Finding the path to Decarbonization of Refining sector

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Abstract

Given the recent strong change on societal and economical context but also with new recent regulations (the Paris Agreement, CO2 price increasing, Greenhouse House Gases quota), industrials are willing to reduce the environmental impact of their activities by improving and upgrading current asset operation. Thus, the major challenge of our industry in the incoming decades will be to reduce CO2 emissions while remaining profitable and competitive.

The sustainable development scenario of IEA puts energy on tracks to meet sustainable energy objectives, with a global temperature increase of less than 2°C by 2100. To reach this target, several options are possible: improve the energy efficiency of existing assets, move to renewables energies, fuel switch or even carbon capture. Several options, but how to select the best option? It depends strongly of climate strategy, existing assets and development plan of each industrial. It is the role of Axens, as consulting team, to support industrials in this challenge by developing a comprehensive roadmap of sustainable process solutions to address this CO2 reduction ambition.

Axens has a dedicated multi disciplinary team with long expertise in master planning, which has privileged access to green technology and carbon capture expertise whose competency is to develop short, medium and long-term plans for decarbonization. Through a holistic and proven approach, Axens supports industrials and develop a specific and customized decarbonization program taking into account baseline set in Group Strategy. The approach and methodology is presented in this paper an illustrated through three different decarburization projects studied by Axens applicable to the Refining sector.

In this Energy Transition context, an increasing number of refineries in the world are being partially or completely transformed from tradition fossil oil refining activity to bio-refineries treating bio sourced or waste feedstocks. First Case Study presents a grass root project feasibility study where two of the most attractive options for production of renewable fuels are compared: HVO and 2G bio-ethanol. These are two of the main sustainable technologies that can be integrated in existing refining sites taking profit of all the synergies with existing facilities and activities.

In Case Study 2 different configurations for sustainable transformation of a multi-site refining system where evaluated for a Client. This case is an example of the very large panel of options that refineries will have to evaluate when defining their strategies to adapt to the Energy Transition and new regulations. Each solution resulting into very different level of investments, different business models and different social and environmental impacts.

Case Study 3 presents the pre-feasibility study for an ongoing project of CO2 capture and transformation to methanol for a cement plant. Carbon Capture is also applicable to Refineries, especially in the main refinery emitters such as FCC unit flue gases and SMR unit syngas or flue gases, which are often the best candidates on medium complex refineries to apply Carbon Capture in a cost –effective way.

Introduction: Green House Gases emissions context and its impact on the Refining sector

- Green House Gases emissions context

Reducing global carbon dioxide (CO2) emissions to net-zero by 2050 and limiting the increase in global average temperature to 1.5°C, is perhaps the greatest challenge humanity has ever faced. The energy sector is responsible for about three quarters of greenhouse gas (GHG) emissions. It thus, is the sector that holds the key to the impact on climate change caused by the GHG.

The World Energy Outlook by the International Energy Agency provides detailed climate mitigation scenarios. The Sustainable Development Scenario (SDS) represents a gateway to the outcomes targeted by the Paris Agreement that would result in global temperature rise of 1,6°C by 2100. IEA introduced a more ambitious scenario in 2021, the NET Zero Emissions by 2050 scenario, presented in the publication "Net Zero 2050: a roadmap for the global energy sector". The different scenarios and targeted emissions reduction are represented in the following figure:

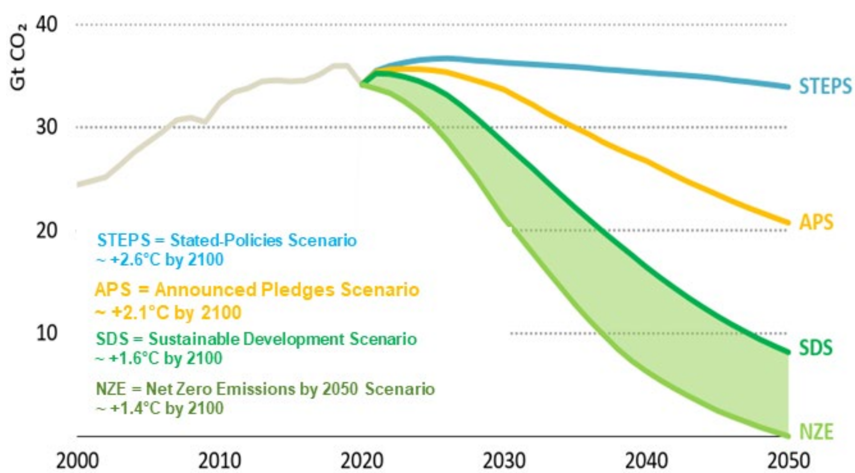

Figure 1 - Global energy-related CO2 emissions in the 2021 World energy Outlook scenarios (IEA)

If we look closely to NZE scenario and its related effort to make on the average annual CO2 emissions reduction, we observe that a variety of measures has to be implemented, showing that a single technological solution is not enough and that a combination of solutions is required. Therefore, each industrial site will have to find and follow the path that suits best its specificities.

