TECHNOLOGIES FOR IMPROVED USE OF GLOBAL BIORESOURCES

for Climate & Biodiversity, Nutrition & Health

TECHNOLOGIES FOR IMPROVED USE OF GLOBAL BIORESOURCES, FOR CLIMATE & BIODIVERSITY, NUTRITION & HEALTH

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ABSTRACT

Improved efficiency in the use of global bioresources, by valorizing what is now wasted or underutilized (crop residues, food-processing sidestreams), is a huge opportunity for food security, nutrition, and health. It can also contribute to climate change mitigation by reducing emissions through the full utilization of harvested biomass, and to biodiversity conservation by leaving more space available for natural ecosystems. Upcycling residual biomass also improve rural/coastal/urban livelihood, by contributing to socio-economic development, creating jobs for many types of skills. The needed technologies for upcycling various types of biomass are developed and available in public domain. However, broader implementation of technologies hindered or slowed down by lack of international collaboration and knowledge-sharing. This paper aims to initiate a new era of efficient and timely sharing circular/biobased-technologies. Co-authored by researchers from five continents, Africa (Ghana, Tanzania), South-East-Asia (Thailand), South-America (Brazil), North-America (US), and Europe (Denmark). The objective is to start giving priority to knowledge-sharing within global bioeconomy. The co-authors, all invited speakers (Feedstock Valorization Workshop, Global Bioeconomy Summit, GBS2024), present innovative technologies for upgrading crop residues, fishery-processing and agro-industrial side-streams, and valorizing bioresources from waste water treatment plants. Innovative technologies and new biobased-value-chains are described. The paper provides insight into national bioeconomy strategies from five continets, framework and action-plans, offering recommendations for accelerating knowledge-sharing. With a strong sense of urgency, the authors emphasize the critical need to transform what is currently wasted into value-adding products and solutions, benefitting climate, biodiversity, food security and public health; and by doing this also stimulate local and regional development and livelihood.

KEYWORDS

Biobased technologies; Biobased products; Biosolutions; Knowledge sharing; International collaboration

Summary

INTRODUCTION

Improved efficiency in use of biological resources represents a significant opportunity for addressing multiple global challenges. By optimized utilization of the harvest, emissions can be reduced, contributing to climate change mitigation. Simultaneously, upcycling biomass that would otherwise have been wasted into valuable food and feed products can free land for more nature and biodiversity. This approach also improve food security, especially important for regions, where climate change poses a growing threat to agricultural productivity. Furthermore, it offers health benefits by transforming fiber-rich crop residues into available, accessible and affordable resources for producing gut-health-promoting food ingredients and feed additives [1].

The scale of the opportunity, upgrading what is now wasted or underutilized, is enormous. Globally, food waste has consistently remained as high as 34% (Source: FAO, https://www.fao.org/home/en). As an add on to this, food processing side-streams, currently underutilized, downgraded, or left to rot and pollute, account for approx. 20% (Source: TNO, https://www.tno.nl/en/). Already developed and published bioprocessing technologies already now make it possible to convert residues and side-streams into nutritious food and feed. This valorization opportunity is for real, even for converting fiber-rich bioresources, previously found digestible only for ruminants, https://fermentationexperts.com/. Such bioprocessing breakthroughs, unlocking the full potential of crop residues, make it feasible to utilize the entire crop plant [2]. Similarly, advancements in technology enable the efficient use of all parts of blue biomass, such as seaweed [3,4] and fish processing sidestreams and by-products, as well as forestry residues [5]. Moreover, the upcycling of microbial biomass, such as residual bacteria and fungal biomass from biomanufacturing and biorefineries represents an additional opportunity to enhance the commercial viability of bio-based production systems [1]. By fully harnessing these resources, we can create sustainable solutions that simultaneously benefit food security, human health, environment, biodiversity and climate.

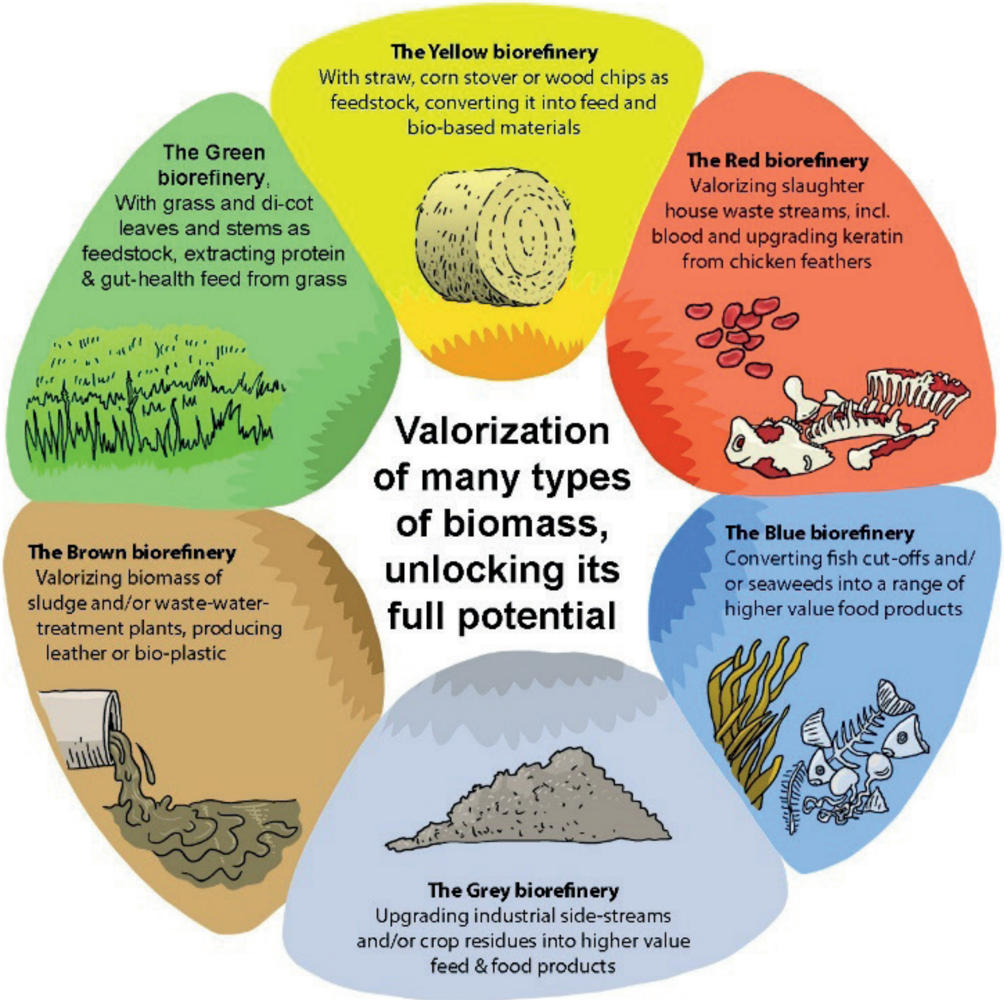

Figure 1.
Circular & Biobased: Unlocking full potential of the many types of biomass, by cascading use, valorizing all Components; courtecy [5].

The objective of the paper is to share experience in bioeconomy and biosolutions, from West and East Africa, Thailand, Brazil, the United States and Denmark (EU). To encourage international knowledge-sharing on how to make value from residues and side-streams, and to accelerate the adoption of circular and bio-based practices worldwide, moving beyond visions and discussions, to generate concrete ideas for real-world implementation that benefit both people and nature (see Fig. 1). Prioritizing the global exchange of knowledge, experience, and know-how within the bioeconomy is critical. Sense of urgency is essential.

It is imperative to share expertise on sustainable and efficient biomass conversion and valorization technologies to improve the utilization of local bioresources. Through global collaboration, we can develop new and even better ideas, concepts and technologies for valorization of local feedstocks, enabling significantly better use of biological resources. For the benefit of livelihoods, climate, biodiversity, food security and health, we must unite industry and academia professors,young talent, and entrepreneurs. By working together, we can design business models that engage stakeholders across the entire value chain, from primary production to high value products, ensuring that new circular and biobased solutions reach and benefit also the end user.

FEEDSTOCK VALORIZATION IN GHANA

By Joseph A. Bentil, KNUST

GHANA CASE 1

Topic: Cassava peels as feedstock for bioethanol production, using on-site tailor-made enzyme production (OSTEP) approach

Climate change is causing significant harm to the global environment, and its effects are exacerbated by the excessive use of fossil fuels, resulting in a rise in worldwide greenhouse gas emissions [6]. Many countries urgently seek to reduce their reliance on crude oil imports due to the increasing demand for energy independence. The recent conflict between Russia and Ukraine has further fueled this desire, as countries recognize the need to overcome the economic burden of rising fuel prices and the importance of reducing greenhouse gas emissions [7].

This study focuses on cassava due to the numerous desirable traits that make it a highly valued crop. These traits include its exceptional ability to withstand drought and heat, its reduced dependence on agricultural fertilizers, and its high starch content. With the projected increase in global and regional population pressure and the impact of climate change, cassava production is expected to rise in the coming decades, making it a crucial crop on a global scale. Despite facing challenges such as drought and poor soil, cassava is also gaining importance as a biofuel crop in addition to its traditional role as a food crop. In Ghana, large quantities of cassava tuber peels and cassava pulp residues are generated [8] with only a small portion being utilized as animal feed, while the remainder is discarded at dumping sites. The improper disposal of waste presents a significant environmental pollution issue, particularly in developing countries like Ghana. Hence, converting excess cassava peels, a waste product, into useful resources such as bioethanol holds great potential to mitigate environmental pollution and stimulate job creation [9]. This aspect forms the central focus of this study.

To fully optimize the use of the cassava peels, the study demonstrated an innovative approach called on-site tailor-made enzyme production (OSTEP), as illustrated in Fig. 2a and 2b. This approach includes growing an efficient biomass-degrading fungus on e.g. cassava peels and harvest the enzyme blend from the culture broth of this fermentation. The enzyme blend harvested is specifically composed by the fungus to have all the enzymes needed for breaking down cassava peels. Next step is to use this harvested blend of enzymes to degrade and convert cassava peels to sugar (monomers and short oligos) and other break down products. This break down product is an excellent substrate for growing yeast, for food and feed or for producing bioenergy. Similarly, the OSTEP strategy [10], can be used for valorizing other types of residues and sidestreams, without need for carrying the cost of buying biomass degrading enzymes. In short, first the chosen fungus is grown on a part of the biomass, then the enzyme-blend-culture broth is harvested and used for breaking down the same residual substrate the fungus was first grown on.

