# Overview of second-generation biofuel projects

Second-generation biofuels produced from lignocellulosic biomass are now one of the main technological options for reducing the climatic impacts imposed by fuels used in transportation. These processes are designed to significantly boost the quantities of biofuels available and to take over from their first-generation counterparts, given the ready availability of raw materials and their excellent environmental performances. They are already the subject of multiple pre-industrial scale projects in many regions of the world as part of R&D programs, and the first industrial installations are already operational or under construction, the majority of them in Europe and the United States. They now require a stable regulatory framework in order to progress to the industrial learning stage required for them to become fully competitive. This is why the current uncertainties surrounding regulations in Europe and to a lesser extent in the United States could delay their development.

## Second-generation biofuels: on their way to becoming an industrial reality but against a still uncertain economic background

Technologies with the ability to convert lignocellulosic biomass into second-generation (2nd-generation) biofuels have been the subject of major research programs over the last 10 years. Nevertheless, despite the fact that gasoline substitutes, such as biomethanol, biobutanol and other biogas, BioSNG, BioDME and biohydrogen are fostering the interest of industry and universities, the technologies that have, until recent years, attracted the greatest research resources are those that produce the benchmark liquid biofuels of bioethanol and synthetic diesel and kerosene.

The lignocellulosic biofuel most commonly envisaged at present for use in diesel-powered vehicles, BtL[1], is a very high-quality synthetic diesel fuel suitable for use in very high concentrations in standard fuel tanks. This type of process enables not only the production of synthetic diesel fuel, but also of synthetic kerosene for aviation. Lastly, the pyrolysis route to diesel production is the subject of a level of research similar to that focused on BtL.

The main gasoline substitute is lignocellulosic ethanol produced using the biochemical[2] route. This is the same product as the ethanol currently marketed, the only difference being the resource and the initial processing stages. In recent years, this was the technology that attracted the majority of research resources, especially in the United States.

These 2nd-generation biofuels produced from forest residues, straw and other lignocellulosic biomass byproducts have made significant advances in the past five years:

- the number of pilot plants and demonstrators in operation and under construction almost tripled between 2008 and 2013. Production capacity has increased by a factor of 10 to around 2.4 billion liters (Gl/y);

(1) BtL: Biomass to Liquids, which combines a gasification unit preceded (or not) by a pre-treatment process (e.g. torrefaction), a Fischer-Tropsch synthesis unit and a hydroisomerisation unit

(2) Process focused principally on pre-treatment (separation of constituents components: cellulose, hemicelluloses and lignin) and enzymatic hydrolysis of cellulose

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- the technologies required to produce these biofuels are approaching maturity. Industrial biotechnology research has made enormous progress, especially in the use of enzymatic processes to treat biomass. Estimates suggest that between 2008 and 2012, the cost of enzyme treatment per liter of lignocellulosic bioethanol produced fell by more than 70%;
- the overall production cost of €0.7 per liter for 2nd-generation bioethanol has become an achievable near-term target, and is close to the cost levels of the historically most economic processes (e.g. sugar cane notably) and the market prices seen in recent years (see Panorama 2014 — Overview of biofuel sectors throughout the world);
- the first commercial lignocellulosic bioethanol production units came into operation in 2013 or will do so during 2014 (Tab. 1).

Table 1

Second-generation biofuel pilot plants and demonstrators worldwide – Existing and under construction — Trend 2008/2013

| Product | Capacity (Ml/y) | | Number of units | |
|---|---|---|---|---|
| | 2008 | 2013 | 2008 | 2013 |
| Cellulosic ethanol | 193 | 1,372 | 27 | 81 |
| Diesel, kerosene (BtL[1], FT) | 1.5 (e) | 649 | 5 | 23 |
| Other* | 37 | 414 | 2 | 12 |
| Total | 231.5 | 2,435 | 34 | 116 |

