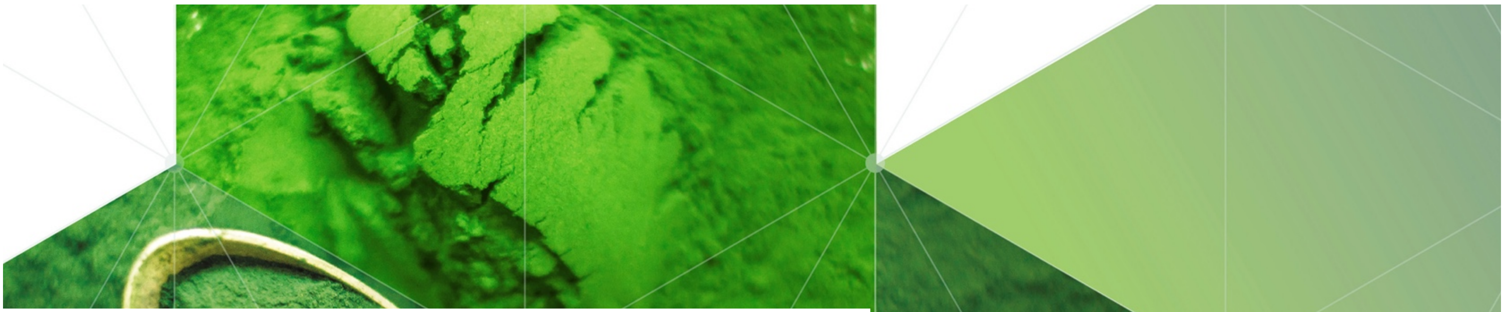
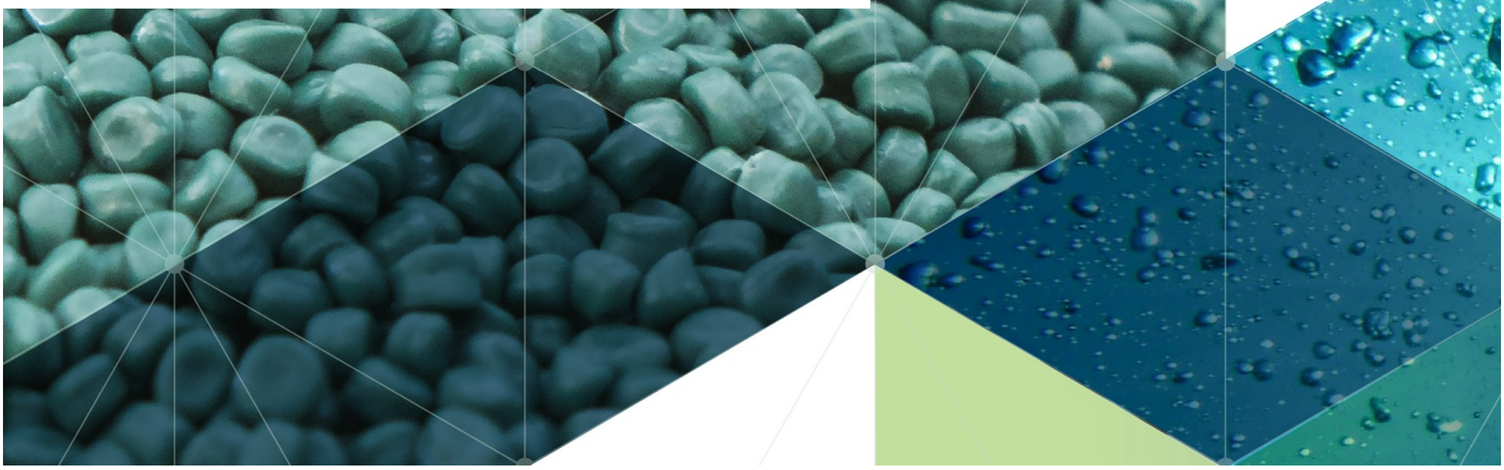


The role of Green Chemistry in accelerating and enabling the energy transition, via circularity, zero carbon and bio-based products

