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FEASIBILITY STUDY ON THE USE OF SUSTAINABLE AVIATION FUELS

ICAO-EUROPEAN UNION ASSISTANCE PROJECT: CAPACITY BUILDING FOR CO_2 MITIGATION FROM INTERNATIONAL AVIATION

Author: Dr. Christoph Weber, LL.M.
Technical Consultant / Sustainable Aviation Fuels

Project funded by the European Union
EuropeAid/Development Cooperation Instrument
DCI-ENV/2013/322-049

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EXECUTIVE SUMMARY

The International Civil Aviation Organization (ICAO) is a United Nations specialized agency working together with its 191 Member States and industry groups to reach consensus on international civil aviation Standards and Recommended Practices (SARPs) and policies in support of a safe, efficient, secure, economically sustainable and environmentally responsible international civil aviation sector.

In its efforts to help reduce carbon dioxide emissions, the International Civil Aviation Organization has developed partnerships with international organizations and states to develop assistance projects and promote a basket of measures designed to support Member States as they work to achieve the global aspirational goals. These goals, adopted by the 37th Session of the Assembly in 2010, seek to improve fuel efficiency by 2 per cent per year from 2020 and to keep net carbon dioxide emissions at the same levels (i.e. carbon neutral growth from 2020).

The 39th Session of the ICAO Assembly, held from 27 September to 7 October 2016, adopted Resolution A39-2: Consolidated statement of continuing ICAO policies and practices related to environmental protection — Climate change, which reflects the determination of ICAO's Member States to provide continuous leadership in the efforts of the international civil aviation sector to limit or reduce its emissions that contribute to global climate change.The 39th Session of the ICAO Assembly also reiterated the global aspirational goals for the international aviation sector adopted in 2010.

A central element of Resolution A39-2 is for States to voluntarily prepare and submit Action Plans on CO_2 emissions reductions activities for international aviation to ICAO. It also lays out an ambitious work programme for capacity building and assistance to States in the development and implementation of their State Action Plans to reduce emissions. ICAO State Action Plans provide an opportunity for States to showcase policies and actions and are intended to be individualized and reflect the specific national circumstances of each ICAO Member State and the opportunities available to them in implementing measures to mitigate CO_2 emissions from international aviation activities.[1] As of November 2018, 111 Member States, representing 92.3 per cent of global RTK had voluntarily submitted their action plan to ICAO, including Burkina Faso.

The ICAO-European Union (EU) assistance project on Capacity Building for CO_2 Mitigation from International Aviation aims to support the 14 selected Member States in Africa and the Caribbean in their efforts to develop and implement their State Action Plans; improve their aviation environmental systems; and identify, evaluate and implement mitigation measures in the selected States. Burkina Faso is among the beneficiary States of this project.

To contribute to the achievement of the ICAO global aspirational goals for the international aviation sector, Burkina Faso has defined an Action Plan for CO_2 Emissions Reduction (APER), wherein one promising measure that has been identified is the development and use of sustainable aviation fuels (SAF), that can reduce life-cycle CO_2 emissions compared to current aviation fuel.

Sustainability is a crucial element in the development of SAF, such that during their production and use, the fuels do not produce negative environmental or social impacts, and should deliver a reduction in carbon emissions (greenhouse gases).

The close interaction of global climate policy and national mitigation measures is an important driver for the production and gradual implementation of SAF.

Political incentives, enabling policies, new international regulatory frameworks and ambitious efforts aimed at reducing aviation emissions provide a basis for the implementation of a SAF supply chain.

[1] ICAO has prepared ICAO Doc 9988, Guidance on the Development of States' Action Plans on CO_2 Emissions Reduction Activities to describe the process of developing or updating an action plan.

Following years of promotion, engine tests and demonstration flight programmes, SAF has become a key element in reducing the environmental impact of international civil aviation. Independent of the underlying SAF production pathway, industries are currently working on developing optimal processes that utilize sustainable feedstocks and that can be produced economically. The ever-increasing number of available SAF conversion technologies expands the range of potentially suitable feedstock sources.

Over the course of the last decade multiple initiatives engaging in the cultivation of various feedstocks and the production of SAF have been established. The scale and scope of these initiatives range from small-scale trial plantations, to full-scale farmer mobilization exercises covering tens of thousands of hectares.

In sub-Saharan Africa climate change has had a significant impact on the region. Given the substantial challenges to addressing climate change, and that the available resources to do so are limited, successful adaptation to the adverse impacts of climate change will require careful planning and the involvement of all national stakeholders, from the government, to local communities. It will also require adequate assistance from the international community to support the States' efforts in this regard. While Africa provides ample opportunities for the domestic production of biomass-based biofuels, experience has already shown that the production of biofuels can potentially have adverse socio-economic and environmental impacts. With reference to commercial scale initiatives in Mozambique, Madagascar, Rwanda, Tanzania and Burkina Faso, low yields, unsolved economic viability gaps, underestimated labour costs and other unintended consequences ultimately resulted in value chain disruptions, lay-offs, abandoned plantations and costly project failure. The early abandonment and collapse of these projects has had negative consequences for local rural communities, due to loss of land tenure, access to natural resources and missed income opportunities.

Bearing the potential risks in mind, there is now a real need for reframing this sector to identify and utilize suitable biomass resources in a responsible and sustainable way.

Considering the economic, social, environmental and strategic interests at stake, this reframing requires a solid evaluation of the underlying assumptions and key supply chain parameters, as well as the societal and environmental impacts. This cannot be done without taking the specific regional context into account. As circumstances for project implementation differ with location, agro-climatic conditions and stakeholders involved, a timely and pragmatic prioritization may therefore prove particularly valuable, thus safeguarding capital, trust and reputation. This puts the focus on sorting, categorizing and eventually rating the major underlying assumptions.

The portfolio of available international reference cases and aviation biofuel initiatives and the rise and fall of the jatropha industry serve as a reminder of the risks involved; recent history particularly offers valuable insight into the challenges, obstacles and pitfalls that need to be closely monitored, constantly adjusted and professionally mastered along the way.

In the end, the close collaboration among stakeholders from the aviation industry, the oil-refining industry, government, biofuel companies, agricultural organizations, and academia is required to meet environmental objectives and properly balance costs and risks.

On the other side of the supply chain, innovative fuel conversion technology solutions come with their own set of challenges. However, it is outside the scope of this study to analyse the details of all chemical, biological and thermal routes (either in use or under development) that lead to the conversion of a specific type of biomass to SAF. While an increasing number of conversion technologies qualify to produce SAF, it is more likely that some parameters early on in the value chain will constitute the key limiting factors. In particular, feedstock type, price and availability are some of the most important parameters when considering the commercial feasibility of alternative aviation fuel projects.

In addition to feedstock productivity, the production cost of SAF ultimately depends on synergistic efforts in all areas, including labour cost, extraction yield, process energy conservation, and balance between jet fuel product and value-added co-products.

As there are still many challenges to overcome and solve, this feasibility study aims to provide a decision tree for the implementation of feedstock and SAF production in Burkina Faso. It categorizes the major stumbling blocks such as biogenic resources, biomass supply, infrastructure, political framework, investment-risk, social challenges, greenhouse gas (GHG) mitigation, sustainability assessment, and provides guidelines, benchmarks and decision support for government agencies, policy makers and project developers.

Evaluating each step of the decision tree and applying a rating scale will enable the development of an "SAF Implementation-Index"; this index may serve as a tool for governments and authorities to:

a) identify the right action items;
b) prioritize implementation measures; and
c) define a conducive policy framework under a given set of agro-climatic and ecological circumstances in a specific region.

Lessons learnt from unsuccessful biofuel projects in sub-Saharan Africa and elsewhere should provide additional practical guidance for bioenergy feedstock production and bioenergy policy design in Burkina Faso, including the need for:

a) a cautious approach before authorizing the cultivation of any new bioenergy feedstock; and
b) prioritized research of the specific bioenergy potential of plants and crops indigenous to Burkina Faso.

A diversified, home grown, and renewable feedstock-based fuel system is crucial in the country's strategy to:

a) achieve energy security;
b) replace a significant portion of aviation fuel required to meet commercial demand;
c) facilitate compliance with environmental regulation and aspirational goals; and
d) increase environmental stewardship.

This study provides an analysis of the implementation of a SAF supply chain, as well as a break down and prioritization of the key parameters and deliverables that will facilitate the successful implementation of priority mitigation measures and the definition of an appropriate policy framework for SAF in Burkina Faso. Above all, this study intends to raise awareness in order to mobilize financial and industrial support, as well as vital political support from the Burkinabe authorities.

Summarizing the key results, the major domestic biomass resources suitable for conversion into SAF include:

- tropical grasses, such as elephant grass;
- agricultural residues (sorghum);
- high yielding oil bearing crops, such as improved jatropha accessions;
- municipal solid waste (MSW);

- cashew and shea nutshell oil; and
- waste animal fats (tallow)

Cashew and shea nutshells represent a Burkinabe specialty. As by-products with no assigned value, decent quantities of feedstock are available for processing and energy conversion with immediate effect.

The cumulative energetic potential of available domestic feedstock sources exceeds the country's oil imports by at least nine times and could easily outweigh Burkina Faso's annual fossil fuel imports.
The wide range of potential raw materials available in Burkina Faso entails an equally diverse range of matching fuel processing solutions to produce SAF.

Arguably, the largest potential for alternative fuels is routed in the Fischer-Tropsch hydroprocessed synthesized paraffinic kerosene (FT-SPK) process which relies on low-cost lignocellulosic feedstock that can be derived from waste or from dedicated energy crops.

Regarding the gasification/FT pathway, further research and development (R&D) could potentially enable modular, small-scale reactors that can convert bio-derived synthesis gas into SAF.

For the time being, the nonexistence of a basic petrochemical or refining infrastructure does not seem to permit an autonomous aviation fuel production capacity in Burkina Faso. Infrastructural and logistical constraints, however, do not exclude the interim export of feedstock and conversion into SAF at overseas processing facilities.

Indeed, Burkina Faso is well positioned to initially focus on feedstock production and biomass processing (e.g. transesterification) which requires less capital-intensive infrastructural facilities.

While any domestically produced alternative transport fuels, such as biodiesel from animal waste fats, jatropha or cashew nutshell liquid (CNSL) cannot replace SAF, they nevertheless can help to raise awareness and attract investors, and thus, represent viable and pragmatic first steps towards the gradual implementation of a future SAF value chain.

Resulting fatty acid methyl ester (FAME) biodiesel-blends could be used, for example, by the ground support handling agency of Ouagadougou Airport which operates the truck and trailer fleet of diesel powered ground support equipment (GSE).

The results and recommendations could be used as a scalable and widely replicable model in sub-Saharan Africa. Ideally, they can help pave the way for neighbouring States to follow the Burkinabe example and create a regional movement towards environmentally conscious development in the future, that is at the same time economically sound and socially acceptable.

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ABBREVIATIONS AND ACRONYMS

AfDB - African Development Bank
AES - Aviation Environmental Systems
AFTF - Alternative Fuels Task Force
ANADEB - Agence Nationale pour le Développement des Biocarburants (National Agency for the Promotion of Biofuels)
ANEREE - Agence Nationale des Energies Renouvelables et de l'Efficacité Energétique (National Agency for Renewable Energies and Energy Efficiency)
ANAC - Agence Nationale de l'Aviation Civile
ANOC - African National Oil Corporation
APROJER - Association pour la Promotion du Jatropha et des Énergies Renouvelables (Association for the Promotion of Jatropha and Renewable Energies)
AtJ - Alcohol-to-Jet
ASTM - American Society for Testing and Materials
ATM - Air Transport Management
APER - Action Plan for CO_2 Emissions Reduction
AU - African Union
BMZ - German Federal Ministry for Economic Cooperation and Development
Boe - Barrel of oil equivalent
Bpd - Barrel per day
CAAFI - Commercial Aviation Alternative Fuels Initiative
CAEP - ICAO Committee on Aviation Environmental Protection
CAAF/1 - First Conference on Aviation and Alternative Fuels
CAAF/2 - Second Conference on Aviation and Alternative Fuels
CCD - UN Convention to Combat Desertification
CCO - Coordination & Cooperation Office
CE - Conseil de l'Entente
CEN-SAD - Community of Sahelo-Saharan States
CHP - Combined heat and power plant
CICAFIB - Comité interministériel chargé de la coordination des activités de développement des filières biocarburants (Interministerial Committee for the coordination of the domestic biofuel sector)
CIF-FIP - Climate Investment Funds' Forest Investment Program
CIRAD - Centre de coopération Internationale en Recherche Agronomique pour le Développement (Agricultural Research Centre for International Development)
CJO - Crude jatropha oil
CNRST - Centre national de la recherche scientifique et technologique (National Research Centre for Science and Technology)
CNS - Communication, navigation and surveillance
CNSL - Cashew Nut Shell Liquid
CO_2eq - Carbon dioxide equivalent
CORSIA - Carbon Offsetting and Reduction Scheme for International Aviation
CPP - Programme National de Partenariat pour la Gestion Durable des Terres (National Partnership Program for Sustainable Land Management)
CTFT - Centre Technique Forestier Tropical
Def Stan - UK Defence Standard 91-091, Issue 09 (Turbine Fuel, Aviation Kerosene Type, JET A-1)
DDO - Distillate diesel oil
DLR - German Aerospace Center
DOA - US Department of Agriculture
DOD - US Department of Defense
DOE - US Department of Energy
DSCH - Direct sugars-to-hydrocarbon
ECOWAS - Economic Community of West African States
EE - Energy efficiency
EIF - Environmental Intervention Fund
EFPRA - European Fat Processors and Renderers Association
ESTs - Environmentally sound technologies
EU - European Union
EUEI - European Union Energy Initiative
FAME - Fatty acid methyl ester
FAO - Food and Agriculture Organization of the United Nations
FCFA - Franc de la Communauté Financière d'Afrique
FIP - Programme d'Investissement Forestier (Forest Investment Program)
FRL - Fuel Readiness Level
FSRL - Feedstock Readiness Level
FT - Fischer-Tropsch
GCF - Governors' Climate and Forest Task Force
GGGI - Global Green Growth Institute
GHG - Greenhouse gas
GJ - Gigajoule
GPC - Cotton producer groups
GWS - Genomic wide selection
H - Hydrogen
Ha - Hectares
HEFA - Hydrogenated Esters and Fatty Acids
HRJ - Hydro-treated renewable jet fuel
HVO - Heavy fuel oil
ICAO - The International Civil Aviation Organization
IEO - Project Implementation & Execution Office

ILUC - Indirect land use change
INERA - Institut Nationale de l'Environnement et de Recherches Agricoles (Environmental Institute for Agricultural Research)
IFSET - ICAO Fuel Savings Estimation Tool
IPS - Industrial Promotion Services
IRAM - Institut de Recherches et d'Applications des Méthodes de Développement (Research and Development Institute)
IRSAT - Institut de Recherche en Sciences Appliquées et Technologies (Research Institute for Applied Science and Technology)
ISFL - BioCarbon Fund Initiative for Sustainable Forest Landscapes
JMI - Jatropha Mali Initiative
Kg - Kilogram
Km2 - Square kilometres
LAE - Laboratory for Aviation and the Environment
LCA - Life-cycle assessment
LFO - Light Fuel Oil
LICs - Low-income African countries
MBMs - Market-based measures
MICs - Middle-income African countries
MIT - Massachusetts Institute of Technology
MJ - Megajoule
Mt - Megatonne
MW - Megawatts
MRV - Measurement, reporting, and verification
MSW - Municipal solid waste
N-P-K - Nitrogen-Phosphorous-Potassium
NSC - National Steering Committee
OECD - Organization for Economic Co-operation and Development
PNDES - Plan National de Développement Économique et Social
PPM - Parts per million
PPO - Pure Plant Oil
PPP - Public-private partnership
RACGAE - Regie Administrative Chargee de la Gestion de l'Assistance en Escale
RE - Renewable energy
REM - REDD Early Movers Programme
REDD+ - Reducing Emissions from Deforestation and Degradation
REEEP - Renewable Energy and Energy Efficiency Partnership
ROPPA - Réseau des organisations paysannes et des producteurs agricoles (Network of farmers' organizations and agricultural producers)
RTK - Revenue Tonne Kilometres
SAF - Sustainable aviation fuels
SARPs - Standards and Recommended Practices
SCADD - Stratégie de Croissance Accélérée et de Développement Durable (Poverty Reduction Strategy)
SDGs - Sustainable Development Goals (United Nations)
SDR - Rural Development Strategy
SEFA - Sustainable Energy Fund for Africa
SIP - Synthetic iso-paraffins
SIP-HFS - Synthesized iso-paraffins produced from hydroprocessed fermented sugars
SN-Sosuco - Nouvelle Société Sucrière de la Comoé
SP/CONEDD - Secrétariat Permanent du Conseil National pour l'Environnement et le Développement Durable (National Council for Sustainable Development)
(National Council for Environment and Sustainable Development)
T - Tons
T1 - Technology level #1
T2 - Technology level #2
TSE - Treated sewage effluents
UEMOA - West African Economic and Monetary Union
UNAPROFIJA - Union Nationale pour la Promotion de la filière Jatropha Curcas (National Union for the promotion of the Jatropha value chain)
UNDP - United Nations Development Programme
UNEP - United Nations Environment Programme
UNPA - Union National des Producteurs d'Anacarde
UNFCCC - United Nations Framework Convention on Climate Change
UN-REDD - United Nations Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries
VCS - Verified Carbon Standard
WASCAL - West African Science Service Center on Climate Change and Adapted Land Use

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1. INTRODUCTION

International aviation emissions currently account for 1.3 per cent of total global anthropogenic CO_2 emissions, and this is projected to increase as a result of the continued growth of air transport. ICAO and its Member States recognize the critical importance of providing continuous leadership in order to limit or reduce the aviation emissions that contribute to global climate change. The ICAO 39th Assembly reiterated the global aspirational goals for the international aviation sector of improving fuel efficiency by 2 per cent per annum and keeping the net carbon emissions from 2020 onward at the same level, as established at the 37th Assembly in 2010. The Assembly also recognized the work being undertaken to explore a long-term global aspirational goal for international aviation in light of the 2°C and 1.5°C temperature goals of the Paris Agreement and more ambitious goals are needed to deliver a sustainable path for aviation as the aspirational goal of 2 per cent annual fuel efficiency improvement is unlikely to deliver the level of reduction necessary to stabilize and then reduce aviation's emissions contribution to climate change.

To achieve international aviation's global aspirational goals, as shown in **Figure 1** below, a comprehensive approach is necessary, consisting of a basket of measures including technology and standards, SAF, operational improvements and market-based measures (MBMs) to reduce emissions.

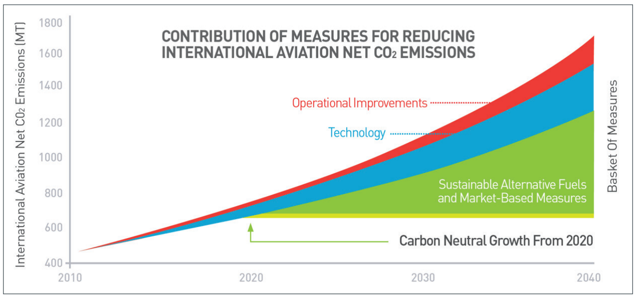


FIGURE 1

Contribution of measures for reducing international aviation net CO_2 emissions

Source: ICAO Environment: GFAAF - Aviation Alternative Fuel Live Feed. Retrieved from https://www.icao.int/environmental-protection/GFAAF/Pages/default.aspx

Mitigating the release of CO_2 emissions into the atmosphere is the main incentive for promoting the use and deployment of SAFs in aviation. CO_2 is emitted from the combustion of SAFs; however, this carbon came from plants and then will be absorbed by newly-growing plants in a closed loop. Since that CO_2 is re-absorbed, SAF provides an environmental benefit over the full product life-cycle, as compared to the production and combustion of conventional jet fuel. Depending on the SAF pathway, SAF can provide up to an 80 per cent reduction in emissions compared to conventional jet fuel.

Beyond CO_2 emissions reductions, there could also be additional benefits, such as promoting new domestic industries and production systems, improving the competitiveness of the aviation and tourism sectors in the State over the long-term, and improving the local air quality by decreasing the particulate matter (PM)[2] emitted by aircraft[3].

With the interconnection between energy and sustainable development, bioenergy[3] is a prime example of how energy can link with other areas, including water quality and availability, ecosystems, public health, food security, and education and livelihoods, and can harness multiple benefits, insofar as the development is properly planned and managed. Through the use of alternative fuels for transportation and bioelectricity, the development of sustainable and modern bioenergy can be promoted both on a small-scale for local use in stand-alone applications or micro-grids, as well as on a large-scale for production and commoditization of bioenergy. At the same time, modern bioenergy can replace inefficient and less sustainable bioenergy systems[4].

1.1 ICAO AND ENVIRONMENT

ICAO is a UN specialized agency, established by States in 1944 to manage the administration and governance of the Convention on International Civil Aviation (Chicago Convention).

ICAO works with the Convention's 191 Member States and industry groups to reach consensus on international civil aviation SARPs and policies in support of a safe, efficient, secure, economically sustainable and environmentally responsible civil aviation sector. These SARPs and policies are used by ICAO Member States to ensure that their local civil aviation operations and regulations conform to global norms, which in turn permits more than 100,000 daily flights in aviation's global network to operate safely and reliably in every region of the world[5].

The 39th Session of the ICAO Assembly reiterated the global aspirational goals for the international aviation sector of improving fuel efficiency by 2 per cent per annum and keeping the net carbon emissions from 2020 at the same level, as established at the 37th Assembly in 2010, and recognized the work being undertaken to explore a long-term global aspirational goal for international aviation in light of the 2°C and 1.5°C temperature goals of the Paris Agreement.

The 39th Assembly also recognized that the aspirational goal of 2 per cent annual fuel efficiency improvement is unlikely to deliver the level of reduction necessary to stabilize and then reduce aviation's absolute emissions contribution to climate

[2] At the engine exhaust, particulate emissions mainly consist of ultrafine soot or black carbon emissions. Ultrafine particulate matter (PM) emissions are known to adversely impact both health and climate (ICAO. Environmental Report: Aviation and Climate Change. Retrieved from https://www.icao.int/environmental-protection/Documents/ICAO%20Environmental%20Report%202016.pdf

[3] S. Christie, 2016. Emissions report and database of systems key performance parameters. s.l.: D4.9 ITAKA project. [3] Bioenergy refers to the energetic use out of a material of biological origin, such as biomass or biofuels.

[4] Nogueira, L. et al., 2015. Sustainable development and Innovation. In: Bioenergy & Sustainability: Bridging the Gaps. Paris: Cedex, pp. 184-217.

[5] ICAO: About ICAO. Retrieved from http://www.icao.int/about-icao/Pages/default.aspx

change, and that goals of more ambition are needed to deliver a sustainable path for aviation. To achieve international aviation's global aspirational goals, a comprehensive approach, consisting of a basket of measures has been identified, namely:

- Aircraft-related technology development – purchase of new aircraft and new equipment to retrofit existing aircraft with more fuel-efficient technology.
- Alternative fuels – investments in the development and deployment of aviation alternative fuels.
- Improved air traffic management and infrastructure use – improved use of communication, navigation and surveillance/air transport management (CNS/ATM) to reduce fuel burn.
- MBMs – researching and building awareness of low cost MBMs to reducing emissions such as emission trading, levies, and offsetting.

All of these measures, in addition to contributing to carbon neutral growth, advance the social and economic development associated with the UN Sustainable Development Goals (SDGs).

ICAO launched a voluntary programme inviting States to develop a State Action Plan on CO_2 emissions reduction from international aviation incorporating the above mitigation measures through its implementation. This programme encourages States to report their CO_2 mitigation activities to ICAO and promotes improved communication on environmental matters within the aviation industry. SAF was identified as an important mitigation measure to help States achieve ICAO's aspirational goals including carbon neutral growth[6]. The specific focus of SAF is on "drop-in fuels", which are fuels fully compatible with fuel certification requirements, existing fuel transport, distribution and storing infrastructure, as well as current aircraft engines. They are handled in exactly the same way as current aviation fuel. ICAO is actively engaged in activities to promote and facilitate the emergence of drop-in SAF by exchanging and disseminating information, fostering dialogue among States and stakeholders, and carrying out dedicated work as requested by ICAO Member States to inform decision-making[7].

ICAO also provides support to Member States in their efforts to improve the environmental performance of aviation. ICAO has developed a "range of Standards and Recommended Practices (SARPs), policies and guidance material for the application of integrated measures"[8] to achieve the following three main objectives adopted by ICAO in 2004:

a) limit or reduce the number of people affected by significant aircraft noise;
b) limit or reduce the impact of aviation emissions on local air quality; and
c) limit or reduce the impact of aviation greenhouse gas emissions on the global climate.

The ICAO Committee on Aviation Environmental Protection (CAEP), a technical committee of the ICAO Council, is undertaking most of this work, assisting the ICAO Council in formulating new policies and adopting new SARPs related to aircraft noise and emissions, and more generally to aviation environmental impact[9]. This technical committee is constituted by 24 Member States and 16 Observers from States and international organizations representing the environmental interests of the aviation sector.

In addition ICAO has developed tools and guidance material to assist Member States address emissions from international aviation[10], including:

i. ICAO Doc 9988, Guidance on the Development of States' Action Plans on CO_2 Emissions Reduction Activities - Includes step-by-step guidance on the baseline scenario calculation, the basket of mitigation measures and the quantification of selected measures.
ii. Environmental Benefits Tool - Provides a framework to automate the calculation of the baseline CO_2 emissions from international aviation, and the estimation of expected results obtained through the implementation of mitigation measures selected from ICAO's basket of measures.
iii. ICAO Carbon Emissions Calculator - Allows States to estimate the CO_2 emissions attributed to air travel, using only a limited amount of input information.
iv. ICAO Fuel Savings Estimation Tool (IFSET) - Can be used to estimate fuel savings obtained through operational measures in a manner consistent with approved models.
v. ICAO Green Meetings Calculator - Can be used to support decision-making in selecting meeting location with minimum CO_2 footprint from air travel.
vi. Action Plan on Emissions Reduction (APER) website - Interactive website reserved to States' action plan focal points to assist them prepare and submit their Action Plans to ICAO.
vii. Aviation Environmental Systems (AES) - An efficient CO_2 emissions monitoring system for international aviation, developed in each beneficiary State of the ICAO-EU assistance project.

1.2 ICAO – EUROPEAN UNION (EU) PROJECT: CAPACITY BUILDING FOR CO2 MITIGATION FROM INTERNATIONAL AVIATION

On 17 December 2013, ICAO and the EU signed an agreement to implement the Capacity Building for CO_2 Mitigation from International Aviation assistance project. This project aimed to assist 14 selected States in Africa and the Caribbean to reduce CO_2 emissions from the aviation sector. Burkina Faso is among the beneficiary States of this assistance project.

[6] For more information on ICAO's Aspirational Goals, refer to http://www.icao.int/annual-report-2013/Pages/progress-on-icaos-strategic-objectives-strategic-objective-c1-environmental-protection-global-aspirational-goals.aspx
[7] ICAO Environment: Alternative Fuels: Questions and Answers. Retrieved from http://www.icao.int/environmental-protection/Pages/AltFuel-IcaoAction.aspx
[8] ICAO Environment: Environmental Protection. Retrieved from http://www.icao.int/environmental-protection/Pages/default.aspx
[9] ICAO Environment: Committee on Aviation Environmental Protection (CAEP). Retrieved from http://www.icao.int/ENVIRONMENTAL-PROTECTION/Pages/CAEP.aspx
[10] ICAO Environment: Retrieved from http://www.icao.int/environmental-protection/Pages/default.aspx

The ICAO-EU *Capacity Building for CO_2 Mitigation from International Aviation* assistance project, is a four-year programme to support 14 selected Member States in Africa and the Caribbean. It offers guidance, resources to prepare feasibility studies, and access to financial resources through partnerships with interested parties in support of the implementation of mitigation measures described in their Action Plans. The overarching objective is to contribute to the mitigation of CO_2 emissions from international aviation by implementing capacity building activities that will support the development of low carbon air transport and environmental sustainability. The ICAO-EU assistance project focuses on the following three areas of activity:

a) improve capacity of the national civil aviation authorities to develop their Action Plan on CO_2 emissions reduction from international aviation;
b) develop an efficient CO_2 emissions monitoring system for international aviation in each selected Member State; and
c) identify, evaluate, and partly implement priority mitigation measures, specifically those measures included within the States' Action Plans that can be replicated by other States.

The model can be replicated and adapted to additional countries, creating a global system of cooperation to take action to reduce CO_2 emissions.

1.3 AVIATION FUEL METHODOLOGY AND ICAO MANDATE

The 38th Session of the ICAO Assembly in 2013 recognized the many actions that ICAO Member States have undertaken and intend to take in support of the achievement of the global aspirational goals, including the development and deployment of SAF, and encouraged further such efforts.

The Assembly also requested states to recognize existing approaches to assess the sustainability of all alternative fuels in general, including those for use in aviation which should:

a) achieve net GHG emissions reduction on a life cycle basis;
b) respect the areas of high importance for biodiversity, conservation and benefits for people from ecosystems, in accordance with international and national regulations; and
c) contribute to local social and economic development, and competition with food and water should be avoided.

An alternative fuel is not necessarily sustainable. In order for an alternative fuel to be considered a sustainable, it will need to meet sustainability requirements. ICAO is currently developing sustainability criteria as part of the work on the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA).

The first generation of alternative fuels, generally referred to as "biofuels", are produced from biogenic sources, such as crops, which can be subject to additional sustainability concerns beyond carbon reduction (e.g. competition with food and water, land-use changes). However, current technology allows the production of fuels from non-biogenic sources, such as municipal wastes, used cooking oil, and agricultural residues, which raise fewer sustainability issues. This diversification of feedstocks facilitates the production of SAF with less dependence on specific natural resources, allowing the establishment of SAF industries in a variety of States, including developing and developed countries. It can also allow the production of SAF closer to airports, which will reduce costs associated with fuel transportation. This flexibility is expected to help the scale-up of SAF production.

The Assembly also requested the ICAO Council to "adopt measures to ensure the sustainability of alternative fuels for aviation, building on existing approaches or combination of approaches, and monitor, at a national level, the sustainability of the production of alternative fuels for aviation".

To fulfil these Assembly requests, in 2013 the ICAO CAEP established an expert group, the Alternative Fuels Task Force (AFTF), to provide technical input regarding the replacement of current aviation fuel with SAF. During the CAEP/10 cycle (2013 to 2016), AFTF was tasked with providing information related to alternative fuels for inclusion in the ICAO environmental trends projections. This involved the definition of a methodology for assessing fuels' life cycle emissions, and projections of scenarios for alternative fuel production up to 2050, with the final objective of assessing the possible range of emissions reductions from the use of aviation alternative fuels). The final results of this analysis were presented during the 39th Session of the ICAO Assembly in 2016.

In addition, the CAEP has ongoing work in regard to calculating the land-use change emissions attributable to alternative fuels developed from various feedstocks, calculating their default life cycle emissions values, developing guidance on potential policies, and developing a set of sustainability criteria that alternative fuels must meet in order to be considered sustainable by ICAO. These sustainability criteria are currently under consideration by ICAO.

In October 2017, ICAO convened its second Conference on Aviation and Alternative Fuels (CAAF/2) in Mexico City, Mexico. Building on the first such ICAO Conference (CAAF/1) held in 2009, the CAAF/2 agreed to a Declaration, endorsing the 2050 ICAO Vision for Sustainable Aviation Fuels as a living inspirational path and calling on States, industry and other stakeholders, for a significant proportion of aviation fuel to be substituted with SAF by 2050, and for international civil aviation to reduce carbon emissions significantly while pursuing all opportunities in the basket of mitigation measures to reduce emissions as necessary. The Conference further agreed that the Vision would be reviewed periodically through a stocktaking process, and elaborated at the next Conference on Aviation and Alternative Fuels, to be held no later than 2025.

1.4 DEFINING THE CHALLENGE

Burning 1 kilogram (kg) of jet fuel generates around 3.16 kg of CO_2, the most abundant GHG. Since the beginning of industrialization, the atmospheric concentration of CO_2 has increased from 280 parts per million (ppm) in 1850 to around 400 ppm in 2015[11]. Today, aviation generates around 2.5 per cent of energy use-related CO_2 emissions. The aviation industry produces just about 800 million tonnes of carbon dioxide equivalents (CO_2eq), and is responsible for about 12 per cent of global transport emissions[12].

Burkina Faso's, and more generally Africa's global share of emissions, is low. Based on all international flights to and from Burkina Faso, the country only contributes 0.02 per cent of international civil aviation CO_2 emissions. Taken together, the whole African continent is responsible for less than 4 per cent of all aviation associated emissions[13]. However, mitigating climate change is neither a question of national responsibility nor causality or liability. Millions of people are already at risk of severe weather conditions (heat waves, droughts, erratic flooding) and food insecurity, without infrastructure protection. The hazards of climate change are taking a heavy toll on lives and livelihoods in Burkina Faso, in that aspects of daily economic and agricultural life are significantly affected. Should living conditions, poverty-related vulnerability and environmental integrity further deteriorate because of accelerated climate change, this may also negatively affect large-scale migration flows. The impact of climate change as a driver of human migration in the near future is expected by many to dwarf all others. Currently, the largest migration corridor within sub-Saharan Africa stretches from Burkina Faso to Côte d'Ivoire. Migration to Europe for economic reasons is increasing rapidly.

In view of the severe consequences of climate change, which are real and pervasive in Burkina Faso, urgent action is required. It is therefore necessary to identify effective measures and policies that can contribute to the reduction of GHG emissions. No matter how small individual mitigation measures may appear in a global context, all efforts that serve to reduce or avoid GHG emissions are valid contributions, whether they are undertaken for the purposes of environmental protection, food security, sustainable development, green growth or carbon neutral growth of international aviation. Taking account of local conditions and limitations in Burkina Faso, the cultivation of energy crops and the production of biofuels present an effective opportunity to actively address the negative consequences of climate change, while implementing accompanying measures that may halt, if not reverse, the process of soil degradation, desertification and deforestation. In this regard, ICAO's aspirational goal of carbon neutral growth from 2020, which is at the core of the rationale for CORSIA, offers an opportunity for Burkina Faso to prioritize and implement effective mitigation measures.

SAF can and will play a critical role in reducing air transport CO_2 emissions. The anticipated continuous strong growth in air transportation demand of around 5 per cent per year over the next decades cannot be compensated by fuel efficiency improvements alone. Technological and operational advances cannot reduce aviation emissions enough to meet ICAO's target of carbon neutral growth. Independent of technology, flight path and infrastructure improvements, there is still no alternative to the gradual introduction of SAF if the environmental impact of aviation is to be reduced over time. Thus, the single largest opportunity to decarbonize air travel is to replace aviation fuel with SAF. ICAO's findings indicate that before factoring in the contribution of carbon offsets, the bulk of the emissions reductions needed for international aviation would have to come from a transition to SAF. ICAO Resolution A39-3 affirms the preference for the use of alternative fuels that provide environmental benefits over market-based measures.

During the second Conference on Aviation and Alternative Fuels (CAAF/2) held in Mexico City in October 2017, ICAO sought an explicit mandate to develop and implement a mechanism to guarantee a smooth transition from the use of global MBMs to the use of SAF as a means to ensure the long-term feasibility of the aspirational goal of keeping the global net CO_2 emissions from international aviation from 2020 at the same level.

However, SAF commercialization is still at an early stage, due to a variety of economic and market challenges. The challenges of developing an effective fuel are significant, as critical aviation fuel requirements are not met by traditional biofuels such as biodiesel and bioethanol. In addition to technical certification standards, the availability of suitable feedstock or biomass at the right location, for the right price and in the right volume poses an additional challenge.

1.5 FOCUS ON FEEDSTOCK

Alternative fuels generally refer to drop-in fuels derived from feedstock sources that can replace aviation fuel without the need to modify aircraft engines or the fuel distribution infrastructure. As a result, alternative fuels have become a key element in the aviation industry's strategy to reduce environmental impacts.

To comply with the industry guidelines and legal requirements, aviation stakeholders including governments, researchers, biofuel companies, agricultural organizations, academia and the oil-refining industry have been teaming up to develop alternative technology solutions that can produce alternative fuels with lower GHG emissions.

Primarily, alternative fuels must meet international physical and chemical specifications (for example ASTM and Def Stan) in order to potentially be a drop-in replacement for the current

[11] Martin Kaltschmitt/ Ulf Neuling (ed.), Biokerosene, Status and Prospects, Hamburg 2018; Christopher J. Chuck (ed.), Biofuels for Aviation, Feedstocks, Technology and Implementation, 2016; International Renewable Energy Agency (IRENA), BIOFUELS FOR AVIATION - TECHNOLOGY BRIEF, Jan. 2017

[12] Cf. ICAO, Onboard a Sustainable Future, ICAO ENVIRONMENTAL REPORT 2016, Aviation and Climate Change, Chapter 4, p.97-176.

[13] Cf. for example Scott Fields, Continental Divide: Why Africa's Climate Change Burden Is Greater, Environmental Health Perspectives 2005 Aug; 113(8): A534–A537

aviation fuel. While overall commercial viability remains a major concern for large-scale deployment and commercialization, the ability of the aviation sector to meet SAF production and GHG reduction targets ultimately depends on the amount of sustainable feedstock that will be available for the sector. The availability of feedstock is one of the main cost drivers and one of the most significant hurdles to be overcome in the scale-up of SAF production. Feedstock availability and cost are crucial for the feasibility and economic viability of every biomass processing activity, irrespective of the final product. Representing one of the largest cost components in the production of SAF, feedstock supply is further compounded by the fact that there are competing uses for biomass e.g. heat, electricity and chemicals. Each feedstock has benefits and drawbacks in terms of costs, availability, yields, etc.

Before engaging in any discussion about SAF production, available and suitable feedstock resources will have to be thoroughly explored and identified. Evaluating feedstock potential and developing aviation fuels cannot be considered in isolation. It is not a stand-alone operation, but rather an integral component of a more complex, multifaceted process that also includes socio-economic, climatic and political components. This applies all the more to developing countries like Burkina Faso, where challenges related to food security, poverty alleviation, rural economic development, population growth, desertification, soil degradation and severe climate constraints need to be addressed simultaneously in order to win social acceptance, stimulate public commitment and mobilize critical domestic support. The more positive side effects and co-benefits that can be associated to the development of a SAF value chain, the better the chances of successful implementation. As a result of this interdependence, a feasibility study will necessarily have to include agronomic, economic, social and ecological aspects.

Therefore, sustainable policy guidelines and successful bioenergy project implementation call for an integrated strategy. To better reflect local conditions in Burkina Faso, such a strategy will require a balance between the interests of the aviation industry, the increasing demand for energy and the need for food security and food production.

Burkina Faso has enormous potential in terms of biomass suitable for the production of biofuels. A range of different feedstocks can be identified. Some are based on oil crops and other non-food feedstock, while others are based on waste sources such as cashew nutshells, MSW and animal fats. In this study, the major biomass resources available for fuel production in Burkina Faso are highlighted, including geographical distribution and key challenges in delivering minimum quantities of biomass. All types of regionally appropriate feedstocks are included, provided that the feedstock has the potential to be:

- delivered at requisite quantity, quality, and cost for existent or emerging conversion platforms; and
- converted to drop-in aviation alternative fuels while concurrently providing environmental and social benefits.

The empirical data in this report was largely obtained during extensive field trips in April, May and November 2017 through key informant interviews with farmers, agronomists, village chiefs, government representatives and local stakeholders.

The assessment of any feedstock is not restricted to its identification and compliance with basic environmental requirements. It also includes the evaluation of potential yields, input requirements, logistics and a first quantitative analysis. The quantification of alternative fuels is influenced by a large variety of factors such as land availability and quality, land tenure, climatic conditions, available infrastructure, logistics, storage facilities, competitive uses and existing demands for other established purposes (e.g. food and feed production), as well as the development of local, regional, national and international markets.

While individual sources of biomass may, prima facie, appear to be suitable, an estimation of the true potential will require an integrated understanding of the entire supply chain. Chances are that constraints on infrastructure, mechanization, storage and transportation may hamper or even prevent the establishment of a functional supply chain capable of utilizing locally available sources of biomass. Instead of aiming directly for ambitious SAF production, identified constraints may rather suggest a phased approach, allowing for the gradual implementation of a supply chain that can initially also include rural electrification and biodiesel options as tangible first steps towards future SAF production.

To better reflect the prevailing domestic conditions of a home grown renewable feedstock base, a high-level quantification will differentiate between (a) biomass that is theoretically available if conditions are met and (b) biomass that is already usable. Any delta will indicate the additional potential of future biomass sources.

1.6 FEEDSTOCK CLASSIFICATION

The feedstocks identified in Burkina Faso are separated into four main groups according to the nature of the compounds that can be used for energy recovery and fuel production:

I. Sucrose/starch (sugarcane, sweet sorghum);
II. Lignocellulosic biomass (agricultural residues, forestry wood residues, energy crops and tropical grasses);
III. Wastes (MSW, animal fat); and
IV. Oil-bearing feedstocks (cotton, jatropha, other native trees);

Fuels produced from lignocellulosic biomass and agricultural waste feedstocks generally provide the highest emission reductions on a life cycle basis[14]. Additionally, there is potential to boost food production simultaneously with fuel production. This is because as food production expands to meet the nutritional needs of the country, there is also increased production of agricultural residues which largely remain unutilized. Typically, for every tonne of crop produced, a certain amount of residue is available in the field after harvest. With efficient collection systems in place, waste from agricultural production can be utilized as fuel for power, heat and alternative fuel production. However, the conversion of agricultural residues may be hampered by the need to maintain soil fertility and as feed for animals in the dry season. Thus, in some cases, only a fraction can be collected without undue adverse impacts on the environment, in particular, soil quality, or on existing or competitive uses.

Dedicated energy crops and tropical grasses, like elephant grass, have significant potential to produce cellulosic material when grown on marginal lands not appropriate for traditional agriculture production, with low carbon stocks and low biodiversity, which can be converted with minimal environmental costs.

In addition to classic oil-bearing crops, wastes can also play an important role in expanding the portfolio of potential SAF feedstocks. Wastes, such as MSW or animal fats are a convenient alternative source for SAF because the benefits are two-fold: they do not compete with food production for land or other resources, and their use can avoid or decrease the cost and impact of their disposal into the environment. In addition, wastes are typically point sourced so there is no requirement to develop a dedicated feedstock collection and production infrastructure. However, wastes are heterogeneous material; the cost of separation and processing are normally high and there may be environmental legislation constraints that must be addressed.

1.7 DOMESTIC BIOMASS POTENTIAL

As the result of a thorough exploration and identification of feedstock resources summarized in **Figure 2** below, the major existing biomass resources in Burkina Faso include, inter alia:

- biomass for ethanol production (sweet sorghum, sugarcane, etc.);
- agricultural residues (corn stover, rice straw and husks, bagasse, etc.); and
- woody biomass residues from forest plantations.

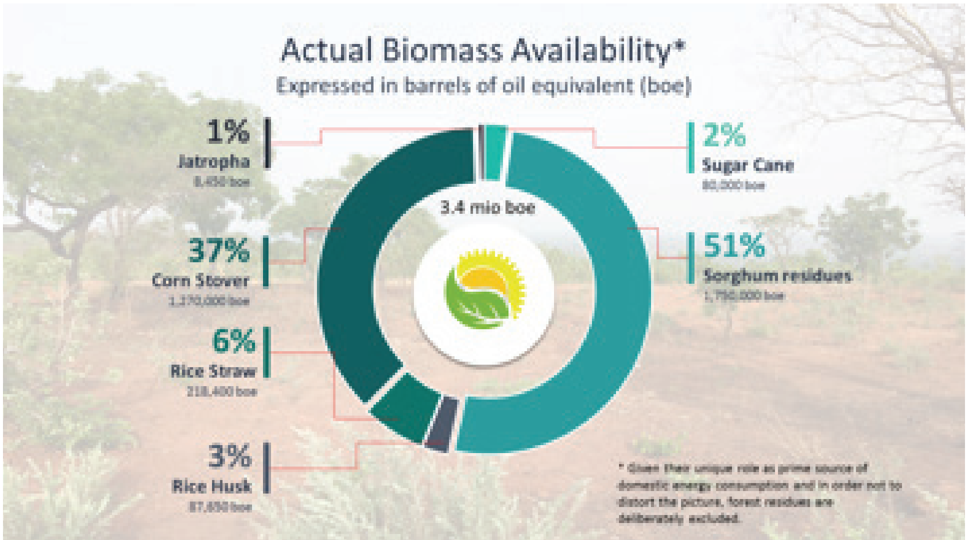


FIGURE 2
Actual Biomass Availability in Burkina Faso
Source: Author

In addition, and as highlighted in **Figure 3** below, the major future biomass resources suitable for conversion into SAF may be identified among:

- tropical grasses, such as elephant grass;
- high yielding oil bearing crops, such as improved jatropha accessions;
- MSW and sewage;
- cashew and shea nutshell oil; and
- waste animal fats (tallow).

[14] Cf. Laboratory for Aviation and the Environment (LAE), Massachusetts Institute of Technology (MIT), Seamus J. Bann, A Stochastic Techno-Economic Comparison of Alternative Jet Fuel Production Pathways, June 2017; Patricia Thornley et al. Maximizing the greenhouse gas reductions from biomass: The role of life cycle assessment, Biomass and Bioenergy, Volume 81, October 2015, Pages 35-43; Jitendra Kumar Saini et al., Lignocellulosic agriculture wastes as biomass feedstocks for second-generation bioethanol production: concepts and recent developments, 3 Biotech. 2015 Aug; 5(4): 337–353.

FIGURE 3

Potential Biomass Availability in Burkina Faso

Source: Author

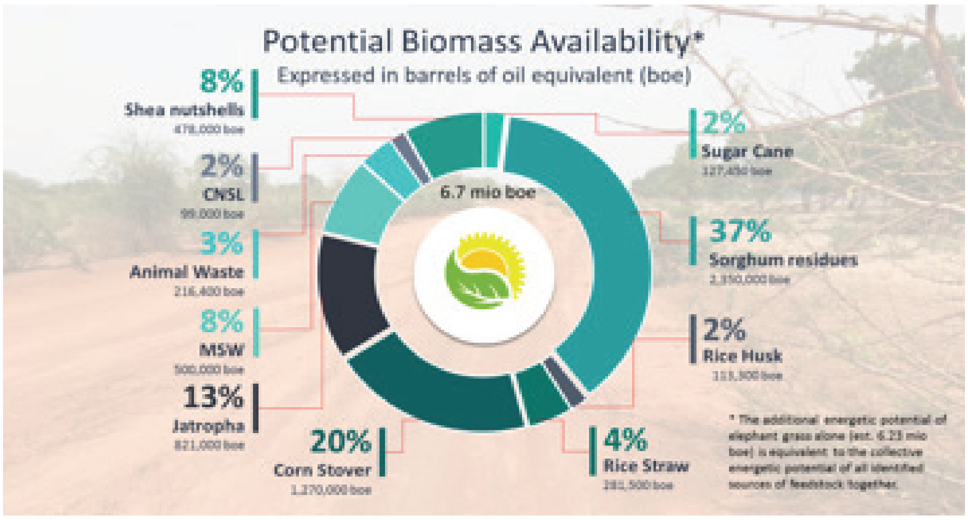


Table 1 below provides an inventory of the various types of biomass that qualify as energy source for the conversion into liquid fuels in general and SAF in particular. The focus of this summary overview has deliberately been restricted to a high-level synopsis of select parameters. In order to enhance the informative value of this synopsis, the main emphasis is put on the comparison of calculated energetic values. The specific calorific value of fuel, measured in Megajoule per kilogram (MJ/kg) is the quantity of energy (heat) produced during combustion of a unit mass of fuel, at constant pressure and under "normal" (standard) conditions (i.e. 0oC and under a pressure of 1.013 mbar). It forms the basis for determining the performance of an energy system.

TABLE 1

Biomass inventory

	Production/ Harvest area		Production volume	Energetic values		
				Specific calorific value (MJ/kg)	Gigajoule (GJ)	Barrel of oil equivalent (boe)
Sugarcane	5 000 ha		500 000 tonnes → 35 000 tonnes sugar → 15 800 tonnes ethanol	29.6 (ethanol)	468 000	80 000
Potential	8 000 ha		800 000 tonnes → 25 300 tonnes ethanol	29.6 (ethanol)	747 000	127 450
Sorghum	1 620 000 ha		1 730 000 tonnes grains 3 460 000 tonnes residues			
Markdown	• Competing use as fodder • Logistics constraints	-30% -20%	→ 1 730 000 tonnes residues → 347 000 tonnes ethanol	29.6 (ethanol)	10^7	1 750 000
Potential	Yield increase [plant breeding] [cultivar selection]	+30%	→ 2 249 000 tonnes residues → 451 100 tonnes ethanol	29.6 (ethanol)	1.3 x 10^7	2 350 000
Rice	172 000 ha		270 000 tonnes			
Rice Husk	172 000 ha		68 500 tonnes			
Markdown	Combustion & steam production	-50%	→ 34 250 tonnes	15	514 000	87 650
Potential	• Yield increase • Sourou valley expansion		+ 10 000 tonnes → 44 250 tonnes	15	664 000	113 300
Rice Straw	172 000 ha		205 500 tonnes			
Markdown	• Competing use as fodder • Logistics constraints	-25% -25%	→ 102 250 tonnes	12.5	1 280 000	218,400
Potential	• Yield increase • Sourou valley expansion		+ 30 000 tonnes → 132 250 tonnes	12.5	1 650 000	281 500
Corn/Maize	790 000 ha		1 500 000 tonnes → 1 286 000 tonnes corn stover	16.5		
Markdown	• Fertilizer & soil enrichment • Logistics constraints	-50% -15%	→ 450 000 tonnes corn stover	16.5	7 425 000	1 270 000
Forest Residues	5 500 000 ha		10 000 000 tonnes	20.0	(2 x 10^8)	(34,000,000)
Markdown	Competing use (fuelwood)	-100%	→ 0.0	20.0	0	0
Elephant Grass	0 ha		0 tonnes	14.6	0	0
Potential	≥ 250 000 ha		5 000 000 tonnes	14.6	(7.3 x 10^7)	(12 450 000)
Markdown	• Logistics and infrastructure constraints • Conversion inefficiencies	-25% -25%	→ 2 500 000 tonnes	14.6	3.6 x 10^7	6 225 000
MSW	--		580 ,000 tonnes	6 – 20 Ø 10		
Markdown	• Collection inefficiencies • Pre-treatment, separation	-25% -25%	→ 270 000 tonnes	Ø 10	2 900 000	500 000
Animal Waste Fat	--		9 000 tonnes	40	360 000	61 400
Potential	--		+ 22 700 tonnes → 31 700 tonnes	40	1 268 000	216 400
Cotton Seed	330 000 ha		116 000 tonnes oil	41.5	4 800 000	821 000
Markdown	• Competing use (food)	-100%	→ 0	41.5	0	0
Jatropha	3 000 – 8 000 ha		≤ 5 000 tonnes seeds → 1 200 tonnes oil (CJO)	40	48 000	8 450
Potential	• 100 000 ha • Selective plant breeding • Introduction of high yielding hybrids		400 000 tonnes seeds → 120 000 tonnes oil (CJO)	40	4 800 000	821 000
Cashew Nutshells	90 000 ha		50 000 tonnes → 35 000 tonnes shells	19 – 22	700 000	120 000
Potential	• + 100% within 5 years • Value chain optimization		→ 70 000 tonnes shells → 14 000 tonnes CNSL	19 – 22 39 - 42	1 400 000 580 000	240 000 99 000
Shea Nuts	6 500 000 ha		450 – 600 000 tonnes nuts			
Potential	• Value chain optimization		→ ≥ 150 000 tonnes nut shell pellets	18.7	2 800 000	478 000

To ensure better comparability and to allow inter-fuel comparison in a common energy unit, the *barrel of oil equivalent* (boe) has been chosen as a joint unit of energy and as the common denominator for all feedstocks. Depending on the characteristics of the individual feedstock, multiple conversion ratios may apply to arrive at the computed results (see overview and synopsis of energy conversion ratios in **Table 2**). Further details on scientific derivations, product specification, average yields and underlying conversion ratios will be dealt with in the specific feedstock sections.