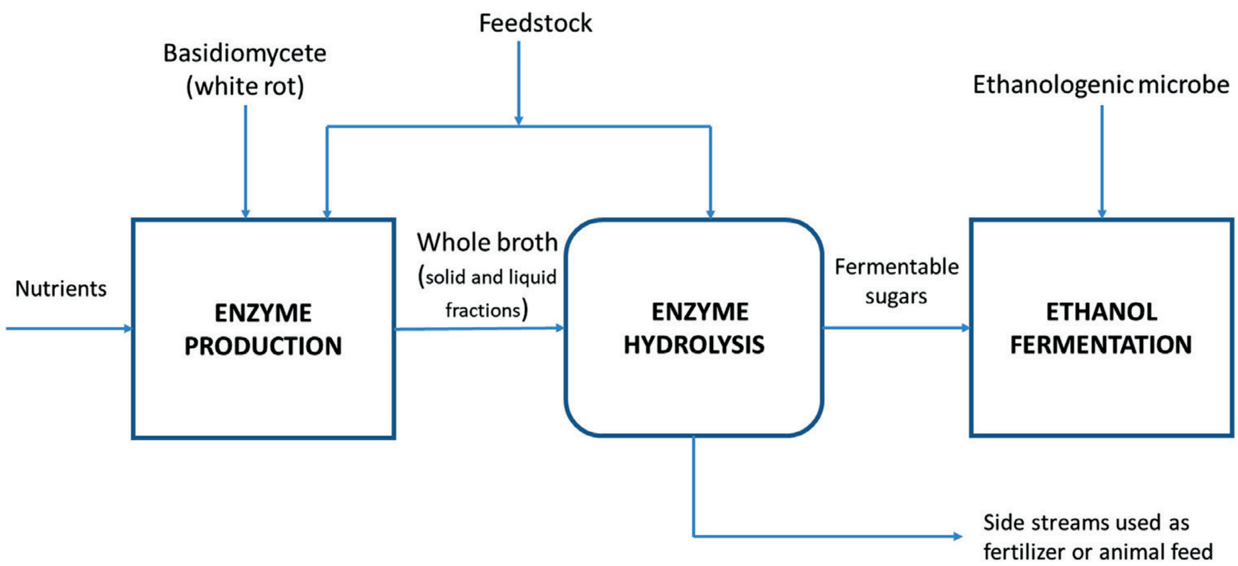

Figure 2a. A schematic overview of the OSTEP process, showing enzyme production, biomass degradation, and bioethanol generation.

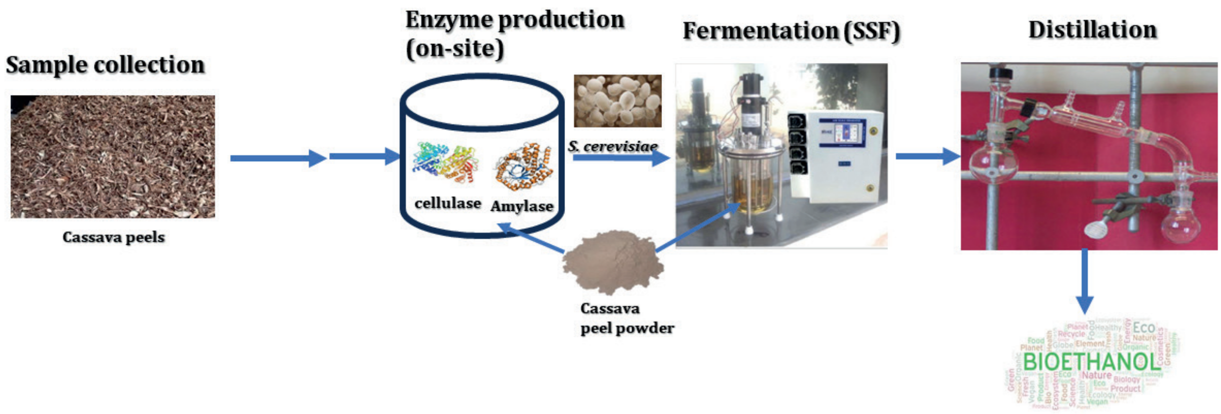

Figure 2b. Production of enzyme blend by growing a strong biomass-degrading fungus on the cassava peels, and subsequently use the harvested enzyme blend for cassava biomass degradation and Bioethanol production. Result: Production of enzyme blend and production of biethanol from cassava peels, using the OSTEP approach.

GHANA, CASE TWO

Topic: Cassava Peel and Corn Cob as Substrate for Mushroom Cultivation

Cassava residues (peels and pulp) are side streams from the processing of cassava tuber and can be converted to other starch-based products. However, it is often regarded as a waste since it is not needed in the main process. The dried cassava peel residue contains high levels of polysaccharides such as cellulose (40%), hemicellulose (21%), and starch (31%) and a very low level of lignin (4%). However, the high sugar / low lignin substrate is not an optimal substrate for mushroom cultivation since the mushroom fungi thrive well in high lignin, high sugar substrates (Fig. 3).

In that case, there is a need to combine other residues with the cassava peels to augment the lignin level. Corn cob, a residue obtained from the corn after harvesting the grains, is composed of a high level of lignin (15%), relative to the cassava peels (Fig4). Varying composites of the cassava peels and the corn cobs were prepared, and it was observed that the composite of 75% corn cob and 25% cassava peel was suitable for mushroom cultivation.

Figure 3. Mushroom production, cultivated on residual biomass.

Figure 4. Ground Cassava Peels, GCP, and Ground Corn Cobs, GCC, and their mixture, 1:3 ratio.

GHANA, CASE THREE

Topic: Enzymatic bioremediation of Oyster Mushroom, Pleurotus ostreatus, grown on different substrates

Around the world, numerous food industries and agricultural sectors generate a significant amount of polluted and toxic agro-industrial waste. The burning and disposal of such waste can seriously harm the environment worldwide. To support the sustainable development of our society with minimal environmental impact, a wide range of pollutants and waste must be removed from the environment [11]. Owing to the severity of the issue and the lack of a workable solution, there is an urgent need for an efficient, economical, and environmentally friendly cleanup, bioremediation technique [12].

Environmental pollution caused by various contaminants, including industrial pollutants and the toxic content of agricultural runoff, poses a significant menace to ecosystems and human health. There are several disadvantages associated with traditional remediation techniques, including high expenses, energy usage, and possible secondary pollution. Therefore, there is a need to explore alternative and sustainable approaches to remediate contaminated environments. One potential solution is the utilization of *Pleurotus ostreatus*, a fungus that can be grown on agricultural waste, as a bioremediation agent [13]. However, the effectiveness and feasibility of this approach need to be thoroughly investigated and evaluated.

In this study, three different substrates were selected for the cultivation of oyster mushrooms: sawdust, corn cob, and coconut fiber, selected due to their abundance, low cost, and potential to enhance fungal growth (fruiting bodies and mycelium) and enzyme production. The fungal biomass obtained from the substrates was homogenized, and the homogenate was centrifuged and purified. The purified crude extract was measured by enzyme activity assays to identify the level of oxidative enzymes, namely, lignin peroxidase, manganese peroxidase, and laccase, as shown in Tab1. These enzymes are responsible for the degradation of industrial pollutants that pose threats to the environment, especially the rivers, lakes, and shallow coastal waters. Results are shown in Tab1.

Tab1: The enzyme activity (U/L) of partially purified oxidative enzymes from substrate-based mushroom (fruiting bodies extracts)

Substrate	Lignin Peroxidase	Manganese Peroxidase	Laccase
Saw dust	26.75 ± 1.47	560.06 ± 20.48	0.61 ± 0.39
Coconut fiber	30.40 ± 5.00	596.07 ± 51.59	1.42 ± 0.05
Corn cob	30.87 ± 3.49	476.92 ± 48.11	2.44 ± 1.76

Conclusion: Different growth substrates impact the level of enzyme production, thus also the remediation potential of the oyster mushroom. The findings of this study could inform the development of cost-effective and sustainable bioreactors for on-site treatment of industrial and agricultural wastewater

GHANA, CASE FOUR, STRATEGY AND PLANNING

Topic 1: Circular Bioeconomy Innovation Hub in Ghana: Strategy and Work Plan for 2023-2025

Background: The One-CGIAR (Consultative Group of International Agricultural Research institutes), initiative 16, “Resilient Cities through Sustainable Urban and Peri-urban (UPU) Agrifood Systems” seeks to provide leadership and support to meet present and future challenges, urban food and resilience challenges, resulting from rapid urbanization and climate shocks and stresses [14]. The initiative has a particular interest in linking waste/sanitation and agriculture through the Circular Economy via Resource Recovery and Reuse (the RRR principle). Initiative 16 has five Work Packages (WP) as shown in Fig. 5.

WP1: Enabling sustainable production of nutritious foods in (peri-) urban zones.
WP2: Building inclusive and sustainable food markets and safeguarding supply chains.
WP3: Strengthening circular bioeconomy, food safety, and the urban environment.
WP4: Improving food environments and consumer behavior for nutrition.
WP5: Strengthening the evidence base and research and innovation capacities for UPU Agri-food System governance and growth.

Figure 5. The five workpackages of the One-CGIAR (Consultative Group of International Agricultural Research institutes), initiative 16: "Resilient Cities through Sustainable Urban and Peri-urban (UPU) Agrifood Systems".

The International Water Management Institute (IWMI) leads WP3 and supports WP5. As part of implementing WP5, an RRR innovation hub will be set up in Ghana, linked to WP3. The hub will showcase existing innovations tested by IWMI under previous CGIAR research and facilitate capacity development and innovations for a circular bioeconomy driven by public and/or private entities through various local partnerships.

Innovation hub activities and set-up in Ghana

Proposed activities for the hub are categorized into 3 components. They are:

- Capacity building in circular bioeconomy (Fig. 6)
- Implementation and/or scaling of existing or innovative RRR business models
- Advocacy and advisory support for policy uptake and the enabling regulatory and financial environment [14].

