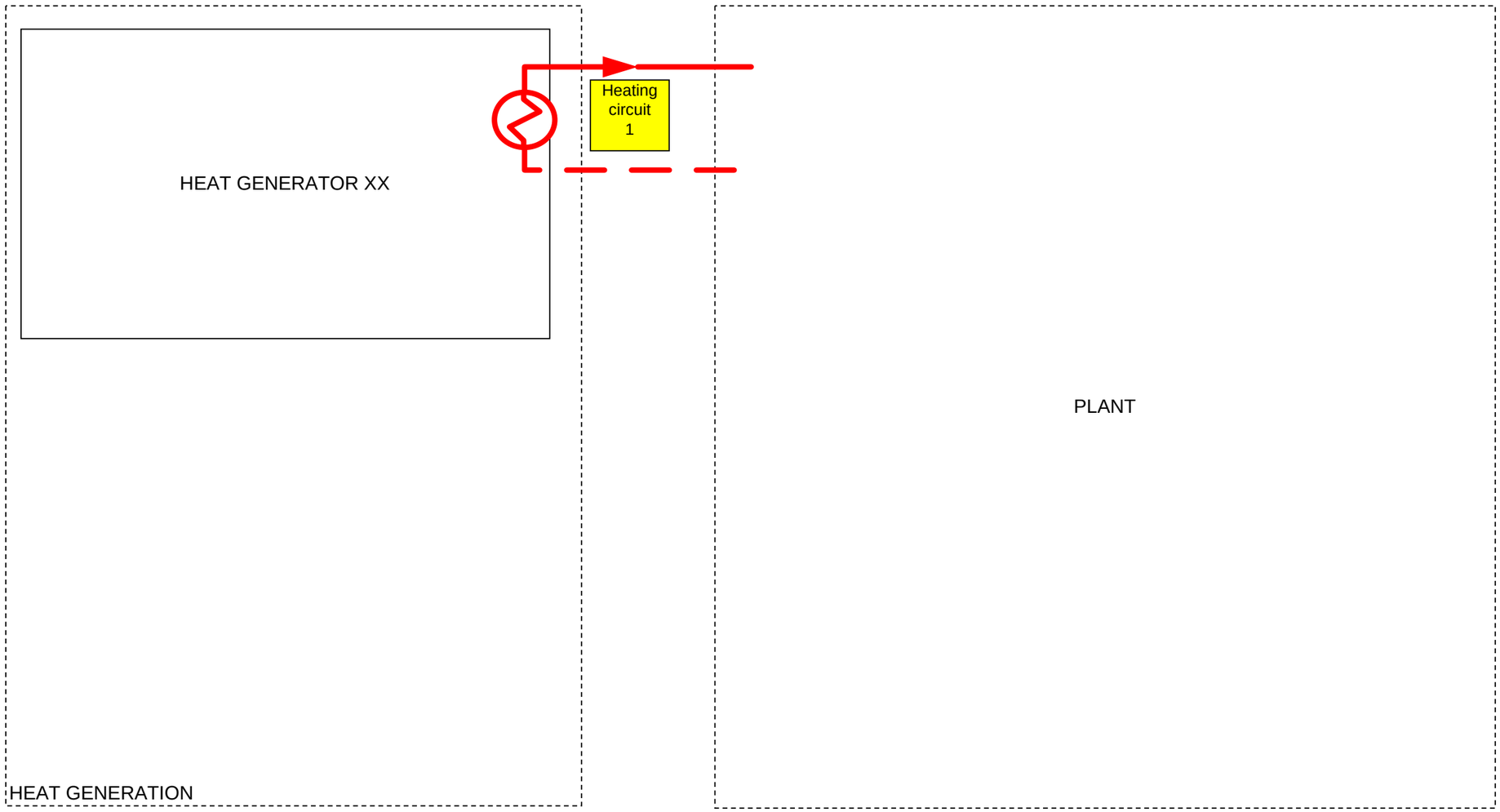
Consumer Description (1)		Heating Circuit N° (2)	Temperature (3)		Allowable Temperature Range (4)		Typical ramp up and down (5)	Continuous OR Intermittent (6)	Effect of heat supply disruption (7)	Consumption leveling (8)	Comments
			inlet	outlet	T_{min}	T_{max}					
Unit A	ITM O2 plant	1	=802°C +50°C	=695°C +50°C			10°/min transitoire phase problem is linked to the oxygen partial pressure control and its evolution at the two sides of membrane	Continuous	membrane no more permeable - membrane material degradation	no	+50°C = T heat - T fluid
Unit B											
Unit C											
Unit D											
Unit E											
Unit F											
Unit G											
Unit H											
Unit I											
Unit K											
Unit L											
…											

Characterization of the futur heat generators (1/2)

Objectives of the sheet

This sheet gathers data on the existing heat generation systems.

❼ *Replace the example here below by the existing heat generation systems for the considered complex / process units. Heating Circuit Numbers shall be in accordance with Sheet 4.*



Characterization of the future heat generators (2/2)

❽ *Fill both table shere in accordance with the heating circuits described in Sheet 4 and with the scheme here above. Definitions of the parameters are given in Sheet 2.*

HEAT GENERATORS

Heating circuit N° (2)	Heat generator description (9)	Fuel type (10)	Fuel Consumption		Power (kWth) (13)			Backup in case of shutdown (14)	Comments
			External (11)	Offgases (12)	Min.	Nominal	Max.		
1	HTR	nuclear				30 201			IMT oxygen plants are futur process (R&D stage) - only nuclear heat is considered (at least, external very high temperature heat source)

MEDIA TABLE

Heating circuit N° (2)	Media type (15)	Temperature (16)		Pressure (17)		Mass flow (18)			Consumed in the process ? (19)	Comments
		inlet	outlet	inlet	outlet	Min.	Normal	Max.		
1	to be determined - depends on the high temperature heat exchanger and associated media fluid									
0										
0										
0										
0										
0										
0										
0										
0										
0										
0										
0										

Industries & Processes

	Partners	Contact	Industries	Plant / Process Units
1	AMEC	Derek BUCKTHORPE derek.buckthorpe@amec.com	Oil sands	Steam Assisted Gravity Drainage
				Cyclic Steam Stimulation
			Petrochemicals	
			Ciment	Pyro processing
			Paper and Pulp	Kraft process
2	Air Liquide	Claire WEBER claire.weber@airliquide.com	Industrial Gas production	Oxygen Production - Ceramic membrane
				CO Production - dry reforming
3	Arcelor Mittal	Gerard Griffay gerard.griffay@arcelormittal.com	Steel Making	Coke Making
				SteelMaking
				Hot Rolling
				Direct Reduced Iron (DRI)
				Power complex
				Lime complex
				Sintering
				Blast Furnace
4	Fortum	Harri Tuomisto harri.tuomisto@fortum.com	Paper and Pulp	
			Oil refinery	
			Co-generation	
			District Heating	
5	FZJ	Werner von Lensa w.von.lensa@fz-juelich.de	Coal	Coal Gasification
				Steam Methane Reforming
6	GDF Suez - Tractebel	Carmen Angulo carmen.angulo@gdfsuez.com	Co-Generation	-
7	NWU/PBMR	Gideon Greyvenstein	Petroleum Products	Fischer-Tropsch
				Steam Methane Reforming
		gideon.greyvenstein@pbmr.co.za	Oil Sands	
8	NWU	Frik van Niekerk frik.vanniekerk@nwu.ac.za	Hydrogen Production	Thermochemical water splitting
				Hybrid Sulfur
				Sulfur Iodine
				High Temperature Electrolysis
9	PROCHEM	Marek Tarka mtarka@prochem.com.pl	Refinery	Aromatics Extractive Distillation
				Crude Oil Distillates Hydrotreatment
				Crude Oil Distillation
10	SAIPEM	Jacques RUER jacques.ruer@saipem-sa.com	Energy Storage	Pumped Heat Electricity storage
11	Technip	Gaetano Iaquaniello iaquaniello.g@ktispa.it	Refinery	
			Hydrogen production	Steam Reforming
				Membranes Steam Reforming
12	USG (DSM) / BEC	Anton Baaten anton.baaten@me.com	Wide Range (Petro)chemicals incl. Urea & Ethylene	Utilities supply
13	ZAK	Marek Zuber marek.zuber@zak.com.pl	Nitrogen Fertilizers	Syngas production
				Hydrogen production
				Nitric acid synthesis
				Ammonia synthesis
				Urea production
			Organic Synthesis	Oxo processes
				Alcohol synthesis
				Phthalate plasticizers synthesis
				Phtalic and maleic anhydride

EUROPAIRS - Task 1.1: End-User Processes
Inventory of data

Please fill this cover sheet for the identification of the document. The list of industries and processes in given in Sheet 6 for reference.

File	AL_Industrial Gas production_CO production_revA.xls

Partner	Air Liquide
Industry	Industrial Gas production
Complex / Process Unit	CO Production - dry reforming
Overall Electrical Power	22.7 MW

Objectives of the document:
This document aims at gathering efficiently relevant data related to the end-user processes.
Each partner is asked to fill one FORM for each complex or process unit (existing & future).
This collection of data is the core of Task 1.1 and will be consolidated in order to de used as base information for Task 1.3.

A notice to correctly fill this FORM is given in a dedicated sheet.

Status of the document

Rev. 0	29/09/2009	First issue by SSA of the document for comments from the partners of Task 1.1, 1.2 & 1.3
Rev. 1	21/10/2009	Issue by SSA of the finale FORM

End-User Requirements fOr industrial Process heat Applications with Innovative nuclear Reactors for Sustainable energy supply

How to use this FORM?

This FORM is divided into 5 sheets:

Sheet 1	**HOME.** This is the cover sheet of the file. Before anything else, please make sure that you have filled the requested information: name of the partner and of the contact - name of the industry and of the described plant / process unit (in accordance with the list given in annex (sheet 6)).
Sheet 2	**NOTICE.** A notice is included in the FORM. It includes the description of the various sheets and a quick definition of the requested parameters.
Sheet 3	**COMPLEX/PROCESS DESCRIPTION.** In this sheet, the partner shall give a simplified flow scheme of the process with basic information such as the name of the process units included in the overall process (/complex) and the name and main characteristics (pressure, temperature, flowrate) of the fluids/products circulating between the units. You are free to use the proposed draft scheme or to include an existing flow scheme (as a jpeg image or as an attached pdf file). You can add any identified safety issues related to this process in this sheet.
Sheet 4	**CONSUMER DUTY.** This sheet focuses, within the process described in sheet 3, on the identification of the heating needs (independently from how heat is generated). Definition and examples of the data requested are given here below. They aim at characterizing the need in terms of physical conditions, operational philosophy, reliability, flexibility and safety.
Sheet 5	**PRODUCER SPECIFICATIONS.** In a second time, this sheet focuses on the existing systems implemented for heat generation. This information will be valuable in order to study the technical and economical impact of the use of HTR as an alternate for generation of High Temperature heat. Two sets of data are asked for: definition of the heat producer and characterization of the heat transportation media. Definition and examples of the data requested are given here below.
Sheet 6	**ANNEX.** Reminder of the list of partners and the related industries and plants / processes.

To be filled in priority

Can be filled in a second time

REFERENCES & GLOSSARY

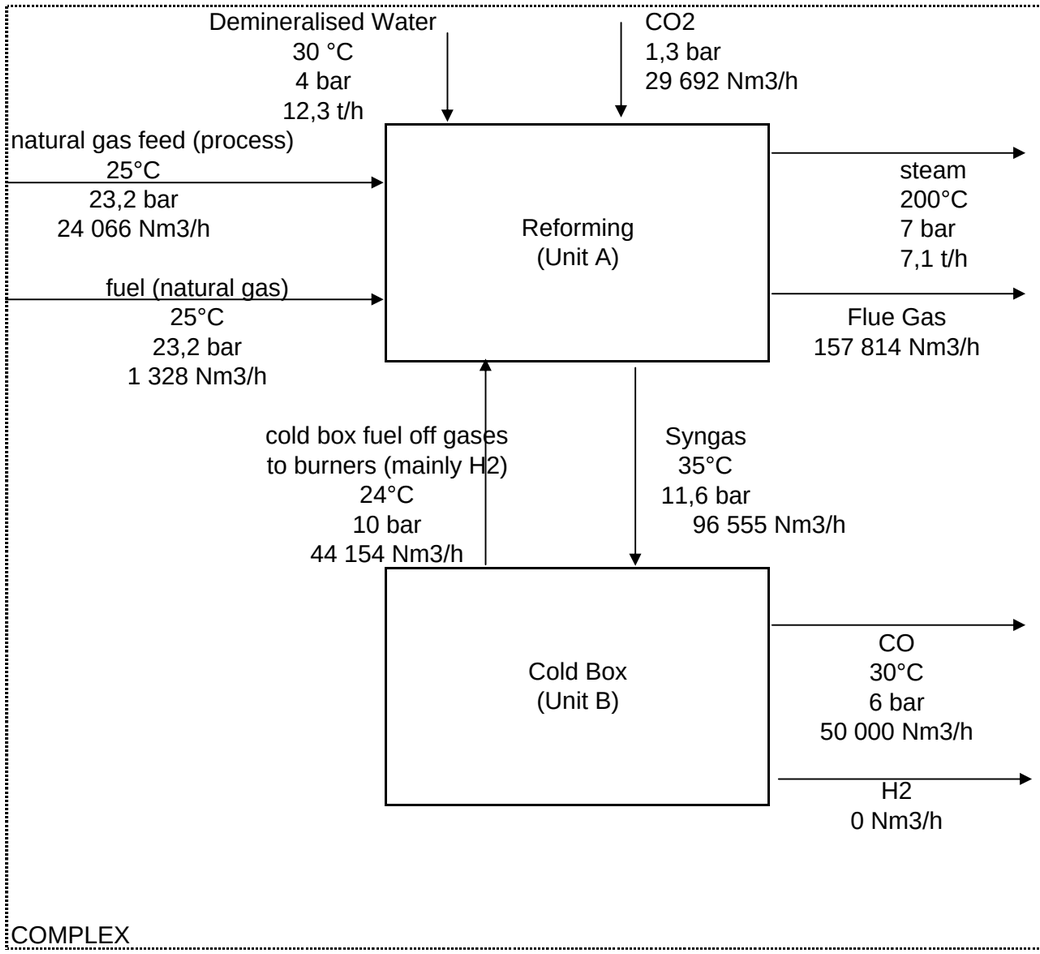
Ref.	*Parameter Name*	*Definition*	*Unit or Example*
		Process Description	
	complex	An ensemble of process units	
	Process Unit	One elementary process unit that can be included in a complex or several complexs	
(1)	Consumer Description	Name of the unit within the process (identical in sheet 3 and sheet 4)	steam reformming, hydrocracking…
		Consumer Duty - NEED	
(2)	Heating Loop N°	To number the heating loops properly allow to navigate easily in the file and to link heat production and heat consumption.	
(3)	Temperature	Temperature of the heating fluid at the inlet and the outlet **of the unit**.	K, °C, °F
(4)	Allowable Temperature Range	Min. & Max. temperatures at which the process takes place at full efficiency and without material damages.	K, °C, °F
(5)	Typical ramp up & down	Typical temperature gradient to be observed during transients (heating up & cool down).	K/min, K/s, K/h…
(6)	Continuous / Intermittent	Need for continuous heat supply (continuous process) or intermittent heat supply (batch process).	C or I (batch duration, number per year…)
(7)	Effect of heat supply disruption	What happens if case of heat supply disruption? Characterize the criticality of the heat supply.	shutdown of the process, degraded performances…
(8)	Consumption Leveling	Is there a possibility of leveling between the various heat loops in the process? Characterize the flexibility.	YES or NO
		Heat Producer Specifications - EXISTING	
(9)	Heat Generator Description	Name of the heat supply utility	
(10)	Fuel Type	Description of the fuel needed for heat generation	gas, coal, offgas (from unit X), electricity…
(11)	Fuel Consumption / External	Periodic consumption of external fuel	tpy, tph, Sm3/y…
(12)	Fuel Consumption / Offgases	Periodic consumption of internal fuel (offgases from another unit)	tpy, Sm^3/y…
(13)	Power	at least nominal power is required	MWh…
(14)	Back-up in case of shutdown	what is the planned back-up in case of the disruption og the normal heat supply?	
(15)	Media Type	Description of the media used for heat transportation between heat generation and consumption.	steam, oil, molten salt…
(16)	Temperature	Temperature of the medium at the inlet and at the outlet of the heat generation system	K, °C, °F
(17)	Pressure	Pressure of the medium at the inlet and at the outlet of the heat generation system	bar, psi…
(18)	Mass Flow	Mass flow rate of the heat transportation medium	tpy, Sm3/y…
(19)	Consumed in process ?	Indicate if the heat medium (for inst. STEAM) is recycled to heat generation OR consumpted afterwards in the process	YES or NO

Simplified Plant & Units flow scheme (1/2)

Objectives of the scheme

This simplified scheme aims at providing an easy understanding of the overall considered process.
You can add as many units as you think necessary.
In addition, please list at the bottom the safety concerns linked to the plant described here below.

❷ *Replace the example here below bythe flow scheme of the considered complex / process unit*



unit A has, among other units, a furnace to heat combustion air, natural gase feed (process), reactive mixture, steam, CO2.

steam heated in the furnace	96.5 t/h
steam injected in reactive mixture	18.8 t/h
steam suplying heat to units	70.6 t/h
steam export	7.1 t/h
almost all the steam is recylced (steam for process and steam for heat)	
make up - DMW to conpensate losses	12.3 t/h

CO2 heated in the furnace	51 456	Nm3/h
CO2 import	29 692	Nm3/h
CO2 from syngas (recycled)	22 816	Nm3/h
CO2 Loss (at compressor, before furnace)	1 051	Nm3/h

Simplified Plant & Units flow scheme (2/2)

❸ *Summarize here the name of the units*

	Consumer Description (1)
Unit A	Dry Reforming
Unit B	Cold Box
Unit C	
Unit D	
Unit E	
Unit F	
Unit G	
Unit H	
…	

❹ *Please detail here below the identified safety concerns related to the process.*

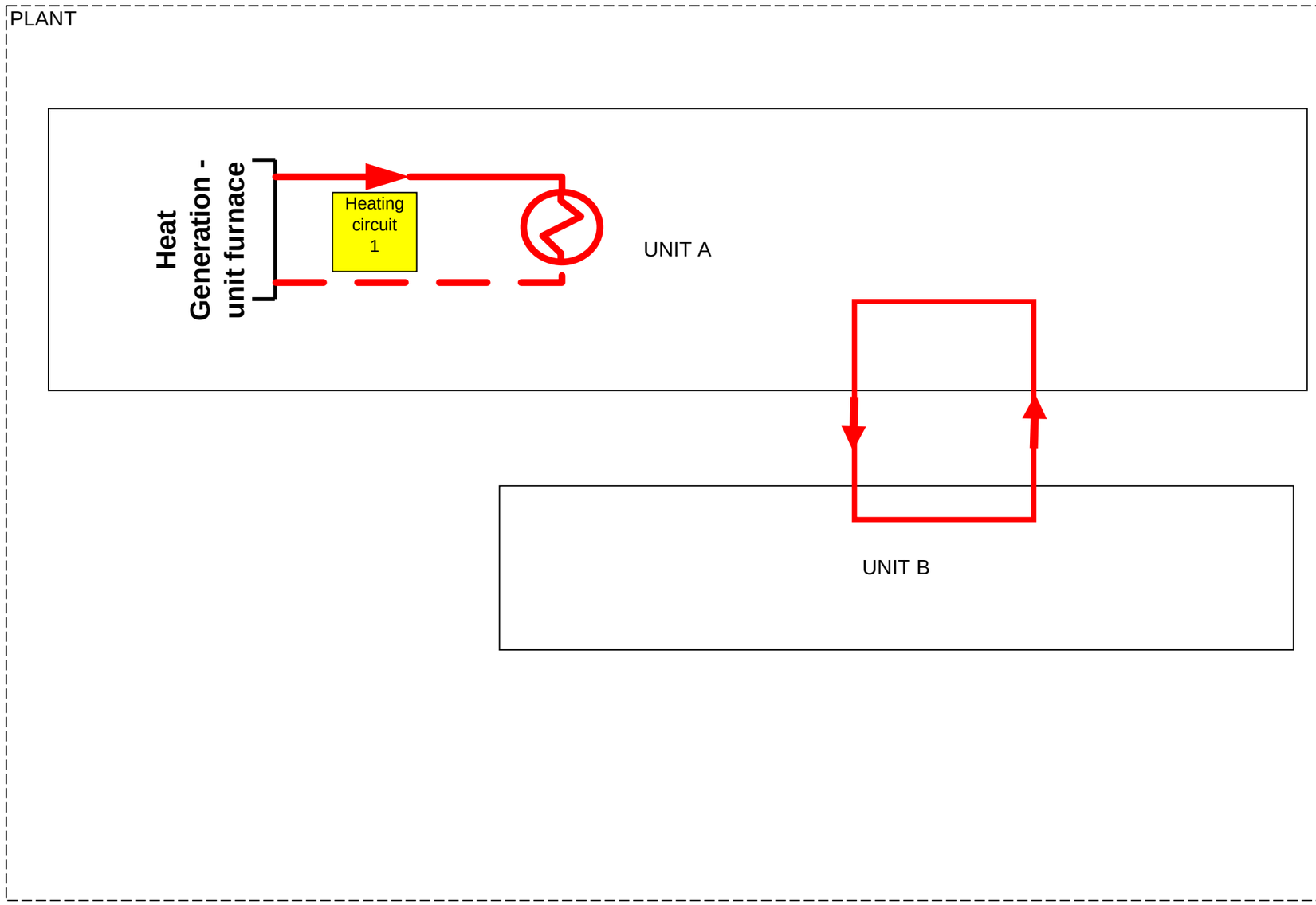
SAFETY CONCERNS.
- High Temperature, toxic & harmful gases : CO and CO2, combustible gases (CH4, H2, etc.), inflammability, high pressure equipments, leak, etc.
- low temperature, toxic gases (CO), combustible gases (H2), high pressure equipment
-
-
-
-
-
-
-
-
-
-
-
-
-
-

Characterization of the heating needs (1/2)

Objectives of the sheet

This sheet gathers the information related to the needs for heat in the plant or process unit.

❺ *Replacet the example here below by the heating needs of the process units described in Sheet 3*



Characterization of the heating needs (2/2)

❻ *Fill the table here in accordance with the units described in Sheet 3 and with the scheme here above.Definitions of the parameters are given in Sheet 2.*

Consumer duty

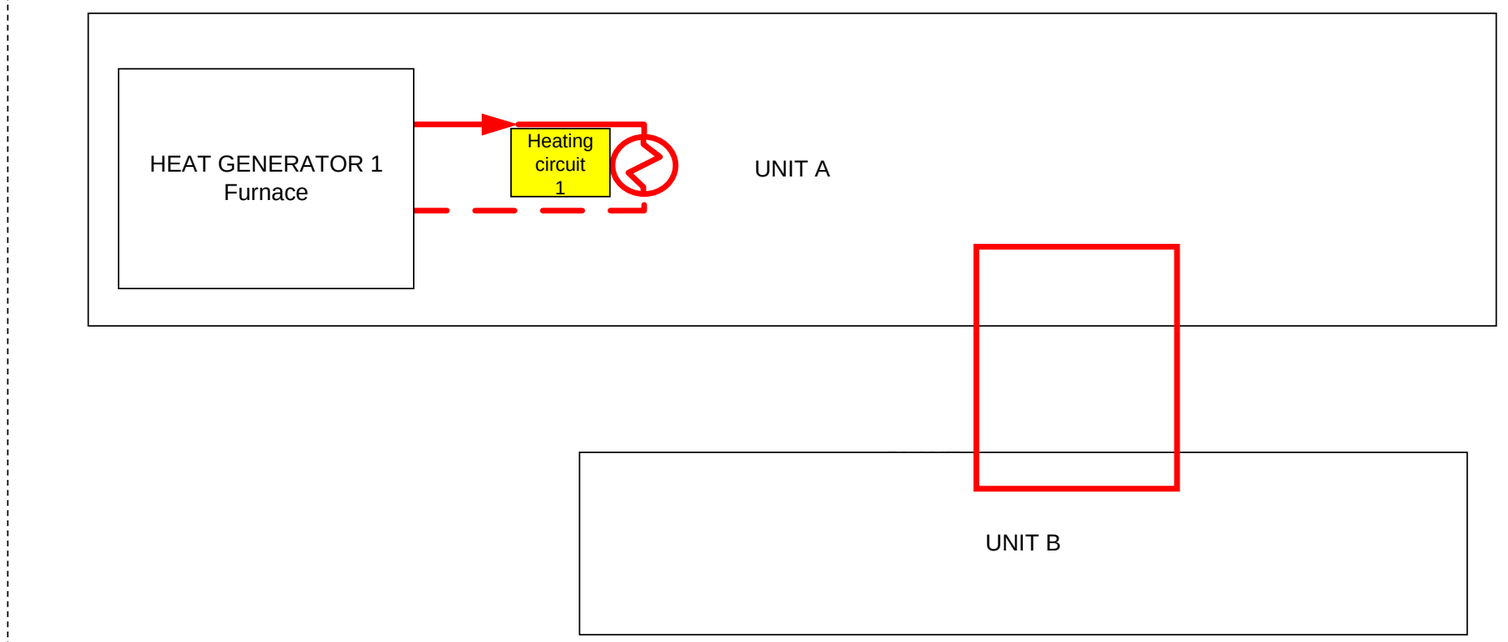
Consumer Description (1)		Heating Circuit N° (2)	Temperature (3)		Allowable Temperature Range (4)		Typical ramp up and down (5)	Continuous OR Intermittent (6)	Effect of heat supply disruption (7)	Consumption leveling (8)	Comments
			inlet	outlet	T_{min}	T_{max}					
Unit A	Reforming	1	1080	140			30°C/h for startup	C	failures in air suply or in natural gas sypply lead to furnace shut down important parameters are pressure and temperature in the radiation zone	No	Temperature inlet / outlet of furnace different streams are heated within the furnace of unit A
Unit A	Reforming	1	1080		higher is the temperature, higher is the production of CO if T is descreasing, the reaction is driven toward the H2 production and tere is a slip of CH4 (not wanted)		1st part of the furnace = radiation zone of furnace suplies the temperature required by the reaction between CH4/CO2/H2O to produce syngas				
Unit A	Reforming	1	1075	140	2nd part of the furnace = heat for natural gas feed (process), reactive mixture, steam, CO2 and combustion air preheating						
Unit B	Cold Box				the cold box does not have a dedicated heat circuit. Steam comes from unit A and then it returns to unit A						

Characterization of the existing heat generators (1/2)

Objectives of the sheet

This sheet gathers data on the existing heat generation systems.

❼ *Replace the example here below by the existing heat generation systems for the considered complex / process units. Heating Circuit Numbers shall be in accordance with Sheet 4.*



Characterization of the existing heat generators (2/2)

❽ *Fill both table shere in accordance with the heating circuits described in Sheet 4 and with the scheme here above. Definitions of the parameters are given in Sheet 2.*

HEAT GENERATORS

Heating circuit N° (2)	Heat generator description (9)	Fuel type (10)	Fuel Consumption		Power (kWth) (13)			Backup in case of shutdown (14)	Comments
			External (11)	Offgases (12)	Min.	Nominal	Max.		
1	fuel combustion	Natural Gas /cold box fuel off gases	1 328 Nm3/h	44 154 Nm3/h		159 085		if there is a break in fuel off gases supply (problems cold box), the make up in natural gas can be boosted to provide the heat required by the furnace	total heat heat exchanger between the combustion gases and the streams-to-be-heated-up / indirect contactor
1	fuel combustion	Natural Gas /cold box fuel off gases				96 260			1st part of the furnace heat required by the reaction to produce syngas (heat @1080°C)
1	fuel combustion	Natural Gas /cold box fuel off gases				62 825			2nd part of the furnace heat for reactive mixture, combustion air, natural gas feed, CO2, steam (heat @140-1075°C)

MEDIA TABLE

Heating circuit N° (2)	Media type (15)	Temperature (16)		Pressure (17)		Mass flow (18)			Consumed in the process ? (19)	Comments
		inlet	outlet	inlet	outlet	Min.	Normal	Max.		
1	combustion gases - exhaust gases	1080	140	~atm	~atm		157814 Nm3/h		no	
0	steam	300	110	25 bar	1,4 bar		70,6 t/h		no	steam suplying heat to units
0										
0										
0										
0										
0										
0										
0										
0										
0										

Industries & Processes

	Partners	Contact	Industries	Plant / Process Units
1	AMEC	Derek BUCKTHORPE derek.buckthorpe@amec.com	Oil sands	Steam Assisted Gravity Drainage
				Cyclic Steam Stimulation
			Petrochemicals	
			Ciment	Pyro processing
			Paper and Pulp	Kraft process
2	Air Liquide	Claire WEBER claire.weber@airliquide.com	Industrial Gas production	Oxygen Production - Ceramic membrane
				CO Production - dry reforming
3	Arcelor Mittal	Gerard Griffay gerard.griffay@arcelormittal.com	Steel Making	Coke Making
				SteelMaking
				Hot Rolling
				Direct Reduced Iron (DRI)
				Power complex
				Lime complex
				Sintering
				Blast Furnace
4	Fortum	Harri Tuomisto harri.tuomisto@fortum.com	Paper and Pulp	
			Oil refinery	
			Co-generation	
			District Heating	
5	FZJ	Werner von Lensa w.von.lensa@fz-juelich.de	Coal	Coal Gasification
				Steam Methane Reforming
6	GDF Suez - Tractebel	Carmen Angulo carmen.angulo@gdfsuez.com	Co-Generation	-
7	NWU/PBMR	Gideon Greyvenstein	Petroleum Products	Fischer-Tropsch
				Steam Methane Reforming
		gideon.greyvenstein@pbmr.co.za	Oil Sands	
8	NWU	Frik van Niekerk frik.vanniekerk@nwu.ac.za	Hydrogen Production	Thermochemical water splitting
				Hybrid Sulfur
				Sulfur Iodine
				High Temperature Electrolysis
9	PROCHEM	Marek Tarka mtarka@prochem.com.pl	Refinery	Aromatics Extractive Distillation
				Crude Oil Distillates Hydrotreatment
				Crude Oil Distillation
10	SAIPEM	Jacques RUER jacques.ruer@saipem-sa.com	Energy Storage	Pumped Heat Electricity storage
11	Technip	Gaetano Iaquaniello iaquaniello.g@ktispa.it	Refinery	
			Hydrogen production	Steam Reforming
				Membranes Steam Reforming
12	USG (DSM) / BEC	Anton Baaten anton.baaten@me.com	Wide Range (Petro)chemicals incl. Urea & Ethylene	Utilities supply
13	ZAK	Marek Zuber marek.zuber@zak.com.pl	Nitrogen Fertilizers	Syngas production
				Hydrogen production
				Nitric acid synthesis
				Ammonia synthesis
				Urea production
			Organic Synthesis	Oxo processes
				Alcohol synthesis
				Phthalate plasticizers synthesis
				Phtalic and maleic anhydride

General overview of Upstream Iron & steelmaking processes

Energy consumption

Introduction: Primary metal manufacturing routes

The choice of steelmaking route is essentially dictated by the required quality of the end product. The production of the primary metal, which is the first stage in the manufacturing process, can involve different routes, Fig. 1, varying in the source of iron and the treatments employed (reduction, melting, etc.).
Iron ores, containing iron in oxidized form, must first of all be reduced, whereas scrap can be used directly in the steelworks as a solid primary metal charge, depending on the grade of steel to be made. Scrap is an impure source of solid iron, since it contains elements such as Cr, Ni, Cu, Sn, Zn, etc., in the form of coatings, alloying additions or impurities, and these are difficult to eliminate.
The reduction of iron ores by carbon can be performed either at low temperature (< 1100°C), to produce solid prereduced pure iron which can be used directly in the steel melting furnaces, or at a higher temperature, followed by melting. In the latter process, of which the blast furnace is the most widespread example, the high purity molten iron dissolves a high concentration of carbon.

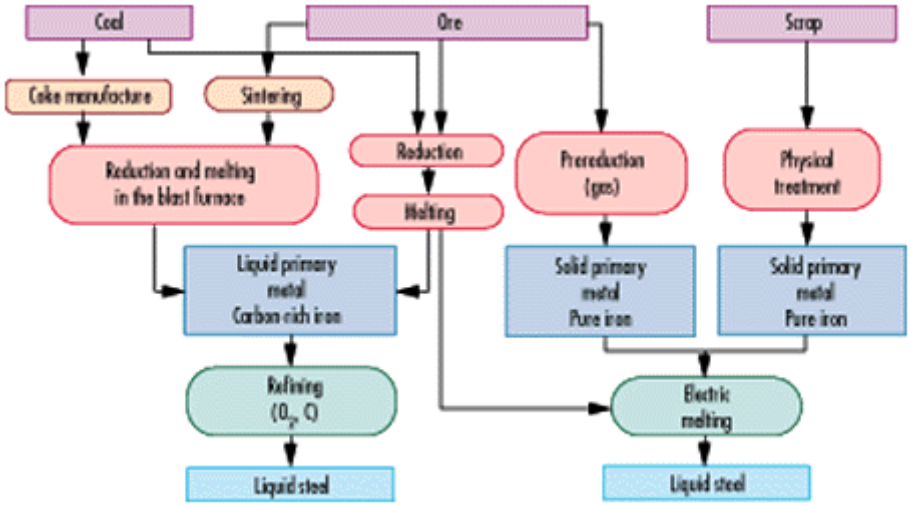


Fig. 1. - The different routes for primary metal production.

Efficient operation of a blast furnace requires prior treatment of the burden materials, including sintering of the ores and pyrolysis of the coals (coke production). The plant concerned involves high capital investments and refurbishing costs, together with large additional expenses to comply with environmental regulations. In response to these disadvantages, various new "reduction-melting" processes have been considered, capable of directly treating the raw materials. With the exception of the Corex process, none of them has yet got beyond the pilot plant stage.

While the production of a ton of primary metal requires a ton of contained iron whatever the production route, the energy consumptions of the different techniques vary considerably. Thus, the use of scrap involves only the energy needed to melt the iron, i.e. about 1.4 GJ/t of metal. In arc furnaces, this energy is supplied in the form of electricity, produced in France essentially from nuclear fuels. In contrast, when the iron is produced from ores, in addition to melting, a further 6.6 GJ/t of energy is theoretically required to reduce the iron oxides. In this case, all of these requirements are fulfilled by the combustion of fossil fuels.

Conventional steelmaking route: The Blast Furnace route

The iron works is the first stage in the manufacture of steel from coal and ore. It is articulated around the blast furnace and the ancillary reactors designed to prepare the burden materials. These include the coke ovens which convert the coal to coke, the sintering plant which physically and chemically pretreats the ore, the Cowper stoves for preheating the combustion air, and the preparation plant for the powdered coal injected in the tuyeres (Fig. 2) . Iron production in the blast furnace has now achieved a state of maturity. Modern integrated steelworks are all designed on the same model, in terms of both technical solutions and production capacities.

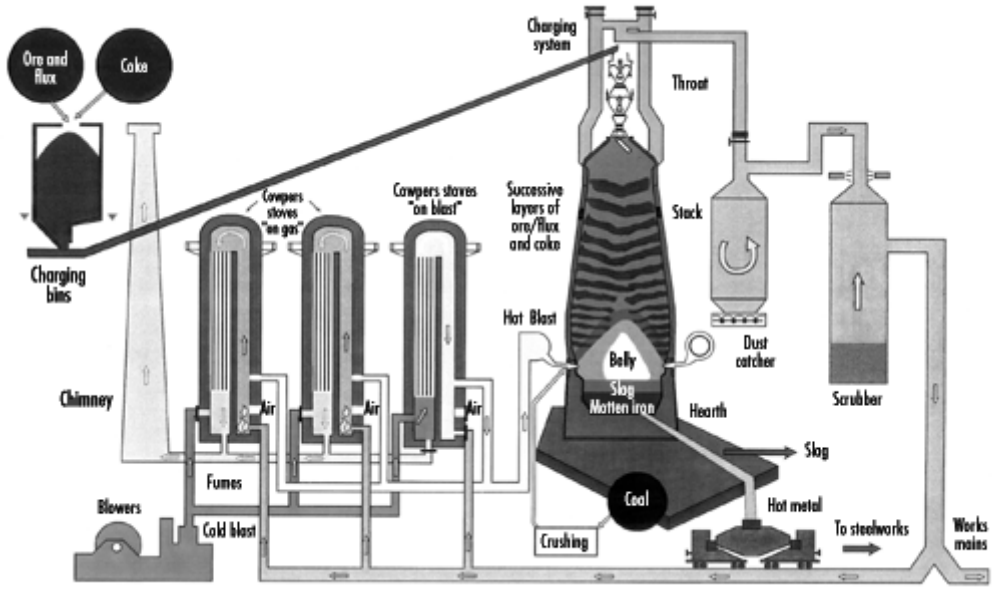


Fig. 2. – Schematic layout of a blast furnace and ancillary equipment

1. The Blast furnace

- **Metallurgical functions of the blast furnace**

In chemical engineering terms, the blast furnace is a counter-current gas-solid reactor, in which the iron oxides are reduced, the iron and gangue are melted and the liquid metal is separated from the slag. It ensures three types of essential metallurgical functions:

- Chemical exchange, mainly via the reduction of iron oxides and the combustion and gasification of carbon.

- Heat exchange, by transfer between the gas and the solids and/or liquids.

- Aerodynamic maintenance of the permeability of the burden, since the chemical and thermal transfer phenomena occur in a granular bed, in which the gas moves in the opposite direction to the solids.

The counter-current operation is essential and is the reason for the excellent thermal and chemical efficiency of the process. The solid charge materials (ore, sinter and coke) are introduced in alternate layers at the top of the furnace. The liquids produced at the bottom are tapped off at a temperature of about 1500°C. The reducing gas, a mixture of CO, H2 and N2, is produced at the tuyeres at a temperature of 2000 to 2500°C, by partial combustion of the coke and auxiliary fuels in the air blast preheated to 1200°C. As it rises through the furnace, the gas, whose temperature is always greater than or equal to that of the solids, exchanges heat with the latter and provides the necessary enthalpy and reducing power for the process. It leaves the furnace after having lost most of its heat (at a temperature of 80-200°C), but with a significant part of its reducing power (%CO/ %CO2» 1), which is used elsewhere in the works.

- **Materials balance in the blast furnace**

The figures of the balance for a modern blast furnace (ArcelorMittal Dunkerque HF 4) are indicated in Table I.

Table I - Materials balance in the blast furnace (for one ton of iron).

	Input			**Output**	
Sinter	1 500	kg/tf	Iron	9 000	tf/jour
Lump ore	150	kg/tf	Slag	330	kg/tf
Coke	295	kg/tf	Top gas	1 480	Nm^3/tf
Coal	180	kg/tf	Dust	10	kg/tf
Hot blast	970	Nm^3/tf			
Oxygen	15	Nm^3/tf			

In ArcelorMittal group, the principal source of iron is sinter, with an addition of lump ore or pellets (presently less than 10 % of the iron charge). Depending on local conditions, some blast furnaces in other countries use up to 100 % of pelletized ore. The injection of pulverized coal at the tuyeres is now widespread, and all the French blast furnaces have been equipped for this purpose since 1990. The replacement of coke by coal (1 kg of coal is equivalent to 0.85 kg of coke) is motivated essentially by the difference in cost. An injection rate of 180 kg/t is now common practice, and considerable efforts are being expended to increase this value up to 220-250 kg/t.

The production of one ton of iron requires about 1500 kg of sinter containing 58 % of iron, 150 kg of ore, a total of 440 kg of fuel and nearly 1000 Nm3 of air preheated to 1200°C (i.e. 1.3 tons of air per ton of iron). The operation generates about 300 kg of slag and 1480 Nm3 of top gas, whose reducing potential is not exhausted. This gas entrains dust particles, which are recovered in cleaning systems. Because of the high degree of reduction of the iron oxides, the overall iron yield of the blast furnace is excellent, corresponding to about 99.5 %.

- **Energy balance of blast furnace**

Analysis of the heat balance in a blast furnace reveals that the formation of the liquid phases and the regeneration of the reducing gas (Boudouard reaction) represent by far the two largest energy requirements. In contrast, reduction of iron oxides and heat losses make up a relatively small proportion of the overall balance (Table II).

For a large blast furnace producing about one ton of iron every ten seconds, the overall power developed is about 1600 MW. Each tuyere can thus be considered as a 40 MW "burner". Examination of the energy balance, which includes all types of energy involved in the process, shows the efficiency to be extremely high, since the non-recoverable energy (sensible heat in the slag and top gas and heat losses) represents only 8 % of the total.

Table II -Heat balance for a blast furnace, in MJ per ton of iron.

Heat	Combustion of coke	1 086	26 %
sources	Combustion of coal	1 232	29 %
(MJ/tf)	Sensible heat in blast (1 180 °C)	1 738	41 %
	Reduction of iron oxides (overall balance)	177	4 %
	Total heat supply	*4 233*	100 %
Heat	Melting and enthalpy of liquids (1 480 °C)	2 005	47 %
requirements	Reduction of the elements forming		
(MJ/tf)	the hot metal	83	2 %
	Carbon solution loss	1 297	31 %
	Sensible heat in the gas (170 °C)	359	8 %
	Water reactions	196	5 %
	Loss	296	7 %
	Total heat requirements	*4 233*	100 %

- **Blast conditions and tuyere injections**

The aim of blast conditioning is to obtain the optimum thermal and chemical conditions in the tuyere zone, and to control the heat input. The blast supplies the oxygen necessary for combustion, and acts as a carrier for the various additions required for the general process economy; oxygen, steam, and particularly auxiliary fuels. The blast volume determines the rate of combustion, and hence the melting capacity and productivity of the blast furnace. The blast pressure, which can reach 4 to 5 bars in large

furnaces, provides a means of increasing the mass flow of gas, and consequently the intensity of transfer phenomena, without hindering gas flow through the burden. The blast temperature determines the distribution of the heat supply between the combustion of coke and the enthalpy of the blast. An increase in blast temperature supplies extra energy without the production of additional gas volume. The adiabatic flame temperature can be used to characterize the blast condition. A sound practice is to adjust the blast conditions so as to maintain a constant flame temperature.

Apart from inducing savings in coke consumption, the injection of auxiliary fuel in the tuyeres has the advantage of cooling the flame, enabling the blast furnace to be operated at the maximum blast temperature authorized by the stoves, corresponding to the optimum economic conditions. The various blast conditioning factors exert opposite effects on the flame temperature and coke consumption, enabling the choice of different strategies for optimizing the blast in order to obtain a constant flame temperature (Table VI). Higher blast temperature and additional oxygen injection tend to increase the flame temperature while decreasing the total gas volume and top gas temperature. Increased moisture content and auxiliary fuel injection produce the opposite results.

Table III - Effect of blast conditions and injections on blast furnace operation (thermal equivalents).