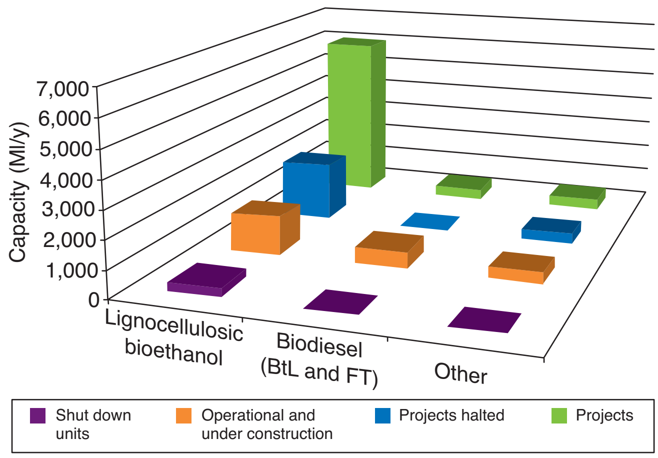
*Biobutanol, biomethanol, bioDME
(e) estimated
*Source: Global Biofuels Center and reports*

Despite these successes, the fact remains that development of 2nd-generation biofuels remains limited, and subject to a series of factors, including the economic crisis and the delay in introducing stable regulatory frameworks. More specifically, these situations have led to the cancellation or postponement of many projects, including some that are partly public funded, and even the shutdown of some units that were already in operation (Fig. 1).

At nearly 650 Ml/y, synthetic diesel and kerosene production units currently represent only around 27% of installed and under-construction 2nd-generation biofuels capacity worldwide.

With 81 units in operation and under construction (almost all of which are pilot plants and demonstrators), lignocellulosic bioethanol production capacity had grown spectacularly to around 1.4 Gl by the end of 2013.

Fig. 1 – Existing and potential 2nd-generation biofuels production capacity – Situation at end 2013




*Source: Global Biofuels Center and reports*

Despite the challenging economic climate and the problems faced by these production channels in finding an economic model for sustained long term development, many projects are now at the design stage. Together, they represent a total capacity approaching 7 Gl, of which nearly 88% is lignocellulosic bioethanol production (Tab. 2).

Table 2

Second-generation biofuels production units worldwide – Existing/Under construction — Projects at end 2013

| Product | In operation and under construction | | Projects | |
|---|---|---|---|---|
| | 2008 | 2013 | 2008 | 2013 |
| | Pilots/ demo/ com. units | Capacity (Ml/y) | Pilots/ demo/ com. units | Capacity (Ml/y) |
| Cellulosic ethanol | 81 | 1,372 | 101 | 6,018 |
| Diesel, kerosene (BtL[1], FT) | 23 | 649 | 14 | 436 |
| Other* | 12 | 414 | 11 | 417 |
| Total | 116 | 2,435 | 126 | 6,871 |

*Biobutanol, biomethanol, bioDME
*Source: Global Biofuels Center and reports*

Analysis of the geographic distribution of existing and potential 2nd-generation biofuels capacity (based on current knowledge of projects in the public domain) shows that around 70% of production capacity will eventually be located in Asia-Pacific and Europe. This high presence in Asia-Pacific is partly the result of the very ambitious number of potential 2nd-generation bioethanol projects announced in China and their unitary capacity, with some plants significantly exceeding 100 Ml/y (Fig. 2).

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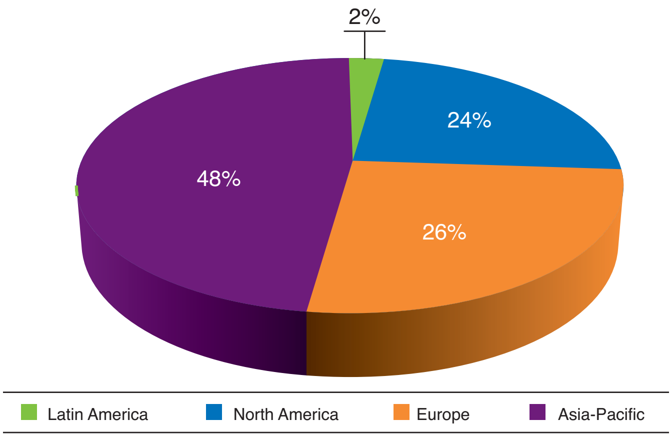
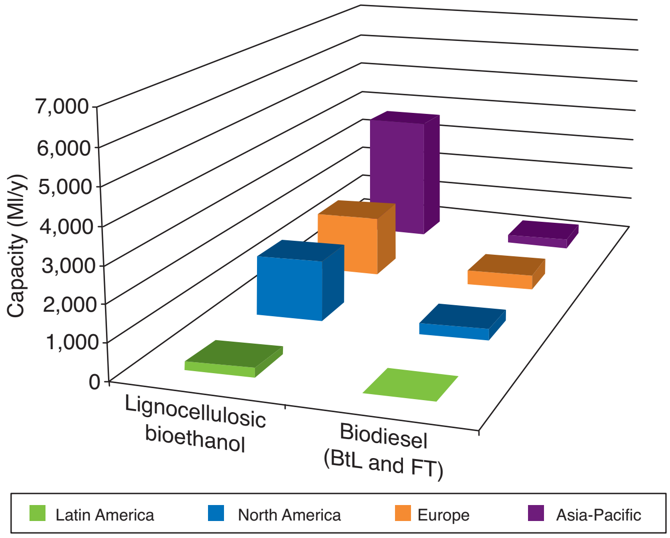
Fig. 2 – Geographic distribution of existing and planned 2nd-generation biofuels capacity — Situation at end 2013