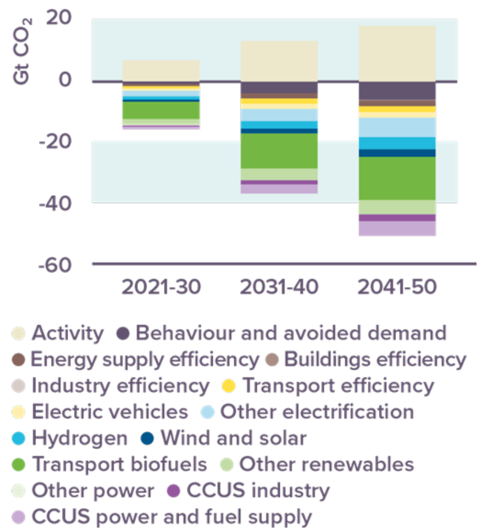

Figure 2 - Focus on NZE av annual CO2 reduction

Among those measures, we can note different solutions and techniques that can be applied in the existing refineries and petrochemical complexes that will be key to reach the decarbonization targets:

- improve the Energy Efficiency of existing units,
- Electrification of energy consuming equipment,
- production of transport Biofuels
- but also the application of Carbon Capture for its utilization or storage.
- last but not least, the existing refineries have strong synergies to be used as platforms to develop the clean Hydrogen sector.

Industrial sectors has all keys in hand to reduce their CO2 emissions by implementing new technologies and transforming their existing assets toward more sustainability. In that respect, most of main industrial players in the Oil & Gas industry have announced ambitious climate strategies and commitments. The challenge for the Refining sector will be to reduce the CO2 emissions, while remaining profitable, competitive and without compromising productivity.

- <u>Finding its Decarbonization path</u>

Defining the best strategy of a refinery to adapt to the energy transition context is not a simple task. There are many variables and factors that one shall consider:

- First, there are multiple **technical paths** to decarbonize an activity and many **technological solutions**. Among these solutions, there are mature solutions already industrially available but also non-mature technology, at a Technology Readiness Level (TRL) of 4 to 6 corresponding to demonstrator level. Defining a decarbonization roadmap shall consider the TRL of the available technologies when selecting the solutions at short, medium and long-term.

- Secondly, we are evolving in a continuously changing **market and regulations** that have a direct impact in the economics of implementing solutions and that obliges industrials to upgrade their products towards more renewable products. Taxation policies and CO2 quotas will have a strong impact on the production costs of existing sites if nothing is done to decrease the emissions. Different CO2 cost scenarios shall be defined and assessed when defining the decarbonization roadmap. Also the regulations for renewables incorporation in carburants, or plastic recycling quotas, needs to be integrated in the transformation plans.

- Beyond these points, the biggest challenge is to develop the transformation strategy best suited to the **existing assets.** Indeed, selecting the best solution is strongly depending on the specificity of the existing asset, of the core activity and the market to be addressed. There is no universal solution and each site will have to find the best action plan according to its context.

- And of course, a final point to look at is the **level of change** involved to reach the decarbonization target. The activity of a traditional fossil oil refinery can be transformed at different levels while maximize the utilization of its existing facilities. As an example, some European refineries have been transformed to bio-refineries, excluding any treatment of fossil oils, while others plan to increase the bio based feedstock treatment while continuing to treat a significant part of its fossil oil capacity.

Methodology: development of Refineries Decarbonization plans

Supported by a dedicated team with strong technical knowledge , Axens has developed a global and customized approach for defining decarbonization of industrial activities, for short, middle and long term projects.

Typical steps of a decarbonization study are summarized here after:

- <u>Market analysis,</u> during this step following points are studied:
    - Market overview on benchmarked potential strategies that have been published focusing on energy abatement options for the oil refining industry in the region.
    - C02 and energy price projections in the concerned region. Different scenarios will be defined and will serve as basis for the study.
    - Market study shall integrate the availability review of alternative feedstocks (renewable oils, biomass, bio-gaz, pyrolysis oils, waste materials etc..)

- <u>Base line definition and diagnosis of current situation,</u>
  During this step Axens defines the energy consumption and CO2 emissions balance at site level, units' level and equipment levels. Energy performances and CO2 emissions are evaluated and compared to the Best Available Technologies and potential reduction of emissions are assessed.