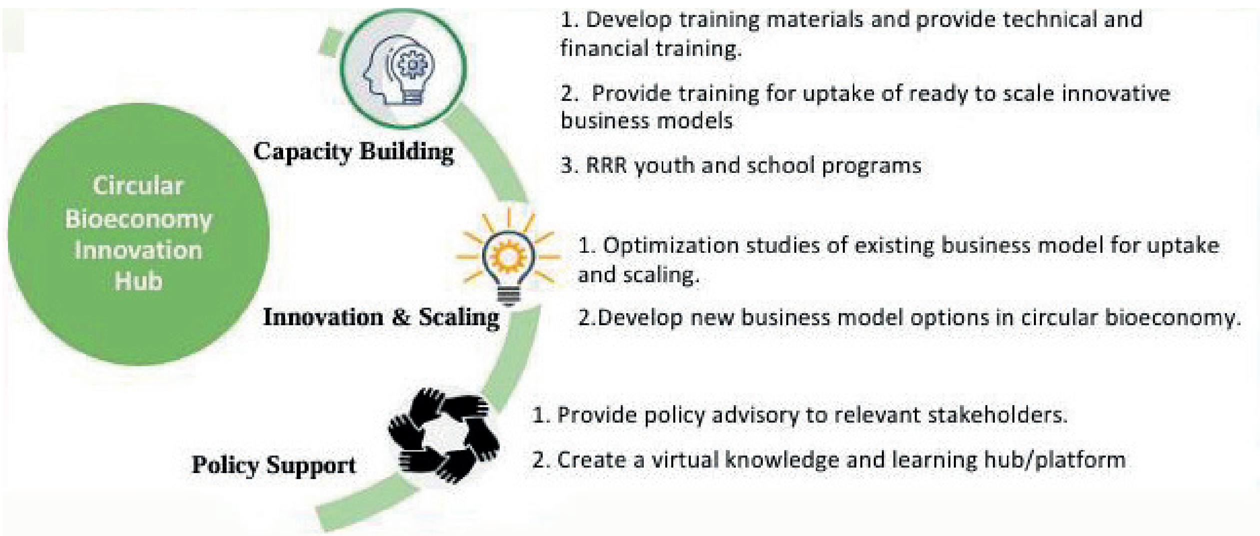

Figure 6. Capacity building in circular bioeconomy.
Source: Dzifa Agbefu and Philip Amoah, IWMI-Ghana, Accra (2022)

Topic 2: Biomass, the Foundation of Bioeconomy

Biomass, a good alternative to fossil fuels, can be obtained from various sources such as agriculture, forestry, and aquatic activities, as shown in Fig. 7. These resources are renewable and have the potential to offset fossil fuel emissions, therefore ameliorating the effects of global climate change and global warming.

Biomass production and its potential to produce renewable bioenergy vary among countries depending on geography, availability of resources, biodiversity, technology, and economy.

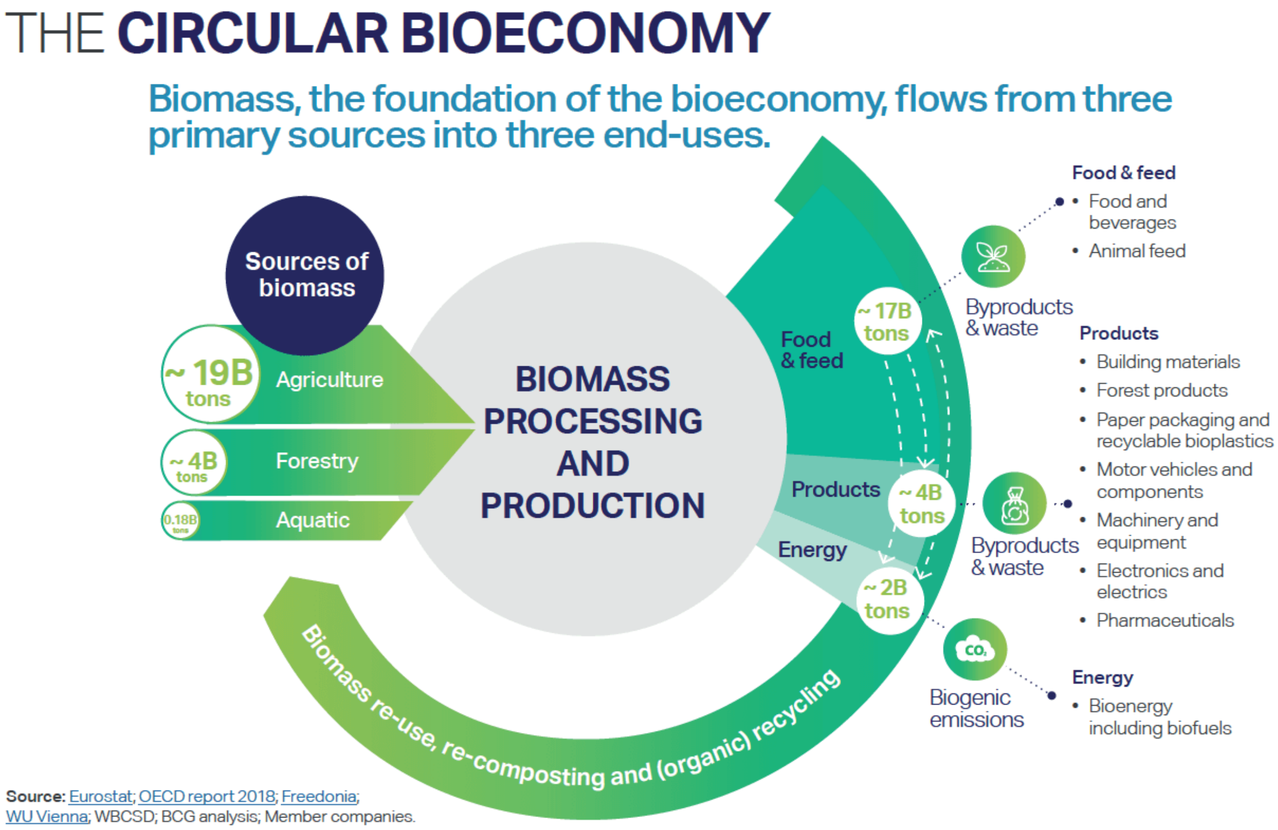

Figure 7. Biomass Processing and Production.
Source: Eurostat, OECD Report 2018

VALORIZATION OF WASTE FROM AGROPROCESSING INDUSTRY
By Karoli N. Njau, Tanzania

Agro-processing constitutes sizeable industries in the Eastern Africa region discharging also untreated or partially treated organic, mixed, wett and dirty wastes into the environment. Proper management of polluting industrial waste is generally perceived as expensive and enforcement of existing laws is weak. Financing of waste related interventions from financial institution through soft loans is perceived as a risky business. Generally, there is low awareness of environmental and socio-economic consequences of polluting the environment.

New achievements in circular and biobased valorization of organic content of waste water. ENVSOL Technology Co. Limited, an offshoot from BioInnovate Africa support (https://bioinnovate-africa.org/) is providing sustainable solutions to industries and institutions in the Eastern Africa region amidst the situation outlined above. Before registering ENVSOLcompany, reseachers from Tanzania, Uganda and Ethiopia collaborated on sustainable treatment of agro-industrial high strength wastewater, resulting in energy recovery and climate change mitigation. The result of the research consortium was the registration of Bioconversion Technology Co. Limited (BIOCON), which was later changed into ENVSOL. Initially the idea was to register one company having operational offices in the three countries but during registration this became impossible because of the laws in each of these countries when a company involves directors of different nationalities having almost equal shares.

ENVSOL is highlighting potential value in form of energy, technical water, organic fertilizer to be generated by upgrading the waste and use this as an incentive to make agro-industries want to invest, knowing that it can be money invested, leading to financial gain. We particularly use the potential for producing energy from organic waste as an attractive value propposition, since energy is expensive and any offset of the energy cost by own-generated energy is highly welcome by the industry. Our philosophy has always been to (1) adequately treat agro-industrial and institutional wastewater to comply with environmental standards (2) recover and reuse nutrients, water and energy and (3) opening for beautification of the waste treatment facility and installations. To be able to achieve these three gains, we combine a number of technologies starting with preliminary treatment to remove solids and modify the waste to be able to treat it. Primary treatment technologies, may need to be supplemented by additional secondary and a tertiary or polishing stage, depending on the stream and the strength of the wastewater. Beautification of the plant and its surrounding plot of land is considered in all processing steps, from design onto implementation and is a signature of our systems. We include landscaping, introduce flowers and make sure that the waste treatment place does not look like the waste itself.

A series of wastewater treatment publications, of relevance for East African climate and conditions have recently been published: [15-22].

Examples: Fig. 8 shows the Constructed Wetland at Nelson Mandela African Institution of Science and Technology, treating wastewater from student dormitory. The system is treating 80 m^3 of wastewater per day. The treated wastewater is used to irrigate bananas and yams. The treatment facility is also used as training laboratory (a true living lab) for students. The grounds also provide areas for resting and leasure. People report to have rested there without knowing that it is a wastewater treatment facility. This facility has attracted two industries and one institution to adopt constructed wetlands in their wastewater treatment technologies. In this case, water and nutrients are the ones recovered to be used for irrigation of banana.

The two industries, namely a meat processing company and a seed processing company have already installed a system composed of Fat, Oil and Grease (FOG) separator as preliminary treatment, Septic Tank and Anaerobic baffled reactor (ABR), respectively, as primary units, supplementary to constructed wetland for secondary and final treatment. One higher learning institution has decided to also adopt a similar system and we are now at design stage for this customer as well.

Figure 8. Beautified constructed Wetland (waste-water treatment plant) at Nelson Mandela African Institution of Science and Technology.

TREATMENT OF WINERY INDUSTRY WASTEWATER

Same philosophy has been applied to the treatment of waste water from the Banana Wine Industry, which had a serious issue with the authorities before the wastewater treatment system was installed (Fig. 9, Fig. 10).

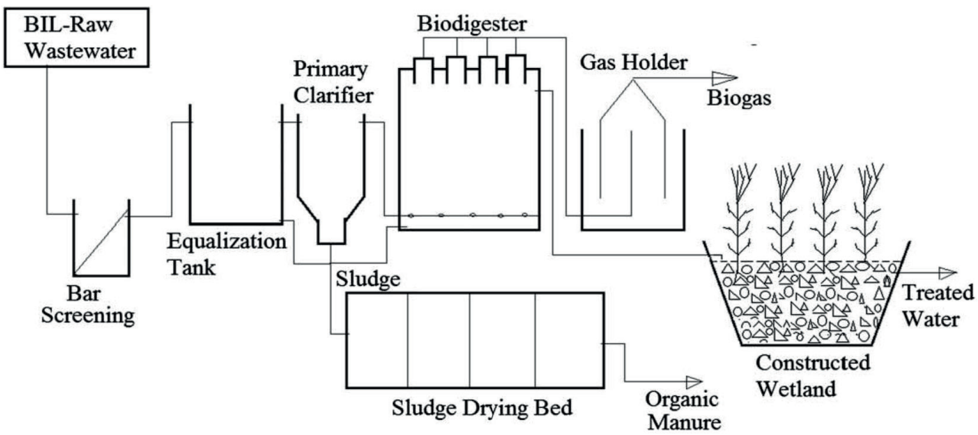

Figure 9. Simplified process flowsheet for the Banana Wine wastewater treatment system.