*Source: Global Biofuels Center and reports*

Fig. 3 – Geographic distribution of existing and planned capacity by type of 2nd-generation biofuel — Situation at end 2013




*Source: Global Biofuels Center and reports*

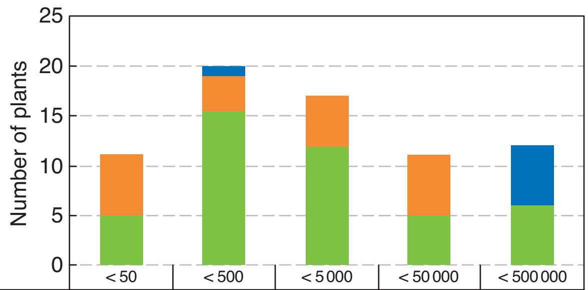
With around 750 Ml/y, the Asia-Pacific region has approximately 30% of the world's existing and under-construction biofuels capacity.

In Europe, current synthetic diesel production capacity represents approximately 20% of the region's total potential 2nd-generation biofuels production capacity.

The United States is home to the largest existing production capacity of lignocellulosic bioethanol, with 765 Ml/y, or 44% of world capacity (Fig. 3).

In its report "Bioenergy task 39", the IEA points up the fact that amongst a sample of 71 2nd-generation biofuels projects, biochemical technologies predominated (43 projects), well ahead of thermochemical technologies (20 projects) (Fig. 4).

Fig. 4 – Distribution of 2nd-generation biofuels projects by type of technology




| | < 50 | < 500 | < 5000 | < 50 000 | < 500 000 |
|---|---|---|---|---|---|
| Chemical | 0 | 1 | 0 | 0 | 6 |
| Thermochemical | 6 | 3,5 | 5 | 6 | 0 |
| Biochemical | 5 | 15,5 | 12 | 5 | 6 |

Output capacity (t/y)

Remark: the one biochemical - thermochemical pilot plant has been split. *n* = 71 plants

*Source: IEA Bioenergy Task 39 report*

## Lignocellulosic ethanol: Europe's first commercial unit

Although the first industrial-scale units appeared in the United States (DuPont, Abengoa, Ineosbio, KiOR and Poet), the 2013 commissioning of the first European commercial unit — the Beta Renewables (approx. 80,000 $m^3$/y) plant in Italy (Crescentino) reflects the nascent maturity of new technologies, and marks the initial steps of the 2nd-generation bioethanol industry towards mass production in Europe. In France, the Futurol project funded under the Ademe AMI (call for expressions of interest) scheme is scheduled to enter its second phase, with the aim of leading to a commercial scale between now and 2016.

Despite the indisputable technological advances achieved, this industry is still young and has more work to do on the long-term economic profitability of its production units, and must therefore look beyond possible economic incentives, such as tax breaks, etc. The legislative framework required to enable market growth also remains a major issue for investors.