- <u>Screening of decarbonization paths and definition of Action Plans</u>
  Next step consists in the identification and screening of the applicable decarbonization paths and solutions best adapted to the existing assets followed by the definition of the Action Plan.
  The following Figure summarizes the different paths and solutions typically applicable to refining sites:

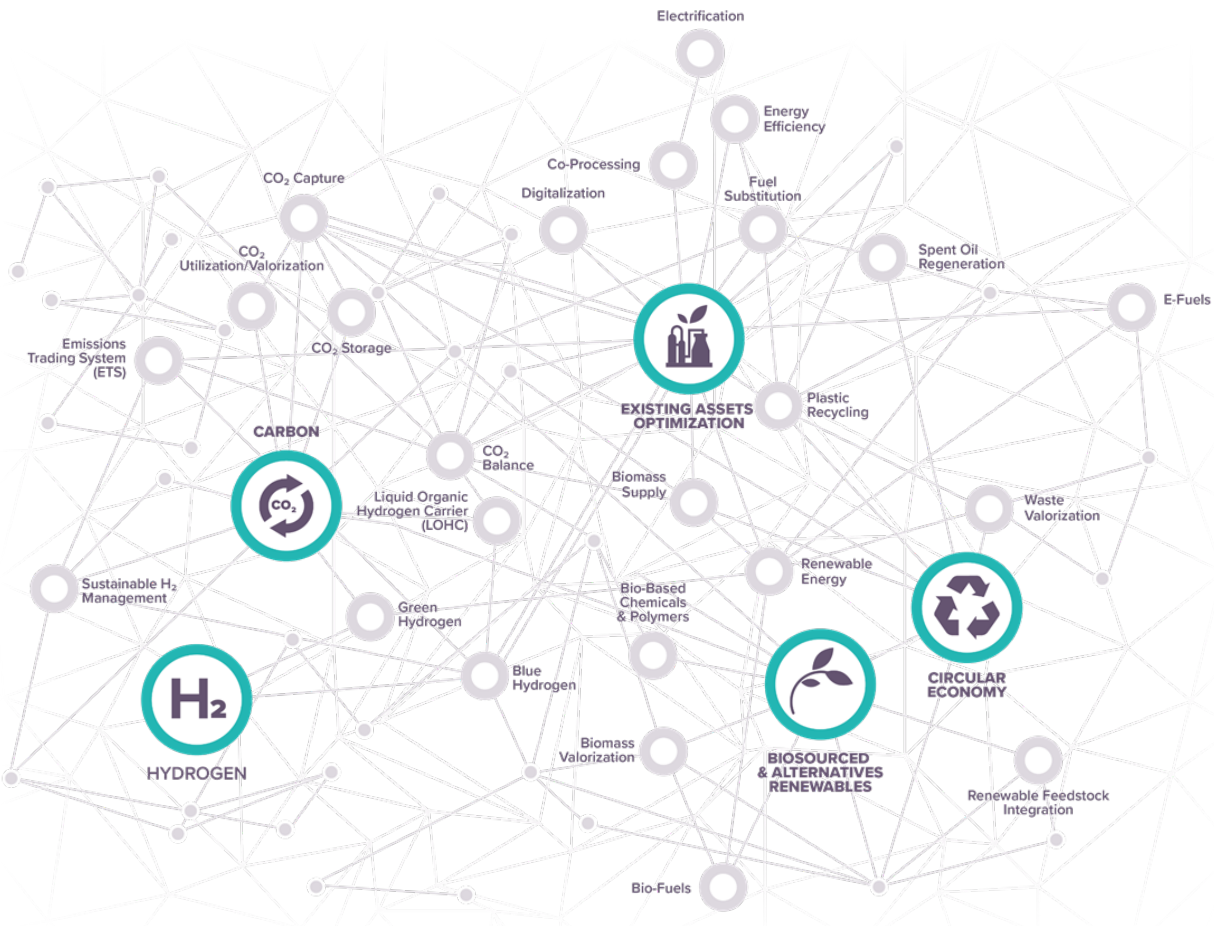

Figure 3. Decarbonization paths

Each applicable solution is developed at a prefeasibility level for multi-criteria comparison and ranking.

Development includes main technical and environmental aspects (such as capacity, process schemes, mass and energy balances, evaluation of emissions reduction impact, utilities, catalyst and chemicals consumption, plot plan area requirements), economical aspects (investment estimate, operating costs, financial and economic study) as well as project implementation schedule and availability / readiness level of technologies.

Based on the above results the action plans and reduction targets at short, medium and long terms are developed.

- Detailed feasibility studies
  Final step is the development of detailed studies for the selected solutions to ascertain the feasibility from technical, economic, environmental and safety points of view and the definition of the basis for the engineering of each project.

The above is of course a generic methodology that shall be adapted to the specificities and needs each client. In the following chapters, three Case Studies of Decarbonization projects carried out by Axens are presented.

Case study 1: Feasibility Study of a standalone Bio-refinery for MGH based on Hydrotreated Vegetable Oil (HVO) and 2G Bio-Ethanol technologies

- The challenge

- Maritime Green Horizon (MGH) is a company specialized and dedicated to the free- and low-carbon energy solutions in the marine environment and port applications.
- Despite a challenging environment, the global biofuels industry is holding steady and driving ahead with new policies, innovations and legislation to promote robust growth in the future.
- The main challenge is the competitiveness of innovative bio-based technologies compared to the conventional technologies in the context of low crude oil price.