Figure 10. Facilities installed to meet the objectives of adequately treating banana wine wastewater, a. recovering nutrients and producing biogas, b. recovering water for re-use and c. beautification. From left to right: (1) Screening (2) Equalization (3) Clarification to produce sludge (3) Sludge dewatering for reuse (4) Buffer tank (5) Biodigester (6) Biogas holding. Observe the whole beautification of the treatment area.

Recently, in January 2025 we have installed an clean cooking energy generating system producing biogas from cowdung and foodwastes for a vocational training institute having about 400 students and 40 staff. The biogas is supplied to the main student kitchen and 10 huseholds in the Institute's surroundings. The provision of the clean cooking has completely changed the ambience of the cooking at the Institute (Fig. 11, Fig. 12).

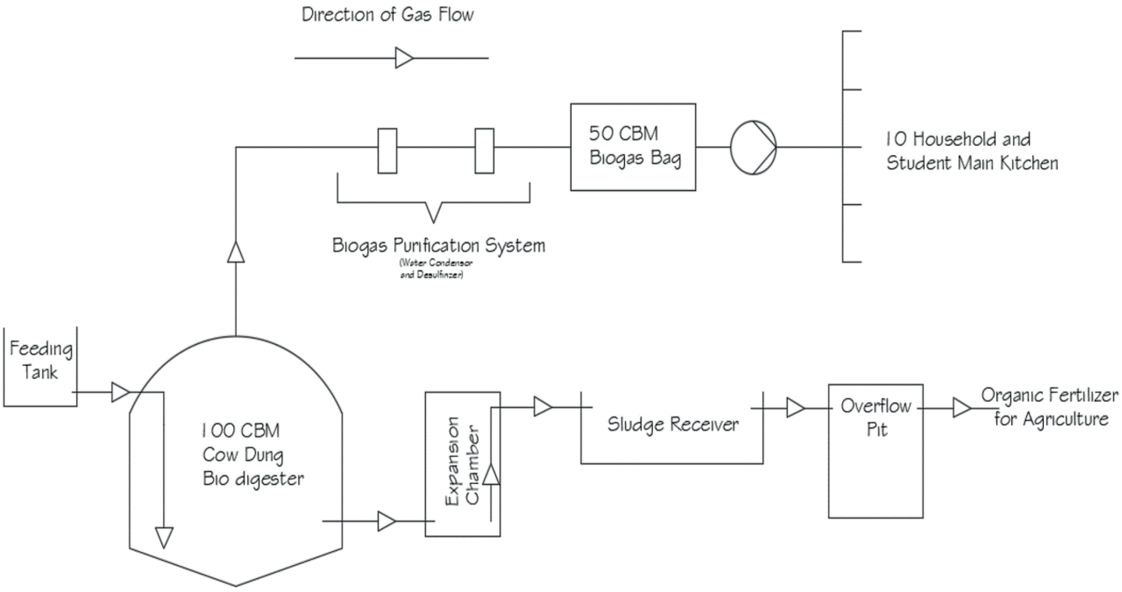

Figure 11. Process Flow Diagram of the 100 CBM bio digester at the vocational training institute.

Figure 12. The new student kitchen in the vocational training institute.

We have also implemented a number of wastewater treatment projects within Tanzania and abroad. Not in all such projects are we recovering biogas, but nutrients and treated water for use in agriculture are always recovered and used. Recovery of biogas is considered only, if it makes economic sense since some of these facilities are too small and recovered biogas cannot be put into economic use by the client. We have implemented systems with biogas recovery to abattoirs, beverage industries, dairy industry, institutions of learning, and also installed systems without biogas recovery to a seed company, a tea company and for meat processing, we have also conducted similar projects in Kenya (Shimo La Tewa Prison in Mombasa), Ethiopia (Modjo Tanneries, in Modjo), Seychelles (Mahe housing complex in Mahe) and Uganda (Seeta Secondary School in Mukono).

For impact, we tell *and* show for succcesful implementation and dissemination of the technologies. The approach we have used so far seems to attract clients particularly the private sector . Although constructed wetlands require large piece of land, their aesthetic value, when properly designed to blend well with the nature around it, can be attractive to many. Albeit, beautification, to hard-technical oriented people may be viewed as not very important, but to a good number of decision makers it meets their psychological needs in making final decisions. However, we have noted that private Industries and Institutions get more convinced when either a presentation is done or they are able to visit one of our sites. One director of a meat processing company said to us after visiting a site " I want exactly the same on my factory" what we do with this general information is to design a system for that particular case meeting all the three objectives of (1) Adequate treatment for compliancy, (2) Recover and reuse energy and/or nutrients and treated water to be used for e.g. irrigation and (3) Beautification. In this manner, our clients always get more than just environmental compliance from the systems we implement.

NATIONAL BIO-CIRCULAR-GREEN ACTION PLAN AND OVERVIEW OF BIOECONOMY IN THAILAND

By Warinthorn Songkasiri, BIOTEC, Thailand

Thailand has been at the forefront of implementing the Bio-Circular-Green (BCG) Economy Model since 2019, aligning with its vision for sustainable and inclusive development and economic resilience. The National BCG Action Plan (2021-2027) prioritizes four strategic sectors, including (i) food and agriculture, (ii) medical and wellness, (iii) energy, material and biochemical, and (iv) tourism and creative economy. The plan targets to raise the economic contribution of these sectors from 21% to 24% of GDP by the year 2027, reinforcing Thailand's position as a regional hub for the bioeconomy.

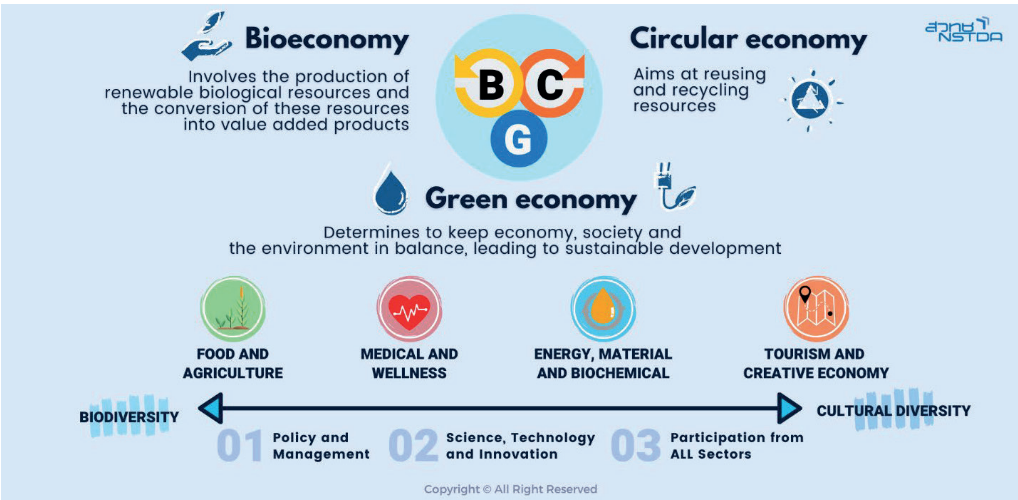

Figure 13. Thailand's BCG economy model.

Thailand's bioeconomy strategy involves the production of renewable biological resources and the conversion of these resources into value-added products, utilizing the nation's biodiversity and cultural diversity. In the agriculture and food sector, the focus is on moving farm production from low-priced commodities to premium products by emphasizing standards for high quality and safety, as well as value creation through advanced processing technology. The government recognizes the potential to multiply the value of crops and biomass by turning them into functional ingredients and building blocks for high-value biochemicals and materials like bioplastics and carbon-based materials using advanced technology. Opportunities in the biorefinery industry for biobased products have also been identified as a key area for development. The country also aims to address its dependence on imported drugs and pharmaceutical products by strengthening local pharmaceutical manufacturing capabilities, which are currently limited to producing generic drugs from imported active pharmaceutical ingredients (APIs). The BCG framework is driven by four pillars: sectoral development, talent and entrepreneurial development, area-based development, and frontier research and innovation. The key enablers supporting the BCG implementation are regulatory reforms, infrastructure and facility development, capacity building, and global partnership creation. The following details showcase infrastructure and facility development in Thailand.

Thailand's bioeconomy strategy was first visualized with the establishment of the National Center for Genetic Engineering and Biotechnology (BIOTEC) in 1983 under the Ministry of Science and Technology (MOST). BIOTEC was then integrated into the National Science and Technology Development Agency (NSTDA) in 1991. BIOTEC creates knowledge and technological platform that can be applied to the national and regional problems. BIOTEC's biorefinery and bioproduct technology research group aims to exploit the use of microbial resources and biotechnology for biomass valorization to a high value chemicals, fuels, and products for agricultural, industrial and medical applications. Biomass of interest are 1st generation biomass, i.e., sugar, starch, oil; 2nd generation biomass, i.e., cassava pulp, bagasse, wood chips, palm empty fruit bunch, fruit residue; and other biowastes (see Fig. 14 and Fig. 15).