In addition ongoing R&D to improve process performance, the quest for economic profitability is also leading developers of these technologies to consider a range of options for encouraging the emergence of new projects. These include:

- cost optimization: installation of a 2nd-generation bioethanol production unit on the same site as an existing 1st-generation ethanol production unit (to share on-site infrastructures and utilities);

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- unit conversion: in Brazil and the United States consideration is being given to converting selected units to produce biobutanol, rather than ethanol (GEVO, A. Process – Alpena).

There are currently around a hundred projects to create new 2nd-generation bioethanol production units. With 18 projects accounting for total annual capacity of 2.5 $Mm^3/y$, China accounts for approximately 40% of potential capacity. In Europe, there are around twenty projects underway with a total capacity of approximately 1.6 $Mm^3/y$.

Although the projects planned are approaching commercial scale, and therefore involve higher capacities and even higher capital investment, many 2nd-generation bioethanol production projects, the majority of them planned in North America (BlueFire Ethanol, Celunol, Iogen-Birch Ills, BP Biofuels-Islands County, etc.), have been either abandoned or postponed. A few projects have also been abandoned in Europe (in Sweden, Austria and The Netherlands), and the Sekab production unit in Sweden has been shut down, essentially as a result of its inability to compete successfully with 1st-generation facilities and the current lack of any clear regulatory scheme that could incentivize development.

## Synthetic diesel and kerosene: Europe is home to a number of commercial-scale projects

Although the continent is having to deal with similar economic profitability issues as those faced by lignocellulosic bioethanol, Europe is putting significant resources in place to bring forward the production liquid, product by synthesis Fischer-Tropsch (FT) in the near and medium terms. Many industry players and technology providers (Uhde, UPM, Axens, etc.) are working on commercial-scale projects. In France, the BioTfueL project aims to develop an integrated offer by 2018.

The major challenge for the BtL channel remains accessibility to a load of sufficient size and flexibility. In practical terms, end product cost price optimization depends significantly on a scale factor that requires extensive facilities and the associated need for very large quantities of resources. These resources will therefore need to take different forms and be of various compositions. The pretreatment of biomass prior to gasification then becomes an important issue, because it is during this phase that the biomass is converted into an intermediary product of homogenous quality. The two main pretreatment techniques are pyrolysis (which produces liquid) and torrefaction (which produces a solid product in powder form).

Combined with the need for the industrialization of future high-capacity units to achieve economies of scale (around 200,000 metric tons of product per year), overcoming these constraints demands the ability to mobilize very large quantities of biomass per metric ton of diesel or jet fuel produced. Co-treatment of biomass loads and refinery byproducts could then offer a solution enabling these stumbling blocks to be progressively removed whilst waiting for the introduction of more appropriate biomass supply systems.

## Europe: seeking a stable regulatory framework

The European Commission's Climate and Energy Package sets a target to reduce GHG (GreenHouse Gases) emissions by 20%, and to generate 20% of energy consumed within the EU from renewable sources. These targets have led to the publication of two biofuels directives:

- Directive 2009/2023/EC, the RED (Renewable Energy Directive) on the promotion of the use of energy from renewable sources, which sets a target for 2020 requiring 10% of all energy used for transportation in member states to be generated from renewable sources;
- Directive 2009/2030/EC, the FQD (Fuel Quality Directive) on the specification of petrol, which obliges suppliers to reduce GHG emissions by at least 6% across the full fuel lifecycle.

In October 2012, the European Commission published a proposed amendment to these Directives, both of which set key priorities for 2020 and are essential reference points for investors, since these regulations will respectively fix the obligations applying to the blending of 1st and 2nd-generation biofuels with traditional fuels, as well as defining their required environmental performances. These symbolic measures involve the introduction of a limit on the contribution 1st-generation biofuels can make to meeting the 10% target for energy from renewable sources by 2020, and the inclusion of ILUC (Indirect Land Use Change) in GHG calculations. The justification for these changes has been the subject of intense debate between stakeholders regarding the real or supposed impact of 1st-generation biofuels on ILUC, and consequently on the methodologies and models used to estimate them.

