# POTENTIAL OF SMALL-SCALE, DISTRIBUTED MANUFACTURING PROCESSES IN ENERGY AND CHEMICAL INDUSTRIES

Hiroshi Uno
Yuji Inada
New Business & Technology Dept., Technology & Innovation Studies Div.
Mitsui & Co. Global Strategic Studies Institute

Technological innovation such as materials informatics is bringing about increasing competitiveness for small-scale, distributed processes, which so far have been not competitive enough in comparison with large-scale, centralized energy manufacturing processes that utilize fossil fuels. This contributes to increasing the feasibility of on-site production, which means that small-scale customers can manufacture at their own companies. When looking at biomass resources, which are, by nature, a small-scale, distributed type of resources, recent progress in studies on enzymes, etc. play a vital role in reducing the conversion cost of biomass resources, and thereby enabling them to be transformed into high-value added products. Moreover, not only agricultural products but also waste are being utilized as distributed resources. In particular, the technological development of systems that utilize waste and residue is progressing. Because of this, also from the perspectives of $CO_2$ reduction and the Circular Economy in Europe, biomass resources are expected to be utilized further in the future. This report considers promising fields and their possibilities, focusing on the functional chemicals field by citing relevant examples of such technological development.

## ENHANCED COMPETITIVENESS OF SMALL-SCALE, DISTRIBUTED PROCESSES

The energy industry and the chemical industry mainly have used large-scale, centralized energy manufacturing processes, which encourages economies of scale relevant to function. Under such circumstances in those sectors, newly developed systems have enabled the accumulation of raw materials, including crude oil and natural gas, and the processing of vast amount of those raw materials. At the same time, the technology to maximize the utilization of derived by-products and generated energy has been also developed. As a result, up to now, production and supply systems have been established at overwhelmingly low cost, and therefore large-scale distribution and storage systems have been created for locations ranging from raw materials producing regions to consuming regions.

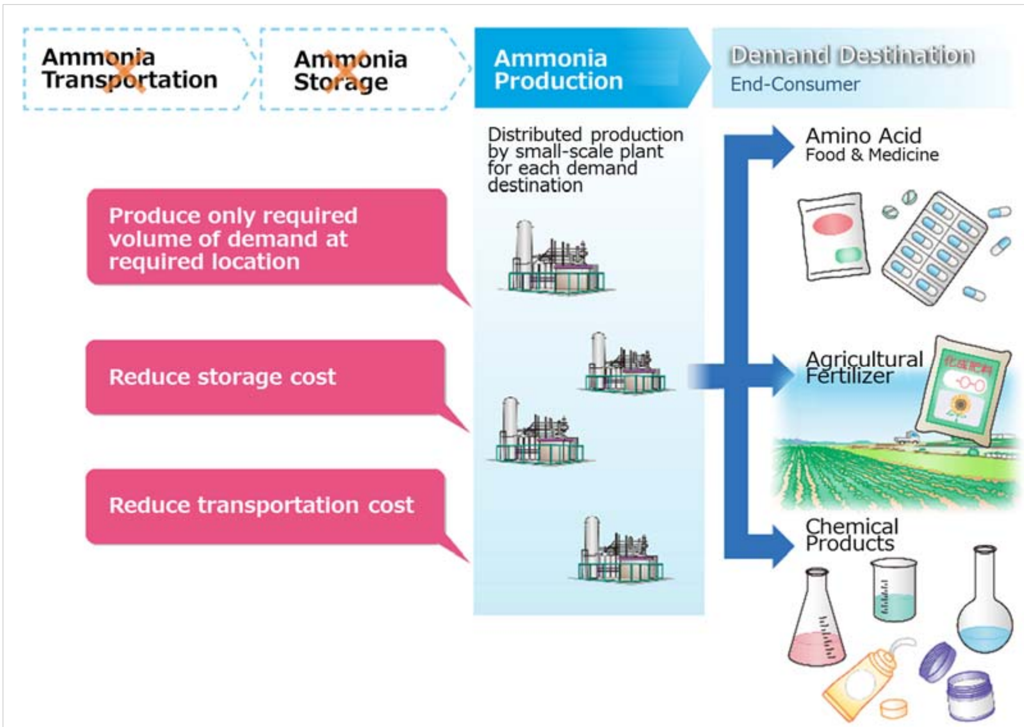
On the other hand, if the demand for products manufactured by a certain industry remains relatively small in scale, then such industry has no alternative but to rely on a distribution system derived from mass production. Accordingly, in such a situation, the transportation cost might account for a high percentage of the total cost.