- The solution

Axens evaluated the feasibility of the two above-mentioned bio refineries, taking into account the provided context and the site location. For each complex, the feedstocks, products and byproducts characteristics were identified and based on the overall material and utilities requirement, the utility generation & distribution, offsite, and auxiliary units (in general OSBL) were preliminary designed.

In addition to the technical aspects, cost estimation and project financial model including the upstream biomass plantation and supply was established based on the economic parameters. The feasibility of both solutions was assessed upon the different price scenarios.

Process schemes of Axens technologies for Hydrotreated Vegetable Oil (HVO) and 2nd Generation Bio-Ethanol, are shown in the figures here after. Axens technologies were used as basis for study purposes.

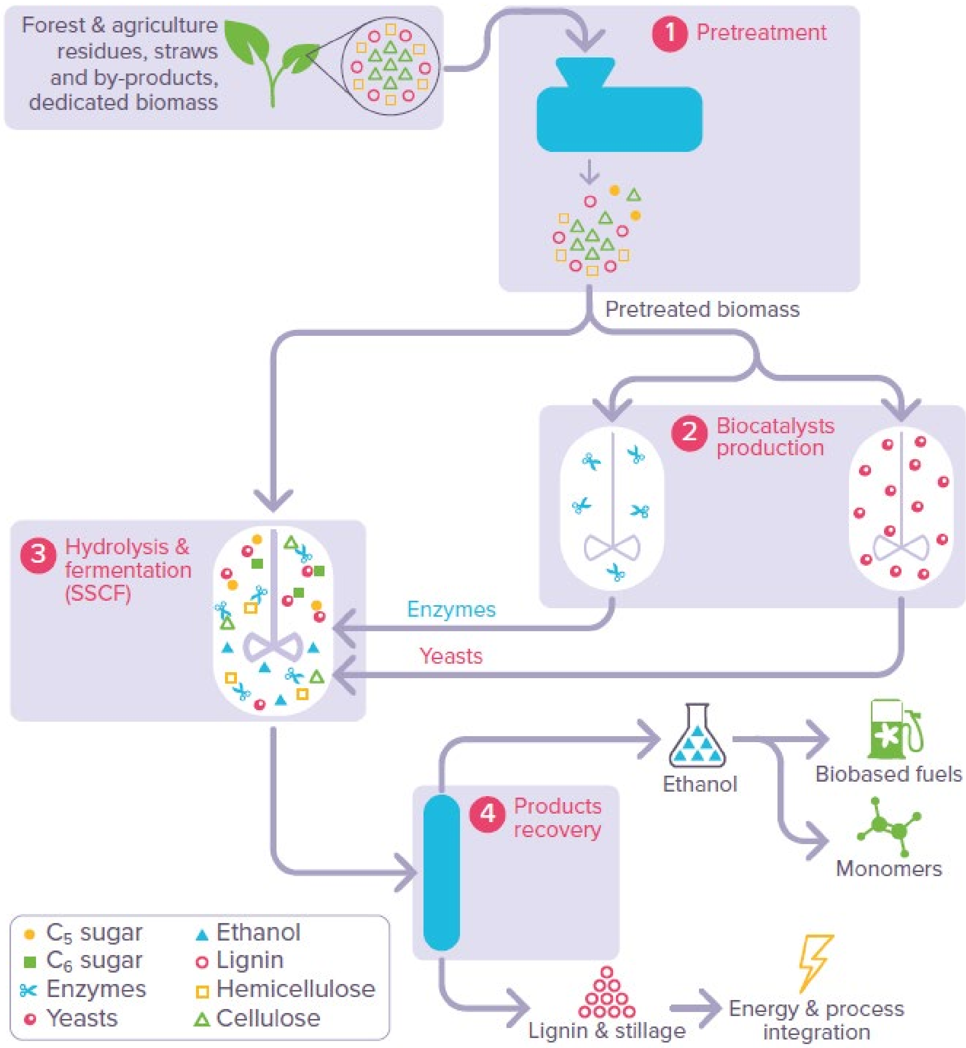

Figure 4. Axens Futurol™ technology simplified process flow diagram

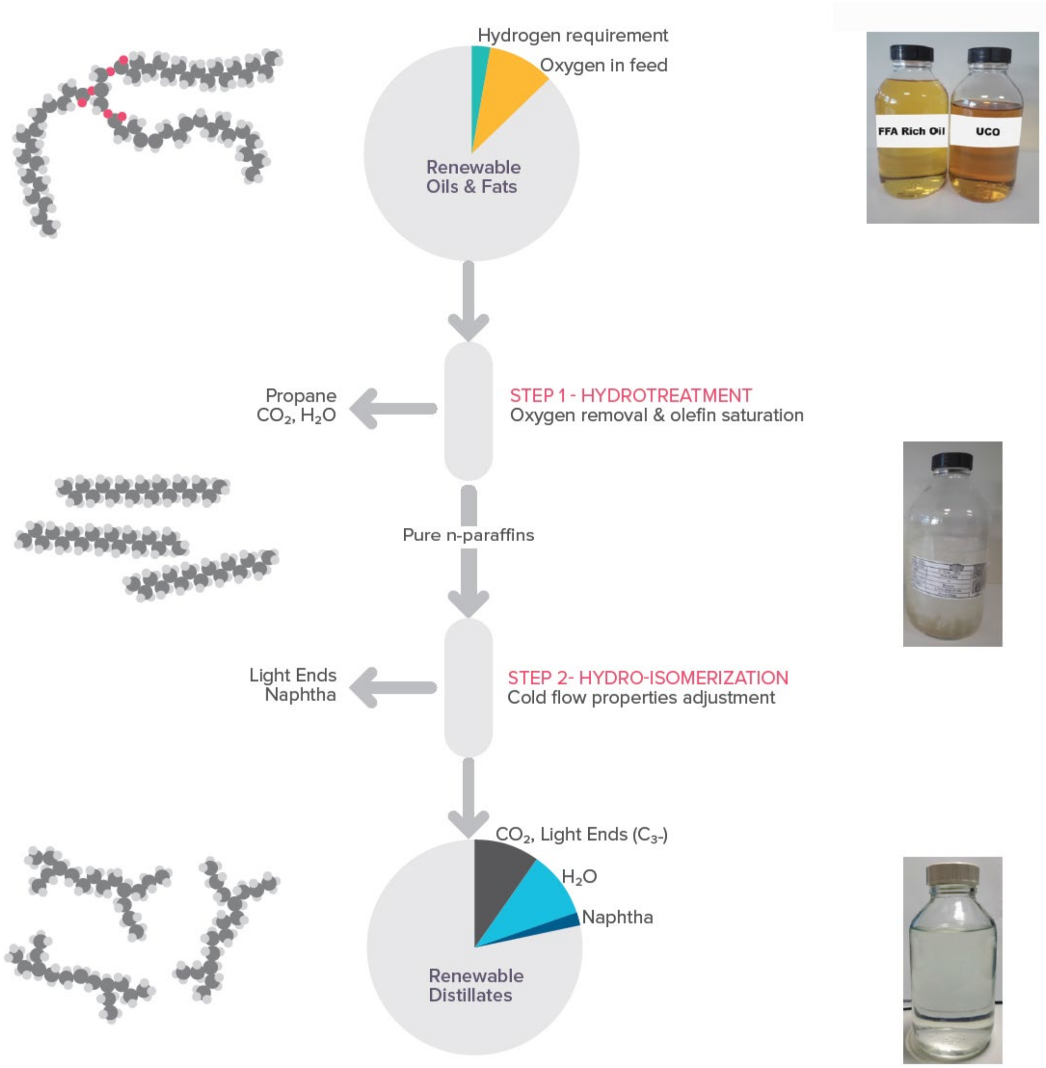

Figure 5. Axens Vegan® simplified process flow diagram

- <u>The results</u>

Thanks to the applied methodology and based on Axens expertise on both technologies supply and consulting services, the feasibility results were delivered to MGH in less than 3 months.

- Anticipated benefits from Axens' robust 2G biofuels technologies include sustainable solutions for motor fuel production and rural economic development while avoiding the limitations of first-generation biofuels.

- The share of biofuels products in motor fuel will continue to expand in the near future. The economic model of the project shows promising results on both complexes.

- The double digit IRR of the Vegan complex, where the sole product was renewable diesel and by applying only the current premiums met MGH's feasibility threshold.

- The same for the Futurol complex, higher bio ethanol price than the current market price was needed in order to fulfill the stakeholder's profitability range.