Parameter	**Temperature**	**Oxygen**	**Steam**	**Coal**
Base	1 200 °C	0 Nm^3/tf	10g/Nm^3	120 kg/tf
Variation	+ 50 °C	+ 10 Nm^3/tf	+ 5 g/Nm^3	+ 20 kg/tf
Effect on				
Coke consumption (kg/tf)	− 5.0	+ 0.5	+ 2.7	− 16.5
Blast consumption(Nm^3/tf)	− 25.1	− 43.8	+ 3.9	+ 9.0
Flame temperature (°C)	+ 33.0	+ 30.0	− 23.5	− 30.6
Top gas temperature (°C)	− 11.8	− 16.9	+ 5.3	+ 16.6

2. The Ore preparation

- **Iron ores**

The iron ores found in nature are extremely diversified. In terms of chemistry, the associated gangue contains from 2 to 10 % SiO2 (for the richest ones), from 0.2 to 3 % Al 2O 3, and variable amounts of impurities such as phosphorus and potassium. The iron itself is generally in the form of hematite, Fe2O3, but may also be present as magnetite, Fe3O4, hydrates or carbonates. The physical state of the ores also varies. Depending on the hardness of the rocks, the mined product can be coarser or finer. In some cases, it is necessary (and easy) to increase the iron content of the

ore by a physical process involving fine crushing to separate the oxides and the gangue, followed by magnetic or densimetric separation. The enriched ore is then very fine, with a particle size from 0.1 to 2 mm.
Modern blast furnaces cannot be operated with charge materials whose composition and size vary in time and with the source of supply. It is therefore necessary to blend the ores to regularize both their chemistry and size distribution, and to sinter the fines in order to obtain a product with particle sizes in the range from 5 to 50 mm. Since it is also necessary to add limestone flux (CaCO3) to neutralize the acidic gangue (SiO2) and control the basicity of the blast furnace slag, this addition is made before sintering. Some ores can be charged directly, after screening to between 5 and 25 mm, provided that they have suitable physical properties (abrasion and thermal shock resistance, etc.). The availability of such products limits their use to about 10-15 % of the total charge.

- **The sintering process**

Reactive grate sintering, involving partial melting, is induced by the combustion of a solid fuel, usually coke dust, mixed with the ore. The mixture is moistened, pelletized, then deposited onto a moving grate to form a bed. Sintering is initiated at the top surface by suction of hot gases from an ignition hood through the bed, and subsequently maintained by a suction air depression. The suction beneath the bed is continued for the time necessary for complete combustion of the fuel. The upper part of the bed is partially cooled by the air depression as the combustion layer propagates downwards. When the sinter reaches the end of the strand, it is transferred to an air cooler which extracts the residual heat.
The heat and matter balances for the process are given in Tables IV and V:

Table IV - Materials balance for grate sintering (kg per ton of sinter).

Input (kg/t sinter)		**Ouput (kg/t sinter)**	
Ore (63 % Fe)	950	Screened sinter	1 000
Fluxes	150	Return fines	260
Coke dust	45	Waste gas (H_2O, CO_2)	145
Total	1 145		
+ Return fines	260		

Table V - Heat balance for grate sintering (MJ per ton of sinter)

Heat	Solid fuel	1 350	Requirements	Drying of the charge	250
supply	Ignition gas	50	(MJ/t. sinter)	Decomposition of	
(MJ/t sinter)	Heat recovered			hydrates,carbonates	150
	in the cooler	20		Formation of CO	200
				sensible heat in	
				the waste gases	320
				Sensible heat in the sinter Losses	300 200
	Total heat supply	1 420		Total requirements	1 420

3. The Coking plant

The direct use of coal in iron smelting reactors has always proved very difficult, due to softening between 350 and 500°C, which makes a thick burden impervious. Coking was developed to solve this problem by providing the following functions:

- Sintering of the coal particles during the low temperature plastic phase, and formation of lumps of coke of appropriate size for use in a shaft furnace (permeability requirement).

- Recovery of the hydrocarbons in the form of readily usable gas (H2 - CH4 - CO) and tar.

- **The properties of coals**

The so-called coking coals are characterized by the fact that they become plastic when heated in the absence of air. They are also known as bituminous coals. Their utility depends both on their degree of evolution and on their plastic properties. The geological age of these coals is between 150 and 300 million years. In practice, this corresponds to a carbon content which varies between 82 and 92 %. About 70 to 80 % of the carbon atoms are in aromatic rings, mostly in condensed phases, while the remaining 20 to 30 % are in the form of saturated cyclic compounds, alkyl radicals or paraffin chains. The plastic properties are characterized by the swelling index, the expansion and the fluidity. The appearance and disappearance of these properties delimit the range of coking coals. Coals also contain a certain amount of mineral matter, including a number of compounds with undesirable effects on the ironmaking process. In practice, the ash content should be less than 10 % and the concentration of alkali metals (Na, K) and phosphorus as low as possible.

- **The basic principles of coking**

When crushed coal is gradually heated in the absence of air, it undergoes a series of transformations:

- Up to 150°C, water is evolved.
- Towards 350-400°C, softening starts, with the formation of a viscous mass, whose viscosity decreases with rising temperature, reaching a minimum at about 450-480°C, then increases again to the point of resolidification. This phase is accompanied by a marked evolution of volatile matter, which causes swelling.

- Between 470 and 510°C, resolidification occurs, with the formation of a porous semi-coke.

- Beyond the resolidification temperature, volatile compounds continue to be evolved and the coke contracts.

In fact, coals able of being used alone are relatively rare. Good coking coals generally form coke of satisfactory quality, but swelling tends to develop high pressures which are unacceptable for the coke oven walls and lead to difficulties on discharging. Current practice is therefore to mix coals of different types, in order to produce a coke suitable for use in the blast furnace under optimum economic conditions. The mixture is crushed to a particle size corresponding to 70 to 80 % < 2 mm. Coarser sizes lead to heterogeneous behavior, and less readily fusible coal particles create crack initiation sites which embrittle the coke. In general, the crushing and blending ensure a uniform mixture.

- **The coke ovens**

Coke ovens are rectangular in section, 12 to 18 m long, 4 to 8 m high and 0.4 to 0.6 m wide. They have two large heated brick walls, an unheated refractory sole and an unheated crown roof with a vertical riser which draws off the distilled gases. The chamber is closed at each end by two airtight doors. The walls are heated to a high temperature (1200 to 1350°C) by flues, constructed in a series of arches inside the walls. Each heating wall is common to two ovens and is divided into about thirty individual flues. The alternating arrangement of heating walls and oven chambers forms a battery of about 25 to 50 ovens, served by the same charging car, ram-leveler and door manoeuvering system. The battery is supplied with gas by a main with branch pipes leading to each heating wall, through a system of distribution pipes and cocks which ensure the same heating time for each oven. Below the ovens and heating walls are a series of regenerators, which contain checker-work bricks. They are alternately heated by the waste gas from the ovens or reheat the air and lean gas (from the blast furnace). When coking is completed, the incandescent coke, at about 1000°C, is pushed out of the furnace by the ram-leveler, and the cracked lumps fall into the coke car which takes them to the quenching tower, where they are extinguished and cooled with several tons of water. The car then comes back towards the ovens and unloads the coke onto a conveyor. The extinguished coke is screened to 25 mm, or sometimes to 40 mm. The coke fines are used as a fuel in the sintering plant or can be charged directly into the blast furnace, in quantities up to 20 kg/t.

Analysis of the materials balance for a coking plant reveals that 80 % of the charged dry matter is recovered in the form of coke, the remaining 20 % being distilled gases and tars (Table VI).
The heat energy required for coking a typical mixture of coals (Table VII) is of the order of 2500 to 3000 MJ/t of dry coal charge. The sensible heat in the discharged coke represents about 45 % of the output, while the heat contained in the distilled raw gases, steam and tar accounts for 30 %, and the combustion gases 15 to 20 %. Heat losses are generally less than 10 %.

Table VI - Example of a materials balance for a coking plant.

Input (kg/t dry coal)		Ouput (kg/t dry coal)	
Dry coal	1 000	Total coke	800
Air	5	Tar	30
		Gas	150
		Formation water	25

Table VII - Example of a heat balance for a battery of coke ovens, charged with a coal blend containing 23 % of volatiles and 8 % moisture

		MJ/t dry coal	%
Heat	Latent heat of the heating gas	2 650	91
sources	Sensible heat of the heating gas	20	0,7
MJ/t coal	Sensible heat of the combustion air	20	0,7
	Sensible heat of the moist coal	15	0,6
	Heat of reaction (by totalizing to 100 %)	200	7
	Total heat supply	**2 905**	**100**
Heat	Sensible heat of the coke	1 315	46
requirements	Sensible heat of the distilled gases	440	15
	Sensible heat + latent heat of	30	1
	condensation of the tar		
	Sensible heat + latent heat of	350	12
	condensation of the water		
	Sensible heat of the waste gases	535	18
	leaving the regenerators		
	Surface heat losses	235	8
	Total heat requirements	**2 905**	**100**

4. The Hot metal refining and the secondary metallurgy

- **The Converter**

The transformation of iron to steel, or refining, is performed by the selective oxidation of the unwanted elements contained in the molten or solid metal. In ancient times, refining was performed by hammering heated solid iron in air. Since the introduction of the Bessemer process, liquid iron is brought in contact with an oxidizing gas, which was initially air, but is now pure oxygen. The reactor, or converter, is composed of a steel shell with an internal lining of refractory bricks, supported by a stout steel ring equipped with trunnions, whose shaft is driven by a tilting system. The internal volume of the vessel is 7 to 12 times greater than that of the steel to be treated, in order to confine the majority of metal projections entrained by the oxygen blast, together with swelling of the slag during periods of foaming.
The heat evolved by the oxidation reactions is sufficient to compensate for thermal losses, to heat and melt all the additions necessary for refining and alloying, and to raise the bath temperature well above its initial level.

Table VIII. - Typical compositions and temperatures of the hot metal charge and tapped steel.

	C	Mn	Si	P	S	O	Temperature
	%	%	%	%	%	%	°C
Hot metal charge	4.7	0.23	0.26	0.080	0.020	–	1 370
Liquid steel	0.05	0.10	0.00	0.015	0.015	0.050	1 650

The raw materials charged into the converter are:

- The liquid hot metal from the blast furnace, whose typical composition is given in Table I.

- Other iron-containing additions, essentially ore and scrap, generally at ambient temperature, calculated so as to adjust the thermal balance and obtain the required steel temperature.

- The additions necessary to form a slag of appropriate composition, involving mainly lime (CaO) and burnt dolomite (CaO.MgO), usually in the form of 20 to 40 mm size lumps.

- Pure oxygen injected either through a multi-hole lance or through bottom tuyeres. In all cases, the oxygen blast has sufficient energy to ensure its contact with rapidly renewed molten metal. Any pre-existing or recently formed oxides are violently separated and dispersed.

Two examples of charge compositions are given in Table II, corresponding to two quite different extreme types of steelworks practice. Depending on the economic circumstances, the preferred cooling agents are either iron ore (and sometimes manganese ore), or scrap. However, in most cases, a certain amount of internally generated scrap (croppings, etc.) is employed, even when the maximum permissible ore addition is made. Conversely, a small amount of ore is always added, even with a maximum scrap charge, for fine adjustment of the thermal balance.

The very large volumes of gas produced by the decarburization reaction, corresponding to 80 Nm3 per ton, are entirely recovered, cooled and cleaned of dust. Their high CO content gives the gas a high calorific value, and it can be used in the burners of the reheating furnaces.

Table IX. - Mass balance in an oxygen converter

		Units	Case 1 : Addition of iron or and internal scrap	Case 2 : Maximum scrap charge
Inputs	Hot metal	kg	929	850
(per ton of steel)	Scrap	kg	121	212
	Ore	kg	30	3
	Lime	kg	24	22
	Dolomite	kg	7	5
	Oxygen	m^3	44	45
Outputs	Steel	kg	1 000	1 000
(per ton of steel)	Slag	kg	51	46
	Gas	m^3	82	75
	Dust	kg	12	12
	Projections	kg	4	4
	Iron yield	%	96.6	96.8

All the reactions involving oxidation of the elements dissolved in the hot metal, including oxidation of iron itself, are strongly exothermic. The energy produced is greater than that necessary both to raise the hot metal temperature from the initial value of 1350-1400°C to the required steel tapping level of about 1650°C, and to heat the slag and dissolve the lime and dolomite additions. The additional energy is used to melt the scrap and/or to reduce and melt the iron and manganese ores. Examples of overall heat balances are given in Table III, for an LBE-type top blown converter.

Supplementary fuel additions, such as coal added in the charge or injected, together with the corresponding extra volume of oxygen, enable the amount of scrap charged to be increased considerably. However, this type of operation degrades the performance in terms of both the productivity and the characteristics (temperature and composition) of the molten steel produced.

Table X. - Heat balance in an oxygen converter.

		Enthalpies (MJ / ton of steel) Case 1: maximun ore charge	Enthalpies (MJ / ton of steel) Case 2: maximun scrap charge
Inputs	Enthalpy of		
	the hot metal	1 142	1 045
	Oxidation of C (to CO)	538	491
	" of Mn	8	7
	" of P	22	19
	" of Si	82	76
	" of Fe	45	40
	Secondary combustion	10	94
	(of CO to CO_2)		
	Unburnt lime	− 2	− 2
	Reduction of ore	− 149	− 15
	Total inputs	1 788	1 755
Outputs	Enthalpy of	1 408	1 408
	liquid steel		
	" of the slag	114	100
	" of the gases	193	174
	Thermal losses	73	73
	Total outputs	1 788	1 755

- **The Electric arc furnace**

Large integrated steel plants, in which steel is made mainly from blast furnace hot metal, can also melt appreciable quantities of scrap in the converters, corresponding to about 200 kg per ton of iron in the example chosen above. In contrast, the electric arc furnace can melt charges consisting of 100 % scrap or prereduced ore.
The heat necessary for melting the sources of solid iron is supplied mainly in the form of electrical energy associated with arcs struck between the metallic charge and one or more graphite electrodes. Additional energy is provided by the combustion of carbonaceous materials introduced with the charge or during the melting operation, usually in the form of solid coal fines, or by gas or oil-fired oxygen burners.

- **The Secondary metallurgy**

Certain operations which have an essential bearing on final product quality are performed during the various secondary or ladle refining treatments:

- The analytical quality of the liquid metal is adjusted, including compositional trimming, not only of metallic alloying elements, but also the control of metalloids (C, H, N, O, P, S), to different degrees depending on the grade.

- The type and content of oxide inclusions is controlled, by deoxidation (or "killing") of the steel, generally with aluminum for sheet steels, by calcium treatment to modify their composition, and by controlled floatation.

- The temperature is controlled by careful management of heat losses during the various operations, by reheating, or where necessary by cooling with the aid of suitable amounts of scrap. The principal means of heating are electric arc or induction ladle furnaces, plasma torch heating in the continuous casting tundish or aluminothermic heating produced by the oxidation of added aluminum with pure oxygen.

These different treatments correspond to a wide variety of chemical reactions, involving the metal, slag or gas phases under favorable oxidizing or reducing conditions. In addition to the success of the individual operations, it is necessary to ensure their mutual compatibility, particularly by eliminating or neutralizing the slag produced by the oxidizing operations, in order to avoid phosphorus reversion during subsequent reducing treatments. Moreover, throughout secondary refining and teeming, care must be taken to prevent contamination (reoxidation, nitrogen, hydrogen and carbon pick-up, etc.), from various sources (contact with the atmosphere, refractories, casting powders, etc.), whose effects can be especially detrimental in high purity grades.

5. The continuous casting

After the primary and secondary refining steps, the molten steel with the required composition and purity must be solidified into the form of a semi-product whose geometry is compatible with that of the final product to be manufactured. Thus, a round section is most suitable for seamless tubes or bars, a square section (blooms or billets) for bars, shaped sections or wires, and a rectangular section (slabs) for sheet products. The exact dimensions of the as-cast product are chosen on the basis of a number of quite different criteria.
The basic principle of continuous casting, represented schematically in Figure 5, is to teem the molten metal onto a dummy bar in a bottomless mold so as to form a solid shell sufficiently strong to contain the liquid during its growth and withdrawal at a constant speed, which is continued until the product has solidified completely.

6. The reheating furnace and hot rolling

In the manufacturing sequence for flat steel products, the hot rolling mill is situated immediately after the melting shop, continuous caster and slab yard. Most slabs are now produced by continuous casting, although the ingot route is still used for certain products.

The as-cast slabs can be considered as intermediate products, whose composition and cleanness is now fixed, but which are not yet differentiated with regard to the geometry (thickness, width, length, weight, flatness, straightness), metallurgical structure or mechanical properties of the final product. The hot rolling operation is an essential stage in the manufacturing process, and all slabs are rolled. The hot rolling mills are therefore high volume workshops.
The products leaving the hot rolling mill can be considered in two categories. In the first of these, they are still intermediate products, destined to undergo other manufacturing operations, such as cold rolling and coating (sheets and cold strips) or normalizing (plates, usually wide). In the second case, the hot-rolled products are already virtually in their finished state, with the exception of certain conditioning operations. This is the case for hot rolled sheet and plates delivered in the as-rolled condition. The first "deliverable" product of a flat product steel plant is a as hot rolled coil, which still retains its oxide scale. In both cases, the hot rolling process must not only confer the required geometry of the products, but must also ensure their suitability for subsequent operations.

- **Principles of hot rolling**

Strip rolling basically involves reducing the thickness of a flat product by passing it through the gap between two rolls rotating in opposite directions, the workpiece being carried through by friction. In one "pass", the thickness of the metal is reduced from e n-1 to e. The desired final thickness is obtained by a series of such passes.
For a hot strip mill operator, who possesses a plant of fixed design, the practical problem is to obtain the final geometry via an optimum rolling schedule (number of passes and reduction per pass), while at the same time respecting certain metallurgical constraints, often expressed in terms of temperature and deformation.

- **Reheating furnace**

In addition to the rolling mill itself, the hot strip mill also contains slab reheating furnaces, whose function is to bring the metal temperature to a level where its rheological properties enable it to undergo the large strains involved in rolling. Moreover, the furnaces act as metallurgical and chemical reactors, with significant effects on the final product.
The products are 180 to 250 mm thick, 1 to 2 m wide rectangular slabs, from 4 to 14 m long and weighing from 5 to 30 tons. Charging can be performed cold (»15°C), warm (»400°C) or hot (³ 700°C). Slab furnace capacities range from 100 to 500 tons/hour, with a mean exit temperature between 1150 and 1250°C.
The table below gives the energy required to heat a ton of steel to 1200°C, with a combustion efficiency of about 65 %, for two charging temperatures (20 and 700°C).

Charging temperature (°C)	**Enthalpy requirement of the metal (MJ/t)**	**Installed furnace power (MJ/t)**
20	815	1 260
700	430	660

For example, a furnace designed to reheat 360 t of cold metal per hour will require an installed power of 126 MW, making it the biggest gas consumer in the integrated steeworks.
In an integrated steelworks, the furnaces are fired with a gas obtained by mixing the off-gases from the blast furnace, coking plant and steel melting shop. The availability of these gases varies with the

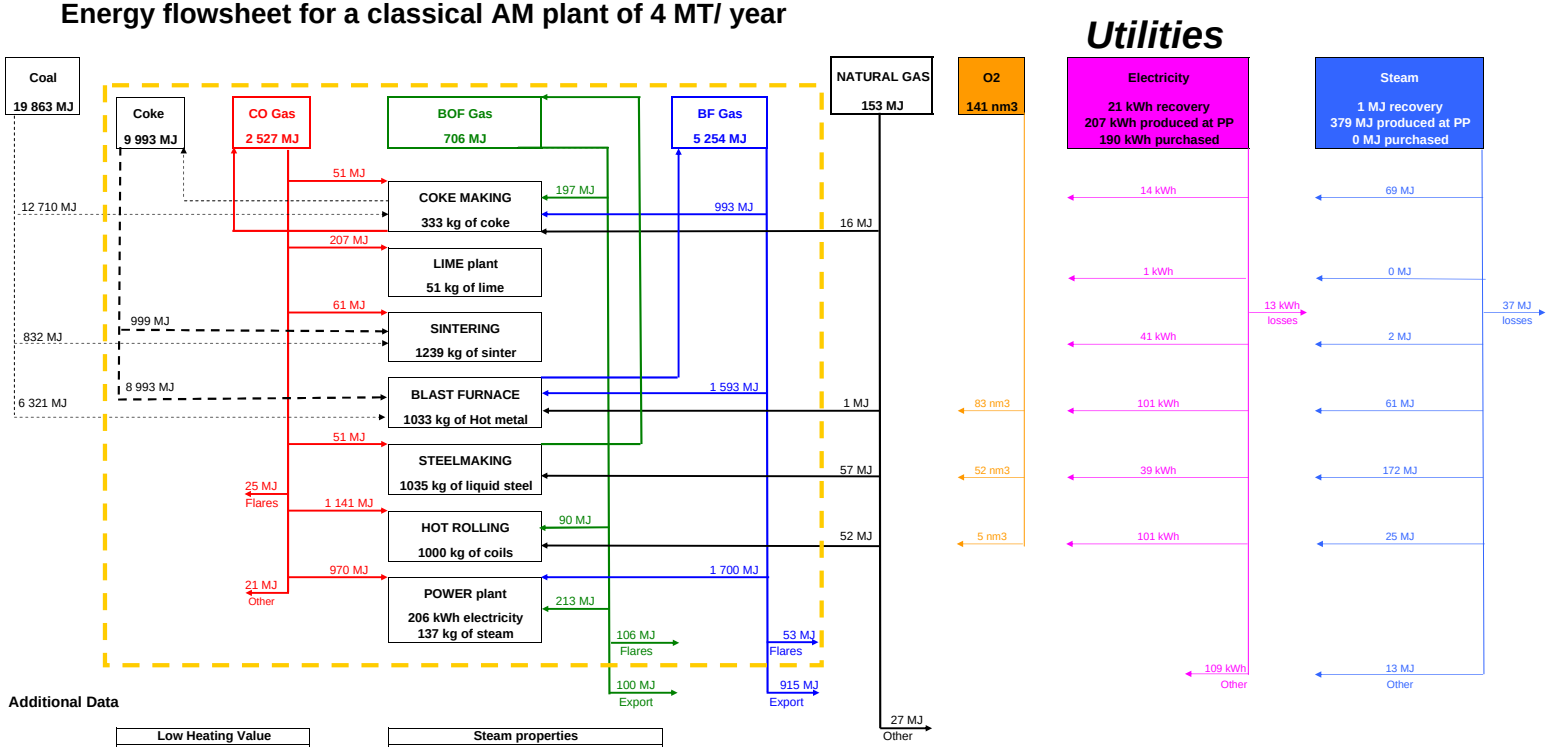
production of the processes concerned, so that they must be conditioned in a mixing station, to obtain a fuel whose characteristic combustion parameters (e.g. Wobbe index, PCI) are practically stable. During mixing, maximum use is made of the process off-gases, adding natural gas where necessary. The mixed gas obtained in this way contains impurities, such as tars, dust and sulfur, which require certain precautions. Its LHV is generally moderate (14 500 kJ/Nm3 , compared to 37 000 kJ/Nm3 for natural gas), and the combustion air must be preheated to obtain a suitable flame temperature. Before being discharged to the chimney, the combustion gases are therefore passed through a heat exchanger in order to transfer part of their sensible heat to the combustion air, which is preheated to about 650°C. With this system, the thermal efficiency of the furnaces is close to 65 %.

After Hot rolling, steel coils are processed in the finishing lines. This part is not described in this document as we just consider the upstream plant, where almost all the energy is used.

7. The power plant

The manufacture of coke and molten iron and refining of the hot metal in the steelworks produce large quantities of gas, which are extensively reused in the integrated plant, to cover the heating requirements of downstream workshops, particularly the reheating furnaces (See Excel file of Energy network). The coke oven and converter gases are rich, whereas the blast furnace top gases have a low calorific value. Depending on the size of the downstream workshops, there is an excess of gas representing about 15 to 30 % of the total produced. This residual gas is burnt in a thermal power station to produce steam and part of the electricity consumed in the works.

Energy flowsheet for a classical AM plant of 4 MT/ year



Additional Data

Low Heating Value	
Coal	**30 MJ/kg**
Coke	**30MJ/kg**
CO Gas	**20.6 MJ/nm3**
BOF Gas	**9.3 MJ/nm3**
BF Gas	**3.8 MJ/nm3**
Natural Gas	**36.8 MJ/nm3**

Steam properties	
Pressure	**10 bar**
Temperature	**200 °C**
Energy	**2 775 MJ/tonne**

EUROPAIRS - Task 1.1: End-User Processes
Inventory of data

Please fill this cover sheet for the identification of the document. The list of industries and processes in given in Sheet 6 for reference.

File	PARTNER_INDUSTRY_PROCESS_revA.xls

Partner	Fortum, Espoo, Finland
Industry	District Heating
Complex / Process Unit	Loviisa 3 NPP/District heating unit
Overall Electrical Power	MW

Objectives of the document:
This document aims at gathering efficiently relevant data related to the end-user processes.
Each partner is asked to fill one FORM for each complex or process unit (existing & future).
This collection of data is the core of Task 1.1 and will be consolidated in order to de used as base information for Task 1.3.

A notice to correctly fill this FORM is given in a dedicated sheet.

Status of the document

Rev. 0	29/09/2009	First issue by SSA of the document for comments from the partners of Task 1.1, 1.2 & 1.3
Rev. 1	21/10/2009	Issue by SSA of the finale FORM

End-User Requirements fOr industrial Process heat Applications with Innovative nuclear Reactors for Sustainable energy supply

How to use this FORM?

This FORM is divided into 5 sheets:

Sheet 1	**HOME.** This is the cover sheet of the file. Before anything else, please make sure that you have filled the requested information: name of the partner and of the contact - name of the industry and of the described plant / process unit (in accordance with the list given in annex (sheet 6)).
Sheet 2	**NOTICE.** A notice is included in the FORM. It includes the description of the various sheets and a quick definition of the requested parameters.
Sheet 3	**COMPLEX/PROCESS DESCRIPTION.** In this sheet, the partner shall give a simplified flow scheme of the process with basic information such as the name of the process units included in the overall process (/complex) and the name and main characteristics (pressure, temperature, flowrate) of the fluids/products circulating between the units. You are free to use the proposed draft scheme or to include an existing flow scheme (as a jpeg image or as an attached pdf file). You can add any identified safety issues related to this process in this sheet.
Sheet 4	**CONSUMER DUTY.** This sheet focuses, within the process described in sheet 3, on the identification of the heating needs (independently from how heat is generated). Definition and examples of the data requested are given here below. They aim at characterizing the need in terms of physical conditions, operational philosophy, reliability, flexibility and safety.
Sheet 5	**PRODUCER SPECIFICATIONS.** In a second time, this sheet focuses on the existing systems implemented for heat generation. This information will be valuable in order to study the technical and economical impact of the use of HTR as an alternate for generation of High Temperature heat. Two sets of data are asked for: definition of the heat producer and characterization of the heat transportation media. Definition and examples of the data requested are given here below.
Sheet 6	**ANNEX.** Reminder of the list of partners and the related industries and plants / processes.

To be filled in priority

Can be filled in a second time

REFERENCES & GLOSSARY

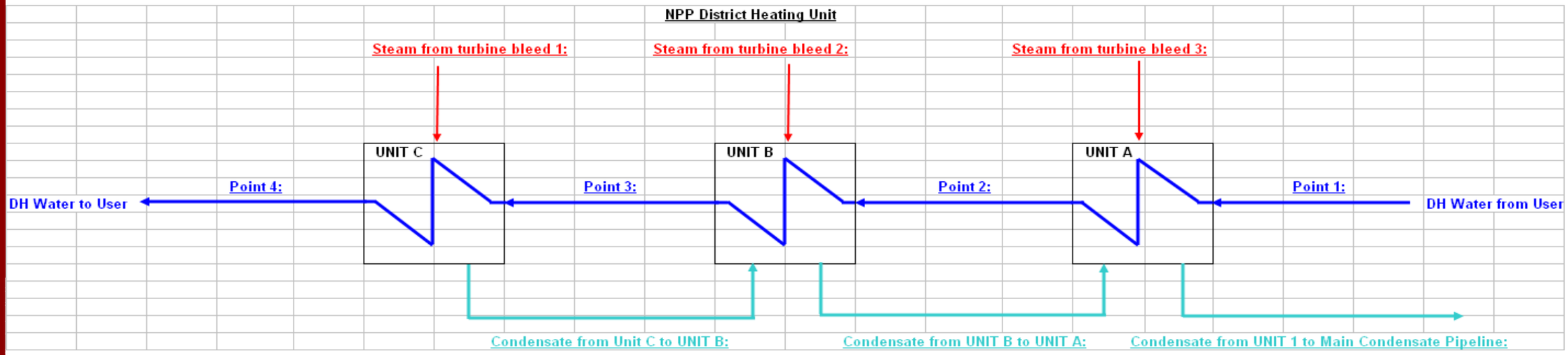
Ref.	*Parameter Name*	*Definition*	*Unit or Example*
		Process Description	
	complex	An ensemble of process units	
	Process Unit	One elementary process unit that can be included in a complex or several complexs	
(1)	Consumer Description	Name of the unit within the process (identical in sheet 3 and sheet 4)	steam reformming, hydrocracking…
		Consumer Duty - NEED	
(2)	Heating Loop N°	To number the heating loops properly allow to navigate easily in the file and to link heat production and heat consumption.	
(3)	Temperature	Temperature of the heating fluid at the inlet and the outlet **of the unit**.	K, °C, °F
(4)	Allowable Temperature Range	Min. & Max. temperatures at which the process takes place at full efficiency and without material damages.	K, °C, °F
(5)	Typical ramp up & down	Typical temperature gradient to be observed during transients (heating up & cool down).	K/min, K/s, K/h…
(6)	Continuous / Intermittent	Need for continuous heat supply (continuous process) or intermittent heat supply (batch process).	C or I (batch duration, number per year…)
(7)	Effect of heat supply disruption	What happens if case of heat supply disruption? Characterize the criticality of the heat supply.	shutdown of the process, degraded performances…
(8)	Consumption Leveling	Is there a possibility of leveling between the various heat loops in the process? Characterize the flexibility.	YES or NO
		Heat Producer Specifications - EXISTING	
(9)	Heat Generator Description	Name of the heat supply utility	
(10)	Fuel Type	Description of the fuel needed for heat generation	gas, coal, offgas (from unit X), electricity…
(11)	Fuel Consumption / External	Periodic consumption of external fuel	tpy, tph, Sm3/y…
(12)	Fuel Consumption / Offgases	Periodic consumption of internal fuel (offgases from another unit)	tpy, Sm^3/y…
(13)	Power	at least nominal power is required	MWh…
(14)	Back-up in case of shutdown	what is the planned back-up in case of the disruption og the normal heat supply?	
(15)	Media Type	Description of the media used for heat transportation between heat generation and consumption.	steam, oil, molten salt…
(16)	Temperature	Temperature of the medium at the inlet and at the outlet of the heat generation system	K, °C, °F
(17)	Pressure	Pressure of the medium at the inlet and at the outlet of the heat generation system	bar, psi…
(18)	Mass Flow	Mass flow rate of the heat transportation medium	tpy, Sm3/y…
(19)	Consumed in process ?	Indicate if the heat medium (for inst. STEAM) is recycled to heat generation OR consumpted afterwards in the process	YES or NO

Simplified Plant & Units flow scheme (1/2)

Objectives of the scheme

This simplified scheme aims at providing an easy understanding of the overall considered process.
You can add as many units as you think necessary.
In addition, please list at the bottom the safety concerns linked to the plant described here below.

❷ *Replace the example here below bythe flow scheme of the considered complex / process unit*



Simplified Plant & Units flow scheme (2/2)

❸ *Summarize here the name of the units*

	Consumer Description (1)
Unit A	Heat Exchanger 1
Unit B	Heat Exchanger 2
Unit C	Heat Exchanger 3
Unit D	
Unit E	
Unit F	
Unit G	
Unit H	
…	

❹ *Please detail here below the identified safety concerns related to the process.*

SAFETY CONCERNS.
-
-
-
-
-
-
-
-
-
-
-
-
-
-
-

Characterization of the heating needs (1/2)

Objectives of the sheet

This sheet gathers the information related to the needs for heat in the plant or process unit.

❺ *Replacet the example here below by the heating needs of the process units described in Sheet 3*

NPP District Heating Unit

Steam from turbine bleed 1:			Steam from turbine bleed 2:			Steam from turbine bleed 3:		
qm	155,50	kg/s	qm	146,42	kg/s	qm	145,91	kg/s
p	2,70	bar(a)	p	1,45	bar(a)	p	0,70	bar(a)
t2	129,98	°C	t	110,36	°C	t	89,96	°C
h2,s	2719,88	kJ/kg	h,s	2669,55	kJ/kg	h,s	2493,39	kJ/kg
h2,w	546,24	kJ/kg	h,w	462,83	kJ/kg	h,w	376,77	kJ/kg
h,evap	2173,65	kJ/kg	h,evap	2206,72	kJ/kg	h,evap	2116,62	kJ/kg
Q,h,evap	338,01	MW	Q2,h	323,11	MW	Q1,h	308,85	MW

Point 4:			Point 3:			Point 2:			Point 1:		
qm	4000,00	kg/s	qm	4000,00	kg/s	qm	4000,00	kg/s	qm	4000,00	kg/s
t	120,00	°C	t	100,00	°C	t	80,00	°C	t	60,00	°C
p	8,00	bar(a)	p	8,67	bar(a)	p	9,33	bar(a)	p	10,00	bar(a)
cp,w	4,24	kJ/kgK	cp,w	4,21	kJ/kgK	cp,w	4,19	kJ/kgK	cp,w	4,18	kJ/kgK
h,w	504,14	kJ/kg	h,w	419,64	kJ/kg	h,w	335,62	kJ/kg	h,w	251,91	kJ/kg

UNIT C | UNIT B | UNIT A

DH Water to User ← DH Water from User

Q,w	338,01	MW	Q2,w	336,08	MW	Q1,w	334,83	MW
Q,h	338,01	MW	Q2,h & Q3,w	336,08	MW	Q1,h & Q2,w	334,83	MW

Condensate from Unit C to UNIT B:			Condensate from UNIT B to UNIT A:			Condensate from UNIT 1 to Main Condensate Pipeline:		
qm	155,50	kg/s	qm	301,92	kg/s	qm	447,84	kg/s
t	129,98	°C	t	110,36	°C	t	89,96	°C
p	2,70	bar(a)	p	1,45	bar(a)	p	0,70	bar(a)
cp,w	4,26	kJ/kgK	cp,w	4,23	kJ/kgK	cp,w	4,20	kJ/kgK
h,w	546,24	kJ/kg	h,w	462,83	kJ/kg	h,w	376,77	kJ/kg
Q3,w	12,97	MW	Q2,w	25,98	MW			

Characterization of the heating needs (2/2)

❻ *Fill the table here in accordance with the units described in Sheet 3 and with the scheme here above.Definitions of the parameters are given in Sheet 2.*

Consumer duty

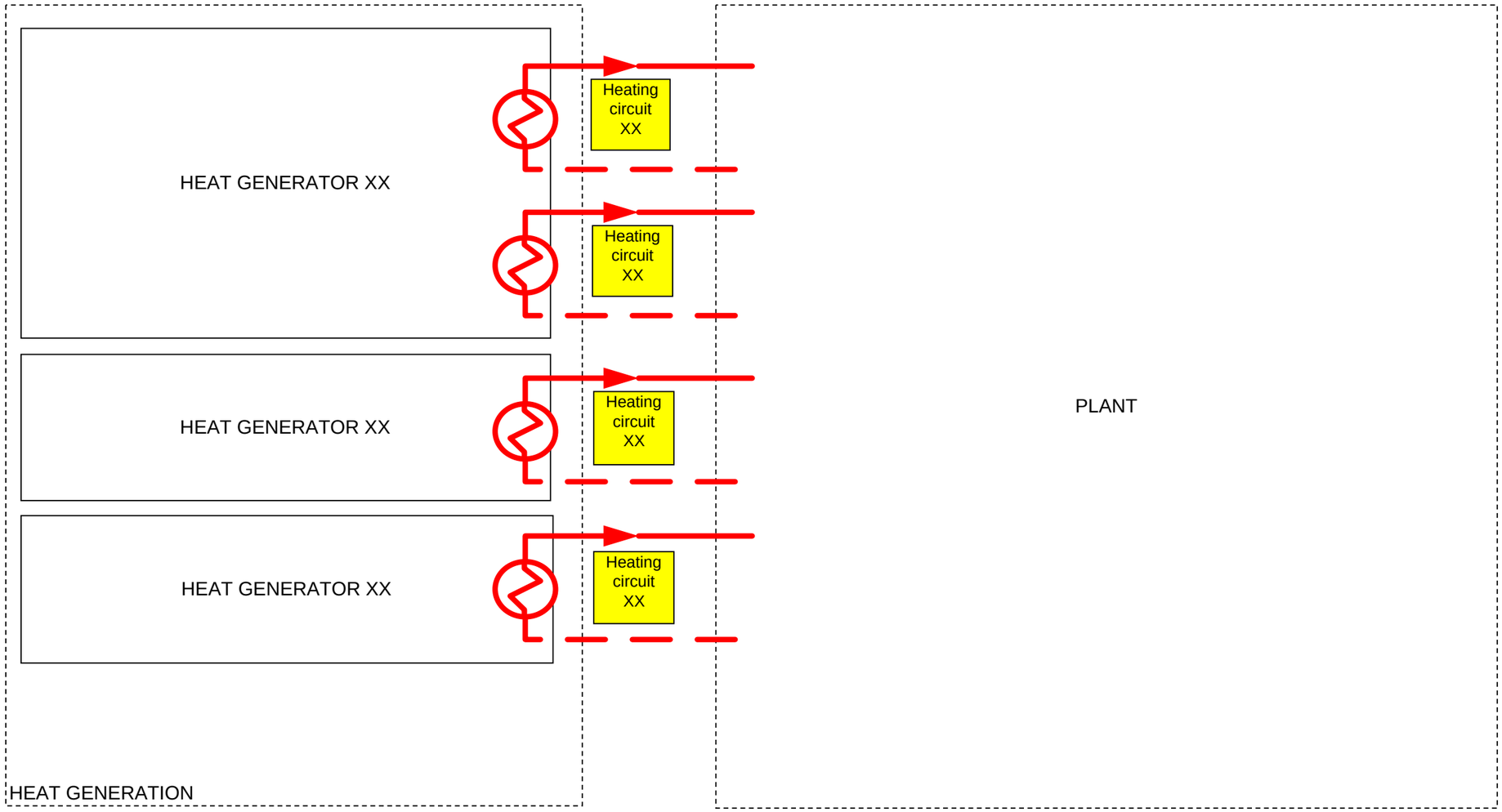
Consumer Description (1)		Heating Circuit N° (2)	Steam Temperature (3)		Allowable Temperature Range (4)		Typical ramp up and down (5)	Continuous OR Intermittent (6)	Effect of heat supply disruption (7)	Consumption leveling (8)	Comments
			inlet	outlet	T_{min}	T_{max}					
Unit A	Heat Exchanger 1	1	90 °C	90 °C	-	-	-	Continuous	Shutdown of process	-	-
Unit B	Heat Exchanger 2	2	110 °C	110 °C	-	-	-	Continuous	Shutdown of process	-	-
Unit C	Heat Exchanger 3	3	130 °C	130 °C	-	-	-	Continuous	Shutdown of process	-	-

Characterization of the existing heat generators (1/2)

Objectives of the sheet

This sheet gathers data on the existing heat generation systems.

❼ *Replace the example here below by the existing heat generation systems for the considered complex / process units. Heating Circuit Numbers shall be in accordance with Sheet 4.*



Characterization of the existing heat generators (2/2)

❽ *Fill both table shere in accordance with the heating circuits described in Sheet 4 and with the scheme here above. Definitions of the parameters are given in Sheet 2.*

HEAT GENERATORS

Heating circuit N° (2)	Heat generator description (9)	Fuel type (10)	Fuel Consumption		Power (kWth) (13)			Backup in case of shutdown (14)	Comments
			External (11)	Offgases (12)	Min.	Nominal	Max.		

MEDIA TABLE

Heating circuit N° (2)	Media type (15)	Temperature (16)		Pressure (17)		Mass flow (18)			Consumed in the process ? (19)	Comments
		inlet	outlet	inlet	outlet	Min.	Normal	Max.		
0										
0										
0										
0										
0										
0										
0										
0										
0										
0										
0										
0										

Industries & Processes

	Partners	Contact	Industries	Plant / Process Units
1	AMEC	Derek BUCKTHORPE derek.buckthorpe@amec.com	Oil sands	Steam Assisted Gravity Drainage
				Cyclic Steam Stimulation
			Petrochemicals	
			Ciment	Pyro processing
			Paper and Pulp	Kraft process
2	Air Liquide	Claire WEBER claire.weber@airliquide.com	Industrial Gas production	Oxygen Production - Ceramic membrane
				CO Production - dry reforming
3	Arcelor Mittal	Gerard Griffay gerard.griffay@arcelormittal.com	Steel Making	Coke Making
				SteelMaking
				Hot Rolling
				Direct Reduced Iron (DRI)
				Power complex
				Lime complex
				Sintering
				Blast Furnace
4	Fortum	Harri Tuomisto harri.tuomisto@fortum.com	Paper and Pulp	
			Oil refinery	
			Co-generation	
			District Heating	
5	FZJ	Werner von Lensa w.von.lensa@fz-juelich.de	Coal	Coal Gasification
				Steam Methane Reforming
6	GDF Suez - Tractebel	Carmen Angulo carmen.angulo@gdfsuez.com	Co-Generation	-
7	NWU/PBMR	Gideon Greyvenstein	Petroleum Products	Fischer-Tropsch
				Steam Methane Reforming
		gideon.greyvenstein@pbmr.co.za	Oil Sands	
8	NWU	Frik van Niekerk frik.vanniekerk@nwu.ac.za	Hydrogen Production	Thermochemical water splitting
				Hybrid Sulfur
				Sulfur Iodine
				High Temperature Electrolysis
9	PROCHEM	Marek Tarka mtarka@prochem.com.pl	Refinery	Aromatics Extractive Distillation
				Crude Oil Distillates Hydrotreatment
				Crude Oil Distillation
10	SAIPEM	Jacques RUER jacques.ruer@saipem-sa.com	Energy Storage	Pumped Heat Electricity storage
11	Technip	Gaetano Iaquaniello iaquaniello.g@ktispa.it	Refinery	
			Hydrogen production	Steam Reforming
				Membranes Steam Reforming
12	USG (DSM) / BEC	Anton Baaten anton.baaten@me.com	Wide Range (Petro)chemicals incl. Urea & Ethylene	Utilities supply
13	ZAK	Marek Zuber marek.zuber@zak.com.pl	Nitrogen Fertilizers	Syngas production
				Hydrogen production
				Nitric acid synthesis
				Ammonia synthesis
				Urea production
			Organic Synthesis	Oxo processes
				Alcohol synthesis
				Phthalate plasticizers synthesis
				Phtalic and maleic anhydride

EUROPAIRS – Task 1.1 End User Processes, Characteristics and Requirements Hydrogen Production

Document number: NWU_Europairs_1209

Revision: 1

by

M.D. Coetzee

November 2009

CHANGE HISTORY

Configuration Control	
Project:	EUROPAIRS
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Revision History			
Revision	**Date**	**Author**	**Description of Changes**
A	18 Nov 2009	MD Coetzee	**Initial Draft for review**
1	19 Nov 2009	MD Coetzee	**Document approved**

Authorisation			
Action	**Designate / Signature**	**Position**	**Date**
Prepared	_____ MD Coetzee	Project Engineer	**December 2009**
Reviewed	_____ Miek Venter	Technical Lead	**December 2009**
Approved	_____ Jan van Ravenswaay	Program Manager	**December 2009**

Original Signed Copy at CMC

Change Forecast

The document format and contents have been approved.

Table of contents

1. Scope

This document aims to provide the reader with relevant data and information related to the end-user processes as required by Task 1.1 in order to consolidate the information for use in Task 1.3. The applicable processes investigated include the Hybrid Sulfur (HyS), Sulfur Iodine (SI) and High Temperature Steam Electrolysis (HTSE) process.