January 2020



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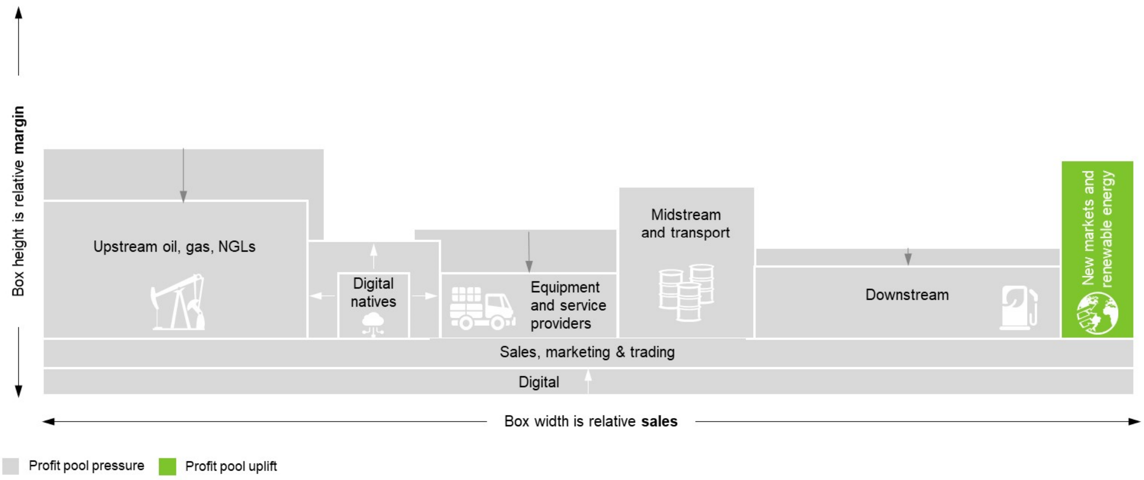
1. Context

The energy transition is driving both producers and customers to rethink their future needs and what kinds of products and solutions will be required to enable a sustainable future in terms of emissions waste and economics. The scale and complexity of the shift required are huge, but it will be driven by asset owners' increasingly moving capital employed from traditional, legacy activities to new 'greener' assets and by customers placing a premium on sustainable products and consumption.

> *Energy transition is the future ecosystems' driving force*
>
> F. Di Amato – Chairman of Maire Tecnimont

Profit pools will shift (Figure 1) – increasing pressure to address sustainability issues on the core business and reduce CO2 emissions from legacy assets is creating new opportunities for traditional players and new entrants, opening up new markets. Environmental remediation, renewable energy, recycling, cleaner fuels are just few examples of the new business areas. As plastics recycled from waste increase in volumes for instance, oil required as feedstock for the plastic industry will significantly reduce, shifting profit pool from the hydrocarbon industry to new segments of the value chain (e.g. waste collection and management, recycling, petrochemicals).

Figure 1: Energy transition is shifting profit pools along the Oil & Gas and Energy value chains

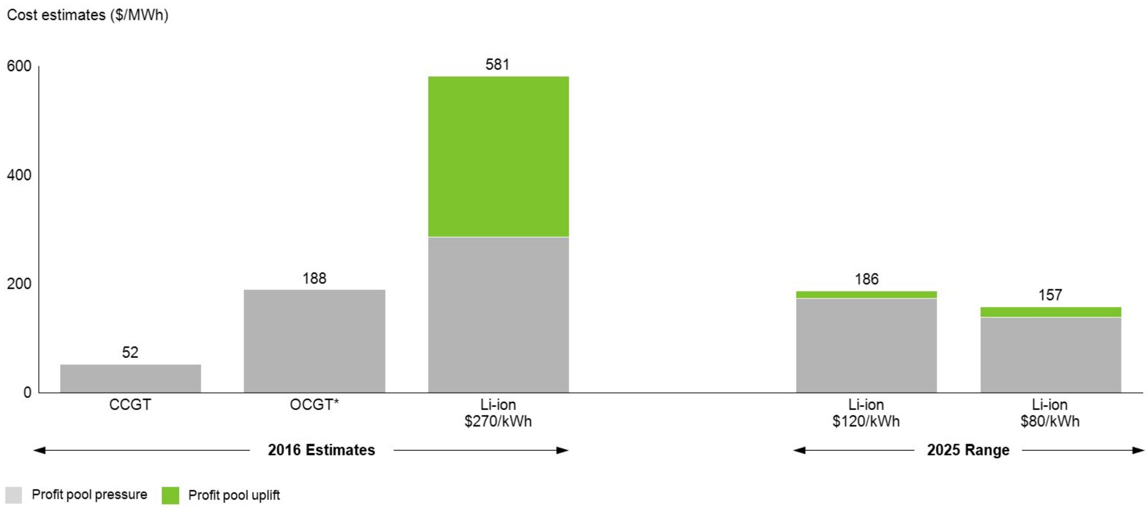


Source: Bain & Company

The pace and scale of the energy transition has to date been driven largely by the technological advances in renewable power generation, regulatory support and falling costs of small-scale energy storage. By 2030, significant cost improvements are for instance forecasted in the area of renewable energies as wind turbine size approach industrial scales or as solar PV module price – and therefore marginal costs – is expect to drop by 30-40%. Therefore, while we see renewable power evolution and impact continuing to rapidly develop, we are anticipating the next 'phase' of change to increasingly reduce the presence of chemical, plastic waste, lubricants in waste and increase in recycling, to see hydrogen scaling featuring as a long term solution and the continued scaling of bio feedstock into transport fuels and petrochemicals.