- Considering that no incentives or financial aids were taken into account in the above economic evaluations, the shifting policies as a result of carbon neutrality and 2050 carbon-emission reduction targets, can bridge the current price gaps as one of the main drivers of the project financial viability and promote such vital projects to meet the latter objectives.

Case study 2: sustainable transformation of a multisite Refining system

- The challenge

A European refiner is evaluating future transformation options for two refineries located in the same country. Both refineries are nearby from each other and present synergies already between them (flux exchange, utilities...).

In the context of European commitment to achieve Net Zero emissions in 2050, Client is committed to sustainability of its business and to reduce GHG emissions.

European financing possibilities are envisaged from programs such as the European Green Deal investment plan for helping industry in their decarbonization and digitalization for a more sustainable industry in Europe.

Moreover, the refinery needs to adapt to the new specifications for bunker fuels.

- The solutions

Refinerie A will be more impacted by this three scenarios as it is a small capacity refinery, has a simple hydroskimming scheme with thermal conversion units shutdown and therefore is less profitable than Refinery B which is higher capacity and with a complex refining scheme.

Three scenarios have been studied for transforming the refineries:

- Scenario 1 –Refinery A partial shutdown for operation as Gasoline Plant

  This scenario requires the shutdown of all processing units in Refinery A with the exception of the gasoline production units :

  - 2 Naphtha Hydrotreatment units
  - Oxystripper
  - Naphtha splitter section
  - CCR and Penex/Molex units
  - LPG recovery section

  In that scenario, 100% of the full range naphtha feedstock will be imported while the crude units are in permanent shut down. Sulphur recovery units including the existing DEA, SWS and Claus plants need to be evaluated in this context of very low throughput.