Calorific value and energy content - conversion ratios					
Kilojoules (kj)	**Megajoules (MJ/kg)**	**Gigajoules (GJ/kg)**	**Kilocalories (kcal)**	**Kilowatt hours (kWh)**	**Barrels of oil equivalent (boe)**
1.000	1	0.001	239	0.28	17×10^{-4}
10^6	1,000	1	238,846	278	0.1706
4.184	4.18	0.00418	1,000	1.16	71×10^{-4}
3.600	3.6	0.0036	860	1	61×10^{-4}
5.861.520	5,861	5.861	1,400,000	1,628.2	1
$3,6 \times 10^6$	3,600	3.6	859,845	1,000	0.614

TABLE 2
Synopsis of underlying energy conversion ratios

1.8 FUEL CONVERSION PROCESSES

Aviation fuels are produced by taking a given feedstock and converting it via industrial processes into a fuel. From a technical perspective and with regard to fuel characteristics, aviation's focus is on so-called "drop-in" fuels, a substitute for current aviation fuel that is completely interchangeable and compatible with current aviation fuel. A drop-in fuel does not require adaptation of the aircraft/ engine fuel system or the fuel distribution network, and can be used "as is" on currently flying turbine-powered aircraft in pure/neat form and/or blended in any amount with other drop-in neat, drop-in blend, or current aviation fuels[15]. In recent years, significant technical progress has been made towards the transformation of biomass into drop-in fuels and the commercialization of sustainable aviation fuels.

As of November 2017, five alternative fuel production conversion processes were certified under the standard ASTM D7566, together with specific blending limits with current aviation fuel (as shown in **Table 3** below).

Annex	Conversion Process	Abbreviation	Possible Feedstocks	Blending ratio by Volume	Commercialization Proposals
1	Fischer-Tropsch hydroprocessed synthesized paraffinic kerosene	FT-SPK	Coal, natural gas, biomass	50%	Fulcrum Bioenergy, Red Rock Biofuels, SG Preston, Kaidi, Sasol, Shell, Syntroleum
2	Synthesized paraffinic kerosene produced from hydroprocessed esters and fatty acids	HEFA-SPK	Bio-oils, animal fat, recycled oils	50%	AltAir Fuels, Honeywell UOP, Neste Oil, Dynamic Fuels, EERC
3	Synthesized iso-paraffins produced from hydroprocessed fermented sugars	SIP-HFS	Biomass used for sugar production	10%	Amyris, Total
4	Synthesized kerosene with aromatics derived by alkylation of light aromatics from non-petroleum sources	SPK/A	Coal, natural gas, biomass	50%	Sasol
5	Alcohol-to-jet synthetic paraffinic kerosene	ATJ-SPK	Biomass used for starch and sugar production and cellulosic biomass for isobutanol production	30%	Gevo, Cobalt, Honeywell UOP, Lanzatech, Swedish Biofuels, Byogy

TABLE 3
Conversion processes approved as annexes to ASTM D7566

[15] Cf. CAAF/2-WP/03 available to download from: https://www.icao.int/Meetings/CAAF2/Documents/CAAF.2.WP.003.1.en.pdf

Thousands of commercial flights have already used “drop-in” aviation alternative fuels and, as of November 2017, four airports have been distributing alternative fuels on a regular basis. Many additional conversion processes are being developed and are at various stages within the ASTM approval process. In order to identify and evaluate the potential and viability of any given combination between a specific source of domestic biomass and a proven technological conversion pathway, a *Feasibility Matrix* of select evaluation criteria illustrated opportunities and major constraints with regard to the maturity of a potential domestic feedstock supply chain as well as the feasibility of the entire supply chain, including available technology options (at the end of each feedstock section). While unfeasible options are sorted out, remaining pathway scenarios for Burkina Faso are prioritized based on the most feasible candidates of feedstock and potentially matching conversion technologies. Evaluation criteria against which the feasibility of any pathway scenario can be gauged include, inter alia, feedstock readiness and availability (including both, current and potential future biomass production volume), transportation distances, storage and logistics, fertilizer and water requirements, market readiness and market pricing, maturity and complexity of conversion technology as well as available strategic and financial support.

Technology readiness differentiates between two technology levels. Technology level 1 (T1) relates to biomass processing and includes basic feedstock processing facilities, pre-treatment activities, feedstock to fuel conversion and oil expelling. In comparison, technology level 2 (T2) refers to advanced fuel processing facilities and relevant fuel conversion pathways, including, inter alia, refining, hydrotreatment and crude fractionation.

Given the low level of agricultural mechanization in Burkina Faso, the installation of technology solutions at the first level (T1) is a major challenge before alternative fuel conversion scenarios can be considered.

The above parameters somewhat resemble the Fuel Readiness Level (FRL) and the Feedstock Readiness Level (FSRL) guidance tools developed by the Commercial Aviation Alternative Fuels Initiative (CAAFI) to communicate technical development and progress from laboratory to commercial use. It is outside the scope of this study to analyse the ultimate economic viability of any specific feedstock/conversion pathway pairing, as this will depend on a variety of factors and a large set of heterogeneous parameters that are continuously in flux and require in-depth investigation. In addition, reliable data is limited and cannot simply be extrapolated as long as technologies are still in the demonstration or pre-commercial stage. However, where relevant and to the extent possible, pragmatic pairing suggestions will be made that best reflect the portfolio of parameters found.

In general, vegetable oils and fats require less processing than the other feedstocks (lignocellulose, sugar, and starch) because the molecules of triglycerides and fatty acids are more similar to the final hydrocarbons in jet fuel. Sugar and starch need to be fermented into intermediate products, and lignocellulose feedstocks require additional steps because they must be hydrolysed to simple sugars, or turned into intermediate syngas or bio-oil. MSW requires the highest processing because of the nature of the feedstock and the complexity of processing involved. Ethanol production from crops containing sugar is a mainstream technology, and has been employed in States such as Brazil for decades.

2. COUNTRY-SPECIFIC PRODUCTION PARAMETERS

2.1 GEOGRAPHY

FIGURE 4
Burkina Faso, a landlocked country in the Sahel region of Africa

Burkina Faso is a landlocked country in West Africa with a surface area of 274,000 km2. Located between the Sahara Desert to the north and coastal rainforests to the south, Burkina Faso shares its borders with six States, namely Ghana, Togo and Benin to the south, Côte d'Ivoire to the west, Mali to the North and Niger to the East. Three river basins drain the country: the Volta basin (63 per cent of the total area), the Niger basin (30 per cent), and the Comoé basin (7 per cent). Located in the heart of West Africa at about one hour thirty minutes flying distance from capital cities of neighbouring States, Burkina Faso offers an ideal regional base to reach out to the Economic Community of West African States (ECOWAS). This regional economic union of 15 countries located in West Africa occupies an area of about 5,300,000 km² which represents one-fifth of the African continent. The ECOWAS population is estimated at 350 million with at least 65 per cent of its population living in rural areas. The vegetation of the sub-region makes subsistence agriculture the dominant preoccupation.

2.2 TRADE AND GOVERNMENT

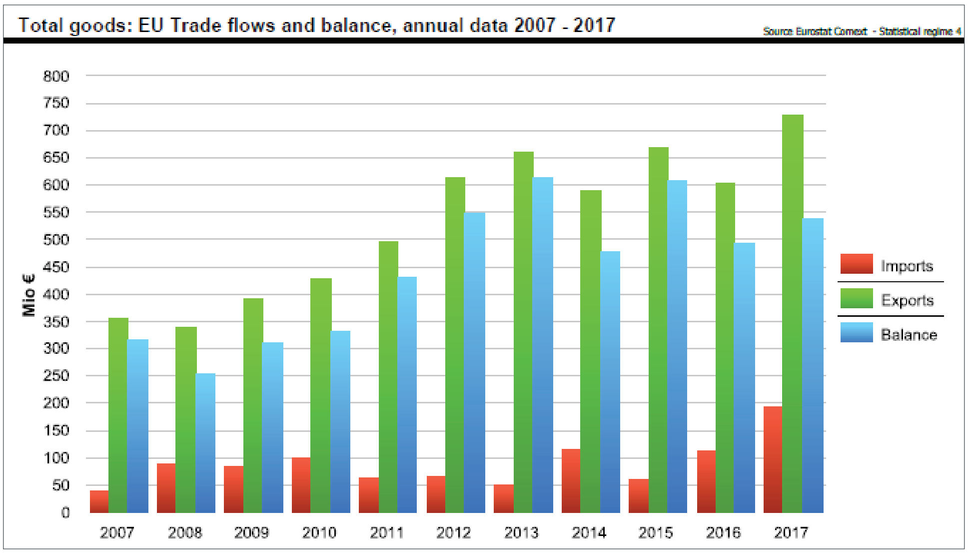
Based on statistics from the International Monetary Fund's World Economic Outlook Database, Burkina Faso's total Gross Domestic Product amounted to USD 33 billion in 2016 (on a purchasing power parity basis). Exports accounted for about 7.6 per cent of total Burkinabe economic output. Main trading partners are China, France and Côte d'Ivoire (imports) and Switzerland, Singapore and Côte d'Ivoire (exports). The single largest export destination of Burkina Faso is Switzerland with an export value of roughly USD 2 billion which represents 59 per cent of all exports and reveals the staggering rise of the country's gold trade. The single biggest trading block partner is the EU, with a total trade value of USD 810 million (€711 million) in 2016. 85 per cent of all exports from Burkina Faso to the EU are dominated by mineral products (gold) and vegetable products (cotton).

The economy of Burkina Faso experienced high levels of growth over the last few years and the country has seen an upswing in gold exploration, production, and exports. Economic growth is expected to reach 5.9 per cent in 2017 due to the recovery of mining. Urban growth rate has increased in the past decade and the urban population could reach 35 per cent of the total by 2026, but towns and cities are still poorly equipped to sustainably manage this growth.

FIGURE 5

European Union, Trade with Burkina Faso

Source: EU Commission, Directorate General for Trade



Burkina Faso's administrative organization is structured around 13 regions, 45 provinces and 351 communes, including 302 rural communes and 49 urban communes.

At the regional and sub-regional levels, Burkina Faso participates in efforts to consolidate the existing major geopolitical and geo-economic groupings, namely the African Union (AU), ECOWAS, the Western African Economic and Monetary Union (UEMOA), the Conseil de l'Entente (CE) and the Community of Sahelo-Saharan States (CEN-SAD).

In July 2016, Burkina Faso adopted its national economic and social development plan, *Plan National de Développement Économique et Social* (PNDES), as the main instrument defining the strategic guidelines for economic and social development for the period 2016-20. The PNDES identifies strategic objectives and implementation measures to support growth and resilience, and improve, inter alia, economic and environmental governance effectiveness.

2.3 DEMOGRAPHICS

Burkina Faso ranges amongst the fastest growing countries in the world with an annual population growth rate of more than 3 per cent. Since the year 2000, the population grew by about 65 per cent. As of today (September 2017), the country counts a population of 19.4 million, and given the underlying growth rate, the population is projected to double by 2040. This will put severe pressure on natural resources and on public and social services. This demographic trend has particularly negative consequences for food security since the country's arable land is limited and agricultural productivity is still on a comparatively low level. To compensate for the low productivity, agricultural areas are expanding quickly.

The agricultural population makes up 16 million people, representing slightly more than 80 per cent of the total population.

Only about a third of the population is literate and unemployment is widespread. Burkina Faso has a young age structure, the result of declining mortality combined with steady high birth rates. More than 65 per cent of the population is under the age of 25. 47 per cent of the population is under 15 years of age.

Migration has traditionally been a way of life for Burkinabe, with seasonal migration being replaced by stints of up to two years abroad. Under French colonization, Burkina Faso became a main labour source for agricultural and factory work in Cote d'Ivoire. Despite its food shortages and high poverty rate[16], Burkina Faso has become a destination for refugees in recent years.

2.4 CLIMATE/SOIL

With an average altitude of 400 m, Burkina Faso enjoys a Sudano-Sahelian dry tropical climate with two contrasting seasons: a short rainy season from late May to October and a long dry season from November to May. Length and intensity of the distinct seasons vary and are increasingly unpredictable.

On average, the annual rainfall ranges from less than 300 mm in the North to more than 1 200 mm in the South. The climate is characterized by a North-South moisture gradient and mainly influenced by the interaction between the West African monsoon system bringing rainfalls from the Southwest during the rainy season and the north-easterly Harmattan winds blowing hot air and dust from the Sahara during the dry season. The monsoonal rainfall is a key element of the regional climate, especially in the semiarid Sahel, where vegetation is highly sensitive to precipitation variability.

On the basis of its annual average distribution of rainfall, the country can be divided into three eco-climatic zones: (1) the Sahelian zone in the north, which experiences rainfall of less than 600 mm over a period of three to four months; (2) the Sudano-Sahelian zone on the Mossi Plateau, where the total annual rainfall ranges from 600 to 900 mm during four to five months of the year; and (3) the southern, more humid Sudanian zone, where the annual average rainfall is more than 1 000 mm and occurs over a period of five to six months of the year (see **Figure 6**). Over the last decades, the 600 mm and 900 mm isohyets have migrated more than 200 km to the south, a sign of desertification. The former 1 400 mm isohyets in the south of the country have totally disappeared (see **Figure 7**).

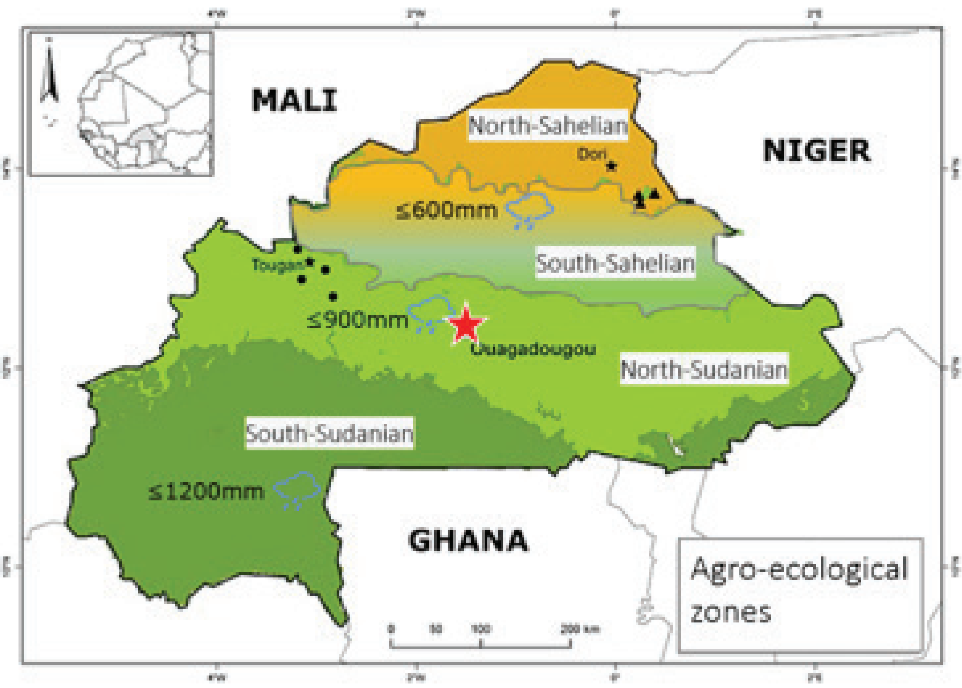
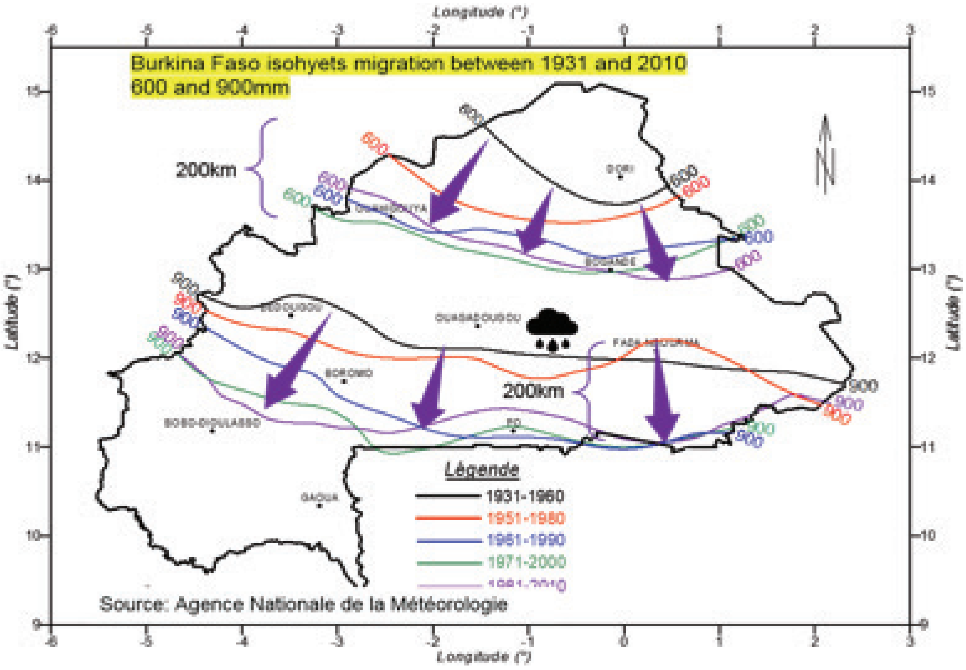


FIGURE 6
Agro-ecological zones

[16] CAs of 2014, more than 40 per cent of the population in all parts of the country lived below the poverty line on less than 153,530 FCFA (i.e. USD 260 per year) or USD 2 per day. Despite an estimated GDP per capita of around USD 660 for 2017 and sustained economic growth of +/- 6 per cent in recent years Burkina Faso is ranking No. 185 out of 188 countries on the 2011 United Nations Development Programme (UNDP) Human Development Index (HDI), which is lower than the average for countries within the same category in sub-Saharan Africa.

FIGURE 7
Isohyet migration patterns

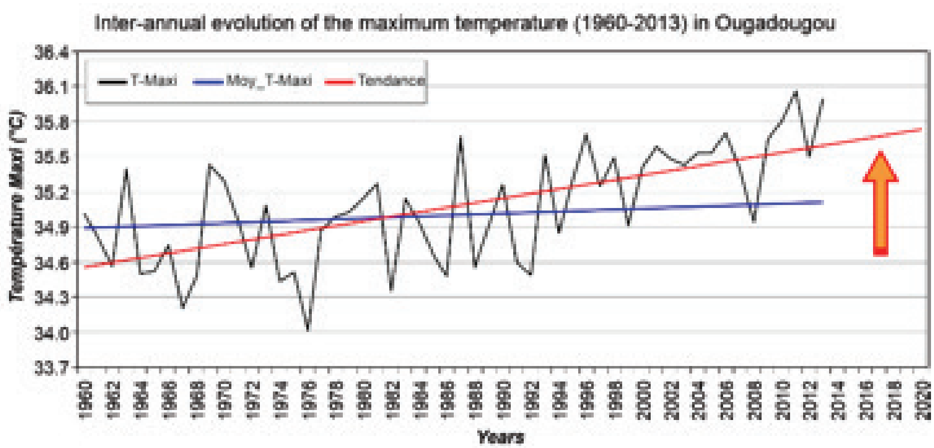


Consistent with the eco-climatic zones, several types of vegetation can be observed from north to south: shrubland steppe and tiger bush *(brousse tigrée)* in the north, shrub savannah and annual grasses *(Piliostigma reticulatum, Guiera senegalensis, Acacia seyal, Acacia radiana, Balanites aegyptiaca)* in the centre, and savannah trees *(Khaya senegalensis/"Dryzone Mahagoni", Tamarindus indica, Lanea microcarpa, Parkia Biglobosa, Butyrospermum parkii, Adansonia digitate/"Baobab", Vitellaria paradoxa/"Shea butter tree" and Pterocarpus)* and perennial grasses *(Andropogongayanus, Cymbopogon/"lemongrass")* in the south and southwest. The southern part of the country is located in the West Sudanian savannah; its natural vegetation is characterized by a denser deciduous shrubland and woodland and is known for its high agricultural potential. Comparatively fertile, non-cultivated arable land with limited market access represents potential areas of expansion only if transportation infrastructure is in place.

In the southwest of Burkina Faso, especially around the city of Banfora, plantations of fruit trees such as mango and citrus fruits as well as nut trees (e.g. cashew and shea nuts) are cultivated. In recent years, these plantation products experienced a considerable rise in production and export value. The length of the growing season varies from less than 60 days in the north to 160 days in the south, with large inter-annual variations.

Observations since 1902 indicate that the country's dry region has expanded southwards over the 20th century. During the same period, average monthly temperatures have increased. The mean monthly temperatures range between 24°C and 36°C. Highs in April and May can reach 43°C and more. Since the 1970s, the country has experienced frequent droughts and a gradual increase in average temperatures (see Figure 8 on the inter-annual evolution of the maximum temperature in Ouagadougou).

FIGURE 8
Steady rise in temperatures in Ouagadougou



In addition, all parts of the country have experienced an increase in the frequency and magnitude of extreme weather events, such as flash flooding during the rainy season, and a general decline in rainfall, making life more difficult for the majority of farmers, as there is little access to irrigated water supplies.

PICTURE 1
Water scarcity affects food security

Burkina Faso is repeatedly facing water scarcity and recurrent food crises, directly disrupting the livelihoods of local communities and thousands of farmers.

Climate variability is already a major constraint on food security, health, environment, and poverty reduction due to the high dependence on the primary agricultural sector, which contributes roughly 30 per cent of the gross domestic product (GDP). Exogenous shocks like droughts, floods, heat waves, locusts, and dust storms are the major climate-related hazards in Burkina Faso, which contribute to problems such as desertification, land degradation, epidemics (e.g. meningitis, cholera), food insecurity, increased poverty incidents, migration away from the central area of the country, and overall development.

2.5 VULNERABILITY TO CLIMATE CHANGE

From a climate change perspective, the Intergovernmental Panel on Climate Change (IPCC) defines vulnerability as the "degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity." With its geographical position, its tropical climate with extensive drought periods, heatwaves and heavy rainfall, and the recurrent flooding of the major rivers (Niger, Comoé and Volta), Burkina Faso is characterized by a strong structural vulnerability. This vulnerability is further accentuated by unpredictable climate variability, increasingly erratic weather patterns and high reliance on rain-fed agriculture. As a result, Burkina Faso is particularly vulnerable to climate change. Widespread poverty further increases the vulnerability to climate change impacts, which regularly affect all areas of Burkina Faso. Severe droughts, excessive rainfall and frequent floods are the most serious constraints. The negative impacts of climate change constrain households in many parts of the country to earn part of their living off the farm. Faced with massive rural poverty and food insecurity, socio-economic vulnerability of the rural population in Burkina Faso is high. Climatic hazards repeatedly destroy dams and water reservoirs and result in low agricultural yields, a severe loss of agricultural production and harvest failures. In the Central Plateau region, three-quarters of the 85 dams and reservoirs are silted and require rehabilitation. In addition, invasions of migratory locusts and many episodes of epidemic diseases have been recorded.

As a consequence, Burkina Faso is repeatedly facing water scarcity and recurrent food crises, directly disrupting the livelihoods of local communities and thousands of farmers. Burkina Faso is also affected by under-nutrition and infectious diseases. Climate change will likely cause shifts in the timing, seasonality, and geographic range of disease epidemics, particularly malaria and meningitis (e.g., pushing the meningitis belt southward). Limited access to water supply and sanitation systems, and frequent floods and droughts aggravate health conditions and disrupt the livelihoods of rural and urban populations.

2.6 LAND DEGRADATION

Close to 90 per cent of the Burkinabe population depend on agriculture for their livelihood. The functioning of the agricultural sector thus becomes a precondition for the overall economic development of the country. However, the agricultural sector is characterized by low productivity, soil erosion and declining soil fertility. The lack of basic minerals such as nitrogen, potassium and phosphorus is aggravated by the practice of extensive agriculture using very little organic matter for conservation and restoration. Extensive farming in combination with recurrent droughts, floods, spreading desertification and deforestation severely affect agricultural activities and contribute to land degradation.

Land degradation is defined as the long-term loss of ecosystem function and productivity caused by disturbances from which the land cannot recover unaided. Land degradation occurs slowly and cumulatively and has long lasting impacts on rural people who become increasingly vulnerable. The UN Convention to Combat Desertification (CCD), of which Burkina Faso is a signatory, recognizes land degradation as a global development and environment issue. Environmental degradation and soil erosion continue to threaten the availability of arable land in Burkina Faso.

At present, 9 234 500 ha of land, or one third of the national territory, have been degraded due to anthropogenic causes and to the effects of climate change.

Extensive land utilization for agriculture by the ever-growing number of agricultural and livestock producers and non-sustainable wood cutting (the main source of energy for all rural households) are considered the main direct causes of land degradation and deforestation in Burkina Faso. The lack of personal capital and access to credits results in extensive farming as characterized by (a) a low level of agricultural inputs; (b) poor mechanization; and (c) minimal (almost negligible) fertilizer application. With a rapidly increasing population and little improvement in agricultural productivity, farmers compensate by expanding cultivated area. Between 2001 and 2014 the agricultural area was expanded by more than 60 per cent. Therefore, it is estimated that the country will soon reach its limit of arable land. Furthermore, this expansion also threatens natural resources, and the pressure on the last remnants of natural vegetation is increasing. In addition, desertification and degraded land constrain villagers to clear forests or let their cattle graze freely to be able to feed their families and earn a living.

One way to contain agricultural expansion and deforestation is to increase the efficient and sustainable use of existing agricultural areas and improve agricultural productivity per hectare, for example by controlled fertilizer usage. The highlighted parameters and constraints must also be considered when analysing potential feedstock sources for SAF production.

ICAO is currently considering the sustainability requirements for SAF. With regard to the specific agro-climatic conditions in Burkina Faso, the perfect feedstock would ideally have to accomplish several goals at once, namely:

- qualify as a sustainable source for conversion into SAF;
- preserve biodiversity and sustain eco-balance;
- stop land degradation and soil erosion;
- regenerate degraded soils; and
- provide a relatively cheap organic fertilizer.

Given the scale and impact of the consequences of land degradation and deforestation, implementing the right policies and mitigation measures becomes an issue of national strategic importance. Some of the many challenges of sustainable land management are addressed inter alia by (a) the Forest Investment Programme (FIP) which provides the framework for the definition and implementation of REDD+ projects, and in particular (b) the National Partnership Programme for Sustainable Land Management *(Programme National de Partenariat pour la Gestion Durable des Terres, CPP)* which has been implemented by the National Council for Sustainable Development *(Secrétariat Permanent du Conseil National pour l'Environnement et le Développement Durable, SP/CONEDD).*

The above initiatives are in line with strategic objective No. 3.5 of the PNDES. Accordingly, the government intends to reverse the trend of environmental degradation and pursue the transition towards a green economy.

PICTURE 2
Recurrent droughts, spreading desertification and deforestation severely affect agricultural activities and contribute to land degradation

2.7 AGRICULTURE

Out of the total area of 27 400 000 ha, 22 per cent is arable land, i.e. 6 million ha. Arable land includes land defined by the UN Food and Agriculture Organization of (FAO) as land under temporary crops (double-cropped areas are counted once), temporary meadows for mowing or for pasture, land under market or kitchen gardens, and land temporarily fallow. Land abandoned as a result of shifting cultivation is excluded. 60 per cent of the arable land is used for cereal production, representing about 13 per cent of the country's total area.

The amount of farmland per person is low, and declining. The sector is dominated by small-scale farms with an average agricultural area per rural inhabitant of less than 1.5 ha. In comparison, the average farm size in sub-Saharan Africa is 2.4 ha, compared to 178.4 ha in the United States and 111.7 ha in Latin America.

Women account for over 70 per cent of the agricultural labour force, but own hardly any land. Traditionally, women are responsible for cultivating the family fields and the collective perimeters of women's farming associations.

Rain-fed agriculture dominates in Burkina Faso, with largely rudimentary agricultural techniques prevailing among small-scale farmers. With only a few exceptions, farmers have no access to tractors or agricultural machinery. Donkeys have traditionally been the main draft animals and primary working partners of farming families in Burkina Faso.

The challenge in coming years is to accelerate growth in production and productivity, by controlling its impact on the environment and natural resources such as land, water and energy, and to foster the adaptability of farming systems to climate change. Increasing agricultural production can only be achieved through sustainable agricultural intensification. This means fostering access to inputs — including the use of fertilizer and seed subsidy policies and securing access to financing and resources for women in particular. Unfortunately, the factors that drive transformation in agriculture — the adoption of technology and access to finance and skills training — are often difficult to deliver economically to smallholder farmers, who are geographically dispersed and poorly connected to markets.

PICTURE 3
National Farmers Day 2017, Kaya, Burkina Faso

The President of Burkina Faso, Roch Marc Kaboré, addressing thousands of farmers at the "Journée Nationale du paysan" in Kaya on 12 May 2017.

2.8 ENERGY

Burkina Faso is simultaneously facing challenges of energy access, energy security and climate change mitigation. With very few energy resources of its own, the country is relentlessly confronted with an insufficient supply of energy in the face of an ever-evolving demand due notably to increased economic and mining activities, population growth and galloping urbanization. Over the last decade, local demand for electricity has increased by about 13 per cent per annum on average, against an 8 per cent increase in supply. Consequently, Burkina Faso is highly dependent on energy imports.

Biomass (wood fuel, charcoal) constitutes 85 per cent of the primary energy consumption, with 14 per cent derived from hydrocarbons (oil products) and 1 per cent from hydro-electricity.

2.8.1 WOOD FUEL

Wood Fuel (or firewood/fuelwood) is the main commercial product of Burkinabe forests. As only 17 per cent of the population, including 3 per cent of rural households, have access to electricity, wood fuel provides over 85 per cent of total primary energy consumption in Burkina Faso.

In rural areas, nearly all energy consumed is biomass based. Over 90 per cent of all households in Burkina Faso use wood as their primary source of cooking fuel. In comparison, butane gas only accounts for 7.8 per cent of domestic energy consumption. As per FAO statistics, Burkina Faso produced some 13 million m3 of wood fuel and 0.6 million tonnes of charcoal in 2012. It is estimated that a family will use at least 3 tonnes of wood each year with a traditional cook stove composed of a few stones on the ground.

PICTURE 4
Traditional wood fuel collection method

For lack of available and affordable alternatives, the dependency on wood fuel and the corresponding depletion of forest resources is expected to continue and even increase in the next decades. While the collection of wood fuel may provide short-term ad hoc relief, it exacerbates energy crises and contributes to the deterioration of natural resources, thus further increasing vulnerability to climate change. Due to poor agricultural yields, wood fuel exploitation is increasingly becoming an additional source of income. Facing poverty and food insecurity, more and more rural women are dependent on the collection, transportation and sale of wood fuel.

Considering the challenges and costs of logistics and transportation, wood collectors receive only 10 per cent of this amount. It is estimated that only 20 per cent of wood fuel is collected from managed forests, while up to 70 per cent is sourced illegally. The widespread uncontrolled practice of cutting trees without any permit is a serious environmental concern. In addition to agricultural expansion and mining, wood fuel exploitation has become one of the main drivers of deforestation and forest degradation. To slow deforestation and reduce pollution from wood fuel, the Government of Burkina Faso has been trying to promote energy-efficient butane stoves.

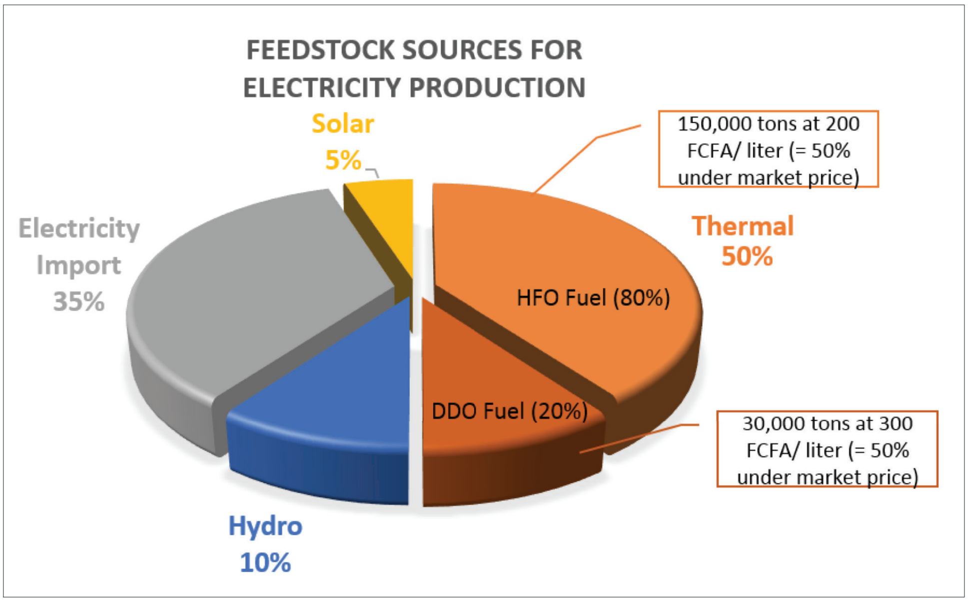
2.8.2 HYDROCARBONS/ FOSSIL FUELS

Africa is the continent with the least number of oil refineries in the world. The continent's oil producers rely on fuel imports to supplement their own production, as the refinery capacity is unable to keep up with demand. While Burkina Faso itself lacks any petrochemical facilities, the closest oil refineries can be found in Ghana *(Tema Oil Refinery/ Tullow Oil)* and Côte d'Ivoire *(Societe Ivoirienne de Raffinage)*. Benin only has a fuel storage depot in Cotonou. Nigeria, the largest economy in Africa, is the region's dominant oil producer, with a daily output of 2.4 million barrels per day in 2015, and four oil refineries, at Kaduna, Warri and two at Port Harcourt.

Without its own oil supplies and domestic refining capacity, Burkina Faso is completely reliant on imported refined products. Hydrocarbon import and storage activities are the monopoly of the Burkina Faso National Hydrocarbons Company (SONABHY), while transportation and distribution activities are open to competition (e.g. Total Burkina, Shell). Lacking its own fossil fuel reserves, annual hydrocarbon imports in 2016 amounted to 180 000 tonnes (mainly by truck from three maritime ports: Lomé in Togo, Cotonou in Benin, and Abidjan in Côte d'Ivoire). These imports consisted of 83 per cent (i.e. 150 000 tonnes) distillate diesel oil (DDO) and 17 per cent (i.e. 30 000 tonnes) heavy fuel oil (HVO). Refined petroleum products represent roughly 20 per cent of the total imports of Burkina Faso. As a state-owned enterprise, SONABHY is the exclusive fuel supplier to SONABEL, the national electricity company responsible for power generation, transmission and distribution of electricity in Burkina Faso.

In terms of electricity, Burkina Faso also relies heavily on thermal-fossil fuel. In 2016, domestic thermal production supplied 60 per cent of the total power generation capacity in the country (50 per cent hydrocarbon thermal and 10 per cent hydroelectric thermal) while 35 per cent of electricity was imported from neighbouring Ivory Coast. Nevertheless, electricity access in Burkina Faso is one of the lowest in the world. Merely 15 per cent of the population has access to electricity, compared to the African average of 40 per cent. The share of renewable energies (mainly solar) currently amounts to only 5 per cent.

FIGURE 9
Breakdown of feedstock sources for electricity production



To facilitate access to energy, hydrocarbons are highly subsidized. State subsidies are intended to maintain the artificially low prices of fuel supplied to SONABEL for electricity generation at FCFA 300 (USD 0.52) per litre of DDO and FCFA 200 (USD 0.34) per litre of HFO. In 2016, total state subsidies to SONABHY reached FCFA 39.5 billion (or nearly USD 70 million). While government oil subsidies may seem beneficial on the surface, the long-term effects are highly damaging, and the Burkinabe government routinely spends millions of dollars a year on subsidy payments, export charges and import charges. The mechanism for adjusting hydrocarbon prices is defined by ministerial orders.

The energy crisis in Burkina Faso is exacerbated with the recurrent breakdown of thermal power generation equipment, delays in the rehabilitation of generators, interruption to the supply of fuel to power plants, lack of adequate investments in the rehabilitation of electrical facilities and the decline in imported power from Côte d'Ivoire. Starting in 2017, the government plans to import 100 MW of electricity from Ghana and 300 MW from Nigeria.

2.8.3 RENEWABLE ENERGY OUTLOOK

Improving energy supply and access to energy are key components of the government's strategic development plan. According to the goals laid down in the PNDES, the Government intends to, inter alia: (a) increase the share of renewables and imported energy in the national energy mix; (b) promote energy autonomy nationwide; and (c) reduce the use of diesel fuel for heavy fuel oil, which should help to lower SONABEL's production costs. To that end, the Government decided to create the National Agency for Renewable Energies and Energy Efficiency (*Agence Nationale des Energies Renouvelables et de l'Efficacité Energétique* (ANEREE)), which has the following roles:

- monitoring, supervising and promoting the renewable energy (RE) and energy efficiency (EE) market;
- establishing a National Strategy for the Promotion of Energy Efficiency;
- supporting, enhancing and piloting projects of national scope;
- bringing together the private sector, non-governmental organizations (NGOs), and technical and financial partners;
- performing commercial services and other public service missions in the RE and EE field; and
- supporting research, innovation and training in the RE and EE field.

To foster the transition towards a green economy, to reduce GHG emissions and to build capacity for climate change resilience, strategic objective No.3.5.1. of the PNDES also foresees the creation of 2 000 eco-villages by 2020 (at a cost estimated by the Ministry of Environment and Sustainable Development of USD 144 million). Simultaneously, the Government aims to increase the contribution of renewable energies to total energy production from 5 per cent to 30 per cent.

Scaling-up renewable energy in the country's current energy mix would not only improve access to electricity but also reduce the country's expensive dependence on imported fossil fuels for electricity generation.

2.9 TRANSPORT INFRASTRUCTURE

The transport sector, and especially road infrastructure, constitute an important asset for the socio-economic development of any country. As the following **Figure 10** illustrates, Burkina Faso's greatest infrastructure challenge lies in the transport sector. Due to its landlocked nature, Burkina Faso is wholly dependent on functioning road corridors to access the seaports in neighbouring States Côte d'Ivoire (Abidjan), Ghana (Accra/Tema), Togo (Lomé), Benin (Cotonou) and Nigeria (Lagos).

While its geographic location positions Burkina Faso as a natural transit hub for West Africa, its landlocked condition imposes a large mark-up on import and export costs. Connecting surface road corridors and distances from the main domestic business hubs (Ouagadougou, Bobo-Dioulasso) to available seaports are all around 1 000 kilometres or more. Average transit time on the road corridor between Ouagadougou and the port of Tema (Ghana) takes 12 to 15 days. Consequently, transport costs are compounded by and very sensitive to any inefficiency in the transit chain, for instance, in customs administration, cross-border waiting times, and logistic costs. In case of crude vegetable oil transport by tank truck, time and challenging climate conditions may furthermore lead to product deterioration as free fatty acids risk building up during lengthy overland transit times.

FIGURE 10
Road corridors to international seaports

Burkina Faso is completely dependent on overland road corridors to access refining, loading and handling facilities at international seaports.

Despite the good condition of the main transit roads, the sheer distance to be covered puts the country at a competitive disadvantage. World Bank and International Bank for Reconstruction and Development (IBRD) data from 2011 reveals that time and costs to export are not only much higher than those faced by Member States of the Organization for Economic Cooperation and Development (OECD) but also than those in other African States. These impediments will certainly affect the economic viability of low value biomass transportation and biofuel production.

TABLE 4
Barriers to Trade
Source: World Bank, Doing Business 2011, and The International Bank for Reconstruction and Development (IBRD), Burkina Faso's Infrastructure: A Continental Perspective, 2011

Burkina Faso's Barriers to Trade

Indicator	Burkina Faso	Niger	Mali	Cameroon	Ivory Coast	Ghana	Senegal	OECD
Time to export (days)	41	59	32	23	25	19	11	11
Cost to export ($ per container)	2,662	3,545	2,075	1,250	1,969	1,013	1,098	1,090
Time to import (days)	49	64	37	26	36	29	14	11
Cost to import ($ per container)	3,830	3,545	2,955	2,002	2,577	1,203	1,940	1,146

A necessary precursor to the development, production, and use of economically viable SAF is the identification of a functional domestic supply chain. This will depend, inter alia, on the existing road infrastructure and the accessibility of feedstock cultivation areas.

While the main roads running through Burkina Faso are usually paved and in relatively good condition, connectivity and accessibility decrease outside the main trunk network, particularly in rural and agricultural production areas where roads are made of dirt or sand. In addition, at least 50 per cent of the classified tertiary road network is impassable during the rainy season. As a result, some of the zones with high agricultural potential (such as the Bagré Zone in the south of the country) are underexploited, as farmers have difficulty getting products to markets. This situation is further aggravated by the fact that Ouagadougou and Bobo-Dioulasso account for over 70 per cent of the country's urban population and that regional capitals lack the economic infrastructure and connectivity with these larger urban centres and their hinterlands.

PICTURE 5
Road infrastructure

Road conditions pose a serious challenge for the collection and transport of biomass and biofuels.

The disconnect between urban centres and the countryside is especially relevant for the collection of high-volume, low-value biomass and its transportation to centrally located conversion facilities. The huge quantities of biomass necessary to support domestic fuel processing operations on a commercial scale make transport and logistics very challenging. Due to their low energy density, large amounts of biomass are required to feed potential production facilities. Handling this bulky material can be expensive and uneconomical outside of a given radius. According to the above referenced IBRD report, less than one-fourth of Burkina Faso's population lives within 2 km of an all-weather road. Benchmarked against other African States, rural accessibility in Burkina Faso is 27 per cent lower than in low-income African countries (LICs) and even 60 per cent lower than in middle-income African countries (MICs). However, basic road access to agricultural production areas and rural farms is a precondition for the organization of a functioning market and biofuel supply chain. Otherwise, even the most promising yield potential and high-value crops will not be sufficient to overcome inadequate rural transport connectivity and compensate for disproportionally high logistics costs. As large-scale feedstock cultivation and biofuel production are directly dependent on the underlying infrastructural conditions, continuous investments into the road network and road maintenance are necessary. Any such investment does not only favour the transport sector per se, but simultaneously contributes to higher level rural and regional development objectives and potentially secures agricultural production worth millions of dollars. The Government has a specific programme to upgrade 5 000 km of rural roads, yearly. The country's Poverty Reduction Strategy *(Stratégie de Croissance Accélérée et de Développement Durable* (SCADD)) also highlights transport services and infrastructure development as a central element for improving the internal and external connectivity and improving trade and economic activities.

3. EVALUATION OF FEEDSTOCK SOURCES FOR BIOFUEL PRODUCTION

3.1 STARCH AND SUGAR CROPS (SUCROSE)

3.1.1 SUGARCANE

3.1.1.1 Feedstock Suitability

One of the dominant global feedstock for biofuel production includes sugars derived from agricultural starches and from sugarcane. Sugarcane is one of the most photosynthetically efficient crops, cultured mainly in warm and tropical regions. The stalks of the cane constitute over 7 per cent of the mature plant and contain up to 20 per cent sucrose by weight.

Sugarcane can be used as a feedstock to produce fuels. For example, Brazilian-produced sucrose is currently the main feedstock for fermentation technologies in the aviation field, such as farnesene production by Amyris. However, sugarcane production is dependent on the specific climate, and despite its high photosynthetic efficiency, the land area needed for significant cultivation is still substantial and potentially in direct competition with other food crops. In addition, any SAF produced from sugarcane would be in direct competition with bioethanol as a gasoline substitute.

In 2014, the Brazilian Development Bank funded an international study analysing the feasibility of biofuel production in sub-Saharan African ECOWAS Member States *(Étude de Viabilité de la Production de Biocarburants dans l'UEMOA)*. All ECOWAS States are challenged by low agricultural productivity and food insecurity. Sustained energy deprivation provides additional obstacles. In this context, biofuel production cannot be pursued in isolation but should ideally be an integral part of a more comprehensive agro-energy plan within and across sectors that also ensures food self-sufficiency and energy access at the same time.

In search of the most suitable feedstock for biofuel production in the ECOWAS States, a total of 12 crops were analysed with regard to their respective energetic potential. Main selection criteria included agricultural suitability, productivity and yield, water requirements, land use and financial viability.

The study came to the conclusion that, among all feedstock sources, only sugarcane-based fuels promise appropriate business perspectives, not only for Burkina Faso, but also for other ECOWAS States. Due to its perfect adaptation to local agro-climatic conditions and its positive socio-economic impacts, the study further concluded that sugarcane qualified as the most cost competitive feedstock. The availability of qualified labour and efficient irrigation systems in combination with Brazilian production technologies were considered as the main underlying factors for a successful business model implementation in ECOWAS Member States.

Three macro-regions were identified for sugarcane-to-ethanol biofuel production in Burkina Faso, due to their natural water sources and irrigation access, agricultural capability of soils, and proximity of critical transportation, storage and logistics infrastructure. They are:

a) the province of Comoé, in the administrative region of Cascades near the border of Côte d'Ivoire,
b) the provinces of Moun Houn, Nayala and Kossi, on the banks of the Black Volta river and north of the town of Dédougou, and
c) the province of Boulgou, to the south-east of Ouagadougou (see **Figure 11**).

Sugarcane requires prime agricultural land, fertilizer and large quantities of water (1 500 to 2 500 mm per year). In Burkina Faso's drylands, sugarcane, therefore, cannot be grown without irrigation. As of June 2017, only 3 per cent of the agricultural land in Burkina Faso was irrigated. Due to climatic reasons and severe water constraints, the suitable area for sugarcane is limited to a relatively small area in the southern part of the country. Natural constraints are reflected in the actual size of the cultivation area.

PICTURE 6
Burkinabe sugarcane plantation

4 000 ha irrigated sugar cane plantation near Banfora/ Cascades in the south-sudanian agro-ecological zone.

Between 2000 and 2014, the irrigated area for sugarcane cultivation in Burkina Faso increased from 4 000 ha to 4 728 ha. According to most recent estimates, the total cultivation area in 2017 slightly exceeded 5 000 hectares.

Based on a production yield of +/- 100 tonnes/ha, the country's annual sugarcane harvest amounts to 500 000 tonnes. Assuming a conservative average yield of 4 000 litres of ethanol per ha, Burkina Faso has currently a theoretical production capacity of 20 000 m3 or 20 million litres of sugarcane-based bioethanol. Considering the energy density of 0.789 kg/m3 and a specific energy content of 29.6 MJ/kg, this converts to 15 800 tonnes and the equivalent calorific value of 468 000 Gigajoule (GJ) or 79 850 boe respectively.

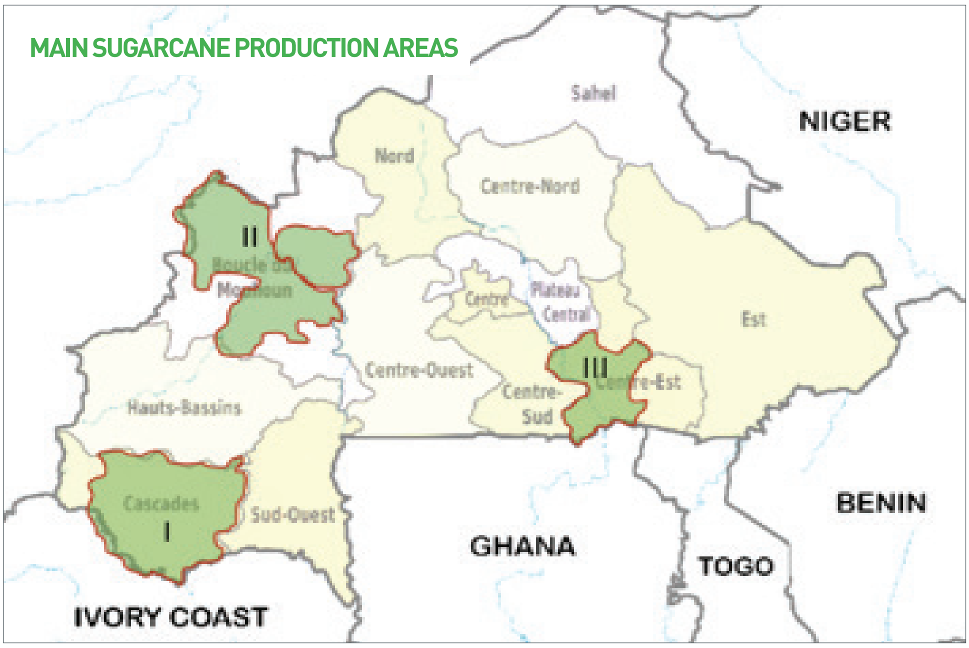


FIGURE 11
Main Sugarcane Production Areas

Former state-owned sugar company SN Sosuco *(Nouvelle Société Sucrière de la Comoé)* produces 35 000 tonnes of sugar and 12 000 tonnes of molasses. SN Sosuco is Burkina Faso's largest private employer, and it is 52 per cent controlled by the Aga Khan Fund for Economic Development acting through its affiliate Industrial Promotion Services (IPS) West Africa. It is based outside of Banfora right at the centre of the Comoé province in the Cascade region. Profiting from the availability of natural water resources (Comoé river, Cascades) and an automated sprinkler irrigation system, SN Sosuco cultivates 4 000 ha of sugarcane. The plant, which dates from 1968, has a processing capacity of 2 400 tonnes of sugarcane per day. Pending the installation of additional irrigation facilities, an extension of the cultivation area to 6 000 ha is under consideration. The production capacity of SN Sosuco is limited by access to water for irrigation.

By adding the cultivation area in the province of Boulgou, which offers access to water resources for irrigation from the Bagré hydroelectric dam on the White Volta river, the total favourable area for irrigated sugarcane cultivation in Burkina Faso could potentially amount to a maximum of 8 000 ha. Applying the same conversion ratios as above, this equals a theoretic future production capacity of 32 000 m3 or 32 million litres of sugarcane-based bioethanol with a calorific value (energy content) of 747 000 GJ which equals 122 460 boe.

3.1.1.2 Feedstock Conversion and Upgrading

In the process of producing crystallised sugar, several by-products are generated. The most important ones include molasses, bagasse and cane juice.

The main source of ethanol in Burkina Faso is sugarcane molasses, a by-product of food-grade sugar production. The yield of molasses from crushed cane ranges from 2 to 4 per cent; given a current theoretical annual sugarcane yield of +/- 500 000 tonnes, this amounts to 10 000 to 20 000 tonnes of molasses. The feedstock can be fermented using yeast or other organisms and distilled into alcohols which can then be chemically processed further into SAF. As of today, sugarcane molasses in Burkina Faso is primarily used for pharmaceutical-grade alcohol. Given the weak demand for pharmaceutical alcohol, there is currently an oversupply of molasses. SN Sosuco's integrated distillery has a limited processing capacity of 7 000 litres of bioethanol per day, or roughly 2 million litres per year. During the ethanol fermentation process a rich biological waste is produced; it is usually put back on the fields as a fertilizer for sugarcane crops.

Bagasse is the fibrous residue that remains after sugarcane stalks are crushed to extract their juice. For every 10 tonnes of sugarcane crushed and processed, a sugar factory produces nearly three tonnes of wet bagasse. The bagasse is typically burned to provide energy for the sugar mill and distillery. While the high moisture content of bagasse, typically 40 to 50 per cent, is detrimental to its use as a fuel, the cellulose-rich bagasse is being widely investigated for its potential for producing commercial quantities of cellulosic ethanol. In comparison to other agricultural residues, bagasse has the advantage of being available at the mill, meaning that the cost of collection and transportation is generally allocated to sugar or ethanol costs.

In addition to the molasses and bagasse available from sugar production, it might also be possible to utilize sugarcane juice as feedstock. However, the diversion of cane juice from sugar production to biofuels would directly interfere with food production and consequently result in a shortage of sugar.

Even though domestic production capacity has been significantly increased since 2012, the annual sugar production of 35 000 tonnes does not even meet 40 per cent of domestic demand. The chronic sugar shortage of at least 90 000 tonnes per year is encouraging sugar trafficking from Brazil. Additionally, illegal imports from Brazil and the EU usually profit from government subsidies. For example, the "Regional Producer Subsidy" is a direct subsidy paid by the Government of Brazil to provide sugarcane producers from the north-north eastern states to balance their cost of production with that of the most developed growing areas in centre-south Brazil. While a tonne of domestic sugar produced in Burkina Faso fetches FCFA 500 000 (USD 874), Brazilian imports transiting trough the seaports of Lomé, Abidjan or Tamalé are selling for FCFA 420 000 per tonne (USD 734), all freights included. With a price differential of at least FCFA 80 000 (USD 140) per tonne, the Burkinabe sugar industry is internationally not competitive. Government subsidies put even more pressure on the domestic sugar industry. In addition, unregulated sugar imports may even pose a public health risk as imported agricultural products have usually undergone chemical treatment. So far, the annulment of import permits has not shielded the domestic market from foreign competition.

