# Syngas production for decarbonised e-fuels' value chain with CPO technology

## The contribution of Fores Engineering in levelling up the maturity of a promising sustainable technology

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In the imperative for sustainable technologies across industries, the heavy logistic sector (aviation and marine) and the hard-to-abate industry stand as pivotal playgrounds for innovation and change from fossil fuels.

Differently from the light transportation sector, clearly addressed more easily by electrified technologies, the solution for the aviation and marine sectors requires a scalable and structured approach, possibly without heavy modification to the assets, but with innovations focusing on the fuel side.

Just focusing on the aviation sector, sustainable aviation fuels (SAF) are readily accessible, very similar to conventional fuels and thus a direct substitute that can be progressively integrated into conventional Jet A-1 fuel blends; SAF deliver substantially lower greenhouse gas emissions (typically around -80% vs Jet A-1) thanks to a specific production process which involves decarbonised hydrogen generation and $CO_2$ recovery and utilisation.

The chart in **Figure1** shows that more than 53% of $CO_2$ emission is expected to be abated by a growing implementation of SAF in upcoming decades, even in a positive scenario when new generation aircrafts (Technology) may contribute for a challenging 34% of abatement (1).

Nevertheless, the predominant SAF variant currently available, namely biofuels, encounters major challenges regarding availability, scalability, as well as concerns surrounding the sustainability of feedstock sources and supply chain limitations.

Power-to-liquid (PtL) synthetic fuel, derived from low-carbon hydrogen and $CO_2$, emerges as a promising solution for long-term utilization, however it has a significantly higher cost compared to other options, and it demands substantial investments in electrolysis and carbon capture technology

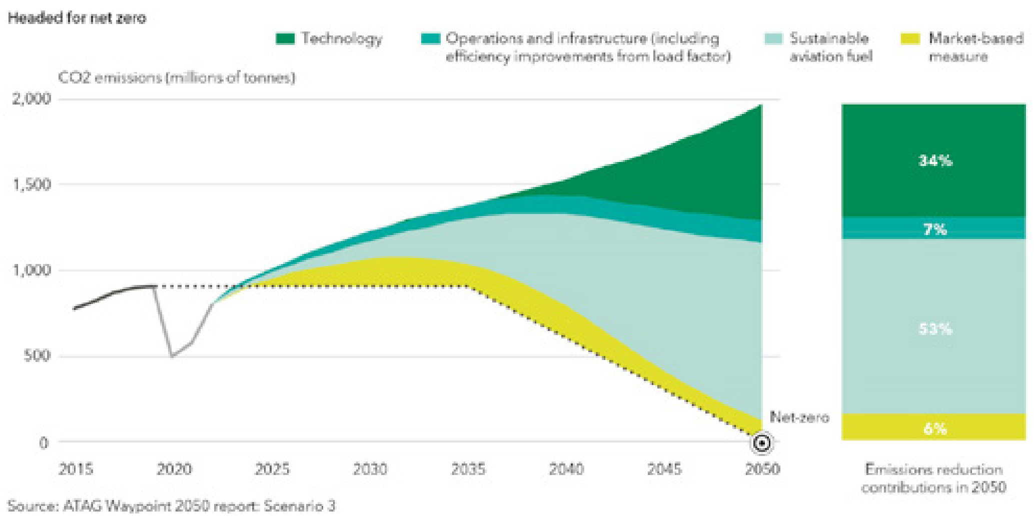


*Figure 1 – Heading for Net Zero*

development and deployment.

As the availability of bio-derived SAF is limited, since agricultural areas should be dedicated to food production, the main contribution to SAF/e-fuel production in the future will have to come from the production of synthetic fuels, which is processed in two-steps:

- the generation of synthesis gas, possibly from low-carbon feedstocks (like methane, waste gases, etc.) integrating also renewable hydrogen and captured $CO_2$;
- a fuel synthesis section, where synthesis gas is transformed into a synthetic liquid fuel, equivalent to traditional fossil fuels; Liquid methanol from methanol synthesis (2) and Liquid hydrocarbons from Fischer-Tropsch synthesis are the main options.

