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GUIDANCE FOR A BIOREFINING ROADMAP FOR THAILAND

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Guidance for a Biorefining Roadmap for Thailand

Biorefineries present an alternative to fossil-based production, and can create employment, wealth and the ecosystem needed to make them function. Thailand is establishing a bioeconomy with widespread biorefining as a strategy for future economic growth. There is political will to establish in Thailand, if feasible, small, decentralised biorefineries to which farmers can locally deliver biomass as feedstock, which can then be processed into bio-based products. This would help to relieve rural poverty, which is still a problem in some areas of Thailand despite progress. Developing a biorefining roadmap will help to assess the feasibility of such an initiative.

Keywords: Bioeconomy, Biomass, Biorefinery, Biotechnology, Innovation, Manufacturing, Roadmap, Research, Thailand

Foreword: This report is a main output of the project, "Realising the Circular Bioeconomy" in the 2019-20 work programme of the Working Party on Biotechnology, Nanotechnology and Converging Technologies (BNCT). The work is part of the umbrella of the Thailand Country Programme (TCP), an OECD-wide programme of work wholly supported through voluntary contributions by Thailand, a participant in the Committee on Scientific and Technological Policy (CSTP).

The report was developed and co-written Jim Philp (OECD), David Winickoff (OECD) and the nova-Institute. Critical support and data for the project were provided by the team of the Office of National Higher Education, Science, Research and Innovation policy Council (NXPO), Thailand, especially Kanchana Wanichkorn and Pranpreya Lundberg. Field work in January 2020, and other meetings, were coordinated by Tiyarat Niamkohphet-Cader (OECD). Through the lens of developing policy approaches for Thailand, the paper is relevant for informing the challenge of realising a circular bioeconomy across the Global North and South.

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Executive Summary

For Thailand, it has become key political objectives to overcome the middle-income trap and decrease inequality. Thailand's success over the last few decades means that labour costs are now higher than competing developing countries, but its level of innovation and technology cannot compete with highly industrialised and innovative countries. Therefore, it is logical to focus on an area such as the bioeconomy, which is high in potential of innovation and technological progress. Several strategic policy documents bear on the Thai bioeconomy, including the National Biotechnology Framework, the Bioplastic Roadmap and the Alternative Energy Development Plan, which are from 2004, 2005 and 2012 respectively. Also the "Thailand 4.0" initiative from 2015 included bioeconomy as a future growth industry and most recently, in 2016, the BCG model (Bio, Circular, Green) was agreed on as a strategy to overcome the middle-income trap.

Biorefineries represent the embodiment of a new production paradigm for the bioeconomy. It is in these biorefineries that feedstock is processed into higher value products. The biorefineries themselves create employment and wealth, but they also create the ecosystem needed to make them function. In these new value chains, policy makers must seek to support the entire chain, especially if the products are to compete in markets already established through using fossil-derived feedstocks. There is political will to establish in Thailand, if feasible, small, decentralised biorefineries to which farmers can locally deliver biomass as feedstock, which can then be processed into bio-based products.

This report examines what would be necessary for Thailand to make a biorefinery roadmap. A roadmap can take many forms and can be of any size. What should be critical to a roadmap is a timeframe to show potential investors the commitment from government to achieve the goals set out. To transform a roadmap from an aspiration requires some mechanism to make sure that the milestones and deadlines of the roadmap are achieved.

This report has identified strengths and weaknesses at a macro-level. There are clearly infrastructure and market strengths in Thailand, with a successful petrochemicals industry and well-developed demand markets for pharmaceuticals, food supplements / nutraceuticals and protein feed. Nevertheless, under the same category, several companies remarked on the strong dependence of imports of technology and machines from foreign countries, and immigration policies do not favour attracting foreign expertise. Other strengths and weaknesses identified were:

- Research, innovation and education: Thailand has a strong university ecosystem and is considered to be good at research, including biotechnology research. However, engineering education was mentioned as a weak point by a few interviewees. Innovation tends to come from start-ups and SMEs, but also, in great part, from foreign investment.
- Biomass availability and sustainability: For important sugar and starch crops, such as sugar cane or cassava, there is constant and secure supply of good yields, while there is also access to pre-treatment of these feedstocks. The abundance of these crops makes competition with food highly unlikely. Transport and logistics still pose some challenges. Since a large proportion of farmers are poor, the costs for sustainability or organic certification are a high barrier to entering new markets.
- Policy and regulation: There is political willingness to support innovative, bio-based industries. In 2019, the Thai government announced a wide range of tax and non-tax incentives for some bio-based industries. However, zoning/city planning was mentioned as another very important barrier due to green zones and production zones being in different locations. This presents an apparent contradiction – it may

be impossible to build biorefineries in rural locations according to this zoning regulation.

Of central importance for a biorefinery roadmap is establishing biomass availability. Thailand is a fertile land in which a variety of crops can be grown. However, it is difficult to get a comprehensive overview of land use and crop structures in Thailand. A rough overview of the most important crops and their domestic usages as well as their export was established. Several key barriers to biomass availability were highlighted; climate change and increasing dryness, potentially drought, were mentioned repeatedly.

Small biorefineries are not necessarily the only goal for a biorefinery roadmap in Thailand. The project identified factors for and against small-scale biorefineries, and there will be occasions when larger scale makes more sense than staying strictly with a small-scale paradigm.

Much of this requires public policy action to be able to grow a private sector that is not sceptical of political disruptions that would leave their investments stranded. The long-term intentions and signals cannot be ambiguous. To this end, the report lays out a range of policy measures that address both the supply- and the demand (market)-side measures. Some of these are:

- Construction of R&D and innovation infrastructures such as pilot and demonstration plants.
- Policies to make use of local feedstocks e.g. those associated with short transportation distances and local job creation.
- R&D subsidies for the academic sector in programmes dedicated to the bioeconomy.
- Creating technology and regional clusters in the heart of the rural environments where biorefineries are envisaged to operate.
- Mandates and targets/quotas for bio-based production.
- Public procurement of bio-based goods.
- Standards and certification, especially for sustainability that prove advantages over fossil-derived products.
- Fossil carbon taxes and emissions incentives to generate the revenues for the introduction of new technologies and disincentivise fossil production.

It is common and easier for governments to support supply-side measures, but governments can be shy of demand-side measures for fear of interfering in and distorting markets. This becomes a delicate balancing act to satisfy the large range of bioeconomy stakeholders, and the biorefining roadmap must capture this balance. The report attempts to show the general policy measures as well as those specific to Thailand.

Introduction

Thailand wishes to promote its bioeconomy, and one way is through biorefining. More specifically, there is political will to establish – if feasible – small, decentralised biorefineries to which farmers can locally deliver biomass[1] as feedstock, process the feedstock into precursors of bio-based chemicals and thus profit from a higher value-added creation than from only selling crops to downstream processers.

This study provides cornerstones that can serve as guidance for a potential biorefinery roadmap. It is based on desktop research (2019–2020) and a fact-finding mission to Thailand in January 2020 in which a multitude of stakeholders from academia, policy and industry were asked for their input through questionnaires/interviews, focus group discussions and a workshop. In addition, several existing bio-based factories were visited.

This report will outline:

- The concept of small-scale biorefineries and their advantages and disadvantages compared to larger biorefineries;
- Thailand's strengths for building a bioeconomy and its drivers;
- Thailand's weaknesses for building a bioeconomy and existing barriers;
- Technological, environmental and social trends and what they can mean for a bioeconomy;
- Potential policy measures that can promote the bioeconomy / biorefining industry.

1.1. What is the bioeconomy?

The vision of what a bioeconomy has evolved in the last decade. The OECD definition of 2009 was about economic impacts of biotechnology, describing the bioeconomy as "the set of economic activities in which biotechnology contributes centrally to primary production and industry, especially where the advanced life sciences are applied to the conversion of biomass into materials, chemicals and fuels" (OECD, 2009). As the concept has grown, other interpretations have been described. A most notable divergence has been in the United States, where the 2012 Bioeconomy Blueprint (The White House, 2012) included human health, for example "personalized medical treatments based on a patient's own genomic information".

The recently (2018) reviewed and updated bioeconomy strategy of the EU takes a similarly broad approach, defining "the bioeconomy [as covering] all sectors and systems that rely on biological resources (animals, plants, micro-organisms and derived biomass, including organic waste), their functions and principles. It includes and interlinks: land and marine ecosystems and the services they provide; all primary production sectors that use and produce biological resources (agriculture, forestry, fisheries and aquaculture); and all economic and industrial sectors that use biological resources and processes to produce food, feed, bio-based products, energy and services" (European Commission, 2018). This definition explicitly excludes biomedicines and health biotechnology. Indeed, it excludes the word biotechnology.

Several countries across the world have adopted their own bioeconomy strategies and the sectors involved in different countries reflects this diversity – a small selection is shown in Table 1.

Table 1. National bioeconomy strategies and relevant economic sectors.

Country	Name of the strategy	Level of Strategy	Date	Sectors of interest	Main focus/key funding areas
Finland	The Finnish bio-economy strategy	National	2014	Forestry, bioenergy, chemical industry, bio-based products, water bodies and the sea, and fresh water	Mostly focused on important renewable resources as the biomass in the forests, soil, fields, water bodies
France	A bio-economy strategy for France	National	2017	Agriculture, forestry, fisheries and aquaculture, bio-based industries, bioenergy, green chemicals	Bioenergy; green chemicals; clusters; circular economy
Germany	German National Bioeconomy Strategy Updated	National	2020	All economic sectors	Harness biological raw materials for a circular bioeconomy; exploit converging technologies
United Kingdom	Growing the Bioeconomy. Improving lives and strengthening our economy: A national bioeconomy strategy to 2030.	National	2018	Food and beverage, chemistry, medicines, industry, agriculture, forestry, waste management	Life sciences, multiple sectors
United States	National Bio-economy Blueprint; Billion Ton Strategy	National National	2012 2016	Health, agriculture and industry	Life Sciences (Biomedicine) and agriculture (multiple areas)

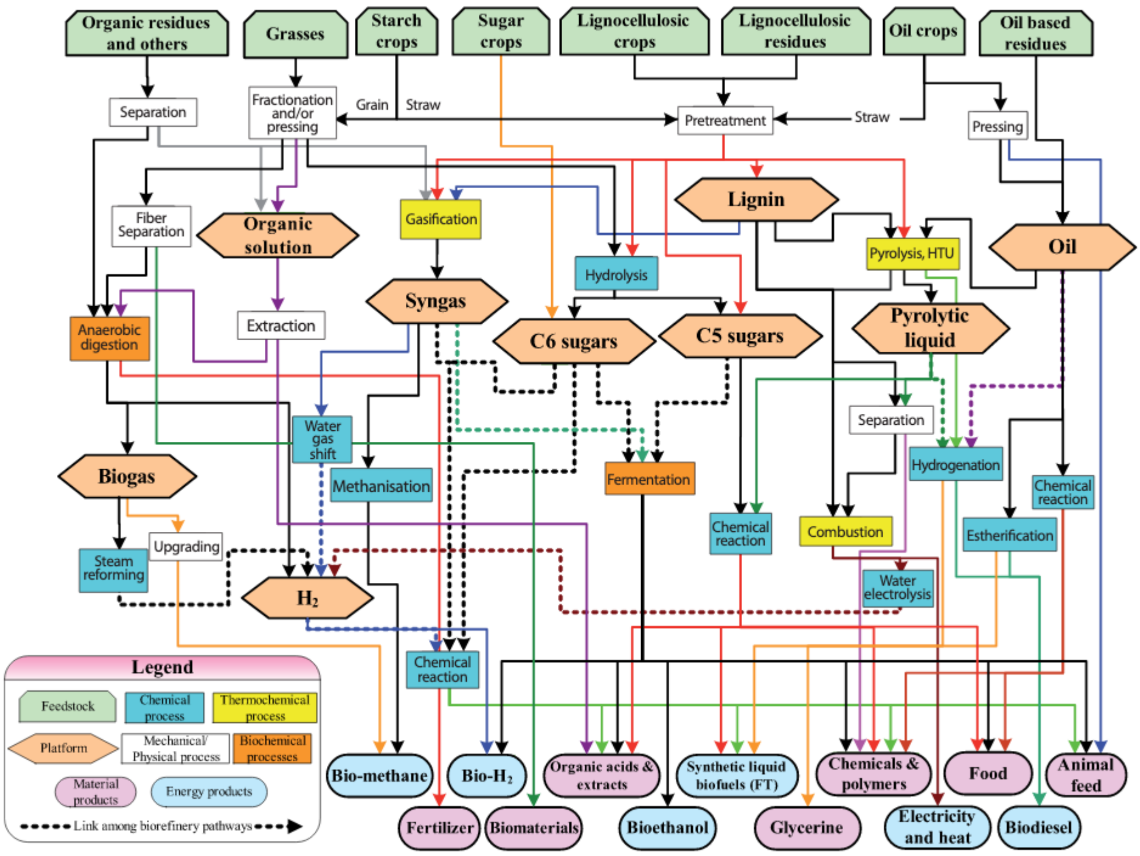
The Thai bioeconomy is framed by several policy documents. There is the National Biotechnology Framework, the Bioplastic Roadmap and the Alternative Energy Development Plan, which are from 2004, 2005 and 2012 respectively. Also the Thailand 4.0 initiative from 2015 included bioeconomy as a future growth industry and most recently, in 2016, the BCG model (Bio, Circular, Green) was agreed on as a strategy to overcome the middle-income trap[2]. Here, four core areas are identified, three out of which belong to the bioeconomy, at least partially: Food and Agriculture, Medical and Wellness, Energy, Material and Biochemical.

1.2. What is a small rural biorefinery?

There is no generally accepted definition of small and large biorefineries, just as a clear threshold can hardly be defined. The classification also depends on the products themselves; the threshold for bulk chemicals is naturally higher than for fine chemicals.

This report sets out to provide guidance on a biorefining roadmap that focuses exclusively on small, (potentially decentralised, rural) biorefineries. However, there is no generally accepted definition of what constitutes such a small biorefinery. The IEA Bioenergy Task 42 "Biorefining" defines biorefining as "the sustainable processing of biomass into a spectrum of marketable bio-based products (food, feed, chemicals, materials) and bioenergy (biofuels, power and/or heat)." (de Jong and van Ree, 2009). Figure 1 illustrates how diverse the feedstocks, processes and outputs of such a biorefinery can be.

Figure 1. Biorefinery classification system



Source: de Jong and van Ree (2009).

In the absence of strict definitions of biorefineries based on size, some working assumptions are given here in Box 1.

Box 1. Biorefinery sizes

There are no strict definitions, but the following can act as a guide for the purposes of this document.

A pilot plant is a pre-commercial production system that employs new production technology and produces small volumes (ten to a few hundred tonnes per year) of new technology-based products, mainly for the purpose of learning about the new technology.

A demonstration plant is an industrial system used to validate an industrial process for commercialisation. It is larger than a pilot plant and the last step before a commercial plant (perhaps a few hundred to thousands of tonnes/year, depending on feedstocks and products).

Small biorefineries have a biomass demand of a few thousand to several tens of thousands of tonnes per year.

Biorefineries with an annual biomass demand of more than 100 000 tonnes can be generally referred to as large biorefineries. There is hardly a threshold possible upwards, and some plants require several million tonnes of biomass feedstock.