- Scenario 2 – Revamp of HDS unit to HVO

  This scenario is the same as Scenario 1 with the following additions:

    - The kerosene HDS in Refinery A remains in service to desulphurize excess kerosene from Refinery B to produce Jet fuel. The kerosene import facilities need to be debottlenecked
    - The existing gasoil HDS units are revamped to produce HVO; the design feedstocks envisaged for the HVO unit are UCO (Used Cooking Oil) and palm oil; the design capacity shall be adapted to the existing units.

  Sulphur recovery units including the existing DEA, SWS and Claus plants need to be evaluated in this context of low throughput.

- Scenario 3 – Grassroort HVO unit

  This scenario is the same as scenario 1 with the following additions:

    - The kerosene HDS in Refinery A remains in service to desulphurize excess kerosene from Refinery B to produce jet fuel. The kerosene import facilities need to be debottlenecked.
    - The existing gasoil HDS in Refinery A units remain in service to desulphurize the Refinery A diesel fraction into 10ppm diesel. The gasoil import facilities need to be debottlenecked.
    - The existing Refinery B gasoil HDS is adapted to process HSVGO into LSVGO 0.5% S and the LGO/LVGO fractions into marine diesel 0.1% S. The unit would be operated in batch mode. This will most likely require a Claus plant debottlenecking at Refinery B to maximize utilization rate of the HDS.
    - A new grassroots HVO unit needs to be built for the processing of UCO (Used Cooking Oil) and palm oil. The various feedstocks would not be processed simultaneously. The hydrogen to this process is coming from the CCR unit.

- <u>The results</u>

A complete technical study has been developped for each scenario with integration to both refinery sites. Key points to be developed and evaluated during the study are the following:

- Identification of bottlenecks on process , utilities or auxiliary units,
- Revamp and/or replacement on main equipment and new equipment,
- Impacts on operation (capacity, severity, performances…),
- Impacts on hydrogen and fuel gas network,
- Impacts on upstream and downstream logistics facilities (storages, pumping stations, export…),
- Manpower impact.
- Evaluation of CAPEX and OPEX of each scenario

Main results are summarized her after:

- Scenario 1 – partial shutdown
    - This is the lowest cost solution in terms of CAPEX and OPEX
    - Impact on decarbonization is stopping fuel production

- Scenario 2 – HDS revamp to HVO
    - The revamped capacity of HVO was selected considering a compromise between the investment costs and the additional capacity gains.

- Scenario 3 – grassroots HVO

- This is the most capital intensive scenario which maximizes synergies of both refineries and the production of high value products
- CAPEX is 3 times than the one in Scenario 2, due to the investment in the new HVO unit but also significant part of it corresponding to the revamp of existing units and auxiliaries
- The HVO capacity in this scenario is 2 times the one on Scenario 2

The results of this Study will be used by Client to evaluate the financial viability of each scenario and make a highly important strategic decision.

This case is an example of the very large panel of options that European refineries have to evaluate when defining their strategies to adapt to the Energy Transition in very competitive context and to new regulations. Each solution resulting into very different level of investments, different business models and different social and environmental impacts.

Case study 3: Carbon Capture and Methanol production in a cement plant

- The context

Cement industry is one of the most polluting industry accounting for 12% of French industrial emissions, so there is a strong willingness to reduce its carbon footprint. Vicat is a French cement producer with the ambitious commitment to become carbon neutral by 2050 on its entire value chain.

A partnership between Vicat and Hynamics has been set to develop the Hynovi project, aiming to capture 40% of the CO2 emitted by Vicat's Montalieu-Vercieu cement plant in eastern France. Carbon produced by the plant will be recovered and combined with Hynamics' low-carbon hydrogen to produce carbon-free methanol. The project is applying for the Important Projects of Common European Interest (IPCEI) program for financing of innovative projects.

- The study

Axens was assigned for the pre-feasibility studies for the Carbon Capture and Methanol production blocks of the project.