> *We are ready to invest in the emerging Golden Era of Chemistry*
>
> P. Folgiero – CEO of Maire Tecnimont and NextChem

Figure 2: Levelized cost of electricity reduced by 30% in 2025 with batteries reaching OCGT plants level



Source: Bain & Company

Technological innovation and in parallel initiatives from international bodies to "regulate" the plastic waste will push for cleaner businesses. In this regard, numerous initiatives were recently launched:

- **United Nations Environment Programme** (UNEP): established a Global Plastic Platform, supporting countries to tackle plastic waste pollution by changing design, production and disposal habits;

- **World Bank**: supports policy reforms and finance investments in solid waste management;
- **Chinese government**: banned the import 24 kinds of foreign solid waste, including plastics, paper products and textiles;
- **EU Commission**: issued a specific strategy for circular economy, declaring that all plastic packaging must be either reusable or cost-effectively recyclable by 2030; thus pushing for the higher use of plastic waste;
- **American Chemistry Council:** defined a target of 100% for US plastics packaging to be recyclable or recoverable by 2030, and 100% plastics of packaging to be reused, recycled, or recovered by 2040; also in this case, increasing the attention towards re-use of plastic waste.

2. Responding to the challenge

With the aim to accelerate the technological innovation in the energy transition, Maire Tecnimont, major global EPC contractor for the refining, petrochemical and fertilizers industries has constituted a dedicated technology vehicle. In early 2019, NextChem was born, consolidating Maire Tecnimont capabilities, technologies, patents and projects, to develop technological solutions with main focus on:

1) Improve re-use of waste through circular economy
2) Use of biological components as feedstock
3) Reduce industrial process pollution

The three areas will be enabled by bold and cost effective technology innovation.

> “*Energy transition requires industrial players to invest in structural interventions: green operations, sustainable products and low carbon supply chains*”
>
> P. Folgiero – CEO of Maire Tecnimont and NextChem

Improve re-use of waste through circular economy

Circularity implies a process of restoration and regeneration in which materials constantly flow around a 'closed loop' system, rather than being used once and then discarded. Above all, it implies keeping the value of these elements in the economy, while limiting leakage into the natural environment.

In 2019, global plastics production resulted in ~300MT[1]; therefore, assuming a relatively constant business activity, the number could potentially increase up to ~400-500MT by 2030.

With this scenario threatening the environment, major governments and companies are taking increasing actions to address the issue.

Several complementary methods of re-generating plastic wastes exist as of today, with different degrees of maturity. The most general differentiation is between mechanical and chemical solutions. While former implies the recycling of recyclable waste into “new” (secondary) plastic raw materials, therefore without changing the basic structure, the second method enables to treat a wider range of non-recyclable plastics waste (e.g. multilayer, mixed-material plastic waste) and turning them into valuable chemicals.

Generally, while mechanical recycling of plastic waste is nowadays the most diffused technology, thermochemical recycling allows to address de-contamination and to some extents (varying case by case) the plastic degradation phenomenon. Therefore, as restricting policies are promulgated, chemical recycling of plastic waste becomes necessary in achieving these targets.

Within the context of chemical recycling, NextChem is focusing on pyrolysis and gasification. Pyrolysis consists in cutting the polymer chain in a non-selective way through pyrolysis process. Therefore, this reaction involves the molecular breakdown of larger molecules into smaller molecules in the presence of heat – leading to the generation of a pyrolysis gas. The outcome product can eventually be further treated through other methods (e.g. steam crackers, polymerization) to close the cycle and turn back to polymers. Main feedstock type is waste plastic mix. Gasification involves heating the waste plastic with oxygen, to produce valuable industrial “circular hydrogen” which can be used to produce – through traditional refineries – diesel and petrol or eventually plastics – through additional steps (e.g. methanation/methanol synthesis, methanol to olefins, polymerization). Main feedstock type is waste plastic mix (or Refuse Derived Fuel, RDF). NextChem is furthermore involved as coordinator in the EU Demeto project focusing on chemical de-polymerization of PET at industrial scale.