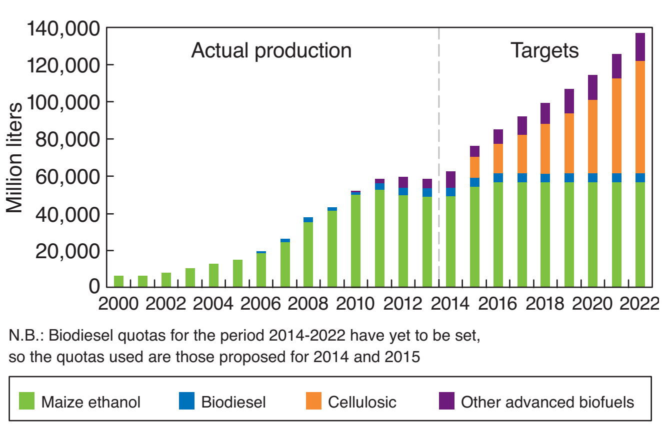
In September 2013, and after much debate, the European Parliament finally agreed on a 6% blend limit for 1st-generation biofuels to achieving the 10% for renewables in energy for transportation, and that ILUC should be included in the sustainability criteria for 2020 (RED2) in "reporting" form. As part of the European co-decision procedure, a new proposal by the Lithuanian Presidency has been published containing the following changes: a maximum 1st-generation blend rate of 7%, no specific target for 2nd-generation and green electricity (left to the discretion of each member state), a double counting mechanism in favor of 2nd-generation (and other waste-based energy generation processes) and default values for ILUC — estimated at zero for 2nd-generation, which would send a very positive signal. However, this proposal had not secured a consensus amongst member states by the end of December. Discussions are set to resume under the Greek Presidency, although there is now less likelihood of a compromise being reached in time for a second reading in the European Parliament prior to the elections and change of Commission.

Added to the contradictory national announcements made recently, and the delays that will probably occur before the final vote, this regulatory uncertainty is likely to nullify the efforts made to provide the long-term visibility required by 2nd-generation investors, who are often the same as 1st-generation investors.

## United States: blend targets remain ambitious

In 2007, the RFS (Renewable Fuel Standard) program was reviewed and extended by the Energy Independence & Security Act (EISA). As a result, the 2022 blend targets for transportation fuels were adjusted to 137 Gl, with different blend rates for different types of biofuel. In the United States, where ethanol produced from maize is the predominant biofuel, the purpose of these differential blend rates is to encourage the emergence of other types of biofuels, particularly cellulosic biofuels (Fig. 5).

Fig. 5 – Production of biofuels 2000-2013 and quotas 2014-2022




*Source: Sia-Partners*

As a result of the relative decline in demand for gasoline, the 2014 biofuels blend mandate initially set a target of 18.15 billion gallons (of which the majority is maize ethanol), raising the risk of breaking through the "ethanol blend wall". This equates to the maximum amount of ethanol that can be blended with gasoline without the risk of causing engine damage: 10%. As a result, the 2014 targets have been revised downwards to reflect this trend in demand, with the EPA now proposing a target of 15.21 billion gallons. This reduction has been very badly received by ethanol producers, who would prefer that measures are introduced to enable the 10% blend wall to be exceeded (including the development of flex fuel vehicles and an E85 distribution infrastructure, like that of Brazil).

Regarding cellulosic biofuels, their effective production currently remains far below the initial targets set by the EPA, which has reviewed its targets on several occasions since 2010. As in previous years, the 2014 mandate is likely to provide proNabis estimate of production, thereby ensuring a captive market for 2nd-generation pioneers.

In response to President Obama's clearly stated intention to reduce pollution and energy dependency, the United States Department of Energy continues to fund many R&D projects intended to accelerate the introduction of 2nd-generation biofuels, thereby driving down the cost of producing gasoline, diesel and other kerosenes from biomass.

## R&D in Europe

As part of the European NER300 funding program, the European Commission is financing a large number of projects designed to introduce commercial-scale biofuel production units and/or demonstrators. Table 3 contains a non-comprehensive summary of the main projects, all of which are at very different stages of development.

In addition to these 2nd-generation biofuels projects, the European Union is also providing financial support for projects like All-GAS, BIOFAT and INTESUSAL to produce 3rd-generation biofuels from algae.