Currently, SAF production is energy and capital intensive and to support the required learning curve for the 2050 targets, it is necessary to invest in scaling up production technologies to industrial maturity that may leverage on largely available feedstocks with high efficiency and minimum $CO_2$ emission.

## SCT-CPO: an innovative, scalable and low carbon emission process

The most utilized synthesis gas production processes are:

- Steam reforming (SR);
- Partial oxidation (Pox);
- Autothermal reforming (ATR).

In addition to the available listed technologies, "Short contact time catalytic partial oxidation" (SCT-CPO) represents the most innovative one, based on a very fast catalytic reaction that allows contact times between reagents (hydrocarbon, steam, air/oxygen) 10.000 – 50.000 times shorter than the ones of traditional catalytic processes for the production of hydrogen. The fast and selective chemistry of the process is confined inside a thin (<1 mm) solid–gas inter-phase zone surrounding the catalyst particles; here, the gas molecules spend a limited time (10-6 seconds) at temperatures variable between 600 – 1200° C, while avoiding the propagation of reactions into the gas phase, that has to remain at a "relatively low" temperature.

This condition favours the formation of primary reaction products (namely CO and H2) inhibiting chain reactions. Moreover, the very high catalytic surface temperatures inhibit its deactivation phenomena related to chemical poisoning effects. For these and other related reasons, this chemical process can be carried out in very small reactors having a very high flexibility towards reactant types and flow variations.

It has also been found that several hydrocarbon feedstocks, even containing sulphur and aromatic compounds, can be fed to a SCT-CPO reactor for producing synthesis gas.

A long-term R&D effort is driving towards the industrialization phase of a technology whose main advantages concern:

- Reduction of investment costs and energy consumption;
- Reduction of overall $CO_2$ production and possibility of an almost complete $CO_2$ capture for the generation of Blue Hydrogen;
- Flexibility towards feedstock composition & production capacity.

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Leveraging on multidisciplinary engineering capabilities and 30 years of experience in integrating technologies and systems in compact layout and robust design for offshore operations, Fores Engineering (Fores) has contributed to the industrial scale-up of the innovative CPO technology with 3 different plant references (designed, built and commissioned), each one addressing different challenges:

- Small dimensions with technical and operational simplicity;
- Possibility of modular construction of prefabricated and skid-mounted units;
- Specific tailor-made design solutions (Mega Syngascooler) on large industrial scale applications.

## The first pilot plant with SCT-CPO technology for the production of hydrogen (Milazzo 2004/ 2005)

Fores has successfully accomplished the design and construction of a first pilot plant through a Lump Sum Turnkey (LSTK) contract, starting from a conceptual engineering developed by ENI (client & IP owner of the