As sugar demand in Burkina Faso already outweighs available supply from domestic production by four times, any diversion of sugarcane juice for the benefit of increased ethanol production seems to be unattractive and should most certainly be discarded.

The individual steps of the conversion process leading to the production of bioethanol as a precursor of SAF are illustrated in **Figure 12** below.

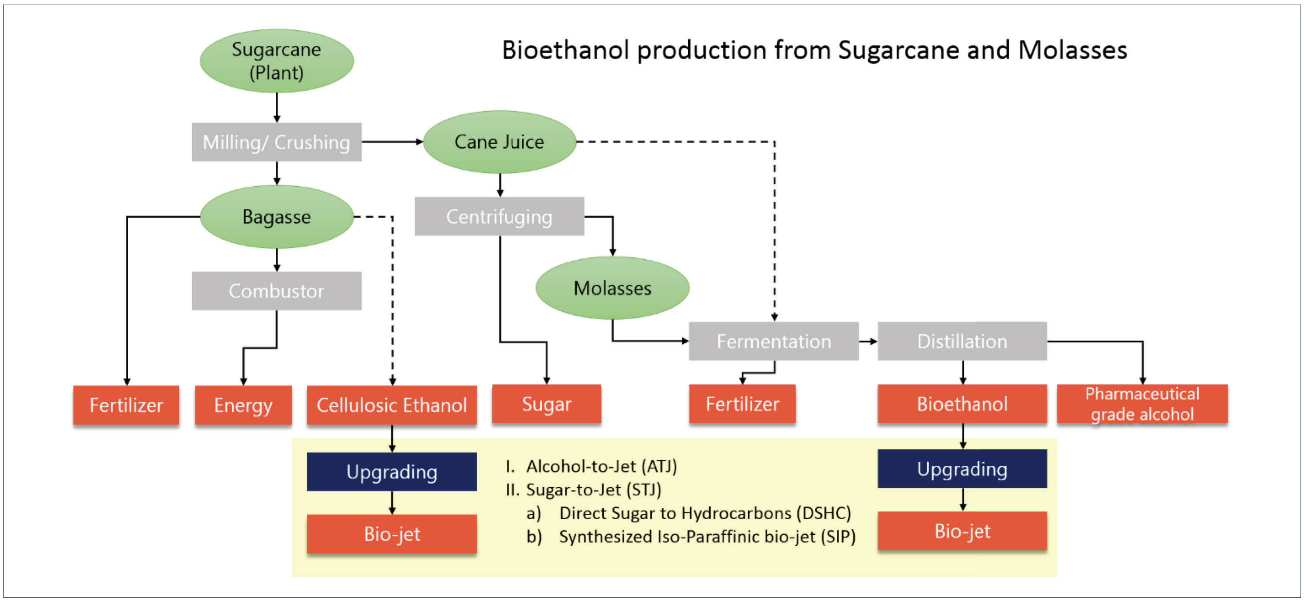


FIGURE 12
Bioethanol production from sugarcane and molasses

Once the sugarcane biomass feedstock has been converted into alcohol, the resulting bioethanol can then be further processed to SAF. For that, ethanol needs to be upgraded to high-grade, long-chain kerosene. Two biochemical processes that convert sugars to hydrocarbons are being used by the industry:

3.1.1.2.1 Alcohol-to-Jet

The alcohol-to-jet (AtJ) process involves the fermentation of sugars to alcohols, such as ethanol or butanol. These are subsequently upgraded to a final product stream that includes not only SAF, but also other hydrocarbons, chemicals and additional by-products. The conversion process typically consists of alcohol dehydration, catalytic oligomerization to jet range alkenes, and finally hydrogenation, as demonstrated by companies such as Swedish Biofuels and Gevo, the first commercial producer of AtJ fuel. Accordingly, any sugar containing bio-based feedstock is first processed into isobutanol by fermentation, prior to being refined into synthetic iso-paraffinic kerosene. Gevo's AtJ fuel based on isobutanol was ASTM approved in April 2016, eligible for up to 30 per cent blending in commercial flight.

3.1.1.2.2 Synthesized iso-paraffins produced from hydroprocessed fermented sugars (SIP-HFS)

Synthesized iso-paraffinic (SIP) SAF can be produced biologically through the aerobic fermentation of sugars by microorganisms to create a hydrocarbon molecule called farnesene. The French-US joint venture between Total and Amyris converts sugars directly into hydrocarbons (such as farnesene) by fermentation with genetically engineered yeasts. Farnesene is then upgraded by hydro-processing into a molecule called farnesane, which can be blended with current aviation fuel. The SIP-HFS production pathway, formerly known as the direct sugars-to-hydrocarbon (DSHC) route, was approved by ASTM International in 2014. Due to the homogenous hydrocarbon composition of this fuel (only one carbon chain length), the maximum certified blending ratio with current aviation fuel is currently limited to 10 per cent.

Direct enzymatic conversion of sugars to hydrocarbons is more challenging and complex from a process technology point of view than the hydrogenation of vegetable oil, which is why the production costs are expected to be significantly higher than for HEFA products according to current knowledge.

A key aspect of SAF production is the requirement for hydrogen (H2) to upgrade oxygen-rich carbohydrate, lignin or lipid feedstocks to hydrogen-rich hydrocarbons that are functionally equivalent to current aviation fuel. Thus, some type of costly hydro-processing step will likely be required for most SAF technology platforms, with external sources of hydrogen used to remove oxygen in the form of water from the starting material, or to saturate double bonds in a final polishing step.

3.1.1.3 Challenges and Constraints

The analysis of potential commercial ethanol feedstocks in Burkina Faso reveals that sugar cane is a leading contender. However, the commercial viability of an ethanol production unit requires a regular and secure supply of raw material and presupposes large-scale agro-industrial production. Challenges may involve having a large enough supply of molasses at a given location to minimize transportation costs to justify construction and operation of an economically efficient ethanol production facility. The volume of sugar-derived feedstock available today does not yet seem to be sufficient to justify an autonomous regional supply chain with a comprehensive production infrastructure. Assuming sufficient supply, the use of sugarcane as feedstock still incurs more than twice the production cost of converting corn into ethanol. As long as it is more profitable to produce ethanol from corn in the United States, it remains rather unlikely that existing distilleries in Burkina Faso will be upgraded or that new commercial ethanol facilities will be set up.

3.1.1.4 Feasibility Matrix

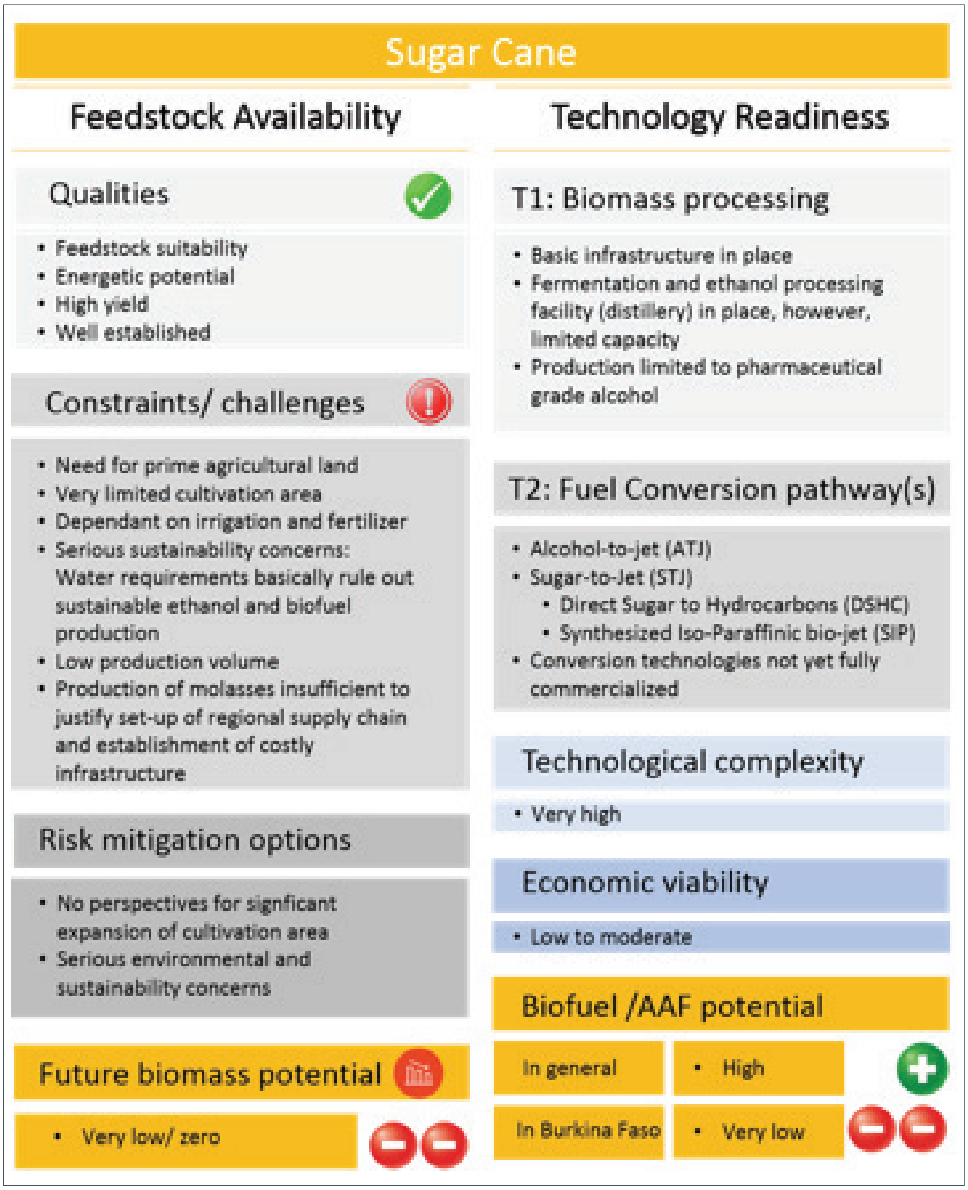
To better evaluate the potential and viability of any given combination between a specific source of domestic biomass (such as sugar cane) and a proven technological conversion pathway, a Feasibility Matrix of select evaluation criteria illustrates opportunities and major constraints with regard to the maturity of a potential domestic feedstock supply chain, as well as the feasibility of the entire supply chain, including available technology options.

To facilitate a quick overview, evaluation criteria against which the feasibility of any pathway scenario can be gauged are narrowed down to two major categories: Feedstock Availability and Technology Readiness.

The analysis of Feedstock Availability takes into account not only the current and potential future biomass production volume, but also land, fertilizer and water requirements, as well as market

The Technology Readiness category differentiates between two technology levels. Technology level 1 (T1) relates to biomass processing and includes basic feedstock processing facilities, pre-treatment activities, feedstock to fuel conversion and oil expelling. In comparison, technology level 2 (T2) refers to advanced fuel processing facilities and relevant fuel conversion pathways, including, inter alia, refining, hydro treatment and crude fractionation.

Given the very low level of agricultural mechanization in Burkina Faso, the installation of technology solutions at the first level is already a major challenge before more advanced and technologically SAF conversion scenarios can be considered.



3.1.2 SORGHUM

3.1.2.1 Feedstock Suitability

Sorghum, together with millets (a group of highly variable small-seeded grasses), is the most important cereal crop in Burkina Faso, followed by maize and rice. The primary demand for sorghum and millets is for food, especially in the dryland regions of sub-Saharan Africa where these are the principal cereal crops.

The environments in which sorghum and millets are cultivated face the toughest environmental challenges, including low and irregular rainfalls, high temperatures, poor soils and inappropriate agronomic practices. Sorghum and millets are well suited to the harsh environmental and climate conditions of Burkina Faso, including areas where other crops either yield poorly or do not grow at all. They are typically cultivated by small-holder farmers in almost all parts of the country, except the southwest, with limited water resources and without application of any fertilizers or other inputs. Main sorghum production areas include the provinces of Yatenga *(Nord)*, Mouhoun *(Boucle du Mouhoun)*, Houet *(Hauts-Bassins)*, Kouritenga *(Centre-Est)*, Sanmatenga *(Centre-Nord)*, Sanguié *(Centre-Ouest)*, Ioba *(Sud-Ouest)* and Zoundweogo *(Centre-Sud)* (see **Figure 13**).

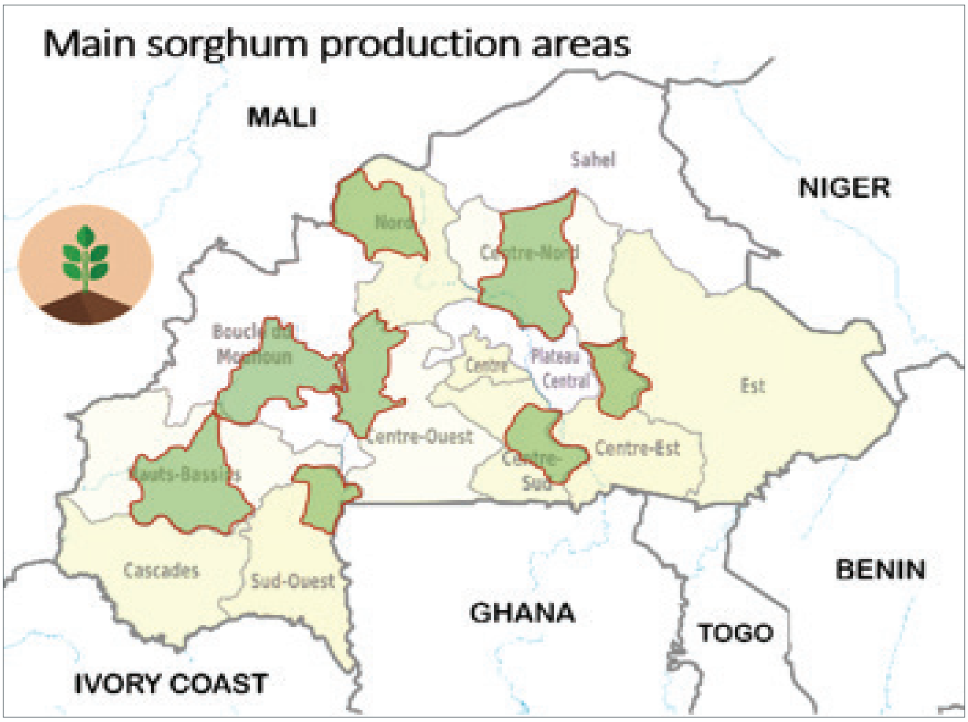


FIGURE 13
Main sorghum production areas

Valued as a multipurpose crop, sweet sorghum is as also called the "camel among crops" as it is well adapted to the semi-arid tropics, resists drought, tolerates high salinity soil and is very water-use efficient. Given its short growing period, high biomass and bio-product potential, tolerance to drought, water-logging, salinity and acidity, and low water requirement, sweet sorghum is the preferred crop for cultivation on drylands in the semi-arid tropics. Dealing with the challenges of climate change and land degradation, dryland cereals will become increasingly suited for production in unfavourable farmland where other crops cannot thrive. In Burkina Faso and across sub-Saharan Africa, sorghum and millets have already become the major suppliers of micronutrients, especially for low-income rural communities. This explains why sorghum and millets make up 75 to 90 per cent of the staple diet of the rural population in Burkina Faso.

Sweet sorghum not only provides grain for human consumption and stover (stalks and leaves) for fodder, but the plant residues are also increasingly being used as feedstock for industrial alternative fuel production. Cultivated varieties of sorghum are commonly grouped according to their end uses, for example, grain sorghum (food and feed), forage sorghum, sweet sorghum (for sugar production) and bioenergy sorghum. There are notable differences in the relative carbon partitioning and morphology between these groups: grain varieties produce large heads of grain rich in starch; sweet sorghums produce a tall, sugar-rich stem; and bioenergy and forage sorghums produce a large amount of vegetative biomass. The composition of the sorghum plant thus seems ideal: while grains can be used for food, other parts of the plant can simultaneously be used to produce fuel. In comparison to maize, rice and wheat, sorghum and millets offer a relatively cheap source of energy without any food-fuel trade-offs. As a dryland crop for biofuel production, sorghum is highly favoured for its effective conversion of atmospheric CO_2 into sugar, making it a viable alternative to sugarcane or maize for the production of ethanol.

Sorghum has been considered as a potential ethanol production feedstock because it accumulates fermentable sugar in the stalk. The juice extracted from sweet sorghum stalks (sorghum juice) usually contains approximately 16 to 18 per cent fermentable sugars which are mainly comprised of sucrose, glucose and fructose and which can be crushed to extract the sorghum juice as raw material for ethanol production. While fuels produced from sugarcane are limited to the molasses as feedstock, a by-product of food-grade sugar production, fuel production from sorghum can make full use of the sugar hydrolysate from the sorghum juice.

In direct comparison to sugarcane, sweet sorghum is much more water-efficient as it extracts only one seventh of the water. While sugarcane consumes two and a half units of water to produce one unit of ethanol, sweet sorghum only uses one unit of water to produce one unit of ethanol.

To evaluate the theoretical energy and potential of fuel produced from sorghum residues, the available amount of feedstock needs to be calculated. Quantification depends on the annual production of sorghum crops and the underlying grain-to-residue (stalk) ratio. The co-existence of more than 250 varieties allows only an approximate but nevertheless realistic estimate. Therefore, the grain-to-residue ratio is estimated at 1:2, i.e. one tonne of grain harvested produces 2 tonnes of stalk. According to the Ministry of Agriculture, sorghum production in Burkina Faso totalled 1 730 000 tonnes in 2016/2017. Considering a harvest area of 1 620 000 ha, this represents an average yield of 1.1 tonnes of grains per hectare. Based on the specific grain-to-residue ratio, total sorghum residue production thus amounts to 3 460 000 tonnes.

However, the fraction of the total biomass production ultimately available for bioenergy will depend upon its competitive uses as well as harvesting, storage and logistics constraints. While production of sweet sorghum for biofuels undoubtedly provides important income to dryland farmers, selling sorghum stover to distilleries, instead of keeping it on-farm and using it to feed livestock may add to problems of fodder scarcity. However, once the sorghum juice for ethanol production has been extracted from the stalks, the bagasse (stalk residue) provides an alternative nutritious animal feed rich in micronutrients and minerals in lieu of the original crop residues. Therefore, a markdown of 50 per cent is be applied. As a result, only 50 per cent of the calculated feedstock potential, i.e. 1 730 000 tonnes, are assumed to be available for transport fuel production without significantly impacting food supply.

The sorghum juice can be directly fermented to produce ethanol fuel. Plant size is the main trait influencing bioenergy yield. In addition, ethanol yields are dependent not only on the amount of fermentable sugar in the plant, but also on the presence, amount and types of inhibitory molecules, such as lignin and ash, and the total amount of biomass produced per plant. Notwithstanding variation in biomass traits in diverse sorghum genotypes, the average ethanol productivity can be estimated at approximately 200 g ethanol per kg of original stem. Considering the energy density of ethanol (0.789 kg/m3), 1 tonne of sorghum dry stalk theoretically produces about 254 litres of ethanol, equivalent to roughly 560 litres of ethanol per ha.

Based on the above parameters, Burkina Faso has a theoretical production capacity of 440 000 m3 or 4.4 x 108 million litres of sorghum-based ethanol. This converts to approximately 347 000 tonnes of ethanol and the equivalent calorific value of 107 gigajoule (GJ) or 1 750 000 boe.

3.1.2.2 Feedstock Conversion and Upgrading

Several methods have been explored for processing sweet sorghum stalks to extract as much juice as possible and to provide timely conversion of the collected sugar into ethanol via fermentation and distillation. Once the sorghum biomass feedstock has been converted into a clean burning fuel with a high-octane rating, the resulting ethanol can then be further processed into aviation fuel. To be considered an aviation fuel, ethanol needs to be upgraded to high-grade, long-chain kerosene. The two main sugar-to-jet conversion pathways that are being investigated by the industry involve the AtJ route and the Synthetic Iso-Paraffin (SIP) route. However, both processes are still in their pre-commercial stage. To support the ASTM SIP-certification process, only a small-scale demonstration plant, producing approximately 24 000 tonnes per annum of farnesene has been operated in Brotas/Brazil. A more detailed overview of lignocellulosic biomass conversion pathways is provided in Section 3.2.4.

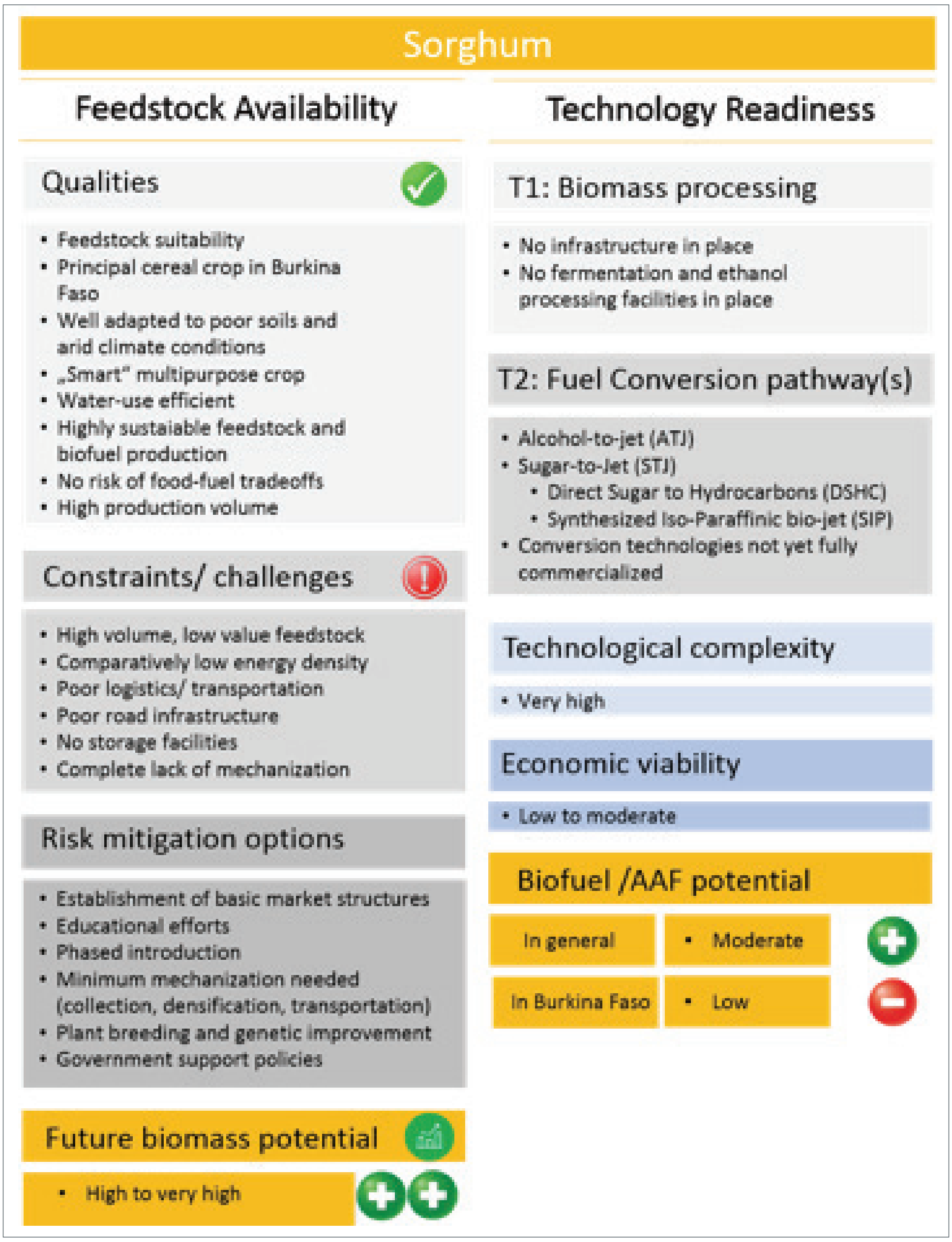
3.1.2.3 Challenges and Constraints

Burkina Faso enjoys ample availability of low cost biomass resources. While the potential of sweet sorghum makes it attractive, sorghum stalks and plant residues represent a high volume, low value feedstock. As a result, logistics, infrastructure and mechanization are of major concern. The huge quantities of biomass required to support commercial scale operations make transport and logistics very challenging. Due to their low energy density, large amounts of biomass are required to feed potential production facilities. Handling this bulky material can be expensive and uneconomical outside of a given radius. Poor road infrastructure and the lack of adequate storage facilities further complicate the establishment of an efficient supply chain. Finally, the low level of mechanization in Burkina Faso is a important impediment towards advancing the agricultural sector in general and promoting the cultivation, harvesting and processing of bulk biomass in particular.
Farm power in West Africa relies to an overwhelming extent

on manual labour, based on operations that depend on the hoe and other manual tools. Such tools have implicit limitations in terms of energy and operational output, particularly in a tropical environment. These methods place severe limitations on the amount of land that can be cultivated per family. They reduce the efficiency of farm operations and limit the efficacy of essential activities such as land preparation, cultivation, weeding harvesting and post-harvest operations, thereby reducing crop yields.

Use of tractors is particularly limited in Western Africa. According to the FAO, less than 8 per cent of cultivated areas in Western Africa are cultivated by tractor. The availability and use of tractors is concentrated in relatively few States (Côte d'Ivoire, Guinea, Nigeria). Pursuant to census data collected by the French agricultural research and international cooperation organization CIRAD, the total number of tractors operating in Burkina Faso in 2006 was 8 600 which represents only 14 tractors per 100 km2 of arable land, used on only 0.4 per cent of all farms (cf. Side, *Stratégie de mécanisation de l'Agriculture familiale en Afrique sub-saharienne).* This compares to 130 tractors in Brazil, 200 in India, 257 in the U.S. and 728 in the UK. Before examining biomass and alternative fuel production potential in Burkina Faso, the question must be asked whether long-term sustainable growth of the agricultural sector is possible replying largely on hand tool technology.

3.1.2.4 Feasibility Matrix



3.2 LIGNOCELLULOSIC BIOMASS

Due to the limited availability of sugarcane, second-generation lignocellulosic fuels may offer a viable alternative as regionally appropriate feedstock. Lignocellulose can be derived from one of four main sources: (1) agricultural residues; (2) wood residues; (3) food waste; and (4) specific energy crops. With regard to local agro-economic and climate conditions as well as traditional cultivation practices in Burkina Faso, agricultural residues suggest further analysis.

3.2.1 AGRICULTURAL RESIDUES

Agricultural residues and more specifically agricultural crop residues constitute a large biomass resource and are potential raw materials for producing several high-value products like fuel ethanol, biodiesel and bioelectricity. Agricultural residues consist of the lignocellulosic material, including the stalks and leaves, left over once the edible portion of the plant, such as the grain, has been extracted. Agricultural crop residues include a wide range of plant parts and biomass materials such as corn stover, straw, husks, stalks and leaves produced during the cultivation and harvesting of crops that are typically not removed from the fields with the primary food or fibre product. Cereal crop farming activity generates very significant quantities of straw residues (over 60 per cent of the total crop, dependent on water and nitrogen availability) that are usually left on the cropland to retain soil nutrients, or incinerated to prevent the spread of pests and uncontrolled fires. A certain fraction of the straw can be sustainably collected (leaving sufficient nutrients in the soil) and used for energy conversion at a biorefinery. The biomass residues contain varying amounts of cellulose (glucose polymers), hemicellulose (polymers consisting of different sugar monomers with both, five and six carbon atoms), lignin and small amounts of lipids, proteins, simple sugars and starches. The combination of cellulose, hemicellulose and lignin comprises around half of the plant matter produced by photosynthesis and represents the most abundant renewable organic resource on earth.

Lignocellulosic biomass resources represent an important future source of renewable energy. Arguably, the largest potential for alternative fuels is routed in a process that makes use of abundant low-cost cellulosic feedstocks. However, the effective utilization of lignocellulosic feedstock is not always practical because of its seasonal availability, variable quality and the high costs of transportation and storage. In addition, the lignin fraction increases the rigidness of the feedstock and might complicate the conversion to biofuels. Depending on the properties of the specific feedstock, lignin can contain as much as 50 per cent of the original biomass energy content. This would most likely lower the overall conversion efficiency. The lignin fraction can, however, be used for other purposes, such as co-firing for heat and energy.

Several factors are important in assessing the suitability of agricultural residues as a feedstock for biofuels. These include the total crop yield, the amount of residue produced, the composition of the crop, and the inherent energy content.

3.2.1.1 Rice Residues

3.2.1.1.1 Feedstock Suitability

After sorghum/millet, maize and cotton, rice is ranked number four in terms of production and consumption. Rice production in Burkina Faso is promising. It employs more than 150 000 smallholder rice farmers and yields are comparatively good. However, the actual national rice production of roughly 270 000 tonnes barely covers 45 per cent of the current consumption needs. As a result, the country has had to resort to rice imports for more than 330 000 tonnes per year over the last six years to meet local demand.

Rice production in Burkina Faso is either fully irrigated, irrigated by water containment (lowland), or strictly rain fed. Yields vary accordingly and can range from 1 tonne/ha (rain fed), to 4 out 7 tonnes/ha (fully-irrigated) as a result of the double cropping season made possible by having full water control. While irrigated rice growing accounts for less than 20 per cent of the rice land area, it provides around 55 per cent of national rice production. In comparison, lowland rice production accounts for about 70 per cent of the rice land area and supplies 40 per cent of national rice production, while strictly rain fed rice growing takes up about 10 per cent of the rice land area and provides 5 per cent of national rice production. Lowland rice growing is the most widely practiced traditional form of production throughout all regions of Burkina Faso, whether on sites with water control (traditional non-developed lowlands) or with partial-control (simple developed lowland or improved lowland). The figures for rice growing potential show 500 000 ha of workable land area of which less than 15 per cent has been developed. The production of rice is still based on a high level of manual labour input. The rice is usually harvested by sickle, and left in the field for drying. The stubble is partly burned, and partly incorporated into the soil to improve the organic matter.

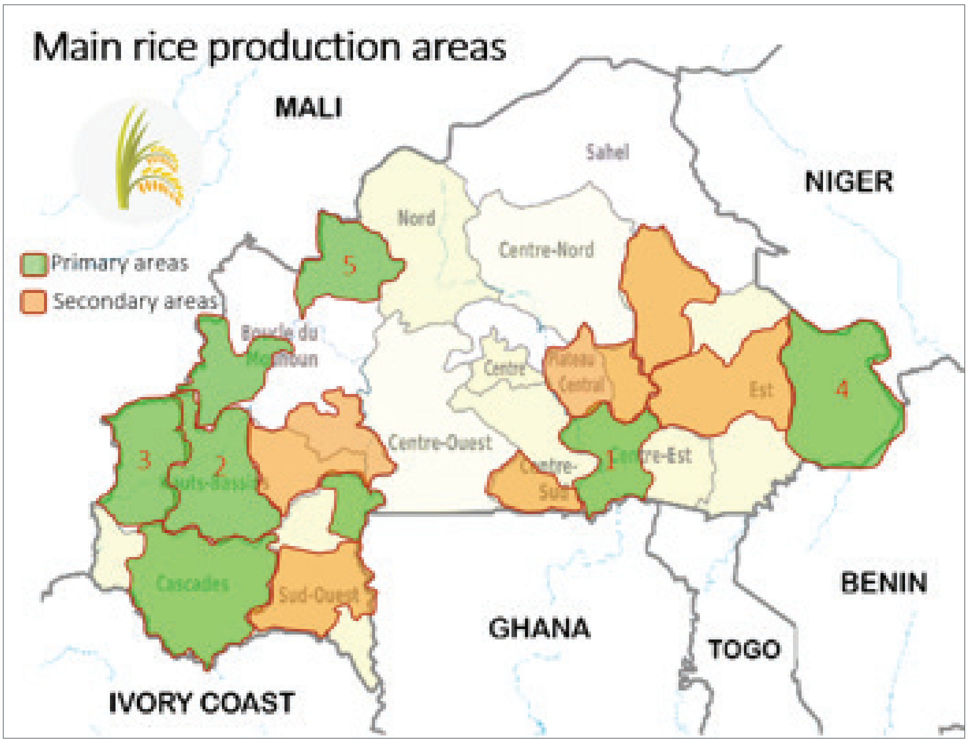


FIGURE 14
Main rice production areas

The main rice producing areas include Boulgou *(Centre-Est)*, Houet *(Hauts-Bassins)*, Kénédougou *(Hauts-Bassins)*, Tapoa (Est) and Sourou *(Boucle de Mouhon)*. Profiting from irrigation opportunities offered by the Bagré dam on the White Volta river in the Centre-East in the province of Boulgou, rice production in Centre-East alone accounts for 23 per cent of the country's rice production. Bagré is a priority region because of its proximity to market, good transport links to Ouagadougou, the recent expansion of irrigated land from 1 800 ha to over 20 000 ha in 2016 and the importance of rice for local smallholders as a cash and staple crop.

To evaluate the theoretical energy and biofuel potential of rice residues in Burkina Faso, the available amount of feedstock needs to be calculated. Quantification depends on the annual production of rice and the underlying grain-to-residue ratio. The cultivation of rice results in two major types of residues, straw and husk, having attractive potential in terms of energy.

Rice straw is the vegetative part of the rice plant *(Oryza sativa L.)*, cut at grain harvest. It is one of the abundant and unused lignocellulosic waste materials in Burkina Faso. Rice straw predominantly contains cellulose (32 to 47 per cent), hemicelluloses (19 to 27 per cent), lignin (5 to 24 per cent) and ashes (18.8 per cent). Rice straw is separated from the grains after the plants are threshed manually. Reflecting the low degree of mechanization, most farmers do not have access to threshing machines.

Rice husks are the most prolific agricultural residue in rice producing countries around the world. Rice husks, the main by-product from the rice milling process, are the hard coating that are protecting the edible grains of rice; they constitute about 25 per cent of paddy weight. Rice husks which consist mainly of lignocellulose and silica are currently not utilized to any significant extent in Burkina Faso. Nevertheless, they have potential as an alternative source of energy. A rough analysis of the underlying calorific values illustrates the importance of rice husk and rice straw as viable sources of energy. Assuming an average grain-to-husk ratio of 0.25, one tonne of rice produces 250 kg of rice husk with an average energy content of 15 MJ/kg at 5 to 12 per cent moisture content and a calorific value equivalent of 3 600 kcal/kg.

In comparison to the husks, it is more difficult to calculate the potentially available volume of rice straw. Depending on plant varieties, cutting-height of the stubbles, soil quality and moisture content during harvest, straw biomass is subject to large fluctuations. Considering an average grain-to-straw ratio of 0.75, one tonne of milled white rice approximately produces 750 kg of straw with an energy content of 12.5 MJ/kg at 10 per cent moisture content and a calorific value equivalent of 3 000 kcal/kg. Rice production in Burkina Faso is estimated at 274 000 tonnes in 2016/2017. Considering a harvest area of 172 000 ha, this represents an average yield of 1.6 tonnes of milled rice/ha.

Based on the specific grain-to-residue ratio, as further outlined in **Table 5**, the theoretical residue potential thus amounts to 68 500 tonnes per year for rice husk and to 205 500 tonnes per year for rice straw. The availability factor of rice straw and rice husk largely depends on the region, collection practices and potential competitive uses.

With regard to rice husk, about half of the husk produced from rice mills is usually burned for the generation of steam to drive mechanical milling equipment. Thus, on average only 50 per cent of the total feedstock potential (34 250 tonnes), will ultimately be available for energy conversion. Given its high cellulose and hemicellulose contents, the remaining husk can be processed into ethanol.

Concerning rice straw, removing the entire straw remaining on a field after harvest is not feasible because residues are important to maintain soil nutrients, moisture, and erosion control. The amount of residue that can be sustainably removed from a field depends, inter alia, on soil organic carbon, wind and water erosion and plant nutrient balance. In the present context, using the amount of straw for energy, which is currently used as fodder for cattle, is not considered to be socially and economically sustainable. In addition, logistics, poor mechanization, poor road infrastructure and the lack of adequate storage facilities are major hurdles for the organization of an efficient and cost-conscious residue supply chain. Assuming that 25 per cent of plant residues are required for soil enhancement and another 25 per cent are currently used for fodder, relevant availability discounts would be applied. As a result, only 50 per cent of total rice straw production (102 250 tonnes) would be considered as potentially available for energy conversion and fuel production.

Considering specific energy density and calorific value parameters of husk and straw, 34 250 tonnes of rice husk have an energy content of 514 000 GJ which equals 87 650 boe. In addition, 102 250 tonnes of husk convert to 1 280 000 GJ and 218 400 boe respectively (see **Table 5**).

3.2.1.1.2 Energy Recovery and Conversion Processes

Rice husk

Although technology solutions for rice husk utilization are well-proven, processing and conversion technologies have not yet been introduced to Western Africa. Rice husk can produce fuels, heat, or electricity through either thermal, chemical, or biological processes. For example, rice husk can be used for power and electricity generation or as feedstock in the rice mills to generate steam for the parboiling process. In Asia, about half of the rice husk generated during milling is usually burned for the generation of steam to drive mechanical milling equipment. Thermal energy recovery processes which may include combustion, gasification, and pyrolysis, typically lead to alternative energy products, such as heat, bioelectricity and syngas.

Alternatively, rice husk could also be transformed into ethanol which serves as a precursor for the upgrading into liquid hydrocarbons, such as alternative fuels. As this process basically relates to the conversion of cellulose and hemicellulose, process details will be analysed collectively for all agricultural residues and energy crops that contain lignocellulosic components suitable for conversion into renewable hydrocarbons (Section 3.2.4 refers in more detail).

TABLE 5
Rice Straw and Husk: Grain-to-Residue-Ratio

Rice straw and rice husk potential for bioenergy production in Burkina Faso

Residue Type	Total Residue Production (t)	Grain-to-Residue Ratio	Discount Factor/ Markdown	Residue Availability for Conversion and Fuel Production (tonnes)
Straw	205,500	4:3 (0.75)	50% (25% fodder + 25% logistics constraints)	102,250
Husk	68,500	4:1 (0.25)	50% (combustion/ milling)	34,250

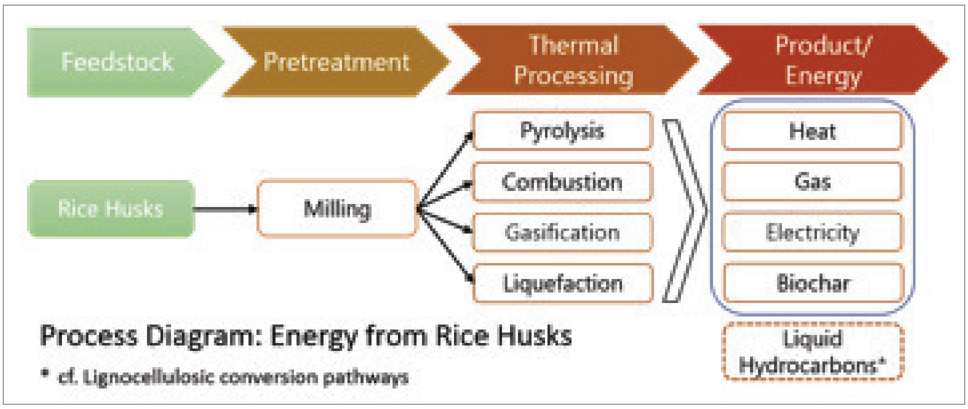


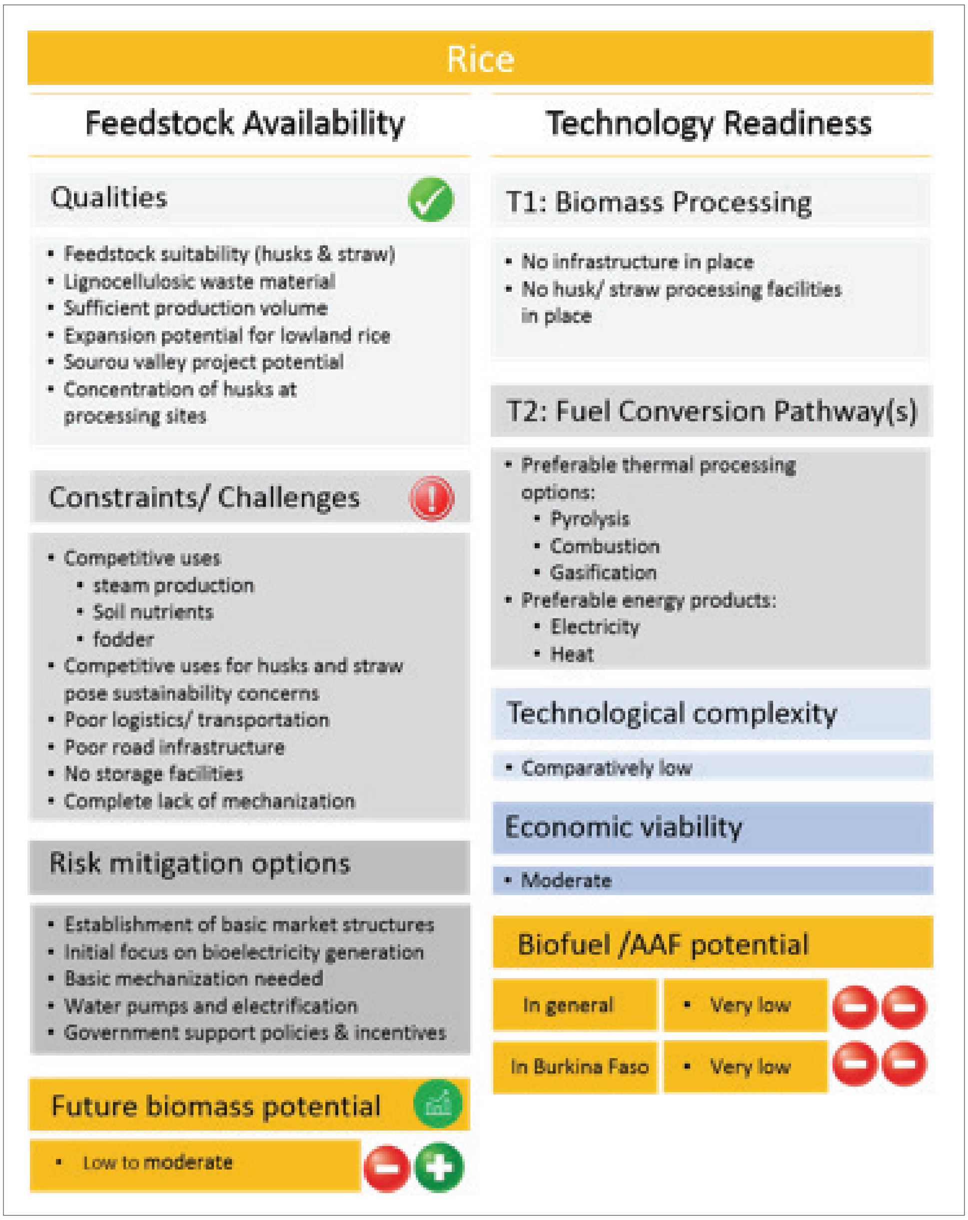
FIGURE 15
Rice husk energy conversion process

Rice Straw

Rice straw can either be processed alone or mixed with other biomass materials in direct combustion, whereby combustion boilers may be used in combination with steam turbines to produce electricity and heat in straw fired cogeneration plants or combined heat and power plants (CHP). For example, the surplus straw from cereal grains plays a large role in the renewable energy strategy of Denmark.

Given its cellulose and hemicellulose components, rice straw equally qualifies as feedstock for ethanol and fuel production (Section 3.1.1.2 refers in more detail).

3.2.1.1.3 Feasibility Matrix



3.2.1.2 Corn/ Maize

3.2.1.2.1 Feedstock Suitability

According to FAO data, maize is the most widely-grown staple food crop in sub-Saharan Africa, occupying more than 33 million ha of land and providing a source of food and livelihood for more than 300 million people. Maize accounts for one-fifth of the calories and protein consumed in West Africa. Over the past decades, maize has become the most marketed and exported cereal in Burkina Faso. It now accounts for 30 per cent of total grain production. In addition to its nutritional values maize also represents a substantial source of stored energy.

While corn starch has been a highly-contested feedstock for ethanol production because of its obvious competition with food production, particularly in the U.S., this section addresses the potential of cellulosic ethanol production not from corn grains, but rather from the utilization of the agricultural residues from maize cultivation, i.e., the cellulosic (non-food) portions of maize. These other parts of the corn plant include primarily corn stover, which is a by-product of corn grain production. Corn stover is a broad term which describes almost all of the above-ground biomass from the corn crop except the grain. This biomass is comprised of structural components including stalks, cobs and leaves. When maize is harvested in the field, the corn grain is separated from the cobs, stalks, and leaves. While the grain is transported for storing and processing, the stover is currently not widely collected or used for alternative purposes. Unlike the corn grains, of which the major component is starch, the main components of corn stover are cellulose, hemicellulose, and lignin. Cellulose and hemicellulose are potential sources of fermentable sugars for ethanol production. Cellulose conversion technology consists of pre-treatment, hydrolysis and fermentation using yeast or other microorganisms. In contrast to grain-based feedstocks, cellulose-based ethanol production requires microorganisms that are capable of producing ethanol from both glucose and xylose.

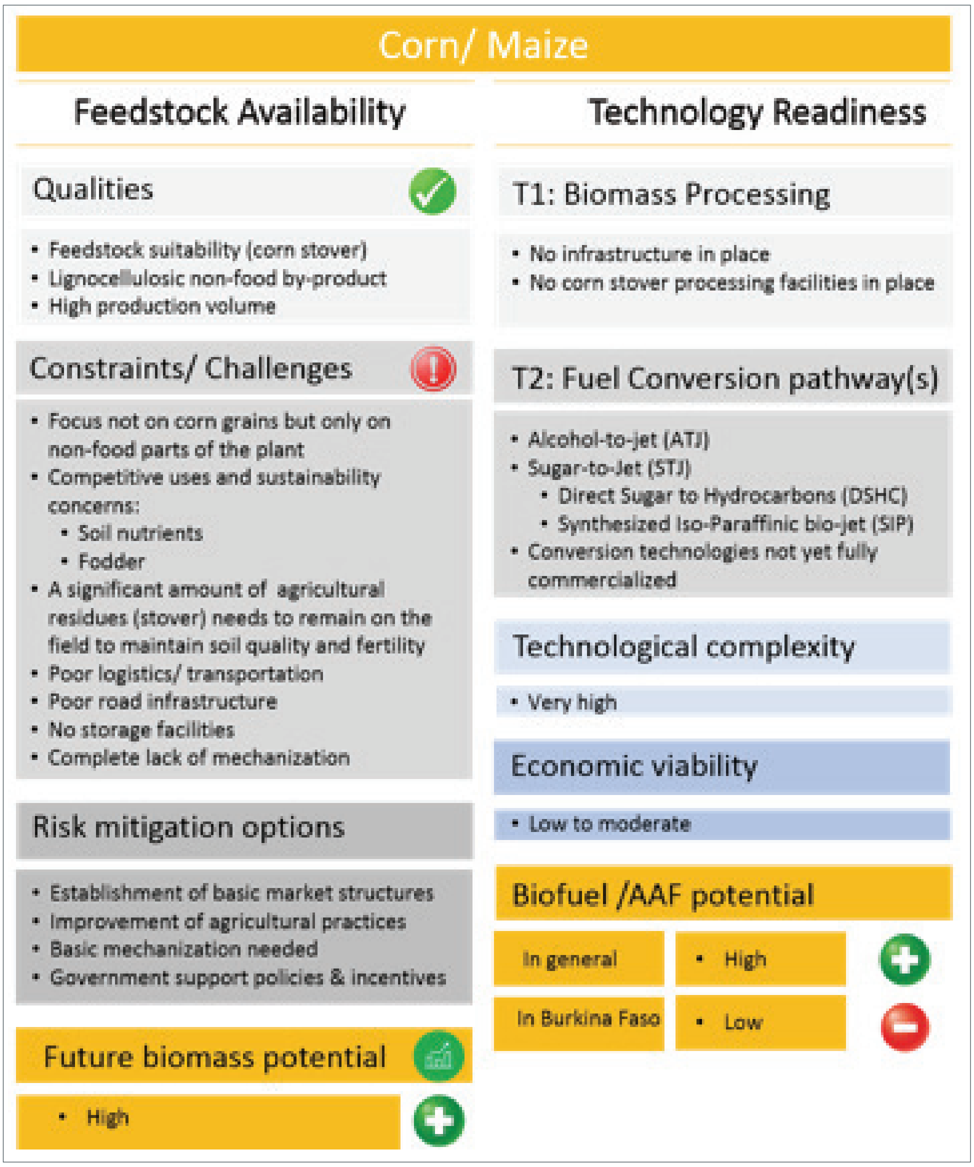
For further process details, refer to the analysis of lignocellulosic conversion pathways.

According to the Ministry of Agriculture, annual maize production in Burkina Faso averages 1.5 million tonnes. In line with plant specific water requirements, main production areas cover 790 000 ha and are concentrated in the provinces of Kénédougou, Houet, Tuy and Comoé in the south-western regions of Hauts-Bassins and Cascades (**Figure 16**). While the average yield in Burkina Faso of 1.9 tonnes per ha is about 20 per cent higher than the regional average yield in East Africa, it is still far below the global average yield of maize (~ 5 tonnes/ha).

FIGURE 16
Main maize production areas

Assuming an estimated grain-to-stover ratio of 7:6, one tonne of grain harvested will produce 0.86 tonnes of corn stover with an average energy content of 16.5 MJ/kg. Applying this ratio to the annual maize production will theoretically result in 1 286 000 tonnes of stover. However, as corn stover contains vital fertilizer nutrients, its complete removal could lead to lower soil organic matter or carbon levels. Since costly commercial fertilizers are no replacement option, a significant amount of stover therefore needs to remain on the field to maintain soil quality and fertility. For those reasons, only about 50 per cent of corn stover shall be considered available for collection and energy conversion. As a result of assumed collection and storage inefficiencies, another 15 per cent needs to be deducted. This still leaves 450 000 tonnes of crop residue feedstock for cellulosic ethanol production. Considering specific energy density and calorific value parameters, 450 000 tonnes of corn stover have an energy content of 7 425 000 gigajoule (GJ) which equals 1.27 million boe. If sustainable, low cost, and environmentally compatible agricultural practices and supply chains can be developed and coupled to cellulose conversion technology, the non-food components of maize production in Burkina Faso have the potential to provide 1.27 million boe per year.

3.2.1.2.2 Feasibility Matrix



3.2.2 FOREST RESIDUES

3.2.2.1 Feedstock Suitability

In addition to agricultural biomass, woody biomass or forest-derived biomass represents one of the largest sources of feedstock for renewable energy today. Examples include small size stems, branches, forestry thinning and tree stumps as well as sawdust, wood fuels and by-products of managed forest plantations. Wood fuels, in general, include all fuels consisting of wood matter, such as wood pellets, wood briquettes and wood chips, but also manually collected forest-derived biomass, such as branches, twigs and other forest residues. Forest plantations are not restricted to produce wood for industrial purposes, but can also deliver large amounts of wood for energy generation and fossil fuel replacement. So-called short rotation forestry plantations with fast-growing tree species and rotations shorter than 20 to 25 years are increasingly being established as a source of renewable energy.

The energy content of wood has little variation in calorific value between species when tested at the same moisture content. The calorific heating value of dry matter varies slightly from one tree species to another (~ 18 to 22 MJ/kg), being slightly higher in coniferous than in deciduous tree species. This is caused by the higher lignin and resin contents in coniferous species. According to the US Environmental Protection Agency (EPA) the calorific value of woody biomass equals 8 400 Btu/lb. This converts to 19.5 MJ/kg.