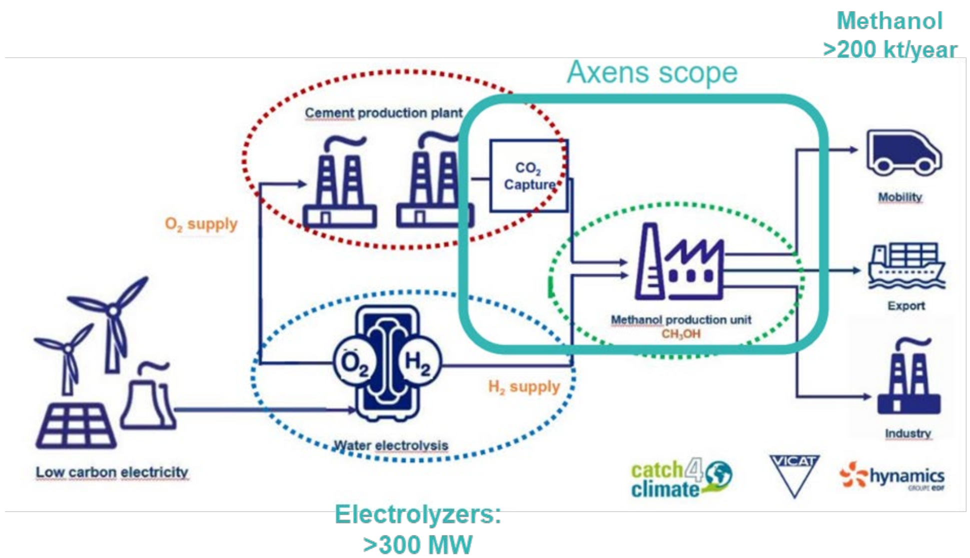

Figure 6. Scope of Axens PFS for Hynovi project

The pre-feasibility study was planned in two phases as follows:

- Phase 1, including
  - A market study on methanol
  - The review of existing distribution logistics for methanol in France, Rhône-Alpes area
  - The identification of technological blocks needed for carbon capture and methanol production
  - A comparative assessment of carbon capture technologies and methanol production technologies (multi-criteria analysis)
  - A quality review of flue gas and selection of flue gas collection point for carbon capture

- Phase 2, including the following items:
  - Consolidated material balance, product yields, effluents, composition, operating conditions, utilities
  - Implementation of treatment facilities on site (required plot area, infrastructures and logistics aspects)
  - Total cost estimate, economic study, sensibility analysis on profitability parameters

- <u>The results</u>
  - Methanol world consumption will continue to grow vigorously up until 2050. Methanol, 99% of which is produced from fossil fuels, is extensively imported into France for use in industries such as transport, chemicals, and construction. It is also used as a synthetic marine fuel.
  - The project will allow a local production of decarbonized methanol that will substitute imported fossil-based methanol, while avoiding direct emissions of half a million tons of CO2 every year.
  - The study shows that Carbon Capture solvent technology is adapted for this application.
  - As for Methanol production unit, heterogeneous catalysis technology was preselected

- Carbon Capture applied to Refining sector

While this Case Study shows the incentives of cement industry to apply Carbon Capture technology, one shall note that this solution is also applicable to the refining sector.

Axens carried out studies to find out what are the main CO2 emitters in a refinery and how Axens DMX™ Carbon Capture technology could reduce the overall CO2 emissions of the refinery. Several refinery configurations where studied, from a simple hydroskimming refinery to medium complex refinery either with FCC or with hydrocracker, and the CO2 emitted at the stack of each unit were evaluated. We plotted as a result the contribution of each unit in the graphic here below to identify where the CO2 capture solutions are best applied in a refinery:

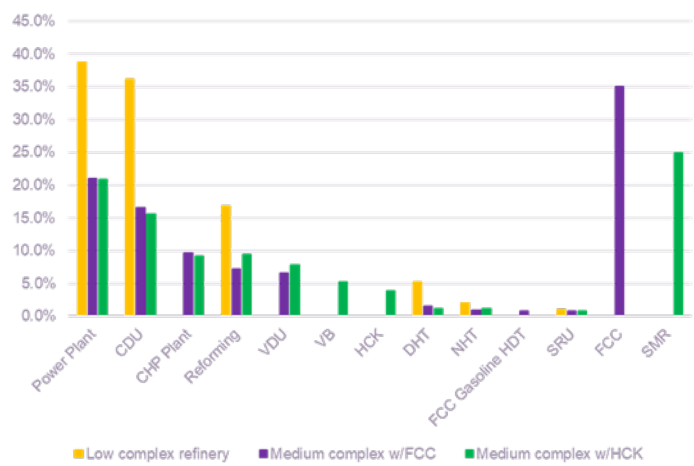

Figure 7. Contribution of refining units to the overall CO2 emissions

Results show that more than 60 % of refineries CO2 emissions can be reduced by addressing the three main emitters (CDU, Power Plant , FCC, SMR,…) of each refinery type.

Above all, although the emissions of a simple hydroskimming refinery are mainly coming from the Power plant and CDU, the FCC unit and the SMR becomes the greatest emitters on medium complex refineries and the best candidates to apply Carbon Capture in a cost –effective way.

Concerning the SMR, it is important to note that there are two main locations on which CO2 can be captured. Either the converted syngas identified as location “A” in the figure here below or the flue gas identified as location B. CO2 absorption on syngas is much more favorable as it is high pressure, the CO2 partial pressure is high and there is consequently a large driving force to absorb CO2. The syngas is quite pure and does not contain any oxygen but only part of the CO2 emitted by the SMR (up to 60%) can be absorbed.