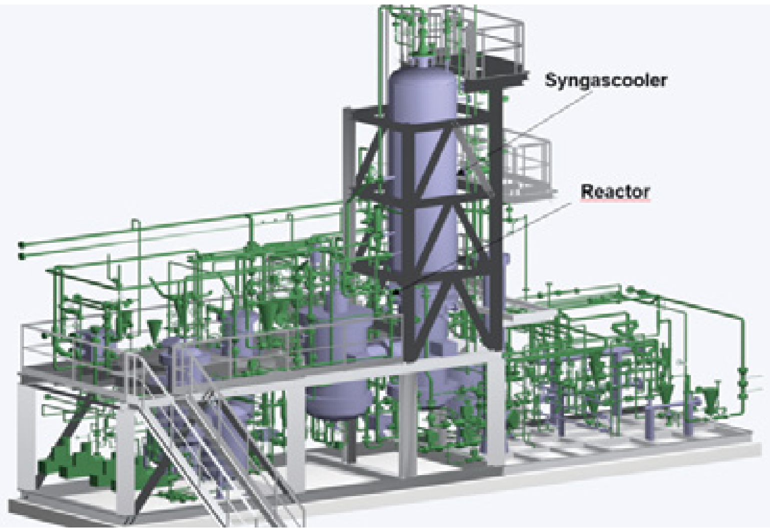


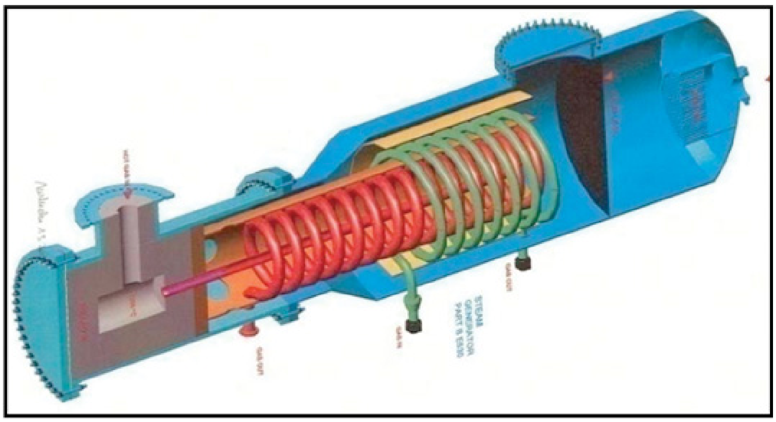

*Figure 2 - 3D view of the first pilot plant operating the SCT-CPO technology built by Fores*

process). The contract included basic engineering, detail engineering, modularisation, plant skid construction, assembly to the site, pre-commissioning and start-up assistance.
Despite the low detail level and the many uncertainties present in the conceptual engineering, the plant was designed and built in only 14 months.
The pilot plant illustrated in **Figure 2** consists of all the process and utilities units needed for the production of hydrogen from methane or other hydrocarbons:

- Compression of air and methane;
- Methane desulphurization;
- Reagents pre-heating;
- STC-CPO Reactor;
- Syngas cooler/steam generator;
- CO-shift;
- Hydrogen purification by PSA;
- Hydrogen compression.

The project aimed to integrate the know-how and resources of the Client and the Contractor to achieve a higher synergy, while introducing innovative design solutions for the plant critical equipment engineering and manufacturing design. An example is relevant to the syngas cooling system, that needs to cool down the syngas out of the reactor from the typical high reaction temperature (800-1000°C) to about 300°C, prior the feed in the "water gas shift" process section.
The syngas cooler system developed by Fores, based on proprietary know-how and a preliminary thorough risk analysis, is specified as a coil-type heat exchanger and has demonstrated to be a better solution both from technical and economical point of view compared to the traditional shell&tube waste-heat boiler, as indicated in the original conceptual design. After several operating years, featured by 200+ start-ups and shut-downs, the solution has demonstrated to be an "intrinsically safe" gas cooling system with extraordinary performance regarding resistance to thermal gradients, process stability and feedstock flexibility.
The 3D view of the reactor-syngas cooling system is showed in **Figure 3**: the 3D model design was carried out by Fores to achieve the best synergy in terms of layout interoperability among the different plant' sections, overall process effectiveness, and easy transportability and maintenance.
Fores skid-based plant design demonstrated several advantages, in particular for the overall project timeline thanks to a concurrent engineering mode through, all the project execution phase and availing a fast track delivery.
As a matter of fact, the plant sections, manufactured in several different skids, have been pre-assembled at Fores site to carry out the factory acceptance test and then separated in standard modules for an easy transportation at the plant location for final test and operation (see **Figure 4**).