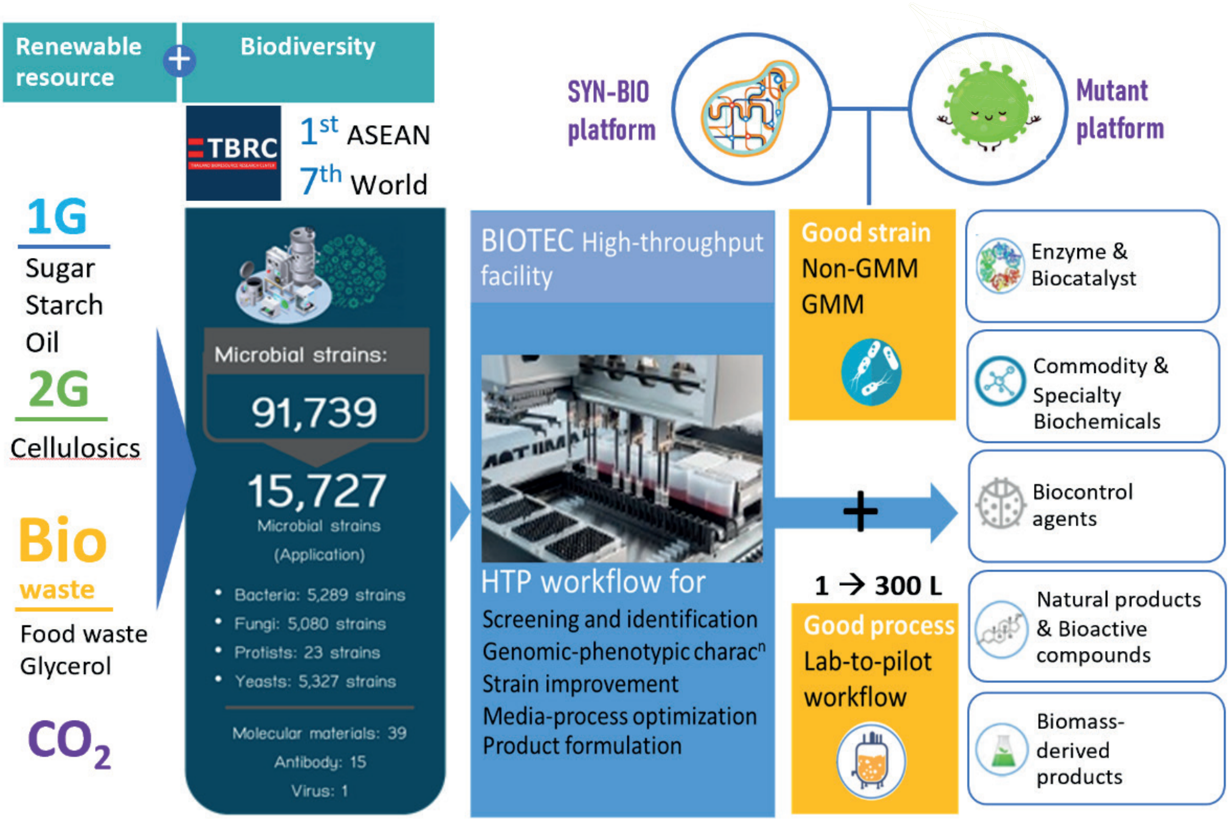

Figure 14. BIOTEC's lab to pilot microbial product development framework.

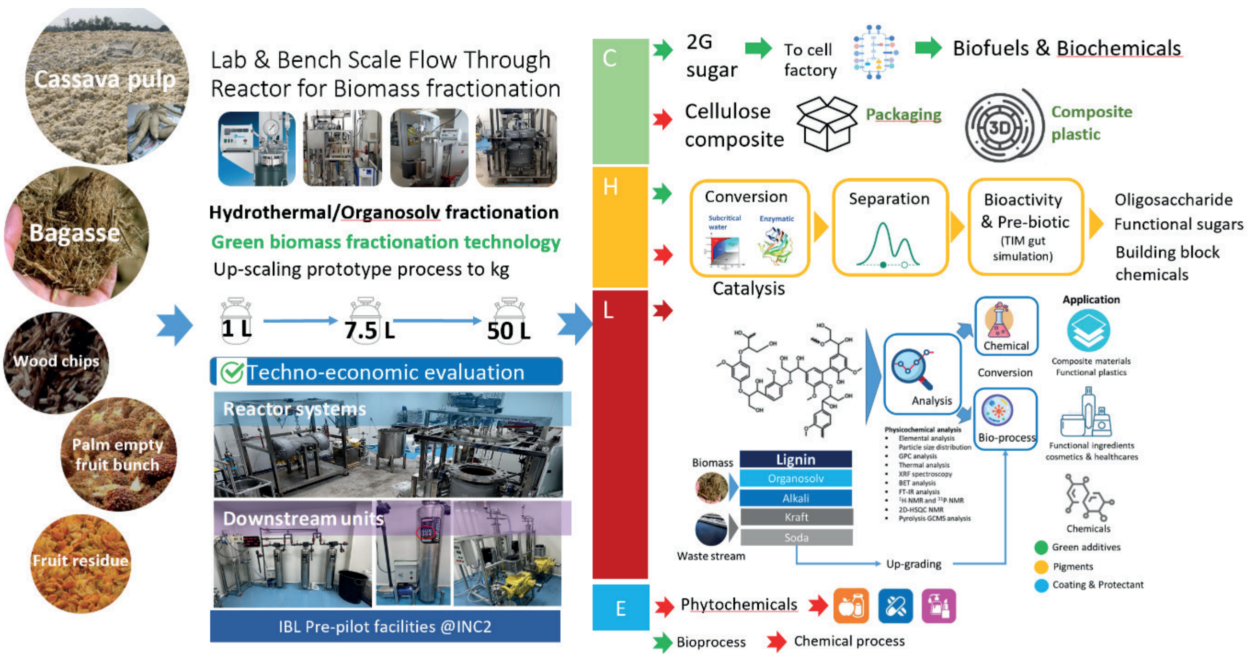

Figure 15. Green fractionation process for 2nd gen biomass valorization to cellulose (C), hemicellulose (H), lignin (L), and other extractives (E).

Thailand Bioresource Research Center (TBRC) is another key national initiative as a repository and provider of biological materials established to support the sustainable utilization of the nation's biodiversity for research, innovation, and industrial application. The center has in place more than 90,000 strains with 15% utilized. The TBRC supports the bioeconomy by providing microbial strains for bioprocessing research, enabling the development of advanced bioproducts and bioenergy solutions.

Thailand has already seen significant success under the BCG framework. E.g. Agriculture and Food:

Through the multi-stakeholder concept, the Thai tapioca starch association (TTSA) has joined force with BIOTEC, King Mongkut's University of Technology Thonburi (KMUTT), Department of Agriculture, Ministry of Agriculture and Cooperatives, and Thai Chamber of Commerce to declare the National Cassava Starch Net Zero Roadmap for the value chain of cassava. The road map aims to reduce greenhouse gas emission by 30% from 2.17 million tons CO_{2eq} annually to 1.52 million tons CO_{2eq} by 2030, and achieve net zero in 2050. Key measures include promoting precision agriculture to minimize nitrogen fertilizer usage for the cassava cultivation sector, reducing starch loss, adopting green solar drying techniques and utilizing renewable energy, such as solar and biogas energy for heat and electricity generation in the starch factories. Further, The stakeholders in the value chain have adopted the circularity concept by utilizing biomaterials, such as cassava stem, leaves, pulp to create high value appropriate and innovative products. Other example is the use of rice husks for bioenergy and the promotion of premium organic rice have increased farmer incomes by 30%, while also contributing to export growth.

Figure 16. Thai National cassava starch net zero road map.

- *Bioenergy:* Molasses- and cassava-based ethanol production has positioned Thailand as Asia's second-largest ethanol exporter, reducing greenhouse gas emissions by 2.5 million tons annually and creating thousands of green jobs. In addition, Thailand is one of the countries that has the successful biogas utilization in agro-based industries, i.e., cassava starch, palm oil, rubber, bioethanol, food industries, and animal farms. The local proven technologies have been transferred for the generation of heat and electricity.

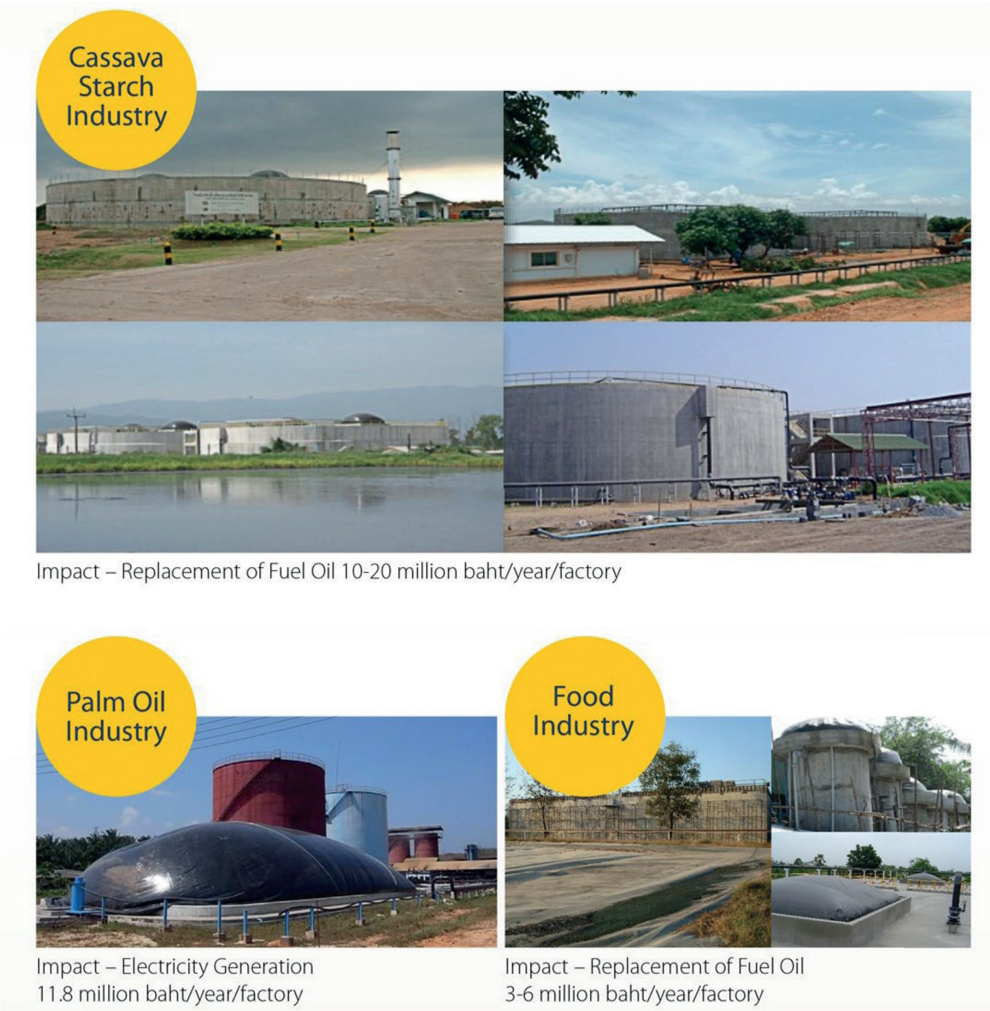

Figure 17. Biogas plants in Thailand.

Building on its extensive experience and expertise, Thailand is well-positioned to reinforce its leadership in the regional bioeconomy. By leveraging its strong agricultural foundation, advanced technological capabilities, and strategic geographic position, the country is advancing a comprehensive framework for inclusive and sustainable economic development. The Bio-Circular-Green (BCG) model serves not only as a mechanism for enhancing economic resilience but also as a paradigm for addressing global challenges through innovative practices and interdisciplinary collaboration.