Source: original analysis

Depending on its production size, biorefineries require significant amounts of biomass that need to be transported. They also require significant investment and surrounding logistics, including energy, water, waste management and labour force. Therefore, small biorefineries could have the advantage that they are easier to implement and that the investment can be realised also by less economically strong stakeholders, for example by farmers or farmer cooperatives. One approach of defining small biorefineries is to define the annual amount of feedstocks required or product output, e.g. below 10 000 tonnes. There is no clear line, however, between the stages of pilot/demo/commercial (both small and large) scale. Another approach could be to set a geographical limit (e.g. 5-10 kilometres radius) from which the biomass can be delivered. There is no general agreement on that, either. Setting such boundaries could be a first stepping stone towards a biorefining roadmap.

This report discusses the advantages and disadvantages of small versus large and rural versus central biorefineries are discussed. Box 2 below has examples of what can be regarded as small-scale biorefineries.

Box 2. Small-scale refineries

Africa: mobile cassava starch refinery. Container-size factory for local pre-treatment of cassava roots that can be transported to the fields of production. Container consists of equipment for washing, drying and dehydration. Waste water, including minerals, can be recycled to the land directly.

Germany: Concept of a small biorefinery based on grass, alfalfa, foliage. Products: cellulose material, proteins, enzymes, carbohydrates, flavour, dyes and, via fermentation, biogas, lactic acid and other organic acids.

Netherlands: Small company Byosis/Zeafuels producing ethanol from corn. Minerals recycled to the field, distillation of the bio-based ethanol-water mixture is performed to a concentration of 70% ethanol. Removal of residual water from the ethanol-water mixture is performed centrally where intermediate products of several small factories are combined.

Netherlands: Grass refining, 2 tonnes/h demonstrator in 2018, 4 tonnes/h grass from regional production end of 2019, 12 tonnes/h regional production capacity in 2020. Commercial introduction end of 2019, fully commercial in 2020. Products: Proteins (feed for poultry, fish, shrimps, pet food), fibres (cattle feed, construction materials, paper, biocomposites), grass juice (bioethanol) and mineral concentrate as organic plant-based fertilizer.

Netherlands: small-scale biorefinery for small scale beet sugar production (2-500 hectares). Less energy and transport, mineral recycled to the field. Only conceptual design so far.

1.3. A biorefinery strategy will depend on the goals of Thai bioeconomy

When designing a biorefinery roadmap, it will be necessary to clearly identify the main objectives and priorities, in order to select the most appropriate types of biorefineries to support and where to build them. Based on the stakeholder interaction, three main goals of the Thai bioeconomy can be described.

1.3.1. Adding to sustainable GDP growth in Thailand over the next 20 years to help overcome the middle-income trap.

While Thailand's GDP has grown from almost zero in 1960 to more than USD 500 billion in 2018, its per capita GDP has been stuck in the middle-income range (between USD 1 000 and 12 000) since the 1980s (World Bank, 2020). It is a key political objective to overcome the so-called middle-income trap, which usually concerns newly industrialised countries who have risen from the low-income range. Their labour costs are now higher than competing developing countries', but innovation and technology is not at a level yet at which Thailand can compete with highly industrialised and innovative countries. Therefore, focusing on an area such as the bioeconomy, which is high in potential of innovation and technological progress, makes a lot of sense. And lately, Thailand has experienced overall success: GDP per capita GDP has risen from USD 6 000 to over 7 000 just between 2016 and 2018 and several innovative companies have invested in Thailand, such as Corbion / TotalCorbion, PTTMCC, and MITR, producing high-value chemicals from bio-based resources.

1.3.2. Raising the prosperity of farmers in Thailand, and reducing inequality

Inequality is an important social issue in Thailand and was also mentioned several times by the stakeholders. It was the most common answer to the question, "In your opinion, which economic and social issues are most pressing in Thailand." The Bank for Agriculture and Agricultural Cooperatives distinguished different levels of wealth/poverty among Thai farmers: 36% are registered as poor farmers, and are living beneath the poverty line. Small farmers represent 63% of their constituency, while only 1% are "high potential people". There are already several initiatives to raise the prosperity of farmers. The bank encourages farmers to work together as a community to improve local capability e.g. mango farming, rice, organic vegetables. These increase income for families. Organic farming for export is seen a key strategy. Integrating other parts of the bioeconomy than food and feed in a strategy that should benefit farmers must be finely balanced.

Delivering feedstocks to the chemical industry on a fixed basis (contract farming) can be beneficial, since it guarantees regular income, minimises risks of losses due to bad weather and farmers do not have to invest without guaranteed demand. Even without contract farming, the chemical industry could be an important alternative outlet, since sugar consumption is decreasing in Thailand. On the other hand, if more lucrative markets are also available (e.g. the organic fruit markets of export countries or big metropoles), it is not necessarily attractive for farmers to only deliver low-value crops such as sugar cane to the chemical companies. However, there are also some examples of high-value ingredients for cosmetics such as soybean oil and keratin oil that are worthwhile for farmers.

1.3.3. Increasing capacity of biotechnology and higher-tech bioproduction

Innovation and technological progress are key to overcoming the middle-income trap. Just now, first generation ethanol is the most prevalent jigsaw piece of the bioeconomy in Thailand. There is research, at least at company level, on second generation ethanol, too (Box 3). Second generation pre-treatment, however, comes with a price tag and it is not clear yet if there are customers willing to pay the extra cost. Among the interviewed stakeholders, there is also awareness that downstream concentration and purification incurs high to very high costs in making many bio-based chemicals. Ethanol can be concentrated by relatively straightforward distillation, and gaseous products can be separated by phase separation. But for many bio-based chemicals more extensive impurities require more expensive recovery technologies (Wu and Maravelias, 2019).

Concerning biotechnologies, there is not a large number of academics and industrial biotechnologists in the country. The academic sector sees a need for more higher education courses and also a need for more foreign talent. During the fact-finding mission, the research team was expecting to find little to no industrial biotechnology pilot plants, but in fact there were at least three at different levels of sophistication (the highest level for pharmaceutical production).

Thus it can be said that biotechnology expertise is present in the country, but excellence is concentrated in clusters. Moreover, it was found that the relevant academics did not communicate with each other effectively. There is a need to understand that strength comes from partnership in biotechnology.

Box 3. First and second generation ethanol

First generation bioethanol plants using sugar and starch from food crops. Second generation uses lignocellulosic feedstocks such as wood, straw and other lignocellulosic by-products or waste stream from agriculture, forestry and food production.

First generation bioethanol plants represent the vast majority of plants. They are under criticism for the fear that they could endanger the food supply as they use the same feedstock as the food industry. For this reason, food crop-based fuels are capped at 7% in the Renewable Energy Directive of the European Union. Higher shares can only be achieved with second generation bioethanol.

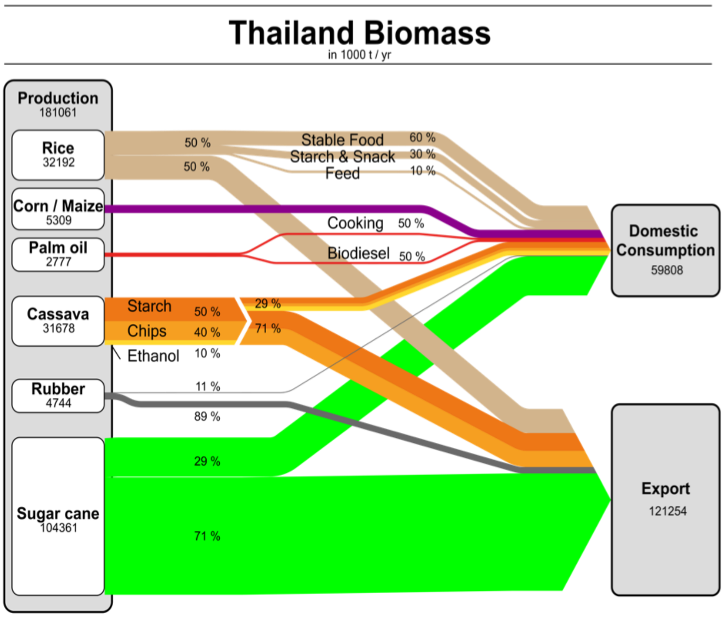
From a scientific point of view, this evaluation is only partially plausible: First-generation bioethanol plants produce – in contrast to second generation – proteins as a by-product, the real bottleneck in the food market. Second generation plants are also technically much more complex and expensive. The advantage of less competition with the food sector is only true for lignocellulosic by-products and waste streams. If wood or short-rotation plantations are grown as feedstock, the land use efficiency is considerably lower than for food crops, which takes away more land from food cultivation and thus endangers food supply and biodiversity.

2. Feedstock types and biorefineries

2.1. Land use and status of biomass production today

Thailand is a fertile land in which a variety of crops can be grown. In 2019, it was the world's second largest exporter of sugar and rice as well as the largest exporter of rubber. It is difficult to get a comprehensive overview of land use and crop structures in Thailand, since there is no centralised information on agricultural usages. Based on FAOSTAT data and expert estimations, Figure 2 gives a rough overview of the most important crops and their domestic usages as well as their export.

Figure 2. Most important domestically produced biomass flows in Thailand.



Source: nova-Institute (2020), based on data from FAOSTAT and BIOTEC.

During the stakeholder interviews, there was agreement that sugar cane, cassava, palm oil and rice straw are the most competitive feedstocks with the highest potential for the bioeconomy (Table 2). Soybean may have potential as a niche market, but is predominantly imported at the moment.

However, there are several limiting factors to biomass availability for the bioeconomy. Most prominently, climate change and increasing dryness were mentioned repeatedly. These hamper the production of rice, making it necessary to focus on alternative crops. Several of the listed high-potential crops bring problems with them as well: rice straw needs to be collected from fields, which means a lot of effort for the farmers without corresponding incentives so far. So, burning still is the predominant practice. Also, if the availability of rice decreases due to climate change, it might also not be the best strategic focus to rely too much on its by-products. It was even mentioned that Thailand might start to import rice. For sugar cane, the limiting factor is a regulatory one. So far, for bio-based chemicals production, it is only allowed to use molasses. The industry would much prefer to be able to directly use the sugar juice instead of only by-products. Industrial starch from cassava can be (and already is) used by the industry; however, cassava requires very quick processing to prevent fouling. The energy costs incurred for the necessary drying are very high too.

The organic fractions of household waste, which play an increasingly important role in circular bioeconomy strategies around the world[3], is not in focus in Thailand at the moment. Even though there might be a high potential in terms of existing volumes especially in large cities, biowaste is currently rarely collected and none of the stakeholders seemed to give any importance to it as a feedstock for industry.

Table 2: Highest potential crops for bioeconomy and their pros and cons

Crop	Pros	Cons
Rice	Experience, existing fields, good conditions so far	Vulnerability to climate change; existing food needs and export markets
Rice straw	Availability, no competition to food	Collection efforts (no incentives), needed for soil quality, dependent on rice availability (impacted by climate change, too)
Sugar cane	Experience, existing fields, even more potential due to resilience to more dryness	Only allowed to use molasses for bio-based chemicals, low value for farmers compared to exporting organic fruit for example
Cassava	Availability, resilience to climate change	Quick processing necessary, energy costs for drying
Palm oil	High experience, good yields, versatile applications	Competition from other SEA countries; increasingly negative reputation in demand countries

2.2. Rough outlook for land use and biomass production

Predicting the future development of land use and biomass production in Thailand is not an easy feat. As mentioned, there is no concerted action to build a coordinated land use plan or similar that addresses how food and feed demand can be covered first, how export can be covered secondly and then also cover the demand of a growing bio-based industry. It is clear that climate change will have an impact on farming, but the extent is not foreseeable. Most farmers are very concerned that they will need more and more irrigation in order to grow rice and other cultures. Sugar is a potential alternative (even though it also requires some irrigation, although less than rice), but the prices for food sugar are currently very low, so other outlets than food – e.g. chemicals – would be welcome, too.

Regarding future developments, the Bank for Agriculture and Agricultural Cooperatives is running several programmes to raise prosperity of farmers, e.g. through working in more collaborative ways, supporting organic farming and through some digitalisation initiatives.

Regarding other new crops and feedstock, stakeholders reported the following:

- Sorghum and sugar beet cultivation has been tried in north of Thailand. Sorghum worked (the climate in the north is more suitably cold), but sugar beet was not good as too many insects attacked it.
- Jatropha and napier grass have been tried, but the trials were not successful.

- Microalgae may be possible but it seems to be quite far away and will probably only be applicable for specialty applications in pharma and food (high value / small volume). There is some research in Thailand on microalgae at small scale.
- Organic waste management is not yet well established. This could be a very large feedstock resource in the future. But most is currently landfilled.
- Hemp/cannabis for CBD (pharma, food additive) and THC (pharma), seeds/oil and fibres/cellulose are grown in North Thailand, but it is still mostly illegal and requires special licenses.
- Chicken feathers are available in high amounts. There already is a facility processing them, but more development is needed to make high-value products from them.

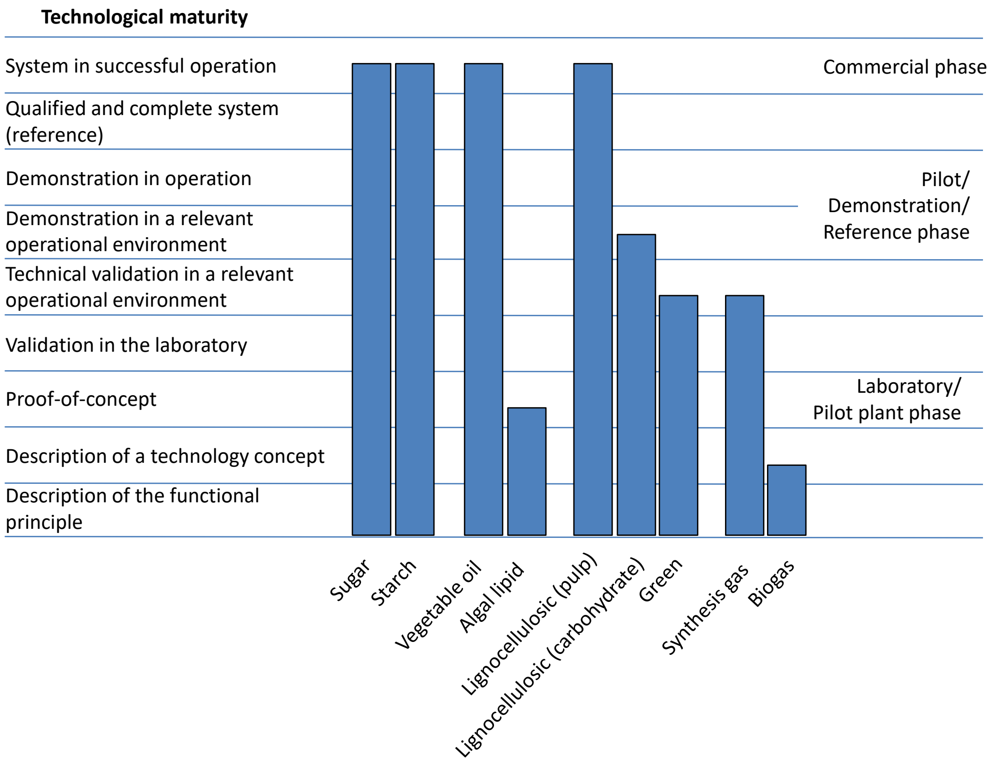
The large sugar refining company Mitr Phol is also working on improving agriculture with the goal of increasing yields while conserving soils and increasing product quality. Notable activities in this regard is the use of organic insecticides and micro-organisms against insects, mechanically removing weeds and leaving leaves on the ground to improve soil structure or utilising them instead of burning them.