From a technical perspective, various pathways have been developed and are being commercialized to convert woody biomass into energy. Woody biomass can be used indirectly by transforming it first into various other forms of solid, liquid or gaseous fuels. As has been practiced throughout history, wood can, for example, be converted into charcoal via partial pyrolysis. Converting forest-derived biomass into SAF would require a combination consisting of gasification and Fischer-Tropsch (FT) conversion of the synthesis gas into aviation fuel. Many Scandinavian countries are demonstrating how biofuels can be an important part of the forestry industry value chain. Major players in the Norwegian power and forestry industries are exploring the possibility of forest-based large-scale SAF production .

3.2.2.2 Challenges and Constraints

While woody biomass and forest residues seem well-suited for conversion into SAF, competing utilizations, logistic constraints and capital requirements may still limit the total energy recovery potential. In the case of Burkina Faso, competitive uses may be particularly relevant.

Forests are the main natural resources of Burkina Faso. They cover roughly 5.5 million ha, equalling 20 per cent of the national territory. However, this does not automatically indicate the availability of forestry biomass as a potential domestic source for aviation fuel production. Independent of sustainability, transportation and economic viability considerations, biomass availability greatly depends on traditional practices and customs. Not only in Burkina Faso but throughout Western Africa, forests play an important role in the social, cultural and economic life of people. Fuelwood and charcoal production are the predominant use of woody biomass. In Burkina Faso, forest-derived biomass and especially fuelwood account for 90 per cent of total energy consumption. No matter how inefficient traditional heating and cooking methods may be, this dependency on fuelwood for daily basic energy needs and the related depletion of forest resources is expected to continue and even accelerate over the next few years.

PICTURE 7
Burkinabe women collecting wood fuel

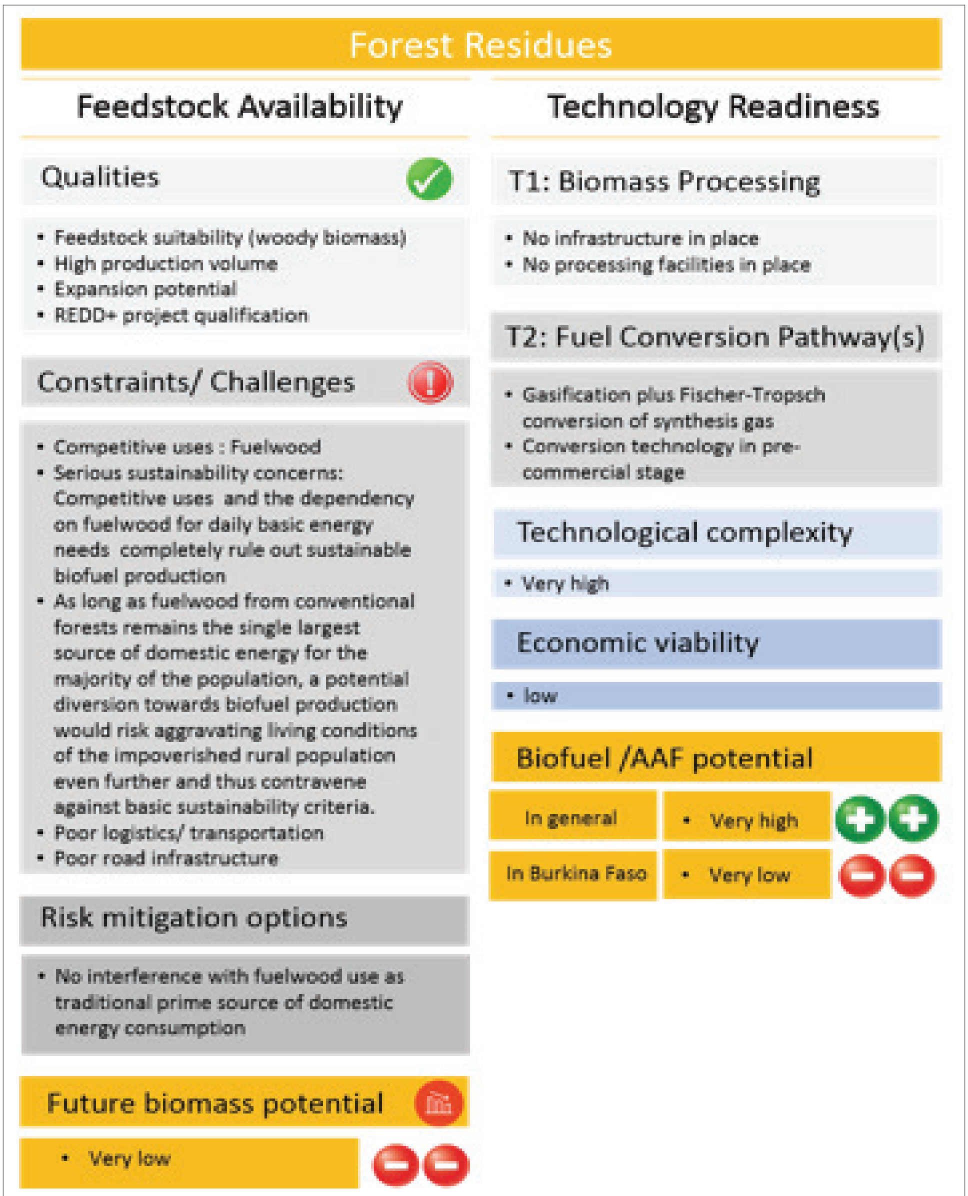
> **As it has become harder to find wood in many zones where forest resources have deteriorated, women and children are required to walk for hours, searching for wood across wider areas.**

On average, Burkina Faso produces some 15 million m^3 of fuelwood annually. Depending on the specific density, this translates into roughly 10 million tonnes. Assuming an average calorific value of 20 MJ/kg, the energy potential equals 2 x 108 GJ or 34 million boe. Nevertheless, fuelwood consumption needs still exceed supply by 40 per cent. The average per capita consumption of fuelwood is two times greater in cities than in rural areas, leading to an over-exploitation of wood resources and a gradual exhaustion of these resources in a large radius around the cities. The process has progressed so far that the supply range for wood to the city of Ouagadougou is approximately 200 km, reaching as far as the Southwest, Centre-West and Eastern regions.

It is estimated that around 110 000 ha of forest are lost each year. Demographic trends, as well as economic and environmental changes have put pressure on almost all of the region's forests, leaving a degraded landscape stricken with erosion, drought and infertile soils. With poverty, population growth and climate hazards as the underlying drivers, agricultural expansion and fuelwood consumption are considered as the major causes. The rate of deforestation and traditional fuelwood utilization preclude any competing use for biofuel production. As long as fuelwood from conventional forests remains the single largest source of domestic energy for the majority of the population, a potential diversion towards biofuel production would risk aggravating living conditions. Even the introduction of improved fuel-efficient cook stoves or alternative sources of energy like solar or biogas are not expected to free up bioenergy potential for alternative uses in the near future.

As a result, potential woody biomass may only become available through reforestation and/or afforestation[17] efforts. In this context, managed forest plantations of fast growing trees on degraded and otherwise unproductive land may offer an alternative solution. Achieving a conversion of non-managed, degraded land into managed forest plantations that combine land restoration with sustainable bioenergy production, while maintaining ecosystem services and traditional community needs is a challenge. Even if afforestation initiatives focused on fast-growing tree species like acacia, eucalyptus, Calliandra calothyrsus or Gliricidia sepium; involved local communities; and were in line with the country's development of a national REDD+ programme and the World Bank funded "Forest and Woodland Management Project", it is unlikely that such initiatives could free up sufficient bioenergy potential for the production of SAF. Independent of the actual afforestation rate and the average forest plantation productivity, the supply shortage of fuelwood is simply too large to meet the needs of the population. This will exclude alternative uses for the foreseeable future.

3.2.2.3 Feasibility Matrix



[17] Afforestation is the establishment of trees on barren land that once supported natural forest cover but has been cleared for other land uses, typically agriculture, generally a long time ago.

3.2.3 DEDICATED ENERGY CROPS (ELEPHANT GRASS)

3.2.3.1 Feedstock Suitability

Beyond wastes and agricultural residues there are also dedicated energy crops that can be cultivated specifically to use their lignocellulose as potential renewable feedstock for alternative fuel production. Dedicated energy crops that can convert solar energy into biomass at a high efficiency ratio include herbaceous woody crops, short rotation forestry crops such as willow or poplar and perennial grasses such as miscanthus or switchgrass. Key characteristics of these energy crops are their low fertilizer-input requirements, low energy cultivation, and ability to grow on marginal land.

In theory, large areas of either marginal, degraded or otherwise non-arable land are available in Western Africa. Confining the cultivation of bioenergy crops to arid and semi-arid regions (such as the South-Sahelian and North-Sudanian climate zones, as indicated in **Figures 17 and 18** below) that are unsuitable for food production because of severe soil, terrain or water constraints, seems an attractive option. The systematic and targeted identification of areas considered degraded or “marginal” would not only prevent any potential food-vs.-fuel conflict, but may actually improve food security and self-sufficiency of Burkinabe farmers as some crops could help to mitigate erosion processes, restore degraded soils and improve soil organic matter.

FIGURE 17
Agro-ecological zones

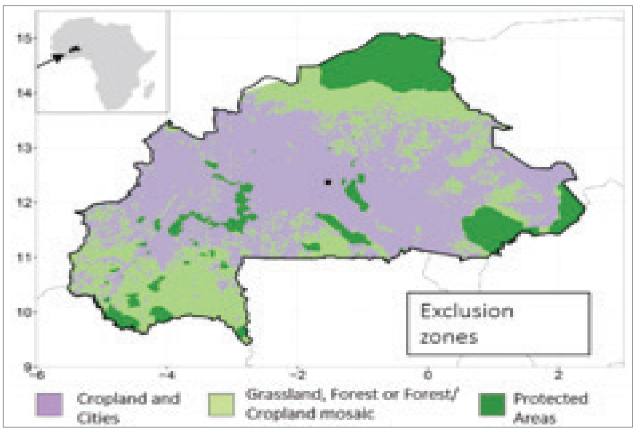


FIGURE 18
Exclusion zones

In Burkina Faso, the South-Sahelian zone which experiences rainfall of less than 600 mm per year and the North-Sudanian zone with an average annual precipitation between 600 and 900 mm, are of particular interest. Land covers in these agro-climatic zones include scrubland steppe and tiger bush in the north, and shrub savannah and annual grasses further south. While unsuitable for cultivation of traditional food crops such as cereal, these tropical and subtropical marginal areas with poor fertility still provide acceptable growing conditions for high yielding and drought tolerant tropical energy grasses and perennial energy crops, such as elephant grass (Pennisetum purpureum), also known as napier grass.

Elephant grass is a species of perennial tropical grasses native to the African steppe. It is an abundant, fast growing herbaceous plant with significant potential as a renewable energy source and as a feedstock for biofuel processing. Elephant grass has low water and nutrient requirements, and therefore can thrive on non-arable and marginal lands. Independent of its energetic and carbon sequestration potential, elephant grass provides a valuable upgrade to Burkinabe landscapes as it prevents and reduces soil erosion. In addition, elephant grass can restore biodiversity of degraded soils and improve overall soil condition. It can also serve as a fire and wind break. While causing lower environmental impacts, lignocellulosic energy crops such as elephant grass typically yield more biomass per hectare than conventional crops. Given its unique characteristics, elephant grass is being promoted, for example, by the Government of Thailand. The National Energy Policy Council has raised the target of power production from this energy crop to 3 000 MW under a 10-year alternative energy development plan (2012 to 2021).

However, the limited experience with growing energy crops on a larger scale in Burkina Faso makes it difficult to predict their future potential as a biomass source for sustainable fuel production. One of the key factors determining whether dedicated energy crops grown in Burkina Faso can be utilized for SAF production will be the yield per hectare.

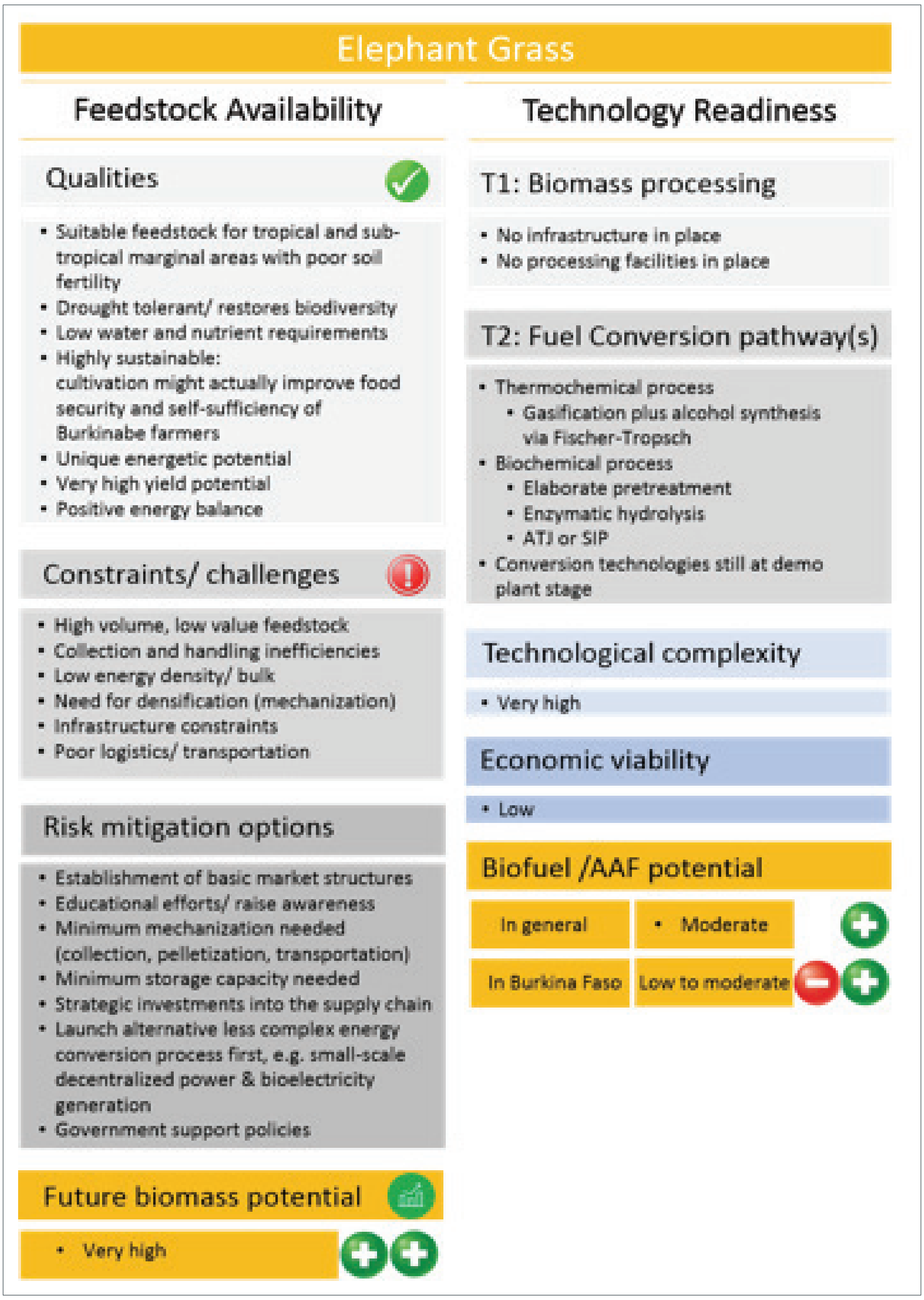
Elephant grass typically has a higher energy output/input ratio in comparison to most other energy crops. It is more adapted to hot seasonal conditions under dry environments and converts solar radiation more effectively during photosynthesis, implying a higher yield potential. The reported biomass productivity of elephant grass ranges from 5 to 43 tonnes/ha annually which corresponds to 100 boe equivalent per hectare.

Cultivation of elephant grass follows conventional farming practices. It out-competes weeds and needs no supplementary nutrients, which in return translates into comparatively low establishment costs. Elephant grass has a very positive energy balance with a ratio of energy output to energy input of up to 25:1, hence making it one of the best potential energy crops for development of efficient and economic bioenergy systems.

3.2.3.2 Challenges and Constraints

While large-scale biomass production seems feasible in Burkina Faso and dedicated energy crops like elephant grass may appear to be an attractive fuel source, expected collection and handling costs must be taken into consideration. The low level of mechanization in Burkina Faso is a huge impediment towards advancing the agricultural sector in general, and promoting the cultivation of energy crops, in particular. The major challenges relate to the processing infrastructure and the establishment of a low-cost biomass supply chain. With a ratio of less than 15 agricultural tractors per 100 km^2 of arable land in Burkina Faso, the envisaged renewable energy supply chain will primarily depend on manual labour. However, tropical grasses are a high-volume, low density business that require at least some basic machinery and motorized farm equipment for harvesting, feedstock collection, and storage. As most biomass resources have a low density, they can only be processed economically if they are made more dense. This will require some degree of compaction into a more manageable form, which means that investments in pelleting facilities may be needed. Transportation is also a critical factor in the use of bulky tropical grasses, and as a result, distances are to be kept short so as not to incur any unnecessary expense if the feedstock is to remain economically attractive as a fuel source.

3.2.3.3 Feasibility Matrix



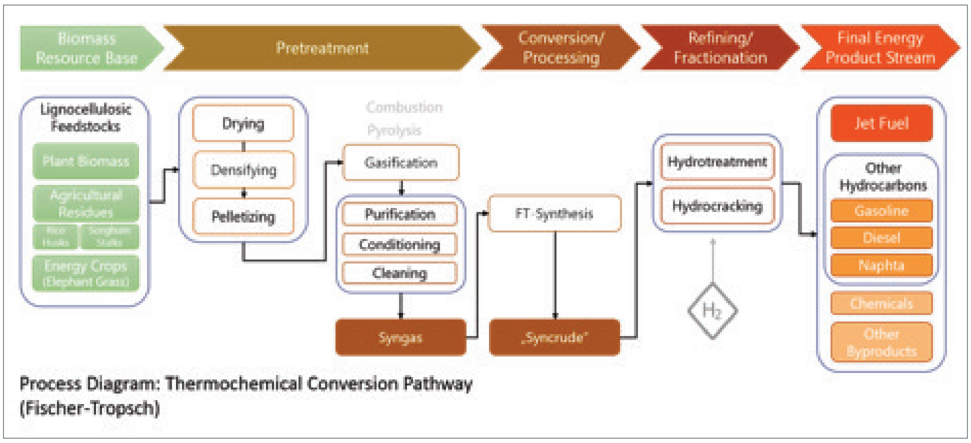
3.2.4 LIGNOCELLULOSIC CONVERSION PATHWAYS

In general, lignocellulosic feedstocks such as agricultural residues and dedicated energy crops can be converted into energy (e.g. heat or electricity) or energy carriers (e.g. oil or gas) using both, thermochemical and biochemical conversion technologies. In the biochemical process, the cellulose and hemicellulose are enzymatically hydrolysed into soluble sugars and then fermented by yeast or bacteria to produce ethanol. Conversely, the thermochemical process produces ethanol via gasification and mixed alcohol synthesis.

3.2.4.1 Thermochemical Process (Fischer-Tropsch Synthesis)

The thermochemical process first transforms lignocellulosic feedstocks into a synthesis gas via gasification under high temperature and pressure. The purified and conditioned syngas which consists of carbon monoxide and hydrogen can then be converted into numerous gaseous and liquid chemicals and liquid hydrocarbon fuels using FT synthesis and catalysts. Final upgrading steps during the refining process include hydrotreatment and hydrocracking. Typically, cellulosic biomass-derived syngas needs to be enriched in hydrogen and cleaned of impurities such as tars, nitrogen and other atoms comprised of anything other than carbon or hydrogen. FT fuels are typically free of sulphur and contain very few aromatics compared to gasoline and diesel, which leads to lower emissions when used in jet engines. Fuels produced by FT synthesis were first certified as alternative aviation fuels in 2009. A generic FT fuel certification was approved by ASTM for up to 50 per cent blending into current aviation fuel. While the biomass-based FT process is proven at a demonstration plant size, scaling up the capital-intensive process remains challenging. Technical challenges and the difficulty of raising finance for capital intensive projects have led to a lack of biomass gasification and catalytic synthesis projects at commercial or large demonstration scale. Few operational or planned projects currently exist globally for methane and mixed-alcohol synthesis.

FIGURE 19
Thermochemical conversion process



3.2.4.2 Biochemical Process

The cellulose-to-ethanol process may also follow a biochemical pathway using enzymatic hydrolysis. Enzymatic hydrolysis first transforms lignocellulosic biomass to fermentable C5 and C6 sugars including glucose and/or oligomers that can then be further converted into valuable intermediate products through biological or chemical approaches. The biochemical conversion of cellulosic biomass to fuels and chemicals through enzymatic hydrolysis of hemicellulose and cellulose offers the potential for higher yields, higher selectivity, lower energy costs and milder operating conditions than thermochemical processes. However, lignocellulosic feedstocks typically require an extensive biomass pre-treatment to free cellulose and hemicellulose fractions from the lignin. During pre-treatment, the cellulose structure is disrupted, the lignin seal is broken, and the hemicellulose is partially removed. This increases the specific surface area that is accessible to enzymes.

Alcohol-to-Jet

Enzymatic hydrolysis may be followed by subsequent fermentation of the sugar molecules into alcohols using either yeast or bacteria. The intermediate products are then upgraded to alternative fuels through a number of conversion steps including catalytic oligomerization, distillation and hydrotreatment. This process is referred to as "Alcohol-to-Jet" (AtJ).

Synthetic Iso-Paraffin

Alternatively, the sugar molecules may also be converted directly to hydrocarbons without an alcohol intermediate product. While the microorganisms carrying out the fermentation can be genetically modified to optimize a highly-specialized fuel production, aerobic fermentation requires continuous supply of oxygen which increases operating costs. This process is referred to as "Synthetic Iso-Paraffin" (SIP).

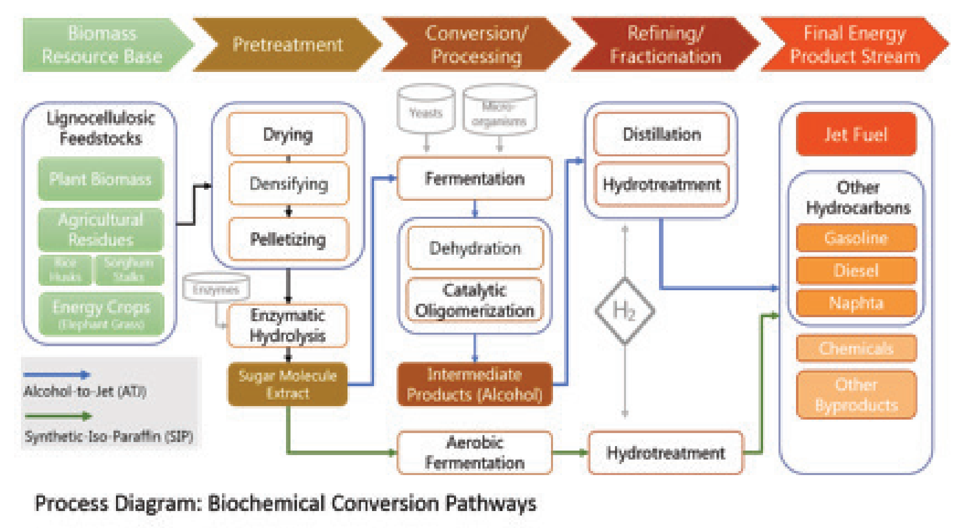


FIGURE 20
Biochemical conversion pathways

Figure 20 shows a simplified process sequence for ethanol production from lignocellulosic feedstocks. The main steps include preparation (size reduction) of biomass, pre-treatment to soften up and disrupt the structure of the cellulose, hydrolysis to break the cellulose down into sugars, and then fermentation of the sugar molecules. The final upgrading to aviation fuel differentiates the AtJ and the SIP processes.

Concerning biochemical conversion pathways, several companies are working on the commercialization of jet fuel from fermentation of biomass. However, for the time being, technology solutions that can convert and upgrade lignocellulosic feedstocks into alternative fuels are still in the pilot or demonstration phase, and not yet commercially available.

As for the thermochemical route, the first commercial biomass-gasification facilities are under construction in the U.S. and Finland. However, gasification technologies will entail high capital costs to both gasify the biomass and convert the resulting syngas to FT liquids. Production costs for SAF from lignocellulosic pathways are estimated to be USD 1 000 to 8 000/tonne, whereas current aviation fuel costs around USD 470 to 860/tonne. The actual purchase prices of agricultural residue-derived SAF for the U.S. Department of Defense ranged from USD 3 091 to 8 983/tonne[18].

It has been demonstrated that Burkina Faso offers a tremendous supply potential of low-cost cellulosic feedstock. Nevertheless, the inherent complexity and costs for the establishment of a seamless supply chain from the raw material resource base to a certified SAF still poses major challenges. A new conversion technology typically follows a risk- and cost-conscious development pathway from the initial lab-scale via small pilot and demonstration facilities to a commercial-scale processing plant. The large risk associated with scaling up fuel production from demonstration to commercial scale of capital-intensive synthetic fuel plants requires coordinated, predictable, and long-term government policies to ensure investor confidence. Depending on financial and political support, strategic industry partners and market developments, this process may take years. As available feedstock is not the limiting factor, chances are that a joint and well-coordinated initiative among ECOWAS States may improve time to market and positively impact commercial viability.

[18] Cf. International Council on Clean Transportation (ICCT), Sammy El Takriti et al., Mitigating International Aviation Emissions - Risks and Opportunities for Alternative Jet Fuels, March 2017; Erik C. Wormslev et al., Nordic Council of Ministers, Sustainable jet fuel for aviation, Nordic perspectives on the use of advanced sustainable jet fuel for aviation, 2016

3.3 WASTES

3.3.1 MUNICIPAL SOLID WASTE (MSW)

3.3.1.1 Feedstock Qualification

MSW, comprising food waste, residential rubbish and commercial waste, has long been identified as a potential feedstock for conversion into alternative fuels. The organic material found in household garbage is rich in hydrogen and carbon, the building blocks for aviation fuel and diesel. Contrary to traditional crop-based feedstocks, waste-based feedstocks have no competing uses, do not require additional land and resolve waste disposal problems. Conversion of MSW to fuel could not only displace petroleum-derived fuels and thus mitigate GHG emissions from transportation, but could also avoid methane and other the GHG emissions conventionally associated with MSW waste management and landfilling.

Landfilling waste of biogenic origin typically releases biogenic CO_2, as well as anthropogenic methane, which would not have otherwise been released. However, depending on the material considered, between 12 and 95 per cent of the carbon in the landfilled waste is sequestered in the soil, which is foregone if MSW is used for alternative fuel production. By avoiding the GHG emissions associated with existing waste management strategies, MSW could offer a significant environmental advantage. Thus, energy recovery from waste can play a role in minimizing the impact of MSW on the environment with the additional benefit of providing a local source of energy.

MSW landfills represent the dominant option for waste disposal in many parts of the world. In general, the comparatively high costs of treatment and disposal alternatives are a major reason for the reliance on MSW landfills, particularly in developing countries. Most of the time, the waste issues in urban areas of developing countries result from a lacking/limited/failing collection and disposal system for MSW. As a consequence, solid and liquid wastes are dumped on streets and open spaces. The indiscriminate and improper dumping of MSW in developing countries is increasing. Therefore, governments and municipalities in several sub-Saharan States are challenged on a regular basis with how to properly manage continuously growing quantities of municipal and industrial waste streams. In Burkina Faso, only Ouagadougou and Bobo-Dioulasso have controlled waste filling sites. According to the Mayor of Ouagadougou and the Head of the Sustainable Development Department of the Municipality of Ouagadougou, the city collects 1 600 tonnes of MSW per day, equalling 580 000 tonnes of household waste per year. While this amount has doubled between 2000 and 2017, hardly 3 per cent of it has been valorised or recycled.

The underlying calorific value of municipal waste and landfill gas generation largely depends on waste composition and ranges from 6 to 20 MJ/kg. As of June 2017, 6 per cent of the municipal waste collected in Ouagadougou consists of paper and carton, while plastics and biodegradable organic matter account for 15

PICTURE 8

Waste collection and sorting pose a logistics challenge

per cent and 36 per cent respectively, resulting in 87 000 tonnes of plastics and 210 000 tonnes of organic waste, annually. This is a potential source of energy worth considering for alternative fuel production, especially since the feedstock is free and the available quantity is poised to grow quickly, in line with the projected high population growth. All organic waste fractions can in theory be used in SAF production.

3.3.1.2 Conversion of MSW into SAF

Depending on the type of MSW used as feedstock, different technologies exist that can convert MSW into liquid fuels. Waste-to-Energy systems typically employ a combination of mechanical, biological or thermo-chemical processes to recover the energy stored in waste. These technologies include gasification, plasma gasification, plasma arc gasification, torrefaction, pyrolysis, thermal depolymerization, anaerobic digestion, mechanical biological treatment, and fermentation[19].

While several types of commercially viable technologies converting MSW into low-carbon renewable transportation fuels are currently in various stages of testing and piloting, a relatively mature conversion technology includes the gasification of biomass or MSW into a synthesis gas followed by FT conversion of the synthesis gas into jet fuel (see **Figure 22**). One of the most advanced processes has been developed by Fulcrum BioEnergy, a U.S.-based sustainable fuel developer; the proprietary thermo-chemical process is centred on the gasification at high temperatures (750oC to 1 500oC) of the organic material recovered from the MSW feedstock and consists of three successive steps:

1. Material processing facility prepares MSW for fuels process; (includes extraction of commercially recyclable material and inorganic waste before delivering a sorted and processed MSW feedstock to the biorefinery);
2. Steam reforming gasification system converts MSW to synthesis gas (“syngas”);
3. FT process converts synthesis gas to syncrude, which is then upgraded to aviation fuel or diesel.

[19] Cf. Maura Farver and Christopher Frantz, Garbage to Gasoline: Converting Municipal Solid Waste to Liquid Fuels Technologies, Commercialization, and Policy, Duke University, April 2013; Laboratory for Aviation and the Environment (LAE), Massachusetts Institute of Technology (MIT), Pooja Suresh, Environmental and economic assessment of transportation fuels from municipal solid waste, June 2016 and LAE, Gonca Seber, Robert Malina et al., Environmental and economic assessment of producing hydroprocessed jet and diesel fuel from waste oils and tallow, Biomass and Bioenergy, Vol. 67, 108-118, Aug. 2014.

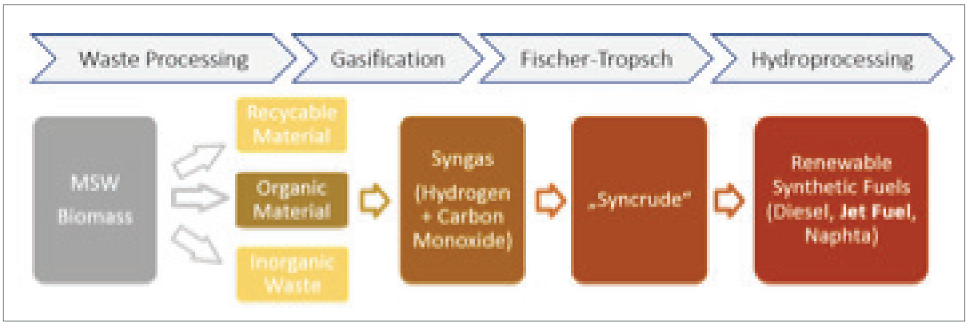


FIGURE 21
Process diagram of MSW conversion into aviation alternative fuel

The Sierra Biofuels plant outside Reno, Nevada is expected to be one of the United States' first fully operational, commercial-scale MSW-to-renewable fuels production plants. The concrete specifications of the plant provide a good reference for an analysis of the comparable situation in Burkina Faso as both cases are using similar feedstock assumptions. Facilitating a direct comparison with the availability of organic municipal waste in Ouagadougou, the Sierra biorefinery has been designed to produce roughly 40 000 tonnes per year of renewable FT syncrude from approximately 200 000 tonnes of prepared MSW feedstock, about the same amount that is available in Ouagadougou.

However, as only organic waste qualifies for conversion into SAF, a feedstock processing facility will first need to size, sort, shred and process the mixed and potentially contaminated MSW into a prepared MSW feedstock for use at the biorefinery. Sorting is a key step in the recovery of energy from municipal waste. Depending on the homogeneity of the waste, substantial sorting costs might thus be incurred. In Ouagadougou, all kinds of household rubbish are typically mixed.

3.3.1.3 Challenges and Constraints

For MSW, the primary challenges are associated with logistics (materials handling) and not with feedstock supply specifically. To bring waste preparation costs down and facilitate the operation of gasifier technologies in the neighbourhood of municipal landfills, the separation at source by residents is ideally required. It appears that upstream waste sorting is the key to ensuring the required feedstock quality for optimal operation of gasifiers and minimal environmental impact of these facilities. However, in order to encourage residents to start sorting at source, i.e. at home, the municipality of Ouagadougou first needs to set up the appropriate infrastructure and modified facilities for waste management in Burkina Faso. This will include, inter alia, the establishment of separate waste disposal, collection and sorting systems for different waste streams, as well as the accompanying measures for environmental education of residents.

In the long-term, it may be possible that the organic fraction of MSW will become available for SAF production in the wake of cheap and efficient waste sorting processes and mature gasification technologies. However, independent of feedstock and technology readiness, significant funding challenges remain. Given the expected capital expenditure requirements and high maintenance and operation costs, the large-scale application of organic waste gasification does not yet seem to be an attractive option for Burkina Faso. Insights into the project and funding structure of the Sierra Biofuel Plant in the U.S. may prove revealing in this regard. Feedstock availability and proven technology were far from sufficient to launch the USD 270 million project. It took significant government (military) and industry commitments, both financially and strategically, to move forward. This included federal bioenergy incentives from multiple agencies (DOE, FAA, USDA, DoD) as well as aviation fuel forward sales and long-term fuel off-take agreements from international airlines.

Regardless of how promising the individual feedstock candidate may be, project size and complexity require unequivocal support, risk sharing and close coordination among a multitude of stakeholders. Recent developments in the U.S. have confirmed that public financial incentives, loan guarantees and funding for commercial production facilities can make the difference between a viable and a failed project. The maintenance and growth of these federal programmes have proven critical for the development of SAF production facilities. Demonstrating its commitment for the development of alternative aviation fuels, the U.K. government announced in August 2017 to provide up to USD 28 million matching funds for projects focusing on the commercialization of advanced low carbon, waste-based aviation fuels.

The U.K. Department for Transport (DFT) is supporting the demonstration and production of low-carbon fuels in general, and SAF in particular, through an Advanced Biofuels Demonstration Competition (ABDC) to encourage significant private sector investment in the development of these waste-treatment and conversion facilities in the U.K.

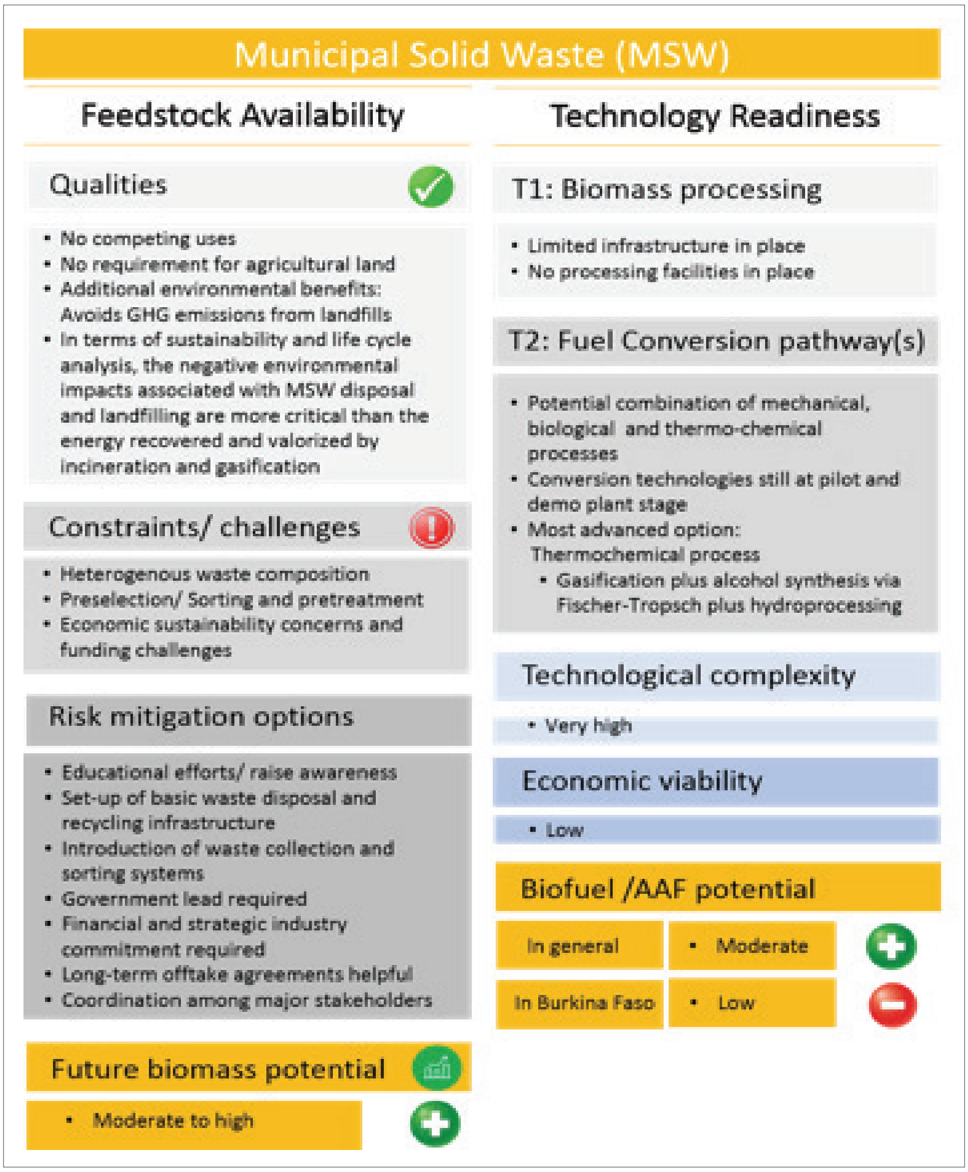
GOVERNMENT & MILITARY INTERVENTION

In June 2011, the Department of Agriculture (DOA), the Department of Energy (DOE) and the United States Navy signed a memorandum of understanding that initiated a cooperative effort:
(1) to create a strong demand signal;
(2) to equally contribute significant funding from each agency; and
(3) to assist in the development of sustainable drop-in biofuel substitutes for diesel and jet fuel.

In January 2017, the U.S. Secretary of Defense announced a USD 55 million funding opportunity for a 10 million-gallon biorefinery capable of producing advanced drop-in bio-equivalent fuels suitable for military use. The so-called "Advanced Drop-In Biofuel Production" project aims to establish a complete domestic value chain including feedstock production, chemical conversion and processing (integrated biorefineries), fuel blending, transportation and logistics.

Over the past ten years, the U.S. Department of Defense (DOD) has repeatedly used financial incentives to help facilitate the development of commercially viable plants for producing biofuels for the military and commercial sectors. The federal government's cost share for targeted investments into alternative fuels production capacity (including the ongoing "Bio-Synthetic Paraffinic Kerosene" project and the "Advanced Drop-In Biofuels Production" project) was about USD 234.1 million.

3.3.1.4 Feasibility Matrix



3.3.2 ANIMAL WASTE FATS

3.3.2.1 Feedstock Qualification

Not only can alternative fuels be refined from many types of flowering plants, agricultural residues and sugars, but also from feedstocks such as animal waste fats and oils. So-called lipid-based biofuel feedstocks such as animal fats (beef tallow, chicken fat, lamb fat, pork lard, yellow grease and the greasy by-product from omega-3 fatty acid production) can play an important role in expanding the portfolio of SAF feedstocks. As a matter of fact, the majority of alterntive fuel available today is derived from oleochemical feedstocks such as vegetable oil, animal fats, and used cooking oil.

If not managed properly, animal carcasses can present a serious health and environmental risk to livestock and humans. The rendering of animal by-products from slaughterhouses makes the material safe and suitable for reuse in several applications. Rendering is a heating process for meat industry waste products that converts waste animal fatty tissue into value-added, purified fats, known as tallow and lard. The solids are usually passed through a screw press to complete the removal of the fat from the solid residue. The rendering process also separates fats from water. The removed water is the single largest output of the process, up to 65 per cent by weight.

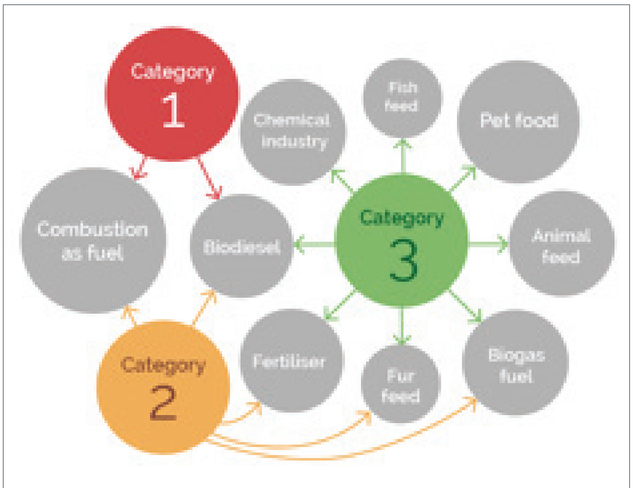


FIGURE 22
Potential use of animal waste fats according to the European Fat Processors and Renderers Association (EFPRA)

In Europe, the U.S. and South America, meat-processing and rendering industries annually produce a large amount of animal fats with different degrees of quality. Depending on the specific risk classification, waste fats may be used as animal feed or for soap, fertilizer, oleochemicals, pharmaceuticals and fuel production. At present, beef tallow makes up 17 per cent of feedstock applied in Brazilian biodiesel production.

In comparison, animal carcasses and waste fat in the meat processing industry in Burkina Faso have no further, let alone competing use, and are typically disposed of, with potentially serious health risks and other negative environmental consequences.

Proper rendering and processing may not only reduce potential health hazards but also provide an attractive opportunity for energy recovery. Tallow has a high energy value. Its physical and combustion properties are very close to fuel oils, such as Diesel, Light Fuel Oil or Heavy Fuel Oil. The average calorific value equals 36 to 40 MJ/kg. According to the U.S. EPA, the energy content of tallow or fat has been calculated at 16 200 Btu/lb. This compares to 17 000 Btu/lb for vegetable oil.

FIGURE 23
Proportion of animal rendered

As of June 2017, Burkina Faso has two major slaughterhouses, located in Ouagadougou and Bobo-Dioulasso. As announced by the Ministry of Livestock and Aquaculture, and in line with the strategic objectives of the PNDES, an additional five modern slaughterhouses are being planned or are already under construction.

The quantity of tallow produced by a plant depends on the type of animals processed and the extent of processing. By multiplying the average proportion of the animal rendered with actual meat consumption data for the city of Bobo-Dioulasso, approximate values for the calculation of available feedstock potential can be derived.

With regard to the underlying parameters as identified in **Table 6** below, total annual feedstock from animal waste fats equals roughly 7 500 tonnes. The Government of Burkina Faso intends to build another modern slaughterhouse in Banfora. With a population size of one fifth of Bobo-Dioulasso, it may be reasonable that this slaughterhouse would add another 1 500 tonnes of available animal fat, totalling an annual feedstock volume of 9 000 tonnes with an aggregate calorific value of 360 000 GJ or 61 400 boe.

	Cow/ Zebu	Pig	Goat/ Sheep
Average weight	400 kg	50 kg	30 kg
Proportion of the animal rendered	32% (≈ 128 kg)	26% (≈ 13 kg)	20% (≈ 6 kg)
Water removal by weight	60% (≈ 77 kg)	60% (≈ 7.8 kg)	60% (≈ 3.6 kg)
Animal fat (tallow, grease, lard) available for processing into biofuels	51 kg	5.2 kg	2.4 kg
Number of animals slaughtered /day	300	1 000	1.000
Feedstock availability/day	15 300 kg (= 15.3 tonnes)	5 200 kg (= 5.2 tonnes)	2 400 kg (= 2.4 tonnes)
Feedstock availability/year (330 days)	5 049 tonnes	1 716 tonnes	792 tonnes
Total feedstock/year			**7,557 tonnes**

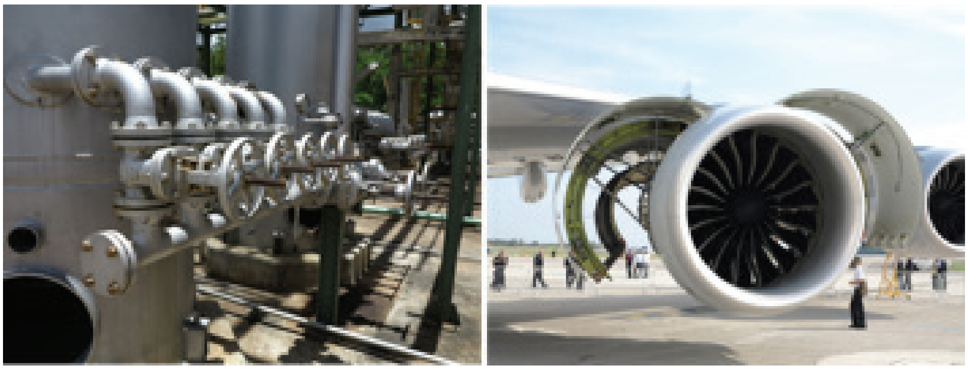
TABLE 6
Slaughterhouse statistics for Bobo-Dioulasso (key parameters as of June 2017)

Considering the population size of Ouagadougou (≈ 2.5 million), i.e. at least three times the size of Bobo-Dioulasso, and assuming the same livestock consumption ratio, the feedstock numbers for Bobo-Dioulasso may be tripled, resulting in a total of 22 700 tonnes of rendered animal fat per year for the city of Ouagadougou. Animal waste fats from additional future slaughterhouse locations in Pouytenga, Kaya and Fada N'Gourma may potentially be added to scale-up production of usable feedstock and thus improve economies of scale. Based on the above conversion parameters, the specific energy value of 22,700 tonnes of tallow equals 908 000 GJ or 155 000 boe.

3.3.2.2 Fuel Conversion Process

Lipid-based feedstocks from animal waste qualify for hydro-processed renewable diesel and alternative fuels (HVO/HEFA), as well as biodiesel (FAME) production, which can be used for airport vehicles.

PICTURE 9
Alternative fuel conversion and refining facilities

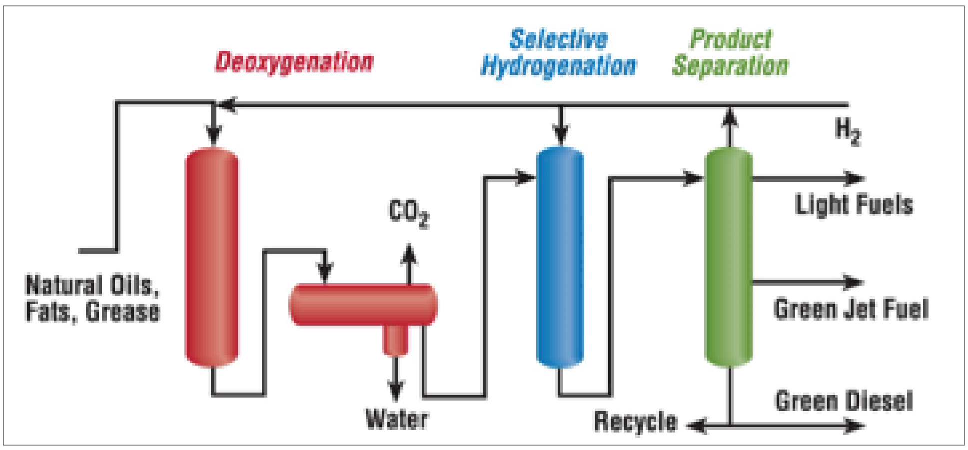


Many different fuel production and conversion processes are being developed at various scales (pilot, demonstration, and pre-commercial) to convert biomass feedstocks into aviation fuel.

3.3.2.2.1 HEFA/HVO

The oleochemical reaction pathway, hydro-processing of lipid feedstocks uses heat and pressure over a solid-state catalyst to break down the long double carbon chains (C_2C bonds) in the fatty molecules of the feedstock, replacing oxygen bonds with hydrogen to convert the unsaturated triglyceride molecules that compose waste fat and fatty acids (such as vegetable oil) into fully saturated synthetic paraffinic hydrocarbons (Alkanes) with a lower molecular weight. Impurities are initially removed by catalytic processes. The fatty acids are then hydrotreated and cracked to achieve the desired hydrocarbon length of 9-16 carbon atoms, depending on the fatty acid profile of the feedstock. Hydroprocessed bio-oils can be sent to fractionation, a process that separates the various fractions of hydrocarbons based on their differences in boiling point temperatures, including jet fuel, diesel, kerosene, gasoline and naphtha (see **Figure 24**).

FIGURE 24
UOP Green jet fuel process diagram



The "fat-derived" or "oleochemical-derived" fuels are often referred to as HEFA, but are also called hydrotreated vegetable oil biofuels (HVO). HEFA-diesel is also known as green diesel or hydrotreated renewable diesel. The process, which can be performed with existing refinery infrastructure, was ASTM-certified in 2011. The conversion technology is mature and currently operates at commercial scale. The two main technologies used to produce HEFA are Neste's NEXBTL, and Honeywell UOP and Eni's EcofiningTM processes.

The EcofiningTM technology has been licensed by several companies and is used in a number of facilities. Profiting from significant and longstanding U.S. military financial support, including grants from the military's Defense Advanced Research Projects Agency (DARPA) and a 77-million-gallon purchase order from the US navy for its "Great Green Fleet" project, the California-based refiner AltAir is one of the pioneer companies using animal waste fats for SAF production. AltAir's primary source of feedstock consists of inedible waste oils and fats, mostly animal fats such as tallow and lard. These waste materials are cheaper than virgin vegetable oils yet have similar physical properties for conversion into aviation fuel. Rather than taking on the capital expense of building a new refinery, the company has retrofitted an existing but idle asphalt plant with HEFA-based process technology developed by Honeywell UOP. The company's agreement in 2014 with United Airlines was the first multi-year fuel supply contract with a commercial carrier. As of October 2017, United is the only airline in North America purchasing SAF for day-to-day operations, and AltAir is the first and only SAF producer in operation on a commercial scale. Despite having the largest SAF purchase agreement, United is covering only 0.16 per cent of its total fuel use with SAF from AltAir.

Although the HEFA technology is commercially mature, costs will remain a significant challenge. Even if waste animal fats were available for free, a stand-alone HEFA processing plant remains unrealistic for the time being. Without basic petrochemical or refining infrastructure in place, there is no opportunity for cost savings through co-location, co-processing or the use of existing infrastructure. Thus, a HEFA plant is neither technically feasible nor commercially viable in Burkina Faso. The estimated high capital and processing cost and in particular, the need for expensive hydrogen, renders the HEFA pathway uncompetitive.

Therefore, waste fat-based feedstocks are more likely to be converted to conventional FAME biodiesel. FAME biodiesel is notably distinct from HEFA aviation fuel; because it retains an oxygen ester, FAME biodiesel is too oxygenated to be used as a drop-in biofuel. According to the jet fuel standards ASTM-D1655 12 and ASTM D7566 14a, a FAME contamination of only 5 ppm will already render jet fuel out-of-spec.