For ammonia manufacturing processes, factories with an annual production volume of one million to two million tons have been constructed on sites such as natural gas producing regions to produce 100 million tons or more of ammonia a year in markets worldwide. There are manufacturers consuming ammonia on a large scale in cases such as the production of fertilizers from ammonia, while there are also customers in the food industry, chemical industry and others, whose requirements for ammonia are sufficiently met with a volume of around one thousand to ten thousand tons a year. Those customers have always requested small-scale, distributed processes, which requires raw materials on a small scale. However, such processes are the outcome of simply downscaling large-scale, centralized energy incentive processes, and therefore cannot be equipped with sufficient production efficiency and competitiveness.

Meanwhile, remarkable technological innovation in recent years in material development by means of materials informatics, which utilizes simulation and statistical analysis, has started to make small-scale, distributed processes rather competitive in terms of conversion efficiency, energy efficiency, and others. For example, in catalyst development, analysis technology using materials informatics has facilitated the clarification of response mechanisms and enabled development in a fast and efficient manner.

One such result can be cited: the attempt to produce ammonia on-site. In April 2017, Tokyo Institute of Technology, Ajinomoto Co., Inc., and Universal Materials Incubator Co., Ltd. jointly founded Tsubame BHB Co., Ltd., which is greatly contributing to starting the domestic operation of pilot plants in 2019 for on-site production by making use of a new catalyst developed by Professor Hosono of the above university (electrode catalyst). (Figure 1)

**Figure 1: Conceptual Diagram of Ammonia Production**



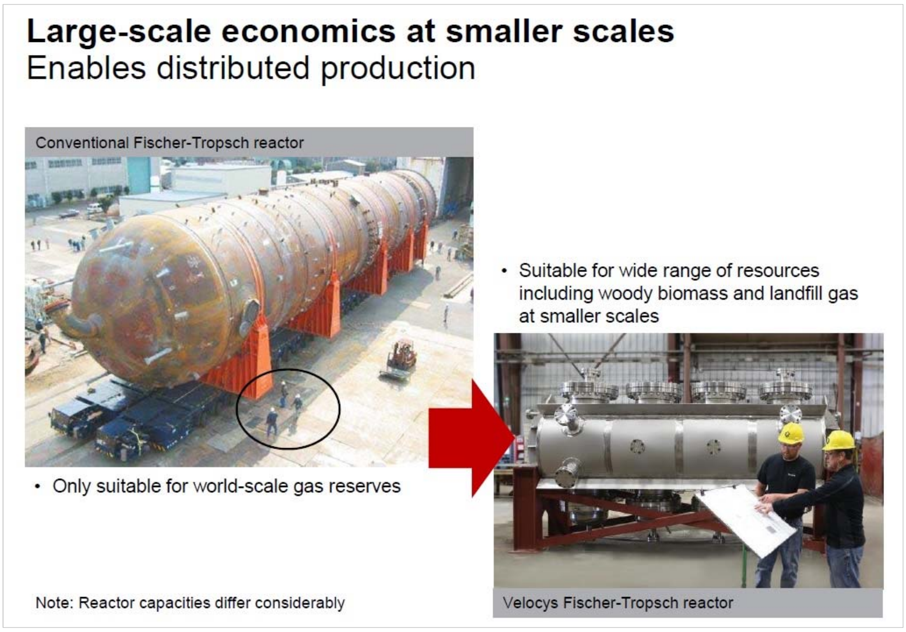

Source: Website of Universal Materials Incubator Co., Ltd. (translated by MGSSI)

In the conventional Haber–Bosch process, which is large-scale and energy incentive, ammonia is synthesized from hydrogen made from natural gas and air under the condition of 20 to 100 MPa (MPa: megapascal pressure unit) and 450 to 550°C. On the other hand, the new catalyst can cause reactions under the mild condition of 1MPa and 300°C or less, which can result in reducing energy consumption to less than half. Therefore, facility cost can be expected to be reduced due to downsizing facilities and lower pressure. Moreover, operational cost can be reduced due to decreasing heating facilities and power. This will pave the way for on-site production.

A similar case can be seen in Fischer-Tropsch process (FT) synthesis. This is a GTL (gas-to-liquid) process, which synthesizes liquid fuel by using gas. FT synthesis is a process for producing liquid fuels, such as gasoline and diesel oil, from natural gas or synthesized gas created through coal-gasification. Sasol and Shell in South Africa, as well as other companies, have large-scale commercial plants with operating capacities of around 8,000 to16,000 kl/day. The reactor for FT synthesis used in this process has become larger in order to achieve economy of scale and remove heat generated through the reaction process in a relatively simple way.