The situation with regard to genetically modified organisms (GMO) is not clear in Thailand. Several trials have been made, sometimes successful, for example by growing papaya that was more resistant to pests. However, GMOs are not widely accepted in Thailand, at least not by all parts of society. Several environmental NGOs protest against GMO crops and there have been allegations that they even destroyed the crops on such trial fields[4].

3. Biorefinery concepts for Thailand

According to the German Biorefinery Roadmap (Government of the Federal Republic of Germany 2012), the technological maturity of the different biorefinery types is quite diverse too (Figure 3). Things have moved on since 2012, but this status has not really changed significantly.

Figure 3. Development status of various biorefinery models.



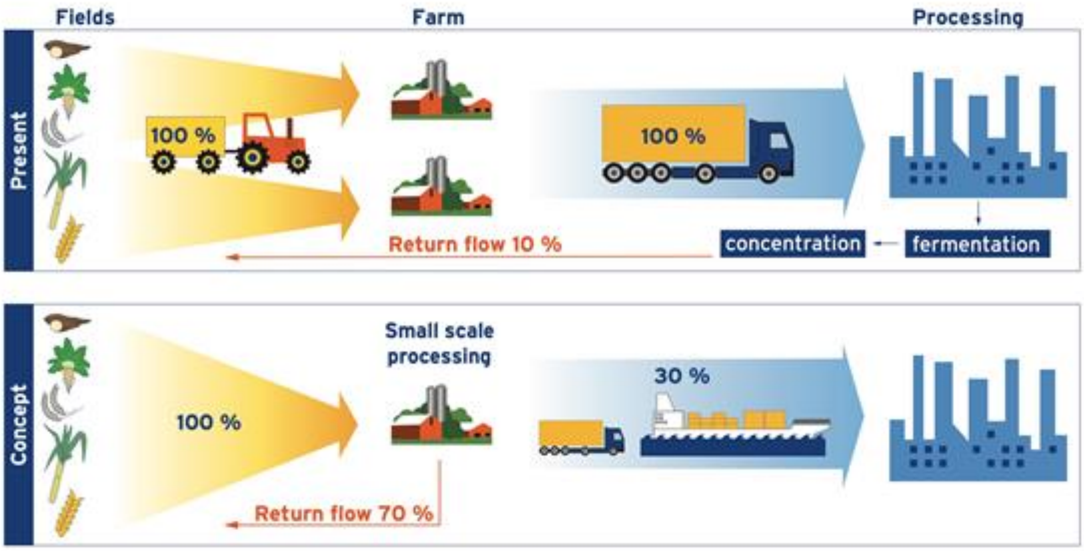
Source: Government of the Federal Republic of Germany (2012).

The concept of building small biorefineries bears several potential advantages:

- Small-scale (pre-)processing of biomass reduces water and thereby transportation costs for further processing steps.
- It makes local (re-)use of biomass or certain fractions (e.g. minerals, nutrients) possible instead of accumulating them at a central processing facility which could further necessitate waste treatment.
- Higher integration of farmers into the value chain provides incentives for innovation, increase in productivity, reduction of costs and recycling – and creates new, qualified jobs.
- While there are economies of scale which support large biorefineries, there could be diseconomies of scale for feedstock supply which support smaller, decentralised biorefineries.
- If there are multiple smaller processing facilities, there may be benefits due to mutual learning and process improvements.

Figure 4 shows the difference between this idea and the presently established system of larger biorefineries.

Figure 4. Differences between larger and small-scale biorefineries; transportation and return flows.



Source: nova-Institute (2020), based on Bruins and Sanders (2012)

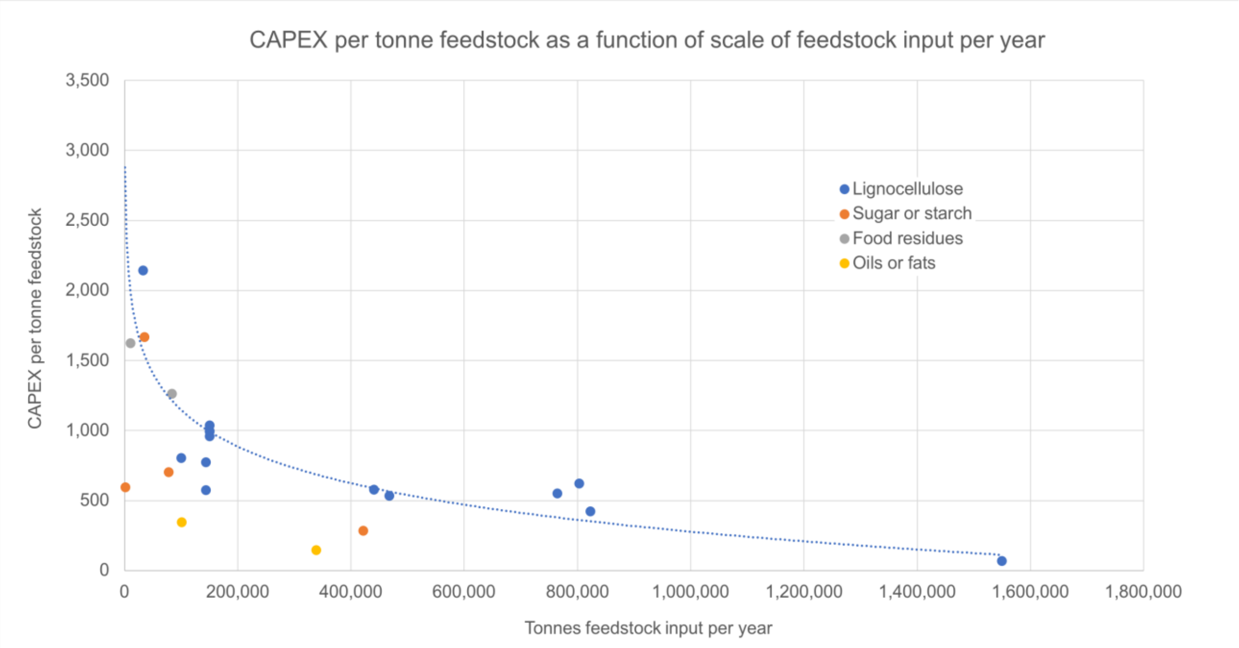
It is still debated whether small-scale biorefineries can be economically feasible. While in theory, it can make sense to have decentralised pre-processing (small-scale biorefinery) and only later on centralised downstream processing, this is only plausible for processes that do not have to fulfil strict safety conditions; this excludes all processes involving hazardous chemicals and genetically modified organisms or pharmaceuticals. Energy intensive processes or processes with a lot of side streams which can be exchanged between different plants benefit most from a "Verbund site"[5] production. Such processes are not favourable in small, decentralised biorefineries.

There are more concerns related to the concept of small-scale biorefineries. During a fact-finding mission to Thailand in January 2020, several experts mentioned the following issues related to the concept:

- Quality of intermediates (impurities).
- Quality management.
- Technology (most advanced technologies work only in central locations, e.g. membrane technology).
- Efficiency (sugar cane syrup, 90% central, only 70-80% decentral) and use of side-streams.
- Wastewater treatment (advanced only central).
- Skilled experts missing in rural areas.
- As a result: economics (economies of scale).

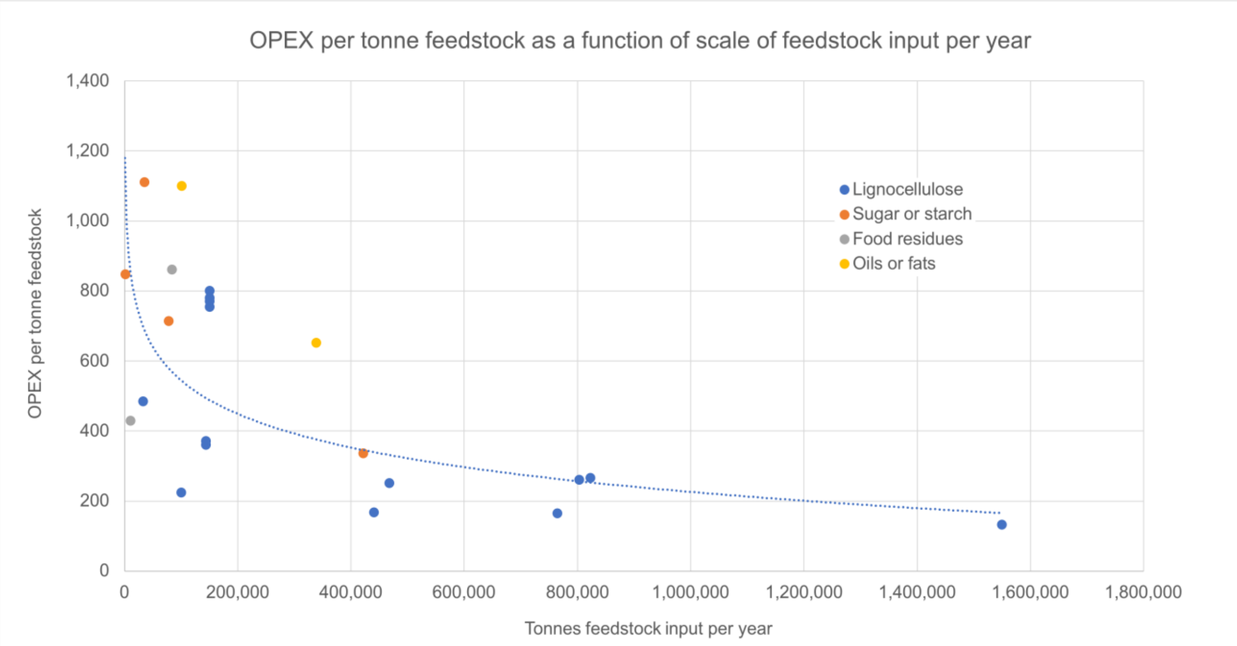
With regard to the last point, economies of scale favouring larger plants, Figures 5 and 6 show how capital expenditure (CAPEX) and operational expenditure (OPEX) per tonne of feedstock decrease significantly with a growing feedstock input per year. The calculations were done based on a multitude of techno-economic evaluations of biorefineries from different authors, in different countries, for different feedstocks and based on different technologies (IEA, 2019; Lopes et al., 2019; IEA, 2014; Piotrowski et al., 2014).

Figure 5. Biorefineries CAPEX per tonne of feedstock as a function of scale of feedstock input per year.



Source: nova-Institute research, 2020.

Figure 6. Biorefineries OPEX per tonne of feedstock as a function of scale of feedstock input per year.



Source: nova-Institute research, 2020

Differentiating central and decentralised small-scale biorefineries is also important, and their comparison reveals advantages and disadvantages. Centrally located biorefineries could benefit from being in close proximity to existing infrastructure and skilled labour, which could be recommended for high-value and technology-intensive processes. On the other hand, decentralised biorefineries would mainly have the objective of reducing transportation costs and of contributing to rural development. Clearly, a strategy document would have to make a decision, whether both objectives should be supported or whether one should be favoured over the other.

There are a few examples of small-scale biorefineries in the world (see a selection in Box 2); however, these almost exclusively cover relatively simple technologies and products (e.g. ethanol). Regarding implementation, stakeholders were somewhat divided during the interviews in January 2020. Some stated that the concept of small-scale biorefining might make sense, while others clearly rejected the idea. The Bank for Agriculture and Agricultural Cooperatives felt that farmers' cooperatives could run the small biorefineries model but a lot of regulations would need to be unlocked. Table 3 sums up the arguments for and against.

Table 3: Advantages and disadvantages of different biorefinery types (sorted by size and location).

Biorefinery type	Advantages	Disadvantages
Small rural	Short ways, low transportation and other logistics costs; more revenue for rural population	Economic feasibility doubtful (risk for farmers and investors); cannot process anything with high-tech or safety requirements; low quality outputs; lack of qualified employees
Large rural	Short ways, low transportation and other logistics costs; economic feasibility higher than for small-scale	Revenue for farmers perhaps less? Difficult circumstances for logistics (roads/water/waste management); lack of qualified employees
Large urban	Economies of scale; connection to energy, water, waste management; able to use high-tech, GMO etc.; qualified staff	Revenue for farmers low; mostly big companies and urban population profit

Source: nova-Institute research (2020).

When looking more specifically at the Thai situation, it is notable how many biorefineries are already in operation. Most of them have an energy focus (bioethanol/biodiesel), but there are also some biorefineries producing chemicals and materials. Table 4 gives an overview of several existing plants (no claim on exhaustiveness).

Table 4. Overview of existing biorefinery plants in Thailand.

Company	Product	Location	Capacity (litre/day)	Capacity (metric tonnes/year)	Feedstock
Thai Agro Energy PCL	Bioethanol	Dan Chang	150 000	62 738	Molasses
KTIS Bioethanol Co., Ltd.	Bioethanol		230 000	96 198	Molasses
Thai Sugar Ethanol Co., Ltd.	Bioethanol		100 000	41 825	Molasses
Mitr Phol Biofuel Co., Ltd.	Bioethanol	Chaiyaphum	500 000	209 125	Molasses
Mitr Phol Biofuel Co., Ltd.	Bioethanol	Kalasin	230 000	96 198	Molasses
Mitr Phol Biofuel Co., Ltd.	Bioethanol	Kuchinarai	320 000	133 840	Molasses
Mitr Phol Biofuel Co., Ltd.	Bioethanol	Dan Chang	200 000	83 650	Molasses
K.I. Alcohol Co., Ltd.	Bioethanol		200 000	83 650	Molasses
KSL Green Innovation PCL	Bioethanol		150 000	62 738	Molasses
KSL Green Innovation PCL	Bioethanol	Bo Phloi	300 000	125 475	Molasses
Thai Roong Ruang Energy Co., Ltd.	Bioethanol		300 000	125 475	Molasses
Maesot Green Energy Co., Ltd.	Bioethanol		230 000	96 198	Cane Juice
Rajburi Ethanol Co., Ltd.	Bioethanol		150 000	62 738	Cassava chips / molasses
E.S. Power Co., Ltd.	Bioethanol		150 000	62 738	Cassava chips / molasses
Thai Alcohol PCL	Bioethanol		200 000	83 650	Cassava chips / molasses
Thai Agro Energy PCL	Bioethanol	Dan Chang	200 000	83 650	Cassava chips / molasses
Impress Ethanol Co., Ltd.	Bioethanol		200 000	83 650	Cassava chips / molasses
Sapthip Green Energy Co. Ltd.	Bioethanol		200 000	83 650	Cassava chips
Thai Ethanol Power PCL	Bioethanol		130 000	54 373	Cassava roots
Taiping Ethanol Co. Ltd.	Bioethanol		150 000	62 738	Cassava roots
P.S.C. Starch Products PCL	Bioethanol		150 000	62 738	Cassava chips
E85 Co., Ltd.	Bioethanol		500 000	209 125	Cassava roots
Ubon Bio Ethanol Co., Ltd.	Bioethanol		400 000	167 300	Cassava roots/cassava chips
Bangchak Bioethanol Co., Ltd.	Bioethanol		150 000	167 300	Cassava roots/cassava chips
T.P.K. Ethanol Co. Ltd.	Bioethanol		340 000	142 205	Cassava chips
Fakwantip Co. Ltd.	Bioethanol		60 000	25 095	Cassava roots

Patum Vegetable Oil	Biodiesel		1 400 000	525 000	CPO
Global Green Chemicals	Biodiesel		1 028 600	385 725	CPO
New Biodiesel	Biodiesel		1 000 000	375 000	CPO
Bangchak Biofuel	Biodiesel		810 000	303 750	CPO, RBDPO
Energy Absolute	Biodiesel		800 000	300 000	Palm Stearin
AI Energy	Biodiesel		500 000	187 500	RBDPO, RBDPS
Absolute Power P	Biodiesel		300 000	112 500	RBDPO
GI Green Power	Biodiesel		200 000	75 000	Palm Stearin
Verasuwan	Biodiesel		200 000	75 000	Palm Stearin
Bio Energy Plus 2	Biodiesel		200 000	75 000	Palm Stearin
Trang Palm Oil	Biodiesel		100 000	37 500	CPO
Bangchak Corporation	Biodiesel		50 000	18 750	Vegetable Oil, CPO, RBDPO
Bio Synergy	Biodiesel		30 000	11 250	Vegetable Oil
Advanced Biochemical (Thailand) Co., Ltd.	Epichlorohydrin	Rayong		120 000	Glycerol from biodiesel plant
Corbion	L-lactic acid	Rayong		100 000	Starch
Total Corbion	Lactide	Rayong		100 000	Starch
PTT MCC Biochem Co., Ltd.	PBS copolymers	Rayong		20 000	Starch
Total Corbion	Polylactic acid	Rayong		75 000	Starch
Multibax Public Co., Ltd.	Polylactic acid	Chonburi		2 200	Starch
Thai Fatty Alcohol	Fatty alcohol and ethoxylates			50 000	Vegetable Oil
Thai Ethoxylate	Fatty alcohol and ethoxylates			50 000	Vegetable Oil
Thai Citric Acid	Citric acid			120 000	Sugar
Global Green Chemicals	Fatty alcohol and ethoxylates			225 000	Vegetable Oil
Mitr Phol Biofuel Co. Ltd.	Diverse bio-based building blocks		Demo level	Demo level	Sugar cane / molasses

Source: Skoczinski et al. (2020); Krungsri (2020); Thai Ethoxylate Co. Ltd. 2020; Thai Citric Acid Co. Ltd. 2020 and field visits by OECD and nova-Institute, 2020.