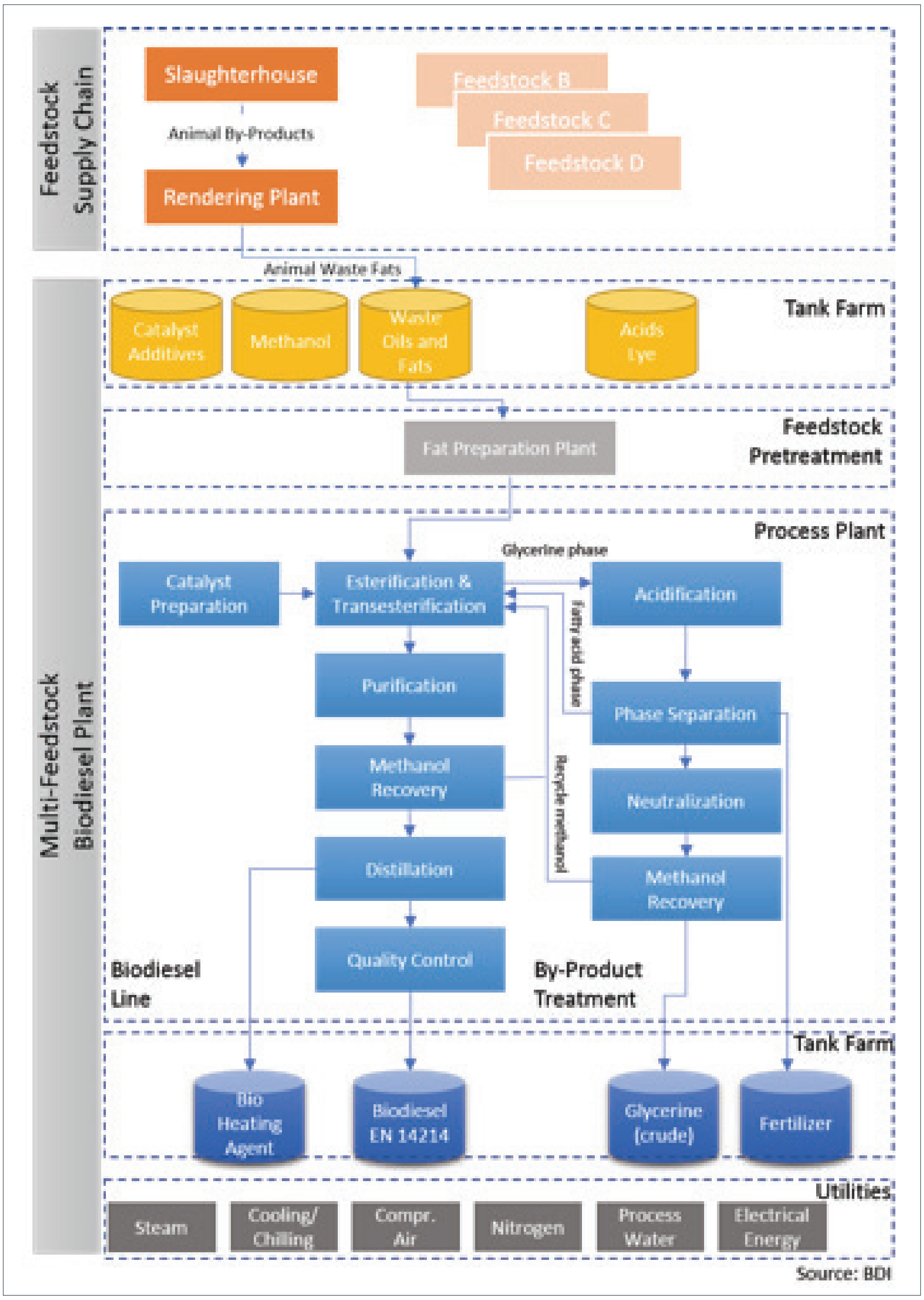
3.3.2.2.2 FAME Biodiesel

In general, biodiesel is an alternative fuel for diesel engines, to be used either 100 per cent neat, or in any blend with fossil-based diesel. While biodiesel cannot replace aviation fuel, it can be used by any airport's diesel-powered ground fleet, such as aircraft tugs, buses and fire-fighting vehicles. For example, Hamburg Airport is one of the first major international airports in the world that has replaced all fossil fuels with renewables in its entire diesel-powered ground fleet.

With regard to the alternative fuel requirements of diesel-powered GSE operating at Ouagadougou airport, refer to Section 3.4.6.2.

The chemical process used to convert waste fats to biodiesel is called transesterification. It is a chemical process that converts the long-chain fatty acids (triglycerides) of raw materials (oils and fats) to methyl esters and glycerine. In the course of the transesterification process, the glycerine back-bone of the fat molecule is substituted by a lower alcohol (e.g. methanol). The resulting biodiesel typically fulfils quality standard EN14214. It can either be used in directly diesel engines or blended with petro-diesel. The fatty acid profile of tallow is fairly similar to palm oil and is well saturated. Therefore, B100 (pure biodiesel) made from animal fat should preferably be used in a very warm climate. One of the important attributes of biodiesel is that it lowers the levels of harmful pollutants in the exhaust of diesel engines. In the case of animal waste fats, this also includes nitrous oxide emissions (NOx). The primary reason for this is probably that animal fat biodiesel has a high cetane number (>60) compared with vegetable oil biodiesel (48 to 55). A higher cetane number is known to lower NOx by lowering temperatures during the critical early part of the combustion process.

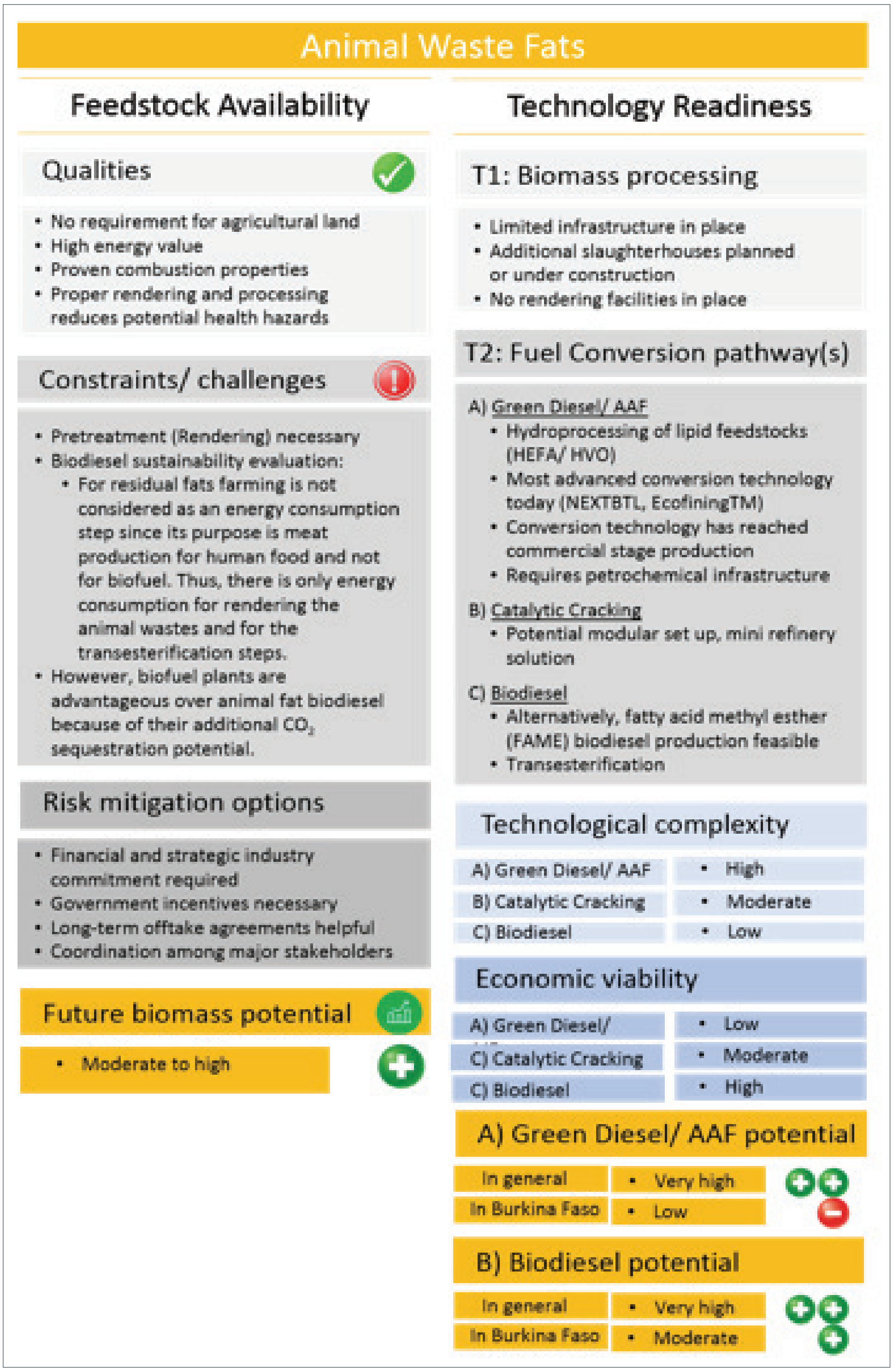
FIGURE 25
Schematic diagram for multi-feedstock biodiesel plant



Assuming a 1:1 conversion ratio from lipid to biodiesel (measured by the mass ratio biodiesel/fat), total tallow and waste-lipid can produce around 7 500 to 9 000 tonnes of biodiesel in Bobo-Dioulasso and around 23 000 tonnes in Ouagadougou. The feedstock volume would justify a commercial facility in the form of a Multi-Feedstock Biodiesel Plant, as illustrated in Figure 25.

Process economics can be improved by recovering methanol and glycerine. In order to enlarge the feedstock input from waste oils and fats to "organic waste" in general, and to facilitate a perfect combination of mass- and energy flows, the Multi-Feedstock Biodiesel plant may be combined with a Biogas plant. Given the proximity of the MSW landfill and slaughterhouse locations in Ouagadougou within the same district, the potential of biogas (methane) production and electricity generation from MSW in Ouagadougou may offer an opportunity to lower production costs and achieve economies of scale.

3.3.2.3 Feasibility Matrix



3.4 JATROPHA

3.4.1 PLANT PHYSIOLOGY AND ECOLOGY

Jatropha is a perennial crop that is cultivated for its high-quality vegetable oil and the conversion of its biomass into multiple renewable energy applications. The plant grows widely across Burkina Faso and in neighbouring West African States.

Crude jatropha oil (CJO) is a non-food type of biofuel made from the inedible nuts of the jatropha tree. The multiple derivatives of CJO and seed cake can be used for many non-food products, such as pharmaceuticals, industrial lubricants, cosmetics, animal feed, bio-electricity and biofuels, including biodiesel and SAF.

PICTURE 10
Jatropha fruit bunch

Jatropha has long been considered the feedstock of choice for the production of SAF. This is primarily because of its fuel properties and cold flow characteristics. It also does not compete in the food supply chain due to its slight toxicity, which makes the oil unsuitable for human consumption.

As with the cultivation of most biofuel feedstocks, jatropha cultivation has led to concerns that jatropha might displace food crops. Unlike some biofuel feedstocks, such as corn and soybeans, most jatropha varieties are inedible and therefore do not create a direct conflict between food and fuel. To the contrary, a well-balanced intercropping scheme may even enhance a symbiotic plant relationship for the benefit of both, food and fuel crops.

Most importantly, the jatropha plant can survive on marginal unproductive land, thus reducing the potential for land use conflicts. Jatropha adapts to poor soil conditions and is known for its tolerance to drought. It can grow in areas with as little as 750 mm rainfall per year and it survives in areas with dry periods longer than 6 months.

Areas where jatropha is propagated are among the most production-insecure regions. Because of the plant's proven adaptation to a large variety of soil and climatic conditions, it seems to be ideal on land that is otherwise unusable. If the soil is penetrable, the jatropha tap roots provide deep-reaching opening avenues for water infiltration and nutrients from layers that annual crops or weeds do not reach. Besides its intensive root structure, it forms an effective barrier to run-off water after heavy rains. Soil erosion could be effectively reduced or completely prevented, and the water-holding capacity of the soil can be utilized to a much greater extent. This is of overriding advantage, especially towards the end of the dry season. The increase in soil fertility would quickly lead to much better vegetation growth on the former barren land.

The requirements for nutrients potassium, nitrogen and calcium are similar to those for growth of other crops, but when the available supply of these nutrients is limited, growth is reduced less than in most other crops. Therefore, jatropha is usually suitable for growing in arid regions of Burkina Faso. Typically, planting, pruning and harvesting of jatropha does not interfere with growing cycles of food crops, such as rice, maize and sorghum.

Long-term cultivation usually results in an increase in soil fertility, especially if stems and leaves from pruning activities are turned into mulch and re-incorporated into the soil. The same applies for a significant part of the seedcake after oil extraction.

Depending on the topography, soil profile and prevailing agro-climatic conditions, jatropha can be combined with other suitable species, comprising agricultural, horticultural, herbal, pastoral and/or silvicultural plants to result in an ecologically viable and socially acceptable agroforestry system.

By evolving, promoting and adopting jatropha-based intercropping systems it is possible to improve the socio-economic conditions in impoverished rural areas and to transform the rural energy scenario, as well as the ecological landscape.

In addition, jatropha plantations can play an important role in rehabilitating degraded lands and supporting reforestation efforts.

3.4.2 CRUDE JATROPHA OIL (CJO)

Jatropha crops are ready for harvest when the fruits reach a yellow colour and a size of 2 to 3 inches in length. In a centralized oil mill, harvested fruits will be de-hulled before seeds can be dried and crushed. The basic jatropha oil expelling process entails several steps. To facilitate oil milling on an industrial scale, seeds are typically pre-treated whereby they are de-hulled by mechanically removing the outer shell, and then may be cracked, ground and boiled to favour oil recovery.

PICTURE 11
Energy-rich jatropha seeds

The kernel (white portion after removal of shells) contains about 50 to 60 per cent oil, which can be used as energy feedstock or can be converted into biodiesel and SAF. CJO makes up 28 to 30 per cent of total seed weight or 46 per cent of de-shelled seed kernel weight. The current extraction technology in place can recover about 78 per cent of the oil contained in the jatropha seeds equalling an extraction ratio of 28 per cent as compared to the total weight. Next generation conversion technology will increase the extraction ratio from 28 to 36 per cent, translating into a substantial mark-up regarding the recoverable volume of CJO (up to 95 per cent oil recovery).

CJO has less than 5 per cent of the sulphur content of alternative biofuels, resulting in significant reductions in sulphur dioxide emissions, a major contributor to acid rain-related environmental impacts.

Jatropha-derived biofuel and aviation fuel was tested by international corporations for all major engine applications including aircraft jet engines. Jatropha feedstock was used, inter alia, for 1 200 Lufthansa biofuel flights in 2011 to 2012. None of the aircraft components (A 321) such as the tanks, fuel lines or engines showed any unusual signs of stress. Since then, a multitude of international airlines have successfully tested CJO-derived fuel in scheduled commercial flights.

So-called bio-synthetic paraffinic kerosene (SPK) derived from jatropha has routinely performed as well as, or better than, JP-8 or Jet-A1 fuel. As a drop-in biofuel, it is fully compatible with current aviation fuel and can be used within aircraft engine fuel systems or fuel distribution networks without any adaptation.
Jatropha-based alterntive fuel has been certified in accordance with the ASTM International standards (ASTM D 7566) and the U.K. Defense Standardization (DStan) which are binding for the application of a fuel within the international civil aviation sector. Bio-SPK can be blended up to 50 per cent with current aviation fuel.

Jatropha-based alternative fuel has demonstrated in numerous flight operations that hydro-treated renewable jet fuel reduces carbon emissions (CO_2) by up to 85 per cent compared to current aviation fuel. The decrease in CO_2 emissions for jatropha-based bio-kerosene is attributed to the high cetane number and the presence of oxygen in the molecular structure of the fuel.

3.4.3 BURKINA FASO CONTEXT: KEY PLAYERS AND INITIATIVES

At the same time that activities began in Tanzania, Kenya, Mozambique, Ethiopia and Mali, jatropha arrived in Burkina Faso in early 2007. Burkina Faso quickly took the lead as producer of the newly popular biofuel plant jatropha. Burkina Faso did not experience significant challenges with respect to land use rights and large-scale plantations, as most domestic projects promoted out-grower farming models and aimed at contracting small-scale farmers. Initially, cultivation activities were dominated by three entities that each pursued a distinct approach: (1) Faso Biocarburant; (2) Agritech Faso; and (3) Belwet.

3.4.3.1 Faso Biocarburant

Unlike in Zambia, Madagascar, Ghana, Tanzania and Mozambique, the initial contract farming model in Burkina Faso did not depend on large-scale plantations and complex land agreements, but rather relied on the mobilization efforts of hired promoters to engage as many farmers and out-growers as possible. Instead of acquiring land and investing in large scale plantation operations of its own, Faso Biocarburant opted for a low-cost solution by leveraging exclusively the skills of the promoters to overcome logistical challenges and set up a network of individual small-scale producers. Besides the compensation for the promoters and the seed buyback costs, the otherwise significant expenses for land lease, land preparation and fertilization did not play any role.

Nevertheless, a functioning market and market pricing never materialized. Seed buyback prices were not negotiated, but fixed arbitrarily.

At its peak in 2014, 3 000 farmers participated in Faso Biocarburant's jatropha out-grower scheme in the province of Sissili. More than 10 million jatropha trees were planted in south-central Burkina Faso. However, crop yields fell short of expectations and operations had to stop. The whole value chain collapsed. As of June 2017, the site of the crushing plant remains deserted. Meanwhile, the farmers union has been dissolved and replaced by the non-governmental organization FNZ (Fédération Nian Zwé), meaning in the local language, "hunger is over".

3.4.3.2 Agritech Faso

As one of the first jatropha companies in Burkina Faso, Agritech Faso promoted intercropping with select vegetable and staple crops to strengthen food security for the local population. Growers were advised to use jatropha as hedging, fencing and reforestation of degraded land, thus not competing with agricultural uses. Unlike Faso Biocarburant, the company did not exclusively rely on independent out-growers and farming cooperatives, but also hired hundreds of their own rural and seasonal employees to work on their own leased land in the firm's nurseries and plantations. Agritech Faso combined elements of a contract farming model with an estate farming model, which required larger upfront investments.

In March 2013, Agritech Faso signed a Memorandum of Understanding with Singapore based JOil to get access to hybrid, high-productivity jatropha seeds and to develop 250 000 ha of intercropped jatropha plantations in West Africa. JOil is a joint venture company incorporated by Temasek Life Sciences Laboratory Limited, Tata Chemicals Asia Pacific Pte Ltd) and Toyota Tsusho Corporation. Temasek Life Sciences is ultimately controlled by Temasek Holdings Private Ltd., the sovereign wealth fund owned by the Government of Singapore. JOil has only been granted 300 ha for field trials in Burkina Faso, of which only 35 ha were ever planted with jatropha. Several months later, the joint venture was over. JOil left Burkina Faso, cutting their remaining plants and destroying all planting materials. Facing significant financial constraints, Agritech Faso ceased all operations by the end of 2013.

3.4.3.3 Belem Wend Tiga (Belwet)

Established in 2008 by the Mossi tribal chief le Larlé Naba Tigré, Belwet Biocarburant is the only remaining jatropha pioneer still active today (November 2017) in Burkina Faso. Belwet is pursuing business opportunities in all sectors of sustainable agroforestry. While the main focus is centred on the cultivation of jatropha and the production of biofuels, Belwet has also established a functioning model for various jatropha by-products. This includes the commercialization of jatropha soap, which is offered and sold in TOTAL gas stations; jatropha seedcake, which is marketed and sold throughout the country as organic fertilizer; and jatropha husks, which are sold as compost. In addition to biofuel production, Belwet is also engaged in providing micro credits, schooling and education, and basic health care.

With regard to jatropha cultivation, Belwet is practicing a balanced contract farming model in central Burkina Faso, promoting intercropping with corn, cashew nuts, mango trees and mung beans. With the support of select donor funding, crushing facilities using technology from India were installed in 2010 in Kossodo, outside of Ouagadougou. Daily crude oil production capacity reached 4 200 litres and biodiesel production capacity was designed for 1 440 litres.

Initially, Belwet offered to buy back jatropha seeds for 70 FCFA (i.e. USD 0.13). This price was later raised to 100 FCFA (i.e. USD 0.18). Countrywide farmer mobilization efforts proved largely successful. In 2008, Belwet managed to activate and engage jatropha farmers nationwide in 71 distinct rural communities and more than 1 200 villages. At its peak, more than 60 000 farmers (mostly women) were organized in ad-hoc producer cooperatives and participated in the buyback scheme. Seed purchase offers were also extended to producers in neighbouring Benin, Mali, Togo and Côte d'Ivoire. However, huge variations of intercropping schemes and plant density (160 to 1 250 plants/ha) made it almost impossible to arrive at scientifically sound statements as to yield and plant performance, as well as plant survival rates under various agro-climatic conditions.

PICTURE 12
Belwet Biocarburant biofuel crushing and biodiesel processing facilities, Kossodo

To counter logistical challenges, seed purchase centres and warehouse facilities were installed at 10 locations throughout Burkina Faso. In 2012, a reported 114 tonnes of jatropha seeds were collected. In the same year, Belwet produced 23 360 litres of CJO and 824 litres of biodiesel. CJO is consumed domestically to power corn and grain mills, as well as water pumps.

While several thousand hectares of jatropha shrubs were ultimately planted, the initiative lacked a functioning market and reliable off-take commitments for CJO and biodiesel. Even though average yield stayed significantly behind expectations, the relatively low output per hectare and commercial viability challenges were not considered the most critical stumbling blocks.

3.4.3.4 Government Initiative(s)

Various parties in Burkina Faso still support a vigorous re-launch and are demonstrating significant efforts to promote jatropha as a source of SAF. In Burkina Faso, the term "jatropha" is widely used as a synonym for the term "biofuels". As a result, jatropha remains at the centre of the country's biofuel strategy and related energy policy considerations. Instead of limiting the plant's role to a mere "cash crop", jatropha is increasingly perceived as a tool of agroforestry, reforestation and land rehabilitation. In addition, the perspective of sustainable rural electrification contributes to the renewed interest and confidence in the envisaged revitalization of the jatropha value chain.

Among the key political promoters is the country's Renewable Energy Directorate (Direction Générale des Energies Renouvelables) inside the Ministry of Energy. According to a ministerial report published in January 2017, it was considered necessary to encourage a legal and regulatory framework which provides a favourable environment for the promotion of the jatropha sector as a source of sustainable biofuels in Burkina Faso. Concrete measures to include the identification and dissemination of more productive varieties; the simultaneous promotion of agro-forestry production systems; the introduction of basic market structures; reliable and consistent seed purchase prices; and the increased use of jatropha seed cake as organic fertilizer. In parallel, private investment shall be encouraged while access for smallholders to credit and finance shall be facilitated. A special governmental institution, Agence nationale des énergies renouvelables et de l'efficacité énergétique (ANEREE), has been assigned as the main implementing agency. ANEREE was set up in October 2016 to, inter alia: formulate and implement renewable energy policies; reactivate ("relance", fr.) and promote the jatropha sector; and mobilize the necessary funding. With regard to domestic biofuel production, any implementing measures will have to assure food security, promote rural development and contribute to the alleviation of poverty in rural areas.

To support the re-launch of the jatropha value chain, the Government proposes to:

- take into account the specific requirements and opportunities of the carbon market and carbon pricing schemes in connection with jatropha plantation projects in Burkina Faso;

- subsidize production factors (such as fertilizers, seeds and pesticides) to increase seed and oil yield;
- provide incentives for seed production by setting a price floor to ensure a minimum revenue stream for smallholder producers and sellers; and to
- encourage investments through customs duty reduction for processing equipment.

3.4.3.5 UNDP initiative

With regard to the intended re-launch of the jatropha value chain and the production of sustainable biofuels the Government of Burkina Faso is supported by the United Nations Development Programme (UNDP). As of July 2017, Belwet has become the main point of reference for the UNDP in Burkina Faso as far as jatropha cultivation is concerned. In cooperation with the Ministry of Energy, the Ministry of Development (Secrétariat Permanant du Conseil National pour l'Environnement et le Développement Durable (SP/CONEDD)) and the Ministry of Agriculture, UNDP is conducting a large-scale jatropha study entitled "Promotion du jatropha curcas comme source d'agrocarburants durable au Burkina Faso". Drawing upon the financial support of the Global Environment Facility (GEF), the project under the same name as the study was officially re-launched by the Ministry of Energy and UNDP in June 2017. By consolidating available data, cultivation experiences and prevalent domestic agronomic parameters, the UNDP's project objective is to develop and promote an economically viable jatropha production model in order to deploy jatropha as feedstock for biofuels at the national level. The project also aims to make a significant contribution to rural development by encouraging decentralized production of CJO as a basis for biodiesel, without interfering with food production. Independent of remaining challenges, UNDP is estimating a total cultivation potential of 500 000 ha without jeopardizing food security. This would represent roughly 5 per cent of the available arable land in Burkina Faso. Project implementation and jatropha commercialization are primarily based on the mobilization efforts of Belwet. Belwet is expected to provide millions of jatropha seedlings towards UNDP's estimated project goal. However, the project has not yet internalized the scientific, agronomic and commercial minimum requirements in order to mitigate known risks and optimize the envisaged jatropha cultivation.

3.4.4 LESSONS LEARNT

3.4.4.1 Yield Expectations

A key feature of the jatropha experience was the large-scale promotion of jatropha based on unproven claims and selective use of available data. This led to the rapid uptake of jatropha, that was facilitated further by an environment that was receptive to the concept of a new biofuel crop. Accepting overestimated yields and unsubstantiated claims at face value, even local authorities embarked on initiatives related to jatropha. Many governments were eager to capitalize on jatropha's perceived social and environmental co-benefits and to reap the promised development benefits that jatropha was claimed to offer. For that matter, hastily drafted national biofuels policies further encouraged private sector investment and widespread jatropha cultivation.

However, yield expectations were typically overestimated and unrealistic. Jatropha performs poorly in areas with low rainfall or low nutrient soil. While jatropha is able to grow on degraded/marginal land or in a water-limited environment, this takes a toll on its ability to produce high yields. Large variations in performance should be expected if a "wild" species is to be used. Baseline productivity predictions should be based on the mean performance of the species in the relevant agro-ecological zone, and not on the performance of a few high performing plants. Overestimations of jatropha yields, incorrect assumptions and insufficient background research, coupled with an overall poor knowledge of jatropha and its agronomy, have been the prime contributors to the collapse of most jatropha projects.

Long-term financial viability will likely require yields above those currently obtained. It remains unknown whether sufficiently high yields from mature trees will be achieved in the long-term. However, for small-scale farmers, even low yielding jatropha can supplement and diversify farm income, rather than becoming a high-value cash crop in its own right. According to reports from former jatropha out-growers in Burkina Faso's Sissili province, approximately one day of picking and preparing 8 kg of jatropha seeds could offer enough income to purchase 9 kg of maize/corn which could feed an average household for 3.4 days. As such, jatropha could add to the overall diversity and resilience of household livelihood strategies. Data from Burkina Faso suggest that the salaries of plantation workers represented a substantive increase in cash income for local households and were a safety net in times of drought when there was a reduction in food crop yields.

3.4.4.2 R&D Deficiencies

In most cases, the lack of sound research prior to the wide-scale promotion of jatropha did not allow for the correct understanding of the plant's local climatic and agro-ecological constraints. At the time when initial investments in large-scale commercialization of jatropha were being made, little was known about jatropha's basic agronomy. The failure of many jatropha projects confirmed the concerns of those who recognized the economic risk of cultivating an undomesticated plant. It became apparent that cultivation outpaced both scientific understanding of the crop's potential, as well as an understanding of how the crop fits into existing rural economies and the degree to which it can thrive on marginal lands.

3.4.4.3 Information Asymmetries

Ideally, all market participants, whether they be producers, buyers, sellers or consumers, need adequate information to make appropriate decisions and operate efficiently. With regard to farmers and out-growers, soil preparation, water and nutrient management, spatial models, plant density and intercropping and crop rotation practices are vital parameters in order to optimize jatropha cultivation under given circumstances. However, internationally available research information had not been extrapolated in time by promoters, investors, government authorities and out-growers. Without central coordination, critical information and best practices were not passed on. Lacking national or international data banks, most plantation initiatives were instead pursued in an isolated manner which ultimately proved costly and misleading. Plant cultivation by trial and error left farmers exposed to maximum risk. Even worse, they were deliberately shielded from critical information about plant performance, yield, pricing and related income opportunities. Given the asymmetry of information, farmers often had no means to evaluate/validate underlying agronomic parameters by themselves. Deliberate information asymmetry can ultimately lead to market failure.

3.4.4.4 Market Inefficiencies & Fragmentation

Independent of the global attention and the opportunity to introduce a new product that meets the aviation industry's surging demand for alternative fuels, there was neither an organized market nor a proper price setting mechanism. Even though farmers and farmer associations were offered seed purchase contracts, production and demand was not coordinated. Producers had little to no certainty that seeds could be sold to the market at a sufficiently high price.

While the formalization of the relationship between producing smallholders and seed purchasers is a prerequisite for ensuring the sustainability of feedstock supply while preserving family agriculture, promoters and trade intermediaries did not manage to set up a reliable and consistent supply chain. Inefficient markets give rise to arbitrage opportunities to the detriment of producers and buyers.

Early jatropha cultivation initiatives in Burkina Faso were largely isolated and implemented on a case by case basis, usually without considering available agronomic knowledge and international experience from failed jatropha projects. As a result, process efficiency was low, and manual labour was proportionally high. Where a consolidation of parallel initiatives could have created economies of scale, in particular with regard to logistics, collective storage and warehousing facilities, mechanization and central seed processing installations, jatropha promoters in Burkina Faso and neighbouring States typically opted for the implementation of stand-alone projects. The ensuing market fragmentation led to low production volumes which only allowed for low-tech oil mills, seed crushing facilities and biodiesel processing plants. While simple machines and basic hand-operated devices for the removal of jatropha fruit shells (decortication) exist, fruit shells are separated from the seeds manually. Traditionally, women crack the fruit using brick or wood and the loosened shells are then removed by hand. However, manual decortication is a time consuming and tedious operation that doesn't permit economically viable scale-up. Similarly, de-husking has not been mechanized. Even semi-automated de-husking could greatly reduce labour requirements and improve process economics. Process automation and mechanization will ultimately require a larger production capacity and hourly throughput. This, in turn, requires cooperation and coordination among individual producers and farming cooperatives. In order to optimize the oil extraction process (e.g. by use of innovative aqueous oil extraction methods) and improve overall performance parameters, extraction facilities with a larger seed throughput usually promise better efficiency ratios and product quality.

3.4.4.5 Transport Costs

Many jatropha projects are located in remote areas making transportation of the feedstock from project sites expensive. Furthermore, the cost (transport and personnel) of collecting small quantities of seeds from scattered smallholder farmers ended up higher than was anticipated.

3.4.4.6 Clash of Competing Interests

The complexity of the biofuel value chain was largely underestimated by market participants and collective efforts were not synchronized. This structural discrepancy led to competing demands that were increasingly difficult to balance between stakeholders:

- Governments and jatropha promoters were seeking to attract donor and foreign investor funding;
- Airlines and product off-takers were focusing on price parity with conventional fuels; and
- Refiners were trying to protect their traditional refining margins and cracking spreads.

In addition, an overly narrow emphasis on sustainability concerns in the critical early phase of project origination often blurred the view for the importance of other key launch parameters, such as technical feasibility, economic viability, economies of scale, logistics, storage, poverty alleviation and other financial, economic and social aspects.

3.4.5 CAPITALIZING ON EXPERIENCE/ MAJOR CHALLENGES

Keeping the significant economic fallout of the global jatropha initiatives and the largely disappointing domestic experience in mind, jatropha may still qualify as a viable energy crop option, provided key conditions are met.

3.4.5.1 Farming (Plantation) Model

The failure of large estate farming plantation models does not necessarily lead to a total failure of jatropha cultivation in Burkina Faso. Cash crops including tea, coffee, tobacco and cotton have also gone through a number of boom-and-bust cycles. Domestic and international experience confirms that alternative jatropha production models that involve smallholder farmers as out-growers or independent producers might indeed prove successful. This so-called contract farming model relates to a mutually beneficial partnership between agribusiness and independent out-growers. Contract farming defines a reciprocal arrangement between multiple producers and a known buyer on the basis of a forward agreement which establishes conditions for the production and supply of certain farm products at predetermined prices. To identify a fair forward pricing for the products to be delivered, realistic yields need to be calculated in order to forecast whether production by out-growers can be profitable at prices the central buyer can afford to pay.

Contract farming is used as a supply chain governance strategy in response to market and institutional failures that characterize the agricultural sector in different stages of development. Contract farming also contributes to poverty reduction as it provides a tool for transforming subsistence farmers to commercial farmers. To balance the risk resulting from information asymmetries between farmers/out-growers and seed processing companies, it is recommended that contracts not be limited to seed purchase provisions but also include clauses on additional input supplies by the contracting firm, such as high yielding hybrid seeds, organic fertilizer, technical advice and training services with regard to basic agronomic practices. The potential positive socio-economic impact of this scheme depends on a number of issues including the quality of provided farming inputs and support services, the quality and performance of the planting material itself and the fairness of the terms of contract. The majority of outgrowing schemes are found to provide planting material to their farmers either free of cost or at reduced price. However, the procurement and distribution of farm inputs may prove particularly costly where tissue culture propagation is used to replicate high yielding jatropha cultivars. Small-scale subsistence farmers in Burkina Faso typically sell their crops right after harvest to meet their immediate financial needs (e.g. school fees, medical expenses). Therefore, they lack the financial means to invest in agricultural inputs for the following season. Without collateral, farmers also have difficulty accessing rural finance. Existing microcredit models have shown limited capacity to increase profitability for these farmers. An inventory credit system, or "warrantage", which allows producers to stock part of their harvest in a warehouse for several months, and use the bags as collateral for a loan if they choose, may give smallholders the means to buy essential farm inputs and high yielding cultivars for the next planting season. In addition, the necessary funding and crop establishment finance will have to be obtained from alternative sources, such as the Government of Burkina Faso, dedicated agrobanks and development banks.

PICTURE 13
Large scale jatropha nursery 30 km outside of Ouagadougou

The nursery has a production capacity of several hundred thousand jatropha seedlings.

Contract farming significantly reduces production costs as it binds less capital and avoids large upfront investments for land lease and land preparation. The same observation applies for labour costs. However, its comparatively small scale by nature (e.g. 1 ha/out-grower) may raise efficiency issues. Prima facie, the relevance of scale seems to argue in favour of an estate farming model to be more economical and efficient. However, yield and profits per unit of land may not necessarily decline in line with diminishing farm or cultivation size. This is largely due to the fact that independent out-growers are typically more incentivized to maximize yield and output since their pay is directly linked to the harvest and not to the time (working hours) spent in the field. In order to calculate additional bioenergy crop revenues of contracted out-growers, the seed purchase price to be offered will have to factor in reasonable yield expectations, the applied intercropping scheme and plant density. Careful design of incentives, paired with a fair allocation of risk (especially yield risk) will help ensure that long term production contracts are acceptable and commercially attractive to farmers.

Overall production efficiency may be further increased by arranging participating farmers in a satellite-like scheme around central seedling nurseries and pilot breeding stations that are equipped with relevant hardware and basic technology support (e.g. de-husking machines).

3.4.5.2 Intercropping: Food plus Fuel

Jatropha is never to replace any other crop, and in particular, not any food crop. To the contrary, the plant only qualifies to complement existing agronomic practices. Negative monoculture experience has shown that farmers cannot be expected to rely on uncertain jatropha yield alone. Unsatisfactory seed production rates pose a substantial economic risk for outgrowers. Owing to the stress of limited water availability, nutrient demand, disease infestation, biodiversity loss and poor yield risk, any jatropha contract farming model will therefore have to be based on practicing inter- or multi-cropping with fruits, vegetables, herbs, spices and select tree species.

Taking into account the competition for physical space, nutrients, water, and sunlight, the rationale behind intercropping is to produce a greater yield on a given piece of land by making use of available limited resources that would otherwise not be utilized by a single crop. When applied to contract farming, intercropping ensures normal farming activities can continue as before whilst an additional, though admittedly small, income source is generated without any negative impact on traditional subsistence farming and food security. As long as jatropha-derived fuels and the income they generate are additional to that from intercropped food production, and do not hinder it or increase pressure for land use change, jatropha does not compete with food production. If fuels are produced carefully using alternative feedstocks that do not compete with food crops and if incorporated in the agricultural landscape in such a way that they do not contribute to land use changes, jatropha can demonstrate a considerable potential.

PICTURE 14
Intercropping samples

Intercropping is the agricultural practice of cultivating two or more crops simultaneously on the same field at the same time while improving utilization of scarce growth resources.

A somewhat symbiotic relationship between the jatropha plants and carefully selected rotating food crops may even enhance the built-in paradigm for land-use optimization, land rehabilitation, long term food security and eco-balance. Intercropping has the additional benefit of enhancing biodiversity, which is important for the control of diseases and insects. Outbreaks of pests and diseases are generally less serious in mixed cropping systems.

Intercropped legumes with their adaptability to different cropping patterns and their ability to fix nitrogen may also offer opportunities to sustain increased productivity. Legumes as intercrops have been advocated not only for yield augmentation, but also for maintenance of soil health, particularly in degraded soil. Thus, inter-cropping jatropha with select leguminous plants is a suitable means to improve soil fertility and decrease topsoil erosion.

Grain legumes include both herbaceous plants like beans, lentils, lupins, peas, cashew nuts and trees such as carob, mesquite and tamarind. Other rotational crops that might also be planted in symbiotic relationship with jatropha include green beans, broccoli, eggplant, okra, lemon grass, elephant grass, onions, sweet corn, and mixed melons.

Intercropping of jatropha with maize and green beans (mung beans) on rehabilitated land shows even greater agronomic benefit compared with sole cultivation of maize or beans. Maize and bean yields will be more stable and will not only increase, but will lead to other ecosystem services like soil stability, water storage capacity and overall fertility.

In addition to staple crops such as maize and soybeans, the most suitable crops for intercropping include leafy and root vegetables, fruits (such as mango), cashew nuts, beans, eggplant, lemon grass, elephant grass, tea, spices, herbs and vanilla.

The ideal choice and composition of intercrops ultimately depends on a multitude of parameters, ranging from soil type (physical and chemical soil characteristics) and nutrient composition, to water availability, plant characteristics (including physiological growth characteristics and canopy architecture of the crops), plant spacing, social structures, basic infrastructure and market demand for organically grown food crops, both locally and internationally.

3.4.5.3 By-Product Commercialization

Instead of commercializing all components of the jatropha fruit, the basic contract farming model practiced in Burkina Faso was mostly limited to an overly simplistic seed buy-back scenario. The intrinsic problem of an out-grower plantation model that only focuses on purchasing seeds from participating farmers is that components of significant value are left aside. However, jatropha seeds and their oil content represent only a percentage of the overall value chain.

The economics of the production of biofuel can be significantly influenced if all plant components, other than the oil which goes for direct conversion into biodiesel and/or aviation fuel, can be appropriately utilized and commercialized.

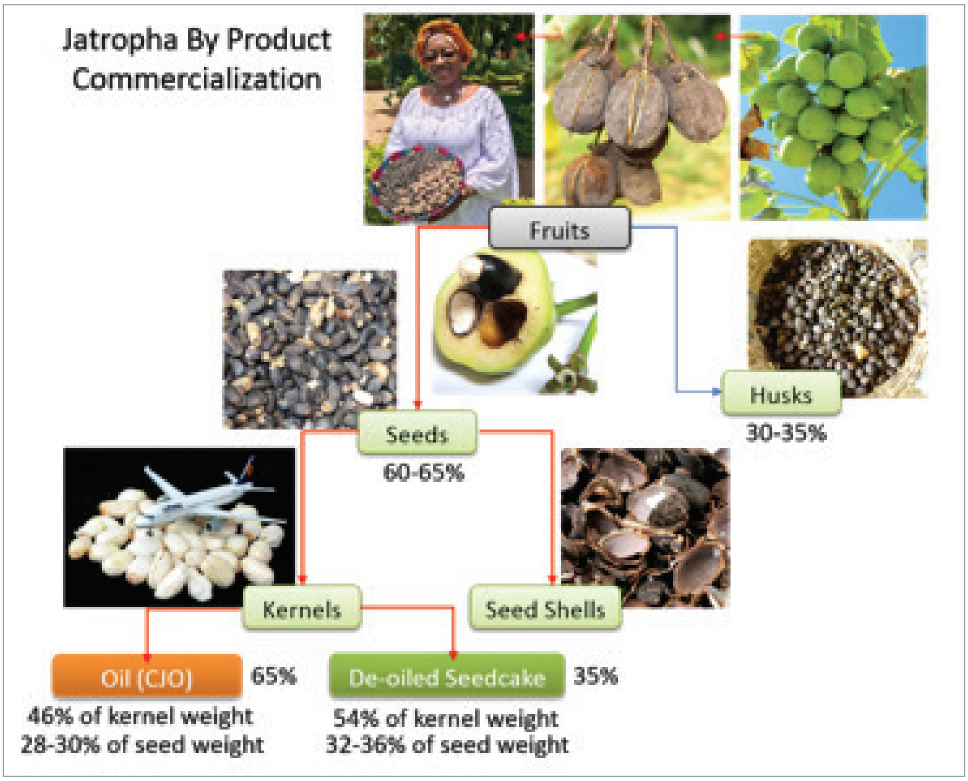


FIGURE 26
Jatropha fruit/seed weight ratios and by product commercialization

During the process of expelling oil from jatropha seeds, only 30 per cent of the seed weight (equalling 46 per cent of the de-shelled seed kernels) is processed into CJO. The remaining seed shells and seed cake contain minerals, proteins, carbohydrates, fibrous material (lignin), oil and various other molecules. The separation and/or extraction of these components and their subsequent treatments through thermal, chemical, catalytic, bio-chemical (enzymatic) and other methods yield highly desirable value-added products.

To exploit the full potential and to increase the chances of achieving economic viability, all by-products will have to be considered and introduced into the market at their own proper value. This includes fruit husks and seed shells. Each jatropha fruit consists of 60 to 65 per cent seeds and 35 to 40 per cent husks by mass, while seeds typically consist of 35 per cent shells (coating) and 65 per cent kernels (nucleus) by mass (see **Figure 26**).

Without even considering sophisticated medicinal or nutraceutical applications the combined value of the most basic by-products, namely: de-oiled seedcake; fruit husks; and seed shells, can easily make up 50 per cent in value of total crude oil.

3.4.5.4 Organic Fertilizer

The most promising value-added by-product is the revenue generated from the commercialization of jatropha kernel meal. After oil extraction from seeds, the de-oiled jatropha seed cake (JSC) is a rich organic source that can be applied as bio fertilizer and soil conditioner. Due to the presence of nitrogen (N/ 5.0 to 6.5 per cent), phosphorous (P/ 2.0 to 3.0 per cent), and potassium (K/ 1.0 to 1.5 per cent) the organic nutrient sources in JSC are even higher than that of chicken or cow manure. Moreover, JSC still contains the compositions of primary and secondary elements required for plant growth. These qualities significantly reduce the need for otherwise chemical inputs, which in return will lower the carbon footprint for growers and reduce negative impacts on surrounding ecosystems. The use of seedcake can actually replace much higher valued chemical fertilizer. Further benefits of jatropha seed cake as organic fertilizer include increased soil organic matter content and improved water-holding capacity of the soil. It improves the physical structure of the soil thus allowing more air to get to the plant roots. Beneficial bacterial and fungal activity increases in the soil; mycorrhizal fungi which make other nutrients more available to plants thrive in soil where the organic matter content is high. Instead of using the residual jatropha seed cake as an organic fertilizer (green manure) it can also be fermented in a biogas plant and subsequently used for electric energy and heat generation. Under the right heat and moisture conditions the fermentation of the press-cake will produce a biogas which can feed a gas-powered generator.

Assuming an average plantation density of 888 plants per hectare and an individual plant performance of 2.4 kg of seeds, one hectare can generate around 750 kg of jatropha kernel meal. Processing is likely to result in a weight loss of 15 per cent. This leaves a potential of 640 kg/ha or just about 30 per cent of seeds harvested.

While monthly international prices for NPK-fertilizers in Africa hoover around USD 250/tonne, chemical fertilizer in Burkina Faso is currently sold for USD 600/tonne (FCFA 350,000). Given its validated nutrient qualities, a conservative cash value of at least USD 200/tonne of jatropha-based organic fertilizer can be considered economically justifiable. Applied to the above example, this translates into a commercialization potential of USD 150/ha.

3.4.5.5 Animal Feed (Non-toxic variety)

Apart from the oil, jatropha kernel meal has gained interest for utilization in animal feed formulations. However, the seed cake contains anti-nutrients and several toxins, such as curcin, phorbol esters, saponins, protease inhibitors and phytates. Meal produced by the commonly cultivated toxic varieties would thus need to be processed for the complete removal of the toxic phorbol ester fraction prior to incorporation in animal feed. This is where the cultivation and processing of non-toxic hybrid varieties and edible jatropha accessions from Central America may offer an attractive advantage.

The nutritional value of jatropha kernel meal is largely determined by the content of available nutrients, in particular protein content, protein quality and the specific composition of essential amino acids. Among the essential amino acids, the most important are lysine, methionine/cystine and threonine. Others include glycine, valine, isoleucine, leucine, and phenylalanine. With a superior amino acid composition, jatropha kernel meal has been found to have at least a 40 per cent higher crude protein content than soybean meal. Key findings concluded by the UN FAO have proven that the protein quality and the nutritional value of non-toxic jatropha kernel meal may even be considered as equivalent to fishmeal protein and that both these protein sources result in similar growth performance, energy expenditure and energy retention.

Under the assumptions that the protein quality of jatropha kernel meal is better or at least equivalent to soybean meal protein, and that jatropha meal can potentially substitute for soybean meal on an equal-weight basis without compromising health, growth performance and nutrient utilization, jatropha kernel meal could reasonably be valued and priced in line with soybean meal.

Soybean meal futures are currently trading at around USD 310/tonne (June 2017). Given that non-toxic jatropha kernel meal is still in the early stage of market introduction, it is probably reasonable to apply a temporary price discount/markdown of 50 per cent. This would fix the jatropha meal market value at about USD 155/tonne with a mid-term upwards tendency directly proportional to the increasing market acceptance as alternative source of protein feed.

Item	Soybean Meal	Jatropha Kernel Meal (JKM)
Crude Protein	≥43.0%	≥60%
Crude Fiber	≤7.0%	9%
Ash Content	≤7.0%	9.6%
Digestible Organic Matter	87.9%	78%
Metabolizable energy (MJ kg-1 DM)	13.3	10.9
Gross Energy (MJ/Kg)		18

TABLE 7
Comparison of key soybean and jatropha propertie

Depending on market acceptance/resistance, individual price development, plantation model design, plant density, yield performance and yield consistency, among others, the alternative commercialization of bio-fertilizer and animal feed offers an additional revenue potential inside a range of at least USD 150 to 200/tonne.

3.4.5.6 Fruit Husks

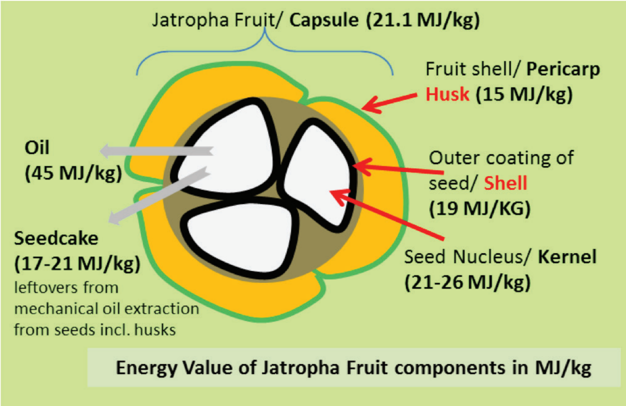


FIGURE 27
Breakdown of energy value of jatropha fruit components

The fruit husks (dried fruit encapsulate) of jatropha have a high-energy content (15 MJ/kg) and heating value. The chemical composition of the husk (3.97 per cent ash, 71.04 per cent volatile matter, and 24.99 per cent fixed carbon) is similar to that of other biomass energy sources. The energetic value can best be leveraged through direct combustion or co-firing. The fruit husks could also be sold along with the seed cake as an additional substrate for the production of biogas. In order to commercialize the intrinsic value of the husks, volume and scale are important. However, as long as fruits are decorticated manually by individual farmers, critical mass is unlikely to be reached. The contract farming model also provides extra challenges for coordinated logistics, transportation and storage which would need to be addressed. However, in this case, fruit husks can still be returned to the fields and used as bio-fertilizer to improve soil condition.

In order to determine the approximate commercial value of the fruit husks, the specific energy content first needs to be converted into boe/ha. In a second step, the interim result can then be multiplied with the prevalent oil price per barrel. To reflect processing (conversion) and handling cost (e.g. transportation, storage), it is suggested to apply a discount of at least 40 per cent.

Sample calculation:

Assuming a seed yield to fruit husk ratio of 1:0.67, a plantation density of 888 plants/ha and a plant performance of 2.4 kg, a seed yield of 2 131 kg/hectare of will also generate 1 421 kg of fruit husks/ha of intercropped jatropha cultivation. The multiplication of this number with the specific energy content of 15 MJ/kg will translate into a 3.51 boe. Depending on the current market price of oil, this represents a potential value of USD 104.70/ha. In other words, the proven calorific value of jatropha fruit husks may justify a market value of USD 70/tonne.

Conversion steps:

1. **1 421 kg husks/ha x 15 MJ/kg = 21 315 MJ = 21 31 GJ**
2. **21.31 GJ / 6.1 boe/GJ = 3.49 boe**
3. **3.49 boe x [50] USD/boe = USD 174.50**
4. **USD 174.50 - [40]% processing cost = USD 104.70**

3.4.5.7 Seed Shells

Jatropha seed shells have an even higher heating value (19.5 MJ/kg) and greater bulk density which makes them more valuable than the fruit husks as a combustible fuel. The seed shells contain 45 to 47% lignin and their calorific value is comparable to wood fuel (Prosopis juliflora). The chemical composition of jatropha shells suggests that it is a good feedstock for energetic conversion. Several conversion technologies have been studied using jatropha seed shells as an energy feedstock. These include briquetting and direct combustion, pyrolysis and bio-methanation. The combustion of jatropha shells is possible without previous processing (e.g. pelletizing). However, pelletizing or briquetting will achieve a reduction of volume and a further increase of energy density. Furthermore, the ash that remains after shell combustion is high in sodium and potassium, making it suitable for soil enrichment and fertilizer use.

Instead of direct combustion or fertilization, shells and husks may equally be brought into a bio-digester where microbes break down the biomass in an anaerobic digestion process. The biomass material discharges a bio-methane gas that is captured in a micro turbine and used to generate electricity in a combustion engine.

Applying the same underlying assumptions as in the example above, a sample production volume of 2 131 kg of seeds will generate 746 kg of shells. Multiplied with the specific energy content of 19.5 MJ/kg, this will translate into 2.38 boe, representing a potential value of USD 119. As processing will take place at the fuel conversion site, this will facilitate handling and reduce related costs. Reflecting this comparative advantage over husks, it might thus be fair to subtract a discount for logistics in the range of 30 per cent instead of 40 per cent. All other conditions remaining the same, the commercial value of seed shells per ha can therefore be calculated with USD 83, equalling USD 111/tonne.

3.4.5.8 Yield Matrix (per hectare)

To illustrate the value creation potential per hectare in addition to the commercialization of the crude jatropha oil itself, the following yield matrix in **Table 8** identifies some reference scenarios with regard to plant density and yield performance. To reflect local conditions in Burkina Faso, all variations pursue an intercropping model. The particular choice of intercropped plant species will determine the spacing requirements between individual plants and plant rows. Realistic plant/row spacing alternatives include 4m x 2m, 5m x 3m and 4.50m x 2.50m. Accordingly, underlying assumptions for plant density per hectare fluctuates between 660 and 1 250 plants. To better reflect the impact of plant density on the overall performance per hectare, seed yield data is broken down into production per plant. This will also facilitate better comparison between the different intercropping models. Individual plant production performance is assumed to span a range from 1.6 kg of seeds per plant (for domestic jatropha accessions) to 3.2 kg of seeds per plant (for first generation non-toxic hybrid jatropha accessions). Further impact on yield performance through use of fertilizer or irrigation shall not be considered.