2. Definitions, Terms, Acronyms and Abbreviations

2.1 DEFINITIONS

None

2.2 TERMS

None

2.3 ACRONYMS AND ABBREVIATIONS

Abbreviation or Acronym	Definition
HyS	Hybrid Sulfur
SI	Sulfur Iodine
HTSE	High Temperature Steam Electrolysis
MMCFD	Million Cubic Feet per Day
SiC	Silicone Carbide
PTFE	Polytetrafluoroethylene
SDE	Sulfur Dioxide Depolarized Electrolyzer
FUS	Feed and Utility Systems
SAD	Sulfuric Acid Decomposition
ELE	Electrolysis
PPU	Product Purification System
EDI	Electro-deionization
HAD	Hydroiodic Acid Decomposition

Abbreviation or Acronym	Definition
BUN	Bunsen Reaction
HRS	Heat Recovery System
CDA	Clean Dry Air
PCHX	Process Coupling Heat Exchanger

3. References

3.1 APPLICABLE DOCUMENTS AND DATA

The following documents and data are applicable:

TITLE	REFERENCE NUMBER
[1] C. W. Forsberg, *Int. Sci. J. Altern. Energ. Ecol.*, 2004, **2**.	N/A
[2] The Energy Information Administration of the Department of Energy, *Annual Energy Outlook 2000 with Projections to 2020*, DOE/EIA-0383, http://www.eia.doe.gov/, 2000.	N/A
[3] Hybrid Sulfur Process Reference Design and Cost Analysis	SRNL-L1200-2008-00002 Rev1

3.2 ADDITIONAL REFERENCE DOCUMENTS AND DATA

The following are additional reference documents and data:

TITLE	REFERENCE NUMBER
None	

3.3 APPLICABLE SOFTWARE

The following software files are applicable:

SOFTWARE DESCRIPTION	VERSION NUMBER	FILE NAME
None		

4. Hydrogen Production Industry

The worldwide consumption of hydrogen is estimated at approximately 50 million tonnes per annum. The majority of this hydrogen is used for ammonia production, which is further processed to make fertiliser. It is also used for heavy crude oil that is converted to clean liquid fuels. The decline in the availability of light crude oil that does not necessitate additional hydrogen for conversion to gasoline is another reason for the increasing demand. Coupled with this is an increased use of heavy crude oils that entails very large amounts of hydrogen for conversion to gasoline. Should the development of automotive fuel cells occur in such a manner so that the desired cost goals are reached, this could lead to the transportation sector also being fuelled by hydrogen. The effect of this could result in an increase in hydrogen consumption over a period of a number of decades of one to two orders of magnitude [1]. Contemporary production of hydrogen makes use of fossil fuels and natural gas, nullifying the environmental advantage of hydrogen. The hydrogen industry in the United States currently produces 11 million tonnes of hydrogen a year, consuming 5% of the country's natural gas usage and releasing 74 million tonnes of CO_2 into the atmosphere [2]. Hydrogen that is produced from alternative process heat applications could solve this problem. At present no large scale, cost-effective, environmentally-attractive hydrogen production process has been identified that can be commercialised in the short term. A number of techniques have been proposed for utilizing alternative process heat applications for the production of hydrogen. These include the Hybrid Sulfur process, the Sulfur Iodine process as well as the Hight Temperature Steam Electrolysis process.

5. Technology Descriptions

The Hybrid Sulfur process incorporates two central technologies, Sulfuric Acid Decomposition (Oxygen Generation) and Sulfur Dioxide Depolarized Electrolysis (Hydrogen Generation) as shown in Figure 1.

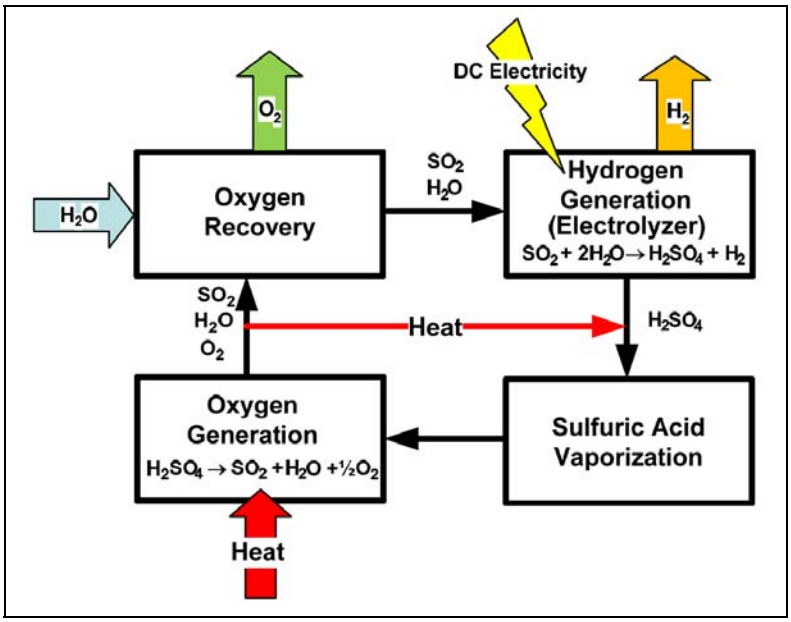

Figure 1: The Hybrid Sulfur Process

The Sulfur Iodine process also uses Sulfuric Acid Decomposition technology, but it replaces the electrolysis technology with two chemical technologies, the Bunsen Reaction and Hydroiodic Acid Decomposition, as shown in Figure 2. Please note that the Bunsen Reaction is denoted as "Chemical Reactions" in Figure 2.

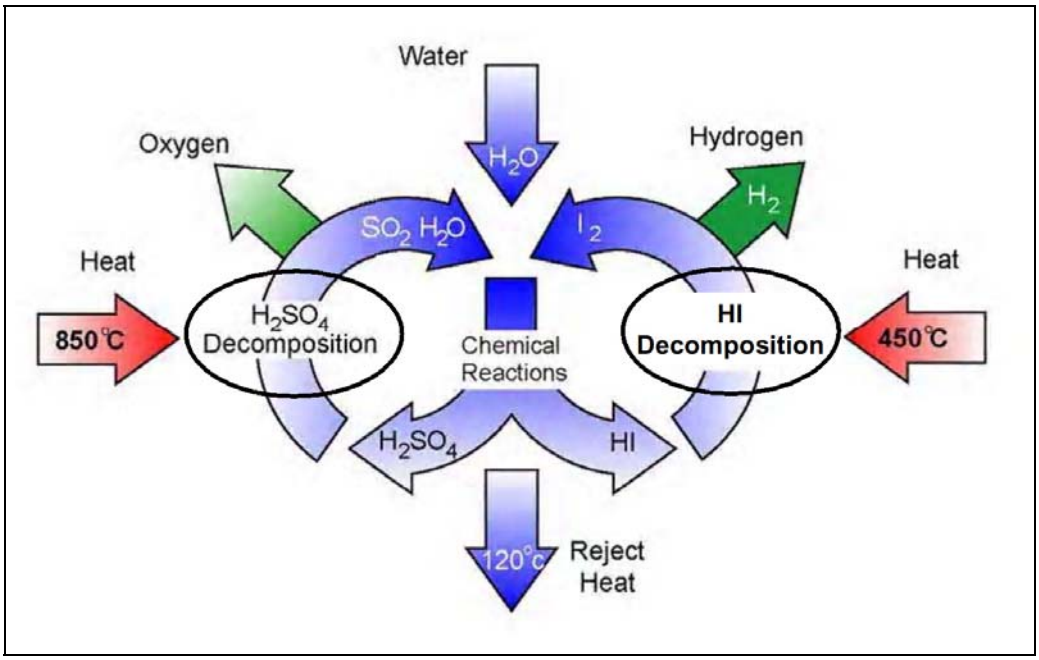

Figure 2: The Sulfur Iodine Process

The High Temperature Steam Electrolysis process is simpler than the previous two processes in that it incorporates only one central technology: steam electrolysis by means of Solid Oxide Electrolysis Cells. The HTSE process is shown in Figure 3

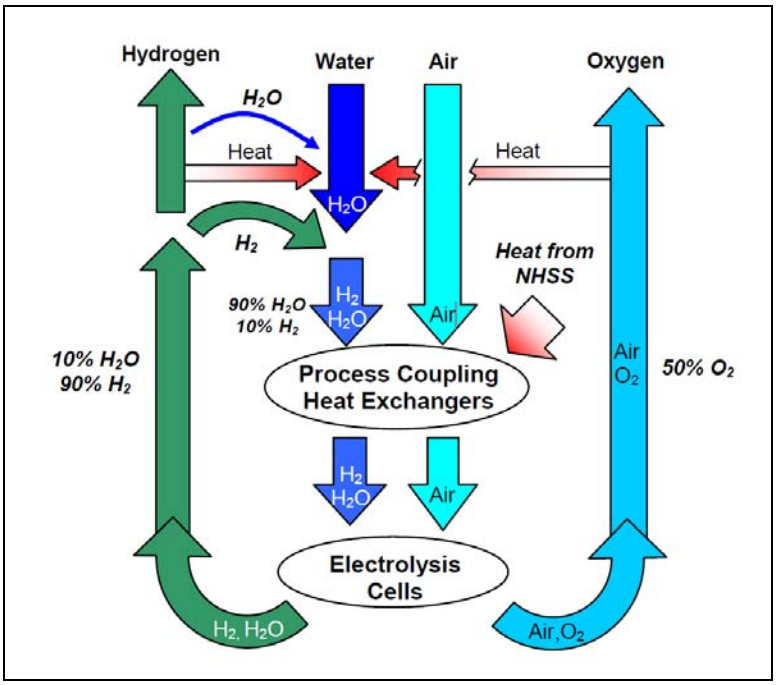

Figure 3: The High Temperature Steam Electrolysis Process

6. Sulfuric Acid Decomposition

Although it is embodied slightly differently in each, this technology is common to both the Hybrid Sulfur and the Sulfur Iodine processes. The point of sulfuric acid decomposition is that it replaces a portion of the energy required to split water provided as work in water electrolysis with heat. It therefore virtually eliminates the thermal losses associated with the generation of electricity from thermal energy for this portion of the water splitting energy. The basic chemistry is simple. Sulfuric acid is first decomposed into water and sulfur trioxide.

$$H_2SO_4 \rightarrow H_2O + SO_3$$

This occurs quantitatively and uncatalyzed at temperatures well below the maximum at which the reactor operates. The more difficult reaction is the decomposition of sulfur trioxide:

$$SO_3 \rightarrow SO_2 + ½\ O_2$$

This step requires a catalyst and estimated conversions at expected operating temperatures (i.e., ~870°C) are about 50%. These reactions are favored as pressure is lowered and temperature is raised. The decomposition reactor should therefore be designed to operate at the highest temperature that can practically be achieved. Although a lower pressure favors the chemical

equilibrium, mechanical considerations in the reactor design make operating significantly below the helium heat transfer medium pressure, that is ~90 bar, difficult.

In its simplest form, the reactor consists of one closed ended SiC tube co-axially aligned with an open ended SiC tube to form two concentric flow paths. A baffle tube may be included to enhance heat transfer. High-temperature heat is applied externally, except near the open end. Concentrated liquid H_2SO_4 is fed at the open end to the annulus, where it is vaporized before passing through an annular catalyst bed. The decomposition reaction takes place in the catalyst bed, using heat provided by the external heat source. SO_2, O_2, and H_2O vapor product returns through the center and loses its heat to the feed through recuperation. Cooled and partially condensed product exits out the open end into a metal base or manifold at a temperature low enough (i.e., ≤ ~250°C, or 523°K) to allow the use of PTFE seals. Imbedding the open ends of the SiC tubes in a metallic manifold facilitates the transition to metal pipe.

The Hybrid Sulfur process uses a low-temperature, liquid phase electrolysis similar to existing electrolytic processes to generate hydrogen from water. The HyS cycle is attractive because the standard cell potential for SO_2-depolarized electrolysis is -0.158 V at 25°C (298°K) in water. The reversible potential increases to -0.243 V if SO_2 is dissolved to saturation at 1 bar total pressure in a 50-wt% H_2SO_4 – H_2O solution, the most likely anolyte. This means that the Sulfur Dioxide Depolarized Electrolyzer (SDE) will consume much less electricity per mole of hydrogen product than water electrolysis, which has a reversible cell potential of -1.229 V at 25°C (298°K). The energy difference has been supplied as heat for the process of decomposing sulfuric acid. The catholyte is water and the anolyte is a solution of sulfuric acid, water, and dissolved sulfur dioxide. Sulfur dioxide is oxidized at the anode to produce sulfuric acid and hydronium ions (i.e., protons). The outlet anolyte stream therefore has a higher concentration of sulfuric acid than the inlet anolyte stream. The protons produced at the anode transport as hydronium ions across the cation-exchange membrane into the catholyte and are reduced at the cathode to produce hydrogen gas. The reactions that constitute this process are as follows:

Anode reaction: $SO_2\ (aq) + 2H_2O\ (aq) \rightarrow H_2SO_4\ (aq) + 2H^+\ (aq) + 2e^-$
Cathode reaction: $2H^+\ (aq) + 2e^- \rightarrow H_2\ (g)$
Overall reaction: $SO_2\ (aq) + 2H_2O\ (aq) \rightarrow H_2SO_4 + H_2\ (g)$

Figure 4 depicts a parallel plate single cell electrochemical reactor and the reaction chemistry that occurs at each electrode.

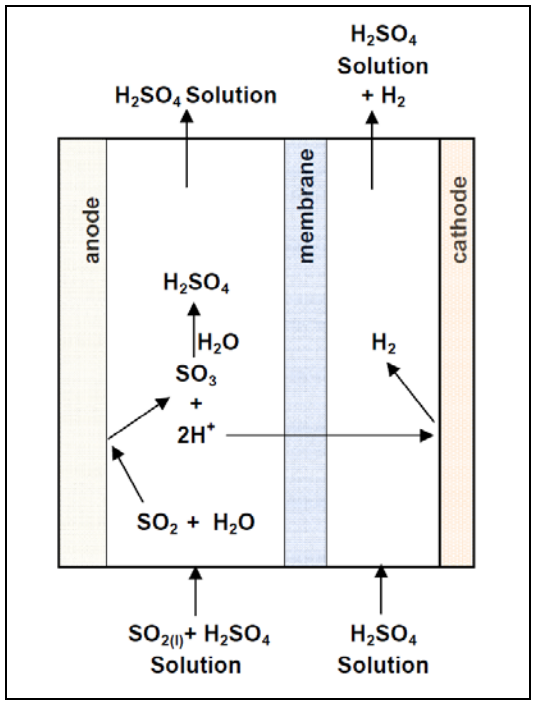

Figure 4: Schematic of Electrolysis reaction

7. The Bunsen Reaction

As described in Section 1, the Sulfur Iodine cycle consists of three coupled chemical reactions: (1) the Bunsen Reaction, (2) Sulfuric Acid Decomposition, and (3) Hydroiodic Acid (HI) Decomposition. The overall process conveniently divides into distinct process sections, as shown in Figure 1-2. The thermodynamic advantage of the Sulfur Iodine cycle is that the energy required to split water can theoretically be supplied entirely as heat rather than as work or electricity as in other water-splitting processes considered here. In reality, as we shall see, this process also requires a considerable input of work. The Bunsen Reaction may be considered the first step of the cycle, where water, sulfur dioxide, and iodine chemically react to form sulfuric acid and hydrogen iodide as follows:

$$2H_2O + SO_2 + I_2 \rightarrow H_2SO_4 + 2HI.$$

The sulfuric acid and hydrogen iodide reaction products are then chemically broken down in subsequent decomposition reactions to produce oxygen and hydrogen gas respectively. Other decomposition reaction products, such as sulfur dioxide, water, and iodine, are recycled back from the associated decomposition reactions to the Bunsen Reaction. As can be seen in Figure 1-2, the Bunsen reaction is exothermic and the two decomposition reactions are endothermic. Unfortunately, the endothermic reactions require heat at much higher temperatures than could be recovered from the Bunsen Reaction. Therefore, in practical terms, the heat from the Bunsen

Reaction is best sent to cooling water and lost. The Bunsen reaction takes place at the interface between two immiscible liquid phases: (1) an iodine-rich phase, which contains the hydroiodic acid product, and (2) a sulfur dioxiderich phase , which contains the sulfuric acid product. These phases must be well-mixed in the reactor while the exotherm is being removed and then separated quickly to prevent the formation of elemental sulfur. Separation of light and heavy phases is readily achievable through gravity separation. The ratio of the densities of two phases is on the order of 2:1. A large excess of liquid iodine must be maintained in the system in order to effect good separation between the hydroiodic acid and the sulfuric acid. This has serious implications for process design and economics. An oxidizing atmosphere is required for the reaction to proceed and product oxygen is usually circulated through the Bunsen reactor to assist in removing sulfur dioxide and to provide this atmosphere. Maintaining adequate concentrations of the reactants in the two liquid phases in the reactor is of prime importance. The phase equilibria, especially of the $HI/I_2/H_2O$ system, as well as the chemical equilibria, must be well understood to provide an adequate basis for process design. The data currently available is limited and not adequate for a robust process design. Reactor design for equipment larger than bench scale has not progressed further than preliminary concepts.

8. Hydroiodic Acid Decomposition

Hydroiodic acid decomposition provides the remaining enthalpy required for the water splitting reaction subsequent to sulfuric acid decomposition and the Bunsen Reaction. In this step, elemental hydrogen and iodine are produced by the simple reaction

$$2HI \rightarrow H_2 + I_2$$

The reaction is not spontaneous and requires a catalyst. Moreover, the chemical equilibrium is not strongly favorable to the decomposition and product iodine must be removed continuously from the reaction zone in order to keep the hydroiodic acid concentration high enough for the reaction to proceed and to produce reasonable yields. As a result, the reaction must be combined with a separation step. Two strategies have been proposed: (1) extractive distillation with phosphoric acid as a solvent and (2) reactive distillation. Most of the investigative work until now has focused on the former strategy. Difficulties and potential costs presented by the introduction of another very aggressive corrosive chemical, especially in an industrial environment, have caused recent attention to shift towards reactive distillation. Unfortunately, the phase equilibrium data for this system is incomplete and process models based on the available data are not reliable. The feasibility of reactive distillation has yet to be established and equipment design for this step has not begun. Perhaps the most serious limitation to this technology lies in the disparity between the atomic weights of iodine and hydrogen. Iodine has an atomic weight of approximately 127 while the

atomic weight of hydrogen is about 1. That means for every kilogram of hydrogen produced at least 127 kilograms of iodine must be circulated back and forth between the HI decomposition step and the Bunsen reaction. However, the HI decomposition is not complete and a large quantity of elemental iodine is needed for the separation of the acids in the Bunsen step. The iodine circulation rate is therefore much larger than the stoichiometric minimum.

9. High Temperature Steam Electrolysis

For large scale hydrogen production, interest in HTSE derives from its prospects for higher overall energy efficiency and reduced electrical energy demand, when compared to conventional water electrolysis. These prospects derive from the following theoretical considerations:

• ***Liquid-to-vapor phase transition using thermal energy, as opposed to electrical energy.*** In conventional electrolysis, electricity provides the energy both to vaporize the water and to split the water into its constituent parts. The relatively low thermal efficiency associated with electricity production increases the total energy requirements. With HTSE, thermal energy (i.e. – process heat) is used to provide the energy for the phase change, thus avoiding electricity production losses for that component of energy.

• ***Thermodynamic requirements for heat and work.*** In theory, as the temperature of the electrolysis process is increased, the amount of energy that must be input as work (i.e., electricity) decreases.

• ***Reduced overvoltage.*** In an electrolysis process, the voltage required to drive the process is a direct indicator of electrical energy demand. The principal advantage of HTSE derives from its reduced over-voltage characteristics, relative to low temperature processes. In conventional electrolysis, hydrogen and oxygen are generated by passing an electric current through a solution of water and an electrolyte. Hydrogen gas is generated at the cathode and oxygen gas is generated at the anode. The basic reactions that take place at the cathode and anode are shown below.

At the Cathode: $H_2O + 2e- \rightarrow H_2 + O- -$
At the Anode: $O- - \rightarrow ½\ O2 + 2e-$

The transformation of water into hydrogen and oxygen gas is endothermic. Energy must be added to the reaction from the environment. At standard conditions, the amount of energy required to transform one mole of water to one mole of hydrogen gas and one-half mole oxygen gas is 285.83

kJ. In general, thermodynamic potential of the system may be described by the system's internal energy that is defined using the following equation.

$\Delta U = \Delta H - p\Delta V = \Delta G + T\Delta S - p\Delta V$

For a reaction at a given temperature and pressure, ΔH is the enthalpy of reaction, ΔG is the change in free energy, and ΔS is the entropy of reaction. The pΔV term is the work associated with the expansion of the gases. Using the above equation, the enthalpy of reaction may be expressed in terms of the change in free energy and entropy:

$\Delta H = \Delta G + T\Delta S$

For the electrolysis of water into hydrogen and oxygen, ΔG is work added to the system in the form of electricity while TΔS is in the form of heat added by the environment. As temperature of the system increases, ΔH and ΔS of the system do not significantly change. Therefore, as the portion of the work provided through heat increases, the portion provided in the form of electricity will decrease accordingly. Figure 1-9 illustrates the thermodynamic potentials for the electrolysis of water for a
temperature range between 25°C to 1000°C and a system pressure of 1 bar. As can be seen in the figure, there is a significant reduction in the amount of electrical work that needs to be

10. Summary Process Description

10.1 HYBRID SULFUR

The HyS cycle consists of four major process sections:

- Feed and Utility Systems (FUS)
- Sulfuric Acid Decomposition (SAD)
- Electrolysis (ELE)
- Product Purification System (PPU)

The FUS and PPU sections include systems that produce the assumed feed water and product purity requirements, respectively. Capacities described in the following discussion are for one production train, with two production trains required to meet the target hydrogen production rate. The hydrogen production capacity for one train is approximately 71 MMCFD.

10.1.1 Feed and Utility Systems

Due to the high degree of internal recycle in the HyS process, impurities contained within the feed water will remain within the process. The result of the concentration of these impurities in the process would cause negative consequences, at a minimum, in the Sulfuric Acid Decomposer. Therefore, it is assumed that the feed water quality must be of the highest purity and that a state-of-the-art water treatment system will be required. At the time of this study, feed water purity requirements for the HyS cycle are not known. Therefore, this design assumes that the water quality requirements are ultra pure water. The design of a water treatment system depends on the source water quality and its analysis. This study assumes that the water source is well water with a minimum hardness of 200 ppm as $CaCO_3$. The pretreatment system includes a multi-media filtration and softener system to remove suspended solids and hardness, respectively. The pretreatment system is followed by a demineralizer system consisting of a reverse osmosis and electro-deionization (EDI) system. For the HyS cycle, the water treatment system capacity is estimated to be 130 m^3/hr. Purified water storage for 48 hours of process water demand and feed water pumps to convey this water are provided. The FUS also includes a wastewater treatment system to treat water treatment wastes and process wastes. It is estimated that the system needs to treat approximately 60 m^3/hr of wastewater. The type of treatment required will depend on the effluent discharge limits imposed by the permitting jurisdiction. For this study, it is anticipated that the wastewater treatment system will consist of an oil/water separation system, final neutralization system, physical/chemical treatment system with mixing tank, and ancillary pumps, instrumentation and equipment. The wastewater treatment system is also treated as a vendor supplied system. The final components of the FUS consist of sulfuric acid and caustic bulk storage and transfers systems. The sulfuric acid system provides makeup to Sulfuric Acid Decomposition. Caustic is required to remove residual sulfur dioxide from the product oxygen in the PPU caustic scrubber. Both sulfuric acid and caustic are delivered as a 50 mass per cent liquid solution. Sulfuric acid is delivered to the Bunsen Reactor as is and caustic is diluted to a 10% by weight solution before being pumped to the scrubber.

10.1.2 Sulfur Dioxide Depolarized Electrolysis

Make up purified water feed is fed to the Catholyte Surge Drum. After being filtered to remove any solid debris or products of corrosion, it is circulated through the cathode of the Electrolyzers. There are four trains of electrolyzers each containing 54 units. Each unit consists of 200 PEM cells. Water is consumed in the electrolyzers forming hydrogen gas and oxygen ions. The ions pass through the cell membrane and react with dissolved sulfur dioxide to form sulfur trioxide ions. Catholyte and hydrogen gas leave the top of the electrolyzer units and are separated in the Wet Hydrogen Knockout Drum. Catholyte is returned to the Catholyte Surge Drum after being cooled by the Vacuum Column feed. Anolyte consisting of 15.5 mass per cent sulfur dioxide dissolved in 43.5

mass per cent sulfuric acid is pumped to the electrolyzer units from the Anolyte Prep Tank. After being cooled by the Vacuum Column feed, most of the anolyte is circulated back to the Anolyte Prep Tank. Approximately 20% of the anolyte is further cooled with cooling water and sent to the Sulfuric Acid Decomposition section. About 40% of the sulfur dioxide in the anolyte is converted to sulfuric acid.

10.1.3 HyS Sulfuric Acid Decomposition

Sulfuric acid feed at about 50% concentration by weight is sent from the ELE section to the SAD section to be decomposed into sulfur dioxide, water, and oxygen. Before being pumped to the decomposer, the acid is concentrated to 75% by weight to maximize the efficiency of the decomposition step. Because the per-pass conversion is only about 50%, a substantial amount of sulfuric acid is recycled. Process heat is recuperated by recovering heat from several flashed vapour and other streams to preheat the Vacuum Column feed. Acid feed to the section is flashed in two stages: the first stage is at atmospheric pressure, and the second stage under vacuum to remove as much sulfur dioxide as possible. The feed is then pumped to one of four Vacuum Columns where water is removed to concentrate the decomposition feed. The vacuum towers operate at a top pressure of about 0.1 bar and a bottom temperature of about 127°C in order to reach the required 75 mass per cent concentration. To handle the column internal vapour load for each train at about 1160 m^3/s, four very large vacuum towers are required along with reboilers, condensers, reflux drums, and pumps. Heat for the distillation, about 108 MW_{th} total for each train of four columns, is provided by imported steam at a pressure of 10 bar. Condensing cooling for the tower, about 204 MW_{th} total for each train of four columns, and a vacuum steam ejector system is provided by imported cooling water. The two-stage steam ejector system provides the vacuum for the system. Uncondensed vapour, primarily sulfur dioxide, is collected from the column and flash drums and is compressed in the SO_2 Recycle Compressor and sent to the bottom of the Absorber Column. The vapour flashed from several streams, both upstream and downstream of the decomposer, is partially condensed and flows to the Absorber Column. Concentrated acid bottoms from the Vacuum Columns are pumped to the Sulfuric Acid Decomposers. Here the decomposition of sulfuric acid into water, sulfur dioxide, and oxygen takes place. The heat for the endothermic reaction and feed heating is provided by helium at 910°C from the NHSS. The helium return temperature from the decomposers is 522°C for a duty of 356 MW_{th} per train. Decomposer product is flashed in four stages to separate product sulfur dioxide and oxygen from unreacted sulfuric acid. Vapour from these flashes is partially condensed using the feed streams to the Vacuum Column and cooling water. The condensate and vapour are sent to the Absorber Column, while the liquid is recycled to the bottom of the Vacuum Column. Liquid condensate and vapour from the flashed streams and Vacuum Column overhead product are all sent to the Absorber Column. The condensate is then used to scrub sulfur dioxide out of the product oxygen. The oxygen product

flows to the Product Purification System and the liquid, primarily sulfur dioxide dissolved in water, flows to the Anolyte Prep Tank.

10.1.4 Product Purification Systems

Purification of the oxygen product from the SAD and the hydrogen product from ELE is required to meet industry standards for these product gases. The design of the purification systems assumes that the feedstocks of water and sulfuric acid are relatively pure and that there are no contaminants in the product gas streams that will require purification other than what is described below. The oxygen produced by the SAD is assumed to be a saleable product and will be delivered to a user or pipeline at an offsite location. This oxygen is conveyed to the PPU and passes through a caustic scrubber to remove any remaining sulfur dioxide. The scrubbed oxygen stream then passes through a set of zeolite drying beds, followed by polishing adsorbers that further remove any residual traces of sulfur dioxide. Both sets of adsorbers are regenerated using a portion of the oxygen product. The hydrogen purification system is designed to remove sulfur species and water from the hydrogen product prior to being discharged to a pipeline. Precautions have been made to remove sulfur species because of the current experience of the migration of sulfur across the cell membrane. The hydrogen gas effluent stream is conveyed from the Wet Hydrogen Knockout Drum to the hydrogen purification system, where it is further compressed to sufficient pressure for discharge to a hydrogen pipeline. Prior to discharge to the pipeline, the hydrogen passes through a set of dryers followed by a hydrogenation reactor to ensure that any sulfur species in the gas are reduced to hydrogen sulfide. Hydrogen sulfide is captured in zinc oxide beds and water produced in hydrogenation is removed in zeolites drying beds. The system is designed to use a portion of the hydrogen product to regenerate the drying beds.

10.2 SULFUR IODINE

The SI cycle consists of five major process sections:

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- Feed and Utility Systems (FUS)
- Bunsen Reaction (BUN)
- Sulfuric Acid Decomposition (SAD)
- Hydroiodic Acid Decomposition (HAD)
- Product Purification System (PPU)

The FUS and PPU sections include systems that produce the assumed feed water and product purity requirements, respectively. A brief process description for each section is provided below. Capacities described in the following discussion are for one production train, with three production

trains required to meet the target hydrogen production rate. The hydrogen production capacity for one train is approximately 52 MMCFD.

10.2.1 Feed and Utility Systems

Due to the high degree of internal recycle in the SI cycle and the absence of any process blowdown streams, it is surmised that any impurities contained within the feed water will remain within the process. The result of the build up of these impurities in the process would undoubtedly cause negative consequences for the operability of the process. Therefore, it is assumed that the feed water quality must be of the highest purity and that a state-of-the-art water treatment system will be required. At the time of this study, feed water purity requirements for the SI cycle are unknown. The assumption has been made that the water quality requirements are ultrapure water. The design of the water treatment system will depend on the source water quality and should be based on a source water quality analysis. This study assumes that the water source is well water with a minimum hardness of 200 ppm as $CaCO_3$. The pretreatment system includes a multi-media filtration and softener system to remove suspended solids and hardness, respectively. The pretreatment system is followed by a demineralizer system consisting of a reverse osmosis and electro-deionization (EDI) system. All the water treatment systems are considered packaged systems. For the SI cycle, the water treatment system capacity is estimated to be 140 m^3/hr. Purified water storage for 48 hours of process water demand and feed water pumps are provided. The FUS also includes a wastewater treatment system to treat water treatment wastes and process wastes. The system is estimated to be capable of treating approximately 67 m^3/hr of wastewater. The type of treatment required will depend on the effluent discharge limits imposed by the permitting jurisdiction. For this study, it is anticipated that the wastewater treatment system will consist of an oil/water separation system, final neutralization system, physical/chemical treatment system with mixing tank and ancillary pumps, instrumentation, and equipment. The wastewater treatment system is also considered as a vendor supplied system. The final components of the FUS consist of sulfuric acid and caustic bulk storage and transfers systems. The sulfuric acid system provides makeup to the Bunsen Reaction. Caustic is required to remove residual sulfur dioxide from product oxygen in the PPU caustic scrubber. Both sulfuric acid and caustic are delivered as a 50 mass per cent liquid solution. Sulfuric acid is delivered to the Bunsen Reactor as is and caustic is diluted to a 10 mass per cent solution before being pumped to the scrubber.

10.2.2 Bunsen Reaction

The Bunsen Reaction section of the process includes an internal feed stream recycle, the Bunsen Reactor, reactor product separation, and a Reverse Bunsen Reactor to remove any residual sulfur from the HIx product stream. The Bunsen Reactor is designed as a multistage tower featuring a

bottom storage section to retain the required mass of iodine and dissolved sulfur dioxide for proper phase mixing and heat of reaction removal. The reactor features three distinct zones:

- ***Scrubbing Zone***. Top third of the tower contains packing for final scrubbing of the vapour phase to remove any iodine. Feed streams to this zone are purified feed water and H_2SO_4.

- ***Final Reaction Zone***. Bottom two thirds of the tower with 9 stages of packing for completion of the Bunsen Reaction. Purified feed water and recovered water from the HAD section are fed at the top of this zone, while recycled SO_2 vapour and O_2 gas are fed at the bottom of the zone.

- ***Bottoms Zone***. Holds the required mass of iodine and acts as a reservoir for the recirculating cooling loop. Iodine and recycled acid from the SAD section are fed into the Bottoms Zone. Most of the Bunsen Reaction takes place in this zone.

The Scrubbing Zone and Reaction Zone are separated by a liquid collection tray with capped chimneys. Liquid collected in this tray is directed to the Reverse Bunsen Reactor for further processing. The Bottoms Zone of the reactor is essentially a CSTR with a residence time of 30 seconds. The iodine feed rate to the Bottoms Zone is approximately 3,400 m^3/hr. This zone also acts as a reservoir for the Bunsen Reactor's recirculating cooling system. This system consists of three parallel heat exchangers each with a dedicated pump. The cooling system withdraws the bottoms liquid from the reservoir, passes the liquid through the heat exchangers, and returns it back to the reservoir. The circulating pumps that pump the reaction mixture through the cooling heat exchangers keep the reservoir well-mixed. Two of the heat exchangers are considered full duty exchangers with the third heat exchanger being used as a trim cooler. Cooling requirements are estimated to be 181.5 MW_{th}. Based on the heat capacity of the reactor bottom liquids, the total cooling system process liquid recirculation rate is estimated to be 4,500 m^3/hr. The amount of cooling water required will be significant and will most likely necessitate a dedicated cooling water system. Air coolers may be considered as an alternative. The Bunsen Reactor product liquid flow rate of approximately 3,750 m^3/hr is conveyed via a 900 mm (i.e., 36 inch) pipe to one of two Decant Tanks for liquid separation. These vessels are designed as decanters with overflow and underflow baffles and a sump for each of the separated phases. The retention time of the product liquid in each vessel, including sump volumes, is set at 8 minutes. Due to the large difference in the phase densities of the liquids, separation can be considered uncomplicated. The iodine and HIx product phase is transferred to a Reverse Bunsen Reactor for further processing. The sulfuric acid phase is pumped to the Vacuum Column in the SI SAD section for concentration before being sent to the Decomposer. The Reverse Bunsen Reactor converts any residual sulfuric acid that may be in the Iodine and HIx product liquid to SO_2 vapour. This vapour is recycled back to the Bunsen Reactor. The Reverse Bunsen Reactor design is essentially the same as the Bunsen Reactor with

the exception that it does not have an iodine Scrubbing Zone, and the Reaction Zone consists of five stages instead of nine. Iodine and HIx separated from the Bunsen Reactor product stream in the Decant Tanks is pumped to the first stage of the Reverse Bunsen Reactor at the top of the tower. A portion of the oxygen product stream exiting the Bunsen Reactor is directed to the bottom of the Reverse Bunsen Reactor. The I_2/HIx and oxygen flow within the tower section is countercurrent. The liquid collected in the reactor's bottom reservoir is pumped to the HAD section of the process.

10.2.3 SI Sulfuric Acid Decomposition

Sulfuric acid feed at about 60% concentration by weight is sent from the Bunsen Reaction to the SI SAD section to be decomposed into sulfur dioxide, water, and oxygen. Before being pumped to the Decomposer, the acid is concentrated to 75% by weight to maximize the efficiency of the decomposition step. Because the per-pass conversion is only about 50%, a substantial amount of sulfuric acid is recycled. Process heat is recuperated by recovering heat from vapour flashed from the reactor product with feed to the concentration step. Acid feed to the section is first preheated in the HP Recycle Acid Flash Condenser. It then flows to one of two Vacuum Columns where water is removed to concentrate the decomposition feed. The vacuum towers operate at a top pressure of about 0.1 bar and a bottom temperature of about 127°C in order to reach the required 75 mass per cent concentration. To handle the column internal vapour load for each train, about 680 m^3/s, two very large vacuum towers are required along with reboilers, condensers, reflux drums, and pumps. Heat for the distillation for both columns, about 51 MW_{th} total for each train, is provided by imported steam at a pressure of 10 bar. A two-stage steam ejector system provides the vacuum for the system. Uncondensed vapour, primarily sulfur dioxide, is sent to the Bunsen Reaction section. Condensing cooling for the tower, both columns, and the vacuum ejector system is provided by imported cooling water. The cooling duty is about 88 MW_{th} total for each train. Concentrated acid bottoms from the Vacuum Columns are pumped to the Sulfuric Acid Decomposers. Here the decomposition of sulfuric acid into water, sulfur dioxide, and oxygen takes place. The heat for the endothermic reaction and feed heating is provided by helium at 910°C from the NHSS. The helium return temperature from the decomposers is 640°C for a duty of 247 MW_{th} per train. Decomposer product is flashed in three stages to separate the sulfur dioxide product and oxygen from unreacted sulfuric acid. Vapour from these flashes is partially condensed using the feed streams to the Vacuum Tower and cooling water. Three streams are sent to the Bunsen Reaction section: low pressure sulfur dioxide, oxygen and sulfur dioxide vapour with liquid water and dissolved sulfur dioxide.

10.2.4 Hydroiodic Acid Decomposition

The Iodine and HIx stream from the Bunsen section is preheated to approximately 260°C using the heat from the vapour and iodine product streams from the Reactive Distillation Column. The iodine/HIx stream is split to flow to either the Vapour Heat Recuperator or the Recovered Iodine Heat Recuperator. A proportional flow control scheme is currently used as the basis for splitting this flow. However, this may be changed to a temperature based control scheme upon further development. The two preheated streams are recombined in a mix tank prior to a final preheat to 272°C in the Distillation Column Reheater using heat from the liquid product of the distillation column. The design of the Reactive Distillation Column has been improved and the number of columns increased, as discussed below. Each column consists of 15 stages and includes a condenser and reboiler, and utilizes ceramic packing. The preheated HIx feed is introduced to each column at stage 12. The total heat demand for the decomposition reaction is approximately 980 MW_{th}, and the total cooling requirement for reflux is approximately 560 MW_{th}. The total cooling requirement and a majority of the heat demand is provided by the heat pumps associated with each column. Approximately 272 MW_{th} of heat is provided by the NHSS helium loop. The total electrical energy required for heat pump compressors is 61.8 MW_e. In consideration of the high column pressure of 37 bar, the heat pump and helium reboilers are designed as kettle reboilers. Residence time of the liquid at the bottom of the column is approximately 80 seconds. Column bottoms product, the iodine-rich stream, is returned to the Bunsen Reaction section after process heat is recovered and the stream is cooled and flashed to the required conditions. The vapor product from the reactive distillation column along with vapor flashed from the column bottoms is cooled and condensed to remove water and iodine from the hydrogen product. Water and iodine are returned to the Bunsen Section. The hydrogen product flows to the Product Purification System.

10.2.5 Product Purification Systems

Purification of the oxygen product from the Bunsen Reaction and the hydrogen product from the HI Decomposition is required to meet industry standards for these product gases. The design assumes that the feedstock of iodine, water, and sulfuric acid are relatively pure and that there are no other contaminants in the product gas streams that will require purification other than what is described below. The oxygen produced by the Bunsen Reaction is assumed to be a saleable product and will be delivered to a user or pipeline at an offsite location. Oxygen produced in the Bunsen Reaction is conveyed to the oxygen purification system and passes through a caustic scrubber to remove any remaining sulfur dioxide that may be present. The scrubbed oxygen stream then passes through a set of zeolite drying beds, followed by polishing adsorbers that remove any residual traces of SO_2. Both sets of adsorbers may be regenerated using a portion of the oxygen product. Similarly, the hydrogen purification system is designed to scrub the hydrogen

gas of iodine and water prior to being discharged to a pipeline. The hydrogen gas product stream is conveyed from the HAD separators to the hydrogen purification system, where it is further compressed to sufficient pressure for discharge to a hydrogen pipeline. Prior to discharge to the pipeline, the hydrogen passes through a set of iodine adsorbers followed by a set of drying beds. The system is designed to use a portion of the hydrogen product to regenerate the drying beds.

10.3 HIGH TEMPERATURE STEAM ELECTROLYSIS

The High Temperature Steam Electrolysis process can be divided into four major process sections which includes the following:

- Feed and Utility Systems (FUS)
- Heat Recovery System (HRS)
- Electrolysis (ELE)
- Product Purification System (PPU)

The FUS and PPU sections are the systems that produce the assumed feed water and product purity requirements, respectively. The HRS system essentially recovers as much heat as possible from the hot hydrogen and sweep gas streams exiting the electrolyzers to preheat the inlet water and sweep gas feed streams. There are two significant recycle streams within the process. The first is the recycle of a portion of the hydrogen product that is mixed with the feed water in order to maintain reducing conditions at the cathode. The second is the recycle of water in the hydrogen product stream. The majority of the water in the process is converted to hydrogen but about 10% is recycled back to the process via the water purification system in the FUS. A brief process description for each section is provided below. Capacities described in the following discussion are for one production train, which is required to meet the target hydrogen production rate of 142 MMCFD.

10.3.1 Feed and Utility Systems

Feed water and sweep gas purity requirements have not been established yet for the HTSE process, particularly with regards to operability of the electrolyzer cells. However, it is assumed that the feed water and sweep gas quality must be of the highest purity and that state-of-the-art treatment systems used for ultra-pure water and specialty gas production systems will be required. This study assumes that the water source is well water with a minimum hardness of 200 ppm as $CaCO_3$. The pretreatment system includes a multi-media filtration and softener system to remove suspended solids and hardness, respectively. The pretreatment system is followed by a demineralizer system consisting of reverse osmosis and electro-deionization (EDI) systems. For

the HTSE, the water treatment system capacity is estimated to be 150 m^3/hr. Purified water storage for 48 hours of process water demand and feed water pumps are provided. Prior to the RO/EDI system, the softened water is used to cool the product hydrogen stream sufficiently to condense the majority of water in the product gas stream. Condensed water is removed in a knockout drum and then directed to the water treatment RO/EDI system to remove any contaminants that may have been picked up in the process. Purified water is stored and then pumped to the feed water deaerator. The hydrogen product gas stream is used to heat the purified water feed to approximately 117°C prior to entering the deaerator. The operating pressure of the deaerator is about 3 bar, which is typical for this type of application. Deaerator materials of construction are 304 stainless steel. High pressure steam generated in the HRS is used to deaerate the feed water. Deaerated water is then pumped to the HRS for further conditioning. The FUS also includes a wastewater treatment system to treat water treatment wastes and process wastes. The system is estimated to be capable of treating approximately 45 m^3/hr of wastewater. The type of treatment required will depend on the effluent discharge limits imposed by the permitting jurisdiction. For this study, it is anticipated that the wastewater treatment system will consist of an oil/water separation system, neutralization system, physical/chemical treatment system with mixing tank and ancillary pumps, instrumentation, and equipment. The wastewater treatment system is also treated as a vendor supplied system. The sweep gas is assumed to be air. Purity requirements for the sweep gas are not known at this time but assumed to be high. Therefore, a state-of-the-art Clean Dry Air (CDA) system is used to remove contaminants and water. The CDA system has a dedicated inlet air compressor. The clean dry air is then compressed by the Sweep Gas Compressor to a pressure of 58 bar and a temperature of 176°C and is conveyed to the ELE. As the sweep gas passes through the electrolyzers, it removes the oxygen generated at the anodes of the electrolysis cells. The exiting sweep gas is about 50% oxygen on a molar basis, and is at a temperature and pressure of 800°C and 55 bar, respectively. The majority of the heat in the sweep gas is recovered in the HRS. However, the sweep gas still has significant energy after passing through HRS. The temperature and pressure of the sweep gas are 142°C and 53 bar. An expansion turbine utilizes this energy. Electricity generated by the expansion turbine is 13.3 MW_e, and the exit temperature and pressure of the Sweep Gas is approximately -43°C and 2 bar. The exit Sweep Gas is assumed to be discharged directly to atmosphere. No consideration is given to recovery of the gas stream for refrigeration purposes.