In addition to these existing commercial plants, more progress is being made with pilot plants using different feedstocks and making different products. For example, one pilot plant uses chicken feathers as feedstock, using keratinase as the biocatalyst and the product will be chicken feed. This might be the first government/industry funded pilot plant in Thailand, as PPPs are uncommon in Thailand according to the interviewed stakeholders. Funding was THB 20 million from each source. This is also the first with fermentation and downstream processing.

During the fact-finding mission in January 2020, two other pilot plants were visited. One produces pharmaceuticals at very high technology levels. The other one was a general purpose biorefinery. Demonstration-scale plants are currently missing in Thailand.

When asked about the feasibility of rural small-scale biorefineries in Thailand, respondents were divided. Industry representatives were quite clear that they do not see any chances for establishing such a concept, for all the reasons already discussed (economies of scale, logistics, quality, skilled labour). Some reported that trials have been made with mini mills both for sugar and palm oil, but they failed for exactly those reasons.

Policy makers, however, were more optimistic. They emphasised that the feasibility of each project depends on its financial model and its location. For local power generation, for example, there is a policy to support such initiatives that can close the investment risk of the communities. One interviewee mentioned a village, in which the community does not burn the rice straw, but has made a business out of it, for example by making paper out of the straw and selling the rice on the food market.

Biogas seems to be something of a mixed case. For local power generation (i.e. directly using the biogas made on a pig farm on that farm itself), there have been positive reports. However, due to changed laws on renewable energy, there is now preference for solar and wind power to feed the excess electricity into the grid, which makes it much less profitable for farmers to invest in biogas technology.

3.1. The pivotal role of demonstration scale

Demonstration is often seen as an essential stage in technology development, but one that is risky and unattractive to the private sector in the absence of market and policy certainty. Using public money to build demonstrator facilities is usually seen as a trigger for private investments. Importantly, foreign companies will see this as serious policy intent and this can help attract international expertise on fermentation technologies.

The essence of the risk is that demonstration facilities are smaller than full commercial-scale plants and often not large enough to make a product at sufficient volume to influence the market. Unless the private sector has great confidence in the facility, it can be seen as an asset that can be stranded once its important purpose is fulfilled; further they may be difficult to repurpose. Governments also perceive this risk. Two possible risk amelioration strategies are given.

The Bio-based Industries Joint Undertaking (BBI JU, www.bbi-europe.eu) in Europe is a model that could suit the ASEAN region. BBI JU has around EUR 1 billion of taxpayers' money and EUR 2.7 billion of private industry money. It conducts projects from research all the way to building flagship plants. This way some of the financial risk for the private sector is mitigated. It would also be an excellent way for Thailand to interact with other ASEAN countries. Box 4 shows a selection of BBI JU flagship projects that illustrate how a collaboration between stakeholders in different countries can be used to breakthrough major technical barriers.

Box 4. BBI JU flagship projects with different feedstocks and products

AgriChemWhey

The AgriChemWhey project proposes to convert the dairy wastes whey permeate and delactosed whey permeate into added-value products – specifically L-Lactic acid, polylactic acid, minerals for human nutrition and bio-based fertiliser - for growing global markets. In the process, it will develop a blueprint for an economic sustainability model that can be replicated throughout Europe. Countries are Austria, Belgium, Germany, Ireland, United Kingdom.

AQUABIOPRO-FIT

The AQUABIOPRO-FIT project's main objective is to promote the increased and efficient use of aquaculture, fisheries and agricultural side streams in feeds and nutritional supplement food products aimed at promoting human health and fitness. Countries are Bulgaria, Greece, France, Netherlands, Norway, Spain.

First2Run

The objective is to build an integrated biorefinery in which low input and underutilised oil crops grown in arid and marginal lands and not in competition with food nor feed, are valorised for the extraction of vegetable oils. These oils will be further converted into bio-monomers (mainly pelargonic and azelaic acids) as building blocks for high added-value bioproducts (biolubricants, cosmetics, bioplastics, additives) through the integration of chemical and biotechnology processes. Countries are Italy, Netherlands, United Kingdom.

LIGNOFLAG

This flagship has an objective of making commercial-scale breakthrough plant to make second generation ethanol. The project will build and operate a commercial flagship production plant for biochemical lignocellulose conversion to cellulosic ethanol with a yearly production capacity of up to 60 000 tonnes/year. Countries are Austria, Germany, Hungary, Romania.

Source: https://www.bbi-europe.eu/projects

A second strategy that is more like a national effort can be seen in a model from the UK (Box 5). The final bullet in this box is of great importance. Every time CPI performs a project, the staff accumulate knowledge in a field that is still very young. This is seen in the UK as a way of building national expertise while performing an essential service for companies.

Box 5. The industrial biotechnology demonstrator in the UK

The Centre for Process Innovation (CPI, www.uk-cpi.com) in the UK uses an open innovation model to derisk process development by providing proof-of-concept testing at scale to accelerate commercialisation.

The CPI model comprises:

- Carrying out market analysis with businesses or partners that have technology or a defined market need.
- Setting up a team of technology, market, and commercial professionals to design assets to develop a range of technologies that meet the market need.
- Finding a combination of private and public investment to build and operate the development assets.
- Private companies (both SME and large companies) use the assets and CPI expertise to prove, develop, and scale up their technology until it is ready for commercialisation.
- Companies then invest their own funds to take the technology to market and create value.
- The development assets are retained and developed by CPI for use by other companies and projects to build a national capability in the sector.

CPI has a facility dedicated to industrial biotechnology that large and small companies can use to develop a bioprocess from strain characterisation to laboratory definition through the pilot to the demonstration scale (Figure 7).

Figure 7. The Centre for Chemical Process Innovation (CPI) industrial fermentation facilities

Note: (A) laboratory, (B) 750 L and (C) 10 000 L fermenters.
Source: adapted from Schieb and Philp (2014)

3.2. Examples of biorefineries at larger scale

The two examples given here, one in existence for several decades in France (Box 6) one under construction in Germany (Box 7), have some similarities and some significant differences. They both have the characteristics of integrated biorefineries in that they produce (France) or plan to produce (Germany) several or multiple products. This model is seen as having a major advantage in that multiple products can spread risk, especially if more than one feedstock can be processed. A major difference is that the example in France mostly uses food crops as feedstocks (so-called first generation) and the example in Germany will largely use wood (non-food) feedstock.

Box 6. The integrated biorefinery model at Bazancourt-Pomacle, France

The Agro-industrie recherches et développements biorefinery hub and Bioraffinerie recherches et innovation at Bazancourt-Pomacle, northern France.

This model may be appropriate in some settings in Thailand. While it acts as a hub for biomass collection and processing in a semi-rural environment, it also allows for small-scale bio-based production and research, development and demonstration all on one site. Of particular interest is the role of the 10 000 farmers in this biorefinery ecosystem. The site employs 1 100 people directly and another 800 indirectly.

Agro-industrie recherches et développements (ARD) is a mutualised private research structure, owned by major players in the French agri-business as well as regional farming cooperatives, the latter being a particular strength. It was created in 1989 by exploiting the notion of value creation through non-food applications to find new opportunities from the produce of its shareholders (e.g. cereals, sugar beet, alfalfa, oilseeds).

The ecosystem

ARD started two subsidiaries – Soliance (molecules for cosmetic products) and BIODEMO, the largest capacity demonstration platform in France, which has hosted Amyris, BioAmber and Global Bioenergies among others. Air Liquide joined the ecosystem in 2009, building a plant to capture CO_2 for sale from bioprocessing activities at the site. In 2018 Givaudan, the world's largest flavours and fragrances company, joined the ecosystem (Figure 8).

The innovation hub Bioraffinerie Recherches et Innovation (BRI) is an open hub in the field of biorefining. BRI brings together various biorefineries at Bazancourt-Pomacle, the R&D centre ARD, as well as the French engineering schools Ecole Centrale Paris, Agro Paris Tech and NEOMA Business School. Therefore, it covers the value chain from fundamental research to the pre-industrial prototype.

Cristal Union is a French cooperative sugar company. Cristanol operates the ethanol fermentation plant. ADM Chamtor transforms and processes wheat into starch-based products. Wheatoleo is a French company that develops innovative surfactants for the detergent, industrial, and plant protection markets. The Futurol project aims to put on the market a process, technologies and products (enzymes and yeasts) to ensure the production of second-generation bioethanol from dedicated whole plants as well as agricultural and forestry co-products, green residues and other biomass lignocellulose.

Figure 8. The ecosystem at the ARD biorefinery

Public support

It has had public financial support from the Ministry of Industry of France, the General Council of the Marne Département, the Region Champagne-Ardenne and the city of Reims. The combination of farming cooperatives, private industry and backing through regional and national public policy and funding is perhaps the optimal model that can be reproduced in many locations.

The farmers

A crucial part of the ecosystem is the 10 000 farmers who supply the feedstocks (wheat and sugar beet). They have an alternative outlet for their produce that gives more certainty year-on-year, which allows them to make investment decisions on their farms. Given systemic problems with low prices for agricultural produce, this can be considered to be a significant element of sustainability.

Industrial ecology shares costs and creates opportunities

Further added value has been created through an industrial ecology network. The end-of-pipe philosophy is clearly insufficient to prevent pollution. Equally, cleaner production has its limits. The industrial ecology approach considers, in the absence of a viable cleaner production alternative, using waste as a marketable by-product. Using waste from one process as an input to another process at the same site removes transportation and waste disposal or treatment costs. Examples of synergies include:

- Water synergy: recovery of condensate: Chamtor uses 50 000 m^3 of surplus condensate during the beet season. This results in energy recuperation and less groundwater pumping.
- Steam synergy: reciprocal steam use.
- Effluent synergy: purification, storage and agricultural use.
- Products synergy: products and by-products from one plant are used as raw materials in another.
- R&D synergy: research programmes are conducted in cooperation with the ARD stakeholders.
- Energy synergy: use of steam from cogeneration to drive industrial processes e.g. in bioethanol production using sugar beet or wheat.
- Organisational synergy: in cooperation with the Industries et Agro-Ressources (IAR) cluster (http://www.iar-pole.com/), synergies such as construction, operation, and training occur.
- Drilling synergy: production of raw water for industrial purposes.

Source: Adapted from Schieb and Philp (2014); OECD (2019).

Box 7. The biorefinery under construction at Leuna, Germany

The Leuna Chemical Complex is a major site of the German chemicals industry. This differs from the ARD, France example in that it is primarily a site of petrochemistry, whereas the ARD biorefinery is set in an agricultural region.

UPM (Finland) will invest EUR 550 million in a state-of-the-art biochemicals biorefinery at Leuna. Technology and process have been developed by UPM over the past ten years, mainly building on the company's own innovation capabilities and selectively working with international partners. The biorefinery is expected to start up by the end of 2022. UPM will produce a range of 100% wood-based biochemicals that enable a switch from fossil-based products to sustainable alternatives in a number of end uses such as plastics, textiles, cosmetics and industrial applications.

The total annual capacity of the biorefinery will be 220 000 tonnes bio-monoethylene glycol (BioMEG) and lignin-based renewable functional fillers. In addition, the biorefinery will produce bio-monopropylene glycol (BioMPG) and industrial sugars made from sustainably harvested beech wood sourced regionally in Germany. MEG is used for the production of textiles, plastics, PET, packaging and industrial coolants while MPG is used in composites, pharma or cosmetics products. Renewable functional fillers are used e.g. in a variety of rubber applications such as tires and seals.

Some of the advantages of the Leuna site for biorefining are: good access to hard wood, investment grants, a tried-and-tested chemical site, strong links to the huge German chemical industry and strong local support. For Thailand, some of these advantages are quite different from those at Bazancourt-Pomacle. This demonstrates that the decision-making processes in Thailand will vary depending on regional, technology and feedstock circumstances.

4. Strengths and drivers, weaknesses and barriers

4.1. Strengths, drivers, enablers

Thailand has a lot of strengths that make it a high-potential country for bioeconomy development, which is also why several large companies have lately made investment decisions to build plants there.

4.1.1. Existing infrastructures and markets

Thailand has a strong petrochemical sector, so in principle there is a good basis for conversion from petro-based to bio-based chemicals and polymer production. Many of the required skills, much of the infrastructure and unit operations are the same or similar, e.g. steam generation or water treatment. Also, there are a multitude of biofuels plants, providing the needed infrastructure and also a lot of know-how for other bio-based operations.

Further downstream, there is also a good infrastructure for chemicals and plastics. Thailand has around 4 000 plastic converters and a well-established automotive industry which serves as a market. Also lately, there has been increasing domestic demand for bio-based and biodegradable plastics. Further well-developed demand markets are pharmaceuticals, food supplements / nutraceuticals and protein feed. In the future there is the hope to develop more markets with high value, such as bio-based plastics, cosmetics and functional food. By-products should be used (as they already are to some extent) to produce energy for the production and if recycling is improved, this could even lead to a completely circular economy.

In urban areas, access to infrastructure such as transportation, water and waste management is excellent. Also, digital infrastructures and network connections were described as very good. The existing markets of food supplements and pharmaceuticals offer good opportunity for bio-based industries, either for offering such products as well, or for example by using a dual approach e.g. making lactic acid both for the food market as well as for the bio-based plastics market. However, it was noted that there is a lot of regulation impacting these markets, too. In rural areas, labour costs are still relatively low. Industry representatives stressed that the market access to other Asian countries is also an important argument in favour of Thailand as a location.

4.1.2. Research, innovation and education

Thailand has a strong university ecosystem and is considered to be good at research, also dedicated to biotechnology. Regarding biotechnology experts, Thailand is among the top 5 in the world, according to one industry representative interviewed. It is a strong claim and very hard to quantify and compare, but it shows that there is significant trust from several industries in the qualification of the Thai workforce. The problem with these experts is, however, that many skilled people rather work in other sectors, e.g. pharmaceuticals, as they do not see bioeconomy as the future yet. With regard to fermentation, Thailand has a strong history and has also developed significant skill in modern fermentation technologies.