TABLE 8
Intercropping scenarios and value composition

Intercropping Scenarios		Seed yield per plant											
		1.6 kg				2.4 kg				3.2 kg			
		Total production performance per ha (in kg)											
A	660 plants/ ha	Husks/ ha	Seeds/ha			Husks/ ha	Seeds/ha			Husks/ ha	Seeds/ha		
			1 056				1 584				2 112		
			Shells (35%)	Kernels (65%)			Shells (35%)	Kernels (65%)			Shells (35%)	Kernels (65%)	
			370	686			554	1.030			739	1,373	
				Kernel Meal (54%)	Oil (46%)			Kernel Meal (54%)	Oil (46%)			Kernel Meal (54%)	Oil (46%)
		704	370	370	315	1,056	554	556	474	1,408	739	741	632
Price/tonne ($)		70	111	150-200	NN	70	111	150-200	NN	70	111	150-200	NN
Value/ha ($)		49	41	56-74	NN	74	61	84-111	NN	99	82	111-148	NN
B	888 plants/ ha	Husks/ ha	Seeds/ha			Husks/ ha	Seeds/ha			Husks/ ha	Seeds/ha		
			1 421				2 131				2 841		
			Shells (35%)	Kernels (65%)			Shells (35%)	Kernels (65%)			Shells (35%)	Kernels (65%)	
			497	924			746	1,385			994	1,847	
				Kernel Meal (54%)	Oil (46%)			Kernel Meal (54%)	Oil (46%)			Kernel Meal (54%)	Oil (46%)
		947	497	499	425	1,421	746	748	637	1,894	994	997	850
Price/tonne ($)		70	111	150-200	NN	70	111	150-200	NN	70	111	150-200	NN
Value/ ha ($)		66	55	75-100	NN	99	83	112-150	NN	133	110	150-199	NN
C	1 250 plants/ ha	Husks/ ha	Seeds/ha			Husks/ ha	Seeds/ha			Husks/ ha	Seeds/ha		
			2 000				3 000				4 000		
			Shells (35%)	Kernels (65%)			Shells (35%)	Kernels (65%)			Shells (35%)	Kernels (65%)	
			700	1,300			1.050	1,950			1.400	2,600	
				Kernel Meal (54%)	Oil (46%)			Kernel Meal (54%)	Oil (46%)			Kernel Meal (54%)	Oil (46%)
		1 333	700	702	598	2 000	1 050	1 053	897	2 667	1 400	1 404	1 196
Price/tonne ($)		70	111	150-200	NN	70	111	150-200	NN	70	111	150-200	NN
Value/ha ($)		93	78	105-140	NN	140	117	158-211	NN	187	155	211-281	NN

3.4.5.9 Breeding & Domestication

Despite the attention that jatropha has received as a source of renewable oil for the production of sustainable and affordable biofuels, jatropha still has to be considered an undomesticated wild species that has not yet benefitted from crop improvement programmes. Even though essential questions around jatropha crop growth, crop management and production have not been addressed adequately, wild jatropha accessions were used to setup large plantations, often not well adapted to local environments and local production systems. Maladaptation of jatropha accessions to the new use has often led to inadequate seed and oil yields per hectare.

The challenge is to develop well adapted, robust, high yielding jatropha varieties for a range of climates and agrosystems, as only high seed and oil yields per hectare will guarantee profitability and a high GHG emission reduction. The main bottleneck to elevate jatropha from a wild species to a profitable biodiesel crop is the low genetic and phenotypic variation found in different regions of the world, hampering efficient plant breeding for productivity traits.

Given the low domestication status of jatropha, genomics offers numerous technologies for collecting genetic information that could be potentially integrated into jatropha breeding to aid in the development of cultivars with outstanding performance based on genetic data alone.

However, wide genetic variation is required in breeding for major agronomically important traits like seed and oil yield, seed and oil composition, flowering behaviour, tree morphology, disease resistance and the absence of anti-nutritional factors that currently prevent the use of jatropha seed meal in animal feed. Plant breeding programmes need such genetic variation to be able to combine positive traits from different plant parents to provide the required profitable and sustainable jatropha varieties of the future.

To increase and stabilize oil yield performance, it is therefore suggested that new genetic variations be identified and used in jatropha breeding programmes. Food crops have been improved in this manner for centuries. Scientific results indicate that outside Central America there is no significant genetic biodiversity in Jatropha curcas. In comparison to accessions found in Africa, the pool of Central American accessions shows very large molecular diversity as assessed by DNA-marker variation. This makes Central America an important source of new genetic variations in jatropha that will prove useful in widening the pool of germplasm available for jatropha breeding programmes. Not only do accessions differ in their genetic constitution, but also show a wide disparity in phenotypic traits like flowering type, tree architecture, oil concentration and fatty acid composition. For example, the average oil content varies between 19 and 40 per cent of the whole seed (seed kernel and seed hull). Depending on provenance, jatropha seed weight varies from 0.48 g (Rwanda) to 0.57 g (Burkina Faso) to 0.76 g (Guatemala, Mexico). Central American accessions also show significantly higher early growth rates, resulting in higher total leaf areas, dry weights, and plant heights. These traits that lead to larger and stronger plants are important for surviving the first stages in the field after transplanting, especially under dry and arid conditions (low precipitation <1 000 mm/year), and for taking advantage of short precipitation periods. Fast, early growth is very beneficial as it is one of the factors positively influencing the yield of seed and oil in the first year of establishment. Central American accessions should thus be considered as the most important source for plant breeding.

3.4.5.10 Tissue Culture Propagation

Jatropha cultivation will only be commercially viable when best quality planting material from selected clones or varieties are used and made available to farmers in large quantities within a short time-frame. The supply of elite planting material on a large scale requires massive production of phenotypically homogeneous cultivars that are adapted to the growth conditions of the selected plantation areas. This puts the focus on nurseries and dedicated breeding centres. Conventional plant multiplication is typically carried out by sowing seeds or planting cuttings directly in the field or after a first period of growth in nurseries. However, this method is time-consuming and entails the disadvantage of producing heterogeneous plants with inconsistent seed yields. In comparison, in-vitro regeneration and micro-propagation techniques may offer a powerful tool for mass-multiplication of uniform high yielding hybrids. Clonal mass propagation through genetic engineering techniques has the advantage of reproducing elite plants that are morphologically homogenous, with a high production capacity and identical yield trajectory. In addition to in-vitro tissue culture techniques for a rapid build-up of large plant quantities, the complementary application of plant growth regulators may be suitable to induce uniform flowering and thus facilitate the synchronization of ripening and harvesting, a pre-condition for commercial production scale-up. However, plant growth regulators and vegetative cloning come at a cost. Enabling tissue culture propagation of elite planting material on a large scale will require a high-tech laboratory set up. The extra costs for setting up a tissue culture lab facility need to be carefully offset against the expected yield gains and related economic returns.

3.4.5.11 Waste Water Irrigation

In Burkina Faso water is a scarce resource and conditions all agricultural activities. To optimize the availability of water and related land-use applications, changes and developments to consider include the potential irrigation of jatropha cultivation sites with wastewater. Instead of intensifying the pressure on water resources, leading to conflicts among users and excessive pressure on land and environment, sewage effluents, after pre-treatment, provide an alternative nutrient-rich water source for salinity tolerant agriculture in the vicinity of cities. Treated sewage effluents (TSE) contain relatively large amounts of nutrients that are potentially available for plant production, while at the same time, the nutrients will be removed from the effluent, thus increasing the quality of the remaining water. The water supply from wastewater treatment plants in Ouagadougou could theoretically allow commercial scale jatropha production or at least efficient plant nursery operations. Using unconventional water sources, such as TSE, represents a potential alternative for irrigation, since TSE contain considerable amounts of nutrients (N-P-K).

3.4.6 FUEL CONVERSION PATHWAYS

Jatropha feedstock based alternative fuel will have to meet stringent manufacturing specifications. Given the requirements for the production of aviation fuel, available options for the processing of non-edible CJO into alternative fuel that meets all critical specifications are limited.

3.4.6.1 HEFA

HEFA is the most realistic oleochemical reaction pathway, which has reached market maturity (see Section 3.3.2.2 for a more detailed description).

HEFA technology is based on the hydro-processing of natural oils and fats (broadly a triglyceride mixture). To transform biofuels into the “drop-in” replacement fuels that are fully compatible with existing fuel infrastructure and aircraft engines, their alcohols, lipids and molecules must be transformed into true hydrocarbons by a complex series of processes collectively known as “hydro-treatment”. These chemical manipulations increase the ratio of hydrogen to carbon, remove all oxygen, and change the structure and blend of the constituent molecules to give the fuel its necessary characteristics. The biomass and vegetable oils that can be hydro-treated are not limited to crude jatropha oil but also include animal waste fats (tallow), cotton seed oil, used cooking oil, cashew nutshell liquid or shea nutshells.

Hydrogenation offers an energy-efficient alternative of producing synthetic biofuels. Hydrogenation removes oxygen and other impurities from feedstocks with high oil content, such as jatropha, and produces hydro-treated renewable jet fuels (HRJ). The resultant fuels are pure hydrocarbon fuels and have indistinguishable physical properties from fossil-based fuels. HRJ fuels tend to have better combustion performance and higher energy content and, most importantly, have good low-temperature stability, making them ideal as a renewable source of SAF.

Currently, the majority of SAFs are derived from oleochemical feedstocks and use the HEFA pathway. This will likely remain the main conversion route over the next five to 10 years, while other bio-jet technologies are still maturing.

One of the main advantages of the HEFA route is that it is possible to integrate this process into an oil refinery, avoiding the need to develop a dedicated production facility. Unfortunately, this option does not exist in Burkina Faso.

Independent of the significant feedstock supply potential, a stand-alone HEFA processing plant remains unrealistic for the time being. The lack of refining capacity will inevitably thwart all efforts. Without even basic petrochemical or refining infrastructure in place, there is no chance for cost savings through co-location, co-processing or the use of existing infrastructure. Thus, a HEFA plant is neither technically feasible nor commercially viable, be it in Burkina Faso or elsewhere in sub-Saharan Africa. The estimated high capital and processing costs, and in particular the need for expensive hydrogen, renders the HEFA pathway uncompetitive.

3.4.6.2 FAME Biodiesel

Unless domestically produced CJO is shipped overseas and upgraded to SAF at existing facilities in Europe, the feedstock is more likely to be converted to conventional biodiesel, chemically also known as FAME. FAME biodiesel is notably distinct from HEFA aviation fuel; because it retains an oxygen ester, FAME biodiesel is too oxygenated to be used as a drop-in SAF. While biodiesel cannot replace aviation fuel, it can nevertheless be used by any airport's diesel-powered ground fleet, such as aircraft tugs, buses and fire-fighting vehicles.

PICTURE 15
Tarmac at Ouagadougou Airport

The diesel-powered fleet of ground support equipment (GSE) is managed by Régie Administrative Chargée de la Gestion de l'Assistance en Escale (RACGAE). Limited monthly consumption needs could easily be provided by domestically produced alternative transport fuels, such as biodiesel from animal waste fats or jatropha.

According to the fuel consumption data provided by the ground support handling agency of Ouagadougou airport, the Régie Administrative Chargée de la Gestion de l'Assistance en Escale (RACGAE), the truck and trailer fleet of diesel powered GSE (including refuelers, pushback tugs, tractors, belt loaders, transporters, passenger boarding steps) consumes on average about 5 000 litres/month. Assuming a specific density of 885 kg/m3, this amounts to 4.4 tonnes/month or just 53 tonnes/year. All truck engine manufacturers have confirmed engine compliance with biodiesel up to a blend of 100 per cent (B100).

The conversion of CJO into biodiesel requires refining. In general, the feedstock and methanol are combined in a reactor in the presence of a catalyst (usually potassium hydroxide or sodium hydroxide) to form methyl ester (biodiesel) and glycerine (co-product). The refining process turns the triglycerides (oils and fats) into esters, separating out the glycerine. The glycerine sinks to the bottom and the biodiesel floats on top and can be siphoned off. This process which substitutes alcohol for the glycerine in a chemical reaction is also called transesterification. Thus, biodiesel is derived from triglycerides by transesterification with short chain alcohols. **Figure 28** illustrates the refining process in a multi-feedstock biodiesel plant.

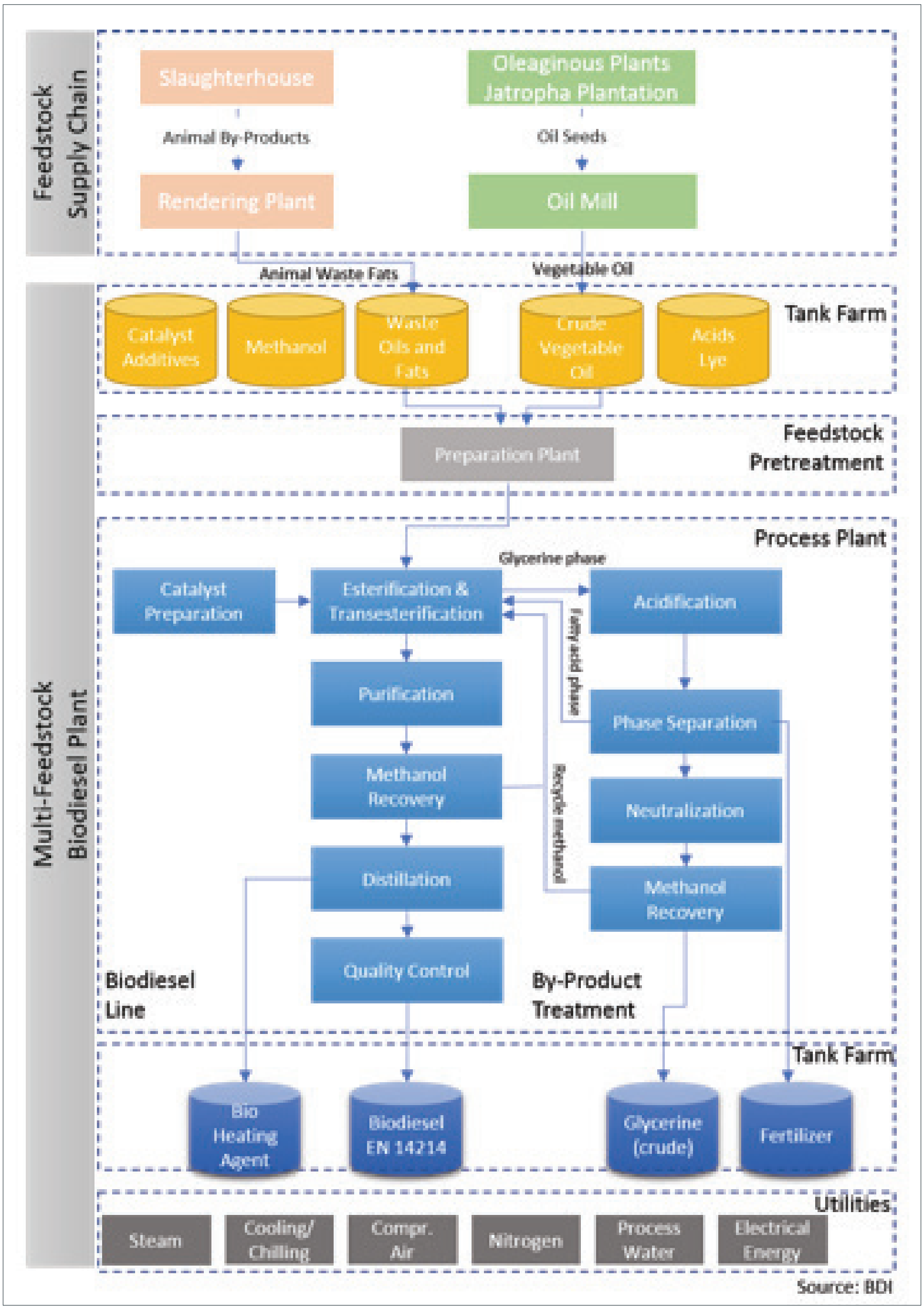


FIGURE 28
Multi-feedstock biodiesel plant (schematic)

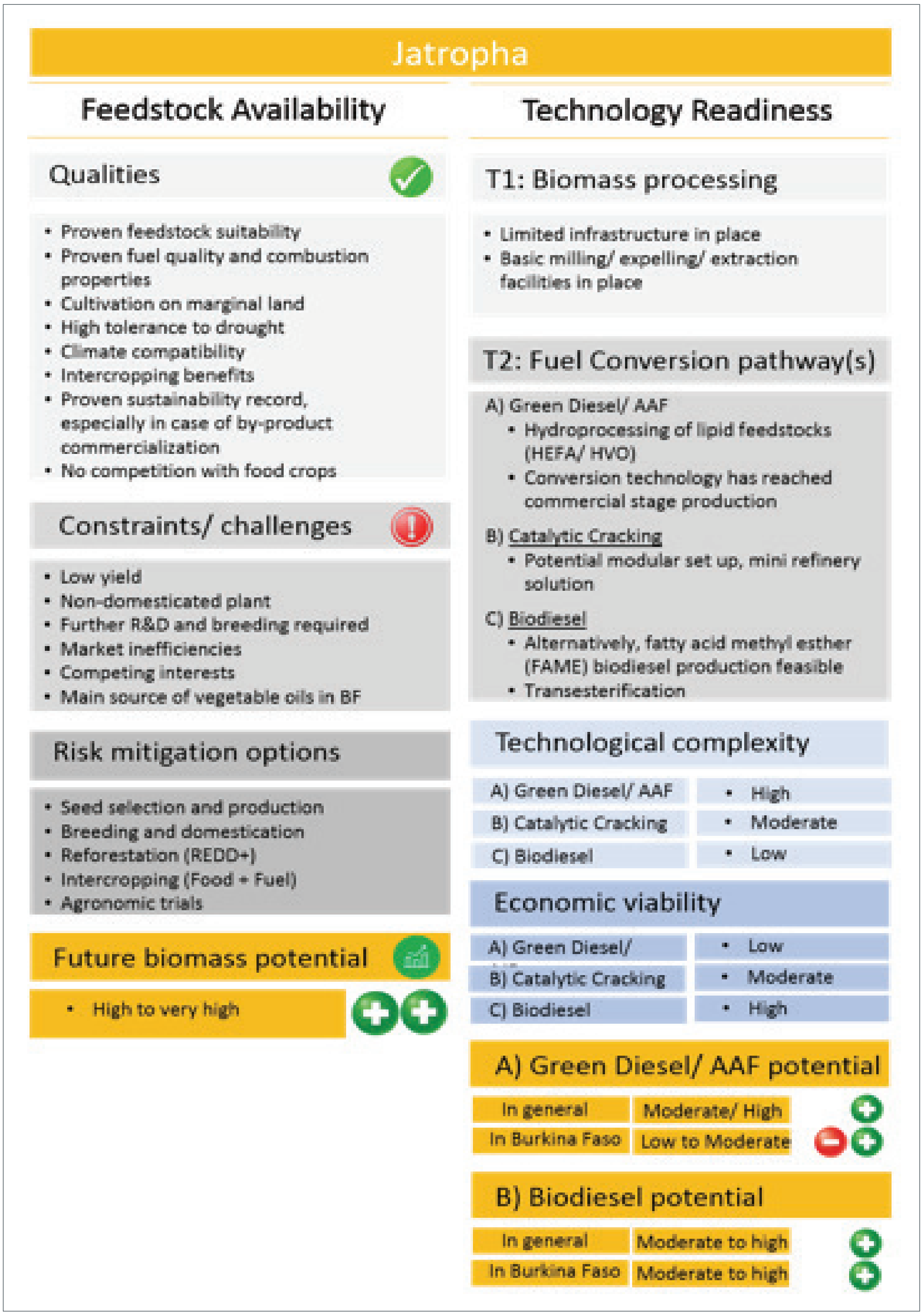
Biodiesel emits significantly fewer greenhouse gases, particularly nitrogen oxide, carbon dioxide and sulphur dioxide, than traditional mineral oil-based diesel fuel. Jatropha based biodiesel emits about two-thirds less in unburned hydrocarbons and almost half as much carbon monoxide and particulate matter as conventional fuel. In particular, it:

- reduces emission of carbon dioxide by 80 per cent;
- reduces emissions of carbon monoxide by 50 per cent;
- reduces emission of aromatic hydrocarbons by 50 to 70 per cent;
- contains almost no sulphur; and
- is biodegradable and non-toxic.

3.4.6.3 Pure Plant Oil (PPO)

Alternatively, filtered and purified CJO may also be used directly without being refined as pure plant oil (PPO or B100) in micro heat and power plants and various types of combustion engines in the marine, construction and agricultural sectors. In this case, virtually no engine or infrastructure modifications are needed.

3.4.7 Feasibility Matrix



3.5 OTHER OIL-BEARING FEEDSTOCKS (CROPS)

3.5.1 COTTONSEED OIL

3.5.1.1 Feedstock Qualification

Burkina Faso is the largest cotton producer in Africa. Cotton is the single most important cash crop in Burkina Faso and its production is constantly growing. Cotton production represents around 4 per cent of Burkina Faso's GDP and is the second-biggest source of State revenue after gold. In 2016, the export trade value of cotton reached USD 420 million, representing roughly 20 per cent of all exports. Cotton is mainly cultivated to meet the basic requirement for cotton fabrics, and around 4 million people depend on cotton cultivation as a source of income. However, the cotton plant does not only provide the cotton lint which is used in the textile industry but also offers secondary by-products in the form of cottonseeds. Cotton has a variety of uses: fibre for textiles, cottonseed oil as a food ingredient, and meal and hulls from crushed cottonseeds as animal feed for livestock and poultry. Cotton thus qualifies concurrently as both a fibre and a food crop.

As of June 2017, one tonne of cotton seeds is valued at USD 138 (FCFA 80 000), while one litre of cottonseed oil fetches 1 USD (FCFA 560). Cottonseeds are therefore a valuable by-product of the cotton plant as they contribute to the overall profitability of the whole production chain. Harvesting 100 kg of cottonseeds produces approximately 30 to 45 kg of fibre (accounting for approximately 85 per cent of the commercial value of the harvest) and approximately 55 to 70 kg of cottonseeds which contain 9 to 12 kg of pure vegetable oil.

The production of cotton in Burkina Faso has grown from around 200 000 tonnes in the early 1990s to reach a peak of 895 000 tonnes in 2014. The country produced 683 000 tonnes of seeds and 230 000 tonnes of fibres during the harvest season 2016/2017. The harvest in 2017/2018 is expected to reach 800 000 tonnes again.

FIGURE 29
Main cotton production areas

Monoculture cotton is cultivated on 800 000 ha, mainly in four cotton zones by farmers organized in more than 8 500 cotton producer groups (GPC) with the support of three cotton companies. Main production areas are Kénédougou (Hauts-Bassins), Mouhoun (Boucle du Mouhoun), Tuy (Hauts-Bassins) and Houet (Hauts-Bassins) (see **Figure 29**).

SOFITEX is the largest cotton company. Being primarily state-owned, it controls over 80 per cent of Burkina Faso's total cotton production. While SOFITEX is responsible for the collection and ginning of cotton, the main seed processing company is SN-CITEC.

While most of the small and medium-sized cottonseed processing facilities and oil mills in the vicinity of the cotton ginning workshops use traditional expeller pressing technology, SN Citec uses the more technologically advanced solvent-based technology. The solvent extraction process allows the recovery of up to 96 per cent of the oil content contained in the cottonseeds. Solvent extraction is the commonly used commercial technique to recover oil from oilseeds. Presently, n-hexane is the preferred solvent throughout the world due to its extraction efficiency and ease of availability, yet hexane has been categorized as a hazardous air pollutant by the US EPA and is included in the list of toxic chemicals.

Given the specific fuel properties and combustion characteristics, the methyl esters obtained from cottonseed oil can potentially be considered as a good alternative fuel and a feasible oil source for FAME-biodiesel production. However, cottonseed oil is the main source of vegetable oils in the country.

With a seed oil content ranging between 14 and 26 per cent, cottonseeds are primarily used to extract edible oil. Originally regarded as a waste by-product, cottonseed oil has been consumed as vegetable oil and food ingredient in Burkina Faso since 1973.

Being the largest and oldest oil mill in the country, SN-CITEC has a maximum production capacity of 15 to 20 000 tonnes of cottonseed oil per year.

SN-CITEC temporarily also operated a biodiesel pilot plant with a production capacity of 12 000 tonnes by processing seeds unfit for human consumption. With a conversion ratio of 5.9 and a fat content of 17 per cent, one tonne of Burkinabe cottonseeds provide about 170 kg of pure vegetable oil and 830 kg of seed meal.

While the 2016/2017 seed production harvest of 683 000 tonnes translates into a potential oil production volume of 116 000 tonnes, oil mills in Burkina Faso produce on average 35 000 tonnes of edible oils per year. Even though the whole production is marketed locally, the country cannot satisfy the actual demand for edible oils. The market requires about 75 000 tonnes of vegetable oil per year, indicating a shortage of 40 000 tonnes. This deficit has to be compensated for largely by palm

PICTURE 16
SN-CITEC in Bobo-Dioulasso

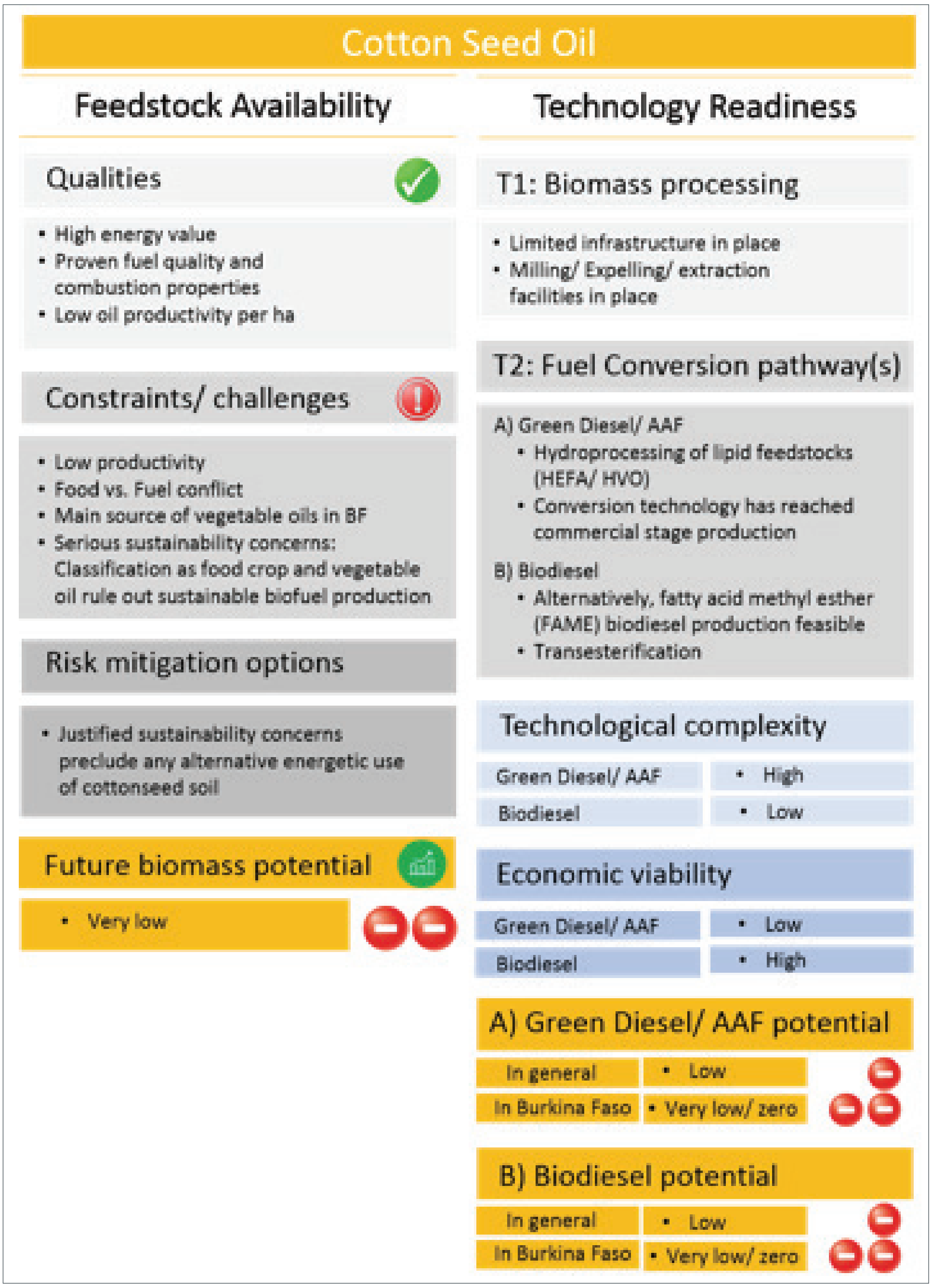
oil imports from Malaysia and Côte d'Ivoire. The gap between domestic supply and demand will deteriorate even further as demand is expected to increase to 164 000 tonnes by 2030. Neighbouring Benin, Niger, Togo and Mali will be confronted with similar food constraints.

3.5.1.2 Challenges and Constraints

The production of biofuels based on cottonseed oil would lead to a shortage of edible oil and should not be encouraged. Despite its comparatively low oil productivity (i.e. 327 to 420 litres/ha per annum) and independent of nutritional concerns, cottonseed oil will continue to fulfil a strategic role as the prime source of vegetable oil supply earmarked for local consumption. Given the forecasted rising demand for edible oils in Burkina Faso and in many other West African States, it is unlikely that alternative crops, such as soybean or sunflower will be replacements to enable cotton to be used as a source of bioenergy.

Therefore, justifiable sustainability concerns will prevent the alternative energetic use of cottonseed oil for years to come. Any kind of commercially and technically feasible biofuel application will consequently have to be disregarded.

3.5.1.3 Feasibility Matrix



3.5.2 CASHEW NUTS (CNSL)

3.5.2.1 Feedstock Suitability

Cashew nuts are currently the third largest agricultural export product of Burkina Faso, after cotton and sesame. Though at first glance it may not appear obvious, the cultivation and processing of cashew nuts serves as an ideal example of pursing several economic, energetic, environmental and social objectives at once, particularly with regard to optimizing food and fuel production.

The cashew tree is an evergreen tropical crop. It is a fast growing, hardy and drought resistant multipurpose tree that can be cultivated in many tropical climatic conditions.

In addition to the production of cashew nuts, the cashew tree is recognized by the FAO as a reforestation tree that also contributes to preserving the environment and improving soil fertility. Their extensive root system makes cashew trees adaptable to a wide range of soil types. As cashew trees have the capacity to rehabilitate degraded soils, preserve water quality and sequester carbon (estimated at 0.33 tonne CO_2e/ha), the development of cashew tree plantations contributes directly to climate change mitigation while providing income opportunities for rural communities.

Cashews were originally introduced to Burkina Faso in the 1960s by the Centre Technique Forestier Tropical (CTFT). The initial aim was to restore degraded soils in the savannah area and to stop desertification. Large-scale cashew cultivation was only initiated by the government in 1980 (project "Anacarde") as a means to improve soil fertility and increase rural incomes, especially for women. It is only since the 1990s that cashews have been grown as an important cash crop. As of today, the cashew sector has gained significant economic importance for Burkina Faso. Cashews are the third most important agricultural export product after cotton and sesame. In less than 10 years the underlying trade value of exported Burkinabe cashews increased from USD 1.5 million to over USD 120 million as of 2017.

The main product of the cashew plant is the curved seed or kernels. While the edible seeds have a high nutritional value, the nutshells are largely considered waste and are commonly discarded. The raw cashew nut consists of approximately 25 to 30 per cent seed and 70 to 75 per cent shell.

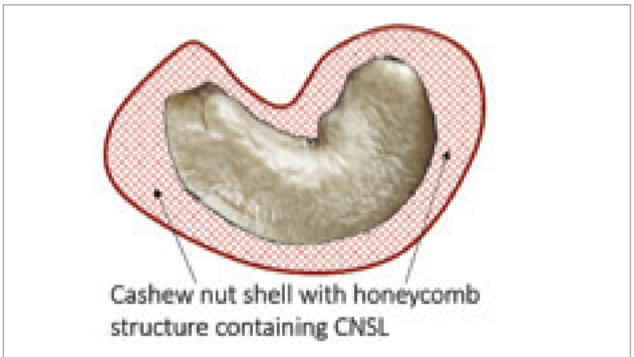


FIGURE 30
Cashew nut inside a nutshell

Cashew nut shells have a net calorific value of 19 to 22 MJ/kg, placing them in the middle of the biomass fuel mean range (14 to 21 MJ/kg). The nutshells with a thickness of up to 3 millimetres contain a dark reddish brown viscous liquid, the so-called cashew nut shell liquid (CNSL) which is situated inside a soft honeycomb structure in between the outer shell and the testa, a thin coating surrounding the kernel. CNSL has a similar quality and heat content as light fuel oil (LFO) with an average calorific value of 39 to 42 MJ/kg. The major components of CNSL are anacardic acid, cardanol, and cardol. The physical and chemical properties of CNSL are within an acceptable range to qualify as feedstock for biofuel production. Structurally, CNSL is different from other vegetable oils due to the presence of a benzene ring. The usual C:H:O ratio for vegetable oils is 78:12:10, whereas the comparable ratio for CNSL is 80:12:08. This may explain the relatively high calorific value. CNSL has a higher density than diesel. It can be reduced by degumming and transesterification. Regarding CNSL commercialization, market prices in China are about USD 250/Mt delivered.

In addition to the cashew kernels and the CNSL, another by-product are the so-called cashew apples. The apples, which are about 10 cm in length and largely exceed the externally attached nut itself in weight, constitute a huge quantity of biomass which might also qualify as feedstock for potential energy recovery. The cashew apples are highly perishable and are typically left to rot in the orchards. It is estimated that 12 to 14 kilos of apples could be converted into one litre of bioethanol.

CNSL converted into biodiesel provides an innovative source for alternative energy generation. The performance of CNSL-based biodiesel blends has been successfully tested and validated in compression ignition engines. Confirming the feasibility of CNSL as a source of biodiesel, blends of CNSL could be substituted for petroleum diesel fuel without major modifications. According to tests conducted in India with CNSL blends in internal combustion diesel engines, the optimum performance of regular diesel engines with CNSL suggests a blend of 75 (diesel):25 (CNSL), with optimized ignition timing and injection pressure of 19° BTDC and 22 MPa (220 bar) respectively.

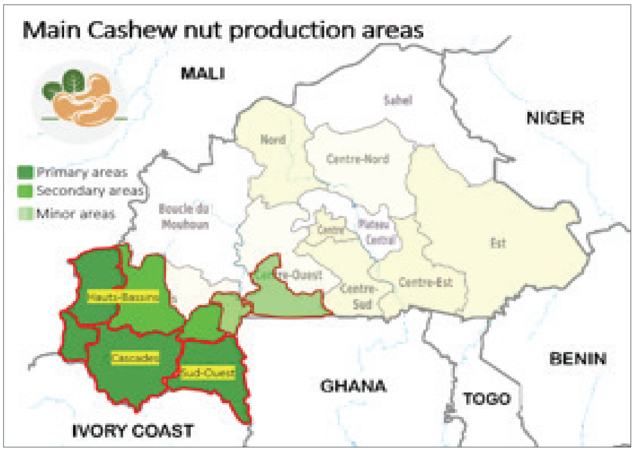


FIGURE 31
Main cashew nut production areas

Quantification of feedstock availability for energy conversion purposes depends on the annual production volume of cashew nuts, the typical weight ratio between shell and CNSL, and the actual volume of nuts processed domestically.

West Africa is one of the main cashew producing areas of the world. In 2016, West African States generated an estimated 1.4 million tonnes, i.e. about 45 per cent of the world's cashew production. At least 70 per cent of the annual production volume consists of cashew nut shells with an approximate energy content of 20 GJ per tonne. Thus, the rough potential for alternative energy production from cashew shells in Africa is 19.6 million GJ or 3.3 million boe. However, scarcely 10 per cent of the energy recovery potential from cashew nut shells is generated domestically as the majority of production is shipped to Asia in raw unprocessed format.

In comparison, cashew plantations in Burkina Faso cover around 90 000 ha with an estimated production volume of 70 000 tonnes of raw cashew nuts (RCN) in 2017. Over 90 per cent of the production areas are concentrated in the regions of Cascades, Sud-Ouest and Hauts Bassins (provinces of Comoé, Léraba, Kénédougou, Poni and Noumbiel), in the South-West of the country (see Figure 31). The cashew nut sector employs more than 50 000 farmers of which 80 per cent are women. Most of the producers are organized in cooperatives. The Wouol Farmers' Association, for example, is a regional level organization uniting 69 farmers' cooperatives with more than 2 500 farmers, of whom more than 70 per cent are women. Wouol operates in 20 communes in the plantation regions bordering Mali, Côte d'Ivoire and Ghana.

Considering a seed-to-shell weight ratio of 30:70 and a CNSL oil content range between 15 and 30 per cent, a rather conservative production volume of 50 000 tonnes of RCN will produce 35 000 tonnes of shells with an energy content of 700 000 GJ or 120 000 boe. Assuming an average oil content of 20 per cent, the amount of CNSL that can theoretically be recovered from the nut shells equals 7 000 tonnes with a calorific value of around 290 000 GJ or 49 500 boe. While this constitutes an attractive feedstock base for a start, only about 15 per cent of the total production volume of RCN is processed locally. Based on the above ratios, this reduces the recoverable CNSL oil to only 1 050 tonnes.

While the Wouol Farmers' Association processes 1 250 tonnes of RCN per year at five processing units, the largest cashew processing company in Burkina Faso is Anatrans, located in Bobo-Dioulasso. In 2016, about 6 000 tonnes of RCN were processed by Anatrans. This is still well below the installed capacity of 10 000 tonnes. However, the processed volume provides 840 tonnes of immediately available CNSL.

Anatrans is one of the biggest employers in the country. Of the 1 500, 85 per cent of its employees are women. In addition, the company directly supports over 4 000 farmers organized in 300 farmer groups that are growing and harvesting the cashew nuts for the processing plant. To secure a steady supply of RCN, Anatrans has built up a strong partnership between farmers' cooperatives and the processing unit. Based on the guaranteed take-off, many farmers even qualify for micro credits.

PICTURE 17-18

Manual decortication of cashew nuts at Anatrans cashew plant

ANATRANS, the largest cashew nut processing plant in the country employs 1 300 women and provides support to over 4 000 farmers organized in 300 farmer groups that are growing and harvesting the cashew nuts for the processing plant in Banfora.

3.5.2.2 Challenges and Constraints

Independent of these successful initiatives, market distortions and irregularities force the Burkinabe cashew sector to forego the largest part of the inherent alternative energy potential. As a result, Burkina Faso cannot fully profit from the cashew nut value chain. Despite the cashew sector's recognized potential and multiple benefits, and despite repeated calls for basic market regulation, a significant proportion of the value chain has gradually been relocated abroad. A handful of foreign States are actively subsidizing their own cashew processing industries and provide incentives to buy all available stock. Independent of transportation costs and logistics, the underlying policy explicitly includes unshelled cashew nuts from overseas. The decline in margins is a direct result of strong demand from processing units in India and Vietnam. Indian processors are benefiting from the subsidies of their government which enable them to offer high prices for cashew supplies from Burkina Faso, bypassing the domestic processing industry. The result is a transfer of added value and jobs from Burkina Faso to India. Accordingly, significant revenue opportunities are lost to foreign buyers and processing companies which are dominating the Burkinabe market, while local processing companies have trouble accessing funding and maintaining operations. Idle processing facilities inevitably restrict the opportunity to benefit from CNSL as a high-quality biofuel feedstock.

3.5.2.3 Biomass Processing and Fuel Conversion

Several methods are available to extract CNSL oil from the cashew nut shells, namely mechanical, thermal and solvent extraction. The mechanical oil extraction process only requires a simple screw press which can handle even small quantities efficiently. Alternatively, the oil could also be recovered by heating in the absence of oxygen. Oil extraction efficiency slightly varies with the method adopted.

After expelling the oil, the remaining residue, i.e. the de-oiled cashew shell press cake, could be used as a cost-effective source of alternative energy to supply a combined heat and power plant (CHP). Also known as cogeneration, CHP refers to industrial processes in which waste heat from the production of electricity is also used for process energy in the renewable fuel production facility. The cogeneration plant would not only generate sufficient electricity to run all the facilities' operations (e.g. expelling machines and decorticators), but coulv also provide the steam required for various steps of the industrial process. In this case, the steam produced by the boiler would weaken the shells from the seeds and provide an efficient source of heat in the drying phase of the cashew kernels.

Physical and chemical properties of CNSL encourage the use of this alternative energy source as biofuel. The specific chemical structure should ensure the complete combustion and reduce the formation of polluting hydrocarbon, carbon monoxide and sulphur oxides during combustion. Depending on the intended ultimate usage, CNSL and particularly decarboxylated cardanol may not even require further conversion processes. Key properties of cardanol are already very close to diesel and transesterified biofuels. The benzene ring and the absence of triglycerides could thus potentially eliminate the need for costly transesterification. While this fuel would not yet meet aviation fuel standards, CNSL-derived biodiesel blends may well qualify ad hoc to power the trucking ground-fleet of the Ouagadougou airport as well as public buses. The potential of a readily available cheap domestic feedstock certainly warrants further in-depth analysis.

3.5.3 SHEA NUTS (KARITÉ)

Occupying the next place in the export earnings of agricultural products after cotton, sesame and cashew nuts is the shea nut. The shea tree (Vitellaria paradoxa, also Butyrospermum parkii) which grows on marginal land is indigenous to Burkina Faso and a traditional food plant. The karité or shea nut is the fruit of the shea tree. The trees which grow wild in the wooded savannah zone can reach 20 meters in height and produce nuts for 200 years. Maximum production capacity is only reached after 45 to 50 years. Shea trees are widespread throughout Burkina Faso. The total cultivation area stretches over 65 000 km2, which equals 28 per cent of the country. Prime locations are the southwestern part of the country and the Plateau-Central region in the provinces of Ganzourgou, Kourwéogo, and Oubritenga.

PICTURE 19
Shea nuts

The shea nut consists of a thin, nutritious pulp that surrounds a relatively large, oil-rich seed. These seeds are manually grinded to extract organic shea butter which is used for cosmetics and skin care products. Shea butter and shea oil are renowned for their antioxidant, anti-inflammatory, moisturizing and skin healing dermatological properties. In addition, shea is a rich source of essential fatty acids, anti-oxidants and vitamins E and A. Annual production of nuts varies between 450 000 and 600 000 tonnes. This makes Burkina Faso the second largest producer in the world after Nigeria. In comparison, total shea nut harvest volume exceeds the production of cashew nuts by a factor of 10 to 12.

Shea butter is one of the most important agricultural export products, with the European Union being the major export market. It is estimated that the sector provides substantial income opportunities for up to 3 million women in rural and urban areas. The sector's strategic value as a tool for job creation, additional sources of income and poverty alleviation has earned shea nuts a reputation as "the women of Burkina Faso's gold".

Reflecting the sector's importance for the socio-economic development of the country, the Government of Burkina Faso has adopted a National Sustainable Development Strategy for the shea industry, from 2015 to 2019. It includes a rolling triennial action plan, consisting of 129 activities ranging from the protection of the shea tree to the coordinated marketing of its products.

Both shea butter and oil, the two main by-products of the shea nut seed, are edible. The qualification of shea seeds and their derivative products as food automatically excludes the alternative use of shea nut seed oil as a potential source of biofuels.

However, the nut shells which are considered an agricultural waste product are still an unexploited source of biomass that may be used as an alternative source of energy, thus complementing the nutritional and dermatological benefits of the nut kernels. Assuming a conservative weight ratio between raw shea nuts and nut shells of 5:2, 500 ,000 tonnes of nuts will generate at least 200 000 tonnes of nut shell biomass waste. Considering an energy density of 18.7 MJ/kg for pelletized shea nut shells and an estimated densification related weight loss of 25 per cent, the compacted 150 000 tonnes of shea nut pellets have an energy content of 2 800 000 GJ, which equals 478 000 boe.

Generating large quantities of shea shells would first require at least a basic mechanization of the production process to facilitate economies of scale. For the time being, traditional practices remain largely based on manual labour. Furthermore, the ultimate availability of nut shells will also depend on potential alternative uses. In this regard, it must be considered that a significant part of the shell biomass waste could potentially be used to generate necessary process energy, thus limiting its availability for biofuel purposes.

3.5.4 NEEM

Neem (Azadirachta indicta A. Juss.) is a member of the mahogany family and is a hardy, fast growing evergreen tree reaching 12 to 18 meters in height with a girth of up to 1.8 to 2.4 meters. It thrives in poor soil and has deep roots that allow it to withstand long periods of drought. Its ability to survive in drought-prone areas makes it very adaptable to the arid and semi-arid zones of Burkina Faso. Reforestation efforts in the Sahel zone have been greatly assisted by the cultivation of neem trees. A mature tree yields up to 50 kg of fruits and 30 kg of seeds. Seed oil content ranges from 25 to 40 per cent. Neem oil consists mainly of triglycerides and large amounts of triterpenoid compounds. It contains four significant saturated fatty acids, of which two are palmitic acid and two are stearic acid. It also contains polyunsaturated fatty acids such as oleic acid and linoleic acids. Because of its physicochemical properties neem oil qualifies as an alternative feedstock for the production of biodiesel. However, while neem oil is not suitable for human consumption, exceptional oil compounds still prohibit its usage as a potential substitute for diesel. Pharmacological constituents offer proven therapeutic qualities. Neem oil has demonstrated remarkable effects, including antibacterial, antiviral, antimicrobial, anti-inflammatory and anti-allergic properties. Neem boosts the immune system on all levels. Most importantly, neem oil qualifies as a natural insecticide. The oil is reported to be effective against at least 200 insects without requiring any sophisticated extraction or preparation equipment. Medicinal, pharmaceutical and insecticidal benefits naturally impact the value of neem oil which sells for USD 20 or more per litre. Being aware of its multi-purpose properties, the Burkinabe Fédération Nationale des Groupements Naam, for example, a large farmer cooperative present in 30 provinces, sells smaller quantities of cold-pressed neem oil to the European pharmaceutical industry. Demonstrated benefits might outweigh potential competitive uses of neem oil as an alternative biofuel. This precludes further quantitative analysis of the theoretical energy and biofuel potential of neem in Burkina Faso.

3.5.6 BALANITE

Balanite (Balanites aegyptiaca) is well adapted to tropical arid lands and can be found everywhere in Burkina Faso. Just like neem, balanite is an evergreen multipurpose plant native to the Sudano-Sahelian region of Africa. Commonly known as "desert date", it is a spiny shrub or small, deep-rooted tree that tolerates heat, drought, sunlight and degraded soils so well that it thrives in the heart of the Sahel. Due to its heartiness, the species has deliberately been chosen for the restoration of the Sahelian ecosystems in the context of the pan-African reforestation project, the Great Green Wall for the Sahara and Sahel Initiative.

The endocarp tissue of the edible fruit encloses a 2 to 3 cm long fibrous seed/ stone (pyrene) which contains 35 to 55 per cent oil which is rich in saturated fatty acids (linoleic, oleic, stearic and palmitic acid). Mature trees are estimated to yield up to 100 kg of stones, which produce 30 to 60 litres of oil. Independent of its validated calorific and energetic properties as well as tested combustion parameters, balanite oil simultaneously qualifies as an edible vegetable oil which is traditionally used for cooking and multiple cosmetic and pharmaceutical applications, including treatment against intestinal worm infections, malaria, epilepsy, asthma and fever. Hence, it should not be considred as a potential source for biodiesel.

PICTURE 20
Multipurpose balanite and baobab trees near Yako, Burkina Faso

4. FEEDSTOCK EXPANSION AND MARKET POTENTIAL

4.1 SUGARCANE

Sugarcane Production/harvest area		Production volume	Energetic Values		
			Calorific value (MJ/kg)	Gigajoule (GJ)	Barrel of oil equivalent (boe)
Existing:	5 000 ha	500 000 tonnes → 35 000 tonnes sugar → 15 800 tonnes ethanol	29.6 (ethanol)	468 000	80 000
Potential:	8 000 ha	800 000 tonnes → 25 300 t ethanol	29.6 (ethanol)	747 000	127 450

FIGURE 32
Sugarcane expansion and market potential

Plant specific water requirements necessarily limit the potential expansion area as alternative regions with sufficient rainfall do not exist. If the amount of land devoted to sugarcane cultivation were to be expanded to increase the available feedstock for the production of biofuels, this might lead to several environmental concerns over deforestation, land degradation, water pollution (as a result of fertilizer applications) and water scarcity, as well as competition for agricultural inputs. If food insecurity and the chronic shortage of sugar in Burkina Faso were not sufficient to incite a significant expansion of the production area, it is even less probable that biofuel considerations and the anticipated environmental dividend associated with lower GHG emissions would do so.

Given the need for irrigation, the potential expansion of the sugarcane cultivation area for the benefit of increased biofuel production risks interfering directly with food production. As the expansion of sugarcane production would likely reduce land available for rice and cereal crops, it will contravene basic principles of sustainability. Thus, the overall future potential for sugarcane as an energy crop in Burkina Faso is almost exclusively limited to existing cultivated areas. The highlighted limitations and constraints disqualify the use of sugarcane as a feasible option for the development of an alternative fuel industry in Burkina Faso.

Other than that, the limited total volume of available ethanol, poor infrastructure and logistics remain challenging. Given the estimated high production costs due to poor infrastructure, high operating costs, outdated technology, and the requirement to irrigate, small-scale sugarcane-based ethanol production can hardly be profitable in Burkina Faso without major process modifications, incentives and policy support. Even if costs for bioethanol production were assumed competitive, the necessary upgrading to bio-jet cannot be properly calculated at this early stage as most R&D initiatives are still in their pre-commercial stage.

Independent of estimated capital costs, the SIP and ATJ pathways are expensive and process intermediates, such as butanol and farnesene, are potentially more valuable as chemical feedstocks or for applications in the cosmetics and pharmaceutical industries.

In addition, the economics of the fuel upgrading process steps, such as dehydration, oligomerization and hydrogenation, also have to be considered. In comparison to oils and fats, sugars and lignocellulosic biomass require siginifcant amounts of costly hydrogen. Most hydrogen is typically produced by the reforming of natural gas, making fossil-fuel consumption a part of the process. Without even a basic petrochemical infrastructure in Burkina Faso, the lack of hydrogen forfeits the domestic upgrading of sugar-based feedstock to bio-jet.

Independent of the specific underlying conversion route, none of the sugar-to-jet or AtJ pathways are commercially viable yet. Technologies are still at the demonstration or small-scale commercial stage. As a result, most companies involved in ongoing commercialization efforts have received significant financial and strategic support. However, even with generous financial assistance from the U.S. Air Force or the U.S. DoD, final alternative fuel costs are not yet competitive.

4.2 SORGHUM

FIGURE 33
Sorghum expansion and market potential

Sorghum Production/ harvest area		Production volume	Energetic Values		
			MJ/kg	GJ	boe
Existing:	1 620 000 ha	→ 1 730 000 tonnes grains → 3 460 000 tonnes residues			
Markdown:	• Competing use as fodder (-30%) • Logistics constraints (-20%)	→ 1 730 000 tonnes residues → 347 000 tonnes ethanol	29.6 (ethanol)	10^7	1 750 000
Potential:	Yield increase [plant breeding] [cultivar selection] (+30%)	→ 2 249 000 tonnes residues → 451 100 tonnes ethanol	29.6 (ethanol)	1.3×10^7	2 350 000

Aside from mechanization and logistica challenges, reliable biomass production volumes are essential to balance supply-demand risks and establish basic market structures. Continuous genetic development through plant breeding is an important tool to improve sorghum production yield, increase drought tolerance and resistance to pests and diseases, and adapt plants to different climatic environments.

The development of successful new breeding methods and improved plant varieties introduced over the last 20 years in the Centre-Nord and the Boucle du Mouhoun regions has already resulted in sorghum yield increases between 10 and 30 per cent compared to traditional varieties. If the current trajectory of genetic improvements in bioenergy sorghum continues, the potentially available feedstock, and in turn bioethanol yields, are likely to increase further.

Many improved sweet sorghum female hybrid parents have already been developed and new hybrid combinations have been identified to exploit heterosis for sugar yield. Selecting the right cultivars and crop production technology may ultimately enhance on-farm yields by 50 to 140 per cent.

A well-coordinated plant breeding programme with improved sorghum varieties will thus have a dual positive effect on food and biofuel production. It provides a vital and reliable source of nutrition for millions of people living in Burkina Faso while simultaneously increasing bioethanol yields. Furthermore, the introduction of high performing sorghum varieties in more marginal regions of Burkina Faso would take advantage of the plant's greater tolerance to irregular or inadequate rainfall, in comparison to cotton and maize.

4.3 RICE HUSKS & STRAW

Burkina Faso has strong unexploited potential for rice growing. It is estimated that less than 15 per cent of the 500 000 ha that could be available for production has been developed. Equally, only a small percentage of the land potentially suitable for irrigation has been developed.