[1] Source: Grand View Research – Plastics Market Analysis and Segment Forecast to 2025 (2018)

Case Study 1 – Integrated plastic recycling approach

NextChem has developed a portfolio of plastic waste recovery solutions based on the concept of applying the best available technology according to the recyclability grade of the plastic waste input. Highly recyclable plastics may have their best valorization through technologies able to produce new raw materials which can substitute virgin polymers for the production of plastic goods. Non-recyclable plastics may find their best destiny in a chemical process able to separate them into their basic molecules and transform them in new chemical feedstock.

The proprietary **MyReplast Upcycling Technology** combines both mechanical and thermo-chemical treatment, allowing to transform rigid plastic wastes back into compounded shapes. The industrial scale plant – located in Brescia (IT) – has been described as EU's most efficient and economically sustainable mechanical plastic waste recycling plant. With an overall capacity of 40KT per annum (corresponding to the average total plastic consumption of 1M people and to 100K m3 of landfill saved per year), a 95% efficiency and a total CO2 reduction of 8.5KT per annum. Three key pillars characterize the recycling plant: (1) Advanced sorting process: cutting-edge sensors, sorting recycling sensors able to sort all ranges of plastic materials, being PP, HDPE and LDPE, followed by PS, ABS and PA the major polymers of interest; (2) High efficiency process: sequential steps from mechanical sorting to grinding, washing and color separation; (3) Upcycling process: finishing plastic flakes to be upgraded into quality material by compounding and extrusion technologies – able to meet even more complex end-uses (e.g. automotive).

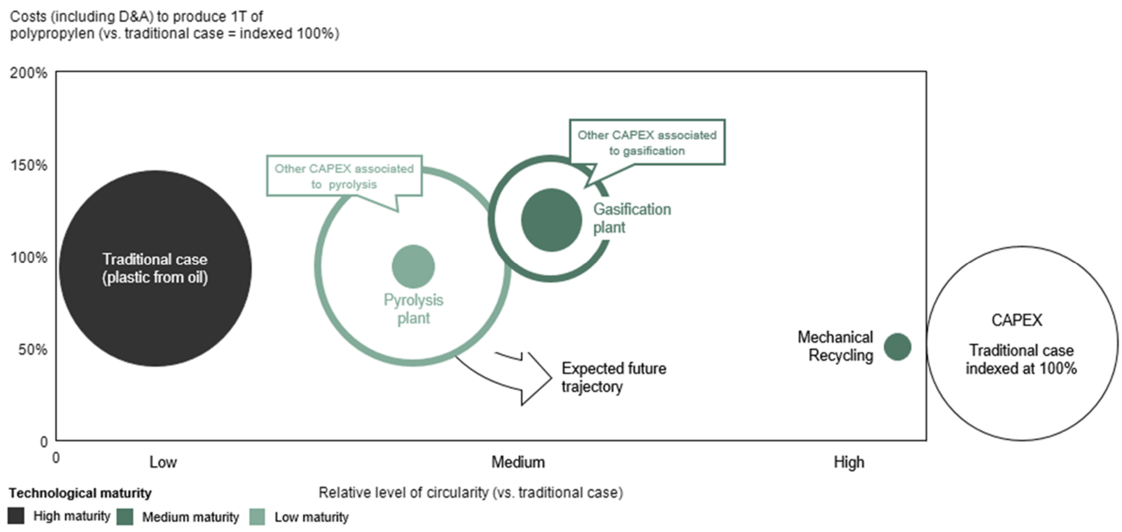
Moving to the **chemical recycling** of plastic waste, NextChem provides two alternative technologies – gasification and pyrolysis – to provide a second life to municipal solid wastes, refuse-derived fuel and non-recyclable plastics. Concerning the gasification process, NextChem has developed an economically viable model to transform feedstock into "circular hydrogen" Syngas. NextChem's technology advantage lies specifically in the flexibility and modularity of the different process phases according to client needs, NextChem can easily integrate methanation, methanol synthesis, methanol to olefins, polymerization and compounding to generate respectively natural gas, methane, monomers, polymers and compounded plastics.

Also for pyrolysis technology, NextChem is developing a specific solution. Besides achieving high conversion efficiency rate (e.g. minimizing formation of waxes), such technology may be integrated, upon client needs, with additional downstream phases such as steam cracking, polymerization and compound.

