Models for Biorefin

■ **The pursuit of sustainable production of chemicals and energy from biomass is gaining momentum. Types of future biorefineries are often categorised according to the raw materials used: lignocellulosic, whole-crop, or green. Alternatively, the basis for classification can be the applied technology platform—either low-temperature fermentation or thermal treatment. Finland can use its strengths to contribute to each of these, with concept and process models supporting the development of biorefinery technology.**

Pertti Koukkari

For obvious reasons, the lignocellulosic approach as the basis for future biomass-harnessing technologies attracts the most attention in Finland. In the European context, the whole-crop and green biorefinery approaches also are of interest, as they incorporate the processing of agricultural biomass, either as grains and cereals or as fresh weight grass.

Two basic technology platforms are being used: hydrolysis of sugars followed by their bioprocessing to chemicals, or thermal treatment in combination with subsequent chemical conversion to products.

Lignocellulose: an obvious choice

For the Finnish chemical and process industry, development in this area brings both interesting and stimulating challenges. Concerning biorefining of non-food lignocellulosic biomass, our forest industry is a world leader in both technology and competitiveness. The new challenge lies in its ability to develop a series of new products such as composite materials, biofuels, chemicals, and nanomaterials for the emerging market.

Any enterprise that is working towards biorefining will increase the complexity of both its production processes and product chains. Such developments can be supported by concept assessment, based on established process models which have been used for more than two decades in the Finnish forest industry.

Thus the evaluation of new concepts can utilise Finland's long-term experience with mass and energy balance simulations, typically covering the whole plant in integrated conventional pulp and papermaking facilities. Concept models can then compare alternative raw material sources and optional pretreatment technologies in terms of the yields of both intermediate and final products.

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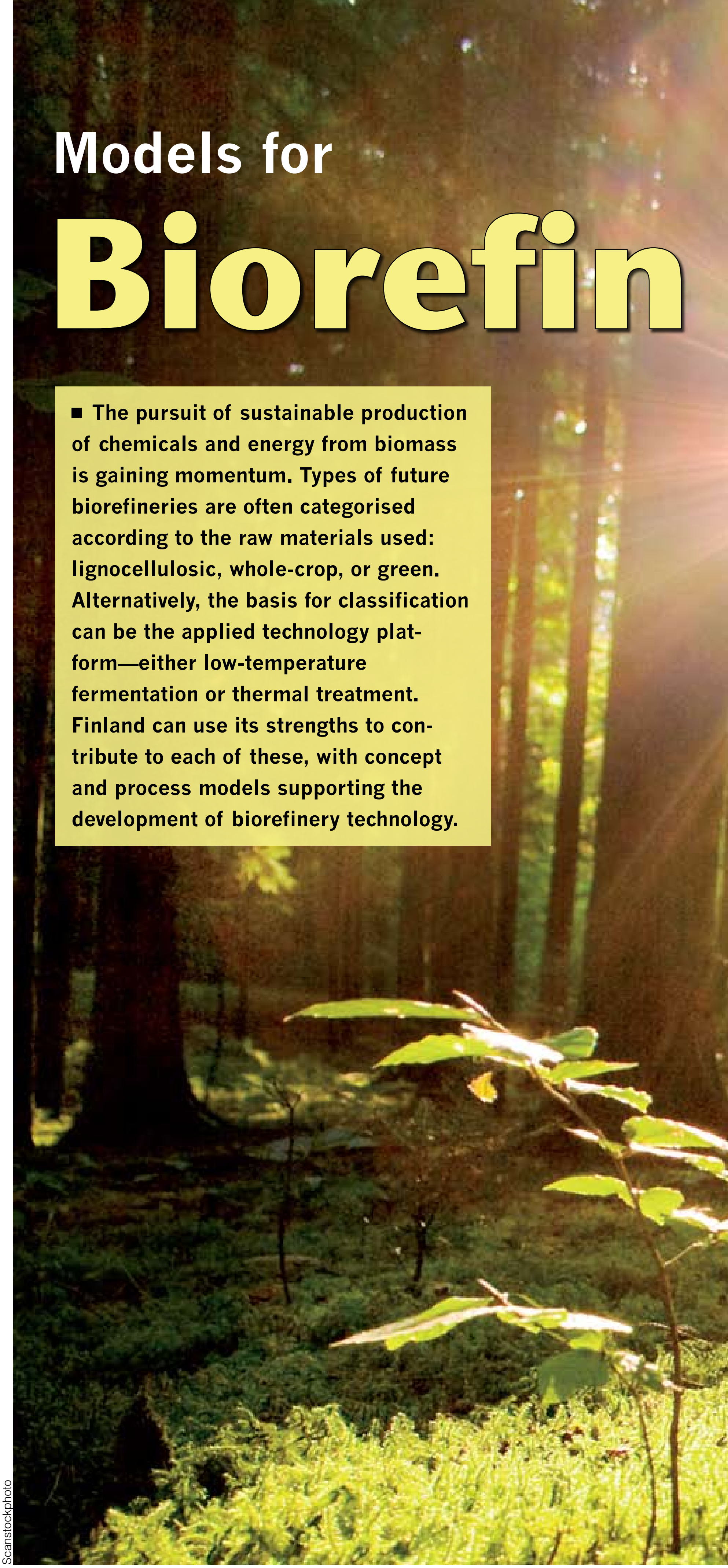

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New light to the forest industry. In future biorefineries, Finland's "green gold" will turn into biofuels, chemicals, and various composite materials.