4.1.3. Biomass availability and sustainability

Thailand has a strong agricultural system and is a hub for non-GMO feedstocks in Asia. This is an important argument for globally acting companies who do not want to be accused of using GMO crops in their products.

For important sugar and starch crops, such as sugar cane or cassava, there is constant and secure supply of good yields, while there is also access to pre-treatment of these feedstocks. This was one of the main arguments of Corbion and Total/Corbion to recently set up their production facilities in Thailand. Sustainability certification is not widespread yet, but Mitr Phol works with the Bonsucro certification scheme, also for exporting bioethanol to Europe.

4.1.4. Policy and regulation

Industry representatives noted positively that there is political willingness to support innovative, bio-based industries. In general, the political landscape is reliable enough for big investment decisions and the currency is stable, making Thailand a safe investment environment.

In 2019, the Thai government announced a wide range of tax and non-tax incentives for bio-based industries from the sectors bioenergy, biochemicals, food, animal feed and biopharmaceuticals. Tax-based incentives include the exemption of corporate income tax for up to eight years, with an additional 50% reduction for five years and the exemption of import duties on machinery and raw materials. Non-tax incentives include the permission to own land and visa and work permit facilitation (Karaman 2019). For bioenergy, there is long-standing political support already (which can also be a barrier, see below). Furthermore, the strong political support of the Eastern Economic Corridor and the planned biorefinery pilot plant in cooperation with Bio Base Europe Pilot Plant has been positively noted and is promising.

Also quite recently, Thailand has announced the banning of plastic bags, making exemptions for bio-based and biodegradable plastics. Furthermore, using bio-based plastics such as PLA is now mandatory in catering products such as spoons and forks, also there are tax reductions for bio-based plastics. Such measures can create domestic market pull and can be beneficial to industries selling such materials.

4.1.5. Others

The growing environmental problems were mentioned several times as an important driver for bioeconomy. Especially water shortages are getting so bad that many stakeholders feel increasing pressure to find better ways of producing and consuming. More climate-resilient crops and additional outlets for farmers can be one way of addressing this problem.

4.2. Weaknesses and barriers

The interviewed stakeholders provided a comprehensive list of existing weaknesses and barriers that hamper the development of the Thai bioeconomy in general and the setting up of small-scale biorefineries specifically.

4.2.1. Existing infrastructures and markets

Water supply is becoming more of a problem due to climate change, especially in rural areas. Several companies remarked negatively on the strong dependence of imports of technology and machines from foreign countries (especially People's Republic of China). Also, all enzymes have to be imported as of now, even though that will probably change due to some future developments at some companies. The enzyme market is relatively small, competitive and dominated by a small number of well-established companies. Growing a domestic production capacity will be difficult without, say, joint ventures with established foreign companies. Box 8 illustrates how Thailand may investigate the feasibility.

Box 8. Is there an opportunity for Thailand in the enzymes market?

The market for enzymes is relatively small, it is of the order of USD 10.6 billion per annum (2020 figure), but has shown good growth.

The market is projected to grow at a compound annual growth rate (CAGR) of 7.1% from 2020 to 2027. Furthermore, the main markets are North America and the Asia Pacific. The main market sectors are food and beverage, cleaning products (detergents and washing powders), biofuel production, animal feed, pharmaceutical, research and biotechnology, with food and beverage dominating the market. The wide range of sectors is promising for newcomers wishing to enter the market. However, the small size of the market and the fact that a small number of companies dominate the market means that it will be difficult to break into the market. Key companies, including Novozymes, DuPont, and DSM, represent over 75% of the market share. Furthermore, the industrial enzymes industry is investment-intensive and has long lead times to market.

The scope of a recent enzymes market analysis (Grand View Research, 2020) covers the following countries: Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, Mexico, Saudi Arabia, South Korea, Spain, Turkey, UK. In other words, there are many countries in a small sector, suggesting that Thailand would have to have an alternative strategy than direct entry to the market from a domestic base. A methodology for Thailand to investigate the prospects of growing its own domestic enzyme market could include the following steps:

- Determine the needs from established industries (quantities, suppliers).
- Determine the academic interest in industrial enzymes in Thailand and the prospects for advanced manufacturing: enzymes are usually obtained from plants, animals and microorganisms. The industry relies on protein engineering to manufacture recombinant enzymes.
- Catalogue all enzyme manufacturing companies already in Thailand, and their production processes, turnover, profitability.
- If there is promise – the combination of available markets, scientists, engineers, infrastructure, entrepreneurs/investors, then the likeliest point of entry is to attract foreign enzyme companies to invest in Thailand.

This will rely on supply- and demand-side policy signals from government. Typically, a willingness to finance a public-private partnership (PPP) to build an industrial demonstrator facility would be a government approach. An advantage here is that plant sizes for enzymes will be much smaller than, say, for biofuels. Thus it could be envisaged that an industrial demonstrator could be built to a production capacity that could later become a commercial plant.

Still, economics are not competitive in many aspects. Even though there was some controversy on this point, many stakeholders remarked that new, skilled experts are missing and companies produce mostly for export. The skilled experts that are there, would rather work for the petrochemical or pharmaceutical industries, as they are more attractive as of now. Especially in rural areas, labour costs are now increasing, too, since many young people leave their villages and go to the big cities.

Also, IT experts are missing. Due to all of these circumstances, a lot of external experts and consultants are needed, but they are not allowed to live and work in Thailand for more than two months. Immigration procedures are a strong barrier for innovative, bio-based industries.

4.2.2. Research, innovation and education

Interviewees from the academic sector remarked that R&D activities in the industry are relatively low, the innovation environment is not very pronounced in general and that there is no ‘R&D mindset’. Normally, innovation comes from start-ups and SMEs, but those have weaknesses in networking. For example, they do not have networks to European or US start-ups and there is no innovation buy-in. Language barriers do their part in preventing better exchange.

Engineering education was mentioned as a weak point by a few interviewees, also mostly from the academic sector. There is the perception that even though there are many engineers from domestic universities, they are not very skilled, since there are too many universities in the country and the quality of the education is not that high. Biochemical engineering does not seem to be addressed at all (or almost at all).

Stakeholders also criticised that everybody works in silos. Also grants often go to single persons, not to teams. Mostly, people like to stick to what they know and there is no 'entrepreneurial / risk taking' attitude. Accordingly, a lot of innovation comes from foreign investment, but this expertise cannot be transferred to national expertise and innovation.

For researchers and technology translation, there is not a lot of patents or licence income. The IP environment is young (about 20 years). Patents are not used as business instruments but as a key performance indicator (KPI). In research, there is not a lot of attention paid to market demand; much more attention goes to technology push, so there is need for techno-economic analysis from the beginning of the research. Not much market analysis is done because KPIs have just been about publications. If academics want their research to be closer to application, they would do well to realise that there is more than publications in journals. This may indicate a need for a change to the reward process for academic career development.

4.2.3. Biomass availability and sustainability

Even though biomass is abundantly available in general, transport and logistics still pose some challenges. Also, too much feedstock is exported at too low prices, while access to feedstock from neighbouring countries is not easy. It is difficult to obtain information on feedstocks, e.g. on pesticide use or sustainability. Only the big mills that produce for export have this information, other companies cannot get access.

Since a large proportion of farmers are poor, the costs for sustainability or organic certification are a high barrier to entering new markets. Certificates last only for one year, so the costs are incurred more than once. Many farmers are not full-time farmers. Especially the younger generation, between their 20s-40s have two jobs at least. During the harvesting they go back home, but most work in the cities, construction sector, logistics, part-time jobs.

4.2.4. Policy and regulation

Several companies complained about a lack of push from policy, so they feel that they have to make too large investments without sufficient backing from politics. This is a more general barrier and when comparing the Thai incentive system to many other countries.

There are some barriers specific to farmers, and there is a very large number of farmers. One reported a specific barrier of high significance: farmers producing sugar cane they are not allowed to sell their products to more than one sugar refiner. On the one hand they are, like farmers everywhere, at the mercy of variable prices (and sugar cane needs some very specific weather conditions at different times in the year), but they would also be at the mercy of unscrupulous sugar refiners seeking to maximise their own profit. Furthermore, it was noted that farmers are also not allowed to sell to a chemical company directly, they are obliged to sell to sugar refiners. However, this was contradicted by another interviewee who reported that there is a new law allowing farmers to sell sugar to anybody now. The effects need to be seen and apparently this knowledge is not common yet.

Another barrier for farmers is the actual price paid by the refiners, which is fixed by regulation. It sounds attractive – farmers get 70% of the sugar price. However, a government official pointed out that this may not be a large amount, depending on the scale of the farm. Farmers are excluded from value-added that is gained from making more valuable products from sugar cane (and from side streams such as molasses and bagasse). Another side to this, however, is that the farmer takes none of the risk and pays none of the investment cost in developing these products. By paying farmers some of the revenues from these value-added products, this could disincentivise the companies investing in these novel products. A more general approach to this conundrum would be of course to set the

70% as a minimum limit of the sugar price and allow for negotiations for higher prices with a more open-ended upper limit.

Zoning / city planning was mentioned as another very important barrier. The barrier here is highly significant in the context of rural biorefining. Green zones and production zones are in different locations. Therefore, it would not be possible to make a chemical like lactic acid in a green zone i.e. a rural area. Also in cities, it is not possible to build factories, even if the processes are very mild. In general, relatively harmless sugar refineries are treated just the same as much more toxic petrochemical plants when it comes to zoning and factory building. This seems to be a regulatory barrier of high importance as it contradicts the ambition of rural biorefining and increasing bioeconomy in general. Its historical context is understandable in the need to prevent pollution and for safety aspects, but an update could be prudent.

In general, environmental policies were described as rather strict, adding costs for chemical companies. But as opposed to the energy sector, there are no incentives to move away from fossil products towards renewables – the chemical sector is not included in any carbon footprint system, emissions trading or other pricing mechanisms for CO_2 emissions. So, there is no regulatory reason to switch from fossil to renewable chemicals.

In the biogas sector, there is a regulatory barrier. It was once possible to sell excess electricity back to the grid, but this option has been removed and preference is given to solar and wind power (even though biogas presents a good renewable option at night, when the feed-in of the other sources is limited). Whilst facilities like pig farms can produce enough biogas for their own power needs, there would be greater incentive to expand the biogas sector if it was possible to sell excess back to the grid.

Regarding the regulation of genetically modified organisms (GMO), there was some contradicting information, which could later be clarified. Like in many countries, it is possible to use GM microorganisms in bioreactors as this is governed by the rules of 'contained use'[6]. There are standard operating procedures to be adhered to and labs are built to BSL 1 and BSL 2 standards. However, GM crops are not allowed as these are governed by 'deliberate release'[7].

Some very specific regulatory barriers were mentioned by interviewees as well:

- Fermentation of vinegar is not possible.
- Foreign companies are not allowed extraction (of high values components).
- Only research up to TRL3 is supported by funding, though this seems to be changing with the new 'Innovation Fund'. This fund will also support TRL 4-7, including market research, economy, technology evaluation, credibility of research, 20% investment support.
- Last but not least, it was more generally noted that herbs have a lot of potential, but a lot of regulations need to be changed.

4.2.5. Others

A lack of networking and collaboration was often mentioned as a problem, and this impression was reinforced in the OECD fact-finding mission, wherein many of the government, academic and industry stakeholders were not well aware of each other. Big companies would like to collaborate more with universities or with SMEs and start-ups, both domestic and international. But also more exchange with other companies, for example from China and Singapore, regarding technologies and investment is desired. Some wish for more support on such activities, others remarked that it is even made difficult to have such an exchange, however, without giving more details. It was also mentioned that more awareness of global competition and global standards is required – it is a high risk to only focus on nationally regulated standards, e.g. on safety and emissions.

It was criticised that NGOs create a communication barrier. There needs to be better communication with the public. One company considered that certification of NGOs would be a good idea, since there is a multitude of NGOs in the country and their credibility is highly variable. The issues that NGOs have are, first of all, biosafety. Then there is the argument that Thailand does not need GMO as there is no food security issue in the country.

5. Outlook and trends

During the research, it became clear that several trends that are of global importance will also impact Thailand's bioeconomy development, and some have already started to do so. This should be put in context of global trends that are emerging. Worldwide, both the bioeconomy (based on biomass feedstock) and biotechnology as a process technology can gain market share. For years the fine chemicals sector (detergents, body care, cosmetics, pharmaceuticals and food additives) has been growing faster than the overall market with a CAGR of 5%. This is also true for cellulose fibres in the textile sector, which even have a CAGR of 5-10%. The largest factories are located in China, India and Europe. There has also been a growing demand for bio-based naphtha over the last two years to produce bio-based standard polymers (polypropylene, polyethylene).

The field of bio-based polymers has been struggling in recent years and shows only average growth rates. Since new investments in PLA (in Europe and China) as well as in bio-based polyamides (China), above-average growth rates of 5-6% will be achieved in the coming years - and thus also for the precursors of organic acids such as lactic and succinic acid. The reason for this growth is that, for the first time ever, international brands are looking for non-fossil materials.

5.1. Extraction of high-value biochemicals

The extraction of high added-value compounds from crops is usually done through conventional methods with solvents such as ethanol, hexane or liquid CO_2. New extraction technologies have been in development to improve extraction of high-value compounds, such as high pressure, pressurised liquid extraction, instantly controlled pressure drop, pulse electric fields, and high-voltage electrical discharges, as well combinations with others. These technologies are considered environmentally friendly, allow the use of lower amounts of organic solvents and the reduction in extraction time and energy consumption, leading to higher yields and high-quality final extracts.

After purification, the extracted compounds are used as food additives, as ingredients of cosmetics and body care, and as pharmaceuticals. Some sectors, such as natural cosmetics or organic food, prefer extracted materials to those produced chemically or biotechnologically. This results in considerably higher market prices. For example, vanillin extracted from vanilla beans costs five to twenty times more than that produced chemically or biotechnologically - even though the vanillin is 100% identical.

5.2. Digitalisation

Several interviewees were confident in the opinion that digitalisation is important for the biorefining sector, even stating that "it affects everything". There was general consensus that Thailand is in a relatively good position, here, among the top 5 in Asia with good infrastructure (fibre optic internet, etc.). However, a lot of parallel investment was mentioned as a potential weakness, and a lack of high-quality education in this sector was noted, too.

Some concrete examples of positive digitalisation impact on the bioeconomy are the following:

- Digitalisation helps understand the supply chains and makes them more efficient, for their business and also for modern farms. Blockchain technology enables secure information transmission, improving knowledge about supply and demand, biomass streams, locally available volumes.
- Traceability and mapping facilitate crop insurance.
- At a more micro level, GPS has several advantages, such as logistics tracking and actually on board of tractors. An interesting point was made about using virtual, GPS-tracked borders for fields and farms rather than actual borders using fences and ditches. This frees up more land for cultivation and saves time during planting and harvesting, thus making the farming more efficient. Since Thailand has a very large number of small farms divided up by ditches and fences, this application of GPS and digitalisation seems like it could have a large effect. GPS is used to identify when and where to harvest, and also to track transportation to the factory.
- Two interesting digitalisation initiatives at the Bank for Agriculture and Agricultural Cooperatives were mentioned. The first is an app from an MIT start-up, and one of its founders is from Thailand. It has some corn crop modelling and forecasting. This start-up worked with the bank, and farmers really want to work with this. Another involves smart farming of cassava, with advice on when to apply fertilizer.
- A very important application of digital tools is monitoring irrigation and weather forecasting.
- Precision farming can enable farmers to use less pesticides and fertilizers, while improving the quality of the crops and also of the soil.
- Financial transfers and digital banking have proven to be helpful to small-scale farmers worldwide. All of the above can minimise the risk of crop failure, reduce costs and improve cash flows for the farmers, while also improving sustainability.
- In the sugar refineries, and this can be extrapolated to biorefineries, factory automation is important and will become more so. This is, of course, about gaining efficiencies – reducing waste, reducing errors, reducing downtime, etc. – thus remaining cost-competitive.
- On the market side, digitalisation improves customer access and customer information.