AÇAÍ SEEDS VALORIZATION AND BRAZILIAN BIOECONOMY NATIONAL STRATEGY

By Roberta P. Espinheira and Ayla Sant'Ana da Silva, Brazil

Palms (family Arecaceae) are among the most important forest plants for humans, serving as one of the most significant sources of non-timber forest products (NTFPs). Various uses are reported for different parts of palms, with particular emphasis on the economic exploitation of their fruits. In the Brazilian Amazon Rainforest, the açaí palm (Euterpe oleracea Mart.) stands out due to its considerable social and economic importance. The primary product of this palm is the açaí fruit, small round dark-purple fruits of about 1 cm in diameter, which are processed to extract their pulp [23].

The consumption of açaí pulp by native Amazonian populations dates to the Pre-Columbian era, a tradition that persists to this day, with some northern populations in Brazil, consuming significant quantities weekly. However, the popularity of açaí surged in the 2000s, mainly driven by its global recognition as a highly nutritious "superfood". This newfound popularity, combined with advancements in the processing and preservation of açaí pulp—through drying or freezing techniques—has enabled its distribution across Brazil as well as exportation to international markets, where it is used in various foods and cosmetics [24].

Thus, the increasing demand has led to significant changes in açaí palm production systems in riverside communities, where agricultural management techniques are being applied in floodplain areas (várzea), the natural habitat of the açaí palm. This was complemented by the development of new açaí palm cultivars, which enabled cultivation in upland areas, reducing dependence on traditional floodplain practices. Additionally, government programs were launched during this period to increase production, ensure quality, and promote best practices across the supply chain [25]. As a result, over the past two decades, açaí production has grown exponentially, by almost 400%, reaching approximately 1.93 million tons in 2023, while generating an estimated revenue of US$ 1.3 billion for the Brazilian economy (sidra.ibge.gov.br/pesquisa/pam and sidra.ibge.gov.br/pesquisa/pevs).

Despite its success, the rapid expansion of açaí production has brought significant challenges, particularly the large amount of residue generated due to the low pulp-to-seed ratio. With ~85% of the biomass being inedible seeds, it is estimated that over 1.6 million tons of seed-residue are produced annually from currently the 1.9 million tons of açaí harvested annually [26]. The lack of public policies and waste management infrastructure has exacerbated urban, sanitary, and environmental issues, especially in key production areas. Improper disposal of açaí seeds contributes to pollution and poses public health risks (Fig. 18). This issue is especially critical in cities and rural areas where açaí is processed, as inadequate regulations and infrastructure make it difficult to manage the increasing volume of waste [27].

Figure 18. (a) Aerial view of an irregular açaí seed disposal site in Moju municipality, Pará, Brazil. (b) Drone-captured image showing a broader view of the same disposal area. (c) Açaí seed disposal site in an urban area of Belém, Pará, Brazil (images from the personal archive of Ayla Sant'Ana).

Due to the perishable nature of açaí pulp, processing must occur in producing cities, which leads to the accumulation of approximately 90% of açaí seeds in specific regions of Pará state, Brazil, where the production is concentrated (sidra.ibge.gov.br/pesquisa/pam and sidra.ibge.gov.br/pesquisa/pevs). While this accumulation of açaí seeds is largely overlooked by most Brazilians, it represents not just an environmental issue, it is also and most importantly a significant opportunity. This scenario facilitates the logistics of incorporating açaí seeds into biorefinery systems, which would enable the production of higher added-value products and energy by effectively utilizing the specific components of this açaí palm seed biomass.

This situation has led to a few studies initiating more comprehensive compositional characterizations of açaí seeds to identify the most suitable industrial applications for this residue and explore their potential for conversion into higher value-added products. [26,28,29]. The results showed that these seeds are rich in mannan polysaccharides and polyphenols, which could be used to produce higher-value products while also generating energy. Indeed, açaí seeds contain a notably high mannan content, comprising approximately 50% of their dry weight [26], whereas other abundant agricultural residues, such as palm kernel cake, coconut fibers, and coffee grounds, have a maximum of 35% mannan [30]. This significant difference highlights the potential of açaí seeds as a valuable source for mannan-derived products.

Traditional methods for disposing of açaí seeds often involve incineration, a process that primarily aims to reduce waste volume but may not fully optimize energy recovery. However, more efficient alternatives have been explored, including the use of açaí seeds for energy generation through controlled combustion and as a partial replacement for ash in civil construction materials (gccassociation.org/concretefuture/votorantim-cimentos/). While the use of açaí seeds as energy and construction materials is promising, the untapped potential of these seeds, rich in bioactive compounds, presents a significant opportunity to develop much higher-value products and drive economic growth in the açaí industry.

In this context, techno-economic viability studies for an açaí seed biorefinery have been carried out, exploring the full utilization of the biocompounds present in the seed [31,32]. The process involves the extraction of a phenolic-rich extract, the application of a chemoenzymatic method for the production of mannose and β-mannan oligosaccharides (MOS), and the subsequent combustion of the hydrolysis residue for electricity generation. According to these studies, the açaí seed biorefinery, by exploring the diversity of biocompounds present in the seed, offers a more attractive value proposition than simple combustion, with an estimated net present value (NPV) of US$ 150 million and a payback period of 2.5 years [31,32].

Polyphenols are bioactive compounds widely recognized for their antioxidant properties and potential health benefits. Specifically, the açaí seeds extract, rich in flavan-3-ol oligomers and polymers, named procyanidins with high degree of polymerization [28]. These compounds exhibit potent antioxidant activity and also possess antimicrobial and antibiofilm properties [33], helping to prevent bacterial biofilm formation and combat pathogenic microorganisms. Also açaí seed extracts have been associated with various pharmacological effects, such as mitigation of inflammation, and aid to cardiovascular and metabolic health [34]. These properties position the açaí seed extract as a potential candidate for applications in food preservation, healthcare, and environmental sustainability, where controlling microbial growth is crucial.

Similarly, MOS and mannose, which can be derived from the efficient hydrolysis of açaí seed mannans, are gaining attention for their prebiotic properties and therapeutic potential in healthcare. MOS supports gut health by fostering beneficial microbiota, while mannose is studied for application in treating urinary tract infections and glycosylation disorders, besides being a valued moisturizing agent in cosmetic industry [35,36]. However, the mannans in açaí seeds are highly crystalline and recalcitrant, making enzymatic hydrolysis alone challenging and necessitating the use of harsh chemicals in combination with enzymatic processes [26, 32,37].

Thus, unlocking the full potential of açaí seeds in a more sustainable manner depends on the discovery and optimization of mannanases—enzymes that can efficiently hydrolyze mannans. In this context, a study focused on the discovery of mannanases specifically for the efficient hydrolysis of linear β-mannans was initiated [38]. By combining bioinformatics and experimental approaches, the research aimed to enhance the hydrolysis of linear β-mannans from açaí seeds.

These emerging scientific initiatives, combined with locally developed solutions, are gradually working towards transforming the use of açaí seeds into a rich source of added value products, of importance for improved rural livelihood. This is specially important considering that açaí, as a leading NTFP in the Amazon, represents a sustainable alternative to traditional economic activities that often contribute to deforestation, pollution, and biodiversity loss [39]. By focusing on the bioactive potential of açaí seeds, the local economy can benefit, while also promoting environmental sustainability.

Açaí not only supports the local economy but also, alongside other NTFPs like Brazil nuts and cassava, plays a crucial role in supporting traditional communities and fostering sustainable land use [40]. Although açaí's revenue is modest compared to dominant crops like soy, corn, and sugarcane—whose combined annual revenues, currently exceed US$ 94 billion (sidra.ibge.gov.br/pesquisa/pam)—it plays an important socioeconomic role in the Amazon. Açaí supports smallholder farmers and traditional communities, integrating into agroforestry systems that align with forest conservation. Unlike large-scale monocultures associated with deforestation, açaí exemplifies of how biodiversity can drive sustainable economic development while addressing pressing environmental challenges [41].

However, the risks associated with over-reliance of açaí superfood production, and shifting it into monoculture-like practices emphasize the need for integrating circular economy principles into the açaí seed-based value chains. By utilizing the biocompounds present in açaí seeds it is possible to develop high-value products that support economic growth, local livelihood, and environmental sustainability. These efforts not only enhance the resilience of the açaí industry, but also lay the foundation for the development of other regional value chains, including guaraná, cupuaçu, buriti, camu-camu, tucumã, bacuri, and babaçu [41].

Brazil's National Bioeconomy Strategy provides a structured framework for fostering sustainable industrial innovation through biodiversity valorization. This strategy follows a bioecological vision, emphasizing the sustainable use, conservation, and regeneration of biological resources while integrating scientific and traditional knowledge. The forthcoming National Bioeconomy Development Plan (PNDBIO) aims to operationalize this strategy, ensuring coordination across government sectors and aligning bioeconomy-related policies [42]. Within this context, the valorization of açaí residues, particularly the seeds, aligns with global efforts to establish circular bioeconomy models. By integrating açaí seed-based value chains, Brazil strengthens its leadership in sustainable bioeconomy while fostering economic resilience in the Amazon region.

Despite these advancements, regional collaboration in bioeconomy remains limited. Establishing stronger partnerships between research institutions, industry, and government across Latin America will be essential to drive joint innovation and knowledge exchange. By fostering these collaborations, Brazil can enhance its capacity to develop high-value bioproducts while ensuring long-term environmental and economic sustainability.


WHEY

VALORIZING ACID WHEY, US
By Genevieve K. Croft, USA

The United States has the capacity to produce over a billion tons of sustainable biomass (crop residues and food and forestry processing side-streams) on an annual basis [43], yet the technologies needed to convert many biomass sources into feedstocks for manufacturing products are lacking. “Turning the carbon we have into the carbon we want” requires new scientific approaches to deconstruct biomass into useful carbon building blocks and convert it into new products [44]. Schmidt Sciences, in partnership with the US Foundation for Food & Agriculture Research (FFAR), launched a research funding effort in 2024 to address this need. The Virtual Institute on Feedstocks of the Future (VIFF) unites five interdisciplinary research consortia, each addressing different aspects of the science, technology, and engineering needed to turn biomass residues and byproducts into valuable products (Fig. 19; see www.schmidtsciences.org/viff for more information).