Below an illustrative graph to compare plastic recycling technologies' current competitive positioning versus the more traditional approach of plastic from oil (e.g. naphtha via a naphtha cracker). In particular, four different variables are taken into considerations: (1) Total costs to produce 1T of polypropylene: taking into consideration all operating costs, including relative depreciation and amortization (traditional case indexed at 100%); (2) Relative level of circularity (vs. traditional case): qualitative variable, computed as the weighted average of: a) share of circular outputs from process; b) volume of green feedstock; (3) Total CAPEX required (traditional case indexed at 100%); (4) Level of technological maturity

As for the case of pyrolysis and gasification plants, the standard capacity of such solutions is much smaller compared to the capacity of subsequent processes plants (e.g. respectively naphtha crackers for pyrolysis and methanol-to-propylene for gasification). Therefore, these processes requires a combined cycles of green feedstock (plastic waste or RDF) and conventional feedstock (naphtha, methanol) to run a full cycle.

Figure 3: Illustrative comparison of mechanical and thermo-chemical processes vs. traditional case of plastic from oil



Note: The following assumption on raw materials costs are considered: Naphtha = 534 US$/ton; Methanol: 342 US$/ton

Source: NextChem

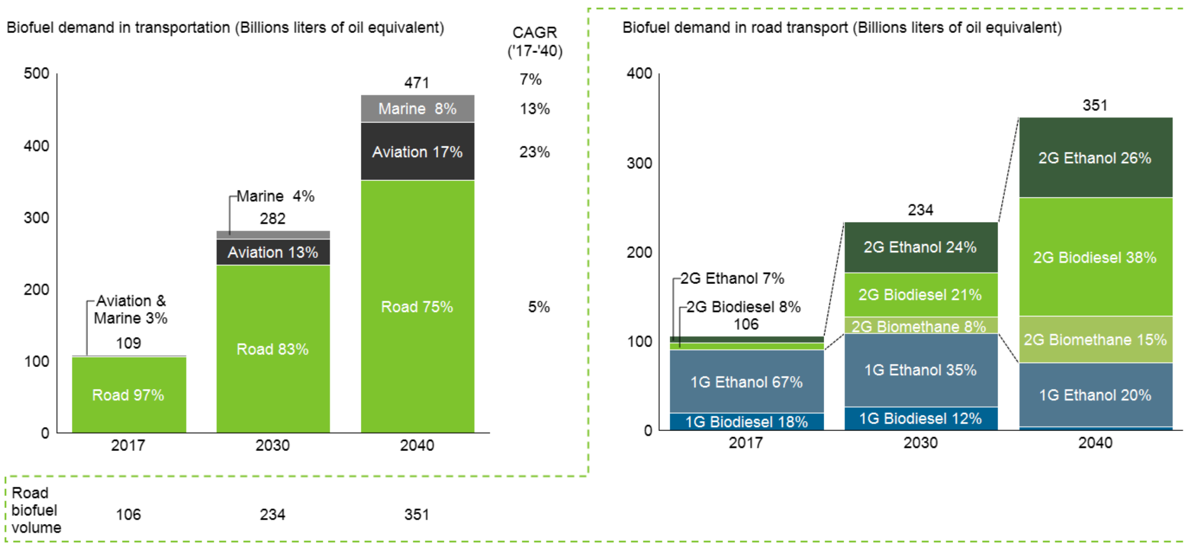
Use of biological components as feedstock

According to the type of feedstock, the International Energy Agency (IEA) recognized three main types of biofuels:

- **Conventional:** fuels produced from food crops, utilizing the starch, sugar and fat in them;
- **Advanced:** fuels produced from non-food crop feedstock, which are capable of delivering significant lifecycle greenhouse gas emissions savings compared with fossil fuel alternatives, and which do not directly compete with food and feed crops for agricultural land or cause adverse sustainability impacts;
- **Novel advanced:** fuels produced from Algae, with higher yield and GHG emissions.

Biofuels have a vital role, together with electric and CNG vehicles to tackle decarbonization in the transport sector. Indeed, global biofuel demand is expected to increase steadily in 2017-2040, with a compound annual growth rate of ~7% - reaching an overall volume of ~470B of liters of oil equivalent globally. Advanced biofuels (or 2nd generation biofuels) will be the driving force of this evolution, as they mitigate sustainability risks associated with changing land use and competition over food production.