5.3. Synthetic biology / biotechnology

Regarding synthetic biology, interviewees also confirmed that it will have immense importance for the Thai bioeconomy ("it will disrupt everything"), but at the same time Thailand is at a very early stage here. As described above, several universities offer programmes in this area, but there is still not a sufficient number of highly-trained professionals.

Some examples that were highlighted in more detail were for example the organisation Biotec and the Institute of Metrology, National Quality Infrastructure (NQI). Biotec seeks as frontiers in bioscience and biotechnology DNA data storage and artificial photosynthesis. At Biotec, there is a National Omics Centre at the Research Park, and also a National Biobank. Biotec has 570 staff: in FY 2018 they produced 221 papers, 33 of them Impact Factor greater than 4. Biotec is developing specialty enzymes e.g. enhanced nutrition, sugar platform conversion, pulp/textile and health products.

The Institute of Metrology, National Quality Infrastructure (NQI) is planning to go further in synthetic biology but cannot find any reference materials. They are aware of the metrology project with Imperial College and the National Physical Laboratory (NPL), United Kingdom.

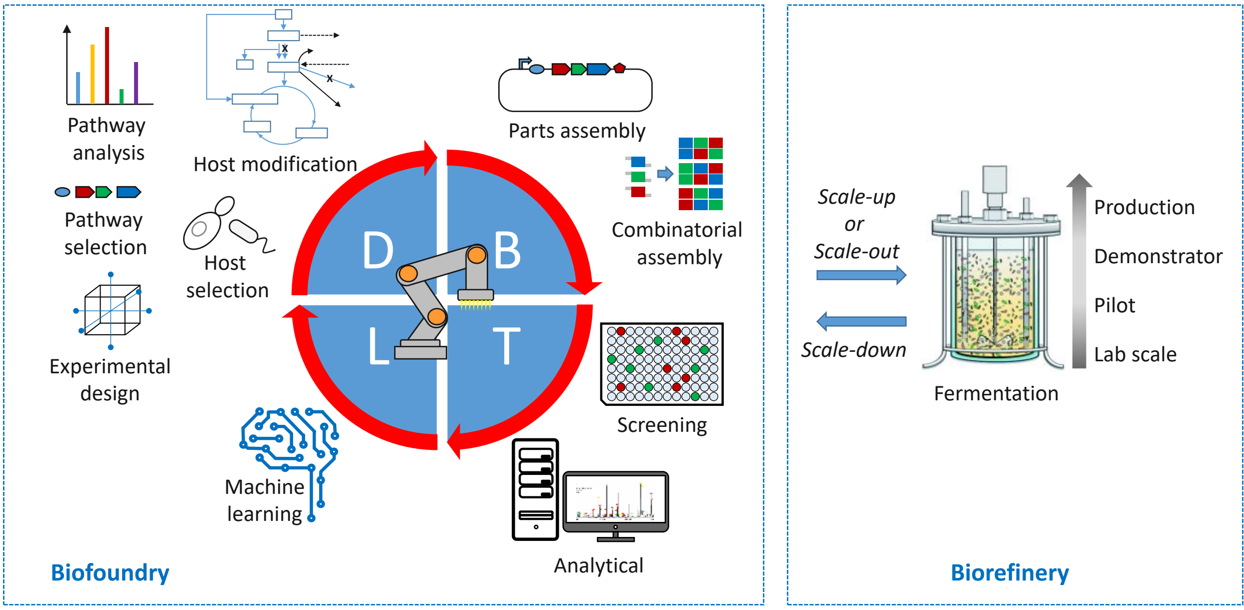
If Thailand is to have a future in this advanced bioeconomy driven by synthetic biology, then it is clear that significant public investments have to be made now to unlock private investments. The United Kingdom is a good case in point: from 2014 onwards, around GBP 350 million of public money has been invested to establish six synthetic biology basic research centres in major universities, one national technology transfer centre and five biofoundries (12 facilities in total). However, the public funding has already leveraged around 5-fold in private sector investments. A case study closer to home is the strategic investments in Singapore to make it a regional synthetic biology hub.

One future possibility is that the automation and digitalisation of biology in biofoundries will make more traditional biotechnology less competitive in the industrial setting. This is done by automating the iterative design-build-test-learn (DBTL) cycle of engineering when applied to biotechnology (Figure 9). It has the potential to speed up the innovation cycle. Moreover, the biofoundry design can be programmed for scale-up, and also scale-down in response to observations in the biorefinery. There are already companies in the United States offering such services, and exactly the relationship in Figure 9 exists between a biorefinery in northern France and Genopole, Evry.

Evidence from the United States for an upcoming OECD report shows that the biofoundries can become the nucleus for building the industrial and innovation ecosystems necessary to complete value chains. This is an extremely important ancillary function as investors need to see a clear path to market as well as an innovative technology. If a single link in the value chain fails, then the value chain fails. Often in biotechnology the failure has been due to technical risk. The aim of the biofoundry is to remove the technical risk, which in turn will remove a business risk, improving investor confidence.

This new form of ‘digital biology’ is driving a need for a new generation of biologists with broader skills. Too often universities emphasise PhD level training, whereas there is a much broader need in building the workforce. There are various routes to this, but again it needs more public investment and in Thailand also needs a different mindset, one where collaboration between ‘competing’ organisations is encouraged. The needs of this education were reviewed recently (Delebecque and Philp, 2019).

Figure 9. How biofoundries interact with biorefineries.



Note: Engineering biology seeks to increase reproducibility to enable the quantitative precision required for modern manufacturing. Standards, automation, and machine learning are key to the success of this approach. Scale-down refers to acquiring data at production scale and transferring the information back to the laboratory via scale-down simulators. If need be, the production strain can be re-engineered and/or new information is back-translated to the fermentation operation for its fine-tuning. The transition to multi-thousand litre bioreactor processes alters conditions greatly from those of the laboratory; for example, oxygen concentration gradients, changes in pH, shear forces on cells. Industrial scale production has its own specific and potentially expensive requirements that can be addressed by biofoundry operations at a distance from a production site. A feature of the biofoundry approach consistent with modern manufacturing is that the site of the design (the biofoundry) can be totally separated from the site of manufacturing (typically the biorefinery).

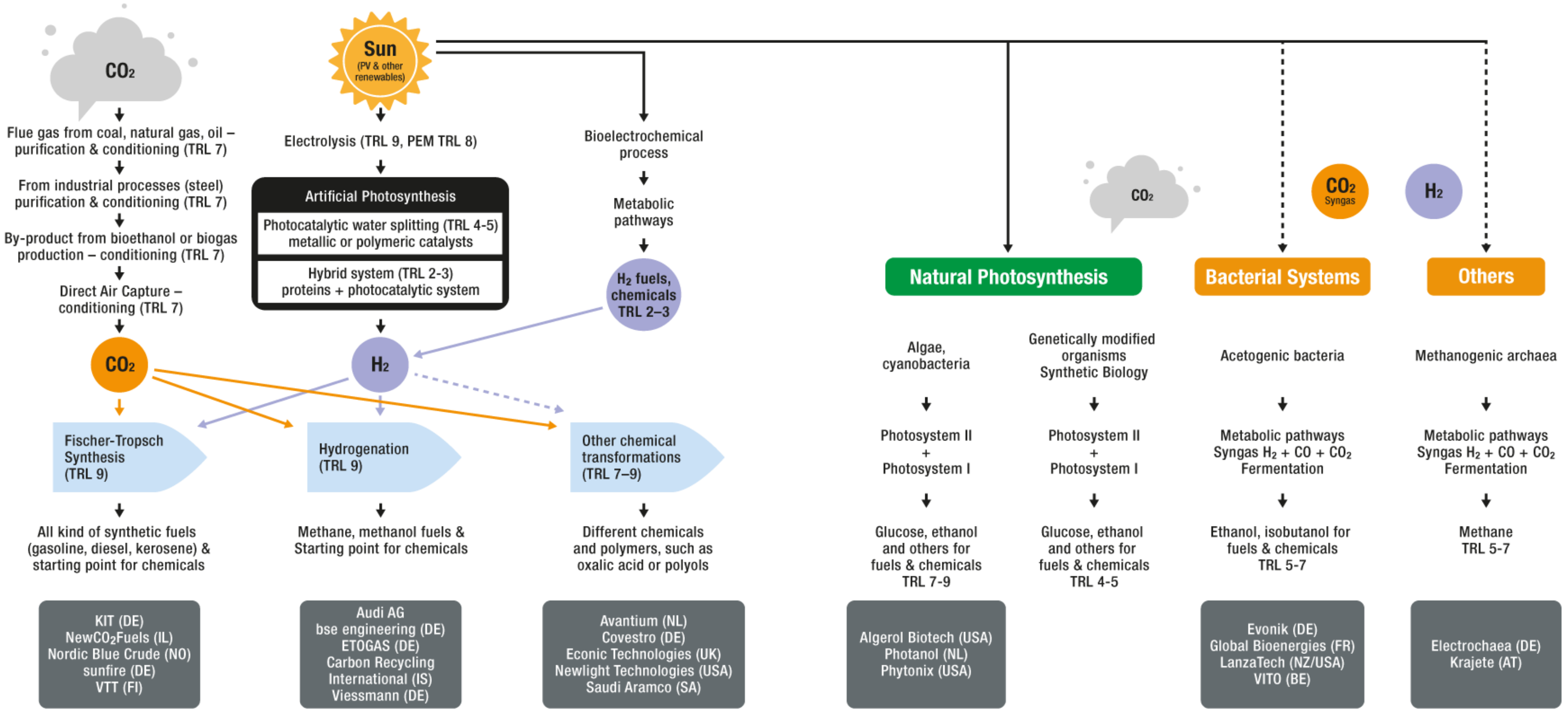
Source: OECD research

5.4. Carbon capture and utilisation (CCU) / synthetic fuels

A topic gaining greater traction worldwide is the capture of carbon-containing effluents (most typically CO_2) and converting them into valuable materials again. The umbrella term for a multitude of potential sources, technologies and products is ‘carbon capture and utilisation (CCU)’ and it could hold a lot of potential for Thailand. Due to its large food and bioethanol sectors, there is a significant amount of biogenic CO_2 emissions arising from the fermentation processes that can be relatively easily captured and further processed. Figure 10 gives an overview of the existing processes and active companies. The use of renewable energy is key to ensure that this does not cause additional CO_2 emissions.

Some first Thai companies are now considering to also go down this path and are talking to international players that could provide technologies, e.g. for producing synthetic jet fuels. In the future, also producing chemicals and plastics from CO_2 could be an option. However, one key feature that needs to be ensured for most of the depicted pathways is the availability of green hydrogen (from water and renewable energy).

Figure 10. Pathways and active companies for CO_2 utilisation with renewable energy.



Source: nova-Institute, 2020.

6. Policy considerations and recommendations

6.1. General considerations and bioeconomy policy measures

6.1.1. Preconditions for a bioeconomy / biorefinery strategy

Objectives

As a sound foundation for any future bioeconomy or biorefinery strategy, the Thai government needs to clarify the major objectives it wants to obtain with such an activity. Is it increased prosperity of farmers / reduced inequality? Improved sustainability of agriculture, better adaptation to climate change, more environmental protection? Is it excellence in science and innovation, pushing for more synthetic biology and competing with the world's leading countries in these areas? Is it increased and more sustainable consumption in the plastic market? Is it reduced dependence on imports for food, materials and machines?

Depending on the answers to these questions, a potential strategy might have very different focus areas. It is not advisable to attempt to design a strategy that covers all of the mentioned objectives – such a scattershot approach will probably fail to address any of the planned goals in the end.

Better information basis

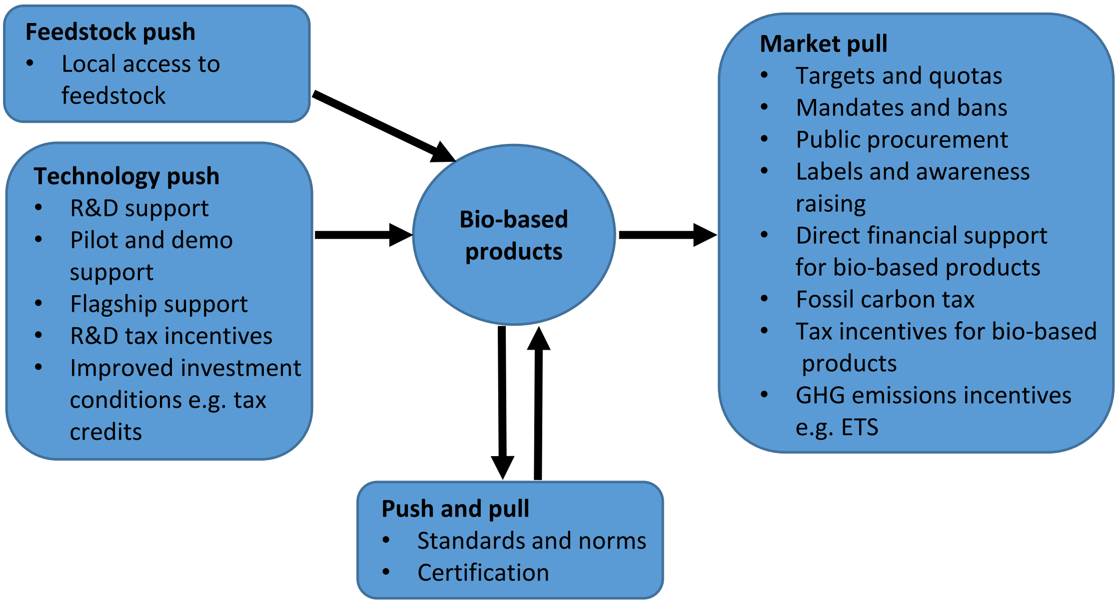
During the research process, it became clear that information on the existing biorefinery structures is scattered and divided between many stakeholders. As a first exercise, it would be recommended to draw up a map of all biorefineries, how they are fed and what kind of products as well as the value-added they create. Also, concerted information on land use and biomass availability (disaggregated by regions or even municipalities) is missing. This could be a very useful tool for any future strategy.

6.1.2. What kind of policy measures are there?

There is a multitude of conceivable policy measures that could be implemented to promote the Thai bioeconomy / biorefining industry. There is a lot of literature on this topic, so a general overview and short summary should suffice at this point.

Figure 11 groups the potential policy measures under three essential categories, which can roughly be translated to supply-side, demand-side and a mixture of both supply and demand-side policies (i.e. cross-cutting measures). This is consistent with the view that both supply- and demand-side policies are needed for effective innovation.

Figure 11. Bioeconomy policy measures.