Adversely, 90% of the CO2 emitted can be absorbed on flue gas but the conditions are harsh; low pressure, low CO2 partial pressure, few % of O2 in the gas.

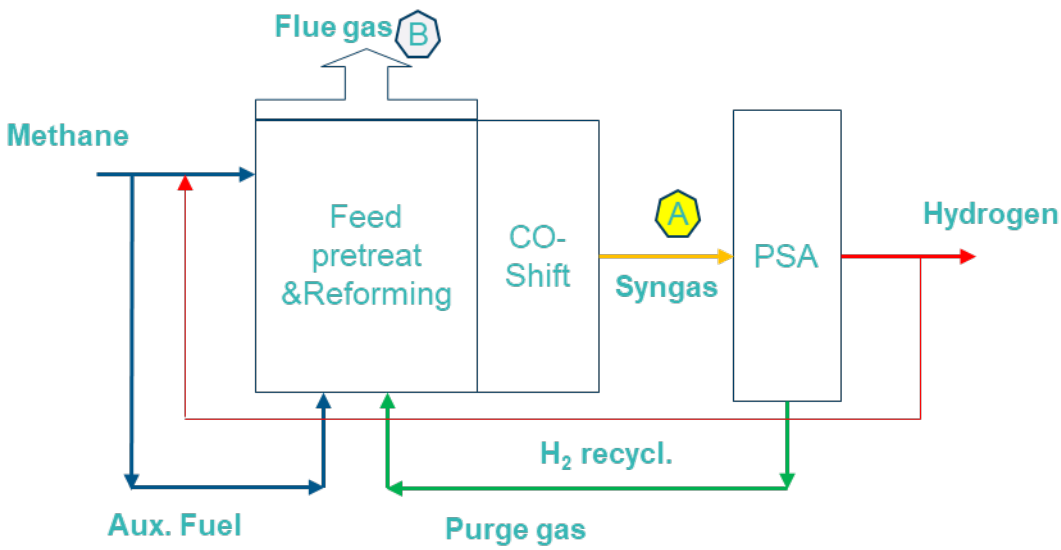

Figure 8. Potential carbon capture points in SMR units

Literature

International Energy Agency, "Net Zero 2050: a roadmap for the global energy sector", 2021

Nomenclature

CAPEX	Capital Expenditure
CCR	Continuous Catalytic Reformer
CDU	Crude Distillation Unit
FCC	Fluid Catalytic Cracking
HDS	Hydrodesulphurization
HSVGO	High Sulphur Vacuum Gasoil
HVO	Hydrotreated Vegetable Oil
IEA	International Energy Agency
IPCEI	Important Projects of Common European Interest
IRR	Internal Return Rate
LGO	Light Gasoil
LSVGO	Low Sulphur Vacuum Gasoil
LVGO	Light Vacuum Gasoil
MGH	Maritime Green Horizon
NZE	NET Zero Emissions
OPEX	Operating Expenditure
PFS	Pre-Feasibility Study
PSA	Pressure Swing Adsorption
SMR	Steam Methane Reformer

Authors

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After graduating from ENSIGC-Tarragona (Spain) as chemical engineer, Mr Pinent-Armengol followed IFP school program to specialize in oil refining.

He started his career with Spie Oil & Gas Services in 2004 as process engineer and was involved in Detailed Engineering projects.

He joined the Process Licensing Department of Axens in 2006 and was in charge of the Basic Design of numerous process units in the field of hydrotreatment and reforming. He was assigned Project Manager for several multiple-units large projects such as new Venezuelan Upgrader.

He moved to Axens Horizon as Project Manager in 2013 where he has been in charge of numerous Feasibility studies for new and revamped refining and petrochemical complexes and has managed several Energy Efficiency Audits and Margin Improvements Programs.

Since 2019 he has been appointed Consulting Sales Manager for Axens Horizon.

Eric Rayssac

Mr Rayssac started his career as a research engineer for Shell in Advanced Process Control in 1987.

He moved then to Petit-Couronne in 1991 Refinery as control engineer. He took a position of production engineer up to 1997, when he moved to Shell Denmark to continue in process control and process engineer in the refinery of Fredericia.

He came back to Petit-Couronne in 2007 as senior process engineer, then as investment project engineer.

He joined Axens in 2013 after the closure of Petit-Couronne refinery as refining expert and project manager.

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Marion Guillevic

Marion Guillevic is Business Developer in Axens Horizon Consulting and Decarbonization Group, in charge of Decarbonation and Energy Transition topics since 2021.

She joined Axens in 2014 after 8 years in Foster Wheeler as Lead Process Engineer, and became Technologist in Axens' Middle Distillates & Conversion – Axens Process Licensing Business Unit, working on Middle Distillates hydrotreatment processes. She also took the lead of Efficient Energy improvement program of Licensing Offer in 2017.

M Guillevic is an engineering graduate from the "Ecole Nationale Supérieure des Industries Chimiques de Nancy" in France and from Chalmers Tekniska högskola in Sweden.