Figure 4: Biofuel demand evolution (2017-2040)



Source: Bain & Company

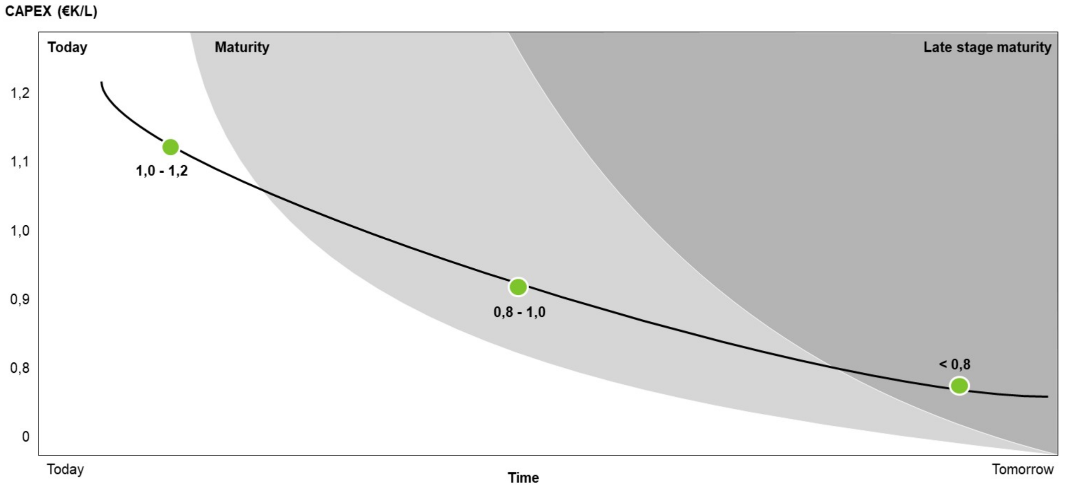
Case Study 2 – Small scale HVO plant: superior performances through modular app

Renewable Diesel (also known as Hydro-treated Vegetable Oil or HVO) and traditional Biodiesel (also known as Fatty Acid Methyl Ester or FAME) are often confused. Both can be made from vegetable oils and residual fats, but are produced differently: Biodiesel by Trans-esterification and Renewable Diesel by Hydro-treating. While FAME presents limits of blending with fossil diesel, Renewable Diesel is a drop-in fuel that meets the petroleum fuel ASTM D975 and EN 590 standards. It overcomes blend limits and is currently used in existing diesel engines without any constraint, and with superior properties versus fossil and FAME.

In the Hydrogenated Vegetable Oil space, while main projects as of today focus on large scale plants (200-600KT per annum), NextChem has in its portfolio, in partnership with the American Saola Energy, an innovative solution of small scale plants (20-40KT per annum). Such solution enables to tackle feedstock availability limitations while reducing logistics, transportation and operations complexity and costs. Furthermore, small scale model allows to distribute the treatment of feedstock next to its origination, then connecting the HVO biofuel to storage tanks. Plants can also be easily integrated to bioethanol production units, to use the Distilled Corn Oil by product as feedstock. In the first industrial scale plant in Kansas (US), with a capacity of 35KT per annum using mainly corn oil as feedstock and with an HVO production efficiency of 96%, NextChem is going to operate an innovative and proprietary pre-treatment and hydro-treatment technology that allow to treat large variety of feedstock, including the most “difficult ones” (e.g. Acid oils).

When looking at the future development, NextChem’s aim is to standardize packages and equipment with a modular approach in order to bring down the capex costs below €0,8K/l from the current €1,0-1,2K/l, and in parallel to ensure a fast time to market and a simple project execution.

Figure 5 – NextChem HVO technology cost curve, CAPEX over time



Source: NextChem

Reduce industrial process pollution

As of today, while transportation usage is the "hydrogen holy grail", industrial applications present the most concrete potential for development. Three main types of hydrogen are capturing attention:

1) **Grey hydrogen:** hydrogen is produced from natural gas through Steam Methane Reforming. The process concurrently produces CO2;
2) **Blue hydrogen:** thermal treatment of methane to produce carbon and gaseous hydrogen, but no CO2. The process can serve as a bridge to longer-term sustainable solutions. In this segment NextChem is focusing on electric steam reforming and CO2 mineralization;
3) **Green hydrogen:** hydrogen is produced from electricity and water through electrolysis. If renewable electricity is used, there is zero emissions generated.

Grey hydrogen is the main solution applicable in a low carbon price environment. Yet, to sustain global decarbonization trend, blue and green hydrogen are expected to grow significantly.