Note: GHG = greenhouse gas; ETS = emissions trading system

Local and international access to feedstocks

There are several advantages to making use of local feedstocks that are currently attractive to policy makers, e.g. sustainability of short transportation distances and creating local jobs. Nevertheless, there are major challenges: supply and value chains are complex and untested; there are huge numbers of suppliers; waste policy is not designed yet to allow wastes to be used as feedstocks. Large quantities of biomass are already being shipped around the globe, with most of it destined for OECD countries. The use of biomass globally is increasing. But there is no international agreement on how to measure sustainable biomass potential (i.e. how much can be grown, harvested and transported sustainably).

R&D subsidy

As industrial biotechnology and engineering biology, but also many chemical catalysts for bio-based processes are still emerging sectors, there will be need for public R&D funding into the medium term before their processes are suitable for reduction to engineering practice. There are now many laboratory successes, numbered at least in hundreds, in bio-based production of fuels, pharmaceuticals, chemicals and materials based on techniques of metabolic engineering and synthetic biology, but hardly any commercialised products. Thus R&D subsidy for scale-up i.e. closer to market, is a measure to consider.

Financing demonstration and full-scale flagship biorefineries

The untried nature of biomanufacturing often means that the private sector is unwilling to accept the financial risks of building full-scale plants in the absence of long-term policy certainty. Apart from dedicated research programmes in university research, the situation requires public research investment closer to market to conquer problems such as scalability, which is a common problem throughout industrial biotechnology and engineering biology applied to bioeconomy goals. Forms of public-private partnerships (PPPs) in close cooperation with market needs are implicated.

Technology and regional clusters

The main rationale for public policies to promote technology clusters and networks is an increase in knowledge spillovers among actors in clusters aimed at creating higher productivity, more innovation and increased competitiveness of firms. However, care is required in cluster policy design as metrics to measure their efficiency are not well defined and accepted, and the success is unpredictable.

Mandates and targets/quotas

Mandates and targets for biofuels production have become standard for their introduction in countries around the world. Using mandates and targets to promote the market uptake of bio-based chemicals and materials is more complex due to the much larger numbers of these compared to the small number of transportation fuels. Mechanisms have been described in literature to overcome this barrier, and especially for drop-in chemicals it is quite easily possible.

Public procurement of bio-based goods

Public procurement can be a powerful market actor that can push for specific products. Globally, there are very few examples of public procurement of bio-based goods. Probably the only usefully documented one is the USDA BioPreferred® programme, which has a catalogue of thousands of bio-based products and offers a voluntary label for qualifying products.

Indirect incentives for investment

Many bio-production companies are young and they may benefit less from R&D tax credits if they have not yet generated taxable income to make immediate use of (non-refundable) R&D tax incentives. This may inhibit innovation and growth of such firms. In the United States, tax incentives are regarded as an important way to stimulate the bio-based materials industry. The OECD has done extensive work on R&D support for small firms.

Fossil carbon taxes and emissions incentives

Substantial research shows that the most cost-effective way to mitigate climate change is to gradually build up a global price signal on fossil carbon through the use of market mechanisms. Governments should use carbon price revenues in ways guided by efficiency. As of 2019, there were 57 carbon prices either in practice or in development. This represents some 11 Gigatons of CO_2 equivalent, or 20% of global emissions per annum, and the figure is steadily increasing (International Bank for Reconstruction and Development / The World Bank, 2019).

Fossil fuel subsidies reform

Globally, fossil fuel subsidies are still gargantuan, of the order of at least hundreds of billions of dollars per annum, even though the fossil industries are fully mature. One estimate runs to trillions of dollars per annum when the cost of environmental damage is factored in. Governments could use the money saved to fund defossilisation projects and biotechnologies as needed in a bioeconomy.

Standards and certification

Standards provide a solid basis for introducing new products and technologies onto the market and a basis upon which further research and development can be built. Standards and certification schemes are also joining-up measures between policy frameworks and practical implementation, providing a link to regulation. Stringent standards and certification give confidence to consumers and industry as they provide credibility to claims of performance and sustainability, such as ‘bio-based’, ‘renewable raw material’, ‘biodegradable’, or ‘reduced greenhouse gas impact’.

Design skills and education initiatives to deliver the workforce of the future

Upstream of all these policy measures is a need for a new form of workforce not seen before, in which various skills and knowledge bases merge and combine. The required multi- and interdisciplinary skills challenge higher education to get out of the discipline-dominated paradigm. Some suggested measures are: changes to undergraduate curricula to include courses beyond science and engineering; more emphasis on mathematics and computation in life science degrees; dedicated research and taught Master courses; interdisciplinary PhD training to include a wider skill set; specific training courses for technicians and apprentices.

Multi-level governance and regulation

Bioeconomy spans regional, national and global connections, creating the need for multi-level governance, which is not easily achieved. Poor coordination can lead to duplication, inefficient spending, a lower quality of service and contradictory objectives and targets.

Complex and time-consuming regulation is far more damaging to small bio-based companies than it is for large companies. Governments could act to reduce this impact. First of all, governments have to understand what the regulatory barriers are before designing appropriate policy. Categorising regulatory barriers among fundamental, conflicting, structural and operational constraints can identify which specific measures are needed.

Communication and raising awareness

Information campaigns for consumers can strengthen the demand for bio-based materials when they convey to consumers that bio-based products possess ecological or other advantages. Labels for bio-based products would strengthen the public awareness of bio-based plastics and their products and would strengthen the trust placed in such products.

6.1.3. The right mix of measures

Choosing and implementing the right mix of measures is of course a very delicate process and requires significant preparation. A lot can be learned from existing bioeconomy processes, among others in the EU. In early 2020, the Independent Bio-based Expert Group[1] released the results of an expert survey in which the effectiveness and probability of implementation of different policy measures for bio-based economy were rated.

The first question of the survey was “Which measures could potentially have a high impact on the bio-based economy?” and resulted in very uniform answers. The experts were in clear agreement that the strongest and most effective measures could significantly move the bio-based economy forward; these key measures were: a fossil carbon tax, a CO_2 tax, quotas, tax credits, removal of fossil subsidies and, mandates/quotas and bans.

[1] The Independent Bio-based Expert Group on the bio-based economy consists of experts from several European Countries working in associations, companies and academia.

The second question was "How difficult is the technical implementation of the measures?" Here, there was a top group of five measures which, in the opinion of the experts, can be implemented comparatively easily: certificates, labels, networks, self-commitments and public awareness. However, these are all soft measures, which can be considered enablers or supporters, and which alone would only have a minimal impact on market growth. The Independent Bio-Based Expert Group interpreted this to mean that only soft measures are regarded as easy to implement in the current political climate –this is indeed reflected in the high number of activities currently taking place in these areas.

The third and final question was: "How probable is the implementation of these measures in today's public, political and industrial context?" On this question, the experts were very much in agreement. Five measures (standards, certificates, labels, networks and public awareness) were considered very likely to be implemented –indeed some of these have already been implemented and are part of ongoing projects or tenders in the EU. All of these are soft measures, again rather enablers/supporters, which alone cannot drive the transition towards a bio-based economy – and which need the stronger measures to be implemented along with them, to have a significant impact (Independent Bio-based Expert Group, 2020). This survey is significant as it illustrates the conundrum around bioeconomy policy that needs to be solved if any significant progress wants to be made. Experts often also agree that it would be a key role of policy to create good framework conditions for bio-based products - the products and the demand will follow.

6.2. Specific measures for the Thai context

6.2.1. Enhance coordination across relevant communities

During the fact finding, it was often criticised that in Thailand, most stakeholders do not collaborate, but only work by themselves – "everybody in silos". While of course there are some examples of successful cooperation, there is still a lot of room for improvement.

Coordinate policy makers

Bioeconomy itself is a cross-cutting issue and the classic political division into domains per ministry cannot meet the requirements needed for designing a comprehensive and meaningful biorefining strategy. Domains such as research and innovation, agriculture, economy and environment need to work together. Standing inter-ministerial committees can be one approach to answering this need, but there is often still the question of budget and decision competence. Exchange of information would be the first step (and is already practised to some degree), but higher relevance in the different ministries for the bioeconomy topic, enhanced budgets and easier decision-making processes are needed, too, for greater effectiveness.

Coordinate biotechnology capacity

In research, exchange is key in order to stay up to date and benefit from cross-fertilisation of disciplines. It was criticised by stakeholders that the relevant academics in Thailand do not communicate well with each other. One possible approach for Thailand is to set up something like the UK Knowledge Transfer Networks (KTNs). As a precursor, in the 1990s and 2000s, the UK government Department of Trade and Industry employed experts to go on roadshows around the country to communicate to companies and the public on particular biotechnologies. This was difficult to set up, relatively expensive to run and in the end reached a very limited audience. The KTNs operate in a similar way, but at their heart is a website resource that has large amounts of information e.g. about funding opportunities with research councils, prizes, upcoming events, etc. This is a mechanism for a country-wide community to stay in touch and take advantages of shared opportunities. Another public incentive could be that project grants are only handed out if consortia with at least two different participants apply for them together.

6.2.2. Regulatory reform

Zoning

When discussing barriers, apparently zoning / city planning is a significant impediment to setting up rural biorefineries. Green zones and production zones are in different locations. Therefore, it would not be possible to make a chemical like lactic acid in a green zone i.e. a rural area. While its historical context is understandable in the need to prevent pollution and for safety aspects, this law would have to be changed in order to allow for decentralised, rural, small-scale biorefineries. Criteria such as size of a plant, water and energy use dimensions, emission thresholds for gases, wastewater and other contaminations, ownership (special rules for farmers / farmers' cooperatives) or the need for toxic chemicals or GMOs in the process could be considered as ground for changes to the existing law. The same could apply to building relatively "harmless" refineries in city areas as opposed to only in industrial zones.

Farmer profit share

The price that farmers receive for sugar is fixed by regulation. They receive 70% of the sugar selling price. However, they receive nothing for the profits made from further processing molasses and bagasse into higher value-added products. The fixed regulation may have been appropriate, when sugar was almost exclusively sold to the food market, but it does not account for the changed realities of a modern bioeconomy. While a fixed minimum price would probably still be helpful to ensure the prosperity of farmers, there should be room for negotiation. Especially farmers need more outlets for their crops, because of failing rice harvests due to climate change. An alternative is that farmer cooperatives could co-own refining plants and share the profit accordingly.

Biosafety (GMOs)

As of now, it is not allowed to grow genetically modified crops on open fields in Thailand. Only the import of already harvest GM corn and soy is allowed for food and feed purposes. Their use must be labelled starting from a threshold of 5%. The contained use of genetically modified organisms is regulated by the 'Biosafety Guidelines for Contained Use of Genetically Modified Microorganisms at Pilot and Industrial Scales' (Biotec, 2015). The use of GMOs for processes therefore does not seem to be a barrier, as long as biosafety rules are observed. However, the strict prohibition of growing GM crops can be a competitive problem compared to Asian neighbours. Furthermore, it might spoil chances to breed more climate- or pest-resilient crops that could be increasingly important to farmers.

Land use strategy

The demands on land use are manifold. Farming versus forestry, plantation forests versus woodland regeneration, wind farms and tourism versus unspoiled landscapes. Thailand wants to produce high-quality and sufficient food both for its own population and for export. It feels the impacts of climate change through increasing drought and therefore needs to dedicate increasing resources to water management. The country has committed to preserving biodiversity under the UN Convention on Biological Diversity (UNCBD) and is expanding areas for solar and wind power generation. Finally, Thailand has growing urban areas with an influx of population and now also wants to increase the use of biomass for chemicals and plastics.

A land-use strategy will help to negotiate the necessary trade-offs between these varied objectives. Land-use strategies often contain the following elements (Lago et al. 2010):

- Agriculture
- Urban areas
- Coastal zones
- Forestry
- Infrastructure
- Water resources
- Energy
- Biodiversity
- Demographic change
- Land use general
- Climate change
- Spatial perspectives
- Development planning
- Cultural heritage
- Soil carbon
- Land tenure
- Rural communities
- Valuing Landscapes
- Tourism and recreation

If this approach seems too daunting for the purpose of a biorefinery strategy, it is also conceivable to only design an agricultural land-use strategy. Especially with the tools of modern technology, it would be possible to map existing fields, record their yields and also make use of climate forecasting (modelling scenarios) to identify different options. Which crops will be resilient to climate change? Will it make sense to focus on the supply of organic fruit for well-paying urban elites? Or can farmers be reasonably made part of a value chain in the bio-based industries? A comprehensive map would help to identify how much biomass is needed to cover the growing food demand (at declining climate conditions) and how much would then be left for energy and material purposes. A mapping of the status quo (including imports and exports) would be an important first step for such an exercise.

Especially under the aspect of competition for food and feed, an integration of agricultural residues, but also of biowaste as a resource, would make sense in a land-use strategy. These factors can relieve the pressure on land, while at the same time covering the needs of people, but the potential seems not to be tapped into at the moment. Other high-tech developments such as synthetic meat or making fuels from biogenic CO_2 via CCU can also be factored into scenario work, as mitigating criteria on the demands on land use.

Bioenergy / biofuels – solar and other renewables, need for a joint strategy

Since bioenergy and biofuels make up an important product category among the outputs of biorefineries, some regulatory reform is also needed in order to avoid disadvantages. Especially with biogas production, there seems to be a significant barrier put up by the preference given to solar and wind energy in the electricity grid. A joint strategy for renewable energy carriers is needed to provide a level playing field.

Support for demonstration/large pilot plants such as in the EEC

More support for innovation closer to market deployment (TRL 6 and up) is needed to overcome the well-described‘valley of death’.

It was criticised by many stakeholders that government funding for research only is available up to TRL 4. Even though it is now being reformed to also cover research and innovation up to TRL 7, also collaboration and support other than finances can be important. The current initiative for the bio-based pilot/demonstration plan in the Eastern Economic Corridor (EEC) is a step in the right direction.

7. Key findings and messages

In order to proceed with setting up a biorefinery roadmap for Thailand, the following items were found to be of crucial importance.

Objectives

At first, the Thai government needs to clearly define one or two main objectives that are supposed to be reached by increased biorefining. Different options are conceivable, but it is highly unlikely that all of them can be obtained with one single strategy, they are:

- Increased prosperity of farmers / reduced inequality?
- Improved sustainability of agriculture, better adaptation to climate change, more environmental protection.
- Excellence in science and innovation, pushing for more synthetic biology and competing with the world's leading countries in these areas?
- Increased and more sustainable consumption in the plastic market?
- Reduced dependence on imports for food, materials and machines?
- Depending on the selection, specific policy measures will be necessary.

Information basis

In order to make informed choices, a better information basis is necessary, especially with regard to biomass and land use. A land use strategy would be a crucial aspect of any kind of biorefinery roadmap, preceded by a comprehensive assessment of the status quo of biomass cultivation and land use.

Coordination / exchange

An often-repeated criticism by stakeholders was that most units operate by themselves – be it policy makers, academics or industry representatives. This is a regular occurrence and was repeatedly found to be a barrier for a stronger bioeconomy, also in other regions in the world. Improved exchange and coordination is needed, be it through inter-ministerial working groups, independent advisory boards, clusters, regular network meetings, etc.

A lot of strengths, some weaknesses were found – regulatory reform seems to be needed in some instances

The Thai bioeconomy is already at a very advanced stage and Thailand provides many advantages for further installations, such as qualified employees, biomass availability and existing infrastructure. However, regulatory action is needed for example to alleviate bureaucratic burdens for setting up biorefineries (zoning law), hiring experts from abroad (migration law), selling sugar at more flexible prices etc. Political will is necessary to follow through on all of this.