Advanced so-called 3rd-generation biofuels produced from algal biomass are still in the R&D phase, but could provide certain practical advantages compared with their 2nd-generation counterparts. Examples include:

- the ability to feed on $CO_2$ from industrial plant waste and nutrients contained in wastewater (however, these practices have yet to be demonstrated on a large scale);

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Tableau 3

Major projects funded 2nd-generation biofuels or partly financed by public funds EU or France

| Project name | Developer | Technology provider | Type of biofuel | Type of biomass | Production capacity (t/y) | Funding (€ million) |
|---|---|---|---|---|---|---|
| BtL /Synthetic Natural Gas — SN G/Biodiesel/DME/Methano | | | | | | |
| OPTFUEL | VW | Choren Industries | FT liquid | Wood | 15,000 | 7.8* |
| Ajos BtL | Forest BtL Oy | Axens (FT Gasel®) | FT liquid | Forestry byproducts | 115,000 | 88.5* |
| BioTfueL | Consortium BioTfueL | Uhde | FT liquid | Mix of ligno. biomass and fossil fuels | 3,750 | 33.3 |
| Stracel BtL | UPM KYMENNE | Thermochemical process | FT liquid, power and heat | Forestry biomass | 100,000 | 170* |
| Syndièse | CEA, Air Liquide, CNIM | Thermochemical process | FT liquid | Agricultural and forestry byproducts | 22,000 | |
| GoBiGas (phase 2) | Göteborg Energi AB | Thermochemical process | SNG | Forestry byproducts and pulpwood | 50,000 | 59* |
| GAYA | GDF Suez & Partenaires | Thermochemical process | SNG | Agricultural and forestry byproducts | 550 | 18.9 |
| EMPYRO | BTG | BTG | Biodiesel | Wood | 17,400 | 5* |
| BIO DME | Volvo | Chemrec AB | DME | Black liquor | 600 | 8.2 |
| Woodspirit | BioMCN | | Methanol | Forestry byproducts | 200,000 | 199 |
| Lignocellulosic bioethanol | | | | | | |
| BIOLYFE | Chetex Italia | Chetex Italia | Ethanol | Misc. | 40,000 | 8.6* |
| FIBREEtOH | UPM | UPM | Ethanol | Fibers | 20,000 | 8.6* |
| Futurol | Procethol 2G | | Ethanol | Agricultural and forestry byproducts | 2,700<br>137,700 | 29.9** |
| KACELLE | Dong Energy | Inbicon | Ethanol | Straw | 20,000 | 9.1* |
| LED | Abengoa | Abengoa | Ethanol | Maize byproducts | 50,000 | 8.6* |
| GOMETHA | Chetex Italia | Chetex Italia | Ethanol | Misc. | 80,000 | 19* |
| SUNLIQUID | Clariant | Clariant | Ethanol | Misc. | 60,000 | 19* |

* Financing program UE NER300 — ** Oseo

- the ability to be based on land unsuited to any form of agriculture, i.e. not in competition with land used for growing food (nevertheless, other constraints apply to unit location, including sunlight levels, availability of water, etc.);
- the theoretical ability to generate much higher levels of energy per hectare than traditional terrestrial plant species.

However, this route to energy generation is still in its infancy as a result of the many obstacles and drawbacks that still exist:

- the fact that the processes involved are very energy-hungry, complex and require large amounts of water, potentially negating any positive environmental benefits;
- very high production costs, which have the effect of changing project target outcomes from fuel to specialist high added-value products. It is significant to note that although there are a large number of European algal biomass production projects and pilot projects (on improving knowledge of algal strains, boosting productivity, growing/harvesting conditions, reactor design, etc.), their practical applications are not always specified or are focused on extracting high added-value products (for use in green chemicals, the food industry, cosmetics, etc.).

It is possible to identify six algal biofuel research projects in Europe that have actually received funding. There are currently five production pilot plants, one of which is focused specifically on producing biofuels for aviation.

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There are several pilot projects in North America, and two companies have set themselves the goal of achieving a semi-industrial scale, although the corresponding timeframes remain uncertain. The total capacity of those units currently at the project stage (some of which may not become reality) internationally is around 0.5 Gl/y.

Lastly, other production processes structured around biotechnology-based approaches are targeting the production of molecules other than ethanol from sugars. Examples include Amyris, a company supported by Total, which has developed a process for producing a jet fuel and possibly diesel, from farnesene which is currently being produced and tested in Brazil.

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