As of 2017, the total hydrogen merchant market was estimated between ~$115-130B[2], with an expected compounded annual growth rate (from 2017 to 2025) in the range of ~6-7% - landing in 2025 at a terminal value of ~$200B.

Looking at practical applications, the largest hydrogen demand arises from the chemical industry (~65% of total consumption). Yet, in the view of energy transition and sustainability, potential application could be extended to other industrial scopes such as refineries and mobility. In this regard, current economics result still insufficient for a scale deployment. In fact, even in the most favorable conditions, green H2 production cost results in ~4-5€/kg vs. ~2€/kg for SMR.

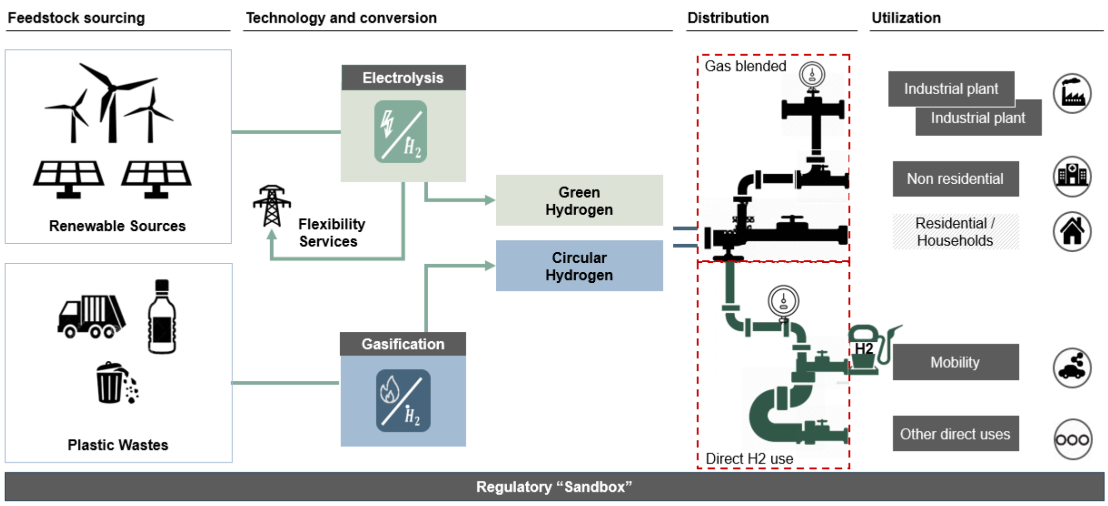
[2] Source: Bain & Company

Case Study 3 – Green and circular hydrogen production scheme: leveraging on renewables and plastic wastes to create new routes for hydrogen

With an eye to the future, costs and technology are the major trends to monitor; in fact, CAPEX reduction as well as decreasing marginal cost of electricity could dramatically lower the hurdle and increase H2 competitiveness. On top of that, “regulatory sandbox” and key stakeholders partnership must also play a role of key enablers. The former in the case of proper incentives schemes, while the second to socialize costs and develop necessary advantages for a future at larger scale.

Below a graphical representation of NextChem ongoing studies to produce and therefore inject green hydrogen and syngas in the gas distribution networks. The potential initiative would leverage on the increasing appealing of renewable energy sources as well as the vast abundance of plastic wastes to produce respectively green hydrogen and syngas, through technologies of electrolysis and gasification. Once produced, these chemicals could be used as feedstock for steel production plants or refineries or could be distributed and used to feed a wide variety of areas both indirectly or directly. In the first case, industrial plants, non-residential structures (e.g. hospitals) and residential places could be the main potential clients, while for the direct case the mobility area is considered as key target. (Figure 7).

Figure 6: Overview of potential green experimental initiative related to green and circular hydrogen