Among the large rice producing areas in Burkina Faso, the cultivation expansion potential in the Sourou valley in Sourou province seems particularly attractive (see Figure 35). As of June 2017, there were 12 000 farmers organized in 25 cooperatives cultivating rice and cereal crops on 6 500 ha of land of which 50 per cent is irrigated. The Sourou river offers a reliable source of irrigation. However, if only the water of the river could be tapped and pumped into primitive canals, irrigated rice cultivation could be expanded to cover a total area of over 30 000 ha. Lack of energy still prevents the installation of pumps needed to elevate the river water by about 4 to 5 meters. With the proper infrastructure and mechanization in place, rice yields of at least 4 tonnes/ha could be realized on irrigated land in the Sourou valley.

Rice Production/ harvest area		Production volume	Energetic Values		
			MJ/kg	GJ	boe
Rice Husk					
Existing:	172 000 ha	68 500 tonnes			
Markdown:	Combustion & steam production (-50%)	→ 34 250 tonnes	15	514 000	87 650
Potential:	• Yield increase • Sourou valley expansion	+ 10 000 tonnes → 44 250 tonnes	15	664 000	113 300
Rice Straw					
Existing:	172 000 ha	205 500 tonnes			
Markdown:	• Competing use as fodder (-25%) • Logistics constraints (-25%)	→ 102 250 tonnes	12.5	1 280 000	218 400
Potential:	• Yield increase • Sourou valley expansion	+ 30 000 tonnes → 132 250 tonnes	12.5	1 650 000	281 500

FIGURE 34
Rice residues expansion and market potential

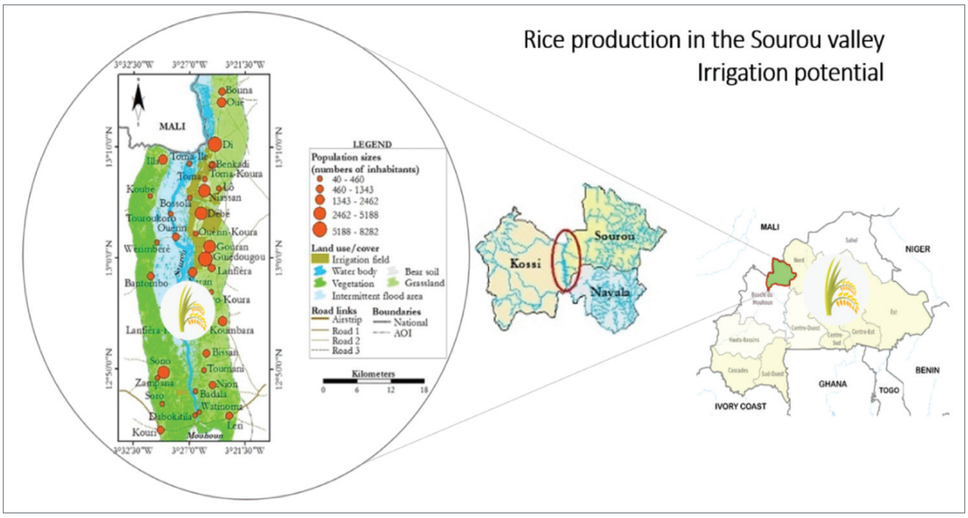


FIGURE 35
Rice production and irrigation potential in the Sourou valley

Based on the above grain-to-residue ratios (Section 3.2.1.1), 20 000 ha of additional rice cropping area could produce 20 000 tonnes of rice husk (20 000 ha x 4 tonnes of rice/ha x ¼) and 60 000 tonnes of rice straw (20 000 x 4 tonnes rice/ha x ¾). If only a fraction of this feedstock was used for the generation of bioelectricity to power the water pumps, the Sourou valley could provide a country-wide reference example for an efficient use of agricultural residues.

Biomass-based electrification projects can be the best practical and cost-effective approach to provide affordable access to electricity even in remote regions of the country, thereby improving the production of both food and fuel through integration and efficiency gains.

4.4 ELEPHANT GRASS

FIGURE 36
Elephant grass expansion and market potential

Elephant Grass Production/harvest area		Production volume	Energetic Values		
			MJ/kg	GJ	boe
Existing:	0 ha	0 tonnes	14.6	0	0
Potential:	≥ 250 000 ha	5 000 000 tonnes	14.6	(7.3 x 10^7)	(12,450,000)
Markdown:	- Logistics and infrastructure constraints (-25%) - Conversion inefficiencies (-25%)	→ 2 500 000 tonnes	14.6	3.6 x 10^7	6,225,000

To quantify the theoretical biomass potential in Burkina Faso, the specific energy content of elephant grass and the availability of suitable land need to be evaluated. Without further geo-spatial analysis and detailed simulation models, it is difficult to calculate the accurate resource potential for energy crop cultivation in Burkina Faso. Based on the conservative assumption that, on average, 10 per cent of the total agricultural area is available, this would translate into a potential cultivation area of 1 million ha.

Furthermore, assuming an average energy density of 14.6 MJ/kg at 10 per cent moisture content and a rather conservative yield of 20 tonnes/ha, and without considering any conversion inefficiencies and losses, 250 000 ha of elephant grass cultivation could generate the equivalent calorific value of 7.3 x 107 GJ or 12.5 million boe. Even with a 50 per cent markdown, the calculated potential would still be enormous in comparison to all other alternative bioenergetic sources. Conservative assessments show that a realistic amount of lignocellulosic biofuel that could be available for the aviation sector is around 3.6 x 107 GJ or 6.25 million boe. The demonstrated energetic potential of elephant grass alone is equivalent to the collective energetic potential of all identified sources of feedstock together. With regard to potential delivery at requisite quantity and quality, elephant grass thus qualifies as one of the most promising sources of biomass.

4.5 JATROPHA

FIGURE 37
Jatropha expansion and market potential

Jatropha Production/ harvest area		Production volume	Energetic Values		
			MJ/kg	GJ	boe
Existing:	3 000 – 8 000 ha	≤ 5 000 tonnes seeds → 1 200 tonnes oil (CJO)	40	48 000	8 450
Potential:	- 100 000 ha - Selective plant breeding - Introduction of high yielding hybrids	400 000 tonnes seeds → 120 000 tonnes oil (CJO)	40	4 800 000	821 000

Considering the above observations, findings, constraints and recommendations (Sections 3.4.4.6, 3.4.5.1, 3.4.5.2, 3.4.5.3, 3.4.5.9 and 3.4.5.10, refer), it is to be determined whether jatropha will find a niche as a biofuel crop in Burkina Faso. This will depend on the strict adherence to proven principles of agronomic science and the rigorous application of a methodology that incorporates all critical elements of the biofuel value chain from feedstock production, to combustion engine.

While major challenges persist, agro-climatic conditions suggest reconsidering the feedstock's economic and energetic potential. The following assumptions related to the jatropha production potential in Burkina Faso are based on field visits, on-site validation and verification, interviews with government representatives, farmers, agronomists, leading scientists, village chiefs and jatropha entrepreneurs as well as soil and climate data and spatial analysis.

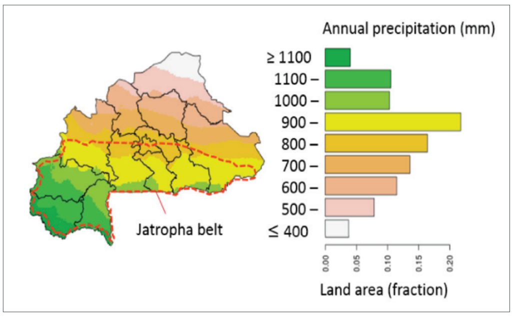


FIGURE 38
Jatropha belt

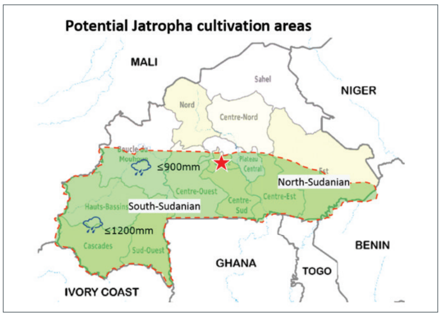


FIGURE 39
Main jatropha cultivation areas

Based on the data collected, the area potentially available for jatropha cultivation extends across the whole country below a virtual line drawn between the cities of Dédougou, Ziniaré, Koupèla and Fada-Ngourma. With the exception of protected areas (national parks, wildlife and cynegetic reserves), rainfed and irrigated croplands, classified forests and water reservoirs, the area covers the major part of the North-Sudanian and South-Sudanian agro-ecological zones.

The boundary indicated in Figure 39 represents the rainfall threshold isohyet for jatropha. The identified cultivation area is in line with the southern ecoregions, from the Plaine Kompienga-Singou in the east, to the Bwa Plateau and Comoé Poni Basin in the southwest, covering a wide bioclimatic gradient (for a top-level compatibility analysis of the jatropha belt with the specific ecoregions of Burkina Faso, see **Figure 40**). With rainfall varying from 650 mm to over 1 000 mm, the marked ecoregions extend over the more humid Sudanian zone. The more favourable climate conditions make them quite suitable for jatropha cultivation, land rehabilitation and reforestation projects. In comparison, no large-scale jatropha cultivation is possible in the northern part of the country. In the arid Sahelian zone the annual rainfall is too little to support cultivation without any irrigation or water management.

Allowing for margins of error and the reservations stipulated above, this qualifies in theory at least 20 per cent of the country's land area, equalling
5.5 million ha.

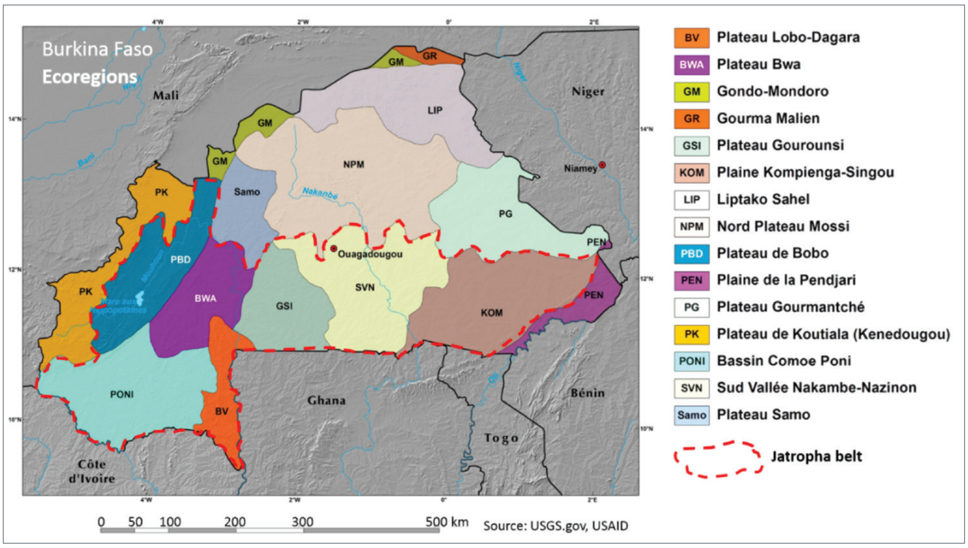


FIGURE 40
Ecoregions of Burkina Faso

However, while land availability per se is a necessary criterion, it is insufficient to either justify or enable the establishment of a regional feedstock supply chain. Independent of the land compatibility in principle, major limiting factors relate to inadequacies of the production infrastructure, transportation and logistics. In addition to a transparent price finding mechanism and a consistent and reliable market demand, this requires collection, storage and mechanized de-shelling, expelling and processing facilities as well as subsidized access to essential inputs such as improved seed, fertilizer, and know-how. Otherwise, well-intentioned mobilization efforts to engage rural communities and scale-up jatropha production on suitable land risk to be counterproductive. To prevent unintended negative socio-economic impacts, conducive market structures are a must. Their implementation calls for capital investments that are not affordable to most smallholders. This, in return, calls for public support and government intervention. The challenge lies in ensuring a fair balance of risks related to economic interests, social and rural development and environmental responsibility. Without the basic elements of a potential jatropha value chain in place, focus on land availability and suitability alone will not be sufficient to calculate production potential. Therefore, it is suggested to apply a further markdown of 90 per cent, still leaving a potential cultivation are of around 500 000 ha, corresponding to 5.6 per cent of the arable land in Burkina Faso. This number is in line with recent estimates of the Ministry of Energy. While this figure has not been formally endorsed by the Government of Burkina Faso, it nevertheless reappears in a series of recent biofuel and renewable energy policy documents.

However, reasonable seed yields cannot be achieved under poor agro-climatic conditions with undomesticated species. Appropriate breeding and seed selection need time and preparation. This turns the supply of elite planting material into a serious bottleneck. Consequently, cultivation and production scale-up depend on plant multiplication efficiencies. Conventional plant multiplication entails the disadvantage of producing heterogeneous plants with inconsistent seed yields. Lacking high-tech breeding centres and specialized nurseries that can produce uniform, high-yielding hybrids requires an additional downward adjustment of the potential jatropha cultivation area. Bearing these caveats in mind, an estimated area of 100 000 ha may seem realistic, yet ambitious. Assuming an average plant density of 1 250 plants per ha, an improved seed yield of 4 tonnes per ha (for first generation non-toxic hybrid jatropha accessions) and a specific calorific value of CJO of 40 MJ/kg, this translates into an energetic recovery potential of 120 000 tonnes of CJO equalling 4 800 000 GJ or 821 000 boe. This amount represents approximately 60 per cent of the country's fossil fuel imports in 2016.

4.6 CASHEW NUTS

The main development constraints on the cashew nut sector are the low yield of plantation, the low capacity of existing processing units (about 10 per cent of production), limited access to credit, and poor organization of the stakeholders. Most of the cashews currently produced come from poorly managed cashew tree plantations or hedges, using non-selected planting material. As a consequence, yields and quality of cashew nuts are comparatively low. Average productivity in Burkina Faso is only around 300 to 450 kg/ha. This compares to a yield of 800 to 1 000 kg in neighbouring Côte d'Ivoire. Improving agronomic practices could potentially double the current production volume per hectare. In addition, high-yielding seedling production from improved planting material and select intercropping with sesame, beans, peanuts and jatropha could increase yields up to 1 200 kg/ha.

To ensure that a fair share of the value-added chain of cashew nut production and processing remains in the country, Burkina Faso needs to take effective steps and provide active policy support to facilitate a competitive cashew processing sector. Key challenges are to ease market and price distortions; raise the domestic value-added; and increase the processing rate of agricultural products in the country. Currently, 90 per cent of raw cashew nuts are processed abroad. If domestic cashew nut processing operations could be reactivated and overall processing capacity increased, this would simultaneously free up a significant volume of available nut shells and related CNSL as feedstock for transesterification and transport biofuel production. A single CNSL production unit in western Burkina Faso, in close cooperation with the national union of cashew producers (Union National des Producteurs d'Anacarde (UNPA)), could help resolve the shell problem of cashew processors in Burkina Faso.

FIGURE 41
Cashew expansion and market potential

Cashew Nutshells Production/harvest area		Production volume	Energetic Values		
			MJ/kg	GJ	boe
Existing:	90 000 ha	50 000 tonnes → 35 000 tonnes shells	19 – 22	700 000	120 000
Potential:	• + 100% within 5 years • Value chain optimization	→ 70 000 tonnes shells → 14 000 tonnes CNSL	19 – 22 39 - 42	1 400 000 580 000	240 000 99 000

The growth potential for cashew cultivation and CNSL production in Burkina Faso is significant. In this respect, reference is made to Nigeria and Côte d'Ivoire. Within only a decade, both States have managed to increase their annual cashew nut production more than tenfold, ranking today among the top 10 cashew nut producing countries in the world.

Just like shea nut production, the cultivation of cashews in Burkina Faso has received governmental recognition as a strategic agricultural sub-sector. In2010, the Government of Burkina Faso adopted a Strategy for Accelerated Growth and Sustainable Development (SCADD) that explicitly recognized the advantages of a domestic cashew nut value chain as a means to effectively contribute to the alleviation of poverty.

In addition to a USD 4 million loan from the Climate Investment Funds' FIP (, Burkina Faso has recently been awarded a USD 5.4 million loan from the African Development Bank (AfDB) to finance a major cashew development project in Comoé basin. Based on an innovative public-private-partnership between the national union of farmers' cooperatives and the Burkinabe government, the project is explicitly designed as a reforestation program (REDD+) aiming to revive the national cashew nut industry and mitigating climate change while reducing rural poverty and GHG emissions. Accordingly, Burkina Faso will be supported to enhance cashew production through plantations with selected varieties and improved management practices; improve cashew processing capacities; and strengthen the capacities of the national-level Wouol Farmers' Association and its 2 500 members. The plantation area is estimated to grow by 25 000 ha.

From an environmental sustainability perspective, the project is designed to mitigate climate change by restoring degraded soils, reversing deforestation and sequestering carbon in cashew tree plantations.

The African Cashew Alliance is forecasting a production increase for West Africa of 34 per cent between 2010 and 2020. Burkina Faso is expected to grow production over the next five years by at least 12 000 tonnes annually. If processed domestically, this could add around 8 400 tonnes of shells or 1 680 tonnes of CNSL every year.

4.7 STRATEGIC AND FINANCIAL CONSIDERATIONS

While a number of conversion technologies are potentially available to produce drop-in SAF, it is more likely that the availability and logistical considerations around the underlying feedstocks will actually be the key factors in determining the validity of a given biofuel value chain. Similar to the difficulties facing the establishment of a sorghum-derived feedstock supply chain (refer to Section 3.1.2.3 for details), the large quantities of agricultural residues required to support commercial scale biofuel operations make transport, infrastructure and logistics particularly challenging. Constraints on infrastructure, mechanization, storage, scalability, cost and process complexity, risk to prevent the establishment of a functional supply chain capable of exploiting locally available agricultural residues and energy sources. For example, a variety of tropical grasses are suitable for bioenergy production. However, despite the promising yield potential of elephant grass, the costs of collection, transportation and storage limit its use as biofuel without further investment into the supply chain.

In many cases, low energy density also requires some form of mechanical densification and pre-treatment to prepare the biomass for further processing and energy conversion.

Another important aspect of agricultural crop residues relates to the question of how much plant biomass is to be left on the soil. Since soil organic matter reposition is essential for long term soil quality preservation as well as nutrient recycling, not all plant residues should be collected for fuel production.

To summarize, each of the analysed feedstocks present different characteristics that make them unique as far as logistics, transportation and storage are concerned. Bulk density, harvest seasonality and storage capacity are critical factors affecting not only feedstock supply, but also alternative fuel manufacturing plant size and the entire economics of biofuel production and scale-up. In addition, logistics directly impact CO_2 emissions, specific carbon footprint and ultimate conversion efficiency.

Of all the energetic recovery options, the production of biofuels and SAF is probably one of the most complex scenarios that require additional public and private investment into infrastructure and mechanization. Preconditions for minimum investments are reliable market structures and predictable prices for agricultural waste products. Otherwise, the mobilization of necessary resources will remain a challenge.

To raise awareness, particularly among the farming population, of the enormous energy potential of agricultural residues and biomass waste, it would be advisable to pursue a phased approach and to begin with a less complex energy conversion process. This could imply, for example, the interim set-up of a small-scale distributed power-generation platform that uses limited amounts of biomass to produce electricity and thermal energy supplies. By deliberately limiting the energy conversion process to smaller size biomass plants for CHP and decentralized energy solutions, farmers would directly benefit from their land's resources hitherto left unexploited, for example, by operating water pumps. At the same time, farmers and stakeholders will gradually become familiar with logistics and process economics, a necessary precondition for large-scale integration of renewable energy sources into the biofuel value chain.

5. CRITICAL SUCCESS FACTORS

5.1 FARMER MOBILIZATION

Setting up a biofuel value chain is a complex undertaking which requires coordination of multiple interdependent parameters and cooperation among all stakeholders. Independent of feedstock related challenges (e.g. agronomics, sustainability, yield and production costs), chances are that (at one point) work force mobilization and training will play a major role. In this context, the notion of 'mobilization' is not restricted to agricultural workforce engagement, but also encompasses capacity-building and training of human resources for mechanization, including technicians and engineers, as well as commercial farmers and agribusiness managers.

For reasons of practicality, scale, time to market and administrative workload, farmer reactivation is highly dependent on aggregators that are positioned, qualified and trusted to pool and represent the interests of hundreds or even thousands of individual farmers. The challenge is to find the right domestic partner/aggregator. Sub-Saharan Africa is among the most ethnically and linguistically diverse regions of the world, with these identities greatly influencing the social, economic and political milieu. For example, in Burkina Faso, traditional chiefs exert an important influence in rural areas and on rural society. The strong influence on the agricultural community results from a unique combination of ancient feudal system, ethnic heritage and constitutional monarchy. As a result, local ethnic authorities have considerable de facto power in allocating land rights, mostly in rural communities that are quite often subject to customary, rather than national law. Tribal leaders and local chiefs also settle disputes and act as formal or ad-hoc arbitrators and judges. Moreover, these leaders typically enjoy significant popular support, and are often more trusted than elected members of the parliament, national courts, and police officers.

The Mossi society constitutes about 40 per cent of the country's population, the largest ethnic group in Burkina Faso. Over the years, their leaders have not only complemented government action, especially in regions where government presence is weak, but have also played a critical role in delivering social services, reducing poverty and promoting sustainable development, thus acting as intermediaries between the central government and the local economy. Their undisputable role in the governance sector and their continuous involvement in active politics and day-to-day affairs have created an atmosphere of trust, responsibility and accountability.

In the interest of mobilizing and facilitating the widest and deepest possible participation of the domestic farming population, tribal leaders and representatives of Burkinabe civil society should be encouraged to assume a mediating role and get engaged in the nationwide re-launch of the envisaged biofuel value chain. Deliberate integration of the civil society and respected tribal leaders may thus help trigger significant mobilization capacity among the farming population.

5.2 SEED SELECTION AND PLANT BREEDING

Independent of the biofuel feedstock identified, seeds are typically the starting material for successful cultivation. During the first months of cultivation, early growth depends strongly on seed quality. Seed quality and genetic purity are fundamental requirements towards successful crop establishment and are a critical component in the profitability of perennial crops. The negative experience with jatropha has demonstrated that proper seed selection and plant breeding programmes are required to maximize major agronomical important traits such as seed and oil yield, seed and oil composition, flowering behaviour, tree morphology and disease resistance.

Genomic wide selection (GWS) is a promising approach to obtain suitable phenotypic evaluations for improving the selection accuracy in plant breeding, particularly in species with long life cycles, such as jatropha. GWS has become an important tool to help breeders in plant and animal breeding due to its performance as a prediction model by associating molecular marker information with phenotypic information, without the need for conducting laborious and expensive phenotyping trials at the beginning of the breeding cycle. By significantly shortening the length of the breeding cycle, GWS improves the efficiency of breeding programmes, allowing breeders to maximize grain yield and seed oil content in jatropha.

Appropriate breeding and germplasm selection should be undertaken early on in the process so that jatropha farmers can benefit from genetically improved planting material. It is very likely that proper plant breeding may partly resolve the problem of unsatisfactory yields and result in high-yielding jatropha varieties. Results from jatropha breeding programmes have only just started to become available and were not used at all in the early African projects. However, a breeding and development cycle for the introduction of a new commercial cultivar may take several years. Only a long period of monitoring the plant will provide the fullest understanding of its yield profile, its resistance to cropping induced biotic stress, climate variability and disease and pest predation. Nevertheless, it should also be noted that the main cash crops in the region have gone through hundreds of years of genetic improvement, something that was never the case with jatropha anywhere in the world.

While the necessary breeding process may take many years, selective plant breeding has already produced energy crops that are far higher yielding than the original cultivars. The German company JatroSolutions claims to have measured heterosis in jatropha hybrids.

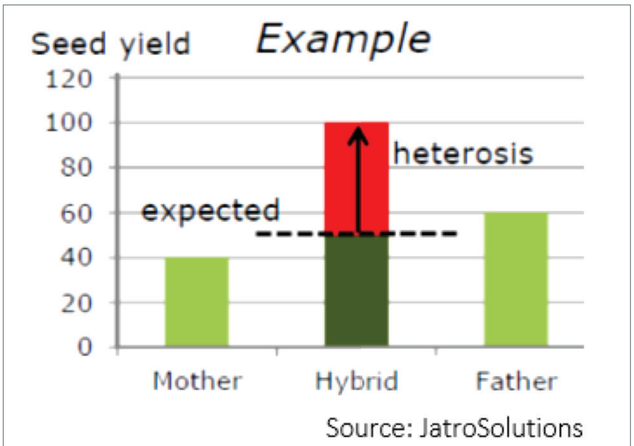


FIGURE 42
Heterosis effect

Heterosis (or hybrid vigour) refers to the phenomenon that progeny of diverse varieties of a species or crosses between species exhibit greater biomass, speed of development, and increased productivity or superiority than both parents. Accordingly, F1 hybrid yields of non-toxic elite jatropha cultivars are significantly higher than comparable yield data for wild plants. In short, an F1 hybrid is the result of crossing two pure lines to achieve the desired result. Scientific breeding programmes have made it possible not only to bring out the outstanding qualities of the parent plants, but in most cases, these qualities have been enhanced and new desirable characteristics added to the resultant hybrid plants. As a result of systematic breeding trials in Madagascar, India, Cameroon and Paraguay, first generation jatropha hybrids are generating 4 tonnes/ha (planting density of 1 250 plants/ha). Second generation jatropha hybrids are expected to perform even better, generating a seed yield of up to 6 tonnes/ha in comparison to wild species with only 0.5 tonnes/ha. In addition to seed and oil yield optimization, the value of the protein-rich kernel meal also increases significantly, as the high yielding cultivars do not need to be detoxified for animal feeding.

With regards to sorghum, the development of successful new breeding methods and improved plant varieties introduced over the last 20 years in the Centre-Nord and the Boucle du Mouhoun regions has already resulted in sorghum yield increases between 10 and 30 per cent compared to traditional varieties. If the current trajectory of genetic improvements in bioenergy sorghum continues, the potentially available feedstock, and thus bioethanol yields, are likely to increase further.

5.3 AGRONOMIC TRIALS

Agronomic trials should be obligatory before scaling up any energy crop production. Painful experience has shown that alleged "miracle crops" have been widely promoted without sufficient evidence about their true potential. Lacking a sound scientific grounding, jatropha cultivation in the early years resembled more of a "gold rush" (new oil rush) than a quest for sustainable green energy. With land use rights secured and thousands of farmers mobilized, cultivation and plantation activities took off everywhere, particularly in Mexico, Brazil, India, Indonesia, Vietnam, Thailand, Malaysia and Madagascar. Jatropha was, for a time, the number one cause of land grabs in Asia and Africa. Madagascar, Tanzania, Mozambique and Rwanda actually experienced some of the most extensive large-scale land allocations for jatropha in Africa, at least on paper. To prevent such symptoms of failure, full and scientifically rigorous trials must be undertaken in the expansion region prior to large-scale promotion of the crop. Extended local field trials conducted under plantation conditions would provide an important first step to build a solid knowledge basis to guide the subsequent expansion of the crop. Any claim that a particular crop can perform far better under certain conditions than competing crops would require sound scientific support before being accepted and implemented on a large scale.

5.4 GOVERNMENT INTERVENTION AND PARTICIPATION

The imbalance of imperfect market structures (conditions) leads to price volatility and the recurrent inability to provide stable and sufficient remuneration for production resources over the long term. To provide agricultural producers with a safety net and create a more stable and more predictable environment, the government may adopt select intervention measures in the agricultural sector to stimulate production and foster commercialization of a given crop.

If biofuel crops are deemed beneficial, then governments, through appropriate policies, should regulate their introduction and support the development of markets and infrastructure.

However, agricultural policies need to be well-coordinated and synchronized. Otherwise, mistakes during the conception phase could hamper achieving the underlying objectives, jeopardise proper implementation, or result in unexpected costs. For example, despite the support that jatropha received in Zambia, the Government still subsidized imported fossil fuels and delayed mandating a standard price for biodiesel. This basically made it uneconomical for jatropha ventures to operate.

In addition to dedicated support policies, the portfolio of direct and indirect subsidies includes:

1) direct payments to farmers;
2) price supports implemented with government purchases and storage;
3) regulations that set minimum prices by location, end use, or some other characteristic;
4) crop insurance;
5) micro-credits; and
6) free distribution of essential farm inputs (e.g. fertilizers, quality planting material such as high yielding jatropha hybrids).

Throughout the past decade, around 10 per cent of the national budget has been typically allocated to agriculture. In line with the Rural Development Strategy (SDR), staple crop production was supported by subsidies on fertilizer, by distributing improved seeds and by supporting the improvement of irrigation systems.

5.4.1 PRICE FLOORS & SEED PURCHASE

Recent history in Burkina Faso has shown that farmers participating in bioenergy crop cultivation schemes were often left stranded without a buyer, a market and an acceptable price for their product. The result was widespread economic and social disenchantment, which needs to be avoided.

The government could be called on to intervene on behalf of their farmers/producers and offer agricultural price floors if the national market for jatropha seeds does not find its own equilibrium price. With a price floor, the government forbids a price below the crop's agreed target price. In order to qualify, producers may be asked to comply with certain sustainability practices and plantation model provisions.

Burkina Faso already has ample experience in providing price support to cotton farmers in order to sustain production and farmers' income. While the production of cotton was introduced at the beginning of the colonial era, large-scale production started after the creation of the French Textile Company (CFDT) in 1949, which set up a stabilization fund that guaranteed remunerative and stable prices for farmers. At the time of independence (1960), cotton production was considered to be the primary source of revenue for financing the country's development.

5.4.2 (PUBLIC) MARKET INTERMEDIARY - CLEARING HOUSE FUNCTION

To mitigate risks related to buyer-seller agreements, the government may consider the role of a market intermediary by providing services similar or comparable to those provided by a clearing house. "Clearing" is the procedure by which an entity (in this case an authorized government agency) acts as an intermediary and assumes the role of a buyer and seller in a transaction to reconcile orders between transacting parties.

Clearing ensures risk management services. It also increases price transparency and provides smoother and more efficient markets as parties can make transfers to a central counterparty (the clearing house) rather than to each individual party with whom they have transacted.

To improve overall market functionality for agricultural products, the PNDES explicitly foresees several concrete measures that would help balance and reduce market risks for farmers. These measures include, inter alia:

- the establishment of a central purchasing counterparty (Centrale d'achat des intrants et du matériel agricoles, No. 186);
- the establishment of an agricultural seed production company (Société de production de semences agricoles, No.197);
- a dedicated mechanism for agricultural risk management (No.258); and
- a dedicated bank for agricultural finance (No.250).

5.4.3 CROP INSURANCE

Agricultural insurance is an important instrument to help farmers manage financial impacts of production risks, principally those caused by (i) weather, (ii) uncontrollable pest and disease and (iii) yield fluctuations. Rationale for government intervention includes the catastrophic nature of climate change related risks, poor yields and market failure. Crop insurance has potential social, developmental, and poverty reduction benefits, as well as fulfilling a role of income stabilization for farmers, financial protection against climate and weather risks, and as a form of collateral to facilitate access to agricultural finance.

Whilst an agricultural insurance premium subsidy is the most common intervention, other enabling measures are equally important, such as technical and administrative assistance.

5.4.4 FARM INPUTS

Input subsidies account for a large share of agricultural public expenditure. For example, the 2007/2008 food crisis pushed the Government of Burkina Faso to support staple crop production by distributing improved seeds and subsidizing half the cost of fertilizers. As of today, the Government continues to provide subsidies to cotton farmers.

Select government subsidies for select farm inputs, such as high-quality planting material, mechanic decorticators or central breeding labs, would also be in line with the strategic objectives of the PNDES. Accordingly, the Government is committed to facilitate access to inputs, equipment and financing and provide market incentives.

With regard to supporting select farm inputs, the Government of Malawi for example has successfully done this by subsidizing fertilizers to maize producers, enabling the country to turn into a net exporter of maize in the region.

5.5 INTRAGOVERNMENTAL COOPERATION

Establishing a biofuel value chain in a developing country requires not only close collaboration across multiple industry sectors, but among relevant government bodies as well.

In terms of the multi-sectoral specificity of biofuels, coordination and concerted action is particularly critical when federal government ministries are deciding which entity will assume leadership on the issue. When government departments and agencies do not coordinate effectively, they may interpret national policy guidance differently, develop different objectives and strategies, and set different priorities, and therefore, not act in concert toward national objectives. Information and transparency constitute important elements in the framework of governance and accountability. Equal and timely dissemination of information is essential for the effective functioning of market forces and the balancing of risks. A robust information exchange among government departments would facilitate the formulation of viable options. Power struggles and ideological conflicts between ministries ultimately endanger the coordination of public action to support the biofuel sector. Instead, the lack of coordination between public actors generates an institutional vacuum which leads to unnecessary conflicts between stakeholders and prevents necessary investments into the biofuel sector.

Seamless coordination, alignment of strategic goals, information sharing, and consolidated long-term government support are needed, especially given the scarcity of resources and the complexity of the challenges involved. Commitment to intragovernmental cooperation can facilitate cooperation in areas of common interest, promote a common operational picture, and enable sharing of critical information and resources. Intragovernmental cooperation is especially important when there are several separate ministries and other governmental agencies that ultimately pursue similar goals and compete for the same resources.

The prevailing alternative energy landscape in Burkina Faso provides an example of scattered and dispersed initiatives, duplication of efforts, multiple lines of authority and competing claims for donor funding and project sovereignty. Instead of increasing the chances of joint success and capitalizing on organizational diversity towards a common goal, stakeholders remain rooted in their own culture, authorities, philosophy and practices, which are sometimes conflicting.

The following list highlights the main actors and promoters that officially share responsibility and oversight of renewable energy issues in general, and biofuel supply chain projects in particular. While a large number of public bodies seems to be involved, their roles are not well defined, which renders policy implementation, resource allocation and project implementation difficult. In addition to the Ministry of Energy (in particular the Renewable Energy Directorate), the Ministry of Agriculture and Food Security, the Ministry of Environment, Green Economy and Climate Change, and the Ministry of Finance, these key actors are involved in Burkina Faso:

- ANADEB — Agence Nationale pour le Développement des Biocarburants (National Agency for the Promotion of Biofuels)
- ANEREE — Agence Nationale des Énergies Renouvelables et de l'Efficacité Énergétique (National Agency for Renewable Energies and Energy Efficiency)
- APROJER — Association pour la Promotion du Jatropha et des Énergies Renouvelables (Association for the Promotion of Jatropha and Renewable Energies)
- CICAFIB[20] — Comité interministériel chargé de la coordination des activités de développement des filières biocarburants (Interministerial Committee for the coordination of the domestic biofuel sector)
- CIRAD — Centre de coopération Internationale en Recherche Agronomique pour le Développement (Agricultural Research Centre for International Development)

[20] The interministerial committee responsible for the coordination of development activities of the biofuel sector was set up in 2008 to promote consultation among institutional actors, define relevant biofuel policies and set up a framework for concerted action involving multiple public and private actors. However, this group is not currently active.

- CNRST — Centre national de la recherche scientifique et technologique (National Research Centre for Science and Technology)
- INERA — Institut Nationale de l'Environnement et de Recherches Agricole (Environmental Institute for Agricultural Research)
- IRAM — Institut de Recherches et d'Applications des Méthodes de Développement (Research and Development Institute)
- IRSAT — Institut de Recherche en Sciences Appliquées et Technologies (Research Institute for Applied Science and Technology)
- ROPPA — Réseau des organisations paysannes et des producteurs agricoles (Network of farmers' organizations and agricultural producers)
- SP/CONEDD — Secrétariat Permanent du Conseil National pour l'Environnement et le Développement Durable (National Council for Environment and Sustainable Development)
- UEMOA — Union Économique et Monétaire Ouest Africain (West African Economic and Monetary Union)
- UNAPROFIJA — Union Nationale pour la Promotion de la filière Jatropha Curcas (National Union for the promotion of the Jatropha value chain)

Coordination and cooperation is needed among all stakeholders towards common objectives. The leverage of cross-governmental capabilities and the translation of national objectives into unified action are essential to unity of effort, and ultimately mission success. Unified planning that considers the capabilities of all stakeholders is particularly important with regard to resource-sensitive challenges and projects.

To achieve the overreaching common objectives of climate change mitigation, GHG emissions reduction, poverty alleviation, rural development and land rehabilitation, they need to be integrated at the strategic level and coordinated at the operational level with the activities of participating government departments and agencies, relevant international organizations, NGOs, and representatives from the private sector.

In Burkina Faso, democratically elected leaders are also encouraged to collaborate with tribal leaders, as historic tribal structures have contemporary significance. Traditional moral authority can provide societies in transition with stability, and for States where democracy has been subverted, wise guidance for retrieving it. In Burkina Faso, civil society is an increasingly important agent for promoting sustainable development and the good governance, in terms of transparency, effectiveness, openness, responsiveness and accountability. The deliberate integration of tribal leaders and civil society representatives has the potential to contribute to a higher level of accountability. If empowered and properly monitored, a strong and vigorous civil society can be a critical driver of reform, offering tremendous potential in activating an engaged and informed citizenry. To ensure unity of effort and reduce/prevent costly inefficiencies, it is vital to integrate any and all willing project partners into joint planning as early as possible, so an integrated, comprehensive and achievable execution plan can be developed. Initial requirements for integration include clear definition of roles, responsibilities and accountability as well as clarification of objectives.

A precondition for this integrated and concerted effort is common understanding. Common understanding will assist in mitigating unnecessary conflict and unintended misconceptions. In this regard, the State, the private sector, and civil society, in their respective roles, must act in a complementary manner, rather than substituting one another. The State will help the market work better by creating the necessary institutions, which will help increase investor confidence and reduce transaction costs. This will take place through the implementation of coherent and effective sector policies with efficient modes of governance and attention to issues of equity and accountability for all development actors.

The main conclusions can be summarised as follows:

i. Intragovernmental cooperation is needed, based on a collaborative environment in which participants are encouraged to solve problems and share information, knowledge, perceptions, ideas, and concepts.
ii. Given the multi-sectoral specificity of biofuels, any central coordinating platform needs to be equipped with operational autonomy, where neutrality, independence and authority need to be ensured.
iii. Despite the multi-sectoral nature of biofuels, their promotion from the sole perspective of energy is not sufficient. Biofuel-related policies focusing on technical and economic aspects of biomass-based energy production without sufficiently taking into account socio-economic and environmental objectives linked to agricultural production are inadequate to secure the level of involvement and support needed. Going beyond the energy dimension and anchoring the issue within the broader field of rural development could help to facilitate the establishment of relationships and critical cooperation between numerous ministries, notably those of agriculture, energy, territory and the environment.

5.6 MARKET DEMAND AND OFF-TAKE COMMITMENTS

Renewable energy ventures that involve the development of upstream bioenergy crop plantations (in particular the mobilization of thousands of farmers needed to cultivate large tracts of land), and related biofuel production require large financial resources from investors. With project developers lacking proprietary financial strength and a solid balance sheet, third party financial support and funding depend to a large extent on project financing. Project finance is an exercise in project risk identification. The more accurately the existing risks can be quantified and controlled, the better the parties involved can negotiate the allocation of such risks to the party most prepared or able to bear each of the risks. Market risk plays a crucial role in the funding process. Without a market and reliable off-take commitments for the envisaged end products, it will be difficult to encourage investments into necessary farm inputs and mobilize large scale production.

A long-term agreement for a defined volume of fuel, at a specified price, provides demand assurance, ideally from a creditworthy counterparty (e.g. jet fuel trading company, airline or airline fuel consortium). Such an arrangement could facilitate the alternative fuel producer to confidently solicit external investor production financing.

Where airlines or relevant counterparts are reluctant to provide reliable fuel off-take commitments, this will lead to a one-sided allocation of risks to the disadvantage of producing farmers. A long-term, bankable fuel off-take agreement is the crucial component needed to trigger third party funding to facilitate commercial production scale-up that will secure future feedstock and SAF supply at pre-agreed prices. Concluding timely airline off-take agreements prior to the launch of large-scale plantation activities will contribute to overall risk balancing between stakeholders involved, help raise third party project funding and accelerate alternative fuel production.

5.7 SUPPLY CHAIN OPTIMIZATION

A necessary precursor to the development, production, and use of economically viable SAF is the identification of a functional domestic supply chain. Such a supply chain for SAF production presents social and economic opportunities that go far beyond the immediate feedstock and fuel-related metrics. The identification and optimization of a domestic supply chain will depend, inter alia, on the region, feedstock, climate, agro-economic and social conditions as well as available infrastructure and logistics. By integrating the country's vital needs for food and energy into the alternative fuel value chain, the civil aviation sector could become a true catalyst for economic and social development in rural Burkina Faso, stimulating green growth, creating new jobs and providing new markets for farmers and producers, while at the same time striving to achieve the industry's ambitious targets for reducing its carbon footprint.

In practice, each component of the SAF supply chain is connected to and influences the other components. For example, the specific source of biomass will determine the most suitable fuel conversion technology. The state of science and technologies in feedstock conversion, in turn, directly affects the quality and quantity of feedstock available for fuel conversion and the R&D to scale-up for commercial production.

While a number of conversion technologies already exist to produce alternative fuels, it is more likely that the availability and logistical considerations around the feedstock will actually be the key factors in determining the feasibility and viability of fuel production (see Figure 43). Key factors in the development of an alternative fuel supply chain are the logistical considerations of where the biomass is grown and how it is collected, stored and processed.

In addition to technical and logistical constraints, significant barriers relate to project financing and risk. The high risks associated with sustainable fuel projects inherently affect the willingness to invest and the availability and conditions of project financing.

Keeping costs under control and pricing of SAF ultimately competitive, calls for a controlled vertical integration of the whole supply chain and the collaborative engagement of multiple stakeholders – irrespective of whether they represent private, public, political, technical or scientific interests.

To balance all types of related risks (production, investment, market, price, political), cross-sector cooperation and partnerships are required. Accordingly, the long-term development and deployment of SAF requires close cooperation and interaction between relevant government agencies, the industry, aviation and SAF stakeholders in the value chain to leverage technological advancement and operational processes. Partnerships between stakeholders operating at different stages along the value chain appear to offer the advantage of conciliating the interests of most of the stakeholders involved.

One potential opportunity for reducing the conversion cost for alternative fuels is to develop partnerships with petroleum refinery owners and/or operators and develop strategies for co-processing or blending renewable derived intermediates with crude oil fractions in existing infrastructure. This strategy has been validated, for example, by Delta Airlines which in 2012 bought a 185 000 barrel per day (bpd) oil refinery in Trainer, Pennsylvania, from ConocoPhillips. Delta's goal for this transaction was to mitigate risk stemming from the "cracking spread" (the price difference between crude oil and jet fuel) and thus, to generate cost savings. Delta hopes to use the Trainer refinery to produce jet fuel at a lower cost than it would otherwise pay on the market. Delta expected the Trainer refinery purchase to reduce its annual costs by USD 300 million. As of December 2016, Delta had decided to start marketing its own gasoline and diesel fuel produced at the refinery, rather than swap it under existing contracts.

To close the loop between feedstock cultivation and full market integration at predictable and competitive prices, efficient and cost-conscious conversion solutions must be taken into account every bit as much as prevailing infrastructure and logistics conditions. In the long run, the full integration of major supply chain parameters promises to be the only way to monitor and control the cost of production and offer competitively priced SAF to the aviation industry.

With no large vertical integrator driving the overall development of the entire supply chain, it will be difficult to manage the simultaneous and independent growth of the feedstock supply chains and conversion facilities at appropriate scales. As highlighted by the Aeronautics and Space Engineering Board, this may prove particularly challenging for feedstock systems that take several years to achieve scale or maturity and have no other viable customers. Several uncertainties exist if the feedstock is available prior to being needed in the conversion facility, such as who will buy it, at what price, if it will be stored without degradation, or who will pay for the storage. At the same time, questions on who will capitalize and build a production facility without the assurance that feedstocks will be available when needed, would also need to be addressed.

Integration does not necessarily mean that all process steps must be implemented at the same geographic location. Economies of scale and competitive advantages may suggest that individual steps may be spread out over various domestic and international locations. In the case of Burkina Faso, this might imply that the domestic supply chain stops with basic feedstock processing (T1) while more complex refining and hydrotreatment operations (T2) would be concentrated at strategic locations overseas. This geographic segmentation would allow Burkina Faso to leverage existing refining, transportation, storage and handling infrastructure associated with SAF production without incurring any additional financial obligations in this respect.

Instead, a temporary and deliberate focusing on biodiesel production could still send a strong signal of commitment while potentially benefiting the airport's diesel-powered ground fleet. Chances are that constraints on infrastructure, mechanization, transportation and capex requirements may risk hampering or even preventing the establishment of a functional supply chain capable of exploiting locally available sources of biomass. Instead of aiming directly for ambitious SAF production, identified constraints may rather suggest a phased approach, allowing for the gradual implementation of a supply chain that can initially also include rural electrification and biodiesel options as tangible first steps towards future SAF production.

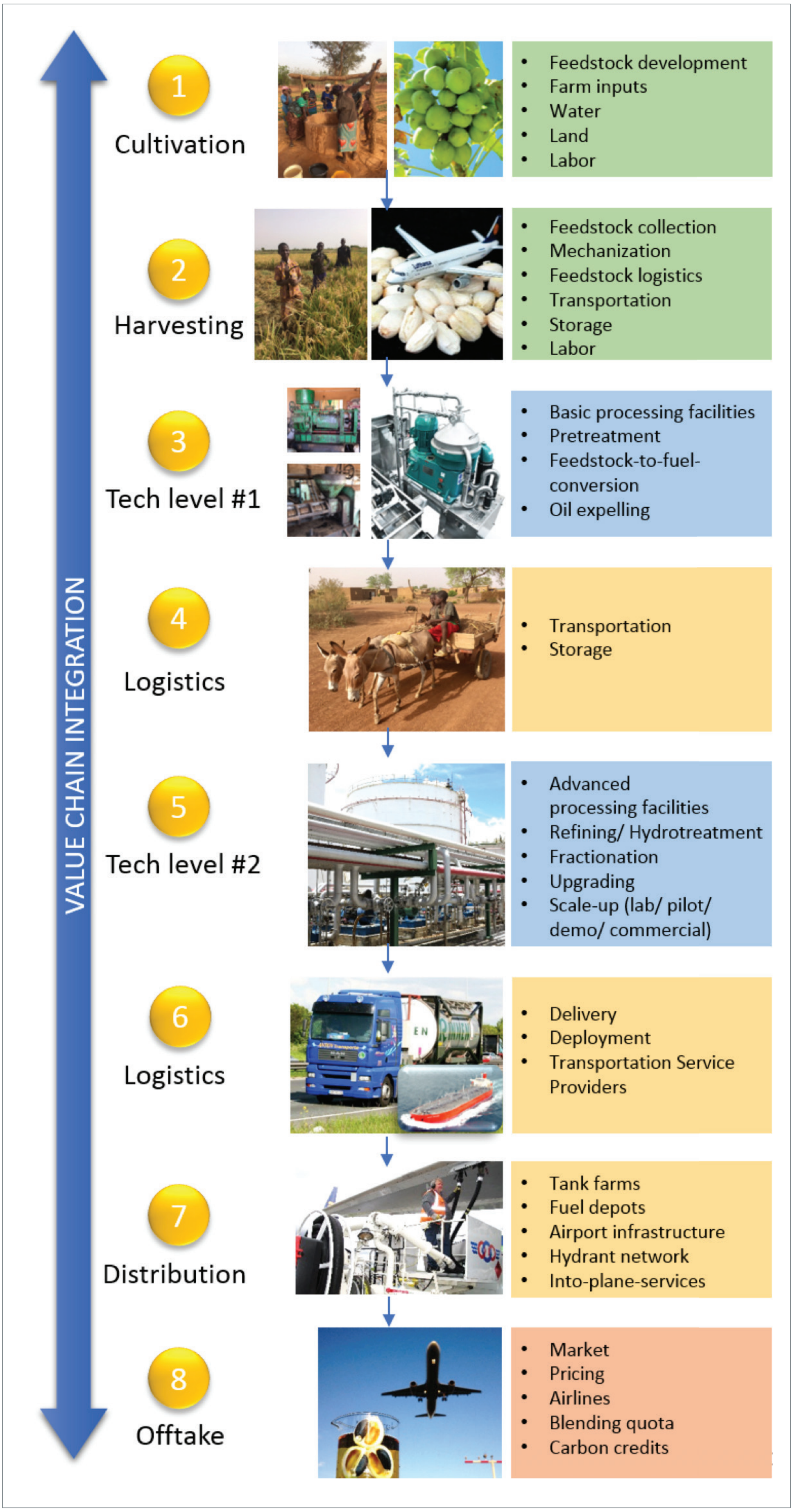
To minimize potential supply chain disruptions, lower capital costs and reduce investment risks, fully integrated domestic and/or regional biomass conversion and refinery technology solutions (T2) will only become a strategic option for Burkina Faso once minimum feedstock production thresholds are reached and tangible stakeholder commitments from airlines and investors are in place. To incentivize and integrate efforts among all stakeholders involved in the SAF supply chain adequate policies and collaborative initiatives will be needed.

5.8 TECHNOLOGY TRANSFER

Sustainable aviation in the context of Burkina Faso, arguably, goes beyond shifting to low carbon fuels or practices in the aviation sector. Achieving sustainable aviation in Burkina Faso requires significant financial assistance, capacity development and technology transfer to address several pre-existing infrastructural deficits. The transfer of technology, the building of capacity and improvements in farming techniques will not only help rural communities in Burkina Faso to gain access to energy, but also increase food production, improve the ability to embark on income generating activities, add value to products, empower women and protect soil from erosion. Developed countries have a general obligation to facilitate the transfer of environmentally sound technologies (ESTs) to developing countries in order to foster emission reduction in key sectors, such as transportation and aviation. Article 4(1) (c) of the United Nations Framework Convention on Climate Change (UNFCCC) explicitly calls upon industrialized countries to promote and cooperate in the transfer of technologies, practices and processes that control, reduce or prevent anthropogenic emissions of GHG in the transport sector. It also provides that developed countries shall promote, facilitate and finance, as appropriate, the transfer of, or access to ESTs and know-how needed by the developing country parties to meet emission reductions targets. However, a pre-condition for the transfer of urgently needed tissue culture propagation and biomass processing and expelling technologies is an adequate level of protection accorded to intellectual property rights. International technology providers need to be assured that their innovations and technological advancements are not abused or deployed without permission or protection under the relevant national regulatory regime. To attract related investments, Burkina Faso needs to make sure that technology providers are not faced with regulatory, institutional and/or bureaucratic barriers that inhibit technology transfer.

FIGURE 43

Sustainable Aviation Fuel Supply Chain



6. SOURCES OF FINANCING

6.1 PUBLIC-PRIVATE PARTNERSHIPS

Public-private partnerships (PPP) and cooperation between the Governmentof Burkina Faso and the private sector, including industry, NGOs and academia are crucial to addressing key scientific and technical challenges and international financing. The PPP approach is not only a strategic tool to mobilize private financing and expertise; it can also ensure better allocation of public resources and typically boost private sector confidence. A new Law on public private partnership was adopted by the National Assembly of Burkina Faso in July 2017. One of the first renewable energy projects involves the solar electrification of 150 schools and 30 general education colleges. As Burkina Faso has already put in place an enabling PPP legislative and regulatory framework, forming public-private partnerships to commercialize the production of biofuels appears feasible. However, and as already stated in this study (refer to Section 6.5), there is a need to improve coordination across various government departments for project approval. For the Government of Burkina Faso, it appears to be worth considering creating a single access point which facilitates the central processing, execution and monitoring of renewable energy projects.

6.2 GOLD REVENUES: REALLOCATING NATURAL WEALTH

From 2008 to 2015, the Burkinabe gold mines paid about USD 2 billion to the Treasury for about 144 tonnes of gold produced. The average contribution over the last three years equalled USD 311 million/year.

Mining could be an important source of financing for the development of the agricultural sector and the implementation of qualified biofuel production projects. In this regard, the mining sector plays a particularly ambiguous role as it is perceived simultaneously as a blessing and a curse. While the increase in gold exploration and production generates the majority of the gross national income and accounts for about 70 per cent of total export revenues, mining activities contribute in a disproportionate way to environmental degradation, loss of agricultural land and social imbalances. Excessive energy needs further highlight the disparity. While less than 3 per cent of the rural population have access to electricity, the recent surge in gold mining and sector-related related industrial energy consumption has even worsened the country's chronic electricity shortage.