10.3.2 Heat Recovery System

Deaerated feed water is preheated using the hot hydrogen product and outlet sweep gas from the electrolyzers. The HRS utilizes a complex series of parallel preheaters, boilers, and superheaters to raise the temperature of the inlet ultrapure feed water to 396°C. The hot hydrogen product and sweep gas streams pass consecutively from the superheaters, to the boilers, and then the

preheaters. Feed water is pumped from the deaerator at a pressure of 65 bar to a pair of preheaters operating in parallel. The total feed water flow to the HRS preheaters is approximately 34 kg/s or 130 m^3/hr. One preheater recovers heat from the hydrogen product gas stream, while the other recovers heat from the outlet sweep gas from the electrolyzers. The deaerated feed water flow is split based on a preset flow setpoint and is trimmed based on the outlet temperatures from each of the preheaters. The feed water is heated to just below the feed water boiling point, approximately 274.5°C. The preheated feedwater then flows to the Feed Steam Drum, which features two thermosyphon boilers: a sweep gas boiler that utilizes the hot outlet sweep gas to boil the feed water and a hydrogen boiler that utilizes the hot hydrogen product stream. Steam exits the feed drum at a temperature of 273.4°C and at a pressure of 58 bar. Flow controllers split the exiting steam flow between the hydrogen and sweep gas superheaters also based on a preset flow setpoint. The superheated steam temperatures exiting the respective superheaters are used to trim this inlet flow control. Steam flows to the Hydrogen Feed Water Superheater and to the Sweep Gas Feed Water Superheater are estimated to be 18.2 kg/sec and 15.4 kg/sec, respectively. Approximately 0.25 kg/sec of the outlet steam from the steam drum is directed to the deaerator. A portion of the hydrogen product is compressed and recycled back through the HRS to preheat and mix it with the steam feed. The recycled hydrogen flow is approximately 0.45 kg/sec, or 10% of the total inlet molar flow to the cathode. Hot hydrogen product is used to heat the recycled hydrogen from 46°C to 275°C in the Recycled Hydrogen Preheater. The preheated hydrogen is then mixed with the steam flow exiting the Feed Steam Drum and the mixture is conveyed to the Hydrogen Feed Water Superheater. The Hydrogen Feed Water Superheater heats the hydrogen and steam flow to approximately 396°C.

10.3.3 Electrolysis

The Electrolysis section of HTSE essentially consists of the Process Coupling Heat Exchangers (PCHX) that heat the inlet feed steam and sweep gas to 870°C and the Electrolyzer. Separate PCHXs are provided for the Hydrogen/steam inlet stream to the electrolyzer cathodes, and the inlet sweep gas stream to the anodes. The electrolyzer comprises 760,000 solid-oxide electrolysis cells.

10.3.4 Product Purification System

The hydrogen purification system is designed to remove water prior to the hydrogen being discharged to a pipeline. The hydrogen gas product stream is conveyed to the hydrogen purification system via the HRS. The hydrogen product pressure and temperature after passing through the HRS is 51 bar and 26°C, respectively. Prior to discharge to the pipeline, the hydrogen passes through a set of drying beds. The system is designed to use a portion of the hydrogen product to regenerate the drying beds, as required.

EUROPAIRS - Task 1.1: End-User Processes
Inventory of data

Please fill this cover sheet for the identification of the document. The list of industries and processes in given in Sheet 6 for reference.

File	PARTNER_INDUSTRY_PROCESS_revA.xls

Partner	North-West University (NWU), Potchefstroom, South Africa
Industry	Hydrogen Production
Complex / Process Unit	Hybrid Sulfur, Sulfur Iodine, High Temperature Steam Electrolysis
Overall Electrical Power	Electrical Power required by HyS is 262.3 MW_eh/h, SI is 226.1 MW_eh/h and HTSE is 478.7 MW_eh/h

For more details, please see attached Document No. NWU_Europairs_H2_Dec09, issued by NWU

Objectives of the document:
This document aims at gathering efficiently relevant data related to the end-user processes.
Each partner is asked to fill one FORM for each complex or process unit (existing & future).
This collection of data is the core of Task 1.1 and will be consolidated in order to de used as base information for Task 1.3.

A notice to correctly fill this FORM is given in a dedicated sheet.

Status of the document
Rev 1 19/11/2009

End-User Requirements fOr industrial Process heat Applications with Innovative nuclear Reactors for Sustainable energy supply

How to use this FORM?

This FORM is divided into 5 sheets:

Sheet 1	**HOME.** This is the cover sheet of the file. Before anything else, please make sure that you have filled the requested information: name of the partner and of the contact - name of the industry and of the described plant / process unit (in accordance with the list given in annex (sheet 6)).
Sheet 2	**NOTICE.** A notice is included in the FORM. It includes the description of the various sheets and a quick definition of the requested parameters.
Sheet 3	**COMPLEX/PROCESS DESCRIPTION.** In this sheet, the partner shall give a simplified flow scheme of the process with basic information such as the name of the process units included in the overall process (/complex) and the name and main characteristics (pressure, temperature, flowrate) of the fluids/products circulating between the units. You are free to use the proposed draft scheme or to include an existing flow scheme (as a jpeg image or as an attached pdf file). You can add any identified safety issues related to this process in this sheet.
Sheet 4	**CONSUMER DUTY.** This sheet focuses, within the process described in sheet 3, on the identification of the heating needs (independently from how heat is generated). Definition and examples of the data requested are given here below. They aim at characterizing the need in terms of physical conditions, operational philosophy, reliability, flexibility and safety.
Sheet 5	**PRODUCER SPECIFICATIONS.** In a second time, this sheet focuses on the existing systems implemented for heat generation. This information will be valuable in order to study the technical and economical impact of the use of HTR as an alternate for generation of High Temperature heat. Two sets of data are asked for: definition of the heat producer and characterization of the heat transportation media. Definition and examples of the data requested are given here below.
Sheet 6	**ANNEX.** Reminder of the list of partners and the related industries and plants / processes.

To be filled in priority

Can be filled in a second time

REFERENCES & GLOSSARY

Ref.	*Parameter Name*	*Definition*	*Unit or Example*
		Process Description	
	complex	An ensemble of process units	
	Process Unit	One elementary process unit that can be included in a complex or several complexes	
(1)	Consumer Description	Name of the unit within the process (identical in sheet 3 and sheet 4)	steam reformming, hydrocracking…
		Consumer Duty - NEED	
(2)	Heating Loop N°	To number the heating loops properly allow to navigate easily in the file and to link heat production and heat consumption.	
(3)	Temperature	Temperature of the heating fluid at the inlet and the outlet **of the unit**.	K, °C, °F
(4)	Allowable Temperature Range	Min. & Max. temperatures at which the process takes place at full efficiency and without material damages.	K, °C, °F
(5)	Typical ramp up & down	Typical temperature gradient to be observed during transients (heating up & cool down).	K/min, K/s, K/h…
(6)	Continuous / Intermittent	Need for continuous heat supply (continuous process) or intermittent heat supply (batch process).	C or I (batch duration, number per year…)
(7)	Effect of heat supply disruption	What happens if case of heat supply disruption? Characterize the criticality of the heat supply.	shutdown of the process, degraded performances…
(8)	Consumption Leveling	Is there a possibility of leveling between the various heat loops in the process? Characterize the flexibility.	YES or NO
		Heat Producer Specifications - EXISTING	
(9)	Heat Generator Description	Name of the heat supply utility	
(10)	Fuel Type	Description of the fuel needed for heat generation	gas, coal, offgas (from unit X), electricity…
(11)	Fuel Consumption / External	Periodic consumption of external fuel	tpy, tph, Sm3/y…
(12)	Fuel Consumption / Offgases	Periodic consumption of internal fuel (offgases from another unit)	tpy, Sm^3/y…
(13)	Power	at least nominal power is required	MWh…
(14)	Back-up in case of shutdown	what is the planned back-up in case of the disruption og the normal heat supply?	
(15)	Media Type	Description of the media used for heat transportation between heat generation and consumption.	steam, oil, molten salt…
(16)	Temperature	Temperature of the medium at the inlet and at the outlet of the heat generation system	K, °C, °F
(17)	Pressure	Pressure of the medium at the inlet and at the outlet of the heat generation system	bar, psi…
(18)	Mass Flow	Mass flow rate of the heat transportation medium	tpy, Sm3/y…
(19)	Consumed in process ?	Indicate if the heat medium (for inst. STEAM) is recycled to heat generation OR consumpted afterwards in the process	YES or NO

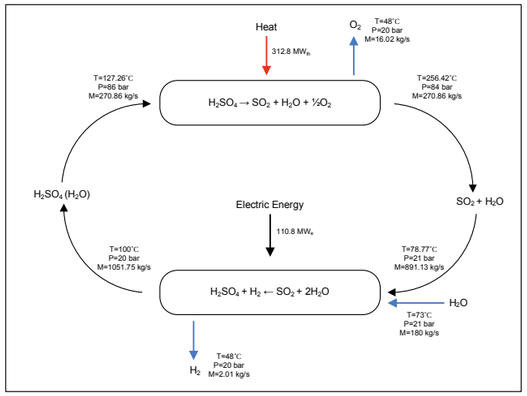
Simplified Plant & Units flow scheme (1/2)

Objectives of the scheme

This simplified scheme aims at providing an easy understanding of the overall considered process.
You can add as many units as you think necessary.
In addition, please list at the bottom the safety concerns linked to the plant described here below.

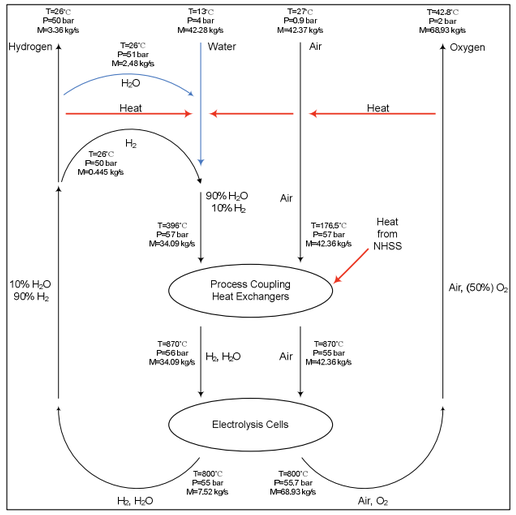
Schemes of Simplified Process Flow Diagram for process Units are enclosed in Document No. NWU_Europairs_H2_Dec09

Prcoess A - Hybrid Sulphur Process (HyS)



Process B - Sulphur Iodine Process (SI)

Process C - High Temperature Steam Electrolysis Process (HTSE)



Simplified Plant & Units flow scheme (2/2)

The name of the Units

	Consumer Description (1)
Unit A	Hybrid Sulphur
Unit B	Sulphur Iodine Process
Unit C	High Temperature Steam Electrolysis

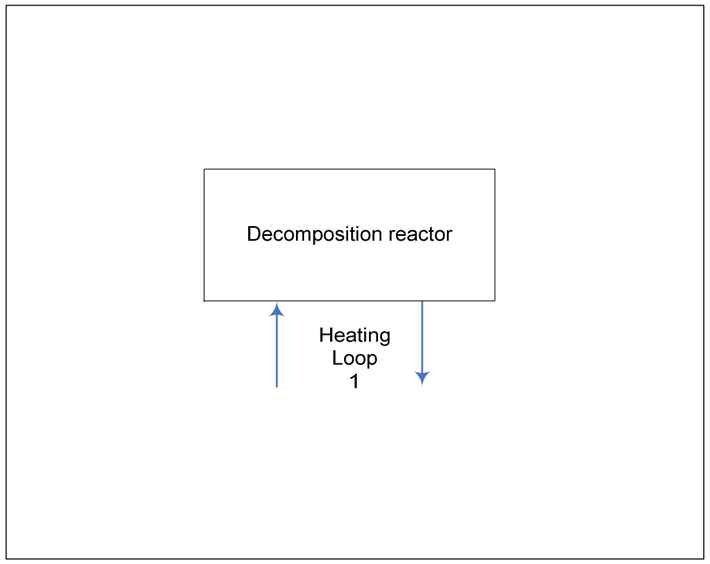
Safety concerns related to the process

SAFETY CONCERNS
Loss of containment of a highly corrosive acid resulting in a release to the environment. High pressure can result in a jet or spray leak
Loss of containment of a toxic gas resulting in a release to the environment. High pressure can result in a jet or spray leak
Loss of containment of a flammable gas at a high pressure and temperature resulting in a fire or explosion
The enhanced flammability of materials in O_2 resulting in an equipment fire
Loss of containment of high pressure Helium. Contamination of He stream due to tube leaks and acid corrosion of He heat exchange equipment
Loss of containment of a highly corrosive acid. High pressure can result in a jet or spray leak.
Loss of containment of a toxic gas.
Loss of containment of a corrosive liquid
Excessive corrosion
Loss of containment of a flammable gas at high pressure and temperature resulting in a fire or explosion
The enhanced flammability of materials in O2 resulting in an equipment fire
Loss of containment of high pressure Helium or cross contamination between primary and secondary He streams due to acid corrosion of He heat exchange equipment
Leak between H_2 and O_2 enriched streams resulting in a fire
The enhanced flammability of materials in O_2 enriched air resulting in an equipment fire
Fire resulting from rotating machinery acting on an O_2 enriched stream
Loss of containment of a flammable gas at high pressure and temperature resulting in a fire or explosion
Loss of containment of high pressure air, steam or He. Contamination of He stream due to tube leaks and materials incompatibility
Equipment fires, vessel failures, hydrogen leaks resulting in fire
Hydrogen leaks resulting in fire

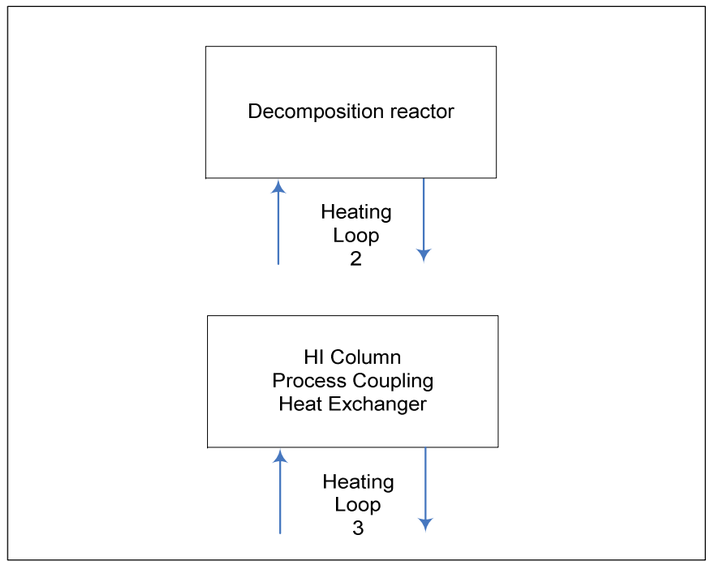
Characterization of the heating needs (1/2)

Objectives of the sheet

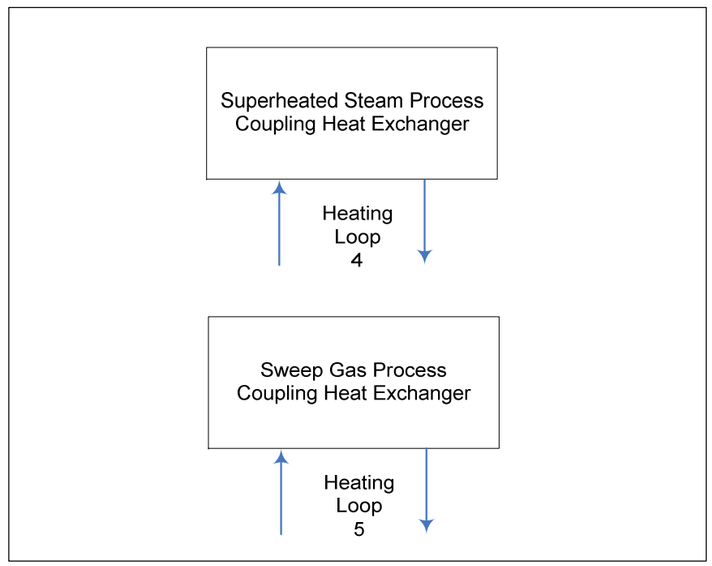
Hybrid Sulphur Process (HyS)



Sulfur Iodine Process (SI)



High Temperature Steam Electrolysis Process (HTSE)



Characterization of the heating needs (2/2)

Consumer duty

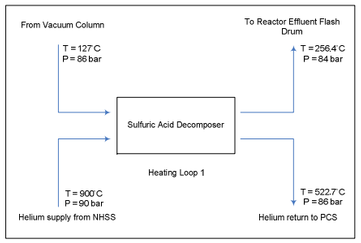
Consumer Description (1)		Steam Circuit N° (2)	Temperature (3)		Allowable Temperature Range (4)		Typical ramp up and down (5)	Continuous OR Intermittent (6)	Effect of heat supply disruption (7)	Consumption leveling (8)	Comments
			inlet	outlet	T_{min}	T_{max}					
HyS	Decomposition reactor	1	900°C	522.7	-	-	-	Continuous	Shutdown of process	-	-
SI	Decomposition reactor	2	910°C	TBD	-	-	-	Continuous	Shutdown of process	-	-
	HI Column PCHX	3	640°C	344°C	-	-	-	Continuous	Shutdown of process	-	-
HTSE	Super-H Steam PCHX	4	910°C	829°C	-	-	-	Continuous	Shutdown of process	-	-
	Sweep Gas PCHX	5	910°C	829°C	-	-	-	Continuous	Shutdown of process	-	-

Characterization of the existing heat generators (1/2)

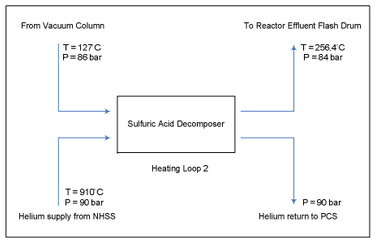
Objectives of the sheet

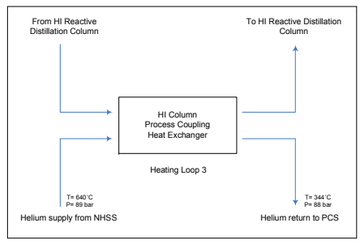
Note:

Hybrid Sulphur

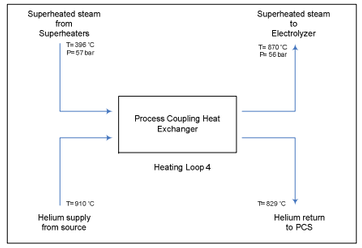


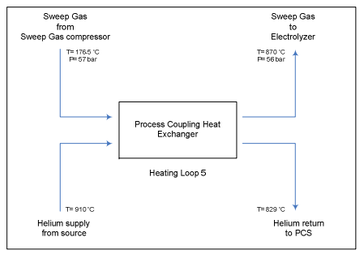
Sulfur Iodine (SI)





High Temperature Steam Electrolysis (HTSE)





Characterization of the existing heat generators (2/2)

HEAT GENERATORS

Heating loop N°	Heat generator description (9)	Fuel type (10)	Fuel Consumption		Power (kWth) (13)			Backup in case of shutdown (14)	Comments
			External (11)	Offgases (12)	Min.	Nominal	Max.		
1	NHSS	Nuclear	-	-	-	312.8 MW	-	Non - System stops	
2	NHSS	Nuclear	-	-	-	247 MW	-	Non - System stops	
3	NHSS	Nuclear	-	-	-	271.5 MW	-	Non - System stops	
4	NHSS	Nuclear	-	-	-	48.84 MW	-	Non - System stops	
5	NHSS	Nuclear	-	-	-	38.85 MW	-	Non - System stops	

MEDIA TABLE

Heating loop N°	Media type (15)	Temperature (16)		Pressure (17)		Mass flow (18)			Comments
		inlet	outlet	inlet	outlet	Min.	Normal	Max.	
1	Helium	-	950°C	-	90	-	-	-	
2	Helium	-	950°C	-	90	-	-	-	
3	Helium	-	950°C	-	90	-	-	-	
4	Helium	-	950°C	-	90	-	-	-	
5	Helium	-	950°C	-	90	-	-	-	

Industries & Processes

	Partners	Contact	Industries	Plant / Process Units
1	AMEC	Derek BUCKTHORPE derek.buckthorpe@amec.com	Oil sands	Steam Assisted Gravity Drainage
				Cyclic Steam Stimulation
			Petrochemicals	
			Ciment	Pyro processing
			Paper and Pulp	Kraft process
2	Air Liquide	Claire WEBER claire.weber@airliquide.com	Industrial Gas production	Oxygen Production - Ceramic membrane
				CO Production - dry reforming
3	Arcelor Mittal	Gerard Griffay gerard.griffay@arcelormittal.com	Steel Making	Coke Making
				SteelMaking
				Hot Rolling
				Direct Reduced Iron (DRI)
				Power complex
				Lime complex
				Sintering
				Blast Furnace
4	Fortum	Harri Tuomisto harri.tuomisto@fortum.com	Paper and Pulp	
			Oil refinery	
			Co-generation	
			District Heating	
5	FZJ	Werner von Lensa w.von.lensa@fz-juelich.de	Coal	Coal Gasification
				Steam Methane Reforming
6	GDF Suez - Tractebel	Carmen Angulo carmen.angulo@gdfsuez.com	Co-Generation	-
7	NWU/PBMR	Gideon Greyvenstein	Petroleum Products	Fischer-Tropsch
				Steam Methane Reforming
		gideon.greyvenstein@pbmr.co.za	Oil Sands	
8	NWU	Frik van Niekerk frik.vanniekerk@nwu.ac.za	Hydrogen Production	Thermochemical water splitting
				Hybrid Sulfur
				Sulfur Iodine
				High Temperature Electrolysis
9	PROCHEM	Marek Tarka mtarka@prochem.com.pl	Refinery	Aromatics Extractive Distillation
				Crude Oil Distillates Hydrotreatment
				Crude Oil Distillation
10	SAIPEM	Jacques RUER jacques.ruer@saipem-sa.com	Energy Storage	Pumped Heat Electricity storage
11	Technip	Gaetano Iaquaniello iaquaniello.g@ktispa.it	Refinery	
			Hydrogen production	Steam Reforming
				Membranes Steam Reforming
12	USG (DSM) / BEC	Anton Baaten anton.baaten@me.com	Wide Range (Petro)chemicals incl. Urea & Ethylene	Utilities supply
13	ZAK	Marek Zuber marek.zuber@zak.com.pl	Nitrogen Fertilizers	Syngas production
				Hydrogen production
				Nitric acid synthesis
				Ammonia synthesis
				Urea production
			Organic Synthesis	Oxo processes
				Alcohol synthesis
				Phthalate plasticizers synthesis
				Phtalic and maleic anhydride

EUROPAIRS – Task 1.1 End User Processes, Characteristics and Requirements Coal to Liquid Process

Document number: NWU_Europairs_CTL_1209

Revision: 1

Status: APPROVED

by

WMK van Niekerk

December 2009

CHANGE HISTORY

Configuration Control	
Project:	EUROPAIRS
Created by:	Willem van Niekerk
Original creation Date:	20 November 2009
Client:	Europairs

Template No: HICC-REP_Rev 1

Revision History			
Revision	**Date**	**Author**	**Description of Changes**
A	30/11/2009	WMK van Niekerk	Initial draft for review
1	15/12/2009	WMK van Niekerk	Approved document for distribution

Authorisation			
Action	**Designate / Signature**	**Position**	**Date**
Prepared	Willem van Niekerk	Process Engineer	**December 2009**
Reviewed	Miek Venter	Process Engineer	**December 2009**
Approved	Jan van Ravenswaay	Program Manager	**December 2009**

Original Signed Copy at CMC

Change Forecast

The document format and contents have been approved.

Table of Contents

1. Scope

This document aims to provide the reader with relevant data and information related to the end-user processes as required by Task 1.1 in order to consolidate the information for use in Task 1.3. The applicable process described is the Coal to Liquid process.

2. Definitions, Terms, Acronyms and Abbreviations

2.1 DEFINITIONS

None

2.2 TERMS

None

2.3 ACRONYMS AND ABBREVIATIONS

Abbreviation or Acronym	Definition
DST	Department of Science and Technology
SASOL	South African company producing liquid hydrocarbons from coal

3. References

3.1 APPLICABLE DOCUMENTS AND DATA

The following documents and data are applicable:

TITLE	REFERENCE NUMBER
None	

3.2 ADDITIONAL REFERENCE DOCUMENTS AND DATA

The following are additional reference documents and data:

TITLE	REFERENCE NUMBER
None	

3.3 APPLICABLE SOFTWARE

The following software files are applicable:

SOFTWARE DESCRIPTION	VERSION NUMBER	FILE NAME
None		

4. Coal-to-liquid conversion

In order to convert solid carbon into a (liquid) hydro-carbon, water is split to produce the required hydrogen. This requires substantial amounts of energy. This energy is supplied by the combustion of coal. Therefore a lot of carbon dioxide is produced in the conversion process. The application of this technology by SASOL will now be described.

4.1 PROCESS DESCRIPTION

The process flow diagram of the SASOL Secunda process is in shown in Figure 1 below. Coal from a mine is screened to remove fines which are sent to the steam plant. The steam plant generates steam that is used in the process (e.g. gasification and steam methane reforming), to generate electricity and drive the turbines of the oxygen plant. The coarse coal is gasified in the presence of oxygen and steam. Oxygen is combusted to raise the temperature to 1350°C. Carbon dioxide is removed from the gas and then the synthesis gas, consisting mainly of CO and H_2 flows to the synthesis reactor where hydrocarbon chains are formed. These are condensed from the un-reacted gas. Methane is reformed with steam and recycled back to the synthesis reactor.

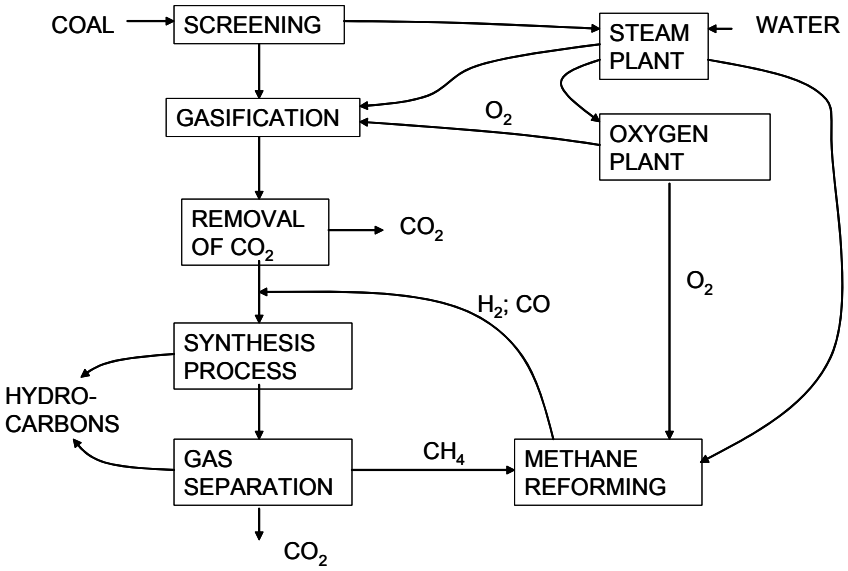


Figure 1: SASOL Secunda process flow diagram.

4.2 GASIFICATION

In the gasification plants coal is fed to 80 gasifiers in total. The feed to a single gasifier [1] and the feed to all the gasifiers at the Secunda works (assuming 80 gasifiers) are given in Table 1 below:

Table 1: Gasifier reactants.

	Single gasifier	Secunda
	kg/h	ton/h
Carbon	25 778	2 062
Oxygen	11 856	948
Steam	50 900	4 072

In the gasifier many reactions take place. Consider the following four. The combustion of carbon in oxygen provides the energy required by the other reactions:

$$C + O_2 \rightarrow CO_2 \qquad \Delta H = 405.5\ kJ \qquad (1)$$
$$C + H_2O \rightarrow CO + H_2 \qquad \Delta H = -118.5\ kJ \qquad (2)$$
$$C + 2H_2O \rightarrow CO_2 + 2H_2 \qquad \Delta H = -77.3\ kJ \qquad (3)$$
$$C + 2H_2 \rightarrow CH_4 \qquad \Delta H = -87.5\ kJ \qquad (4)$$

The amount of carbon consumed in each reaction is determined by making the following assumptions (for one gasifier):

- The total carbon consumed in the four reactions is 25 778kg/h,
- All the oxygen is consumed during the oxidative reaction of carbon (reaction 1),
- The mole percent methane in the product is 10%,
- The mole percent CO_2 in the product is 30%.

This leads to the gas composition shown in Table 2:

Table 2: Gasifier product gas composition.

Component	Concentration Mole[%]
CH_4	10.0
CO	20.4
CO_2	30.0
H_2	39.6

For this composition, the distribution of carbon and energy in a gasifier are given in Table 3 below:

Table 3: Consumption of carbon in different reactions in a single gasifier.

Reaction	kmol C/h	Energy [MW] Released (+) Required (-)
1	370.5	41.7
2	726.0	-23.9
3	696.1	-14.9
4	355.5	-8.6

Approximately half of the carbon is converted to carbon dioxide in reaction 1 and 3. The carbon dioxide must be removed before the gas can be fed to the synthesis reactors.

The energy released by the combustion of the carbon is less that the total requirement and the shortfall is 5.8MW per gasifier. The steam consumed in reaction 2 and 3 is less than the amount fed according to Bunt and Waanders [1]. The flow rate of the excess

steam is 13 ton/h (per gasifier). For saturated steam at the gasifier pressure of 3000kPa [2], this represents 10MW – which is more than the deficit left by the combustion of carbon and explains the production of steam in the jacket of the gasifiers.

The carbon dioxide and sulphur dioxide are removed and the cleaned gas flows to the Synthol plant where the Fischer-Tropsch reaction takes place, converting CO and H_2 to liquid hydrocarbons.

UTILIZING ALTERNATIVE ENERGY SOURCES

An external heat source can be used to supply the steam necessary for the gasification reaction. The gasifiers at the Secunda plant operate at 3 000kPa [2] but the design of the gasifier is flexible and the design pressure can be varied between 2 000 and 10 000kPa [3]. Superheated steam is blended with the saturated steam generated in the jackets of the gasifiers, mixed with the oxygen and fed to the gasifier. The optimum degree of superheat is determined by conflicting requirements [4] and a high degree of superheat is not necessarily desirable. The main criterion is to keep the gas temperatures well above the dew point to avoid possible condensation down stream of the steam/oxygen mixer [4]. This can also be promoted by pre-heating the oxygen. Assuming saturated steam at 3 000kPa is used in the gasification process; to generate 4 072ton/h would require heat at a rate 2 030MW. At the moment coarse and fine coal are separated and the fine coal used to generate steam. If an alternative energy source is used, an application for this fine coal must be found.

Using an external source of heat to supply the reaction heat for the gasification reaction would not be practical. Firstly the temperature in the coal rises to 1 350°C [2] and secondly it would not be possible to transfer heat at a high enough rate from the walls of the gasifier to the moving coal bed. Pre-heating the oxygen also has limited potential as raising the temperature of the oxygen to a single gasifier by 100°C would require only 305kW.

4.3 SYNTHESIS

Two important reactions that take place here are the Fischer-Tropsch synthesis reaction and the water-gas shift reaction:

$$nCO + (2n+1)H_2 \rightarrow C_nH_{(2n+2)} + nH_2O \qquad (5)$$

$$H_2O + CO \rightarrow H_2 + CO_2 \qquad (6)$$

Although the water-gas shift reaction produces CO_2, it also produces hydrogen which is advantageous. Both reactions are exothermic. For octane, (n=8) the Fischer-Tropsch reaction releases 1 260MJ/kmol octane and the water-gas shift reaction releases 41MJ/kmol hydrogen. The hydrogen content of natural gas is higher and with natural gas as feedstock, the water gas shift reaction is not required – eliminating the production of the associated CO_2.

The heavier hydrocarbons are condensed and the un-reacted hydrogen, methane and lighter hydrocarbons, flow to the gas separation plant.

4.4 COLD SEPARATION AND METHANE REFORMING

In the cold separation plant, carbon dioxide is removed and hydrogen, methane and other hydrocarbons are separated at low temperature and the Hydrogen re-circulated to the

synthesis reactors. In the reforming plant methane is reacted with steam at high temperature:

$$CH_4 + H_2O \rightarrow CO + 3H_2 \qquad (7)$$

This is an endothermic reaction and in order to supply the energy required by this reaction, methane is partially combusted in oxygen:

$$CH_4 + 1.5\ O_2 \rightarrow CO + 2H_2O \qquad (8)$$

For an outlet temperature of 900°C, 40% of the methane in the feed is consumed in the partial oxidation reaction.

Bibliography

[1] Bunt JA, Waanders FB. Trace element behaviour in the Sasol-Lurgi MK IV FBDB gasifier, Part 2. Fuel 88 (2009) pp 961-969
[2] Mangena S. Effective utilisation of coal in Sasol – A Sasol FBDB™ gasification technology perspective, SACPS International Conference **"**Coal Powering the Future" – Secunda, South Africa 2009.
[3] Turna O. Sasol-Lurgi Fixed Bed Dry Bottom Gasification for Fuels and Chemicals, 2nd International Freiburg Conference on IGCC & XtL Technologies, May 2007.
[4] Turna O. Solids Gasification Dept. LURGI. Communication by e-mail. 23 November 2009.
[5] Botha L. A techno-economic evaluation of the use of hydrogen in a steel production process, utilizing nuclear process heat. Masters dissertation, North West University, 2009.
[6] Van Wylen GJ, Sonntag RE. Fundamentals of thermodynamics 6th edition. Wiley 2002.
[7] Austin GT. Shreve's chemical process industries 5th edition. McGraw-Hill 1984.

EUROPAIRS - Task 1.1: End-User Processes
Inventory of data

Please fill this cover sheet for the identification of the document. The list of industries and processes in given in Sheet 6 for reference.

File	Fischer Tropsch

Partner	NWU/PBMR
Industry	Petroleum Products
Complex / Process Unit	Fischer-Tropsch
Overall Electrical Power	MW

Objectives of the document:
This document aims at gathering efficiently relevant data related to the end-user processes.
Each partner is asked to fill one FORM for each complex or process unit (existing & future).
This collection of data is the core of Task 1.1 and will be consolidated in order to de used as base information for Task 1.3.

A notice to correctly fill this FORM is given in a dedicated sheet.

Status of the document

Rev. 0	29/09/2009	First issue by SSA of the document for comments from the partners of Task 1.1, 1.2 & 1.3
Rev. 1	21/10/2009	Issue by SSA of the finale FORM

End-User Requirements fOr industrial Process heat Applications with Innovative nuclear Reactors for Sustainable energy supply

How to use this FORM?

This FORM is divided into 5 sheets:

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To be filled in priority

Can be filled in a second time

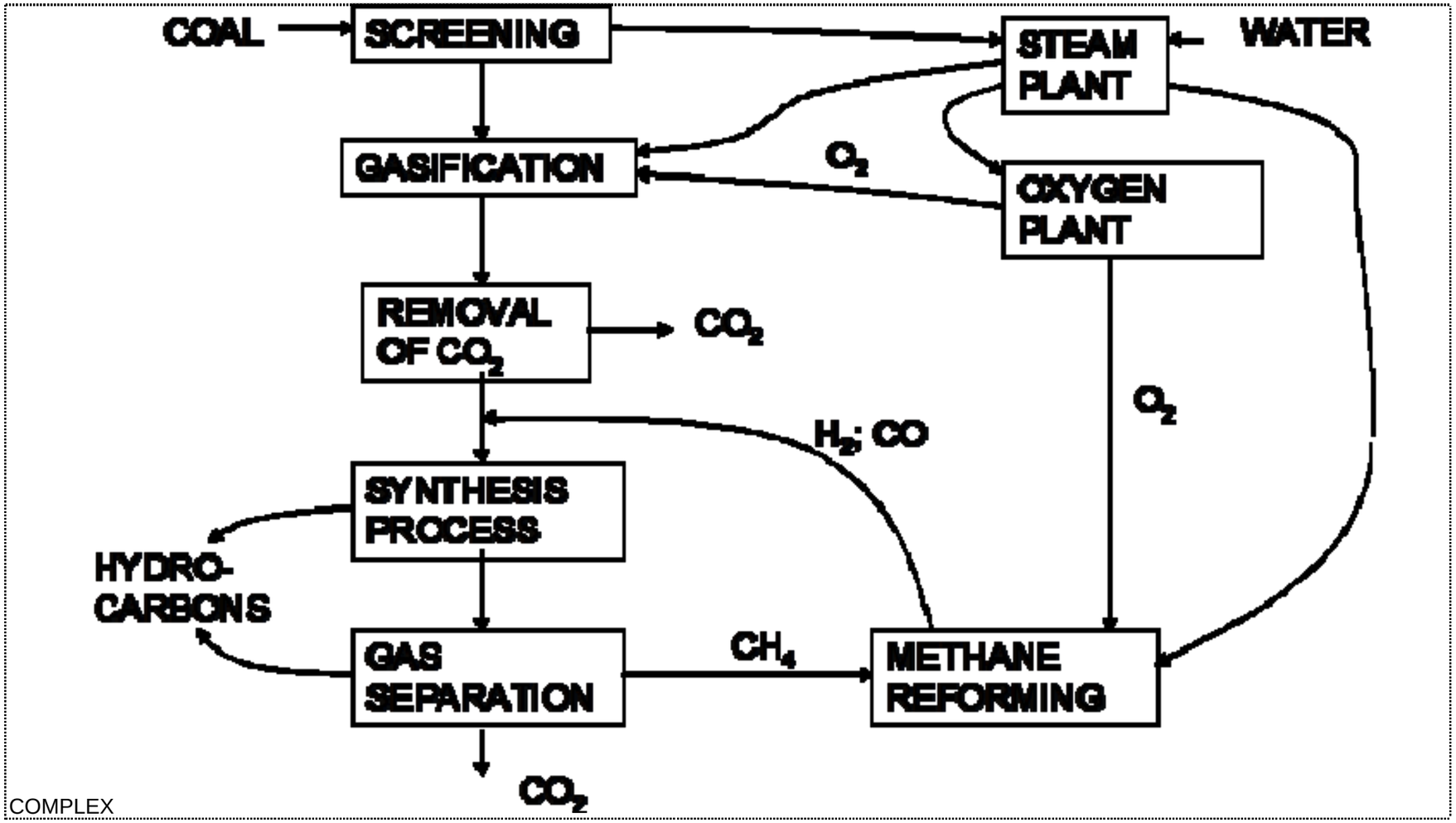
REFERENCES & GLOSSARY

Ref.	*Parameter Name*	*Definition*	*Unit or Example*
		Process Description	
	complex	An ensemble of process units	
	Process Unit	One elementary process unit that can be included in a complex or several complexs	
(1)	Consumer Description	Name of the unit within the process (identical in sheet 3 and sheet 4)	steam reformming, hydrocracking…
		Consumer Duty - NEED	
(2)	Heating Loop N°	To number the heating loops properly allow to navigate easily in the file and to link heat production and heat consumption.	
(3)	Temperature	Temperature of the heating fluid at the inlet and the outlet **of the unit**.	K, °C, °F
(4)	Allowable Temperature Range	Min. & Max. temperatures at which the process takes place at full efficiency and without material damages.	K, °C, °F
(5)	Typical ramp up & down	Typical temperature gradient to be observed during transients (heating up & cool down).	K/min, K/s, K/h…
(6)	Continuous / Intermittent	Need for continuous heat supply (continuous process) or intermittent heat supply (batch process).	C or I (batch duration, number per year…)
(7)	Effect of heat supply disruption	What happens if case of heat supply disruption? Characterize the criticality of the heat supply.	shutdown of the process, degraded performances…
(8)	Consumption Leveling	Is there a possibility of leveling between the various heat loops in the process? Characterize the flexibility.	YES or NO
		Heat Producer Specifications - EXISTING	
(9)	Heat Generator Description	Name of the heat supply utility	
(10)	Fuel Type	Description of the fuel needed for heat generation	gas, coal, offgas (from unit X), electricity…
(11)	Fuel Consumption / External	Periodic consumption of external fuel	tpy, tph, Sm3/y…
(12)	Fuel Consumption / Offgases	Periodic consumption of internal fuel (offgases from another unit)	tpy, Sm^3/y…
(13)	Power	at least nominal power is required	MWh…
(14)	Back-up in case of shutdown	what is the planned back-up in case of the disruption og the normal heat supply?	
(15)	Media Type	Description of the media used for heat transportation between heat generation and consumption.	steam, oil, molten salt…
(16)	Temperature	Temperature of the medium at the inlet and at the outlet of the heat generation system	K, °C, °F
(17)	Pressure	Pressure of the medium at the inlet and at the outlet of the heat generation system	bar, psi…
(18)	Mass Flow	Mass flow rate of the heat transportation medium	tpy, Sm3/y…
(19)	Consumed in process ?	Indicate if the heat medium (for inst. STEAM) is recycled to heat generation OR consumpted afterwards in the process	YES or NO

Simplified Plant & Units flow scheme (1/2)

Objectives of the scheme

This simplified scheme aims at providing an easy understanding of the overall considered process.
You can add as many units as you think necessary.
In addition, please list at the bottom the safety concerns linked to the plant described here below.



COMPLEX

Simplified Plant & Units flow scheme (2/2)

❸ *Summarize here the name of the units*

	Consumer Description (1)
Unit A	GASIFICATION
Unit B	STEAM PLANT
Unit C	OXYGEN PLANT
Unit D	SYNTHESIS PLANT
Unit E	GAS SEPARATION
Unit F	REFORMINNG
…	

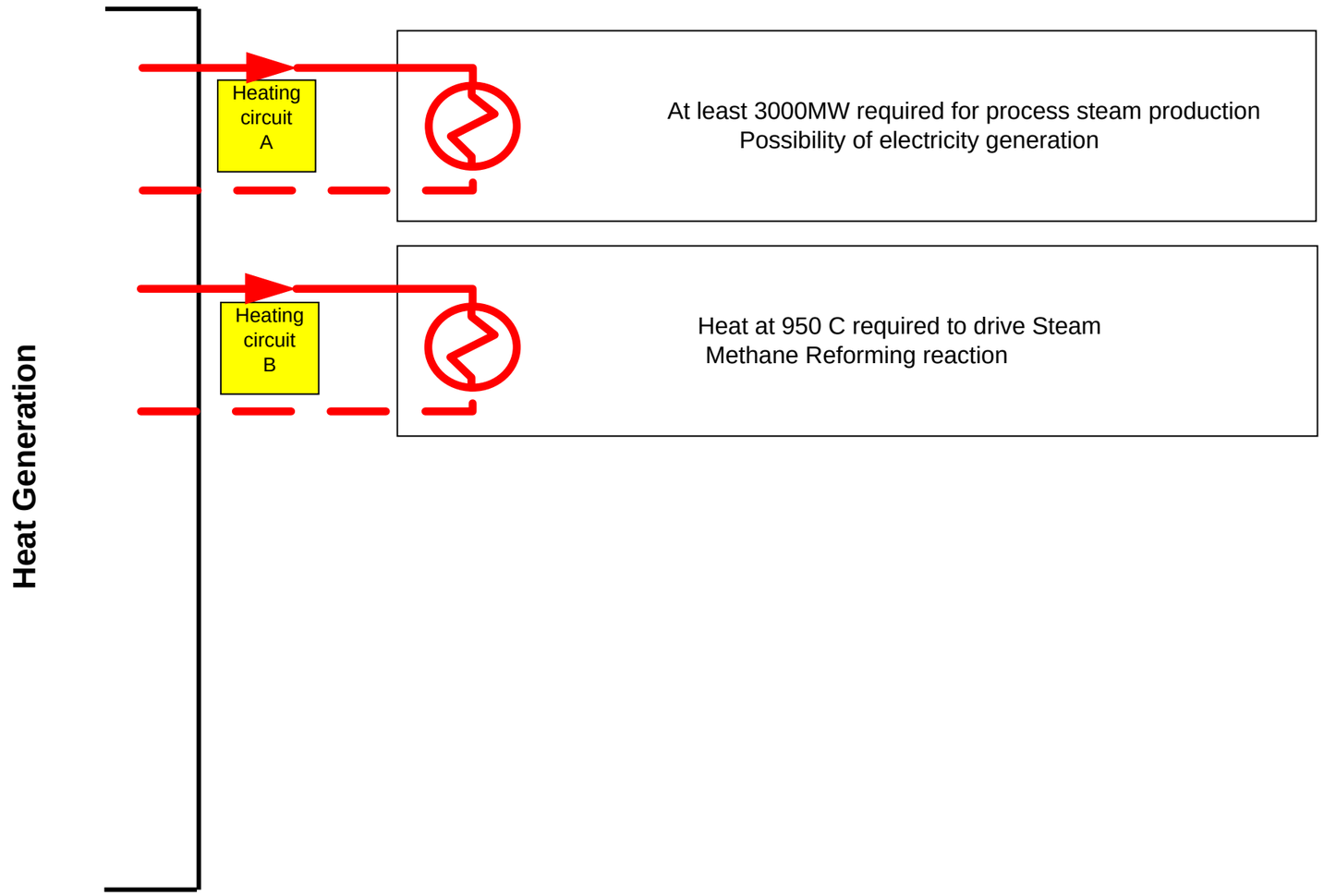
❹ *Please detail here below the identified safety concerns related to the process.*

SAFETY CONCERNS.
Presence of coal, oxygen and steam, high process temperatures.
Normal safety concerns for a coal fired steam plant
Presence of oxygen
Presence of gaseous and liquid hydrocarbons
Presence of low temperature, heavier than air hydrocarbons
Presence of oxygen, steam and methane and high process temperatures.
-
-
-
-
-
-
-
-
-

Characterization of the heating needs (1/2)

Objectives of the sheet

This sheet gathers the information related to the needs for heat in the plant or process unit.