*Figure 3 - 3D view of the reactor-syngas cooling system*



## Second SCT-CPO plant with CPO technology for the production and distribution of hydrogen for Mobility ("Zero Regio" project – 2006/2008)

After the success of the first application, Fores engaged in a new and challenging case for the technological development in the "Zero Regio" project.
Although the capacity of this plant (50 Nm3/h) is 10 times lower with respect to the first plant (500 Nm3/h), the footprint of the solution is 25 times compressed to generate a sustainable solution for a small-scale hydrogen application. The plant was built to generate hydrogen "on site" at a multi-fuel distribution station, being the first Italian station also providing hydrogen among the fuel supplies for

*Figure 4 – Preassembly of the skids at Fores site (Forlì)*

mobility. The project involved the construction of the entire section of the hydrogen production plant including the auxiliaries, featuring in particular:

- The SCT-CPO reactor and a quencher;
- The Water gas shift reactor;
- A PSA unit;
- Utilities;
- DCS and control room;
- Mechanical and instrumental interconnecting.

Fores has successfully accomplished the design and construction of this small-scale plant through a LSTK contract, starting from a basic engineering design developed by ENI.
The contract included the improvement of basic engineering and detail engineering design, modularisation and compression, the procurement and the plant skid construction and supervision to commissioning and start-up assistance.
The biggest challenge faced by Fores lied in the need of a high compression factor for a high-density modularised technological solution ensuring, at the same time, a proper access for all maintenance activities in line with reliable operation, consistently with Oil&Gas safety requirements.
The plant was built in Fores own workshops and started running in June 2008 at the multi-fuel station in Mantua (Italy) with a lead time of only 11 months from Notice to Proceed.

During its operations, the system confirmed the technology expectation and the EU sponsor of the project declared it suitable and approved for small-

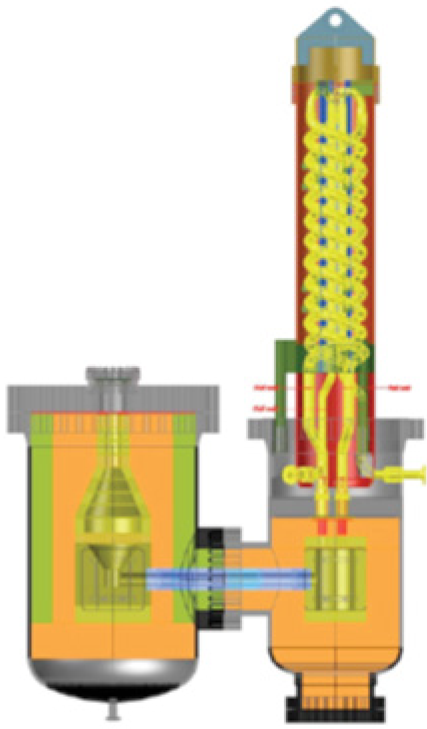


*Figure 5 – SCT-CPO critical process package (Mixer-Reactor-syngas cooler)*

3D model | Casing structures | Final completed assembly

*Figure 6 – Taranto plant from 3D model to operational in refinery*

scale production of hydrogen at fuel station for hydrogen vehicles.

## Third plant with SCT-CPO technology a commercial scale demonstration plant

### (Taranto refinery project – 2019/2021)

For any innovative technology the final and most challenging experience is the "scale up" to industrial maturity for commercial operation. Fores has successfully accomplished this step in an integrated plant-type solution provided for Taranto Refinery, with a production design of 10'000 Nmc/h of hydrogen.
Based on the positive experience of the syngas cooler proposed by Fores for the pilot plant in Milazzo, the Client entrusted Fores with the development of the best solution for syngas cooling and its complete design both from thermal and mechanical point of view.
Also in this case, Fores proposed a coil-type heat exchanger and carried out its complete design (from conceptual to detail engineering) with the objective of obtaining the best integration with the SCT-CPO reactor, which was based on the Client's IP.
The plant has been contracted on a LSTK basis, starting from a basic engineering developed by ENI. The activity involved the process and detail engineering, the complete engineering and construction of critical process package (Mixer-Reactor-syngas cooler, see **Figure 5**), module engineering and packaged unit construction, as well as assistance on the site during the assembly, plant operation and pre-commissioning phases (see **Figure 6**).
The Reactor-Syngas cooling process package is the core of SCT-CPO technology and was designed taking into account the experience in engineering and construction of the two previous projects (Milazzo, Zero Regio) and the operating experience of the Milazzo pilot plant.