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Currently under development, the first forest biorefineries are seeking to utilise side streams or by-products of pulp and papermaking as the feedstocks for their bioproducts. Consequently, the focus in raw material studies is on harvesting residues, remains of debarking and knots. Finding added value for various subsidiary fractions from process streams, typically extracted hemicelluloses, lignin, and pulping liquor components, is also widely studied in ongoing research programmes.

However, one may suggest that additional feedstock sources will be needed to meet the increasing future demand for bioproducts, particularly when value-added goods beyond fuel components are sought.

As volumes in conventional pulp and paper making have been decreasing, perhaps permanently within the borders of Finland, an obvious target for long-term techno-economic scenarios is to assess the boundary conditions for the optional uses of present feedstock streams as raw materials for new biomass-based products. Such studies then provide a reliable methodological base for continual and flexible decision making in the development of competitive biorefining technologies.

Green biorefineries: an acid opportunity?

The utilisation of vegetable oils (rape, palm) for biofuel components has been commercialised and is constantly supported by the oil refining business. For any future whole crop concept, a technology base thus largely exists. Green biorefineries, which are still under development, will convert 'natural wet' biomass (grass, clover, algae) to energy, chemicals, materials, and feed.

When developing sustainable 'release and catch'—the complete circulation of atmospheric CO_2—biorefining from fresh biomass, it should be kept in mind that formic acid, often yielded from the process, is a biocompatible chemical whose demand will increase. Its two important uses are preserving biomass for further processing and enhancing biogas production.

As the transport distances for fresh biomass will always be limited—the collection range of biomass for economic biogas production is some 40 kilometres in diameter—processing will promote local preservation of biomass by silage techniques.

In Finland there is a unique long-term experience in the production of formic acid—with an annual capacity of over 100,000 tonnes, Kemira is second in the world—as well as experience with its uses, many of which are particularly targeted to whole-crop and green biorefining.

The major advantages of the new pioneering technologies are the ability to utilise all of the raw material in value-added products, and their prospects for allowing completely closed processes that do not use chlorine or sulphur compounds.

Manufacturing formic acid could also be combined with thermochemical processing to produce synthesis gas. In the currently used methylformiate-catalysed process, the HCOOH molecule is produced from carbon monoxide and water. The syngas-hydrogen is removed from the process and can be utilised for other purposes, as is done now for hydrogen peroxide production.

An obvious alternative for the large-scale production of Fischer-Tropsch wax from bio-syngas could be to use a fraction of the CO-gas to make formic acid. Depending on the rural conditions, the excess hydrogen could then be used for the on-site hydroformulation of the FT-wax to second generation biodiesel.

Yet another manufacturing option is the large-scale recovery of formic and levulinic acids from the thermal hydrolysis of cellulosic raw material. The latter would then offer various upgrading routes as a 'wood-based platform chemical'.

The future techno-economic assessment of such technologies could take place in connection with European R&D activities focusing on the green biorefinery model. Such studies should then consider transverse process alternatives as well as local market viabilities of all optional products.

Sugar brings new challenges

In Finnish biorefining, the sugar fermentation route is so far confined to innovative methods for producing bioethanol. Concurrently, extensive research activity is supported by the European Union, Tekes and the Academy of Finland in ongoing projects to create direct bioprocessing methods for second generation bioethanol and value-added chemicals.

An essential research objective is the effective bioproduction of monomers such as sugar acids and their derivatives. For such research, VTT Technical Research Centre of Finland has a strong international position and well-recognised know-how, being particularly experienced in both bacterial and yeast fermentation and in the physiology of microbes.

The recovery of valuable fractions from fermentation broths and their conversion to, for instance, polymeric materials in economic downstream processing, combine the biorefining effort with the problem-solving of chemical engineering.

Both unpredicted combinations of components and a great amount of excess water in the broth or hydrolysis mixtures will create new challenges for chemists. A typical mixture may include alcohols, acids, and ketones with a 5:1 or more water-to-product ratio.

In the chemical industry over the last few decades few, if any, new concepts have been brought to practical production without simulation using process models. Experimental progress in laboratory-scale development of novel bioprocesses will generate a need for their quantitative engineering.

Yet today, understanding of the functions of biological organisms is still largely based on averaging and correlating parameter values based on experimental observations from heterogeneous cell populations. For successful management of future bioprocesses, a combination of methods, ranging from functional analyses of intracellular processes to advanced chemical engineering techniques will become necessary. ❐

The writer works at VTT Bio and Process Technology as Research Professor on modelling of sustainable chemical systems.

pertti.koukkari@vtt.fi