Compared with this, the reactor for FT synthesis developed by Velocys in the UK adopts a special internal structure equipped with a high-quality heat conversion function called “micro-channel”. That structure realizes a process efficiency of about ten times that of a conventional reactor, enabling removal of reaction heat and substantially downsizing the scale of the reactor (Figure 2). As a result, FT synthesis at a scale of 160 kl/day has become possible, which was not profitable in the past.

**Figure 2: FT Synthesis Reactor**
**(Note that the change of scale is clear when comparing reactor size with people)**




Source: Website of Velocys

Velocys presents its efforts to introduce small-scale synthesis process by using biomass as a raw material. Aside from that, this reactor offers a wide range of capabilities. For example, it can be introduced for small-scale emission gas generated as a surplus by-product in factories in the metallurgical industry, etc., where FT synthesis has not been able to function well in terms of scale.

## BIOMASS RESOURCES AND THEIR SMALL-SCALE AND DISTRIBUTED PROCESS

Biomass resources are carbon neutral raw materials which do not cause CO2 levels to increase. In addition, their products are encouraged to be introduced as renewable energies contributing to reduction of CO2 emissions. However, biomass is mainly made up of agricultural products. Because of this, except for biomass resources such as corn in the US and woodchips, whose supply systems are organized at a relatively large scale, they can be said to be potentially small-scale and distributed resources. Therefore, production of biofuels and biochemicals, most of which are substitutes for products derived from fossil fuels, is so costly with respect to collecting raw materials that their production processes cannot be competitive with large-scale, centralized energy manufacturing processes. Under existing circumstances, overcoming difficulties has required government support, including incentives for introduction and subsidies for CO2 reduction.

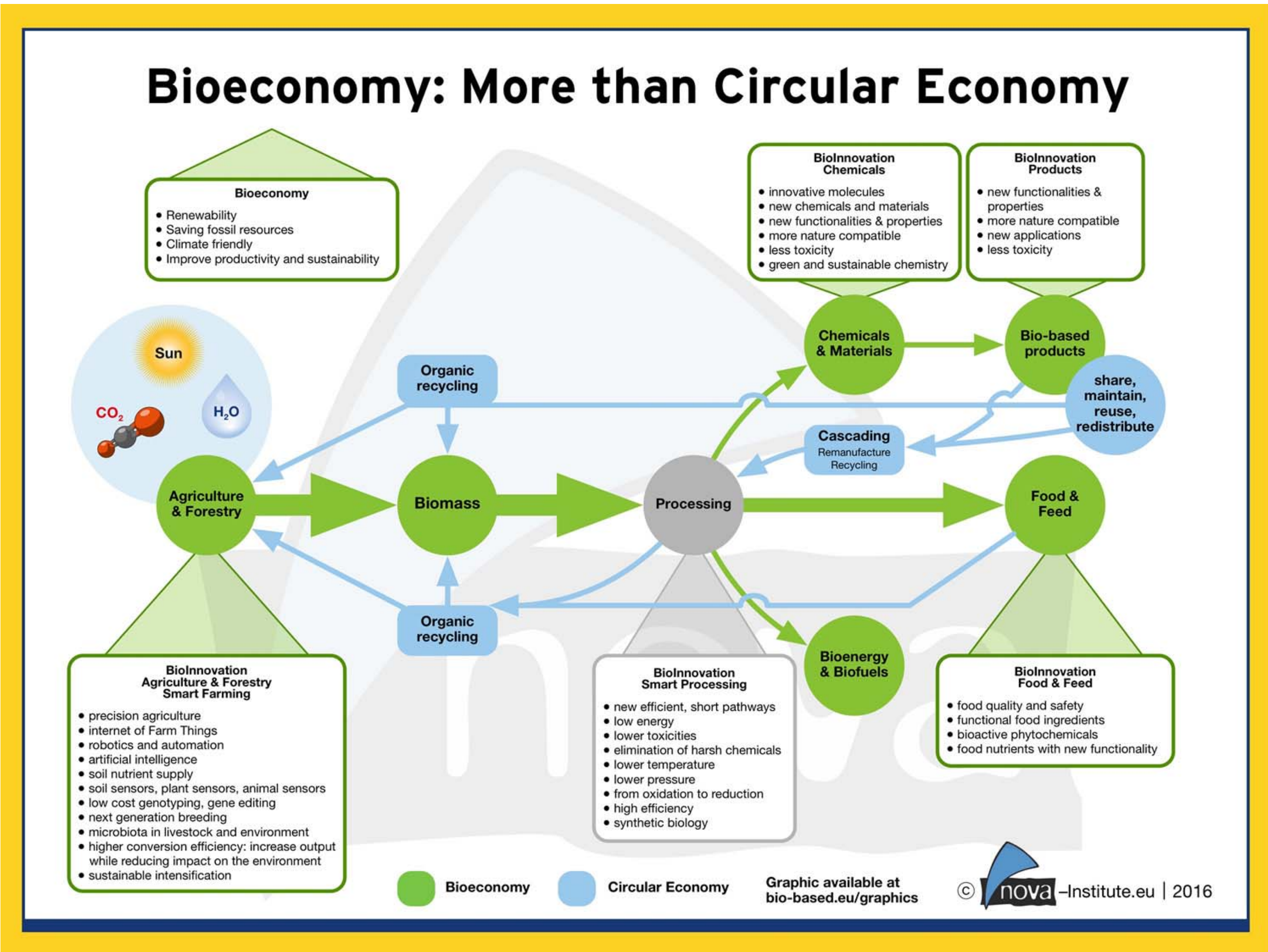
Meanwhile, bioinformatics utilizes biotechnology, which is epitomized by genome editing technologies, and therefore with the application of bioinformatics, the development of the metabolic process and enzymes brings about increased feasibility of the abovementioned process at a low cost and with more efficiency. Under such a situation, economic benefits can be expected to generate through the production of high-value added products. Furthermore, the range of raw materials which can be processed has widened, and thereby not only agricultural products but also distributed resources such as urban waste are in sight. This is recognized as a new move called the “bioeconomy”. In this sense, the utilization of biomass has been developing.