## Future Scale-up of the process for higher capacities and enabling design features

On the basis of engineering and operating experience in three CPO plants, in the past years Fores has also explored the scale-up potential of the CPO process and its adaption to various client's downstream applications in several engineering studies:
- a 15,000 Nm3/h unit to produce hydrogen for a 20 MW hydrogen Combined Cycle gas turbine power plant for an Italian power producer;
- a 10,000 Nm3/h unit for debottlenecking a steam reformer in a refinery;
- a 8,000 Nm3/h unit with temperature control and integrated CO-shift heat exchanger;
- a single stream 600,000 Nm3/h CPO unit for a mega-methanol plant for a Middle East client.

For the last on the list, a new single stream "mixer-reactor-syngas cooler" concept for a capacity of 600.000 Nm3/h has been developed. Such large gas

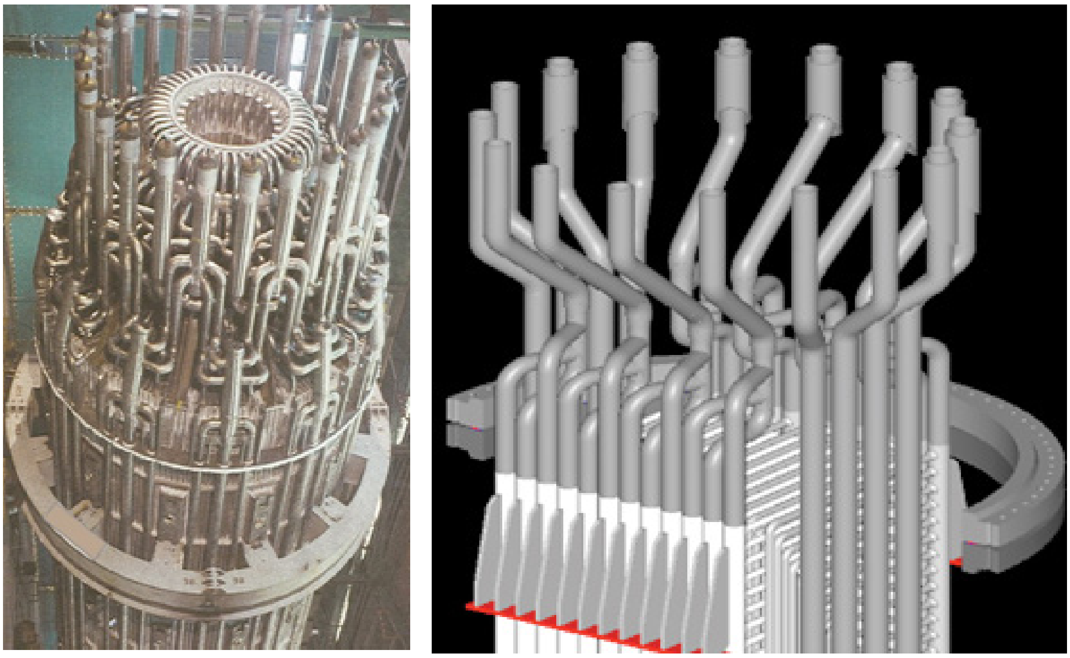


*Figure 7 - Details of feedwater inlet and steam outlet headers: 7a) Tampa operated syngas cooler downstream coal gasification process (courtesy of J. Wilhelm, TecfinTRE-Engineering Excellence Library; 7b) Fores Mega Syngas cooler design downstream gas-fuelled CPO process*

quantities exceed by far the scale-up limit of the existing syngas coolers and waste-heat boilers, which are based on a fired-tube design.

In order to win the challenge, Fores has developed an in-depth engineering analysis on the largest syngas cooler ever built: designed to cool down 400,000 m3/h "dirty syngas" from a Texaco coal gasifier in an IGCC power plant (one of the earlier application featured with $CO_2$ capture and Hydrogen ready gas Turbine). This "water tube" syngas cooler was successfully in operation for 12 years at Tampa Electric 'zero emission' hydrogen power station and confirmed the industrial maturity of the design.