Characterization of the heating needs (2/2)

❻ *Fill the table here in accordance with the units described in Sheet 3 and with the scheme here above.Definitions of the parameters are given in Sheet 2.*

Consumer duty

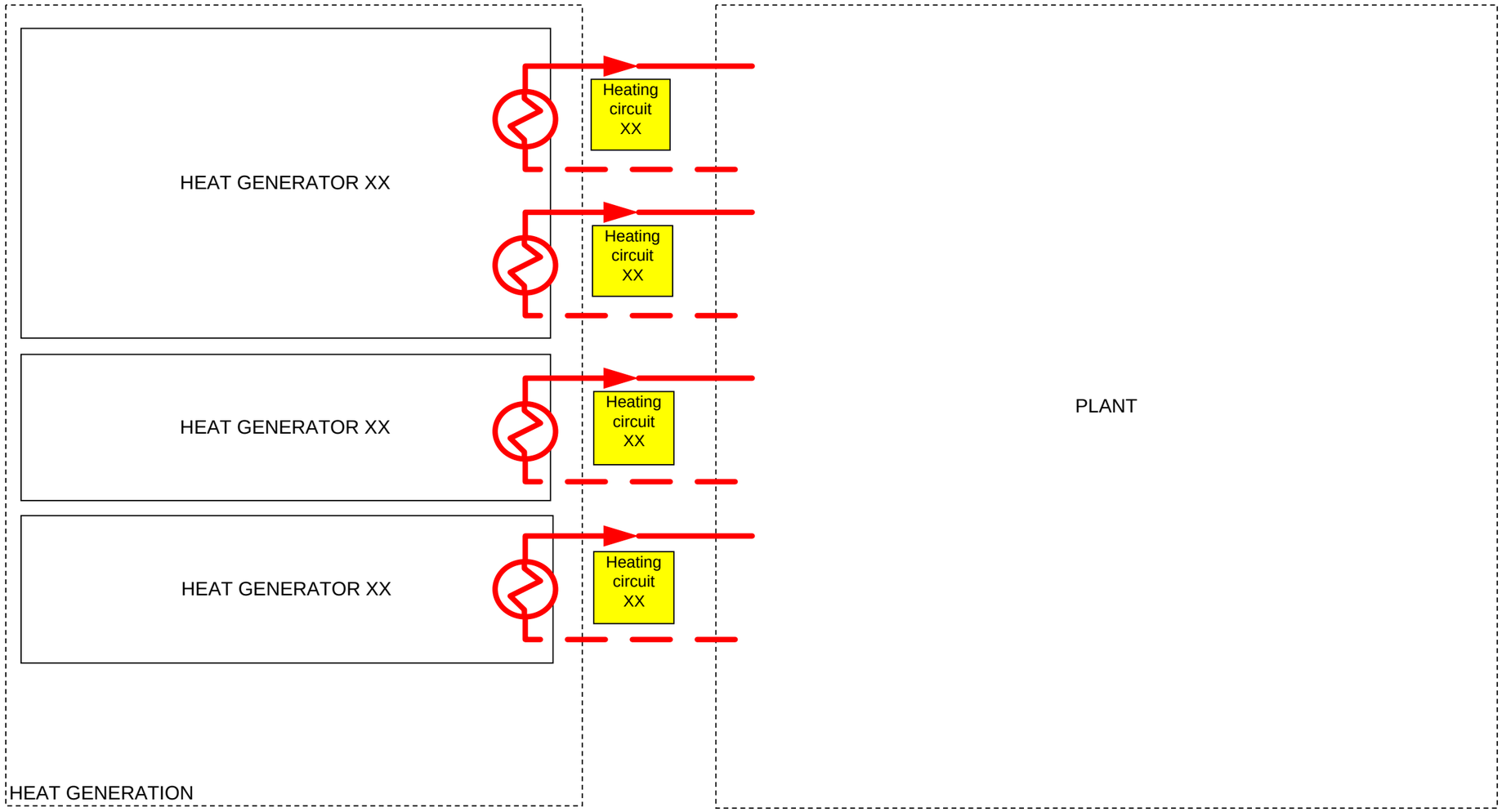
Consumer Description (1)		Heating Circuit N° (2)	Temperature (3)		Allowable Temperature Range (4)		Typical ramp up and down (5)	Continuous OR Intermittent (6)	Effect of heat supply disruption (7)	Consumption leveling (8)	Comments
			inlet	outlet	T_{min}	T_{max}					
Unit B	STEAM	A	500					CONTINUOUS	UNIT SHUTDOWN		
Unit F	SMR	B	950	500				CONTINOUOS	DISRUPTION		
…											

Characterization of the existing heat generators (1/2)

Objectives of the sheet

This sheet gathers data on the existing heat generation systems.

❼ *Replace the example here below by the existing heat generation systems for the considered complex / process units. Heating Circuit Numbers shall be in accordance with Sheet 4.*



Characterization of the existing heat generators (2/2)

Fill both table shere in accordance with the heating circuits described in Sheet 4 and with the scheme here above. Definitions of the parameters are given in Sheet 2.

HEAT GENERATORS

Heating circuit N° (2)	Heat generator description (9)	Fuel type (10)	Fuel Consumption		Power (kWth) (13)			Backup in case of shutdown (14)	Comments
			External (11)	Offgases (12)	Min.	Nominal	Max.		

MEDIA TABLE

Heating circuit N° (2)	Media type (15)	Temperature (16)		Pressure (17)		Mass flow (18)			Consumed in the process ? (19)	Comments
		inlet	outlet	inlet	outlet	Min.	Normal	Max.		
0										
0										
0										
0										
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0										
0										
0										

Industries & Processes

	Partners	Contact	Industries	Plant / Process Units
1	AMEC	Derek BUCKTHORPE derek.buckthorpe@amec.com	Oil sands	Steam Assisted Gravity Drainage
				Cyclic Steam Stimulation
			Petrochemicals	
			Ciment	Pyro processing
			Paper and Pulp	Kraft process
2	Air Liquide	Claire WEBER claire.weber@airliquide.com	Industrial Gas production	Oxygen Production - Ceramic membrane
				CO Production - dry reforming
3	Arcelor Mittal	Gerard Griffay gerard.griffay@arcelormittal.com	Steel Making	Coke Making
				SteelMaking
				Hot Rolling
				Direct Reduced Iron (DRI)
				Power complex
				Lime complex
				Sintering
				Blast Furnace
4	Fortum	Harri Tuomisto harri.tuomisto@fortum.com	Paper and Pulp	
			Oil refinery	
			Co-generation	
			District Heating	
5	FZJ	Werner von Lensa w.von.lensa@fz-juelich.de	Coal	Coal Gasification
				Steam Methane Reforming
6	GDF Suez - Tractebel	Carmen Angulo carmen.angulo@gdfsuez.com	Co-Generation	-
7	NWU/PBMR	Gideon Greyvenstein	Petroleum Products	Fischer-Tropsch
				Steam Methane Reforming
		gideon.greyvenstein@pbmr.co.za	Oil Sands	
8	NWU	Frik van Niekerk frik.vanniekerk@nwu.ac.za	Hydrogen Production	Thermochemical water splitting
				Hybrid Sulfur
				Sulfur Iodine
				High Temperature Electrolysis
9	PROCHEM	Marek Tarka mtarka@prochem.com.pl	Refinery	Aromatics Extractive Distillation
				Crude Oil Distillates Hydrotreatment
				Crude Oil Distillation
10	SAIPEM	Jacques RUER jacques.ruer@saipem-sa.com	Energy Storage	Pumped Heat Electricity storage
11	Technip	Gaetano Iaquaniello iaquaniello.g@ktispa.it	Refinery	
			Hydrogen production	Steam Reforming
				Membranes Steam Reforming
12	USG (DSM) / BEC	Anton Baaten anton.baaten@me.com	Wide Range (Petro)chemicals incl. Urea & Ethylene	Utilities supply
13	ZAK	Marek Zuber marek.zuber@zak.com.pl	Nitrogen Fertilizers	Syngas production
				Hydrogen production
				Nitric acid synthesis
				Ammonia synthesis
				Urea production
			Organic Synthesis	Oxo processes
				Alcohol synthesis
				Phthalate plasticizers synthesis
				Phtalic and maleic anhydride

EUROPAIRS - Task 1.1: End-User Processes
Inventory of data

Please fill this cover sheet for the identification of the document. The list of industries and processes in given in Sheet 6 for reference.

File	PARTNER_INDUSTRY_PROCESS_revA.xls

Partner	PROCHEM S.A, WARSAW POLAND
Industry	CRUDE OIL PROCESSING
Plant / Process Unit	Aromatic extractive distillation

Objectives of the document:
This document aims at gathering efficiently relevant data related to the end-user processes.
Each partner is asked to fill one FORM for each plant or process unit (existing & future).
This collection of data is the core of Task 1.1 and will be consolidated in order to de used as base information for Task 1.3.

A notice to correctly fill this FORM is given in a dedicated sheet.

Status of the document

REV A	First Issue

End-User Requirements fOr industrial Process heat Applications with Innovative nuclear Reactors for Sustainable energy supply

How to use this FORM?

This FORM is divided into 5 sheets:

Sheet 1	**HOME.** This is the cover sheet of the file. Before anything else, please make sure that you have filled the requested information: name of the partner and of the contact - name of the industry and of the described plant / process unit (in accordance with the list given in annex (sheet 6)).
Sheet 2	**NOTICE.** A notice is included in the FORM. It includes the description of the various sheets and a quick definition of the requested parameters.
Sheet 3	**PLANT/PROCESS DESCRIPTION.** In this sheet, the partner shall give a simplified flow scheme of the process with basic information such as the name of the process units included in the overall process (/plant) and the name and main characteristics (pressure, temperature, flowrate) of the fluids/products circulating between the units. You are free to use the proposed draft scheme or to include an existing flow scheme (as a jpeg image or as an attached pdf file). You can add any identified safety issues related to this process in this sheet.
Sheet 4	**CONSUMER DUTY.** This sheet focuses, within the process described in sheet 3, on the identification of the heating needs (independently from how heat is generated). Definition and examples of the data requested are given here below. They aim at characterizing the need in terms of physical conditions, operational philosophy, reliability, flexibility and safety.
Sheet 5	**PRODUCER SPECIFICATIONS.** In a second time, this sheet focuses on the existing systems implemented for heat generation. This information will be valuable in order to study the technical and economical impact of the use of HTR as an alternate for generation of High Temperature heat. Two sets of data are asked for: definition of the heat producer and characterization of the heat transportation media. Definition and examples of the data requested are given here below.
Sheet 6	**ANNEX.** Reminder of the list of partners and the related industries and plants / processes.

To be filled in priority

Can be filled in a second time

REFERENCES & GLOSSARY

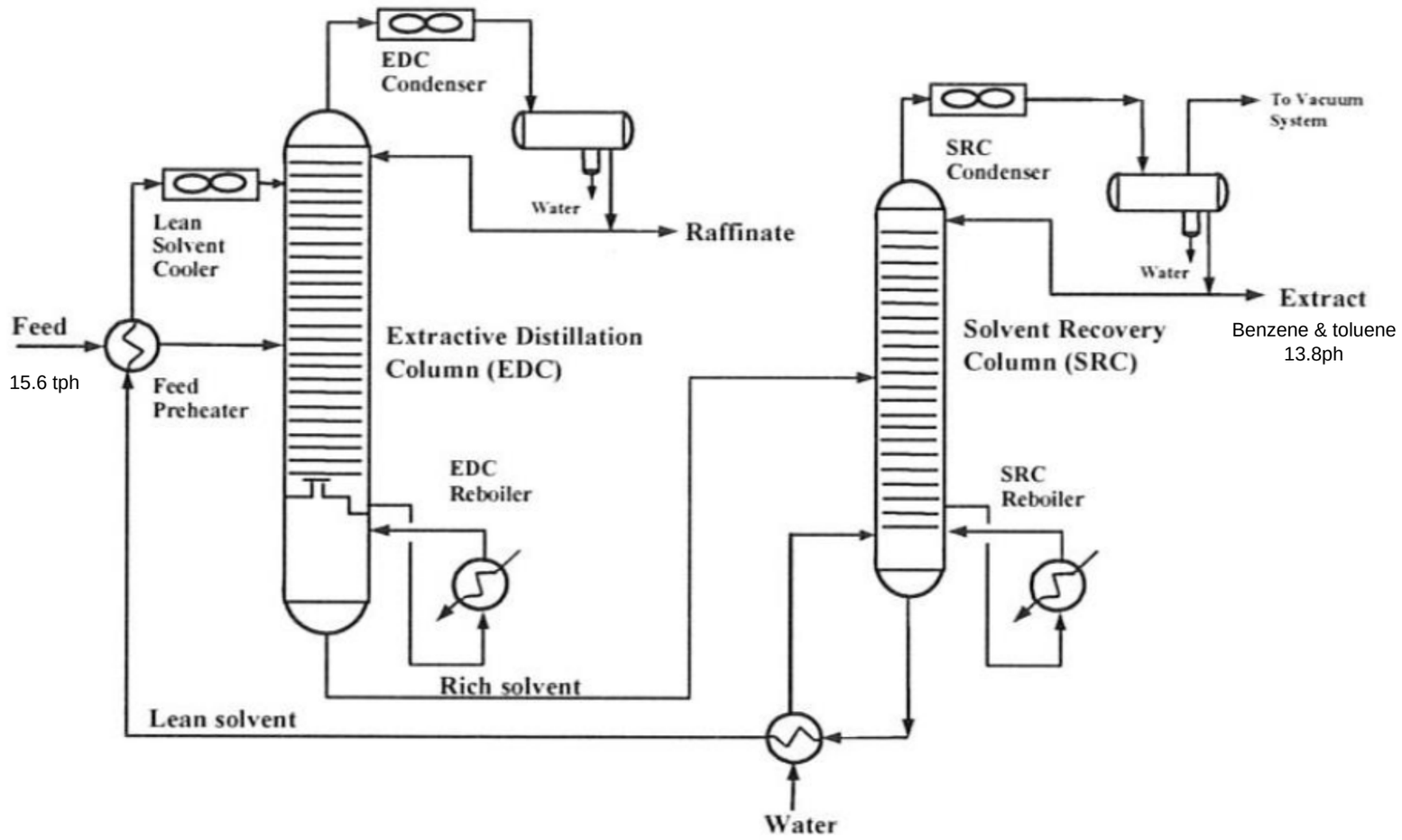
Ref.	*Parameter Name*	*Definition*	*Unit or Example*
		Process Description	
	Plant	An ensemble of process units	
	Process Unit	One elementary process unit that can be included in a plant or several plants	
(1)	Consumer Description	Name of the unit within the process (identical in sheet 3 and sheet 4)	steam reformming, hydrocracking…
		Consumer Duty - NEED	
(2)	Heating Loop N°	To number the heating loops properly allow to navigate easily in the file and to link heat production and heat consumption.	
(3)	Temperature	Temperature of the heating fluid at the inlet and the outlet **of the unit**.	K, °C, °F
(4)	Allowable Temperature Range	Min. & Max. temperatures at which the process takes place at full efficiency and without material damages.	K, °C, °F
(5)	Typical ramp up & down	Typical temperature gradient to be observed during transients (heating up & cool down).	K/min, K/s, K/h…
(6)	Continuous / Intermittent	Need for continuous heat supply (continuous process) or intermittent heat supply (batch process).	C or I (batch duration, number per year…)
(7)	Effect of heat supply disruption	What happens if case of heat supply disruption? Characterize the criticality of the heat supply.	shutdown of the process, degraded performances..
(8)	Consumption Leveling	Is there a possibility of leveling between the various heat loops in the process? Characterize the flexibility.	YES or NO
		Heat Producer Specifications - EXISTING	
(9)	Heat Generator Description	Name of the heat supply utility	
(10)	Fuel Type	Description of the fuel needed for heat generation	gas, coal, offgas (from unit X), electricity…
(11)	Fuel Consumption / External	Periodic consumption of external fuel	tpy, tph, Sm3/y…
(12)	Fuel Consumption / Offgases	Periodic consumption of internal fuel (offgases from another unit)	tpy, Sm^3/y…
(13)	Power	at least nominal power is required	MWh…
(14)	Back-up in case of shutdown	what is the planned back-up in case of the disruption og the normal heat supply?	
(15)	Media Type	Description of the media used for heat transportation between heat generation and consumption.	steam, oil, molten salt…
(16)	Temperature	Temperature of the medium at the inlet and at the outlet of the heat generation system	K, °C, °F
(17)	Pressure	Pressure of the medium at the inlet and at the outlet of the heat generation system	bar, psi…
(18)	Mass Flow	Mass flow rate of the heat transportation medium	tpy, Sm3/y…

Simplified Plant & Units flow scheme (1/2)

Objectives of the scheme

This simplified scheme aims at providing an easy understanding of the overall considered process.
You can add as many units as you think necessary.
In addition, please list at the bottom the safety concerns linked to the plant described here below.

❷ *Replace the example here below bythe flow scheme of the considered plant / process unit*



Simplified Plant & Units flow scheme (2/2)

❸ *Summarize here the name of the units*

	Consumer Description (1)
Unit A	Aromatic extractive distillation

❹ *Please detail here below the identified safety concerns related to the process.*

SAFETY CONCERNS.
- Presence of inflammable and explosive substance, risk of fire, exposure to benzene
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-
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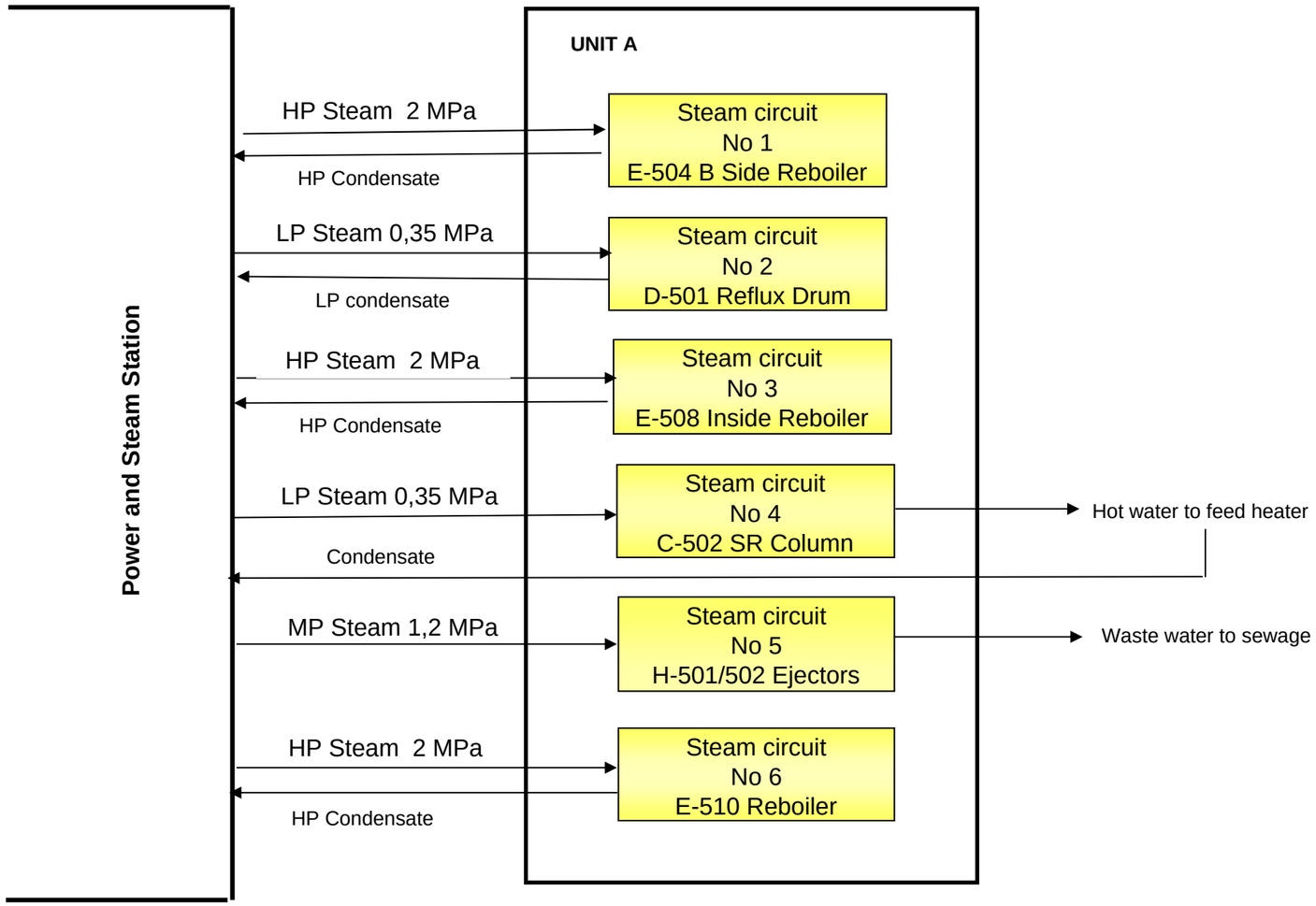
Characterization of the heating needs (1/2)

Objectives of the sheet

This sheet gathers the information related to the needs for heat in the plant or process unit.

❺ *Replacet the example here below by the heating needs of the process units described in Sheet 3*



Characterization of the heating needs (2/2)

❻ *Fill the table here in accordance with the units described in Sheet 3 and with the scheme here above.Definitions of the parameters are given in Sheet 2.*

Consumer duty

Consumer Description (1)		Heating Loop N° (2)	Temperature (3)		Allowable Temperature Range (4)		Typical ramp up and down (5)	Continuous OR Intermittent (6)	Effect of heat supply disruption (7)	Consumption leveling (8)	Comments
			inlet	outlet	T_{min}	T_{max}					
Unit A	E - 504 B	1	210	209 (cond)	210	230	± 10 ° C	Continuous	Unit shutdown	NO	DOC
Unit A	D - 501	2	170	150	150	200	± 20 ° C	Intermittent	Process disturbances	YES	
Unit A	E - 508	3	210	209 (cond)	210	230	± 10 ° C	Continuous	Unit shutdown	NO	
Unit A	C - 502	4	175	X	155	185	± 15 ° C	Continuous	Unit shutdown	NO	Stripping
Unit A	H-501/502	5	200	180	190	210	± 15 ° C	Continuous	Unit shutdown	NO	Pulling vacuum
Unit A	E - 510	6	210	209 (cond)	210	230	± 10 ° C	Continuous	Unit shutdown	NO	

Characterization of the existing heat generators (1/2)

Objectives of the sheet

This sheet gathers data on the existing heat generation systems.

❼ *Replace the example here below by the existing heat generation systems for the considered plant / process units. Heating LoopNumbers shall be in accordance with Sheet 4.*

Characterization of the existing heat generators (2/2)

❽ *Fill both table shere in accordance with the heating loops described in Sheet 4 and with the scheme here above. Definitions of the parameters are given in Sheet 2.*

HEAT GENERATORS

Heating loop N° (2)	Heat generator description (9)	Fuel type (10)	Fuel Consumption		Power (kWth) (13)			Backup in case of shutdown (14)	Comments
			External (11)	Offgases (12)	Min.	Nominal	Max.		

MEDIA TABLE

Heating loop N° (2)	Media type (15)	Temperature (16)		Pressure (17)		Mass flow (18)			Comments
		inlet	outlet	inlet	outlet	Min.	Normal	Max.	
0									
0									
0									
0									
0									
0									
0									
0									
0									
0									
0									

Industries & Processes

	Partners	Contact	Industries	Plant / Process Units
1	AMEC	Derek BUCKTHORPE derek.buckthorpe@amec.com	Oil sands	Steam Assisted Gravity Drainage
				Cyclic Steam Stimulation
			Petrochemicals	
			Ciment	Pyro processing
			Paper and Pulp	Kraft process
2	Air Liquide	Claire WEBER claire.weber@airliquide.com	Industrial Gas production	Oxygen Production - Ceramic membrane
				CO Production - dry reforming
3	Arcelor Mittal	Gerard Griffay gerard.griffay@arcelormittal.com	Steel Making	Coke Making
				SteelMaking
				Hot Rolling
				Direct Reduced Iron (DRI)
				Power Plant
				Lime plant
				Sintering
				Blast Furnace
4	Fortum	Harri Tuomisto harri.tuomisto@fortum.com	Paper and Pulp	
			Oil refinery	
			Co-generation	
			District Heating	
5	FZJ	Werner von Lensa w.von.lensa@fz-juelich.de	Coal	Coal Gasification
				Steam Methane Reforming
6	GDF Suez - Tractebel	Carmen Angulo carmen.angulo@gdfsuez.com	Co-Generation	-
7	NWU/PBMR	Gideon Greyvenstein	Petroleum Products	Fischer-Tropsch
				Steam Methane Reforming
		gideon.greyvenstein@pbmr.co.za	Oil Sands	
8	NWU	Frik van Niekerk frik.vanniekerk@nwu.ac.za	Hydrogen Production	Thermochemical water splitting
				Hybrid Sulfur
				Sulfur Iodine
				High Temperature Electrolysis
9	PROCHEM	Marek Tarka mtarka@prochem.com.pl	Refinery	Aromatics Extractive Distillation
				Crude Oil Distillates Hydrotreatment
				Crude Oil Distillation
10	SAIPEM	Jacques RUER jacques.ruer@saipem-sa.com	Energy Storage	Pumped Heat Electricity storage
11	Technip	Gaetano Iaquaniello iaquaniello.g@ktispa.it	Refinery	
			Hydrogen production	Steam Reforming
				Membranes Steam Reforming
12	USG (DSM) / BEC	Anton Baaten anton.baaten@me.com	Wide Range (Petro)chemicals incl. Urea & Ethylene	Utilities supply
13	ZAK	Marek Zuber marek.zuber@zak.com.pl	Nitrogen Fertilizers	Syngas production
				Hydrogen production
				Nitric acid synthesis
				Ammonia synthesis
				Urea production
			Organic Synthesis	Oxo processes
				Alcohol synthesis
				Phthalate plasticizers synthesis
				Phtalic and maleic anhydride

EUROPAIRS - Task 1.1: End-User Processes
Inventory of data

Please fill this cover sheet for the identification of the document. The list of industries and processes in given in Sheet 6 for reference.

File	PARTNER_INDUSTRY_PROCESS_revA.xls

Partner	PROCHEM S.A, WARSAW POLAND
Industry	CRUDE OIL PROCESSING
Plant / Process Unit	Crude oil distillate hydrotreatment unit

Objectives of the document:
This document aims at gathering efficiently relevant data related to the end-user processes.
Each partner is asked to fill one FORM for each plant or process unit (existing & future).
This collection of data is the core of Task 1.1 and will be consolidated in order to de used as base information for Task 1.3.

A notice to correctly fill this FORM is given in a dedicated sheet.

Status of the document

REV A	First Issue

End-User Requirements fOr industrial Process heat Applications with Innovative nuclear Reactors for Sustainable energy supply

How to use this FORM?

This FORM is divided into 5 sheets:

Sheet 1	**HOME.** This is the cover sheet of the file. Before anything else, please make sure that you have filled the requested information: name of the partner and of the contact - name of the industry and of the described plant / process unit (in accordance with the list given in annex (sheet 6)).
Sheet 2	**NOTICE.** A notice is included in the FORM. It includes the description of the various sheets and a quick definition of the requested parameters.
Sheet 3	**PLANT/PROCESS DESCRIPTION.** In this sheet, the partner shall give a simplified flow scheme of the process with basic information such as the name of the process units included in the overall process (/plant) and the name and main characteristics (pressure, temperature, flowrate) of the fluids/products circulating between the units. You are free to use the proposed draft scheme or to include an existing flow scheme (as a jpeg image or as an attached pdf file). You can add any identified safety issues related to this process in this sheet.
Sheet 4	**CONSUMER DUTY.** This sheet focuses, within the process described in sheet 3, on the identification of the heating needs (independently from how heat is generated). Definition and examples of the data requested are given here below. They aim at characterizing the need in terms of physical conditions, operational philosophy, reliability, flexibility and safety.
Sheet 5	**PRODUCER SPECIFICATIONS.** In a second time, this sheet focuses on the existing systems implemented for heat generation. This information will be valuable in order to study the technical and economical impact of the use of HTR as an alternate for generation of High Temperature heat. Two sets of data are asked for: definition of the heat producer and characterization of the heat transportation media. Definition and examples of the data requested are given here below.
Sheet 6	**ANNEX.** Reminder of the list of partners and the related industries and plants / processes.

To be filled in priority

Can be filled in a second time

REFERENCES & GLOSSARY

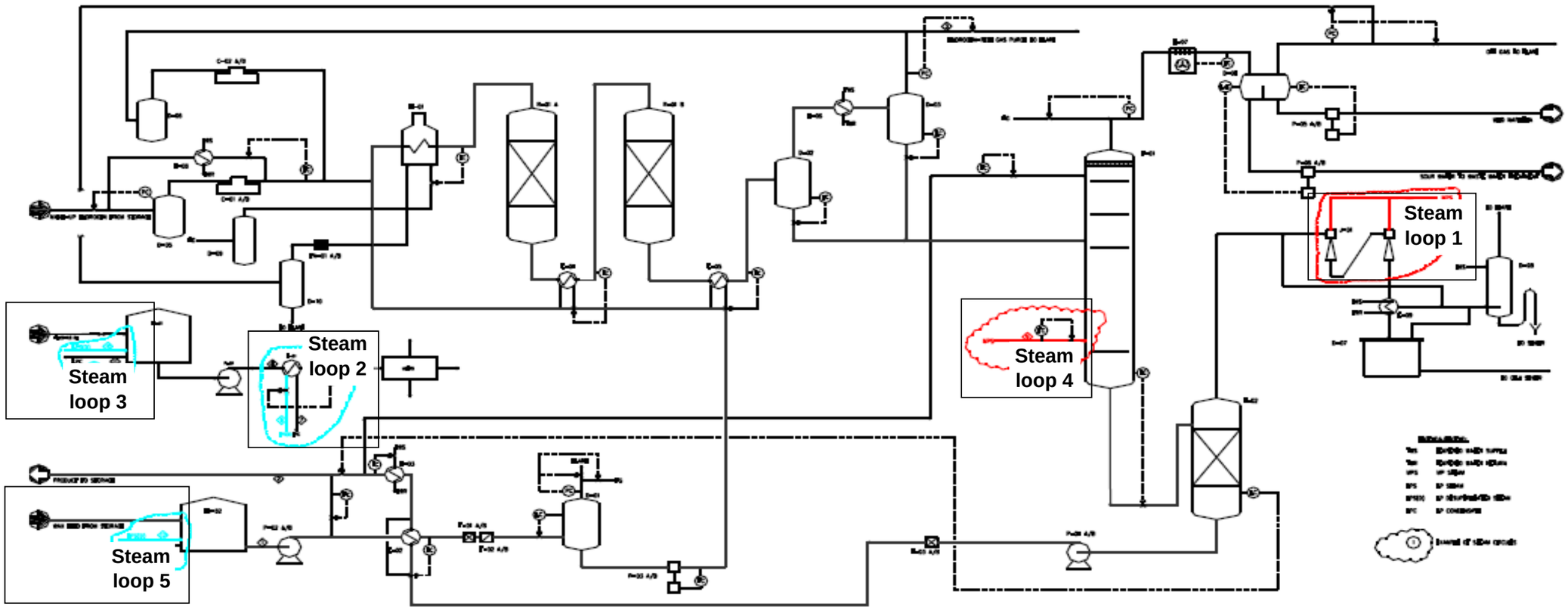
Ref.	*Parameter Name*	*Definition*	*Unit or Example*
		Process Description	
	Plant	An ensemble of process units	
	Process Unit	One elementary process unit that can be included in a plant or several plants	
(1)	Consumer Description	Name of the unit within the process (identical in sheet 3 and sheet 4)	steam reformming, hydrocracking…
		Consumer Duty - NEED	
(2)	Heating Loop N°	To number the heating loops properly allow to navigate easily in the file and to link heat production and heat consumption.	
(3)	Temperature	Temperature of the heating fluid at the inlet and the outlet **of the unit**.	K, °C, °F
(4)	Allowable Temperature Range	Min. & Max. temperatures at which the process takes place at full efficiency and without material damages.	K, °C, °F
(5)	Typical ramp up & down	Typical temperature gradient to be observed during transients (heating up & cool down).	K/min, K/s, K/h…
(6)	Continuous / Intermittent	Need for continuous heat supply (continuous process) or intermittent heat supply (batch process).	C or I (batch duration, number per year…)
(7)	Effect of heat supply disruption	What happens if case of heat supply disruption? Characterize the criticality of the heat supply.	shutdown of the process, degraded performances..
(8)	Consumption Leveling	Is there a possibility of leveling between the various heat loops in the process? Characterize the flexibility.	YES or NO
		Heat Producer Specifications - EXISTING	
(9)	Heat Generator Description	Name of the heat supply utility	
(10)	Fuel Type	Description of the fuel needed for heat generation	gas, coal, offgas (from unit X), electricity…
(11)	Fuel Consumption / External	Periodic consumption of external fuel	tpy, tph, Sm3/y…
(12)	Fuel Consumption / Offgases	Periodic consumption of internal fuel (offgases from another unit)	tpy, Sm^3/y…
(13)	Power	at least nominal power is required	MWh…
(14)	Back-up in case of shutdown	what is the planned back-up in case of the disruption og the normal heat supply?	
(15)	Media Type	Description of the media used for heat transportation between heat generation and consumption.	steam, oil, molten salt…
(16)	Temperature	Temperature of the medium at the inlet and at the outlet of the heat generation system	K, °C, °F
(17)	Pressure	Pressure of the medium at the inlet and at the outlet of the heat generation system	bar, psi…
(18)	Mass Flow	Mass flow rate of the heat transportation medium	tpy, Sm3/y…

Simplified Plant & Units flow scheme (1/2)

Objectives of the scheme

This simplified scheme aims at providing an easy understanding of the overall considered process.
You can add as many units as you think necessary.
In addition, please list at the bottom the safety concerns linked to the plant described here below.

❷ *Replace the example here below bythe flow scheme of the considered plant / process unit*



Simplified Plant & Units flow scheme (2/2)

❸ *Summarize here the name of the units*

	Consumer Description (1)
Unit C	Crude oil distillate hydrotreatment unit

❹*Please detail here below the identified safety concerns related to the process.*

SAFETY CONCERNS.
- Presence of light hydricarbons and hydrogen, high process temperature and pressure, exposure to hydrogen sulfur
-
-
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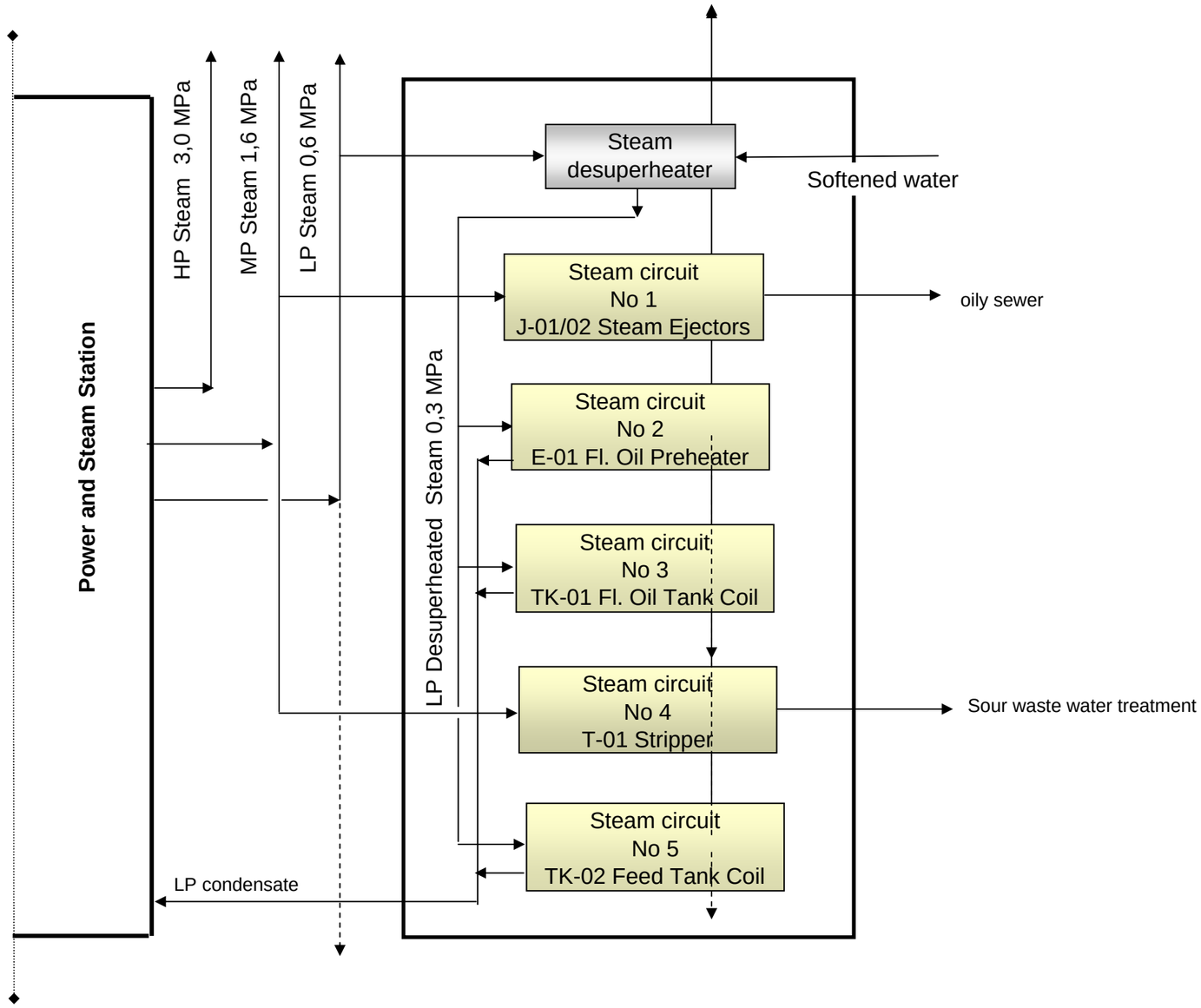
Characterization of the heating needs (1/2)

Objectives of the sheet

This sheet gathers the information related to the needs for heat in the plant or process unit.

❺ *Replacet the example here below by the heating needs of the process units described in Sheet 3*



Characterization of the heating needs (2/2)

Fill the table here in accordance with the units described in Sheet 3 and with the scheme here above.Definitions of the parameters are given in Sheet 2.

Consumer duty

Consumer Description (1)		Heating Loop N° (2)	Temperature (3)		Allowable Temperature Range (4)		Typical ramp up and down (5)	Continuous OR Intermittent (6)	Effect of heat supply disruption (7)	Consumption leveling (8)	Comments
			inlet	outlet	T_{min}	T_{max}					
Unit C	J-01/02	1	227	220	220	260	± 20 ° C	Continuous	Unit shut down	NO	Pulling vacuum
Unit C	E-01	2	150	140 (cond)	146	154	± 4 ° C	Continuous	Process disturbances	YES	Saturated
Unit C	TK-01	3	150	140 (cond)	146	154	± 4 ° C	Continuous	Process disturbances	YES	Saturated
Unit C	T-01	4	227	X	220	260	± 20 ° C	Continuous	Unit shutdown	NO	Stripping
Unit C	TK-02	5	150	140 (cond)	146	154	± 4 ° C	Continuous	Process disturbances	YES	Saturated

Characterization of the existing heat generators (1/2)

Objectives of the sheet

This sheet gathers data on the existing heat generation systems.

❼ *Replace the example here below by the existing heat generation systems for the considered plant / process units. Heating LoopNumbers shall be in accordance with Sheet 4.*

Characterization of the existing heat generators (2/2)

❽ *Fill both table shere in accordance with the heating loops described in Sheet 4 and with the scheme here above. Definitions of the parameters are given in Sheet 2.*

HEAT GENERATORS

Heating loop N° (2)	Heat generator description (9)	Fuel type (10)	Fuel Consumption		Power (kWth) (13)			Backup in case of shutdown (14)	Comments
			External (11)	Offgases (12)	Min.	Nominal	Max.		

MEDIA TABLE

Heating loop N° (2)	Media type (15)	Temperature (16)		Pressure (17)		Mass flow (18)			Comments
		inlet	outlet	inlet	outlet	Min.	Normal	Max.	
0									
0									
0									
0									
0									
0									
0									
0									
0									
0									
0									

Industries & Processes

	Partners	Contact	Industries	Plant / Process Units
1	AMEC	Derek BUCKTHORPE derek.buckthorpe@amec.com	Oil sands	Steam Assisted Gravity Drainage
				Cyclic Steam Stimulation
			Petrochemicals	
			Ciment	Pyro processing
			Paper and Pulp	Kraft process
2	Air Liquide	Claire WEBER claire.weber@airliquide.com	Industrial Gas production	Oxygen Production - Ceramic membrane
				CO Production - dry reforming
3	Arcelor Mittal	Gerard Griffay gerard.griffay@arcelormittal.com	Steel Making	Coke Making
				SteelMaking
				Hot Rolling
				Direct Reduced Iron (DRI)
				Power Plant
				Lime plant
				Sintering
				Blast Furnace
4	Fortum	Harri Tuomisto harri.tuomisto@fortum.com	Paper and Pulp	
			Oil refinery	
			Co-generation	
			District Heating	
5	FZJ	Werner von Lensa w.von.lensa@fz-juelich.de	Coal	Coal Gasification
				Steam Methane Reforming
6	GDF Suez - Tractebel	Carmen Angulo carmen.angulo@gdfsuez.com	Co-Generation	-
7	NWU/PBMR	Gideon Greyvenstein	Petroleum Products	Fischer-Tropsch
				Steam Methane Reforming
		gideon.greyvenstein@pbmr.co.za	Oil Sands	
8	NWU	Frik van Niekerk frik.vanniekerk@nwu.ac.za	Hydrogen Production	Thermochemical water splitting
				Hybrid Sulfur
				Sulfur Iodine
				High Temperature Electrolysis
9	PROCHEM	Marek Tarka mtarka@prochem.com.pl	Refinery	Aromatics Extractive Distillation
				Crude Oil Distillates Hydrotreatment
				Crude Oil Distillation
10	SAIPEM	Jacques RUER jacques.ruer@saipem-sa.com	Energy Storage	Pumped Heat Electricity storage
11	Technip	Gaetano Iaquaniello iaquaniello.g@ktispa.it	Refinery	
			Hydrogen production	Steam Reforming
				Membranes Steam Reforming
12	USG (DSM) / BEC	Anton Baaten anton.baaten@me.com	Wide Range (Petro)chemicals incl. Urea & Ethylene	Utilities supply
13	ZAK	Marek Zuber marek.zuber@zak.com.pl	Nitrogen Fertilizers	Syngas production
				Hydrogen production
				Nitric acid synthesis
				Ammonia synthesis
				Urea production
			Organic Synthesis	Oxo processes
				Alcohol synthesis
				Phthalate plasticizers synthesis
				Phtalic and maleic anhydride

EUROPAIRS - Task 1.1: End-User Processes
Inventory of data

Please fill this cover sheet for the identification of the document. The list of industries and processes in given in Sheet 6 for reference.