Source: NextChem

3. Partnerships and practical steps

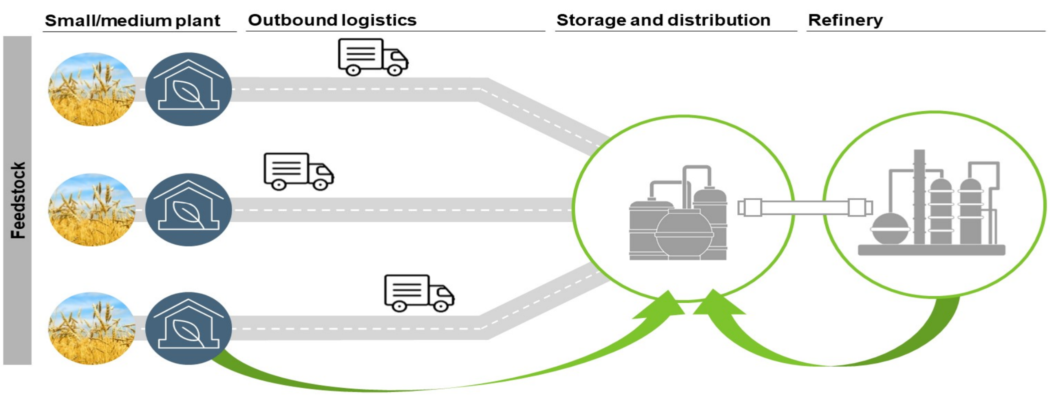
The new industry shape will include a much greater rate of collaboration across large scale and distributed green companies. Therefore, the site of the near future will likely comprise – in a distributed or integrated logic – oil refining, petrochemicals production, renewable power generation, bio feedstock and fuel production, waste collection and recycling, hydrogen production.

Indeed two “green” industrial business models will emerge:

(1) Brownfield integrated business model – where green technology units will be integrated into industrial clusters to leverage existing infrastructure (storage, logistics) and assets (refinery conversion units). This solution will be typically preferred in large industrial clusters contexts where large feedstock volumes are needed or available. Examples of technologies are waste to methanol, waste to fuels, hydrogen production, waste plastic to chemicals. This model offers a great solution for green technology adoption to exploit advantages of scale and costs while maintaining flexibility and choice.

(2) Distributed business model where green technology / plants will be of small-medium size and distributed on the territory. The aim is to be in proximity of the feedstock and reduce inbound logistic costs and complexity. Renewable fuel is a good example of the potential for distributed business: to reduce the biomass logistical constraints driven by high volumes, companies decentralize biomass processing locally. Biomass is then transported in liquid status, which considerably reduces both costs and complexity and then stored and transformed into fuel at already existing refineries, thus leveraging the existing assets and reducing the capex needed for the conversion (such solution typically requires a retrofitting of the FCC to enable co-processing).

Figure 7: Overview of a distributed business model



Source: NextChem

> *The industry will embrace agile ways of working: this implies to fail-fast technology, to wider collaborations, to move quickly from pilots to industrial scale*
>
> P. Folgiero – CEO of Maire Tecnimont and NextChem

In both models, distributed or integrated, given the innovative aspect of both the business model and the technology, there is a common trend of developing partnerships for joint development between the different actors of the value chain, to socialize costs and risks, but also to develop the right conditions to test the first pilots. Indeed, there is a need to both secure the intake of the new feedstock (waste, organic biomass) and ensure a stable offtake from the market. Therefore, the ability to develop partnerships between technology providers, industrials / energy companies, and feedstock management companies (being it waste or agricultural biomass) is a relevant key success factor for the green industry development.

> *“We see a world of opportunities from co-development of disruptive technologies and JV to create green chemistry capacity and joining forces to further the debate*
>
> P. Folgiero – CEO of Maire Tecnimont and NextChem

Driven by a strong priority of accelerating the innovation in the energy transition and making it real, NextChem is collaborating across the green chemistry value chain. NextChem has launched different innovative partnerships with Eni, to strengthen the competitiveness – as chemical green hub – of Porto Marghera (Venice) and Livorno. In the Porto Marghera case, the two companies have signed a partnership agreement to develop and implement a conversion gasification technology to produce hydrogen from solid urban waste and non-recyclable plastic - while minimizing environmental impact. Moving forward, NextChem expanded its collaboration with Eni by launching a commercial cooperation agreement to build-up a “waste to methanol” plant in Livorno refinery. Also in this case, the vehicle for the production of methanol will be syngas – a direct output of chemical gasification processes.

From joint development of technology with major energy companies, NextChem is moving towards a more integrated approach where it acts as project developer of more articulated solutions. Indeed NextChem orchestrates the contribution of the different actors involved: from industrials and producers, waste managers and suppliers, public authorities and regulators as well as investors. As such, NextChem is driving the establishment of new green business models, working alongside both producers and consumers to achieve a common goal that is tacking up the energy transition challenge.

In this space NextChem is a partner to develop innovative business models and technological solutions in a wide range of areas. The flexible business models enable for fast track solutions and simple piloting of new technology, always backed by consolidated engineering procurement and construction global capabilities of Maire Tecnimont Group that will also enable the delivery and scale up at global level.

More information on Nextchem can be found online: www.nextchem.it