For the natural gas-based mega-methanol project, Fores has developed a simplified design version with a capacity of 600,000 Nm3/h, maintaining the "water tube" principle and the proven mechanical design elements of the Tampa syngas cooler, and issuing a relevant patent application for this enabling feature to such large scale up design. The most challenging part in developing Mega Syngas coolers is the design of the headers for feedwater inlet and steam outlet (see **Figure 7**).

**"On the basis of engineering and operating experience in three CPO plants, in recent years Fores Engineering has also explored the scale-up potential of the CPO process and its adaption to various client's downstream applications in several engineering studies**

## The right partner to design and execute a variety of industrial-scale applications on CPO technology: Fores Engineering

As illustrated in the above projects, Fores has given a significant contribution to the development and scale-up of CPO technology to industrial maturity. During these projects, Fores has gathered a significant engineering know-how, for the design of turnkey supply of CPO based syngas production plants of all sizes. Three operating references over the entire range of capacities from 50 to 10,000 Nm3/h indicate that CPO technology is a viable solution for synthesis gas production, ready to be integrated with downstream synthesis processes for the production of e-fuels and SAF. For small and medium production capacities under 10,000 Nm3/h, modularised preassembled and pre-commissioned CPO units represent by far the most cost effective solution.

Considering the entire capacity spectrum, the performed engineering studies confirm an interesting upscale potential to mega size units for large industrial applications, which offer economies of scale that may effectively contribute in the future to produce synthetic "low to zero emission" fuels at affordable prices.

Along with technological maturity, where Fores is ready to provide its engineering know how and

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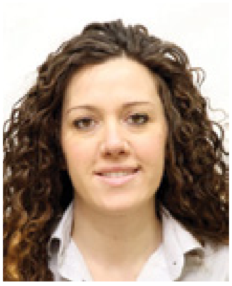
digitalisation platforms aiming to a continuous design and operational improvement, at industrial level there is a consistent value chain maturity to be developed to enable sustainable CAPex and OPex.

While for modular small-size application Fores is capable to serve as one-stop-shop for a turnkey delivery integrating Clients and Partners process IP, for large-size applications, Fores focus its value proposition in the engineering and construction of the critical part of the CPO process, along with all Digital and Safety systems design and delivery. Based on its durable experience in serving offshore clients and large contractors, Fores provides "tailor made solutions", not only on the equipment packages (modular or plant-based), but also on maintenance activities aiming to secure an overall lifecycle sustainability.

## Literature


*1) Air Transport Action Group, Waypoint 2050 Report, "A vision of net-zero aviation by mid-century", April 2023*

*2) Basini L., Mondelli N., Mondelli C., Furesi F, Impiantistica Italiana, N. 1, 2022*


## Maria Auriemma

Maria Auriemma is Process and Mechanical Discipline Manager in Fores since 2019, leading the design and engineering of several challenging projects in Petrochemical and Oil&Gas fields. She started her career as Process Engineer in ENI-Versalis and developed a solid technical background on the full engineering span (Feasibility study, Basic Design, FEED, EPC), further contributing to Energy Transition targets, including the solutions' maturity and scale up of Hydrogen related projects.