As a typical example of that, the manufacturing of biochemical products in papermaking factories can be cited. When looking at FIT (feed-in tariffs) in the power generation sector, offering substantial incentives at early introduction has brought about competitiveness for solar and large-scale wind power generation, since significant reduction of facility costs for such power generation has been achieved. On the other hand, power generation by utilizing woodchips, a biomass resource, is difficult to realize in the current situation without subsidies, because it does not have a big potential for technological development. However, paper manufacturers, in particular, are now taking measures to repurpose their factories, whose utilization rate has declined, shifting to the manufacturing of biochemical products. Such move is going forward mainly in Europe. Process development aims at producing sugar by utilizing woodchips as a raw material, and then converting sugar to useful chemical products, etc. Its future development can be expected, because it has the advantage of curbing initial investment by converting some existing papermaking facilities.

As far as expansion of raw materials is concerned, the focus is on the Circular Economy now. Originally, the concept was announced in Europe in 2015, and has been developed since then. This includes policy packages such as expansion of recycling and reuse. As a final goal, they serve as measures to reduce the volume of landfills. The Circular Economy encompasses not only raw materials for biomass such as urban waste, but also technological developments for utilizing waste plastics.

As a combination of the bioeconomy, which is aimed at manufacturing products from biomass resources, and the Circular Economy, which is aimed at recycling of final products, small-scale and distributed business development in Europe is expected to be promoted in the future by the utilization of biomass resources and recycled resources (Figure 3).

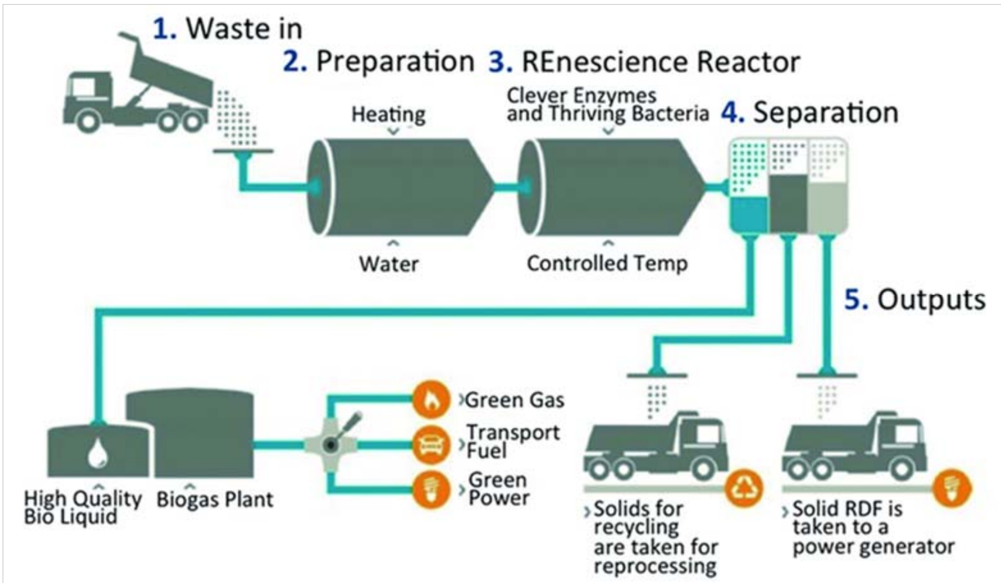
**Figure 3: Bioeconomy and Circular Economy**