File	PARTNER_INDUSTRY_PROCESS_revA.xls

Partner	PROCHEM S.A, WARSAW POLAND
Industry	CRUDE OIL PROCESSING
Plant / Process Unit	Crude oil distillation unit

Objectives of the document:
This document aims at gathering efficiently relevant data related to the end-user processes.
Each partner is asked to fill one FORM for each plant or process unit (existing & future).
This collection of data is the core of Task 1.1 and will be consolidated in order to de used as base information for Task 1.3.

A notice to correctly fill this FORM is given in a dedicated sheet.

Status of the document

REV A	First Issue

End-User Requirements fOr industrial Process heat Applications with Innovative nuclear Reactors for Sustainable energy supply

How to use this FORM?

This FORM is divided into 5 sheets:

Sheet 1	**HOME.** This is the cover sheet of the file. Before anything else, please make sure that you have filled the requested information: name of the partner and of the contact - name of the industry and of the described plant / process unit (in accordance with the list given in annex (sheet 6)).
Sheet 2	**NOTICE.** A notice is included in the FORM. It includes the description of the various sheets and a quick definition of the requested parameters.
Sheet 3	**PLANT/PROCESS DESCRIPTION.** In this sheet, the partner shall give a simplified flow scheme of the process with basic information such as the name of the process units included in the overall process (/plant) and the name and main characteristics (pressure, temperature, flowrate) of the fluids/products circulating between the units. You are free to use the proposed draft scheme or to include an existing flow scheme (as a jpeg image or as an attached pdf file). You can add any identified safety issues related to this process in this sheet.
Sheet 4	**CONSUMER DUTY.** This sheet focuses, within the process described in sheet 3, on the identification of the heating needs (independently from how heat is generated). Definition and examples of the data requested are given here below. They aim at characterizing the need in terms of physical conditions, operational philosophy, reliability, flexibility and safety.
Sheet 5	**PRODUCER SPECIFICATIONS.** In a second time, this sheet focuses on the existing systems implemented for heat generation. This information will be valuable in order to study the technical and economical impact of the use of HTR as an alternate for generation of High Temperature heat. Two sets of data are asked for: definition of the heat producer and characterization of the heat transportation media. Definition and examples of the data requested are given here below.
Sheet 6	**ANNEX.** Reminder of the list of partners and the related industries and plants / processes.

To be filled in priority

Can be filled in a second time

REFERENCES & GLOSSARY

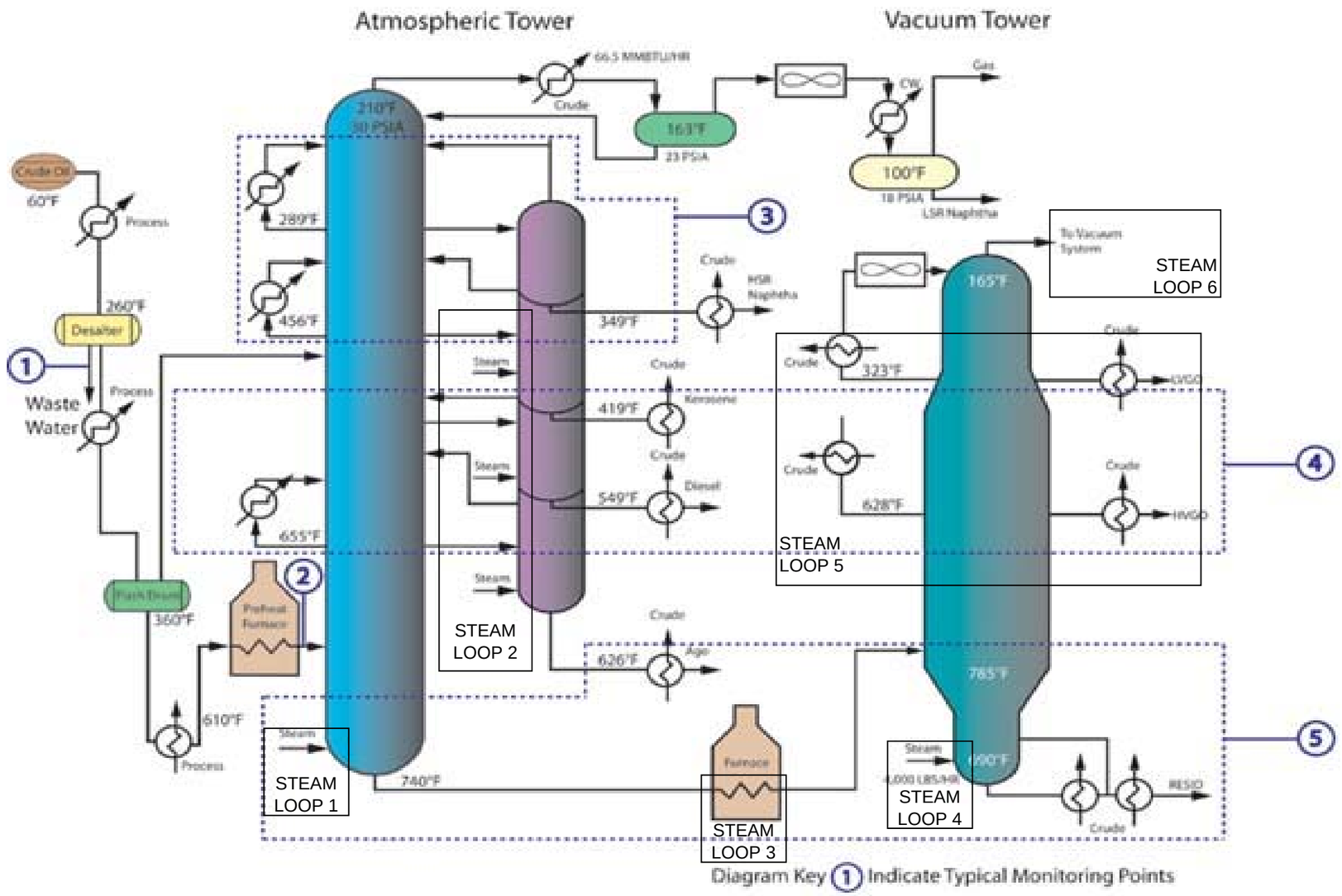
Ref.	*Parameter Name*	*Definition*	*Unit or Example*
		Process Description	
	Plant	An ensemble of process units	
	Process Unit	One elementary process unit that can be included in a plant or several plants	
(1)	Consumer Description	Name of the unit within the process (identical in sheet 3 and sheet 4)	steam reformming, hydrocracking…
		Consumer Duty - NEED	
(2)	Heating Loop N°	To number the heating loops properly allow to navigate easily in the file and to link heat production and heat consumption.	
(3)	Temperature	Temperature of the heating fluid at the inlet and the outlet **of the unit**.	K, °C, °F
(4)	Allowable Temperature Range	Min. & Max. temperatures at which the process takes place at full efficiency and without material damages.	K, °C, °F
(5)	Typical ramp up & down	Typical temperature gradient to be observed during transients (heating up & cool down).	K/min, K/s, K/h…
(6)	Continuous / Intermittent	Need for continuous heat supply (continuous process) or intermittent heat supply (batch process).	C or I (batch duration, number per year…)
(7)	Effect of heat supply disruption	What happens if case of heat supply disruption? Characterize the criticality of the heat supply.	shutdown of the process, degraded performances..
(8)	Consumption Leveling	Is there a possibility of leveling between the various heat loops in the process? Characterize the flexibility.	YES or NO
		Heat Producer Specifications - EXISTING	
(9)	Heat Generator Description	Name of the heat supply utility	
(10)	Fuel Type	Description of the fuel needed for heat generation	gas, coal, offgas (from unit X), electricity…
(11)	Fuel Consumption / External	Periodic consumption of external fuel	tpy, tph, Sm3/y…
(12)	Fuel Consumption / Offgases	Periodic consumption of internal fuel (offgases from another unit)	tpy, Sm^3/y…
(13)	Power	at least nominal power is required	MWh…
(14)	Back-up in case of shutdown	what is the planned back-up in case of the disruption og the normal heat supply?	
(15)	Media Type	Description of the media used for heat transportation between heat generation and consumption.	steam, oil, molten salt…
(16)	Temperature	Temperature of the medium at the inlet and at the outlet of the heat generation system	K, °C, °F
(17)	Pressure	Pressure of the medium at the inlet and at the outlet of the heat generation system	bar, psi…
(18)	Mass Flow	Mass flow rate of the heat transportation medium	tpy, Sm3/y…

Simplified Plant & Units flow scheme (1/2)

Objectives of the scheme

This simplified scheme aims at providing an easy understanding of the overall considered process.
You can add as many units as you think necessary.
In addition, please list at the bottom the safety concerns linked to the plant described here below.

❷ *Replace the example here below bythe flow scheme of the considered plant / process unit*



Simplified Plant & Units flow scheme (2/2)

❸ *Summarize here the name of the units*

	Consumer Description (1)
Unit B	Crude oil distillation unit

❹ *Please detail here below the identified safety concerns related to the process.*

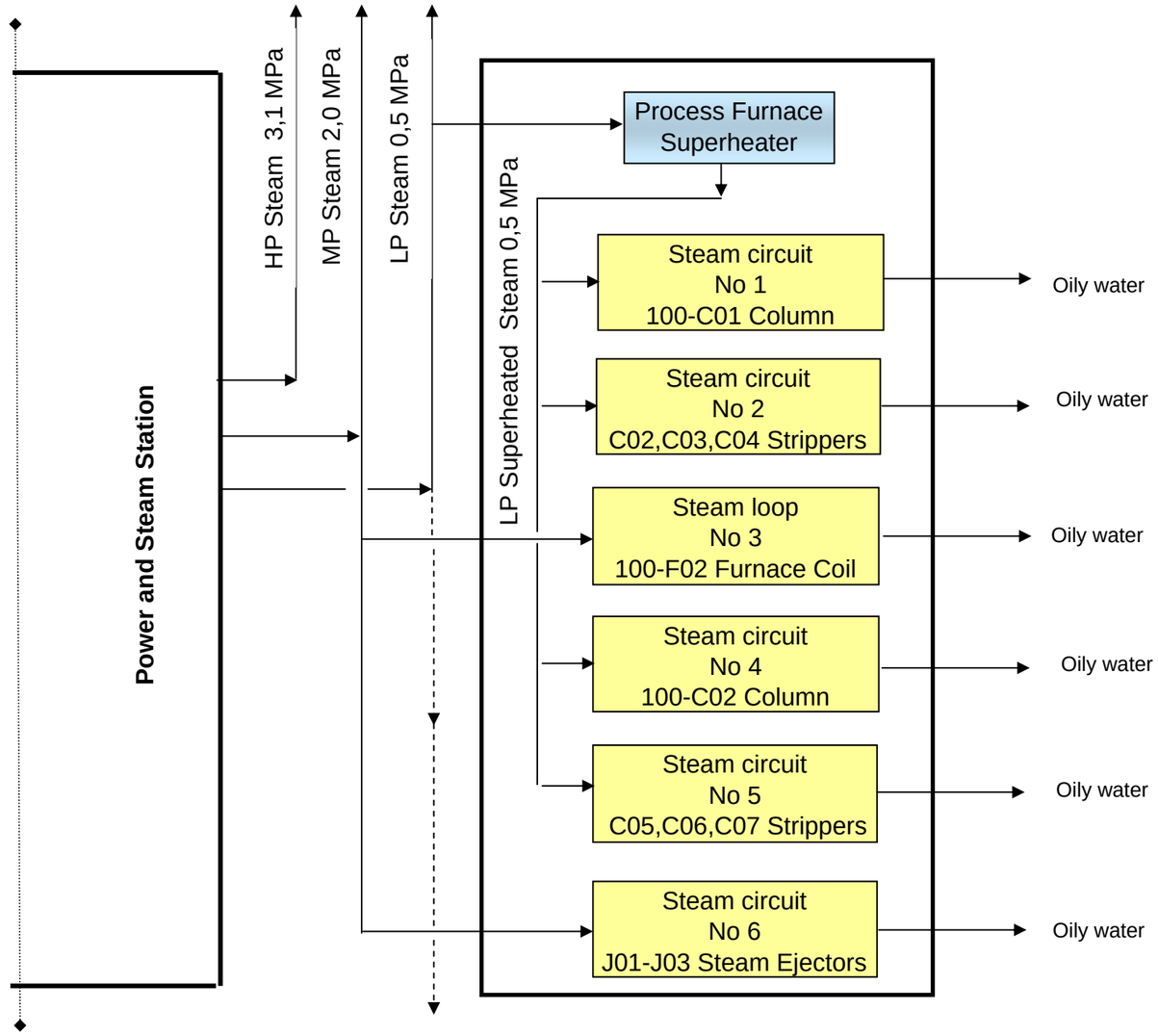
SAFETY CONCERNS.
- High process temperature, risk of fire, exposure to vapours of light hydrocarbons
-
-
-
-
-
-
-
-
-
-
-
-
-
-
-
-

Characterization of the heating needs (1/2)

Objectives of the sheet

This sheet gathers the information related to the needs for heat in the plant or process unit.

❺ *Replacet the example here below by the heating needs of the process units described in Sheet 3*



Characterization of the heating needs (2/2)

❻ *Fill the table here in accordance with the units described in Sheet 3 and with the scheme here above.Definitions of the parameters are given in Sheet 2.*

Consumer duty

Consumer Description (1)		Heating Loop N° (2)	Temperature (3)		Allowable Temperature Range (4)		Typical ramp up and down (5)	Continuous OR Intermittent (6)	Effect of heat supply disruption (7)	Consumption leveling (8)	Comments
			inlet	outlet	T_{min}	T_{max}					
Unit B	100-C01	1	350	X	346	354	± 4 ° C	Continuous	Unit shutdown	NO	Stripping
Unit B	C02,C03,C04	2	350	X	346	354	± 4 ° C	Continuous	Unit shutdown	NO	Stripping
Unit B	100-F02	3	234	XX	220	275	± 20 ° C	Continuous	Unit shutdown	NO	Turbulence
Unit B	100-C02	4	350	X	346	354	± 4 ° C	Continuous	Unit shutdown	NO	Stripping
Unit B	C05,C06,C07	5	350	X	346	354	± 4 ° C	Continuous	Unit shutdown	NO	Stripping

Characterization of the existing heat generators (1/2)

Objectives of the sheet

This sheet gathers data on the existing heat generation systems.

❼ *Replace the example here below by the existing heat generation systems for the considered plant / process units. Heating LoopNumbers shall be in accordance with Sheet 4.*

Characterization of the existing heat generators (2/2)

❽ *Fill both table shere in accordance with the heating loops described in Sheet 4 and with the scheme here above. Definitions of the parameters are given in Sheet 2.*

HEAT GENERATORS

Heating loop N° (2)	Heat generator description (9)	Fuel type (10)	Fuel Consumption		Power (kWth) (13)			Backup in case of shutdown (14)	Comments
			External (11)	Offgases (12)	Min.	Nominal	Max.		

MEDIA TABLE

Heating loop N° (2)	Media type (15)	Temperature (16)		Pressure (17)		Mass flow (18)			Comments
		inlet	outlet	inlet	outlet	Min.	Normal	Max.	
0									
0									
0									
0									
0									
0									
0									
0									
0									
0									
0									

Industries & Processes

	Partners	Contact	Industries	Plant / Process Units
1	AMEC	Derek BUCKTHORPE derek.buckthorpe@amec.com	Oil sands	Steam Assisted Gravity Drainage
				Cyclic Steam Stimulation
			Petrochemicals	
			Ciment	Pyro processing
			Paper and Pulp	Kraft process
2	Air Liquide	Claire WEBER claire.weber@airliquide.com	Industrial Gas production	Oxygen Production - Ceramic membrane
				CO Production - dry reforming
3	Arcelor Mittal	Gerard Griffay gerard.griffay@arcelormittal.com	Steel Making	Coke Making
				SteelMaking
				Hot Rolling
				Direct Reduced Iron (DRI)
				Power Plant
				Lime plant
				Sintering
				Blast Furnace
4	Fortum	Harri Tuomisto harri.tuomisto@fortum.com	Paper and Pulp	
			Oil refinery	
			Co-generation	
			District Heating	
5	FZJ	Werner von Lensa w.von.lensa@fz-juelich.de	Coal	Coal Gasification
				Steam Methane Reforming
6	GDF Suez - Tractebel	Carmen Angulo carmen.angulo@gdfsuez.com	Co-Generation	-
7	NWU/PBMR	Gideon Greyvenstein	Petroleum Products	Fischer-Tropsch
				Steam Methane Reforming
		gideon.greyvenstein@pbmr.co.za	Oil Sands	
8	NWU	Frik van Niekerk frik.vanniekerk@nwu.ac.za	Hydrogen Production	Thermochemical water splitting
				Hybrid Sulfur
				Sulfur Iodine
				High Temperature Electrolysis
9	PROCHEM	Marek Tarka mtarka@prochem.com.pl	Refinery	Aromatics Extractive Distillation
				Crude Oil Distillates Hydrotreatment
				Crude Oil Distillation
10	SAIPEM	Jacques RUER jacques.ruer@saipem-sa.com	Energy Storage	Pumped Heat Electricity storage
11	Technip	Gaetano Iaquaniello iaquaniello.g@ktispa.it	Refinery	
			Hydrogen production	Steam Reforming
				Membranes Steam Reforming
12	USG (DSM) / BEC	Anton Baaten anton.baaten@me.com	Wide Range (Petro)chemicals incl. Urea & Ethylene	Utilities supply
13	ZAK	Marek Zuber marek.zuber@zak.com.pl	Nitrogen Fertilizers	Syngas production
				Hydrogen production
				Nitric acid synthesis
				Ammonia synthesis
				Urea production
			Organic Synthesis	Oxo processes
				Alcohol synthesis
				Phthalate plasticizers synthesis
				Phtalic and maleic anhydride

EUROPAIRS

KTI PROJECT No 80670

END-USER REQUIREMENTS FOR INDUSTRIAL PROCESSE HEAT APPLICATIONS WITH INNOVATIVE NUCLEAR REACTORS FOR SUSTAINABLE ENERGY SUPPLY

TASK 1.1: End user processes, characteristics and requirements

HYDROGEN PRODUCTION BY STEAM REFORMING OF HYDROCARBONS

Roma, November 2009

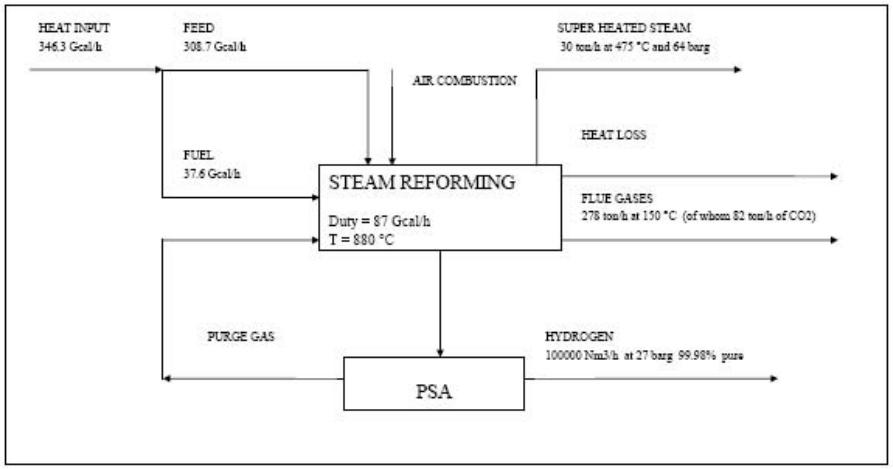
Characterization of the existing heat generators (1/2)

Objectives of the sheet

Conventional hydrogen plant based on steam reforming (SR) of natural gas or refining off-gases, naphta or LPG, are net exporter of steam to the refining steam headers.
Steam is raised in the convection section of reformer by cooling the flue gas coming from the radiant section, where the steam reforming reaction is taking place.
Several architectures are possible depending on the site constraints.
Two different schemes are herewith presented: the minimum steam export configuration (figure 1) and the one where CO_2 is recovered (figure 2).
CO2 recovery is not so common today, but being the SR one of the motor producer of CO_2 in a refinery, could become in a nearby future a mandatory option. Within such a second architecture the export steam is quite reduced.
Feed + Fuel consumption is indicated in terms of heat input (flow of hydrocarbons x LHV). A typical process description is given.

FIGURE 1

MINIMUM STEAM EXPORT CONFIGURATION



STEAM BOILERS SPECIFICATION

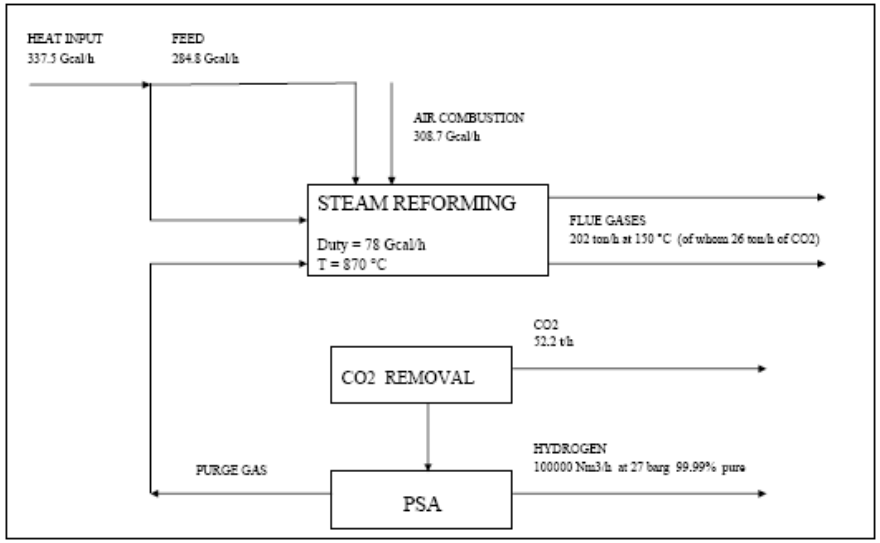
Boiler No	Fuel	Steam outlet, nominal conditions		Steam boiler output, t/h		Boiler operating thermal power
		Temperature (°C)	Pressure (MPag)	Nominal	Operating	
Total						

STEAM TURBINE SPECIFICATION

Turbine No	Type		Steam inlet nominal data		Turbine nominal power Mwe
			Temperature (°C)	Pressure (MPag)	
Total					

FIGURE 2

CO_2 RECOVERED CONFIGURATION



STEAM BOILERS SPECIFICATION

Boiler No	Fuel	Steam outlet, nominal conditions		Steam boiler output, t/h		Boiler operating thermal power
		Temperature (°C)	Pressure (MPag)	Nominal	Operating	
Total						

STEAM TURBINE SPECIFICATION

Turbine No	Type		Steam inlet nominal data		Turbine nominal power Mwe
			Temperature (°C)	Pressure (MPag)	
Total					

TASK 1.1: End user processes, characteristics and requirements

HYDROGEN PRODUCTION BY STEAM REFORMING OF HYDROCARBONS

PROCESS DESCRIPTION FOR HYDROCARBON PRODUCTION OF HYDROCARBONS

Europairs

KTI Project No 80670

	06/11/09			GI	GI
REV.	**DATE**	**STATUS**	**WRITTEN BY**	**CHECKED BY**	**APPROVED/AUTHORIZED BY**
DOCUMENT REVISIONS					

INDEX

1. GENERAL

The process design is based on the Steam Reforming technology to convert the hydrocarbon feed, in presence of steam, into hydrogen rich gas, further processed in a purification step in a PSA unit.

2. PLANT DESCRIPTION

The design is based on the production of hydrogen from the following feedstocks:

- Light Virgin Naphtha
- LPG
- Natural gas (available in the future).

2.1. Feedstock Desulphurization

Naphtha or LPG are received from the battery limit and fed under level control to the Naphtha Feed Drum V-101 or the LPG Feed Drum V-102.

From the feed drums the liquid feeds are pumped under flow control using the Naphtha pumps P-101A/B and the LPG pumps P-103 A/B, respectively.

The liquid feed is then mixed with recycle hydrogen from the Hydrogen Recycle Compressor K-102 A/B.

The mixture is vaporized and superheated in the Feed Vaporizer E-107 and in the Feed Preheater E-102, using as heating medium steam and the effluent from the High Temperature Shift Converter R-103.

In the future operation (Natural Gas case), Natural Gas is received from the battery limit and fed under pressure control to the Natural Gas K.O. Drums V-106A/B.

From the K.O. Drum, natural gas is compressed by means of natural gas compressors K-101A/B, and sent to preheating.

The feed flow rate set point is regulated to maintain the process pressure in the desulphurization section of the plant.

The vaporized and preheated feed is fed to the Hydrogenator R-101, where in presence of a CoMox catalyst all the organic sulphur is hydrogenated to hydrogen sulphide according to:

$R - SH + H2 \Rightarrow RH + H2S$ (1)

Olefins, present in the LPG, are hydrogenated as well. This hydrogenation reaction is exothermic and causes an increase of the temperature:

$$R – CH = CH – R + H2 \Rightarrow R - CH2 - CH2 – R + Q1 \quad (2)$$

CoMox catalyst must be kept under sulphided state. If feed containing very low sulphur amount, below 2 ppm is used, DMDS (Di-Methyl Di-Sulphide) has to be added, by DMDS dosing system A-103, to avoid catalyst de-sulphidation.

During start-up recycle hydrogen is imported from B.L. until the plant can generate its own.

The feed from the Hydrogenator is fed to the Desulphurizers R-102A/B, containing zinc oxide catalyst that reacts irreversibly with the hydrogen sulphide:

$$ZnO + H2\,S \Rightarrow ZnS + H2\,O \quad (3)$$

The two Desulphurizers are operating in series (lead-lag system). When the zinc oxide of the lead reactor is spent, it is taken off-line. The remaining reactor then becomes the lead reactor. The spent zinc oxide of the off-line reactor is replaced by a fresh load zinc oxide, and this reactor is then brought back on-line as the lag reactor.

A system of piping and valves allows these operations to be carried without allowing untreated gas to reach the reformer system.

The feed leaving the desulphurization section contains less than 0.1 ppm hydrogen sulphide.

During the start-up, when the feed is first introduced into the plant, it is necessary to check that adequate desulphurization is being achieved before introducing the feed (together with steam) to the Pre-reformer. The vaporized feed leaving the desulphurizers is therefore sampled and checked for sulphur content. Until low levels of sulphur are confirmed, the vaporised feed is recirculated under pressure control back to its feed drum via Naphtha Recycle Cooler E-121 whit feed condensation. Non-condensable components together with hydrogen escape under pressure control to flare from the feed drum.

2.2. Prereforming

The desulphurized feed flow rate is set at the value expected to give the desired hydrogen production rate. Superheated process steam is added to give the desired steam/feed weight ratio. This mixture is then pre-heated in the Prereformer Preheat Coil E-132 and passed to the Prereformer R-104 A/B. The temperature can be influenced by changing the degree of process steam superheating.

The required inlet conditions vary depending on the type of feed used. Inside the reactor, a very active catalyst converts higher hydrocarbons to an equilibrium mixture of methane, carbon oxides, hydrogen and steam as follows:

1. Reforming of higher paraffins, naphtenes, aromatics:

   $$C_n H_m + n\,H_2O \Leftrightarrow n\,CO + (2n+m)/2\;H_2 \qquad (4)$$

2. Methane reforming:

   $$CH_4 + H_2O \Leftrightarrow CO + 3H_2 \qquad (5)$$

3. Shift reaction:

   $$CO + H_2O \Leftrightarrow CO_2 + H_2 \qquad (6)$$

The reactor operates adiabatically, so the final composition and temperature are determined by the interaction between heats of reaction, stoichiometry and equilibrium conditions at any given temperature/ pressure. Virtually complete conversion of higher hydrocarbons is achieved at the inlet conditions and catalyst volume selected for this plant.

If the feed flow rate is to be increased (e.g. due to higher hydrogen product demand), the control system ensures that the process steam flowrate is increased to the new level ahead of the feed flowrate changes.

Similarly, if the feed flowrate is reduced, the steam flowrate decrease lags behind the feed reduction. In this way, the risk of damage to the catalyst by a too low steam to feed ratio is avoided.

Since the catalyst gradually degrades with time, provision has been made to switch over on-line to a second reactor with fresh catalyst, so hydrogen production is not interrupted.

Nitrogen is used to purge hot feed vapors from the spent catalyst. Nitrogen heated by a start-up heater, warms up the reactor with fresh catalyst before bringing it on-line, in order to avoid the risk of feed re-condensing inside the reactor and subsequently damaging the catalyst.

2.3. Steam Reforming

The effluent is mixed with additional steam to give the desired overall molar steam to carbon ratio. The mixture is further pre-heated in the Reformer preheat Coil E-131 and is distributed over the catalyst tubes of the Steam Reformer H-101, where most of the methane in the feed gas is converted to hydrogen, carbon monoxide and carbon dioxide in the presence of steam over the nickel catalyst.

The product gas that leaves the reformer is essentially an equilibrium mixture of hydrogen, carbon monoxide, carbon dioxide, methane and steam (according to reaction (5) and (6) given above).

The process steam added to the feed is in excess of the stoichiometric quantity, which also prevents any carbon formation on the catalyst.

The carbon formation may happen by:

- CO disproportion $2CO \Leftrightarrow C + CO2$
- CO reduction $CO + H2 \Leftrightarrow C + H2O$
- Methane cracking $CH4 \Leftrightarrow C + 2H2$
- Polymerization and dehydrogenation of the intermediates (obtained by the initial decomposition and which are then reformed) if their concentration is sufficiently high
- Thermal cracking of the feedstock

The carbon formed from the CO disproportion and CO reduction is defined as thermodynamic (or Bouduard) carbon.

Its formation is instantaneous and the carbon is laid down in the catalyst pores and the catalyst must be replaced.

The carbon formed by thermal cracking or by polimerization and dehydrogenation of the intermediates is laid down on catalyst surface and it can be removed by reaction with steam or CO2.

The steam/carbon ratio of the Reformer feed must always be higher than the critical value below which carbon formation can occur.

The control system ensures that the overall steam to carbon ratio is at the desired value or higher as the feed flow rate to the Reformer is changed (e.g. during a production capacity change). This is in addition to the steam to feed ratio control on the Prereformer (see above).

The overall reforming is strongly endothermic and the conversion of methane is favoured by high temperatures.

The heat has to be supplied externally to achieve the required conversion. This is provided by combustion of PSA purge gas as the priority fuel and refinery fuel gas as the make-up fuel.

2.4. Conversion of Carbon Monoxide

After the Reformer effluent is cooled down in the Process Gas Boiler E-101, the effluent is fed under temperature control to the High Temperature Shift Converter R-103, where the major portion of carbon monoxide reacts with steam and is converted to hydrogen and carbon dioxide, according to reaction (6) given above.

Due to the exothermic nature of this reaction there is a temperature rise over this reactor. Some of the heat content of the process gas leaving the HT shift converter is recovered in a train of exchangers.

First the hot process gas stream is split into two streams:

One passes through the Feed Preheater E-102 (see section about Desulphurization above), the other passes through the Process Steam Superheater E-103.

The desired feed temperature for the Desulphurization section is achieved controlling the fraction of the process gas passing through the Feed Preheater.

The degree of superheating of the Process Steam is controlled by passing the flow of steam round the Process Steam Superheater.

The process gas streams are then recombined and used as heating medium in the BFW Preheater E-104 and in the Degasifier Feed Preheater E-105.

The partially cooled and condensed process gas stream passes to the Hot Condensate Separator V-104, where process gas is separated from contaminated steam condensate. The process gas is then further cooled/condensed to the required PSA inlet temperature in the Process Gas Air Cooler E-120, and then in the Process Gas Cooler E-106.

Any resulting condensate is then recovered in the Cold Condensate Separator V-105, before passing the process gas to the PSA Unit A-101 for hydrogen product recovery and purification. The condensate from separators is mixed with demi water from battery limit and sent to the Degasifier V-108 after preheating.

2.5. Purification of Hydrogen by Pressure Swing Adsorption (PSA)

The resulting process gases, coming from the separators of both the trains, are sent together to the common PSA Unit.

The hydrogen is recovered from the process gas by adsorption of the methane, carbon monoxide, carbon dioxide, nitrogen and water vapor on suitable adsorbents.

The PSA Unit uses a pressure swing adsorption process, in which the impurities from the process gas are adsorbed at the high feed gas pressure, and are then desorbed at a low pressure in a repeated cycle having two basic steps (adsorption and regeneration).

The unit comprises of a number of adsorbers and the hydrogen remaining in an adsorber at the end of the adsorption step is used for re-pressurisation and purging of the other adsorbers in line.

Regeneration of the adsorbent is carried out in the following steps:

- Depressurization by equalisation on with adsorbers which are in the repressurisation steps.
- Providing the purge for another adsorber.
- Depressurisation to low level pressure of about 0.35 barg. During this step a part of the impurities are removed from the adsorbent.
- Purging at low pressure with hydrogen, whereby the remaining impurities are removed.
- Re-pressurisation by equalisation with adsorbers, which are in the depressurization steps.
- Re-pressurisation to adsorption pressure with product hydrogen.

Each adsorber is cycled through the same adsorption/regeneration sequence. The waste gases, which are being released during the regeneration, are sent to the Steam Reformer Furnace.

2.6. Heat Recovery and Steam System

The steam production on the hydrogen generation unit exceeds the Reformer requirement and there is a net production of steam, which is exported to plant battery limit.

Steam generation is performed in the Process Gas Boiler (E-101) and in the Steam Generation Coils (E-130 A/B), with a natural BFW circulation system. In the Steam Drum (V-103) steam produced is separated by the boiler feed water circulating.

The saturated steam from the steam drum is splitted in four different streams:

- Part of the steam is sent to the degasifier as stripping steam of the feed water;
- A part is superheated in the Process Steam Superheater (E-103) and then used as process steam and mixed with the desulphurized feed and prereformed stream;
- Part is used to vaporize liquid feed
- The excess steam is also superheated in the Steam Superheat Coil (E-133) and sent to battery limit under steam drum pressure control.

The evaporation of the water in the system will result in a concentration of the non-volatile impurities contained in the boiler feed water. A too high concentration of impurities has to be avoided for these reasons:

- Impurities may be carried over with the steam from the steam drum and deposited on the reformer catalyst;
- Impurities may deposit on heat transfer surfaces reducing the heat transfer and thus increasing the metal temperature of the tubes.

The concentration of impurities is kept to an acceptable level by bleeding off continuously part of the water (blow down), then flashed in the Continuous Blow Down Drum (V-111). Flashed steam is sent to the Degasifier V-108, while the remaining water is cooled down in the Blow Down Cooler (E-108) and sent to the battery limits.

Process condensate from the two separators is mixed with fresh demi water imported from battery limits. The resulting stream is preheated in the Degasifier Feed Preheater (E-105) before feeding it to the Degasifier (V-108).

In the degasifier, the demineralized water is kept free by O_2 and other dissolved gases by stripping with steam in the top section of the equipment.

The boiler feed water stream from deaerator is preheated in the Boiler Feed Water Preheater (E-104), using as heating medium the shift effluent and sent to the steam drum;.

Conditioning chemicals are added into degasifier and steam drum by Chemical Dosing Unit A-102.

2.7. Fuel System

For the heat to be released by combustion in the reformer furnace, two fuel gases are used:

- purge gas from PSA unit;
- fuel gas from the Battery Limit.

All the purge gas is fired in the reformer furnace as priority fuel and the remaining heat is supplied by firing of make-up fuel gas.

A combustion control system controls the fuel and combustion air rate using as input:

- temperature of flue gas, leaving the radiant section;
- purge gas flow rate;

Combustion air is supplied by Combustion Air Fans B-101A/B, preheated in the Air Preheater E-140 by means of the flue gases and sent to the burners. Flue gases are drawn from

the furnace by the Flue Gas Fans B-102A/B and discharged to the atmosphere through the stack.

2.8. Start-up nitrogen circulation

In order to warm the plant during start-up, the Natural Gas Compressor K-101A/B circulates nitrogen round the process train.

One of the Compressors is installed in order to be used as start-up compressor, while the second Compressor will be installed when the unit is switched to natural gas operation.

Make-up nitrogen is imported from B.L. and added to the compressor suction, as required.

The nitrogen is taken from just upstream of the PSA unit A-101 and is circulated by Natural Gas Compressor K-101A/B.

The heat from the reformer firing warms the circulating nitrogen, which in turn warms up the process steam. The flue gases warm-up the export steam.

While the steam generated in the Unit is at low a pressure to be useful it is blown off via the silencer SL-101.

EUROPAIRS

KTI PROJECT No 80670

END-USER REQUIREMENTS FOR INDUSTRIAL PROCESSE HEAT APPLICATIONS WITH INNOVATIVE NUCLEAR REACTORS FOR SUSTAINABLE ENERGY SUPPLY

TASK 1.1: End user processes, characteristics and requirements

HYDROGEN PRODUCTION BY MEMBRANE STEAM REFORMING OF HYDROCARBONS

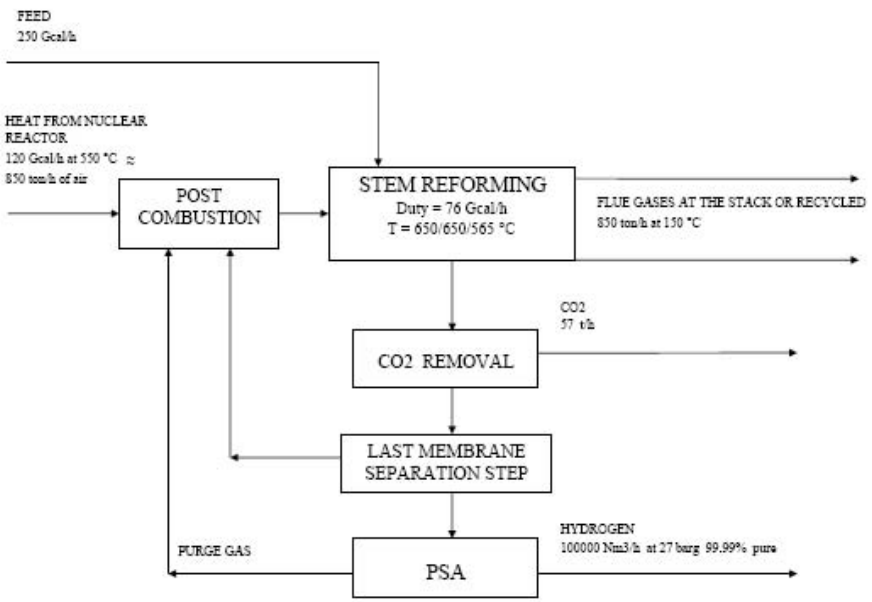
Roma, November 2009

Characterization of the existing heat generators

Objectives of the sheet

The integration of reforming and membrane modules technology within a nuclear power station could make the production of hydrogen less expensive than in the case of the conventional steam reforming and reduces the overall CO_2 production. The new architecture proposed consist of a heat exchanger where air is heated up fluids as helium, apos combustion chamber, a reforming-membrane system based on three reaction/separation steps, a retentate recirculator, a hydrogen cooler and compressor, and a final PSA.

MEMBRANE STEAM REFORMING



STEAM BOILERS SPECIFICATION

Boiler No	Fuel	Steam outlet, nominal conditions		Steam boiler output, t/h		Boiler operating thermal power
		Temperature (°C)	Pressure (MPag)	Nominal	Operating	
Total						

STEAM TURBINE SPECIFICATION

Turbine No	Type		Steam inlet nominal data		Turbine nominal power Mwe
			Temperature (°C)	Pressure (MPag)	
Total					

TASK 1.1: End user processes, characteristics and requirements

HYDROGEN PRODUCTION BY MEMBRANE STEAM REFORMING OF HYDROCARBONS

PROCESS DESCRIPTION

Europairs

KTI Project No 80670

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1. INTRODUCTION

The core of the process is a Reforming and Membrane Modules (RMM) where heat of reaction is supplied from nuclear reactor via an indirect exchanger.

In order to minimize the reformer heat duty and to simplify design and metallurgy of the reforming tubes, the reaction temperature has been set to 600-650 °C whereas separation modules are placed downstream the reforming sections, in order to better manage the temperature technological threshold of the Pd-based membranes (500 °C about).

2. COMPARISON BETWEEN REFORMING AND MEMBRANE MODULES (RMM) AND MEMBRANE REACTOR (MR)

The technology proposed has not to be confused with membrane reactor (MR).

In MR the selective membrane is assembled directly inside the reaction environment, so that the hydrogen produced by the reactions is immediately removed. A draft of the membrane reactor (MR) is shown in Figure 1: the steam reformer is composed by two concentric tubes, the catalyst pellets are packed in the annular zone (reaction zone), while the membrane is the internal tube itself (permeation zone). The heat flux is supplied from the external and a sweeping gas is sent in the inner section to carry out the hydrogen permeated: the sweeping gas could be water vapour to make easier the recovery of hydrogen at the reactor outlet (by a simple condensation process).

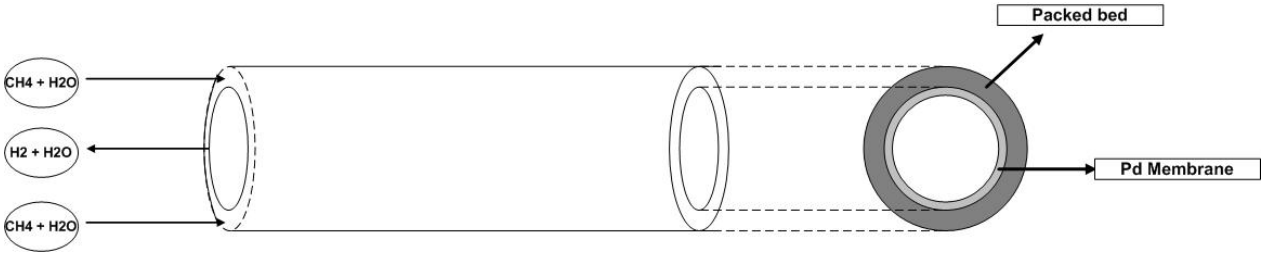


Figure 1- Steam reforming membrane reactor draft

In RMM the hydrogen selective membrane is assembled in separation modules applied downstream to reaction units. This configuration is composed by a series of reaction-separation modules: the reformer feed is sent to a convective steam reformer where it is partially converted into hydrogen; then hydrogen is recovered through a Pd alloy membrane separation module, while the retentate is sent to the next step or recycled to the first module. The operating temperature can be reduced thanks to the high temperature (450°C about) hydrogen separation between reaction steps, and it is possible to replicate the RMM until the desired natural gas conversion is achieved. Figure 2 reports a conceptual layout of the process scheme.