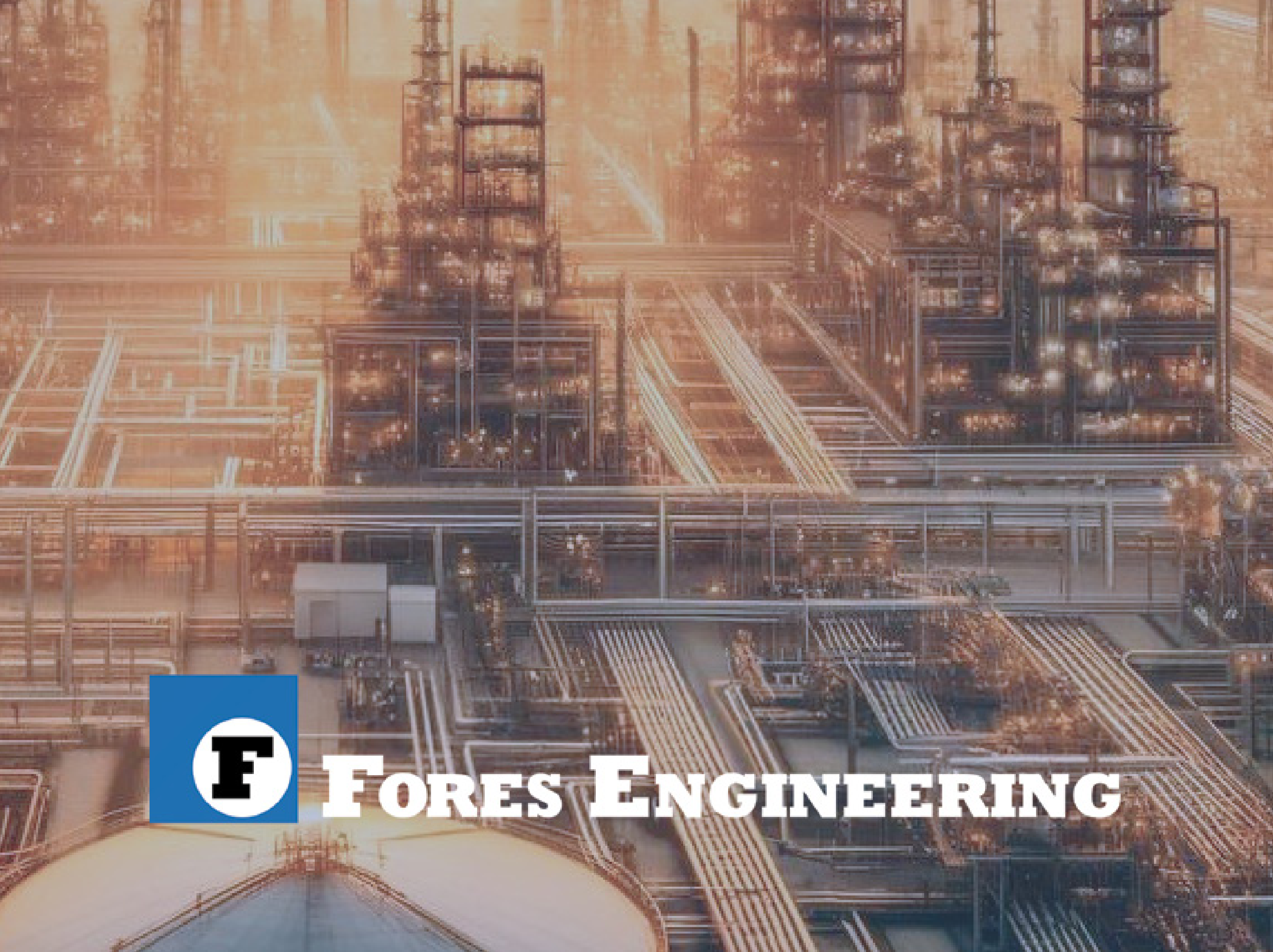


## Fabio Nardone

Fabio Nardone is the Head of the Business Development in Fores, since 2019 leading business growth and diversification, with a special focus on innovative solutions for the Energy Transition & Digital Transformation. He has been working in the Energy industry for more than 15 years in companies with high technological content in a very competitive arena. During his professional career, he has built up a solid experience in technological innovation and international strategic and commercial partnerships management, which are a pivotal for his current mission.

# SHAPING THE PRESENT FOR A SUSTAINABLE FUTURE

FORES INNOVATIVE SYNGAS PRODUCTION FOR DECARBONISED E-FUELS' VALUE CHAIN WITH CPO TECHNOLOGY INTRODUCES THE DAWN OF A NEW TOMORROW



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