Source: Website of Bio-based Economy, nova-Institute

For example, Ørsted (formerly Dong Energy), the largest energy company in Denmark is developing methane gas production business, as an alternative to natural gas, through a methane fermentation process by using an enzyme. This process was, in fact, developed by REnescience under the umbrella of Ørsted. Although it is difficult to promote this process on a large scale as is the case of fossil fuel, because urban waste as raw materials can be provided from the area where such waste is collected, this process encourages enzymatic saccharification prior to methane fermentation, which enables significant reduction of fermentation time and stable gas generation. This process facility under REnescience could be described as a more high-value one for methane gas supply sources (Figure 4).

**Figure 4: REnescience—Processing Flow of Urban Garbage**




Source: Website of Modern Power Systems, Global Trade Media

## FUTURE POSSIBILITY OF DEVELOPMENT OF SMALL-SCALE, DISTRIBUTED PROCESS

As mentioned above, small-scale, distributed processes are expected to be developed in terms of covering the limitations of large-scale, energy incentive processes. In addition, such processes are expected to be developed as a solution for raw materials with quantitative constraints on their collection, such as biomass resources and recycled resources. Furthermore, they have the advantage of enabling the production of various chemicals from biomass, which promotes high expectations for the development of processes to produce high-value added products. However, considering appropriate supply volume via supply chains and the economic performance of an entire plant using utilities such as process steam, etc., a certain scale is necessary for such processes to function. To achieve competitive equipment cost, securing an annual production volume for that equipment of about several thousand to several tens of thousands of tons appears to be needed.

As for products which possess the following characteristics, small-scale, distributed processes are deemed to be easily applicable.

1) **A product whose distribution cost is relatively high compared with its production cost:** As seen in the case of ammonia, on-site production for small-scale customers that cannot benefit from large-scale production and mass transport as commodity. The cost of transport and storage of ammonia is high because ammonia is poisonous. That is why on-site production is more acceptable for manufacturing ammonia.

Similar to ammonia, methanol is a product which is produced on a large scale and transported in mass quantity as commodities. However, methanol does not require transport and storage conditions as strict as those for ammonia, and therefore demand for on-site production is not so strong. Under such circumstances, there is still a likelihood that small-scale, distributed processes will be put into practice for methanol because consumers have an interest in procurement of self-contained types of raw materials, if incentives for utilizing biomass resources and waste as raw materials of methane synthesis become available.

2) **Use of waste or redundant by-products:** Urban waste and waste plastics have the constraint that high costs cannot be imposed on collection and transport. Therefore, they are mainly collected in a limited area. Because of this, small-scale, distributed processes are easily applied to them. Currently, the main types of recycling are thermal recycling, which generates energy through combustion, and material recycling, which reuses waste. However, if higher added-value process development advances in such a way as the combination of raw material gasification and conversion process, utility value will increase.

   Factories and plants do not produce large–scale quantities of by-products. Therefore, currently, sometimes by-products are reused inside a factory or plant, or burned and disposed of. On the other hand, however, similar to the case of waste, a process to convert by-products to high-value-added products could be applied.

3) **Fields where biomass resources are an advantage:** As seen in the example of a paper manufacturers, there is a likelihood that various chemicals will be produced from biomass in the future. Although only some processes, such as ethanol fermentation via conversion from sugar, are currently commercialized, further advancement of bioinformatics and materials informatics is promoting improvement of bio process and catalyst development. As a result, processes to manufacture high-value added products or to utilize CO2 itself as a raw material are becoming available. There are difficulties with the commercialization of some processes in terms of cost and scale, notwithstanding the carbon neutral value of biomass resources. Nonetheless, their competitiveness has improved.