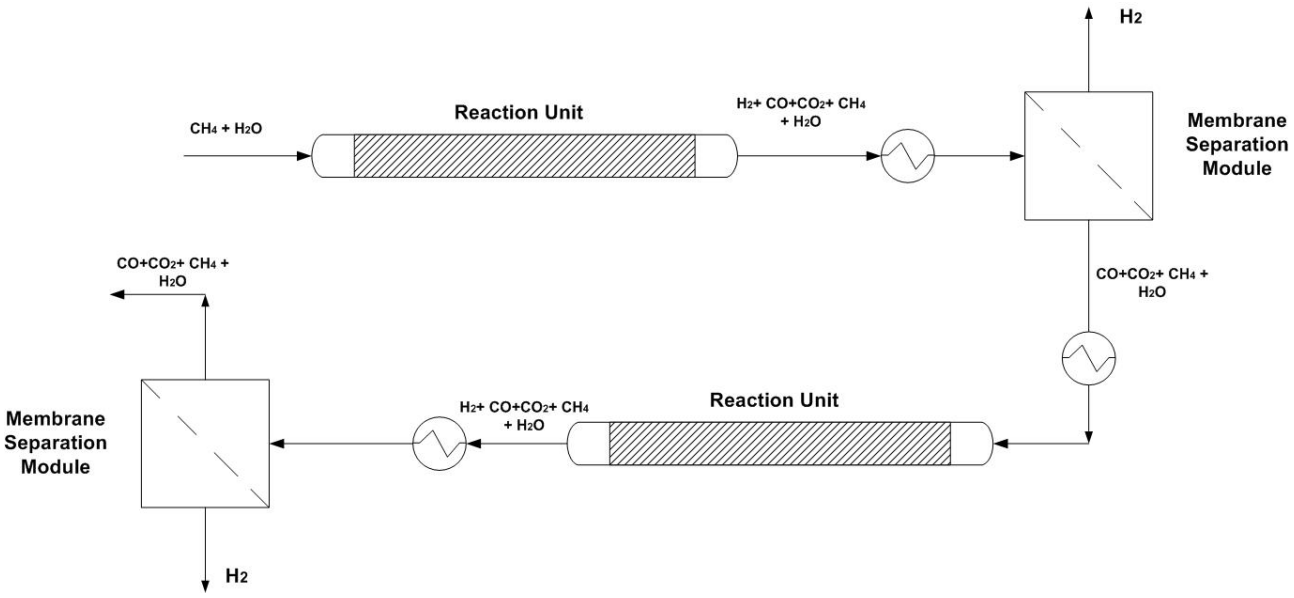


Figure 2- Two Reformer and Membrane Modules process scheme

The first configuration isn't yet devises suitable for commercial applications. As a matter of fact, the membrane reactor has to work at 500°C at least to assure remarkable methane conversion enhancement in respect to the traditional steam reformers imposing industrial operating conditions. But it is well known that at this temperature the membrane suffers for differential thermal expansion between selective layer and support, which could lead to the lack of adherence and to a strong reduction of membrane selectivity towards hydrogen.

Separating the membrane module from the reactor allows to control the membrane operating conditions and to monitor the behavior of the most delicate component in the system in a safer way. This is crucial in an industrial application.

So the main benefits of MR are:

- Possibility to decouple reaction and separation operating conditions: the reforming and separation module temperatures can be optimized independently, both increasing methane conversion for each reaction step and membrane stability and lifetime.

- Simplification of the mechanical design of membrane tubes relative to those embedded in catalyst tubes; a simple “shell and tube” geometry can be selected for the tubular separation module.

- Simplification of membrane modules maintenance and of catalyst replacement.

3. MEMBRANE INTEGRATION BENEFITS

The application of hydrogen selective membranes in steam reforming process leads to the following main benefits:

Strong reduction of the reaction temperature. Avoiding the equilibrium condition to be achieved allows the promotion of the reactions at lower temperatures (500-650°C); due to the lower thermal level involved, a heat exchanger with a heating fluid could be used in the place of the furnace, with the following advantages:

efficiency of the heat transfer from the external source to the reactor;

lower exergy of the heating fluid in comparison with the high temperature combustion gas used in the furnace, which means a lower heating cost;

the possibility to use different heating fluids, depending on their availability;

simple integrability of the reformer in industrial plants, wherever a hot fluid is available or thermal recovery is sought; a high value added fuel as hydrogen is produced (plug-in and retrofit concepts);

the easy scalability (scale-up or scale-down) of the system and therefore its applicability in many fields (small-medium-large scale);

use of cheaper alloy steel, since the tubular reactor is less stressed.

Process efficiency increase. The lower temperature results in an increase of overall process efficiency, since the heat supplied is better exploited. It's foreseen that the global process efficiency should increase from the 65-80% of today's technology up to 85% and more for all the plant sizes.

Large methane saving. Reduction of reaction temperature means that the heat duty requirement is lower than for the traditional process. The heat flux from the external source to the catalytic bed should be about 30-40 kW/m^2 instead of 80 kW/m^2 and more of the traditional process. Therefore, a smaller amount of methane has to be burned. The lower thermal level could allow the coupling of the reformer with a different and clean energy source, nullifying the fraction of natural gas to be burned for process heat requirements.

Reduction of CO_2 emissions. The methane saving leads to a reduction of the greenhouse gas emissions, since less or no carbon dioxide is produced by the methane combustion. In a traditional process, the ratio (CO_2 released)/(H_2 produced) is 8 - 12 kg_{CO2}/kg_{H2}, depending on the process efficiency. An increase of the efficiency could lead to a reduction of GHG emissions within the range 20-55%, up to 5.5 kg_{CO2}/kg_{H2} if a renewable energy source is used for process heat duty.

Easier CO_2 purification. Membrane integration into the reaction environment ensures a first substantial hydrogen separation step (up to 90% of the hydrogen produced can be removed);

as for CO_2 separation, because of the higher carbon dioxide partial pressure in the reformer outlet stream, due to the hydrogen removal, physical separation methods could be used to separate CO_2 rather than the chemical adsorption in mono-di-ethanol ammine (MDEA), which is a very expensive separation process.

Reduced dependence on natural gas cost. Increasing the reaction efficiency and reducing the amounts of methane to be burned to supply the process heat duty requirements lead to a reduction of the total amount of methane required for producing a mass unit of hydrogen. Therefore, although a higher plant cost has to be supported because of the increasing reactor complexity, the hydrogen price would be less dependent on the natural gas. Obviously, the total hydrogen cost will be influenced on the Pd-based membranes, which are nowadays expensive. However, a large industrial production of this component surely will reduce the price, making the membrane steam reforming process more competitive.

4. PLANT DESCRIPTION

Basic plant configuration is shown in Figure 3.

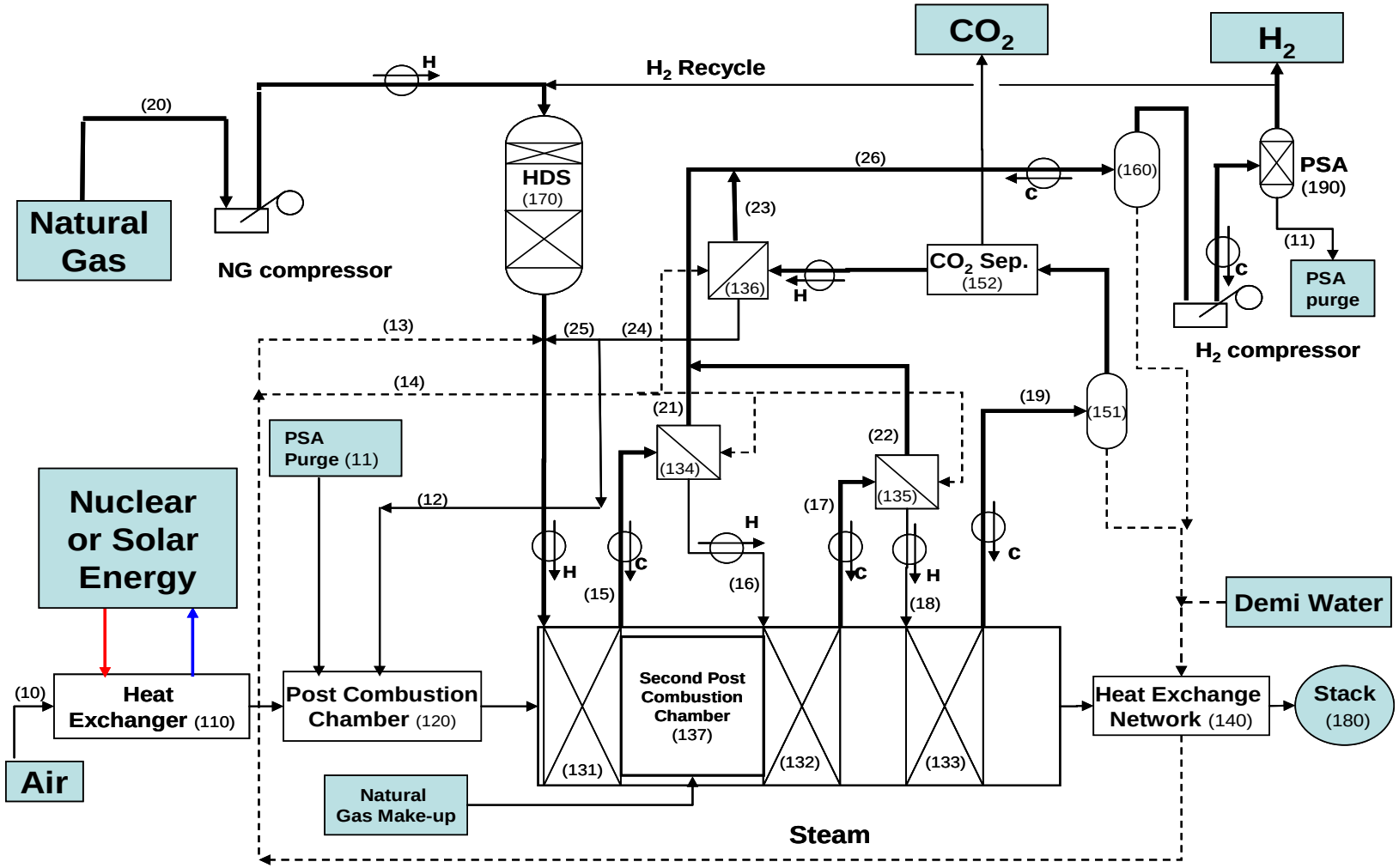


Figure 3 - Process scheme with CO_2 removal

Natural gas is compressed, heated and mixed with hydrogen recycle before entering the HDS reactor, where sulphur compounds are hydro-desulfurized to form H_2S which is removed by adsorption with ZnO.

The desulfurized feed is mixed with recycle process stream and then with steam in order to achieve a ratio ranging from 2.5 to 4 mol H_2O / mol C. The steam to carbon ratio (S/C) used to reform the hydrocarbon feed depends on the type and quantity of the hydrocarbons present in the natural feed. The feed gas enters the first reforming step at a temperature around 580°C and exits at 650 °C. The reformed gas, before entering the first separation module, is cooled down to 450°C. Such a temperature allows a proper operation of Pd-based composite membranes. Pd-alloy membranes are characterized by a very high selectivity towards hydrogen; therefore it can be assumed that the permeate side stream is composed by H_2 and the sweeping gas (water steam), used to remove the hydrogen permeated; such a mixture is cooled and water steam is condensed and separated. The retentate from the membrane unit moves to the second reforming step.

In the second and third reforming steps residual methane is reformed up to 90%. Before entering the third separation module, CO_2 is removed from such reformed streams. This operation allows a higher hydrogen flux $\boldsymbol{J_{H_2}}$ to be obtained, due to the increased hydrogen partial pressure in the retentate side, as shown by Sieverts law:

$$\boldsymbol{J_{H_2}} = \frac{\boldsymbol{B_H}}{\boldsymbol{\delta}} \cdot \left(\boldsymbol{p}_{\boldsymbol{H_2,r}}^{0.5} - \boldsymbol{p}_{\boldsymbol{H_2,p}}^{0.5} \right) \qquad (1)$$

In eq.(1), $\boldsymbol{B_H}$ is the hydrogen permeability, $\boldsymbol{\delta}$ is the membrane thickness, $\boldsymbol{p_{H_2,r}}$ and $\boldsymbol{p_{H_2,p}}$ are the hydrogen partial pressures in the retentate and in the permeate side, respectively.

A part of the retentate is recycled to the feed entering the first reforming step.

The hydrogen permeated is separated from water steam by condensation and routed to a compression section and to a PSA unit where the final purification is carried out. A portion of the H_2 produced is recycled to the feed where it is needed to keep in the reduced (active) state the catalyst in the early part of the reformer.

Reforming reactors are heated by hot air which is preheated up to 550°C in a heat exchanger. Nuclear, as energy sources, to heat a thermal fluid to be used in the heat exchanger. The temperature of the preheated air is further increased in a post-combustion chamber where all the purge gas from the PSA unit together with some of natural gas and the not recycled retentate are burned to achieve a proper temperature.

5. CONVECTIVE STEAM REFORMING

The reforming reactors consist of several tubes filled with catalyst. Such bundles of catalyst tubes are installed in a sort of convective section as shown in Figure 4.

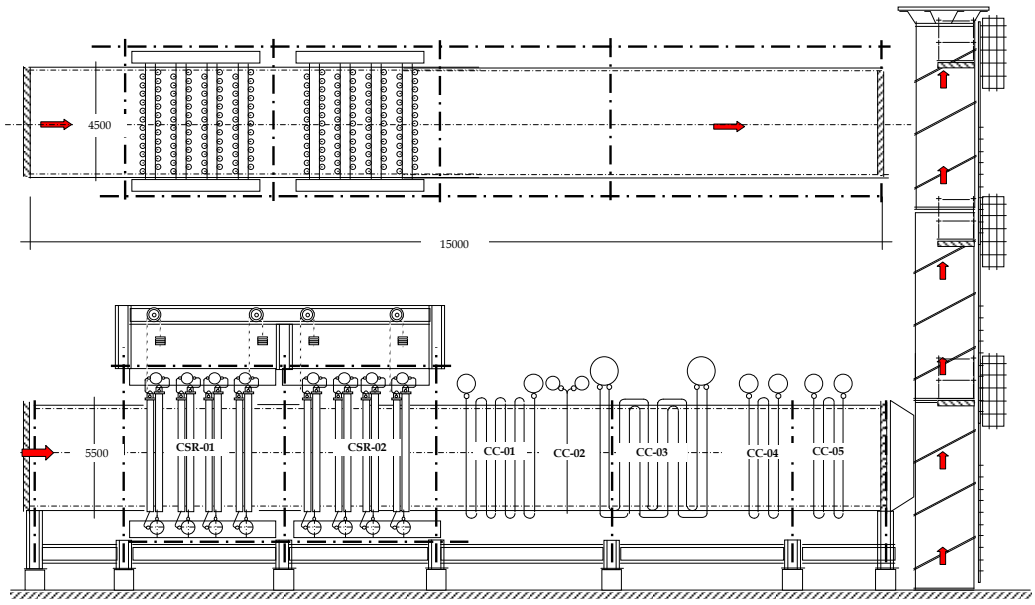


Figure 4 - Convective Steam Reformer

The remaining part of this convective section is used to recover heat from the hot air to preheat the process stream, to generate and superheat process steam and preheat the boiler feed water (BFW). Before discharging such exhaust air to the stack, heat could also be recovered to produce industrial water from sea or brackish water by an evaporative desalination unit.

6. REFORMING AND MEMBRANE MODULE

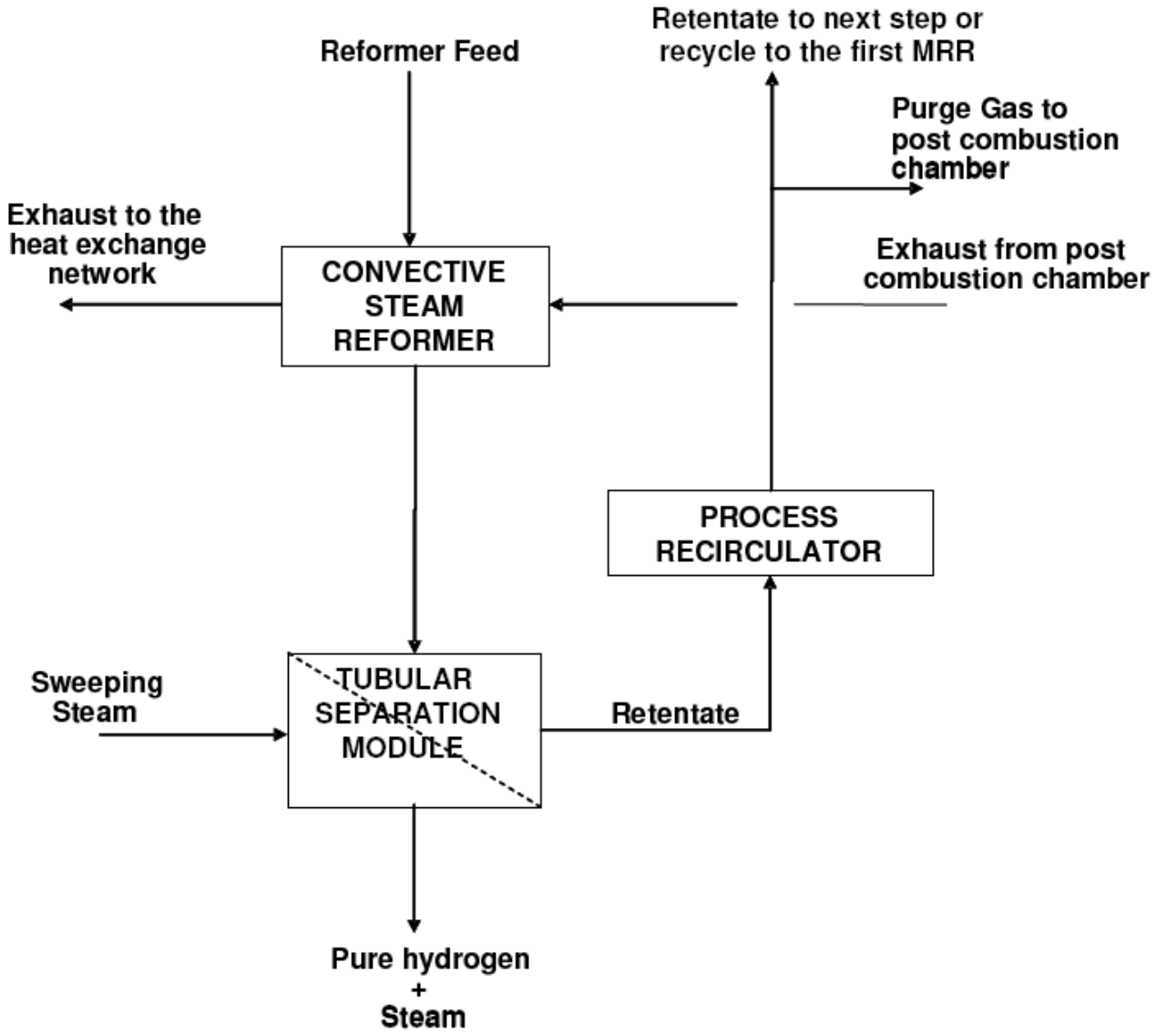


Figure 5 - Single Reforming and membrane module

A typical unit consists of a reforming reactor followed by a separation module (Figure 5).

The retentate of the membrane module can proceed to the next step or can be recycled back to the first unit. Number of stages and recycle ratio are given by the required feed conversion. The recycle ratio is defined as the ratio between the flow rates of the recycled stream and of the retentate stream leaving the membrane module.

The membrane separation module, consisting of a tubular or planar membrane made by Pd/Ag supported on porous stainless steel, was simulated assuming a counter-current mode operation with a permeation process that follows the Sievert's law.

EUROPAIRS

KTI PROJECT No 80670

END-USER REQUIREMENTS FOR INDUSTRIAL PROCESSE HEAT APPLICATIONS WITH INNOVATIVE NUCLEAR REACTORS FOR SUSTAINABLE ENERGY SUPPLY

TASK 1.1: End user processes, characteristics and requirements

REFINERY FIRED HEATERS
(DUTIES AND OPERATING CONDITIONS)

Roma, December 2009

Characterization of the existing heat generators (1/2)

Objectives of the sheet

Fired heaters are found in almost every process in a petrolium refinery and represent the predominant type of equipment for heating of process stream. Fired heaters can change from the quite small, a reboiler for instance, to the very large as the topping or platformer which could arrive to 100-150 Gcal/h of absorber heat (duty). In figure 1 a schematic rapresentation of a refinery is shown (the fired heaters are represented with the letter H). A list of fired heaters and related duties for a 10 MMton/year refinery is listed on figure 2 together with inlet/outlet temperature for each service and predominant fuel. The overall firing may exceed 600 Gcal/h, without considering boilers and steam reformer.

FIGURE 1

SCHEMATIC RAPRESENTATION OF A REFINERY

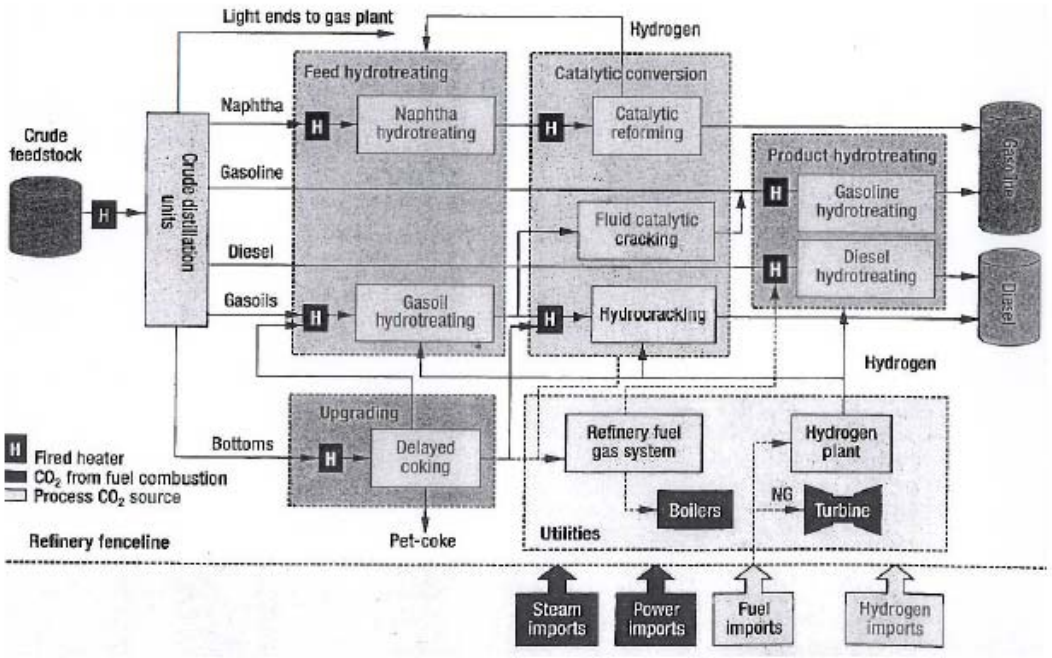
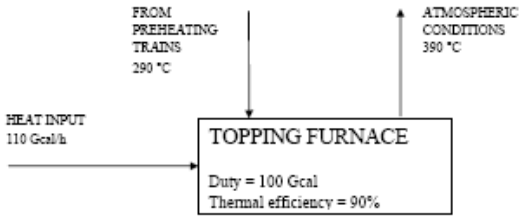


FIGURE 2

TYPICAL REFINERY FIRED HEATER



FIRED HEATER SPECIFICATION

Type	Fuel	In-Out Temperature (°C)	Design Duty (Gcal/h)	Operating Duty (Gcal/h)
TOPPING	gas	290/390	100,00	85,00
VACUUM	gas	350/410	40,00	35,00
PLATFORMER (1)	gas	420/540	200,00	170,00
REACTOR FEED HEATERS	gas	430/470	30,00	25,00
STRIPPER REBOILER	gas	250/270	15,00	13,00
FRACTIONATOR FEED HEATER	gas	320/400	45,00	40,00
REFORMATE REBOILER	gas	150/170	30,00	25,00
OTHER HEATERS	gas	240/280	50,00	40,00
MILD/HYDROCRACKING	gas	300/350	100,00	90,00

(1) several furnaces

PROCESS DESCRIPTION

EUROPAIRS

KTI PROJECT No 80670

END-USER REQUIREMENTS FOR INDUSTRIAL PROCESSE HEAT APPLICATIONS WITH INNOVATIVE NUCLEAR REACTORS FOR SUSTAINABLE ENERGY SUPPLY

TASK 1.1: End user processes, characteristics and requirements

REFINERY FIRED HEATERS (DESIGN AND OPERATIONS)

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REV.	**DATE**	**STATUS**	**WRITTEN BY**	**CHECKED BY**	**APPROVED/AUTHORIZED BY**
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1. INTRODUCTION

Of the energy consumed in a typical chemical processing or petroleum refining plants approximately 75% is burned is the form of hydrocarbons fuel in fired heaters and steam boilers.

In a modern refinery with a capacity of 10 million ton per year the overall amount of heat fired may reach 600-800 Gcal/h depending on of the refinery architecture, manly through refinery gas.

The presence of larger and larger hydrogen steam reformer is adding extra firing

With few exceptions, as steam superheater for styrene process, steam reforming and some pyrolysis heaters, in most of application the outlet temperature of the fluids to be heated fall in the range of 200-450 °C, with the exception of the platforming where such a temperature is reaching 550°C.

It is quite clear that thinking to replace such direct fining with a indirect heating by steam or a different medium, represent an important use of nuclear generated heat which however by is requiring to solve two major issues:

- the redesign of fired heaters into a sort of convective exchangers

- the change the refinery architecture in order to transform the excess refinery gas into products. Feeding the steam reformer partially solve such a problem.

Last but not least is it important to stress that with a partial or total direct firing replacement, the “new refinery” is going to have zero emissions.

Under such a circumstance it is useful explore such a possibility and to give some details on the fired heater design and its operation.

2. WHAT IS A FIRED HEATER?

A fired heater, for our purposes, will include a number of devices in which heat liberated by the combustion of fuel within an internally insulated enclosure is transferred to fluid contained in tubular coils. Typically, the tubular heating elements are installed along the walls

and roof of the combustion chamber, where heat transfer occurs primarily by radiation, and if economically justifiable, in a separate tube bank, whereat transfer is accomplished mainly by convection.

Industry identifies these heaters with such names as process heater, furnace, process furnace and direct-fired heater, all of which are interchangeable.

The fundamental function of a fired heater is to supply a specified quantity of heat at elevated temperature levels to the fluid being heated. It must be able to do so without localized overheating of the fluid or of the structural components.

Fired-heater size is defined in terms of its design heat-absorption capability, or duty. Duties range from about a 1 million Gcal/h for small specialty units to about 100 Gcal/h for superproject facilities such as the mammoth steam hydrocarbon-reformer heaters. By and large, the vast majority of fired-heater installations fall within the 5 to 100 Gcal/h range.

Process industry requirements for fired heater are divided, in the main, into a half-dozen general service categories. These categories can be designated and described as follows:

Column reboilers. This is normally considered one of the mildest and least critical of fired-heater applications. The charge stock taken from a distillation column is a recirculating liquid that is partially vaporized in the fired heater. The mixed vapor-liquid stream reenters the column, where the vapor condenses and releases the heat of vaporization. Reboiler applications are characterized by relatively small differentials between the inlet and outlet fluid temperatures across the fired heater, and by substantial vaporization (typically, 50% or more of the charge stock is vaporized). Depending on the particular application, reboiler heater outlet temperatures generally fall in the range of 200-270°C.

Fractionating-column feed preheaters. Fired heaters in this service tend to be the workhorses of many process operations. The charge stock (usually all liquid, although some feeds may contain a nominal amount of a vapor at the inlet) is sent

to the fired heater following upstream preheating in unfired equipment. In the fired heater, the fluid temperature is usually raised high enough to achieve partial vaporization of the charge stock.

A typical example of this service is the feed heater for an atmospheric distillation column in the crude-oil unit of a petroleum refinery. Here, crude oil entering the fired heater as a 250°C liquid might exit near 380°C with about 60% of the charge stock vaporized.

Reactor-feed preheaters. Fired heaters in this application raise the charge-stock temperature to a level necessary for controlling a chemical reaction taking place in an adjoining reactor vessel. The nature of the charge stock and the heater operating temperatures and pressures can vary considerably, depending on the process. The following examples illustrate the diversity of the applications performed by reactor-feed preheaters:

Single-phase/single-component heating such as steam superheating in the reaction sections of styrene manufacturing processes. In the service, the fluid temperature across the fired heater increases from an inlet temperature of about 380°C to an exit temperature of approximately 750°C.

Single-phase/multicomponent heating, such as the heating of mixtures of vaporized hydrocarbons and recycle hydrogen gas prior to catalytic reforming in a refinery. In this service, the charge stock enters the fired heater at about 400°C and exits at approximately 550°C.

In reformers, the fluid pressure may range from about 10 to 40 bar g. Severe restrictions on fluid pressure drop are normally associated with this service.

Mixed-phase multicomponent heating, such as the heating of mixtures of liquid hydrocarbons and recycle hydrogen gas for reaction in a refinery hydrocracker. Fluid temperature typically run from 400 °C at the inlet to 500°C at the outlet. Operating pressures may reach 100-150 bar g, depending on the process.

Heat supplied to heat-transfer media. Many plants furnish heat to individual users via an intermediate heat-transfer medium. A fired heater is generally employed to elevate the temperature of the recirculating medium, which is typically a heating oil, Dowtherm, Therminol, molten salt, etc. Fluids flowing through the fired heater in these systems almost always remain in the liquid phase from inlet to outlet.

Heat supplied to viscous fluids. Oftentimes heavy oil must be pumped from one location to another for processing. At low temperatures, where the oil may have so high a viscosity as to render pumping infeasible, a fired heater is employed to warm the oil to a temperature that will facilitate pumping.

Fired Reactors. In this category are heaters in which a chemical reaction occurs within the tube coil. As a class, these units represent the fired-heater industry's most sophisticated technology. The following two applications typify the majority of installations:

Steam hydrocarbon-reformer heaters, in which the tubes of the combustion chamber function individually as vertical reaction vessels filled with nickel-bearing catalyst. In reformers that yield hydrogen, fluid outlet temperatures range from 850-880°C.

Pyrolysis heaters, used to produce olefins from gaseous feedstocks such as ethane and propane and from liquid feedstocks such as naphtha and gasoil. In cracking heaters, where chemical reactions occur in the coil, the tubes and burners are arranged so as to assure pinpoint firing control. Fluid outlet temperatures in heaters designed for liquid feedstocks are in the 850-900°C.

3. MANY VARIATIONS IN DESIGN AND LAYOUT

There are many variations in the layout, design, and detailed construction of fired heaters. A consequence of this flexibility is that virtually every fired heater is custom-engineered for its particular application.

The simplest type of fired heater follows the so-called “all radiant” design, wherein the entire tube coil is arranged along the walls of the combustion chamber or radiant section. This design is characterized by low thermal efficiency and normally represents the lowest capital investment for a specified duty. The terminology “all radiant” is somewhat of a misnomer. Convection currents do exist, due to the flow of flue gases through the combustion chamber, and these currents account for a portion of the total heat absorbed in the radiant section.

In addition to the radiant section, all modern fired heaters include a separate convection section. The residual heat of the flue gases leaving the radiant section is recovered in this section, primarily by convection. Using this heat for preheating the charge stock, or for other supplementary heating services, increases the thermal efficiency of the fired heater.

The first few rows of tubes in the convection section are subject to radiant heat transfer, in addition to convective transfer from the hot flue gases as they flow across the tubes. because these tube rows are usually being subjected to the highest heat-transfer rates in the fired heater, they are aptly termed “ shield” or “shock” tubes.

4. HORIZONTAL VS. VERTICAL

The principal classification of fired heaters, however, relates to the orientation of the heating coil in the radiant section; i.e., whether the tubes are vertical or horizontal. Horizontal arrangements in Fig. 1, salient features of each configuration are noted here:

Vertical-cylindrical, all radiant. Here the tube coil is placed vertically along the walls of the combustion chamber. Firing is also vertical, from the floor of the heater.

Heaters of this type represent a low cost, low-efficiency design, which requires a minimum of plot area. Typical duties are 0.5 ÷ 3 Gcal/h.

Vertical-cylindrical, helical coil. In these units, the coil is arranged helically along the walls of the combustion chamber, and firing is vertical from the floor. Although these heaters are grouped with the others having vertical tube designs, their in –tube characteristics resemble those of horizontal-tube fired heaters.

This design also represents low cost, low efficiency, and requires a minimum of plot area. The tube coil is inherently drainable. One limitation on these units is that generally only one flow path is followed by the process fluid. Heating duties run from 1 to 5 Gcal/h.

Vertical-cylindrical with crossflow convection. These heaters, also fired vertically from the floor, features both radiant and convection sections. The radiant-section tube coil is disposed in a vertical arrangement along the walls of the combustion chamber. The convection section tube coil is arranged as a horizontal bank of tubes positioned above the combustion chamber.

This configuration provides an economical, high-efficiency design that requires a minimum of plot area. The majority of new, vertical-tube fired-heater installations fall into this category. Typical duty range is 1 to 50 Gcal/h.

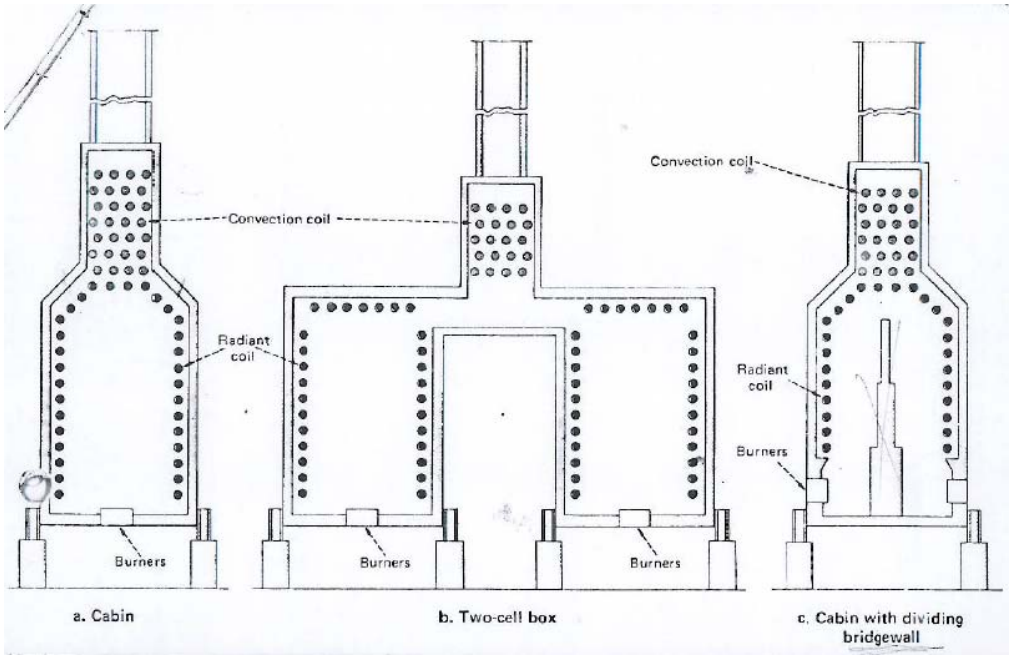


Fig. 1 Six basic designs used in horizontal-tube fired heaters. Radiant-section coil is horizontal

Vertical-cylindrical with integral convection. Although this design is rarely chosen for new installations, the vast number of existing units of this type warrants its mention in any review of fired heaters.

As with the previous types, this design is likewise vertically fired from the floor, with its tube coil installed in a vertical arrangement along the walls. The distinguishing feature of this type is the use of added surface area on the upper reaches of each tube to promote convection heating. This surface area extends into the annular space formed between the convection coil and a central baffle sleeve. Medium efficiency can be achieved with a minimum of plot area. Typical duty for this design is 1-30 Gcal/h.

Horizontal tube cabin. The radiant-section tube coils of these heaters are arranged horizontally so as to line the sidewalls of the combustion chamber and the sloping roof or “hip”. The convection-section tube coil is positioned as a horizontal bank of tubes above the combustion chamber. Normally the tubes are fired vertically from the floor, but they can also be horizontally fired by sidewall-mounted burners located below the tube coil. This economical, high-efficiency design currently represents the majority of new, horizontal-tube, fired-heater installation. Duties run 5-50Gcal/h.

Two-cell horizontal tube box. Here the radiant-section tube coil is deployed in a horizontal arrangement along the sidewalls and roof of the two combustion chambers. The convection-section tube coil is arranged as a horizontal bank of tubes positioned between the combustion chambers. Vertically fired from the floor, this is again an economical, high-efficiency design. Typical duties range from 10-100 Gcal/h. For increased capacity, the basic concept can be expanded to include three or four radiant chambers.

Horizontal tube-cabin with dividing bridgewall. Again the radiant-section tube coil is arranged horizontally along the sidewalls of the combustion chamber, and along the hip. The convection-section tube coil takes the form of a horizontal bank of tubes positioned above the combustion chamber. A dividing bridgewall between the cells allows for individual firing control over each cell in the combustion chamber. Available options permit horizontal firing with sidewall-mounted burners (as shown), or vertical firing from the floor along both sides of the bridgewall. A typical duty range for this design is 5-50 Gcal/h.

Horizontal-tube, double-fired. Horizontal radiant tubes are arranged in a single row and are fired from both sides to achieve a uniform distribution of heat-transfer rates around the tube

circumference. Such heaters are normally fired vertically from the floor. They are often used for pyrolysis application.

5. HEATING-COIL ARRANGEMENT

The normal flow of process fluid through a fired heater starts at the inlet to the convection section. The stream moves through the convection section counter-current to the flow of flue gases, then into the shock bank. After leaving the shock bank, it passes into the radiant section, where the major portion of the heat is absorbed.

Adjacent tubes are connected by means of 180-deg return bends or plug-type headers. Each bank of consecutive tubes in which the fluid travels from entry until exit is known as a “pass”, or parallel stream. (This definition differs from that applied to unfired heat-transfer equipment.) In a two-pass heater, the fluid is distributed into two streams at the inlet, with each stream flowing separately through its respective tube coil and then recombining after exiting from the heater. A single-pass or “series-flow” heater with 40 tubes, for example, would be equivalent in area to a two-pass heater having two coils of 20 tubes each. The primary constrain affecting the selection of the number of passes and tube size is the allowable pressure drop. The fewer the number of passes, the less the potential for flow maldistribution.

Each heater application must be evaluated individually with regard to the number of passes and tube size. Such evaluation must examine not only the cost of the heater but also the cost of external distribution and collection manifolds, pass control valves, and other ancillaries. For normal heating applications, a tube coil consisting of 4-in.IPS (iron pipe size) tube often represents the lowest heater investment (excluding externals). As tube diameter increases or decreases from this size, the heater cost tends to become progressively more expensive.

6. THERMAL EFFICIENCY

For each fuel, profiles can be developed at constant values of excess air to express the heat extracted from the products of combustion as a function of flue-gas temperature. The percentage of the heat extracted from the flue gas will range from 0% at the flame temperature, to 100%, at the datum flue-gas temperature of 15 °C. This heat includes that heat absorbed by the charge stock plus the heat lost from the heater casing. At any flue-gas

temperature, the differential between the percent heat extracted and 100% constitutes the percent heat loss up the stack.

Assuming that the fuel and combustion air are supplied at the datum temperature of 15 °C, for a given combination of flue-gas temperature and excess air, the percent heat extracted from the flue gas is:

$$\%\,\text{Heat extracted} = \frac{(100)\,(\text{Heat available, Kcal/Kg fuel at flue gas temp.})}{(\text{Net heating value of fuel, Kcal/kg})} = \frac{H_A}{H_F}(100)$$

The heat transmitted from the heater casing to the atmosphere via radiation and convection (the so-called “radiation loss”) is generally assessed at 1½ to 2% of the heat fired for conventional installations, and at 2 to 2½% for heaters with extensive hot-duct runs and/or air preheaters.

The actual or calculated thermal efficiency of the heater is computed as the percent has extracted less the percent radiation loss. The heat fired is then determined from the relationship:

$$\text{Thermal efficiency} = \frac{\text{Heat absorbed kcal/h}}{\text{Heat fired kcal/h}}(100) = \frac{Q}{Q_F}(100)$$

The quantity of fuel consumed is obtained as follows:

$$\text{Fuel consumed, Kg/h} = \frac{\text{Heat fired, kcal/h}}{\text{Fuel heating value, kcal/kg}} = \frac{Q_F}{H_F}$$

The flue-gas mass flowrate is approximated by multi-plying the fuel consumption rate by the appropriate weight ratio of flue gas to fuel.

The foregoing relationships define the interdependence of excess air, flue-gas temperature and thermal efficiency. In the design of heaters having convection section, thermal efficiency is determined by selecting the flue-gas temperature. Specification of this temperature is normally contingent upon that of the process fluid at the inlet. A typical design basis would assume a temperature approach of about 30-50 °C between flue-gas temperature and inlet fluid temperature.

A temperature differential of this magnitude represents a reasonable balance between thermal efficiency and capital investment. However, many criteria affect the temperature approach for a particular application. These include fuel value, project payback time, minimum stack-height requirement, type and material of extended surface, auxiliaries such as soot blowers,

etc. In the case of all-radiant heaters without convection sections, the designer does not have the degree of freedom to select the design flue-gas temperature. For these heaters, the temperature is equal to the residual radiant-section gas temperature.

7. RADIANT SECTION

In order to evaluate the split in heat absorption between radiant and convection sections, it is necessary to determine the radiant efficiency – the fraction of heat liberated that is absorbed by the heat-transfer surface in the combustion chamber. For a given fuel at a given value of excess air, the radiant efficiency can be shown to be a function of the residual radiant-section gas.

The selection of the average radiant transfer rate is, essentially, the first step in the process design of a fired heater. By definition, the average radiant rate represents the heat transferred to the charge stock in the radiant section, divided by the total radiant-section heat-transfer surface, based on the tube O.D. The higher the design radiant rate, the less the amount of heat-transfer surface, the smaller the heater, and the lower the investment cost.

Unduly high radiant rates, however, result in higher maintenance cost. Because the refractories and tube supports are exposed to higher temperatures, they have shorter service lives. Furthermore, high tube-wall temperatures reduce tube life and raise the potential for coke deposition and product degradation. Actual radiant transfer rates will reflect the experience of both the user and the designer. A tabulation of typical rates for various commercial heating services is shown. in Table 1.

Distribution of the radiant heat-transfer rate around a tube is not uniform. In fact, the rate varies substantially around the tube circumference, depending upon the ratio of tube spacing to tube diameter, and upon the firing mode – i.e., whether the tubes are fired from one side or from both sides.

Service	Average radiant rate* Btu/h/ft^2 (based on O.D.)
Atmospheric crude heaters	10,000-14,000
Reduced-crude vacuum heaters	8,000-10,000
Reboilers	10,000-12,000
Circulating-oil heaters	8,000-11,000
Catalytic-reformer charge and reheat heaters	7,500-12,000
Delayed coker heaters	10,000-11,000
Visbreaker heaters—heating section	9,000-10,000
Visbreaker heaters—soaking section	6,000-7,000
Propane deasphalting heaters	8,000-9,000
Lube vacuum heaters	7,500-8,500
Hydrotreater and hydrocracker charge heaters	10,000
Catalytic-cracker feed heaters	10,000-11,000
Steam superheaters	9,000-13,000
Natural-gasoline plant heaters	10,000-12,000

* For tubes spaced at twice the nominal diameter, fired on one side and backed by refractory.

Tab. 1 Typical heat transfer rates across the radiant sections of heaters in various services

8. CONCLUSION

From we said on a previous section it is quite clear not only the importance of the firing in the energy balance of a typical refinery, but the realignment required of the existing conventional design to adapt to indirect heating mode. It is not only the fact that heat will be exchanged by convection and not only by radiation + convection, but we need to consider the coil geometry, the pressure drop limitation on the process side and the presence of two phases in most applications.

It is than important to reconcile heat transfer made with the specific process features into a truly novel design for the “unfired” heaters.

Such a task although not trivial is still possible.

EUROPAIRS - Task 1.1: End-User Processes
Inventory of data

Please fill this cover sheet for the identification of the document. The list of industries and processes in given in Sheet 6 for reference.