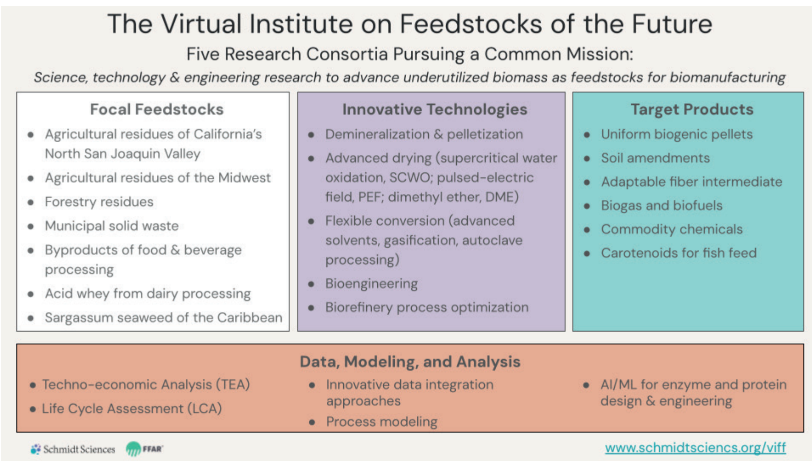

Figure 19. Alternative biomass feedstocks research projects funded via the Virtual Instituteon Feedstocks of the Future.

Among funded VIFF projects, the Dairy Industry Waste Valorization (DIWAV) team, led by researchers at Massachusetts Institute of Technology (MIT), is developing new uses for acid whey (Fig. 20), a byproduct of Greek yogurt production. For every unit of Greek yogurt produced, two units of acid whey are generated as a byproduct [44]. The United States produces acid whey in quantities ranging from an estimated 2 million metric tons [MMT], [45] to 3.6 MMT (G. Stephanopolous, *personal communication*) per year. Acid whey cannot be released freely due to its high biochemical oxygen demand and low pH [46] : If released directly into waterways, it uses up dissolved oxygen in the water, killing fish, and reduces its pH, leading to water acidification and disrupting ecosystems [47]. As such, safe disposal of acid whey is an added cost to Greek yogurt producers [48]. Despite these challenges, acid whey is a potentially valuable resource, as it is rich in useful components such as lactose, minerals, and proteins [46].

Figure 20. New method for valorization of acid whey, a side-stream of the dairy yoghurt production, a VIFF project together with the US Dairy Industry Waste Valorization (DIWAV) team, led by researchers at Massachusetts Institute of Technology (MIT). Acid whey valorization. Image courtesy of C. Katsimpouras.

DIWAV researchers are developing an innovative means of transforming acid whey from a noxious waste stream into a circular biomass resource. The team is developing bioengineered strains of *Yarrowia lipolytica* capable of efficiently fermenting acid whey to produce carotenoids for use in a variety of products. Carotenoids are pigments valued for their antioxidant properties for use in food, feed, and cosmetics. The DIWAV research team is already producing lycopene, and intends to expand production to additional carotenoids. Their initial target product is a fish feed supplement, with the opportunity to expand to new products as successes are demonstrated.

FUTURE PERSPECTIVES FOR VALORIZING UNDERUTILIZED BIOMASS

This acid whey research is one example of the many opportunities that new science, technology, and engineering can offer to valorize neglected biomass residuals and address environmental challenges. The wide variety of available and underutilized biomass sources (e.g., forest thinnings, agricultural harvest residues, municipal solid waste) and the technical challenges yet to be overcome to derive value from these materials calls for a concerted focus on interdisciplinary research progress toward sustainability goals.

The VIFF Program has identified four elements of success for research efforts in this space:

1. Identify a high-impact target feedstock. Opportunities abound to leverage scientific research to improve our use of residual biomas and by-products. Selecting a high-potential feedstock in need of solutions can increase impact. In the DIWAV example, acid whey was identified as an economically environmentally challenging waste product that contains valuable components and is also available in large quantities from point sources in a specific industry. If successful, this research will mitigate environmental and economic harms, while providing new commercial and nutritional opportunities.

2. Assemble a multidisciplinary, multisectoral team. Biomass wastes and byproducts are challenging to utilize and will require creativity and contributions from diverse science, technology, and engineering disciplines. In the case of DIWAV, the research team aims to achieve success by engaging individuals from academic and industry research settings with experience in microbial metabolic engineering, process engineering, product development, and data analysis. Unusual partnerships can yield new insights.

3. Partner with waste producers. Great ideas for biomass waste and byproduct utilization must be cross-referenced with insights from essential actors in the eventual adoption of new approaches. For example, partnerships with producers of biomass residues can improve researchers' understanding of where, how, in what quantities and qualities, and at what cost they can be sourced during the initial lab phase and any commercial scale up to follow. Such partnerships can provide critical insights into supply-chain logistics.. In the case of DIWAV, the research team partners with Dairy Management, Inc. (DMI), a U.S. dairy trade association with intimate knowledge of the U.S. dairy industry. DMI is helping the research team to map where acid whey is produced and to facilitate access to acid whey from various locations.

4. Begin with customers in mind. There is little point in developing a product without an existing or potential market. Collaboration with future customers can ensure that the products developed meet market demands and can achieve commercial viability. Early establishment of a customer base will support successful outcomes. In the case of DIWAV, they partner with industry researchers to develop a product for an interested market: feed for farm-raised fish. By partnering with a potential customer from the outset, the research team and the customer can work together to develop an effective and valued product.

NEW METHODS FOR UPGRADING THE GREEN, YELLOW, RED AND BLUE BIOMASS

By Lene Lange And Anne Maria Hansen, Denmark

EU invested in a billion euro, industry led, public/private collaboration program, research, innovation, development and scaling for unfolding the potential of circular and biobased bioeconomy. The two programs, BBI-JU (2014-2021, https://www.bbi-europe.eu/) and CBE-JU (2021-2028, https://www.cbe.europa.eu/) focused on next generation bioeconomy. To move from "wheat straw and corn stover to bioethanol, chemicals or materials", to implementing the cascading use principle, aiming at unlocking the full potential of the biomass. Recovering the higher value products first, and only converting the residual fiber-rich components of the biomass for production of bioenergy.

However, already prior to BBI-JU and CBE-JU Denmark had a pioneering role in the development of international, large-scale biomanufacturing industries, Novo Nordisk revolutionized the production of human insulin (https://www.novonordisk.com/about/our-heritage.html), producing human insulin in baker's yeast for a large part of the world's diabetics. Similarly, Novonesis -a recent merger of Novozymes and Chr Hansen (https://www.novonesis.com/en) grew to be world-leading in large scale biomanufacturing of industrial enzymes and microbial starter cultures. In parallel, Danish university research has been at the forefront of enzyme discovery, enzyme improvement, and the design of enzyme-based processing technologies for more efficient use of the bioresources.

Danish farmers have together formed cooperatively owned food processing industries, dairy-, potatoe-, and meat-processing and crop-breeding. Notably, cooperative ownership has been conducive for pioneering implementation of valorization of side-streams and by-products, unlocking the full potential of the biomass [5]. In the past 5-10 years a new generation of Start-Up companies, for improved use of the bioresources have emerged in Denmark, making both nutritious and climate friendly food and feed, as well as biobased building materials (made by growing fungal mycelium in fiber-rich plant-derived residues, https://www.naturpladen.dk/). For knowledge sharing, information and inspiration, a brief description of valorization of the green, yellow, red and blue biomass is given below (see Fig. 1 for meaning of the color-code). All the cases are a result of efficient public/private collaboration, successfully developing and scaling biomass conbversion technologies. Commercialized in Denmark and beyond, by start-up companies or industries. For example, the valorization of whey by Arla Foods has contributed a revenue increase of 5.4%. This growth was driven by strong demand for specialized proteins for food ingredients. Danish biogas industry now recovers 20% of agricultural waste for energy production

Higher value products from dairy industry side-streams: The Danish dairy industry has made significant advancements in valorization of whey, a by-product of cheese production. Beginning in the 1980s, the Danish dairy company Arla Foods initiated conversion of whey into high-value food ingredients. A business that by 2015 surpassed cheese sales in revenue. Today whey-based food ingredients are used in diverse applications such as ice cream, baby food (infant formular), health-promoting food, diets (e.g. for athletes or weight loss), low fat cheese as well as functional food ingredients. This transformation highlights the economic, nutritional and climate friendly potential of dairy side-streams. With global whey production exceeding 200 million tons annually, replicating this "circular and biobased" success in oth¨er regions of the world could significantly reduce waste of bioresources and create new economic opportunities in the dairy sector, generating jobs, development and rural livelihood (https://www.arlafoodsingredients.com/).

Improved use of starch extraction by-products from tuber crops: Valuable protein ingredients can be extracted from the by-products of tuber-based starch production. The Danish company KMC has developed technologies for making new, higher value products from the protein content of the extraction pulp, previously downgraded. Potato proteins are now the focus of several commercialized technologies. These include the extrusion of heat-coagulated proteins to create meat analogues [49] and the isolation of highly native proteins through Expanded Bed Adsorption [50]. The latter are highly functional, (providing gelling, foaming and emulsifying capabilities), serving as sustainable alternatives to animal-derived proteins, such as egg white in a range of food applications. Suggestion: Similar valorization approach to be developed and used for other starch extraction crops. The technologies are scalable and adaptable to other high-starch crops like cassava, sweet potato or yams, which are common crops in tropical regions, offering opportunities for climate and food security friendly, circular and biobased protein valorization in all parts of the world (see also the Thailand cassava text above).

Gut-Health-Promoting Feed from Oilseed Residues. Residues, from oilseed processing, e.g. rapeseed meal, have been successfully co-fermented with brown seaweed using lactic acid bacteria to create gut-health-promoting animal feed (developed and commercialized by Fermentation Experts, Denmark). This innovative feed combines the probiotic effects of lactic acid bacteria, prebiotic oligosaccharides (produced by bacterial enzymes), and anti-inflammatory metabolites generated during the fermentation [51]. This approach has proven particularly beneficial for livestock, such as pigs and chickens, contributing to improved gut health and overall health and productivity. Notably, improved animal gut-health opens for significant reduction of antibiotics in production of meat. Studies have shown that fermented rapeseed meal can reduce antibiotic use in pig farming by up to 40%, improving both animal health and sustainability. Suggestion: Similar valorization approach to be developed and used for other oil seed extraction pulps, such as e.g. sunflower.

Valorization of Animal By-Products. Technologies have been developed and scaled for extracting valuable products from slaughterhouse by-products, e.g. animal innards, producing high value biological products for life science and nutrition from e.g. upcycling bovine by-products, or creating added value from turning animal blood into food, feed and biotechnology products (including medicin or food supplements for iron deficiency). The Danish company Sera Scandia A/S (https://serascandia-csc.com/) was founded in Venezuela in 1975 (as suppliers of porcine pancreas glands to Novo Nordisk) and later expanded across Latin America. Since then, Sera Scandia has become an expert in creating value from animal by-products. Sera Scandia A/S has now offices in North America, South America and Europe.