Anticipate future challenges with biomass availability

Climate change already presents significant challenges to the agricultural sector in Thailand, and it is expected that biomass availability will be further impacted in the future. It therefore stands to reason to already look beyond the currently used resources and open up ways to utilise more forestry and agricultural residues, but also biowaste collected from households, restaurants, markets and large events. This will further increase acceptance of the bioeconomy strategy, also by environmentalists and potential customers.

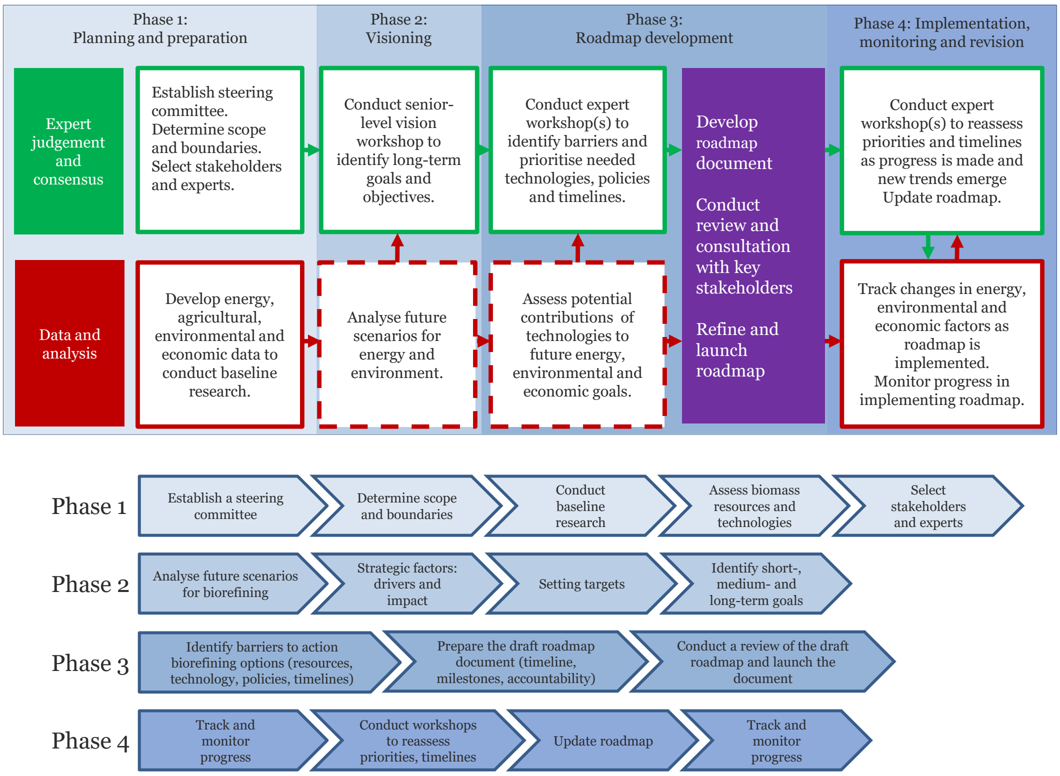
Key messages for different target groups

In order to make the biorefinery roadmap a success, a large number of stakeholders need to be involved. Apart from better coordination of already active units as described above, it would be ideal if the biorefinery strategy could also address new stakeholders in a way that convinces them to become active. They need to be informed about the opportunities and strengths each in their own language, e.g. investors and banks, farmers, technology providers, small and large enterprises, researchers, educators, etc.

8. Concrete actions

The OECD/IEA and the FAO produced a guide to roadmap development specific to bioenergy. This can be adapted to the needs of biorefining in Thailand. In outline, the methodology is shown in Figure 12.

Figure 12. The roadmapping process



Source: adapted from IEA (2017)

The concrete actions in Phases 1-4 are tabulated and individual sub-actions can be filled to make a complete picture of the biorefining roadmap process (Table 5).

Table 5. Phases towards a biorefinery roadmap

Concrete measures are in cells in different shades of blue and correspond to phases 1-4 in Figure 12.

Phase 1

Establish a steering committee	Determine scope and boundaries	Conduct baseline research	Assess biomass resources and technologies	Select stakeholders and experts
Involve all relevant ministries e.g. agriculture, R&I, fisheries, waste management.	What can the roadmap be expected to achieve?	What are the economic goals?	Biomass availability data.	Consult with industry thought leaders.
	What are the timelines?	What are the social goals e.g. addressing inequality?	Biomass utilisation strategy e.g. is there under-utilised land?	Consult with farmers' cooperatives.
		Key sectors e.g. energy, industry, agriculture.	Map of existing biorefineries.	Consult with civil society more generally e.g. environmental NGOs.
		Consider trade-offs e.g. food security, environmental protection.	Affects on water resources, soil quality and carbon sequestration.	Consult with relevant academics.
		Potential for competition between sectors.	Which feedstocks, and processing technologies can deliver the largest GHG emission savings?	
		Potential for synergies between sectors.	What processing technologies are already available?	
		Determine key food staples, current production and locations, net trade positions, major agricultural and forest export crops.	What biotechnologies are already available?	
			Strength in plant breeding.	

Phase 2

Analyse future scenarios for biorefining	Strategic factors: drivers and impact	Setting targets	Identify short-, medium- and long-term goals
Often driven by international agreements or accords. Often nowadays these relate to climate	New processing pathways e.g. biotechnology.	A clear statement of the desired outcome, accompanied by a specific course of actions for reaching it will form the mission statement.	Create jobs.
	Increase trade in sustainable products?		Foster rural development.
	Reduce reliance on fossil resources for industry?		Economic growth, improve balance of payments.
			Reduce poverty.
			Increase turnover and GDP.

Phase 3

Identify barriers to action biorefining options (resources, technology, policies, timelines)	Prepare the draft roadmap document (timeline, milestones, accountability)	Conduct a review of the draft roadmap and launch the document
Land use strategy.		
Enzyme technology, other biotechnologies.		
Competition with other socio-economic activities.		

Logistics constraints to biomass supply chain.		
Environmental concerns e.g. water availability, deforestation, biodiversity.		
Local skills availability.		
Upfront investment costs.		
Lack of private investors.		
Feedstock cost/availability.		

Phase 4			
Track and monitor progress	**Conduct workshops to reassess priorities, timelines**	**Update roadmap**	**Track and monitor progress**
Monitor the deployment and consider whether the roadmap needs adjusting in light of experiences gained since implementation.	Improve policy settings, modify targets, or adjust institutional frameworks.		Iteration.
Establish metrics to capture impact.	Capture changes in drivers e.g. climate targets, economic aspirations.		
Establish a hierarchy of metrics.			

Endnotes

1. This is the biological raw material used to make fuels or other bio-based products: solid biomass such as wood, plant and animal products, gases and liquids derived from biomass, and the biodegradable components of industrial and municipal wastes. Processing and conversion derivatives of organic matter are also biomass.
2. The middle-income trap: GDP per capita growth slows down once a country approaches an intermediate level of development OECD (2017), "Working Paper No. 340: No sympathy for the devil! Policy priorities to overcome the middle-income trap in Latin America", DEV/DOC/WKP(2017)6.
3. https://www.europarl.europa.eu/news/en/press-room/20180411IPR01518/circular-economy-more-recycling-of-household-waste-less-landfilling
4. http://webdb.dmsc.moph.go.th/ifc_toxic/a_tx_2_003c.asp?info_id=298
5 https://www.forbes.com/sites/stevebanker/2018/09/18/one-of-the-worlds-most-innovative-supply-chains/#500704a05fae
6. In Europe, the Directive 2009/41/EC on contained use of genetically modified microorganisms.
7. Directive 2001/18/EC on the deliberate release of GMOs into the environment.

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Annex 1: What is in a biorefinery roadmap?

1. A biorefinery, or any technology roadmap, has greatest success when it has broadest appeal. If this is an aspiration for Thailand, then the text should encourage any reader to follow it to the end. A benchmark might be low-income farmers as this group is one of the major groups that the roadmap should benefit – these are land investors. Another key stakeholder group may be potential financial investors as there will be a high need for private sector investment. Thus, if the roadmap contains, for example, complicated biochemical pathways or biorefinery flowcharts, then it will appeal to a narrow range of stakeholders, and miss the larger audience.

2. As with a business plan for a new business that one wishes to seek investors for, a good target assumption is that the potential investor may dedicate the time of his or her morning commute into Bangkok to reading the roadmap. Any over-complication may end the investor's interest. If it grabs the imagination for the investor to follow up further, then the roadmap has made a success. It is often assumed that investors look to invest in new technologies simply because they are new technologies. But seasoned investors will look at the entire value chain, and look for weak points. Why invest in a new smart phone company if there is no or limited mast coverage? Weaknesses may not even be technological. There are plenty of examples of well-meaning environmental projects that have been resisted by specific sub-populations.

3. Quite remarkably, there are plenty of technology roadmaps that do not have a timetable. But again, it should be kept simple, stating what the milestone is and when it is to be delivered. The date is most likely to be a specific year, not 'quarter 3, 2025'. But it might also be helpful to say whether the milestone is near-, medium- or long-term as this demonstrates a strategic pattern of thought. Therefore, roadmap designers and writers must articulate goals, describe the strengths of the country and how weakness will be addressed, demonstrate the opportunities, and crucially, detail milestones and next steps.

4. There is no magic length for a roadmap. However, consistent with the above about keeping things simple, above all the roadmap should convey all the required information without being verbose – keep it as short as needed.

Foreword

5. One page or less that sets out the history to the roadmap – the societal imperatives, perhaps Grand Challenges such a climate change, food security, fossil resource uncertainty and depletion. Stress that the roadmap is industry-led and developed with a whole variety of stakeholders.

- How does the roadmap address these challenges?
- How much is the government spending to achieve these goals?
- What is the period the roadmap covers and what are the expected achievements at the end of that period?

Introduction

6. What is biorefining and why it is important to Thailand. This should put the policy in the wider context e.g. what is the master policy? (e.g. part of the national plan for the Thailand Eastern Economic Corridor? Achieving sustainability, alignment with the UN Sustainable Development Goals?.)

7. If stakeholders only read the introduction to the roadmap, then the introduction should spell out the opportunities and what the country can call on that already exists. But an objective of the Introduction should be to want to make stakeholders read further. Decision-makers, CEOs and other figures with authority need to be engaged right here. What the government might want stakeholders to see here are bold, simple statements (not facts and figures, just the statements themselves – the figures can come later), such as:

- Large volumes of sustainably-sourced feedstock available for biorefining, and the infrastructure for international trade in biomass and products.
- Existing ecosystems of feedstock owners, technology companies, clusters, researchers, investors, etc.
- Existing industry infrastructure – logistics, utilities, services, skilled workforce.
- Access to a growing skills, training and education resource.
- A (growing) academic and industrial research network to grow a bio-based sector.
- Perhaps most important of all, a strong commitment from government to make this sector work for the good of the population.

What are the opportunities for Thailand and what is the objective of the biorefinery roadmap?

8. Thailand is probably the leading nation in the ASEAN region in bio-based products and processes already. Where does Thailand want to position itself: in its region, in Asia, in the world? And what are the main objectives of increasing biorefining – they can be manifold (e.g. farmers' prosperity, high-tech exports, etc.).

9. This is a place where the roadmap could break out the different biomass sources e.g. food crops, municipal solid waste, brewing waste, forestry and forest waste. For this, Thailand should look beyond 'waste' materials such as forestry and agricultural residues. All forms of biomass should be considered as energy density and land efficiency are much higher for crops like sugarcane compared to waste forestry and timber. In addition, technologies for waste gas fermentation, such as industrial sources of CO and CO_2 are maturing. An important highlight would be to mention that the large number of existing energy-focused biorefinery plants can be relatively easily further developed to produce higher value-adding chemicals.

What is the scale of the resource in Thailand? (i.e. tonnages)

Where are they?

10. Can they be accessed easily, can biorefineries be built at sufficient scale where the resources are present? So far, information is not available on a comprehensive scale, a land use strategy should be a crucial part of the biorefinery roadmap. Figures 5 and 6 speak to the CapEx and OpEx at varying levels of biorefinery scale. Small and rural is unlikely always to be the answer.

What is done with this resource at present?

- E.g. rice straw burning creates little value and also creates health problems from smoke.
- E.g. fisheries waste could be more than half the weight of each fish – is it thrown overboard at sea, is it processed to fish meal, is it landfilled?
- E.g. if direct food use of sugar cane is decreasing, how can greater added value be created?

What can be done with this resource in biorefineries?

- E.g. what sectors can be regarded as strengths, like bio-based plastics?
- E.g. what sectors could be further developed, like high-value health care and cosmetic ingredients?

What resources need longer term development?

- E.g. waste industrial gases from steel making, food-grade CO_2 from brewing.
- E.g. marine micro- and macro-algae.

What and when are the targets?

11. Technology roadmaps have a target date in mind for implementation. Targets seen today are often 2030 or 2050. Regarding biorefining, Thailand's roadmap might consist of:

- Higher-value, lower production volume products to meet new economic and societal goals;
- Liquid biofuels to meet national climate targets;
- Biogas as a contribution to the energy balance, especially in the rural environment.

12. In any event, central to the creation of a biorefinery roadmap is to be able to measure the expected outputs and to plan the biorefining infrastructure accordingly. Other common measures for the country will be jobs created and contributions to GDP. From our learnings the Thailand roadmap will want to stress the contributions to jobs, with an emphasis on rural and semi-rural jobs, where there are large populations of farmers on relatively low incomes.

13. A timetable can come early or late in the structure, but is vital to instil confidence in the target audience. Without it they may feel it is an aspirational document. A timetable is commitment from government, and is more likely to attract investments.

Roadmap monitoring and policy coordination

14. With these estimates in place, this generates the need for a solid policy framework that will need to take account of land use policy. The basic elements of the policy framework are identified in Figure 11. One central element of the policy strategy would be to clearly follow the declared objectives and describe systematically, how the proposed policy measures will help to achieve these. Creating demand for bio-based products can be one crucial element of such a strategy and there are a variety of mechanisms, both regulatory as well as socio-economic (also see Figure 9). Inherent to the Biorefinery Roadmap, a monitoring mechanism should be considered to ensure that milestones and deliverable are being met.

15. It is of primary importance to the future bioeconomy that key industry sectors emerge from their silo positions and cooperate. The roadmap should open the eyes of these different sectors to the possibilities when cooperation is enabled. However, most government ministries have little experience with direct contact and interaction with high-technology sectors. Government agencies fill this gap, and a primary role for these is to invite private sector investments into public research. They have also to mobilise expertise and information. Relating specifically to the bioeconomy, two of the more obvious ways to coordinate ministries, agencies and industry sectors is through independent advisory bodies and industry associations.

16. Independent advisory bodies are usually associated with a government agency and government officials interact with industry sectors largely through them. Thus, a crucial role can evolve for advisory bodies; they can mediate the influence of government and industry over each other. They can help government agencies define new research fields and develop new policy ideas. They can be central to consensus building between ministries, agencies and their industry partners. Arguably the most well known in the bioeconomy is the German Bioeconomy Council, the advisory body to the German Federal Government. Its role is the implementation of the German bioeconomy research and policy strategies, but most of its focus is on research and publications, not on actual commercial implementation.

17. Industry associations can play similar coordinating roles, especially because they are closer to industry than advisory bodies. They can coordinate industry actors to inform policy appraisal. They are likely to have members who are familiar with foreign industry and policy. They provide another platform through which government officials can explore the feasibility of new policy ideas. Good examples of bioeconomy-relevant industry associations are bioplastics associations in Europe and Asia. The mission of European Bioplastics is to "*advance the economic and regulatory framework in Europe to allow for the bioplastics market to grow and flourish*".