File	PARTNER_INDUSTRY_PROCESS_revA.xls

Partner	
Industry	
Plant / Process Unit	

Objectives of the document:
This document aims at gathering efficiently relevant data related to the end-user processes.
Each partner is asked to fill one FORM for each plant or process unit (existing & future).
This collection of data is the core of Task 1.1 and will be consolidated in order to de used as base information for Task 1.3.

A notice to correctly fill this FORM is given in a dedicated sheet.

Status of the document

Rev. A	29/09/2009	First issue by SSA of the document for comments from the partners of Task 1.1, 1.2 & 1.3

End-User Requirements fOr industrial Process heat Applications with Innovative nuclear Reactors for Sustainable energy supply

How to use this FORM?

This FORM is divided into 5 sheets:

Sheet 1	**HOME.** This is the cover sheet of the file. Before anything else, please make sure that you have filled the requested information: name of the partner and of the contact - name of the industry and of the described plant / process unit (in accordance with the list given in annex (sheet 6)).
Sheet 2	**NOTICE.** A notice is included in the FORM. It includes the description of the various sheets and a quick definition of the requested parameters.
Sheet 3	**PLANT/PROCESS DESCRIPTION.** In this sheet, the partner shall give a simplified flow scheme of the process with basic information such as the name of the process units included in the overall process (/plant) and the name and main characteristics (pressure, temperature, flowrate) of the fluids/products circulating between the units. You are free to use the proposed draft scheme or to include an existing flow scheme (as a jpeg image or as an attached pdf file). You can add any identified safety issues related to this process in this sheet.
Sheet 4	**CONSUMER DUTY.** This sheet focuses, within the process described in sheet 3, on the identification of the heating needs (independently from how heat is generated). Definition and examples of the data requested are given here below. They aim at characterizing the need in terms of physical conditions, operational philosophy, reliability, flexibility and safety.
Sheet 5	**PRODUCER SPECIFICATIONS.** In a second time, this sheet focuses on the existing systems implemented for heat generation. This information will be valuable in order to study the technical and economical impact of the use of HTR as an alternate for generation of High Temperature heat. Two sets of data are asked for: definition of the heat producer and characterization of the heat transportation media. Definition and examples of the data requested are given here below.
Sheet 6	**ANNEX.** Reminder of the list of partners and the related industries and plants / processes.

To be filled in priority

Can be filled in a second time

REFERENCES & GLOSSARY

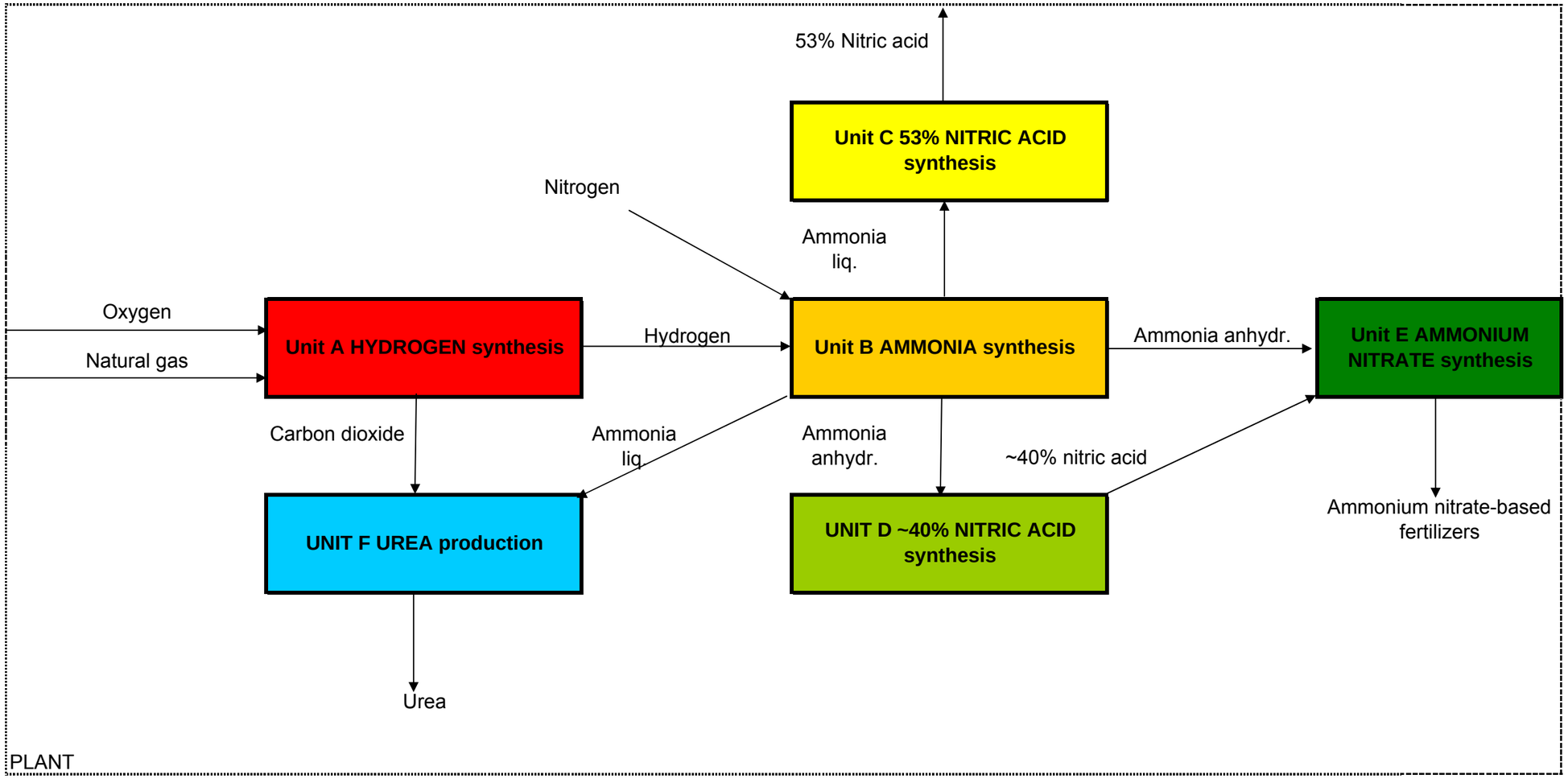
Ref.	*Parameter Name*	*Definition*	*Unit or Example*
		Process Description	
	Plant	An ensemble of process units	
	Process Unit	One elementary process unit that can be included in a plant or several plants	
(1)	Consumer Description	Name of the unit within the process (identical in sheet 3 and sheet 4)	steam reformming, hydrocracking…
		Consumer Duty - NEED	
(2)	Heating Loop N°	To number the heating loops properly allow to navigate easily in the file and to link heat production and heat consumption.	
(3)	Temperature	Temperature of the heating fluid at the inlet and the outlet **of the unit**.	K, °C, °F
(4)	Allowable Temperature Range	Min. & Max. temperatures at which the process takes place at full efficiency and without material damages.	K, °C, °F
(5)	Typical ramp up & down	Typical temperature gradient to be observed during transients (heating up & cool down).	K/min, K/s, K/h…
(6)	Continuous / Intermittent	Need for continuous heat supply (continuous process) or intermittent heat supply (batch process).	C or I (batch duration, number per year…)
(7)	Effect of heat supply disruption	What happens if case of heat supply disruption? Characterize the criticality of the heat supply.	shutdown of the process, degraded performances..
(8)	Consumption Leveling	Is there a possibility of leveling between the various heat loops in the process? Characterize the flexibility.	YES or NO
		Heat Producer Specifications - EXISTING	
(9)	Heat Generator Description	Name of the heat supply utility	
(10)	Fuel Type	Description of the fuel needed for heat generation	gas, coal, offgas (from unit X), electricity…
(11)	Fuel Consumption / External	Periodic consumption of external fuel	tpy, tph, Sm3/y…
(12)	Fuel Consumption / Offgases	Periodic consumption of internal fuel (offgases from another unit)	tpy, Sm^3/y…
(13)	Power	at least nominal power is required	MWh…
(14)	Back-up in case of shutdown	what is the planned back-up in case of the disruption og the normal heat supply?	
(15)	Media Type	Description of the media used for heat transportation between heat generation and consumption.	steam, oil, molten salt…
(16)	Temperature	Temperature of the medium at the inlet and at the outlet of the heat generation system	K, °C, °F
(17)	Pressure	Pressure of the medium at the inlet and at the outlet of the heat generation system	bar, psi…
(18)	Mass Flow	Mass flow rate of the heat transportation medium	tpy, Sm3/y…

Simplified Plant & Units flow scheme (1/2)

Objectives of the scheme

This simplified scheme aims at providing an easy understanding of the overall considered process.
You can add as many units as you think necessary.
In addition, please list at the bottom the safety concerns linked to the plant described here below.

❷ *Replace the example here below bythe flow scheme of the considered plant / process unit*



Simplified Plant & Units flow scheme (2/2)

❸ *Summarize here the name of the units*

	Consumer Description (1)
Unit A	Hydrogen synthesis
Unit B	Ammonia synthesis
Unit C	53% Nitric acid synthesis
Unit D	~40% Nitric acid synthesis
Unit E	Ammonium nitrate synthesis
Unit F	Urea production

❹ *Please detail here below the identified safety concerns related to the process.*

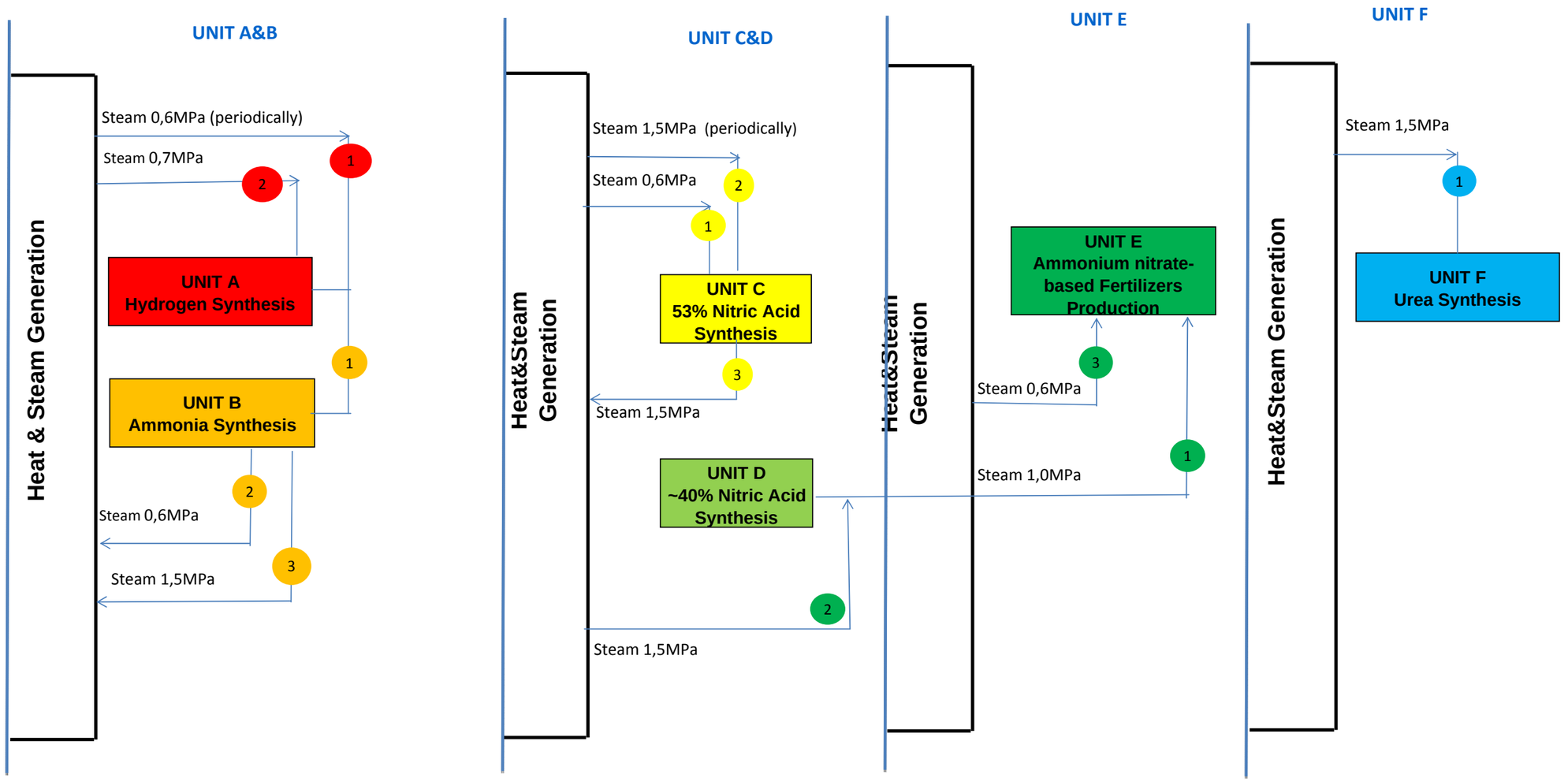
SAFETY CONCERNS.
-high pressure process, high process temperature, presence of hydrogen
-high pressure process, high process temperature, presence of hydrogen, anhydrous ammonia
-high process temperature, presence of liguid ammonia, nitric acid
-high process temperature, presence of anhydrous ammonia, nitric acid
-presence of anhydrous ammonia, nitric acid
-high pressure process, presence of liquid ammonia
-

Characterization of the heating needs (1/2)

Objectives of the sheet

This sheet gathers the information related to the needs for heat in the plant or process unit.

Replacet the example here below by the heating needs of the process units described in Sheet 3



Characterization of the heating needs (2/2)

❻ *Fill the table here in accordance with the units described in Sheet 3 and with the scheme here above.Definitions of the parameters are given in Sheet 2.*

Consumer duty

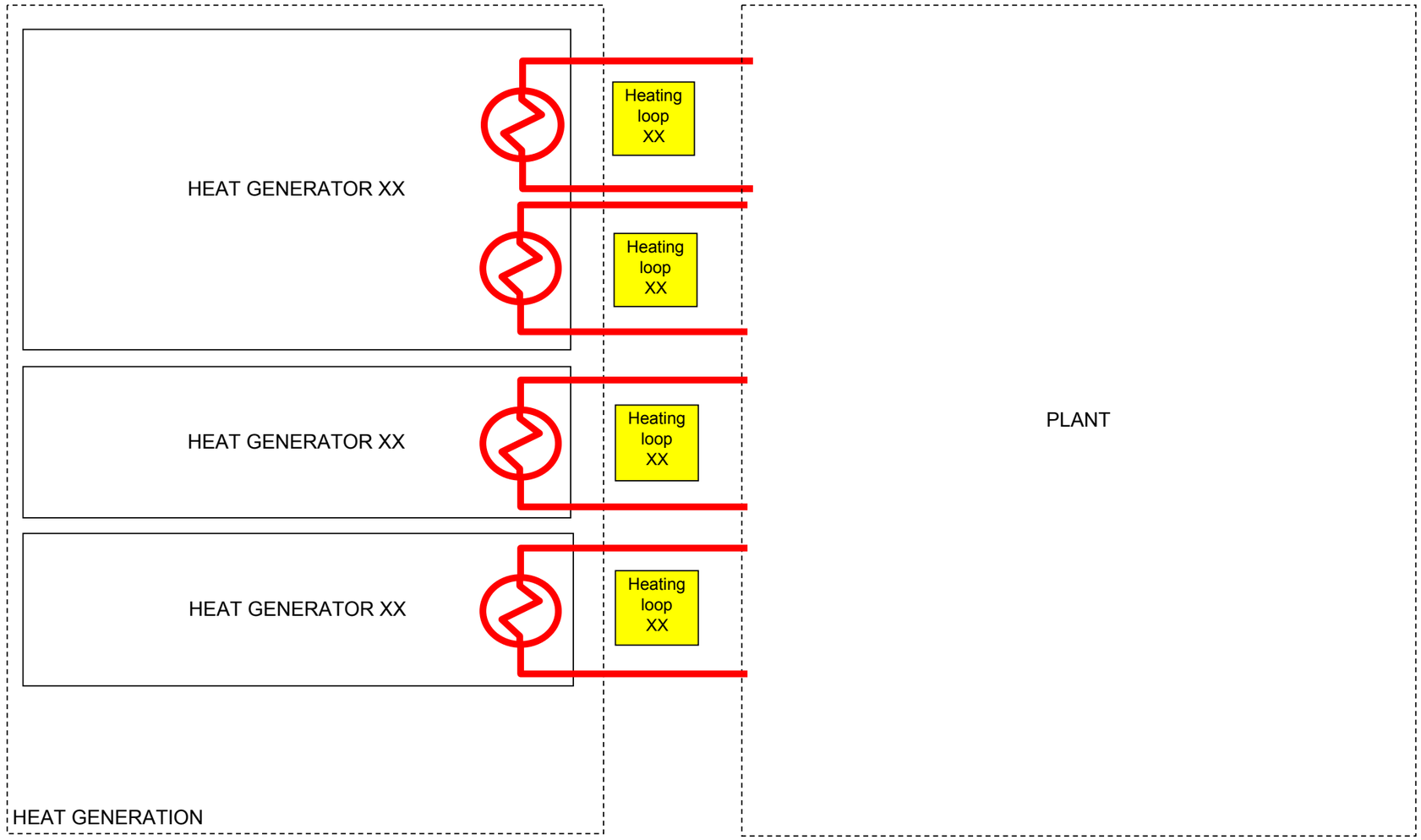
Consumer Description (1)		Steam circuit N° (2)	Temperature (3) [°C]		Allowable Temperature Range (4) [°C]		Typical ramp up and down (5) [°C]	Continuous OR Intermittent (6)	Effect of heat supply disruption (7)	Consumption leveling (8)	Comments
			inlet	outlet	T_{min}	T_{max}					
Unit A	Hydrogen synthesis	1	200	-	230	270	±10	Intermittent	Impossible start-up	NO	
Unit A	Hydrogen synthesis	2	415	-	400	480	±10	Continuous	Process disturbances	YES	(8) steam pressure reduction
Unit B	Ammonia synthesis	1	200	-	170	300	±10	Intermittent	Impossible start-up	NO	
Unit B	Ammonia synthesis	2	-	190	190	200	±10	Continuous	-	NO	
Unit C	Ammonia synthesis	3	-	260	260	300	±10	Continuous	-	NO	
Unit C	53% Nitric acid synthesis	1	200	-	190	230	±10	Continuous	Plant shutdown	NO	
Unit C	53% Nitric acid synthesis	2	290	-	270	290	±10	Intermittent	Impossible start-up	NO	
Unit C	53% Nitric acid synthesis	3	-	300	290	310	±10	Continuous	-	NO	
Unit E	Ammonium nitrate synthesis	1	180	-	170	250	±5	Continuous	Plant shutdown	NO	
Unit E	Ammonium nitrate synthesis	2	290	-	270	290	±10	Continuous	Plant shutdown	NO	
Unit E	Ammonium nitrate synthesis	3	220	-	170	230	±10	Continuous	Plant shutdown	YES	(8) steam pressure reduction
UnitF	Urea production	1	260	-	250	290	±5	Continuous	Plant shutdown	YES	(8) steam pressure reduction

Characterization of the existing heat generators (1/2)

Objectives of the sheet

This sheet gathers data on the existing heat generation systems.

❼ *Replace the example here below by the existing heat generation systems for the considered plant / process units. Heating LoopNumbers shall be in accordance with Sheet 4.*



Characterization of the existing heat generators (2/2)

❽ *Fill both table shere in accordance with the heating loops described in Sheet 4 and with the scheme here above. Definitions of the parameters are given in Sheet 2.*

HEAT GENERATORS

Heating loop N° (2)	Heat generator description (9)	Fuel type (10)	Fuel Consumption		Power (kWth) (13)			Backup in case of shutdown (14)	Comments
			External (11)	Offgases (12)	Min.	Nominal	Max.		

MEDIA TABLE

Heating loop N° (2)	Media type (15)	Temperature (16)		Pressure (17)		Mass flow (18)			Comments
		inlet	outlet	inlet	outlet	Min.	Normal	Max.	
0									
0									
0									
0									
0									
0									
0									
0									
0									
0									
0									

Industries & Processes

	Partners	Contact	Industries	Plant / Process Units
1	AMEC	Derek BUCKTHORPE derek.buckthorpe@amec.com	Oil sands	Steam Assisted Gravity Drainage
				Cyclic Steam Stimulation
			Petrochemicals	
			Ciment	Pyro processing
			Paper and Pulp	Kraft process
2	Air Liquide	Claire WEBER claire.weber@airliquide.com	Industrial Gas production	Oxygen Production - Ceramic membrane
				CO Production - dry reforming
3	Arcelor Mittal	Gerard Griffay gerard.griffay@arcelormittal.com	Steel Making	Coke Making
				SteelMaking
				Hot Rolling
				Direct Reduced Iron (DRI)
				Power Plant
				Lime plant
				Sintering
				Blast Furnace
4	Fortum	Harri Tuomisto harri.tuomisto@fortum.com	Paper and Pulp	
			Oil refinery	
			Co-generation	
			District Heating	
5	FZJ	Werner von Lensa w.von.lensa@fz-juelich.de	Coal	Coal Gasification
				Steam Methane Reforming
6	GDF Suez - Tractebel	Carmen Angulo carmen.angulo@gdfsuez.com	Co-Generation	-
7	NWU/PBMR	Gideon Greyvenstein	Petroleum Products	Fischer-Tropsch
				Steam Methane Reforming
		gideon.greyvenstein@pbmr.co.za	Oil Sands	
8	NWU	Frik van Niekerk frik.vanniekerk@nwu.ac.za	Hydrogen Production	Thermochemical water splitting
				Hybrid Sulfur
				Sulfur Iodine
				High Temperature Electrolysis
9	PROCHEM	Marek Tarka mtarka@prochem.com.pl	Refinery	Aromatics Extractive Distillation
				Crude Oil Distillates Hydrotreatment
				Crude Oil Distillation
10	SAIPEM	Jacques RUER jacques.ruer@saipem-sa.com	Energy Storage	Pumped Heat Electricity storage
11	Technip	Gaetano Iaquaniello iaquaniello.g@ktispa.it	Refinery	
			Hydrogen production	Steam Reforming
				Membranes Steam Reforming
12	USG (DSM) / BEC	Anton Baaten anton.baaten@me.com	Wide Range (Petro)chemicals incl. Urea & Ethylene	Utilities supply
13	ZAK	Marek Zuber marek.zuber@zak.com.pl	Nitrogen Fertilizers	Ammonium nitrate-based fertilizers production
				Hydrogen production
				Nitric acid synthesis
				Ammonia synthesis
				Urea production
			Organic Synthesis	Oxo processes
				Alcohol synthesis
				Phthalate plasticizers synthesis
				Phtalic and maleic anhydride

EUROPAIRS - Task 1.1: End-User Processes
Inventory of data

Please fill this cover sheet for the identification of the document. The list of industries and processes in given in Sheet 6 for reference.

File	solvay - europairs.xls

Partner	SOLVAY SA
Industry	CHEMICAL & PLASTICS
Complex / Process Unit	PROCESS 1 - SODA ASH
Overall Electrical Power	For process: around 5-15 MW electrical and 150 - 350 MW thermal (it depends of the size of the plant

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Status of the document

Rev. 0	29/09/2009	First issue by SSA of the document for comments from the partners of Task 1.1, 1.2 & 1.3
Rev. 1	21/10/2009	Issue by SSA of the finale FORM

End-User Requirements fOr industrial Process heat Applications with Innovative nuclear Reactors for Sustainable energy supply

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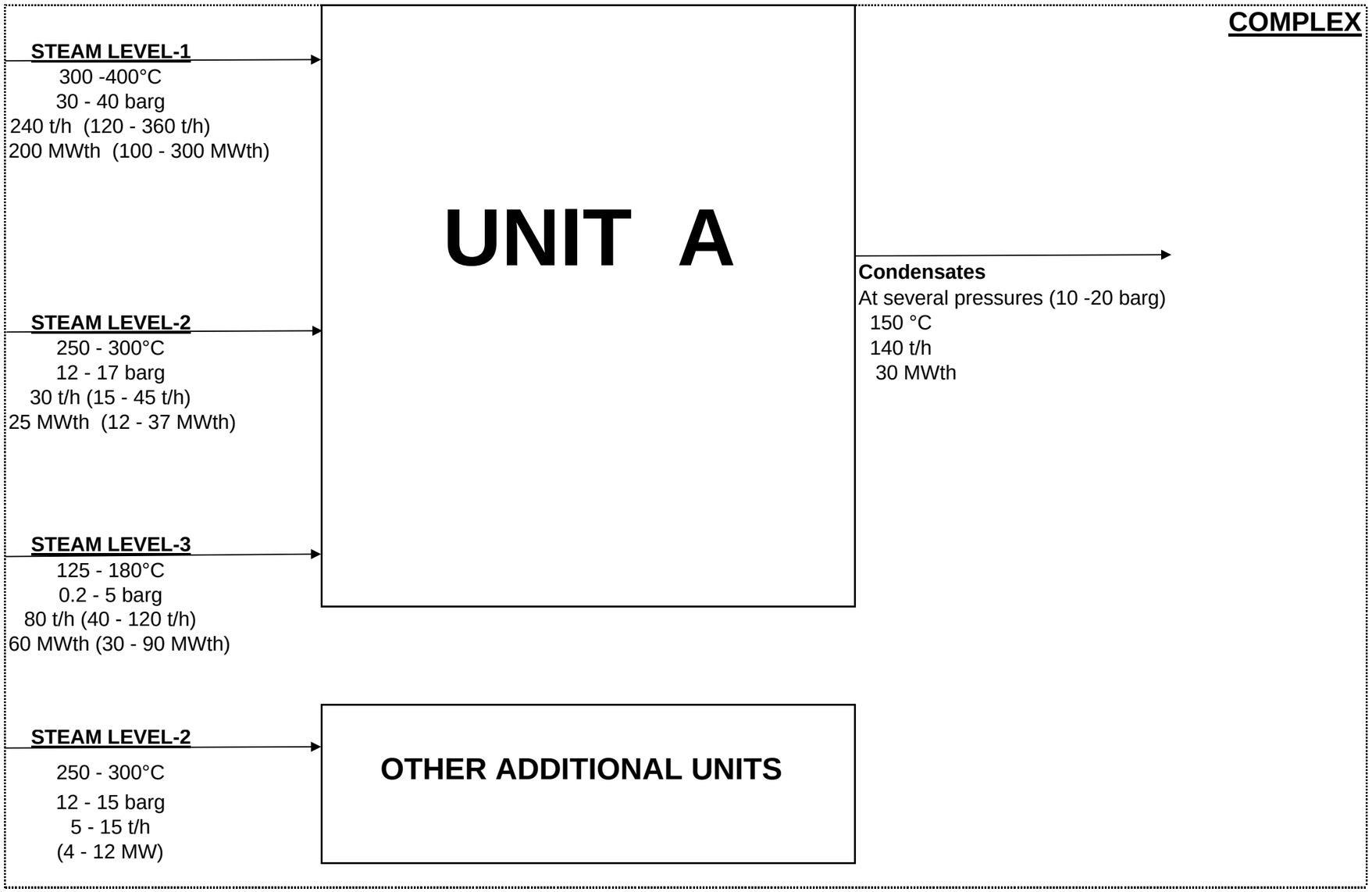
(6)	Continuous / Intermittent	Need for continuous heat supply (continuous process) or intermittent heat supply (batch process).	C or I (batch duration, number per year…)
(7)	Effect of heat supply disruption	What happens if case of heat supply disruption? Characterize the criticality of the heat supply.	shutdown of the process, degraded performances…
(8)	Consumption Leveling	Is there a possibility of leveling between the various heat loops in the process? Characterize the flexibility.	YES or NO
		Heat Producer Specifications - EXISTING	
(9)	Heat Generator Description	Name of the heat supply utility	
(10)	Fuel Type	Description of the fuel needed for heat generation	gas, coal, offgas (from unit X), electricity…
(11)	Fuel Consumption / External	Periodic consumption of external fuel	tpy, tph, Sm3/y…
(12)	Fuel Consumption / Offgases	Periodic consumption of internal fuel (offgases from another unit)	tpy, Sm^3/y…
(13)	Power	at least nominal power is required	MWh…
(14)	Back-up in case of shutdown	what is the planned back-up in case of the disruption og the normal heat supply?	
(15)	Media Type	Description of the media used for heat transportation between heat generation and consumption.	steam, oil, molten salt…
(16)	Temperature	Temperature of the medium at the inlet and at the outlet of the heat generation system	K, °C, °F
(17)	Pressure	Pressure of the medium at the inlet and at the outlet of the heat generation system	bar, psi…
(18)	Mass Flow	Mass flow rate of the heat transportation medium	tpy, Sm3/y…
(19)	Consumed in process ?	Indicate if the heat medium (for inst. STEAM) is recycled to heat generation OR consumpted afterwards in the process	YES or NO

Simplified Plant & Units flow scheme (1/2)

Objectives of the scheme

This simplified scheme aims at providing an easy understanding of the overall considered process.
You can add as many units as you think necessary.
In addition, please list at the bottom the safety concerns linked to the plant described here below.

❷ *Replace the example here below bythe flow scheme of the considered complex / process unit*



Simplified Plant & Units flow scheme (2/2)

❸ *Summarize here the name of the units*

	Consumer Description (1)
Unit A	
Other additional units	

❹ *Please detail here below the identified safety concerns related to the process.*

SAFETY CONCERNS.

- More than 10 European plants in the specified thermal power demand range
- Nonstop process, 8760 hours/year
- It is a stable and continuous process without important heat demand changes
- Values of steam pressure and temperature are fixed in each plant (for each level). Steam pressure and temperature range and steam consumption range are specified to integrate all the European plants.
- Process power consumption (as electricity) is in the range of 5 and 15 MW elec (fonction of the size of the plant)
- There is two mainly applications for the steam:
  - **Heat:** for calcining, drying and distillation chemical process
    Steam temperature is adapted to the condition process demand of each site
  - Steam levels-1 (30-40 barg) and level-2 (12-17 barg) is used for drying, calcining and to move turbocompressors / turbopumps,
    According to the design of each site, steam consumption indicated in the flow-sheet could be transfered from LEVEL-1 to LEVEL-2, but total heat (LEVEL-1 + LEVEL-2) demand remains constant (for a defined size of the plant and a determined production)
  - Steam level 3 (0,2 - 5 barg) is used mainly for Distillation process, It could be saturated steam
  - For a determined plant, it will be necessary an detailed analysis case by case,
  - Network pressure conditions are usually controlled by back pressure steam turbines,
  - Around 40 % of the total steam consumption is recovered as condensates in the power plant
  - **Mechanical Power:** to move some process turbocompressors and turbopompes
    A minimal level of superheater temperature is necessary in the steam to avoid water droplet at the last stages of the steam turbine

- Usually as heat, in small quantities compared with Unit A (5 -10 t/h by unit)

- In some complex, it could be several of these units

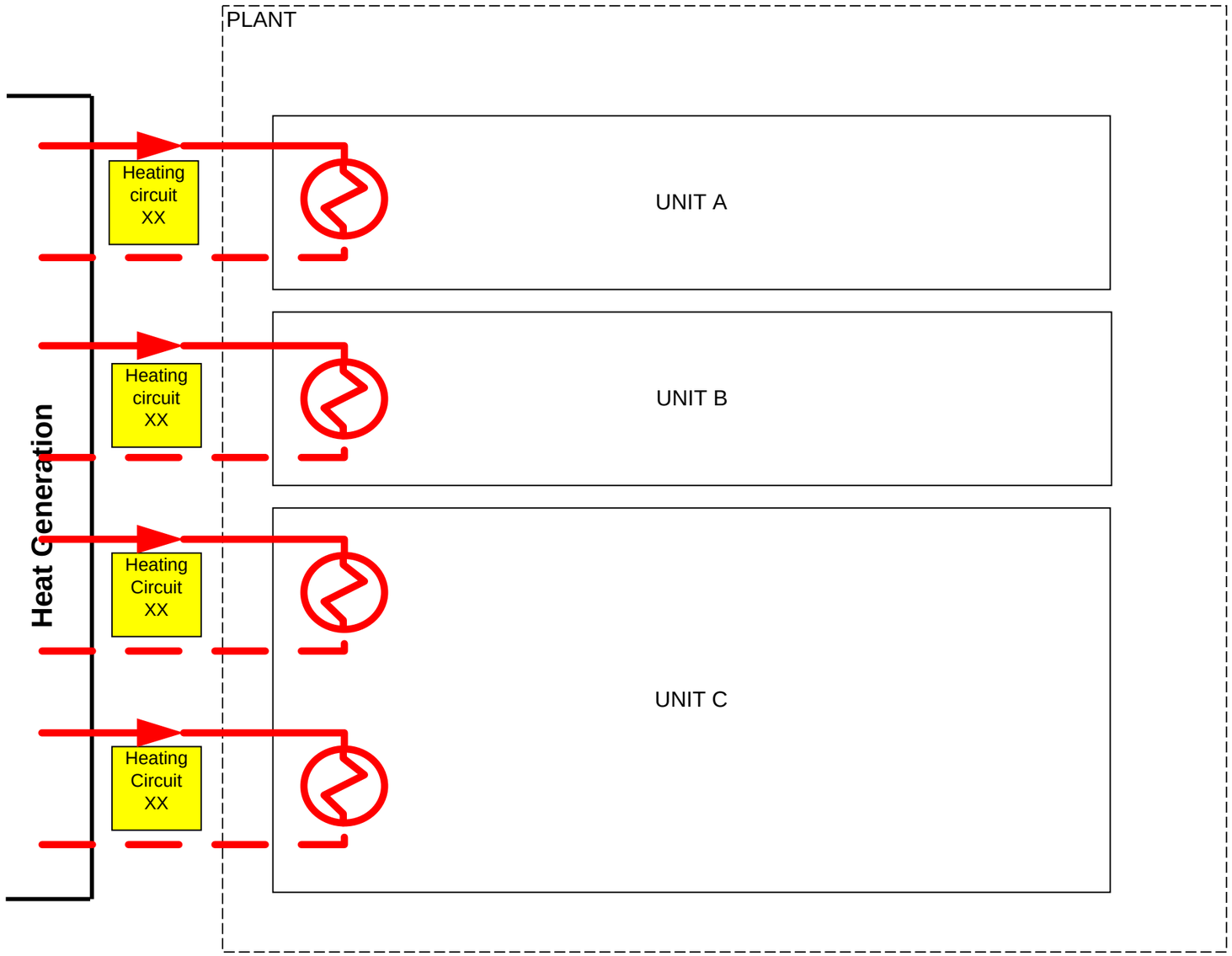
Characterization of the heating needs (1/2)

Objectives of the sheet

This sheet gathers the information related to the needs for heat in the plant or process unit.

Chemical process is so complicated that we consider it is not worth to go deeply into (see attachment in the e-mail

❺ *Replacet the example here below by the heating needs of the process units described in Sheet 3*



Characterization of the heating needs (2/2)

❻ *Fill the table here in accordance with the units described in Sheet 3 and with the scheme here above.Definitions of the parameters are given in Sheet 2.*

Consumer duty

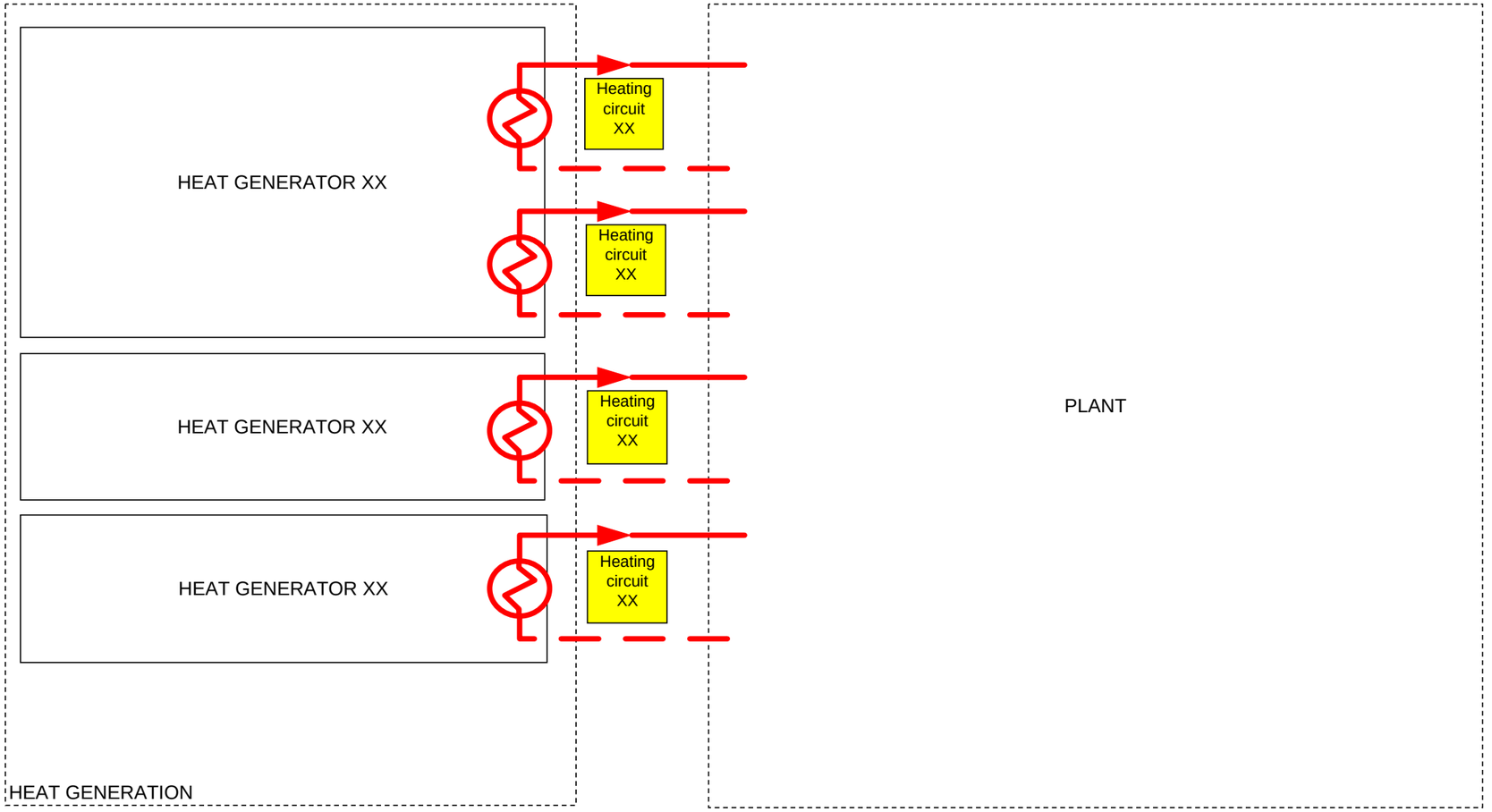
Consumer Description (1)		Heating Circuit N° (2)	Temperature (3)		Allowable Temperature Range (4)		Typical ramp up and down (5)	Continuous OR Intermittent (6)	Effect of heat supply disruption (7)	Consumption leveling (8)	Comments
			inlet	outlet	T_{min}	T_{max}					
Unit A											
Unit B											
Unit C											
Unit D											
Unit E											
Unit F											
Unit G											
Unit H											
Unit I											
Unit K											
Unit L											
…											

Characterization of the existing heat generators (1/2)

Objectives of the sheet

This sheet gathers data on the existing heat generation systems.

❼ *Replace the example here below by the existing heat generation systems for the considered complex / process units. Heating Circuit Numbers shall be in accordance with Sheet 4.*



- In all cases: high efficiency **COMBINED HEAT AND POWER GENERATION**
- **Heat conveyor for process is always steam.** Condensates are recovered as 40 % of the total steam consumption
- Several kind of Combined Heat & Power Generation are possible (according to each local conditions and sites):
  - Gas turbine + Heat Recovery Steam Generator + Steam turbines cogeneration
  - Coal boilers (140 bar or 100 bar) and steam turbines,
  - Biomass or secondary fuel cogeneration

- Process steam (level-1, 2 and 3) is proceeding from extraction and back-pressure steam turbines

- They are **minimal two similar boilers running in paralell** (coal boilers or gas turbines+ HRSG), It could be also both at the same plant
- As backup, there are similar coal or classical gas boilers

Characterization of the existing heat generators (2/2)

Fill both table shere in accordance with the heating circuits described in Sheet 4 and with the scheme here above. Definitions of the parameters are given in Sheet 2.

HEAT GENERATORS

Heating circuit N° (2)	Heat generator description (9)	Fuel type (10)	Fuel Consumption		Power (kWth) (13)			Backup in case of shutdown (14)	Comments
			External (11)	Offgases (12)	Min.	Nominal	Max.		

MEDIA TABLE

Heating circuit N° (2)	Media type (15)	Temperature (16)		Pressure (17)		Mass flow (18)			Consumed in the process ? (19)	Comments
		inlet	outlet	inlet	outlet	Min.	Normal	Max.		
0										
0										
0										
0										
0										
0										
0										
0										
0										
0										
0										

Industries & Processes

	Partners	Contact	Industries	Plant / Process Units
1	AMEC	Derek BUCKTHORPE derek.buckthorpe@amec.com	Oil sands	Steam Assisted Gravity Drainage
				Cyclic Steam Stimulation
			Petrochemicals	
			Ciment	Pyro processing
			Paper and Pulp	Kraft process
2	Air Liquide	Claire WEBER claire.weber@airliquide.com	Industrial Gas production	Oxygen Production - Ceramic membrane
				CO Production - dry reforming
3	Arcelor Mittal	Gerard Griffay gerard.griffay@arcelormittal.com	Steel Making	Coke Making
				SteelMaking
				Hot Rolling
				Direct Reduced Iron (DRI)
				Power complex
				Lime complex
				Sintering
				Blast Furnace
4	Fortum	Harri Tuomisto harri.tuomisto@fortum.com	Paper and Pulp	
			Oil refinery	
			Co-generation	
			District Heating	
5	FZJ	Werner von Lensa w.von.lensa@fz-juelich.de	Coal	Coal Gasification
				Steam Methane Reforming
6	GDF Suez - Tractebel	Carmen Angulo carmen.angulo@gdfsuez.com	Co-Generation	-
7	NWU/PBMR	Gideon Greyvenstein	Petroleum Products	Fischer-Tropsch
				Steam Methane Reforming
		gideon.greyvenstein@pbmr.co.za	Oil Sands	
8	NWU	Frik van Niekerk frik.vanniekerk@nwu.ac.za	Hydrogen Production	Thermochemical water splitting
				Hybrid Sulfur
				Sulfur Iodine
				High Temperature Electrolysis
9	PROCHEM	Marek Tarka mtarka@prochem.com.pl	Refinery	Aromatics Extractive Distillation
				Crude Oil Distillates Hydrotreatment
				Crude Oil Distillation
10	SAIPEM	Jacques RUER jacques.ruer@saipem-sa.com	Energy Storage	Pumped Heat Electricity storage
11	Technip	Gaetano Iaquaniello iaquaniello.g@ktispa.it	Refinery	
			Hydrogen production	Steam Reforming
				Membranes Steam Reforming
12	USG (DSM) / BEC	Anton Baaten anton.baaten@me.com	Wide Range (Petro)chemicals incl. Urea & Ethylene	Utilities supply
13	ZAK	Marek Zuber marek.zuber@zak.com.pl	Nitrogen Fertilizers	Syngas production
				Hydrogen production
				Nitric acid synthesis
				Ammonia synthesis
				Urea production
			Organic Synthesis	Oxo processes
				Alcohol synthesis
				Phthalate plasticizers synthesis
				Phtalic and maleic anhydride
14	SOLVAY	Roberto MORON roberto.moron@solvay.com	Chemical & Plastics	Process with:
				- High heat demand (usually steam)
				- Or High electricity demand (electrolysis process)
				Big cogenerations