The Blue Bioeconomy, using all parts of the fish: Pioneered by Iceland, the Nordic countries, including also the Danish enzyme processing and food research, have contributed to the development of methods for optimizing the utilization of fish and shellfish under the "100% fish" concept (https://www.kerecis.com/the-100-fish-project/). Historically, fish processing has focused primarily on fillets, which account for only between half or one-third of the whole fish, while the remaining parts were downgraded or discarded. The ‚100% fish' concept involves utilizing all parts of the fish, including heads, bones, skin, and innards, to create products such as fish oil, collagen, and medical-grade materials, thereby eliminating waste. Over the past decade, initiatives led by Iceland's Ocean Cluster, with contributions from Denmark (DTU), have demonstrated how all parts of the fish can be valorized. For example, fish heads are dried and exported (to be used for African delicacies), bones are converted into health supplements, collagen is extracted from tails and fins for use in beverages and wound healing, and fish skin is repurposed for medical or textile applications. Other innovations include the use of fish liver for fish oil, roe for consumption, and fish innards for medicinal purposes. Denmark is now collaborating with African countries through the Technical University of Denmark (DTU) to implement the "100% fish".

Figure 21. Overview of the 100% Fish concept, unlocking the full potential of all parts and components of the catch.

The Green Biorefinery, Protein Extraction from Grass: The Green Biorefinery concept, which involves the valorization of grass as a protein resource, represents a significant step toward sustainable agriculture. The process begins with the mechanical screw drive pressing of grass to separate protein-rich juice from fiber-rich pulp. Soluble proteins are then precipitated from the juice and used as animal feed or food ingredients. This process has been developed in collaboration with Danish universities [52] and scaled, commercially pioneered by Vestjyllands Andel (https://www.vja.dk/). Further advancements are, e.g. conversion of hemicellulose in the pulp into the prebiotic xylan-oligosaccharides (XOS) and sold as a higher value f¨eed additive [2]. Utilizing not just the protein but also the hemicellulose fibers have been shown to enhance the commercial viability of the Green Grass Biorefinery, while offering gut-health-promoting effects, inherently opening for reduced need for antibiotics. Grass valorization not only reduces the need for imported soy-based protein-rich animal feed but also decreases greenhouse gas emissions by promoting local, sustainable feed production, to substitute for long-distance imported products. Another benefit of switching fra cereal to grass ist hat grass roots in temepate climate are active year round, hereby reducing agricultural field run-off, with excess of nutrients, polluting rivers, lakes and shallow parts of the sea.

Fungal Fermentation for Sustainable Food Production: Fungal fermentation offers a promising solution for, converting agricultural residues or side-streams into healthy and climate friendly food.

The fungal species chosen could be e.g. the edible fungi, *Fusarium venenatum* (ascomycete), or *Pleurotus ostreatus* (basidiomycete). The Danish Start-Up company MATR-Food (https://matrfoods.com/our-story/), grows fungal mycelium on e.g. oat, peas, lupin seed, red beets and potato, hereby producing plant- and fungal-based burgers or minced. The mycelium of the fungal fermentation gives a chewing-texture, much the same as animal meat and not the least the fungal mycelium gives the burger the umami-delicious taste. Another start-up in Denmark, making plant and fungi-based food is Tempty. Using fungal mycelium gives plant-based food an umami deliciousness, making more people choose climate-friendly food, as it both tastes good and feels good, in being more climate and biodiversity friendly than meat. This innovation supports the transition to more sustainable diets by offering environmentally friendly alternatives to conventional meat products. Globally, fungal fermentation could play a key role in addressing food security by providing nutritious, dietary fibers and protein-rich, sustainable and umami delicious alternatives to meat also in regions with limited agricultural resources. It is an area with high potential also for improved rural livelihood.

Fungal Mycelium for Sustainable Building Materials Fungal mycelium has also been explored, scaled and commercialized as a key component in the production of eco-friendly building materials. By growing fungal mycelium on fiber-rich residues, such as cereal straw, pea or rape-straw, hemp or saw dust. The enzymes produced by the mycelium of wood-degrading fungi (e.g. species of the basidiomycete *Ganoderma*), open-up the recalcitrant plant fibers. By this enzymatic, fiber-degrading process the fungal mycelium and the fiber-rich plant residues are together converted into a composite plant- and fungal mycelium-based building material. Such “Nature Boards” are primarily used in door e.g. for improved acoustics or for isolation (Naturpladen, https://www.naturpladen.dk/. These nature boards can also be customized for beauty, by using colorful fungal species, making them attractive for both functional and decorative purposes. Fungal- and residue-based building materials offer a sustainable alternative to conventional insulation and acoustic panels, reducing the need for synthetic and inorganic-resource demanding materials and hereby lowering carbon footprints in construction. Also in Global South such building materials, produced by plant- fibers and fungal mycelium could valorize local resources for making also building materials.

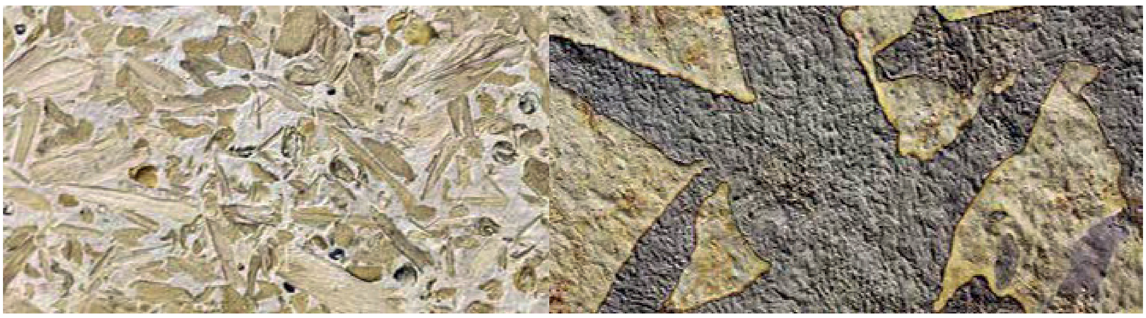

Figure 22. Circular and biobased building materials, produced by growing fungal mycelium on fiber-rich residues, such as cereal straw, pea- or rape-straw, hemp or saw dust. For acustics and beautification (Courtecy of Naturpladen, Denmark, Jon Strunge, CEO, founder & owner).

CONCLUDING REMARKS AND FUTURE PERSPECTIVES

The feedstock valorizations described in this study, with contributions from scientists from five different continents, send a clear and compelling message: Valorization of diverse biomass resources through bioprocessing, previously underutilized, downgraded or wasted, is not just a possibility for a distant future -it is a reality. Information about such technologies, as well as the skills, expertise and competence are accessible or even available for building a more biobased society are present in all continents and in many countries. These efforts go beyond the production of bioenergy (biogas or biofuel) from agricultural residues. There is a growing interest in unlocking the full potential of the huge volumes of biomass; producing also higher value products, e.g. health promoting food; and using only the residuals for bioenergy production.

Given the urgency of global challenges, we need to give full attention and priority to international collaboration and knowledge sharing. There is no time for slow, incremental progress. We do not have the time for slow organic growth, where too many countries and regions have to start from scratch, valorizing the almost 50% of all harvested and produced. Climate change is already impacting agricultural food production threatening food security. More food and feed produced, to ensure food security under climate change challenged agriculture; for nutrition and health. Mitigating climate change demands immediate reduction in greenhouse emissions, including those from agricultural production of food and feed. Simultaneously, stopping biodiversity loss by giving more space to nature and significantly reducing use of artificial fertilizer and chemical pesticides, by substituting both by biobased solutions. Moreover, advancements in public health, including promotion of gut health through improved circular and biobased food and feed. This can be realized by leveraging bioprocessing technologies to valorize fiber-rich biomass that is currently underutilized; being available, accessible and affordable substrates.

In conclusion: There is a pressing need for rapid implementation of improved biomass utilization strategies to upgrade resources that are currently wasted or underexploited. Accelerating the development of skills, technologies, policies, and infrastructure is critical, and this requires extensive knowledge sharing and collaboration at local, national, regional, and international levels. It can be expressed mathematically. If each and every part of the world have to invent most or a big part from scratch, progress is too slow to meet the demand for solutions and improvements now. The inherent complexity of biological systems, the challenges of scaling bioprocessing technologies, and the region-specific availability of feedstocks necessitate a collaborative and systematic approach to knowledge sharing and collaboration.

RECOMMENDATIONS

TO ADDRESS THESE CHALLENGES, WE PROPOSE THE FOLLOWING STEPS:

- Give high priority to national, regional and international dedicated bioeconomy collaboration and knowledge-sharing within circular and biobased technologies and products. Position it as an important and integrated part of the global and local food security, climate change mitigation, protection of biodiversity and One Health agenda.

- Develop an online platform database, where advancements in feedstock valorization technologies can be systematically curated and presented. Accessible to researchers, innovative entrepreneurs, being local farmer-cooperatives, innovative local Start-Ups or industries and to politicians and decision makers, developing visions and strategies and action plans for development of their countries. Such circular and biobased platform-initiative could possibly be hosted and maintained by global organizations such as the International Advisory Council on Global Bioeconomy, the World Bioeconomy Association. The authors of this paper are committed to contributing all the information presented here, gathere¨d from five continents, as a starting point for this new circular and biobased bioeconomy knowledge hub. The platform could include case studies, best practices, and open-access tools for researchers, industries, and policymakers, fostering both local and international collaboration to accelerate the adoption of biomass valorization technologies.

- Establish a new “Bioeconomy & Biosolution, PhD & Supervisor Network”. Hereby enabling PhD students, from different countries and different continents, to work together with

PhDs from other countries. PhDs are young scientists, energetic, highly motivated and working at least full time and very focused on their project. Further, all PhDs have experienced and knowledgeable supervisors. Engaging the supervisors within this PhD Network, gives access to experienced guidance and frontier knowledge. Optimally, in such a "PhD Feedstock Valorization" program the experimental research should be conducted in regions, where feedstock-valorization is most urgently needed; hereby opening for improved local rural, coastal and urban livelihood.

DECLARATIONS

Author Contribution declaration, for each of the 9 Sections in the maniúscript

1. Introduction, Lene Lange, Denmark
2. Joseph Bentil, Ghana
3. Karoli N Njau, Tanzania
4. Warinthorn Songkasiri
5. Roberta Pereira Espinheira and Ayla Sant'Ana da Silva, Brazil
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