PICTURE 21
Artisanal gold mining in Burkina Faso

In recent years, the discovery of gold and the start of large-scale mining operations has drawn attention away from the agricultural sector. Occupying the fourth position in Africa, Burkina Faso has become the fastest growing gold producer in the world with some of the most productive mines and the highest graded gold deposits.

The extraction of gold is environmentally hazardous at virtually all stages and makes land unusable for agriculture. The construction and exploitation usually involve the clearing of land given that most modern gold mines in Burkina Faso are open-pit. This has led to significant deforestation, diversion of water streams and erosion. When the ore is extracted, the process of separating gold from other materials involves use of highly hazardous chemicals, which can lead to harmful soil and groundwater contamination. If top soil has not been preserved in time, ultimate mine closure can lead to irreversible environmental degradation.

In view of its environmental damage, the gold mining sector is somewhat predetermined to contribute its share to social and economic development and help the country sustain its growth and self-reliance.

All gold mines in Burkina Faso are majority-owned by foreign multinational companies. As a result, the main avenues through which Burkina Faso benefits from the mineral revenues is through government tax revenues, a 10 per cent free equity State participation (carried interest) and the entitlement to a 3 to 5 per cent sliding royalty on gold production (cf. Art. 13 Essakane Mine exploitation license). The effectiveness of this mechanism depends in turn on the fairness of the mining concession agreements negotiated.

How to share mining revenues between the central government and local communities in mining and rural areas is a highly contentious issue in Burkina Faso. The amount of any additional revenues from mineral development to allocate to the local level as opposed to other national purposes is a political decision within the sphere of sovereign government. Few countries with mineral development have been able to resolve this issue satisfactorily.

However, minerals and mining revenues are essential to address climate change and contribute to the pursuit of sustainable development goals. How to ensure that mineral resource wealth contributes to sustainable economic development has been a perennial topic concerning many African States. It is an especially pressing issue in a country that is rich in resources, but performs poorly on a host of development indicators.

The Preamble of the Roxgold Sanu S.A. Yaramoko Concession (2015) explicitly recognizes that the country's mineral resources play an important role for the economic development of Burkina Faso. In addition, the new Mining Code, which was passed in 2015, provides various options to procure financial resources that are specifically aimed at measures in favour of "local development" and "land rehabilitation". The code foresees the creation of four new funds, including a local Development Fund and a Rehabilitation Fund. Accordingly, exploitation license holders are obliged to pay 1 per cent of their monthly gross turnover (or the value of the extracted minerals) to the local Development Fund. The State will also pay 20 per cent of its mining revenues (i.e. royalties paid by mining operators) into the Development Fund. Similarly, the Rehabilitation Fund will also be financed through a mandatory annual contribution from mining companies that will be determined based on an environmental impact assessment. Depending on the interpretation of "local development" and "land rehabilitation", there appears to be an opportunity at present to secure urgently needed funds for select agricultural projects directly from the mining sector. In connection with environmental protection obligation provisions under existing license agreements (cf. e.g. Art 11 Essakane Mine exploitation license, or Art. 11 Roxgold Sanu S.A. Yaramoko Concession), it is arguable that the Government of Burkina Faso has the regulatory authority to enforce compliance with environmental, development, rehabilitation, health, and other standards. In other words, a portion of gold revenues may be used to address the challenges of climate change and contribute to the most pressing sustainable development needs. This may well include, among others:

- fertilizer and essential input subsidies;
- price support schemes and feedstock floor pricing;
- basic market infrastructure; and
- seed propagation labs.

A partial reallocation of natural wealth also seems to be supported by the main strategic objectives of the PNDES. According to objective No. 3.5.1., the sustainable management of natural resources shall explicitly include the fight against the exploitation of mineral resources.

Concrete challenges to be addressed include the improvement of mining impact on local development; the improvement of control and monitoring of mining activities; and the appropriate use of mining revenue.

If Burkina Faso demonstrates that it can reallocate at least a small percentage of gold and or other mining revenues to sustainable bioenergy and biofuel production projects, such commitment could be interpreted as responsible, self-reliant action that could trigger matching funds from foreign governments, donors and investors.

6.3 CAPITALIZING ON REFORESTATION AND AGROFORESTRY

In addition to jatropha, two other indigenous plant species have been identified as a potential feedstock source for biofuel production, i.e. cashew trees and shea trees. To overcome low yield, logistics and infrastructure constraints and install basic processing facilities, funding requirements are significant.

To alleviate public and government funding pressure, innovative valuation and pricing models may be required. On the one hand, socio-economic co-benefits could potentially be quantified and credited towards the cost of production (Sections 6.4 and 6.6, refer). Placing a fair price on carbon, on the other hand, could also facilitate commercial viability of large-scale feedstock production projects.

Recognized carbon offsets include emission reduction credits from the UNFCCC's Clean Development Mechanism, through which States purchase emissions reductions from developing countries, or from other formal carbon offsetting programmes, such as the Verified Carbon Standard (VCS) or the Gold Standard. A tradable offset "credit" is generated for each tonne of CO_2 equivalent that is abated by eligible GHG-reducing activities. These credits can then be purchased and retired by parties, such as airlines and States, to formally offset their emissions and contribute to achieving emissions reduction goals.

GHG emission reductions can potentially be certified and traded as credits in the carbon market, providing additional revenue that can facilitate the deployment of SAF projects and mitigate projects' investment cost. Tradable carbon credits can basically be generated in two different ways, be it through the production and use of SAF in replacement of current aviation fuel, or from preceding projects and activities leading to the production and use of alternative fuels. This may include carbon sequestration from reforestation and bioenergy plantation activities, such as biomass feedstock development and production.

In another scenario, the generation of carbon credits would not be directly linked to the emissions reductions related to the use of alternative fuels, but rather to specific aspects of the feedstock production process, which constitutes a critical upstream milestone in the total supply chain. Linking feedstock production to the generation of eligible carbon credits could help incentivize early financial engagement by aircraft operators. Methodologies to determine the portfolio of eligible carbon offsetting programmes are still under development. The ICAO Council will determine which types of offsetting programmes, emissions units and carbon credits will ultimately be eligible for use by aircraft operators intending to comply with regulatory offsetting requirements.

By expanding the focus beyond the original energy and biofuel value chain to also include the positive side-effects of reforestation, land rehabilitation and carbon sequestration, the Government of Burkina Faso may tap into necessary alternative sources of funding.

In addition to energy recovery and biofuel production, the extra dimension of reforestation and agroforestry brings its own specific advantages and merits. No matter whether the underlying motivation for potential funding support is driven by renewable energy or forest conservation concerns, they prove to be two sides of the same coin linked by the leitmotif of the fight against climate change. Ideally, this nexus can prove mutually advantageous by providing a stabilizing effect on project implementation and by securing overall project viability.

A balanced mix of policies with an emphasis on reforestation can pursue parallel goals, such as:

(1) mobilizing international financing to:
   a. reduce GHG emissions;
   b. facilitate the reduction of deforestation and forest degradation; and
   c. promote sustainable forest management; as well as

(2) lay the ground work for a distinct biofuel value chain in its own right.

Depending on land use compatibility issues and the specific plants/trees in question, reforestation, agroforestry and carbon sequestration projects in Burkina Faso may simultaneously qualify as renewable energy projects. Several African reference examples exist (e.g. the "Gilé REDD+ Project" in Zambézia, Mozambique or the "Cashew Infrastructure Development Project" in Zambia) where the underlying commercialization of carbon credits (awarded for the avoidance, sequestration, or reduction of 1 tonne of CO_2e) reveals relevant funding opportunities.

6.3.1 COMOÉ BASIN CASHEW PROJECT

In 2010, Burkina Faso was one of the eight pilot beneficiaries of the FIP, an initiative of the world Bank's Strategic Climate Investment Fund. The FIP seeks to facilitate the reduction of deforestation and forest degradation and promote sustainable forest management, thereby helping to reduce GHG emissions, maintain the forest carbon stock and reduce poverty. In 2013, the Burkinabe Wouol Farmers' Association submitted a proposal for a cashew development support project in the Comoé Basin (covering the Cascades, Hauts Bassins and Sud-Ouest regions) which was accepted for funding.

Cashew trees offer multiple benefits, in that they:

1) create income in rural areas;
2) restore degraded soils; and
3) sequester carbon (~ 0.33 t CO_2e/ha) in areas where land is increasingly degraded.

It is worth noting that cashew planting was first introduced in Burkina Faso for this purpose and not to produce cashew nuts. Accordingly, the intended plantation of 25 000 ha of cashew in agroforestry is expected to increase carbon sequestration capacity and reduce rural poverty, directly benefiting thousands of producers and small processors. Other positive social impacts include securing and diversifying agricultural produce, strengthening food security, and improving the availability of production, processing and storage infrastructure and equipment.

While officially labelled as an effort to address climate change, the addition of 25 000 ha of new cashew plantations to the existing cultivation area will also increase the availability of cashew nut shells and thus CNSL oil. Based on a planting density of 60 trees/ha (allowing the producers to simultaneously plant other crops such as ginger, hibiscus, sesame, peas and groundnuts without creating additional land pressure) and an improved yield of 800 kg/ha, an additional production capacity of 20 000 tonnes of raw cashew nuts per year will provide around 14 000 tonnes of shells with a recoverable CNSL oil content of 2 800 tonnes. This feedstock source for biofuel production is in addition to the benefits described above and the commercialization of 3.8 million tonnes of CO_2 emissions that are estimated to be generated by the project.

The cashew project will be implemented over a five-year period (2017-2021) by a Project Coordination Unit to be located within the Ministry of the Environment, Green Economy and Climate Change. Key performance indicators to be monitored include, inter alia:

1) cashew productivity;
2) the amount of cashew nuts processed and certified;
3) the surface area of the new agroforestry plantations;
4) additional CO_2 sequestration;
5) the number of jobs created in the cashew sub-sector;
6) the number of farmers trained in good organic farming practices;
7) the number of cooperatives supported in farm management (including women); and
8) the number of processing units upgraded or constructed.

6.3.2 SHEA REFORESTATION PROJECTS (GHANA AND MALI)

While the feedstock production potential from cashew plantations ultimately remains limited, reforestation projects using shea trees seem to be a particularly attractive option for Burkina Faso. Shea trees are ubiquitous in Burkina Faso. Intensification of shea nut production in the south-western part of the country and the Plateau-Central region should be possible and have the potential to sustainably increase people's income and reduce net GHG emissions from improved agricultural and forestry practices.

The optimization of shea nut production through a system transition from exclusively wild harvest to a semi-intensive agroforestry system has the potential to offer several advantages at once, namely, climate-change mitigation, improved resilience to climate change, socio-economic development benefits, and feedstock cultivation for biofuel production. The likelihood of success depends on how successfully a range of challenges can be addressed, which depends, inter alia, on local rules, regulations and incentives, the use of domesticated varieties, the future market environment for both carbon and tradeable shea butter, and the available funding and successive installation of nut shell processing facilities.

The wild shea tree is a slow-growing species, which is an obstacle to the participation of rural farmers in projects that intend to increase the shea population. The use of domesticated varieties would be crucial because it provides early yields, as well as yield stability and reliability and disease tolerance.

6.3.3 JATROPHA AGROFORESTRY PROJECTS (MALI AND SENEGAL)

Land-use practices that increase terrestrial stocks of biocarbon prevent GHG emissions and can thus be considered as key components in controlling or mitigating global climate change. Depending on project design, validation, monitoring and verification, jatropha based agroforestry and afforestation land management practices that increase CO_2 absorption hold the potential to produce carbon credits that can be commercialized. At the same time, jatropha agroforestry projects incidentally also provide feedstock for biofuel production. Funding for carbon credit commercialization efforts may thus indirectly facilitate biofuel production.

For example, the Jatropha Mali Initiative (JMI) was validated in 2012 as one of the first VCS agroforestry projects in West Africa. Located in the Kayes region of south-western Mali, the project implements agroforestry systems by cultivating jatropha on 15 000 ha of degraded land. Jatropha is used to stabilize and improve soil fertility and provide windbreaks. JMI works with thousands of individual farmers that are grouped in the regional Union des Sociétés Coopératives des Producteurs de Pourghère du Cercle de Kita. Each farmer has been assigned a plot of 0.5 to 2 ha and jatropha is planted at a density of 1 200 trees/ha.

Similarly, the Jatropha Agroforestry Project Senegal was validated under the VCS in 2013 and operates in several semi-rural areas of Senegal, around Fatick, Kaolack and Kaffrine. The project applies sustainable management practices for the purpose of carbon storage (in plant biomass and soil), as well as providing opportunities for income and development for the local population. The project proponent is the African National Oil Corporation (ANOC) which collaborates with 20 villages and more than 7 000 farmers.

6.4 REDUCING EMISSIONS FROM DEFORESTATION AND DEGRADATION (REDD+)

While land degradation in Burkina Faso is progressing at an annual speed of 250 000 to 400 000 ha, 110 000 ha of forest cover are being lost every year.

The international community is aware of the climate-regulating role of forests and trees and has created a mechanism aimed at Reducing Emissions from Deforestation and forest Degradation (REDD) and enhancing the conservation and sustainable management of forests and forest carbon stocks, a mechanism usually referred to as REDD+. The acronym denotes a carbon finance concept developed in 2008 under the UNFCCC. The concept encourages society to financially value forests for their carbon sequestration, storage and other services. REDD+ has been recognized as a mitigation strategy and financial incentive through Article 5 of the 2015 Paris Agreement.

Under REDD+, tropical countries are to be financially compensated for accomplished objectives in reducing deforestation and forest degradation, sustainably managing forests, conserving forest carbon stocks and reinforcing forests' carbon sequestration capacity. While the protection of forests is regarded as one of the most promising mitigation measures for combating climate change, the expected carbon offset payments are only a part of the advantages that forest and tree conservation can bring to developing countries. Beyond carbon benefits, forest carbon projects also deliver a range of other environmental and social benefits, often referred to as co-benefits under REDD+, especially when compared to carbon reductions in other sectors such as land-fill gas management. These include enhancing biodiversity-rich primary forest, creating sustainable livelihoods for impoverished local communities, protecting watersheds, providing climate resilience to sustainably produced crops, as well as a range of ecosystem services such as mitigating flooding, reducing soil erosion and conserving water resources.

A broad range of programmes has been designed to support States and subnational jurisdictions in the development and implementation of REDD+ related carbon financing and results-based payment programmes. These include, among others:

- The United Nations Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries (UN-REDD), a programme of the UN FAO, the UNDP and the United Nations Environment Programme (UNEP).
- The Readiness Fund of the World Bank-managed Forest Carbon Partnership Facility supports efforts in tropical and sub-tropical developing countries to adopt national REDD+ strategies, develop reference emission levels, design measurement, reporting, and verification (MRV) systems, and establish REDD+ national management arrangements that include proper environmental and social safeguards.
- The REDD Early Movers Programme (REM), a programme of the German Federal Ministry for Economic Cooperation and Development (BMZ). REM places emphasis on incorporating agriculture sectors, and provides technical and policy advice on the development of functional systems for carbon financing, advisory support on gender sensitive benefit sharing programmes, on safeguards and monitoring, and on development of REDD registers, reference levels and MRV systems.
- The BioCarbon Fund Initiative for Sustainable Forest Landscapes (ISFL), managed by the World Bank on behalf of Germany, Norway, the United Kingdom and the United States. The programme focuses on REDD+ and land-use planning in developing countries, and uses results-based finance to create landscape-level change. It promotes reducing greenhouse gas emissions from deforestation and forest degradation in developing countries, and from sustainable agriculture, as well as smarter land-use planning, policies and practices.
- The Jurisdictional and Nested REDD+ pilot programmes of the non-profit Verified Carbon Standard (VCS JNR). VCS JNR works with civil society partners and host governments to link the development of national and subnational REDD+ policies and programmes and to generate lessons for policymakers.
- The Governors' Climate and Forests Task Force (GCF). GCF is a subnational collaboration among 29 states and provinces from Brazil, Indonesia, Ivory Coast, Mexico, Nigeria, Peru, Spain, and the United States. GCF promotes REDD+ and low emissions rural development and seeks to link these activities with voluntary and compliance-based programmes to reduce GHG emissions.

[21] Rambøll, SUSTAINABLE AVIATION BIOFUEL - STATUS 2017, Helsinki, May 2017

Based on aggregated data from Ecosystem Marketplace, the cumulative value of implemented forest conservation carbon offset projects as of 2016 reached USD 480 million with an average price of USD 5.02/tonne CO_2e. This compares to a transaction volume of USD 293 million and an average price of USD 7.68/tonne CO_2e for tree planting projects and a cumulative value of USD 120 million and an average price of USD 8.42/tonne CO_2e for improved forest management projects.

In Burkina Faso, the creation of a General Directorate on Green Economy and Climate Change integrating REDD+ now provides the Ministry of Environment with an adequate body to implement and supervise any REDD+ specific carbon financing activities.

6.5 MANAGING THE COST PREMIUM OF SAF

While the cost of SAF relative to current aviation fuel has decreased substantially from its first introduction in 2008, a significant price differential remains; the reduction in life-cycle GHG emissions come at a production cost 3 to 5 times greater than petroleum-derived fuels. With a jet fuel price average for 2017 of USD 509.20 USD/Mt this amounts to an average price for alternative aviation fuel in the range of USD 1.527 to 2.546/tonne. In a recent report for the Norwegian aviation sector and airport operator Avinor, the Danish engineering, design and consultancy company Rambøll estimates the cost of aviation biofuel production at USD 0.90 to 3.20/litre, compared to current aviation fuel at USD 0.50 to 0.64/litre[21].

These variations and the price premium of SAF are highly dependent on assumptions around the SAF production process, the feedstock used, the production technology, plant scale, the fraction of aviation biofuel in the biocrude mix, the specific policy environment and other factors and cost drivers. The main production cost drivers for SAF are feedstock cost and composition, capital cost, petrochemical infrastructure, overall yield of conversion, quality and composition of the produced SAF, operating expenses, financial requirements and logistics. According to Rambøll, the lower end of the production cost of SAF can be achieved only through HEFA-derived fuels, which utilize oil crops and animal fats as feedstock, two bioenergy resources highly relevant for production in Burkina Faso.

For the envisaged long-term replacement of petroleum-based fuels with SAF the real challenges lie beyond science alone. The most significant barriers to the commercial deployment of SAF are economic rather than technological. There is little doubt that a multitude of innovative fuel conversion technologies can produce a fuel that replicates aviation fuel from sustainable alternative raw materials. However, doing so in a cost-effective, affordable way and at the scale that the aviation industry requires is the bigger problem. Fuel production may be prohibitively expensive if the biomass yield is insufficient, biomass availability limited, or the conversion technology inefficient or capital-intensive. Except for individual airlines that have shown willingness to pay a "voluntary" sustainability premium for smaller demo-scale quantities of SAF, airlines are generally not prepared to pay a higher price for SAF compared to that for current aviation fuel.

To bridge the gap between current SAF production costs and current aviation fuel prices, and to incentivize commercial-scale deployment of SAF, alternative pricing models are needed. In this context, the quantification and monetization of avoided climate damages and ancillary benefits as illustrated in **Figure 44** may offer a theoretical solution.

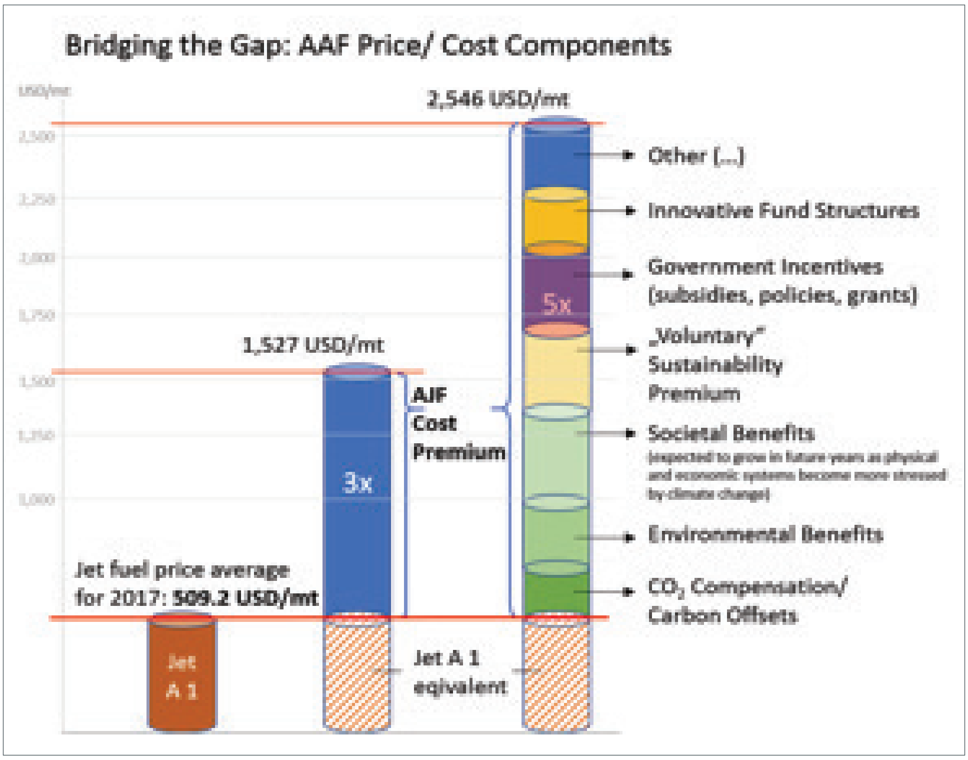


FIGURE 44

Bridging the GAP: Alternative fuel price/ cost components

One established price component that could potentially bring down the cost for SAF relates to CO_2 compensation and carbon offsetting. Taking arbitrage into consideration, the maximum price for SAF that an airline may be willing and capable to pay for equals the price of fossil kerosene plus the price of the CO_2 emissions certificates (or similar market-based compensation measures) saved. However, not all carbon prices are created equal. Carbon pricing policies and offsetting mechanisms are quite heterogeneous. Moreover, the cost of emitting CO_2 dropped to less than USD 10/tonne in 2017. Assuming a 100 per cent offsetting of CO_2 by using SAF, every tonne combusted avoids the need for certificates for 3.15 tonnes of CO_2. With carbon trading at less than USD 10/tonne, it is far more economical for aircraft operators to burn regular fuel and pay the carbon penalty by purchasing emissions units, than to switch to SAF. Even by quadrupling the cost of carbon, it is still significantly cheaper adding the CO_2 compensation penalty to the price of Jet A-1 fuel than the projected selling price of USD 2 546/tonne for SAF. Acknowledging airlines' small competitive margins, there may be little incentive for them to use SAF as is the case today[22].

To balance the negative effects of the remaining SAF cost premium, additional environmental, economic, and societal impacts of bioenergy technologies need to be considered in a holistic assessment of their feasibility, including potential impacts on air, water, and soil quality, land use patterns, commodity prices, energy and food security, poverty alleviation and livelihoods.

[22] Cf. Buse, Market Commercialization of Alternative Aviation Fuels, in: Martin Kaltschmitt/Ulf Neuling (ed.), Biokerosene, Status and Prospects, p.741 – 759, Hamburg 2018

However, quantification and monetization of avoided climate damages and ancillary environmental and societal benefits (e.g. reducing erosion, restoring degraded soils, enhancing biodiversity, creating new agricultural opportunities in areas not amenable to the production of food crops) remain a challenge. Lacking binding definitions and industry practice, values attributed to individual price components can merely be regarded as approximations. The Laboratory for Aviation and the Environment (LAE) at the Massachusetts Institute of Technology (MIT) has developed techno-economic models for evaluating alternative fuel production costs and analyses societal benefits and costs of pursuing various fuel options. Accordingly, the fuel cost premium of SAF compared to recent Jet A-1 market prices is still greater than the monetized net present value of the aggregated climate benefits for any SAF production pathway under consideration today[23]. However, the climate-cost trade-off may evolve over time due to learning-by-doing of nascent SAF production technologies and the increasing societal value of GHG emissions mitigation. Insofar as learning-by-doing contributes to improvements in efficiency and a reduction in process input requirements, the life-cycle environmental impact of SAF production may gradually improve. According to Rambøll, the expected rate of learning is assumed to be around 8 per cent, which implies an 8 per cent reduction in production costs each time the production is doubled. All of these time-dependent factors indicate that the climate damages mitigated by replacing Jet A-1 with SAF may ultimately balance and potentially even exceed the additional cost premium of producing SAF at some point in the future, even if that is not the case today.

Meanwhile, neither market forces nor government action alone will be sufficient to drive the fuel-switching process and replace petroleum-based fuels with SAF. Regardless of whether the monetization of fuel-switching related benefits can ultimately balance the price gap, the high price premium remains a major hurdle. Independent of the identified climate-cost trade-off, another question is how to equally share the burden.

Many airlines and early movers in the aviation industry have made early investments in SAF to meet their own voluntary carbon emissions goals and to stimulate the market. Further market participants and aviation stakeholders may be called upon to help reduce the cost delta and advance SAF development. In addition to the airline industry itself, potential addressees with a vested interest also include governments, development banks and NGOs, as well as airport authorities, oil majors, fuel suppliers and other established actors in the production value chain.

Recent examples of a direct engagement include strategic investments into the feedstock and SAF supply chain by airlines (e.g., Cathay Pacific, Southwest Airlines, United, and others), logistics companies (e.g., FedEx), and oil majors (e.g., BP and Shell).

In particular the international oligopoly of oil majors might be well advised to take on some production-cost risk and to consider amending their portfolio of products by integrating comparatively small portions of SAF. The oil majors not only have extensive expert knowledge of all stages of the process chain, but also of a highly standardized and cost-optimized transport and storage chain that facilitates the lowest cost production and distribution of their products. Given their de facto control over logistics, pricing and the overall process chain, established oil majors and jet fuel suppliers are natural addressees to step in and bear part of the cost premium. Transfer pricing in the various process steps could make it possible to compensate SAF related costs, while still optimizing total return.

However small, the cost disparity between SAF and current aviation fuel is still a hurdle that market forces alone are unlikely to overcome. As of today, none of the certified feedstock-to-fuel pathways are profitable on a stand-alone basis. Without strong public intervention, commercial scale SAF deployment is unlikely to happen.

It is likely that a range of strong government production incentives (including subsidies, grants and loan guarantees) and innovative fund structures will be needed to cover the gap. Only long-term stable policies and objectives, including sufficient economic incentives and proper recognition of SAF's positive environmental externalities, can encourage the necessary capital investments from both the public and private sectors.

By means of dedicated State guarantees and insurance programmes, the government could, for example, implement a guaranteed minimum price (i.e., a price floor) for both feedstock producers and low carbon fuel investors, thus mitigating market risks and investor uncertainty. Whenever market or policy shifts occur that drop the value of either a feedstock or a finished fuel product below the agreed-upon price floor, the policy would pay out the difference. Similarly, a guaranteed price cap covering the risk of high SAF production costs for a fixed volume might encourage airlines to enter into long-term off-take agreements.

Alternatively, a CO_2 fund could be established by uniting the income from carbon compensation payments to purchase, on behalf of participating airlines, the feedstock required for biofuel and SAF production. This way, the market risk would be placed upon the fund and the environmental charges, and CO_2 compensation paid by the airlines and aggregated in the fund would directly contribute to the production of feedstock.

[23] Laboratory for Aviation and the Environment (LAE), Massachusetts Institute of Technology (MIT), Mark Douglas Staples, Bioenergy and its use to mitigate the climate impact of aviation, Feb. 2017 and Seamus J. Bann, A Stochastic Techno-Economic Comparison of Alternative Jet Fuel Production Pathways, June 2017

6.6 VALUING CO-BENEFITS OF CLIMATE CHANGE MITIGATION

Although the premium has decreased considerably, the current cost of SAF is still at least three times higher than for current aviation fuel. This deficiency has been an important factor in their slow take-up and large-scale production. Independent of the underlying conversion pathway, alternative fuel production costs will continue to remain uncompetitive for the foreseeable future, with the predictable negative consequences on profitability and internal rates of return. To compete with fossil fuels, alternative fuel requires conventional and innovative forms of price support.

The application of carbon pricing, preferably combined with increasing costs of carbon (i.e. above the current market value), may help to temporarily bridge the price gap between current aviation fuel and alternative fuel. However, even carbon-credit revenues that reflect the social costs of carbon may not be sufficient to enable greater numbers of projects to move from demonstration to commercial scale. As a result, additional streams of financing are required.

By recognizing the co-benefits of low carbon investments, investors, donors and government entities can go beyond valuing GHG reductions through carbon credits. To facilitate raising project finance, ancillary benefits that go beyond the original GHG emission reduction and fuel switching goals also need to be taken into account. The associated benefits of developing, producing, and using SAF can go far beyond the immediate benefits of reducing the impact of international aviation on the global climate; they can provide opportunities for greater economic growth, expanded employment, revitalized infrastructure, and reduced inequality throughout States' economies.

Bridging the price premium gap will ultimately require valuing and properly pricing environmental, economic and social co-benefits. These associated benefits include numerous positive externalities created by the production and consumption of biofuels and SAF.

Climate policy and climate induced investments rarely take place for the sole purpose of mitigating climate change, but most typically serve other primary purposes, with the co-benefit being climate mitigation. This is especially true in developing countries, where basic development objectives (such as food security, poverty alleviation, improved health, energy access, optimized water resources and appropriate land use) often take precedent over climate objectives for the allocation of scarce resources.

This correlation was explicitly recognized during CAAF/2 and is well reflected within the framework of the UN SDGs. Accordingly, UN SDG 15 explicitly recognizes that well-planned SAF feedstock development can at the same time protect, restore, and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, halt and reverse land degradation, and stop biodiversity loss. In addition, UN SDG 2 also recognizes that sustainable fuel production holds the potential to end hunger and malnutrition, achieve food security and promote sustainable agriculture.

The social, environmental and economic "side effects" of an integrated renewable energy supply chain in general, and a potential multi-feedstock pilot plant operation for SAF production in particular, can vary considerably and may actually outweigh the importance and monetary value of climate change mitigation benefits. Sample co-benefits may include, inter alia:

- contribution of the project to the national economy, energy supplies and the number of people employed in the sector;
- energy security;
  - improved access to energy;
  - reduced dependence on fossil fuel imports;
  - decreased disruption in energy supply;
  - rural electrification;
- balance of trade considerations;
  - savings from reduced imports of fossil fuels, associated with increased reliance on domestic renewable energy endowments;
- reduction in life-cycle GHG emissions and climate change adaptation;
  - sustainability gains/positive environmental impacts;
  - improved local water resource management
  - international and sector recognition;
- technology transfer and clean energy partnership
  - technological spill over;
  - access to world-class technology at preferential conditions: share and profit from expertise in technology and innovation to secure new business opportunities;
  - installing low-carbon technologies typically has systemic impacts well beyond GHG emission reductions;
  - technical role model;
- demonstrate policy and business leadership;
- positive effects on food security;
- positive health effects[24];
- biofuels can serve as a stimulus to rural economies;
  - rural economic benefits are a key rationale behind the expansion targets and biofuel policies and incentives established by producer country governments around the world;
  - employment and income generation;
  - ecosystem impact, improvement of soil and land use (reforestation, land rehabilitation);
  - infrastructure improvement;
  - poverty reduction;
  - recognition of community needs;
  - positive implications of biofuel feedstock cultivation including industrial-scale plantations, smallholders growing independently for defined markets, and diverse arrangements under which companies contract smallholders to produce feedstock on their behalf, will each have their own unique set of impacts.

[24] For example, various studies estimated average health co-benefits at USD 58 to 380/tonne of CO2, reduced, with benefits higher in developing than developed countries.

If properly valued, these ancillary benefits may at least partially offset cultivation and production costs, and thus encourage project implementation and competitive pricing. Various academic studies have concluded that social, environmental and economic co-benefits can represent between 50 to 350 per cent of direct benefits from investment in energy efficiency and renewable energy sources, with health benefits dominating. According to research carried out by the Centre for Environmental Policy, Imperial College London in partnership with the International Carbon Reduction and Offsetting Alliance, offsetting one tonne of CO_2 may generate an additional USD 664 in economic, social and environmental benefits to the communities where carbon reduction projects are based. The estimation of these co-benefits largely depends on the context in which the project takes place and the modalities of implementation, which prevents deriving generally applicable rules on the size of these ancillary benefits.

To reduce costs and obstacles to investment for both feedstock cultivation and biofuel production, co-benefits of climate change policies need to be integrated into the financial equation from the outset (i.e. project launch). The monetization of development co-benefits could significantly improve financial viability, based on calculated net present values and internal rates of return.

In addition to potential carbon sequestration benefits (see Sections 6.3 and 6.4), environmental credentials and socio-economic benefits could potentially be quantified and credited towards the cost of production. This would facilitate overall commercial viability and encourage broad market uptake.

The major challenge is how to translate heterogeneous co-benefits into economic terms and how to value and monetize their impact on the financial rate of return. Co-benefits are rarely measured, quantified, or monetized, and even less frequently do they enter the quantitative decision-making frameworks applied to climate change and biofuel production.

Direct market valuation methods typically monetize benefits on the basis of production or cost data. Therefore, they can only be applied to goods or services (i.e., the benefits being monetized) for which markets exist. However, the difficulty is that resource efficiency, energy access, improved agricultural practices, sustainability of ecosystems and preservation of biodiversity, to name but a few examples, do not have a direct monetary value and therefore need to be estimated. Without proper market pricing, estimation of the intrinsic monetary value ultimately depends on what investors/donors are voluntarily willing to pay. Motivation to recognize a certain value and thus willingness to pay for select co-benefits may include sustainability related reputation, brand image, market differentiation, philanthropy, environmental credentials, or supply chain management considerations.

Barriers to the implementation of projects that are high in co-benefits are related to a failure to monetize the value (in terms of willingness to pay) of such co-benefits/social assets. A successful fundraising and incentivization strategy therefore must provide mechanisms that:

- assess and quantify the co-benefits associated with mitigation actions identified;
- establish who is willing to pay for the provision of such co-benefits/ social assets;
- determine their willingness to pay per "unit" of created co-benefit/social asset; and
- facilitate a transaction of this willingness to pay to the producer of these co-benefits.

As a result, it is recommended that the financial viability and bankability of feedstock cultivation and biofuel production projects should not be analysed on sector-specific merits alone. Instead, feedstock cultivation and biofuel production should be considered as a source of opportunity to advance other policy objectives simultaneously, for which separate funding may be available. While the trigger for the launch of an alternative fuel project may ultimately be influenced by considerations related to renewable energy, biofuels and GHG emissions reductions, ancillary benefits as described above may open up additional dedicated funding programmes and financial instruments formally reserved for environmental or social development projects. This correlation between underlying motivation and ancillary benefits demonstrates that the strategic promotion of co-benefits can play an important role in the ultimate mobilization of alternative funding sources. In fact, in some cases, policies may seek the co-benefits as the primary target, while climate change mitigation and renewable energy financing become a collateral effect.

7. CONCLUSIONS

7.1 FEEDSTOCK PRIORITIZATION

Based on the analysis in the previous chapters, the major domestic biomass resources suitable for conversion into SAF include:

- tropical grasses, such as elephant grass;
- agricultural residues (sorghum);
- high yielding oil bearing crops, such as improved jatropha accessions;
- MSW;
- cashew and shea nut shell oil; and
- waste animal fats (tallow).

Lignocellulosic feedstock offers the highest potential in terms of volume with energy recovery estimates exceeding 9 million boe, though such estimates are highly variable when taking into account the identified logistical, technical and economic restrictions, as well as any competing utilization.

Despite its challenges, authorities and stakeholders in Burkina Faso nevertheless seem to favour the cultivation of jatropha over alternative energy crops and other domestic sources of biomass. Cognizant of lessons learnt and project-related challenges and pitfalls, the re-launch of the jatropha value chain remains regarded as one of the most realistic and achievable renewable energy options due to the plant's modest soil requirements, allowing it to be grown on land that is marginal or unsuitable for other agricultural uses.

The concentration of smaller waste fractions at one location makes animal waste fats and MSW potentially attractive for biofuel production. However, the organic fraction of MSW may only become available in the wake of cheap and efficient municipal waste collection and sorting technologies.

While the expansion of sugarcane appears limited due to irrigation needs and sustainability concerns, cashew and shea nut shells represent a Burkinabe specialty. As by-products with no assigned value, decent quantities of feedstock are available for processing and energy conversion with immediate effect. Ongoing plantation projects promise further yield and production volume increases which are conducive for any commercialization efforts.

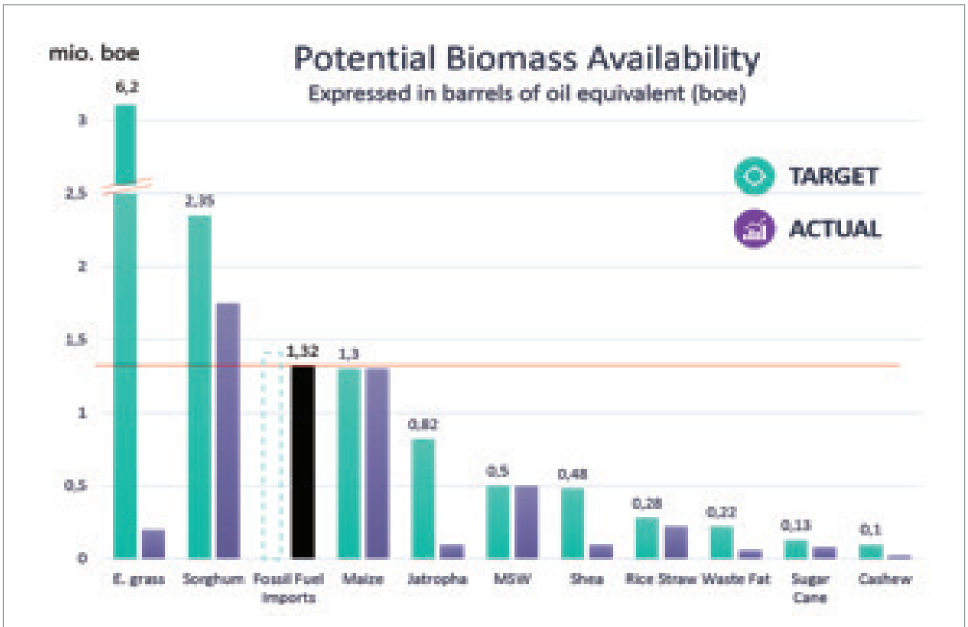


FIGURE 45
Potential biomass availability

To put things into perspective, it is helpful to compare the energetic value of the total potential biomass availability with annual fossil fuel imports. As of 2016, Burkina Faso imported approximately 150 000 tonnes of heavy fuel oil (HFO) and 30 000 tonnes of distillate diesel oil (DDO). Based on an average calorific value of 43 MJ/Kg or 7.33 boe/tonne of fuel imported, the collective energetic value of all fuel imports in 2016 equalled 1.3 million boe. This compares with over 12 millon boe in terms of domestic biomass availability. In other words, the demonstrated energetic potential of alternative feedstock sources exceeds the country's oil imports by at least nine times. Even allowing for methodological inconsistencies and a high margin of error, it is fair to conclude that theoretically available domestic feedstock supply could easily outweigh Burkina Faso's annual fossil fuel imports. The comparison shows at least the potential for domestic biofuel production. **Figure 45** above provides a breakdown of feedstock sources and their respective contribution to the potential biomass availability in Burkina Faso.

PICTURE 22
Bioenergy and food crop harvest

Farmers present their harvest of intercropped jatropha, maize and green beans in the community of Toeghin, Yimkonka village.

As the market for alternative fuels remains in its infancy, market growth will be driven by a wide number of factors, including economic and technical feasibility, as well as the signals provided by ICAO in terms of what feedstock types are deemed eligible under CORSIA. At the same time, the much larger oil and biofuel markets will also drive change and compete with the aviation sector for feedstocks, production capacity and consumers.

Finally, the question of whether rural households or specific target groups own land or can obtain the rights to use land for energy crop cultivation is of critical importance to the success and sustainability of biofuel projects, in Burkina Faso, as well as in Sub-Saharan Africa more generally.

7.2 FUEL CONVERSION TECHNOLOGIES

A multitude of fuel conversion technologies is being developed at various scales (pilot, demonstration, and pre-commercial) to transform biomass-based feedstocks into aviation fuel[25]. The wide range of potential raw materials available in Burkina Faso entails an equally diverse range of matching fuel processing solutions. There are many possible combinations of feedstock, pre-treatment options, conversion technologies and downstream processes that

[25] For an overview of ongoing international commercialization efforts, see International Renewable Energy Agency (IRENA), BIOFUELS FOR AVIATION - TECHNOLOGY BRIEF, Jan. 2017; Wei-Cheng Wang et al., Review of Biojet Fuel Conversion Technologies, National Renewable Energy Laboratory (NREL), July 2016; International Council on Clean Transportation (ICCT), Anastasia Kharina, Nikita Pavlenko, Alternative jet fuels: Case study of commercial-scale deployment, Oct. 2017

can be followed as potential pathways to produce transport biofuels, alternative fuel and bio-chemicals. In practice, feedstock characteristics pre-determine the choice of the most fitting conversion pathway. The molecular composition of plant matter is an important determinant for the feasibility and efficiency of biomass processing. For example, while woody biomass is composed of firmly bound fibres with high lignin content, grassy energy crops have more loosely bound fibres and lower lignin content. Also, residues from agriculture and agroindustry typically contain less cellulose (20 to 40 per cent) than forestry or energy crops (30 to 50 per cent).

The most promising fuel conversion technologies for Burkina Faso that are relatively mature include:

- hydro-treatment and upgrading of waste oils or plant-based oils (oleaginous crops) to SAF (HEFA-SPK);
- gasification of biomass or MSW into a synthesis gas followed by FT conversion of the synthesis gas into SAF (FT-SPK);
- AtJ synthetic paraffinic kerosene (ATJ-SPK);
- synthesized iso-paraffins produced from hydroprocessed fermented sugars (SIP-HFS); and
- synthesized kerosene with aromatics derived by alkylation of light aromatics from non-petroleum sources (SPK/A).

In comparative terms, HEFA-SPK has the lowest production complexity. Its downside is the need for expensive hydrogen to hydrotreat the biomass. Hydrogen is a key input needed for almost all SAF production processes because the ratio of hydrogen atoms to carbon atoms in aviation fuel molecules is typically higher than the hydrogen-to-carbon ratio in feedstocks. While hydrogen represents a significant portion of operating cost in most conversion processes, it is not readily accessible, particularly at reasonable cost. In many cases, hydrogen can be supplied from the conversion of natural gas, but natural gas infrastructure is also limited.

It is possible that the largest potential for drop-in biofuels is routed in the FT-SPK process which relies on low-cost lignocellulosic feedstock that can be derived from waste or from dedicated energy crops. Advantages of this pathway include the flexibility and wide availability of feedstocks. Cellulosic waste materials and biomass are ubiquitous in Burkina Faso and include agricultural waste and plant residues. In addition, there is a wide range of tropical grasses and climate resilient fast-growing trees that are suitable as dedicated cellulosic biofuel crops. However, synthetic fuel processing facilities come with high economic risks as they are highly capital intensive. Indeed, all conversion technologies have high capital costs and require large production facilities to achieve economies of scale.

Project viability with attractive returns for private investors is only expected to kick in with economies of scale and an oil production capacity beyond 20,000 mt per annum. To bridge the viability gap and reduce investment risk, government support and development funding schemes will be necessary.

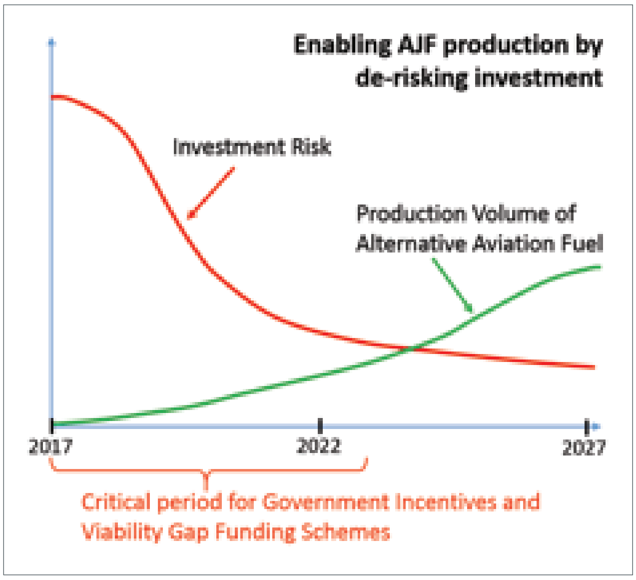


FIGURE 46
Enabling SAF production by de-risking investment

In fact, process economics of SAF production are dependent on many variables, such as composition and cost of feedstock, conversion efficiency or product yield, co-product credits, plant size, process design, energy conservation, and degree of maturity of the technology.

Without basic petrochemical or refining infrastructure in place, there is no chance for cost savings through potential brownfield co-location, co-processing or the use of existing infrastructure. This excludes any autonomous SAF production capacity in Burkina Faso for the time being. In order to improve production efficiency and reduce unit costs, further R&D will be needed. Regarding the gasification/FT pathway, R&D could potentially enable modular, small-scale reactors that can convert bio-derived synthesis gas into aviation fuel.

Encouraging the willingness of private and institutional investors will require a significant degree of public intervention. As long as markets are still in the process of development and production volumes of competitively priced alternative aviation fuels remain low, viability gap funding schemes may be needed to de-risk critical investments.

In addition to the conversion processes and technology solutions already certified and approved as annexes to ASTM D7566, another five conversion processes are currently being investigated and are going through the approval process for inclusion as an ASTM D7566 annex (see overview in **Table 9**).

FIGURE 47
Select processing technologies: complexity and cost overview

Processing	Description	Complexity	Capex	Opex
Refining	Common refinery technology	– – Very complex	– – Very high	+ + Very low
Gasification Fischer-Tropsch	High-temperature gasification plus conversion of syngas to liquid fuel	– – Very complex	– – Very high	+ + Very low
Depolymerization	Decomposition of polymers at high temperature under pressure to paraffins, aromatics and polyaromatics	– Complex	– High	– High
Biological conversion	▪Fermentation to terpenes & hydrogenation ▪Fermentation to alcohol, dehydration, oligomerization & hydrogenation	– Complex	+ Moderate	– – Very high
Hydrotreating & Isomerization	Hydrogenation of triglycerides from plant oil or animal fats under pressure at high temperature & isomerization	– Complex	– High	O Moderate
Catalytic cracking (greasoline®)	Catalytic cracking, decarboxylation and deoxygenation of triglycerides from plant oil or animal fats at high temperature	O Moderate	O Moderate	+ Low
Transesterification	Transesterification of triglycerides from plant oil or animal fats into mono-alkyl esters of long-chain fatty acids (Bio diesel)	+ Simple	+ Low	+ + Very low

TABLE 9
Alternative fuel conversion processes currently within the ASTM approval process [26]

	Conversion Process	Abbreviation	Possible Feedstocks	Commercialization Proposals	Notes
1	Catalytic Hydrothermo-lysis Jet/ High Freeze Point HEFA	CHJ/ HFP- HEFA	Bio-oils, animal fat, recycled oils	Chevron Lummus Global, Applied Research Associates, Blue Sun Energy	Bio-oils reacted with water under high temperature and pressure conditions. Could be used without blending
2	Co-processing bio-oils in existing refineries	Co-processing	Bio-oils	Chevron, Phillips66, BP2	Co-processing is based on the processing of bio-oil with conventional middle distillates in existing refineries.
3	Alcohol-to-jet synthetic paraffinic kerosene	ATJ-SPK (besides isobutanol)	Biomass used for starch and sugar production and cellulosic biomass for alcohol production	Gevo (butanol), LanzaTech (ethanol)	ASTM is reviewing production of jet fuel from butanol and ethanol in addition to isobutanol, which has already been approved as ATJ-SPK (Annex 5).
4	Alcohol-to-jet - synthetic kerosene with aromatics	ATJ-SKA	Biomass used for starch and sugar production and cellulosic biomass for alcohol production	Byogy, Swedish Biofuels	Fuel produced with bio-aromatics to allow for higher blend percentages.
5	HEFA Plus	Green Diesel	Bio-oils, animal fat, recycled oils	Boeing	First test flights with a 15% HEFA-diesel ("green diesel") blend already took place[3]

However, in terms of technology readiness, the new processes have not been demonstrated at a level greater than pilot or demonstration scale. They are thus of much lower technological maturity and associated with greater uncertainties and risks. It is widely accepted that one of the key aspects limiting the progression from pilot to demonstration plant, and from demonstration to commercial plant is the scale and risk associated with the required investment. Independent of technological achievements the remaining risks and costs associated with developing integrated demonstration and first commercial plants, as well as the uncertainty in market uptake and value of the output fuels, remain a significant barrier to realizing commercial production.

Among the approved processes, only HEFA fuels have been produced at commercial scale (e.g. Neste Oil, UOP, ENI, Dynamic Fuels). As of today, existing HEFA capacity produces predominantly diesel fuels, with only a small fraction of aviation fuels. The development and deployment of HEFA aviation fuels has progressed from single demonstration flights by airlines and equipment manufacturers to multi-stakeholder supply-chain initiatives including civil, military and government aircraft operators, fuel producers and airports. A recent report by France's Académie des Technologies and Académie de l'Air et de l'Espace concluded that vegetable oil-based HEFA bio-jet is likely to remain the only economically viable option in the near future.

[26] Cf. CAAF/2-WP/-7 Table 2 – available to download from: https://www.icao.int/Meetings/CAAF2/Pages/Documentation.aspx

Project	Location	Feedstock	Technology	Capacity* (M gallons/year)	Operation Year [anticipated]
Fulcrum Sierra BioFuels	Story County, Nevada	Municipal solid waste (MSW)	Gasification, FT	10	[2019]
Emerald Biofuels	Gulf Coast	Fats, oils, and greases	HEFA	88	[2017]
Red Rock Biofuels	Lakeview, Oregon	Woody biomass	Gasification, micro-channel FT	16	[2017]
AltAir Fuels	Los Angeles, California	Fats, oils, and greases	HEFA	40	2016
REG Synthetic Fuels	Geismar, Louisiana	Fats, oils, and greases	HEFA	75	2014
Diamond Green Diesel	Norco, Louisiana	Fats, oils, and greases	HEFA	150	2013
SG Preston	South Point, Ohio	Fats, oils, and greases	HEFA	120	[2020]
SG Preston	Logansport, Indiana	Fats, oils, and greases	HEFA	120	[2020]

* All fuels are total gallons of production for combined jet and diesel.

Source: U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy

TABLE 10
Operational or planned U.S. Aviation Jet Fuel and Green Diesel Production Facilities (2017)

An alternative near-term opportunity could also be the production of SAF by means of a catalytic thermal cracking mini-refinery. With regard to capex, opex and overall process complexity, the German catalytic cracking conversion technology developed by Fraunhofer enjoys a competitive advantage over all other fuel technology pathways in operation or under development today. This includes the HEFA process as the main and most established competitive fuel conversion pathway.

In the near future, thermochemical conversion technologies are the most likely option to provide the large alternative fuel volumes requested by the aviation industry. In comparison, the high market value of intermediates produced via alternative biochemical conversion routes can often achieve much more attractive purchase prices in chemical, lubricant and cosmetic markets than lower valued kerosene and jet fuel fractions.

As Burkina Faso currently lacks petrochemical infrastructure, it is unlikely that alternative fuel will be developed or deployed in the near-term unless domestically produced feedstock is exported, converted in petrochemical complexes and refineries overseas and then re-imported. Meanwhile, Burkina Faso is well positioned to initially focus on feedstock and biomass processing (e.g. transesterification) which require less capital-intensive facilities.

Fully integrated domestic and/or regional refinery technology solutions (T2) will only become a strategic option for Burkina Faso once minimum feedstock production thresholds are reached, a basic petrochemical infrastructure is in place or under construction, and tangible stakeholder commitments from airlines and investors are secured.

7.3 LAND USE CHANGE AND GHG LIFE-CYCLE

Emission reductions from biofuels vary by production pathway, feedstock, and fuel produced. There is broad consensus that the GHG emission reductions resulting from the use of alternative fuels should be calculated on a life-cycle basis. The full life cycle of SAF comprises feedstock production, harvesting, feedstock handling and extraction, preparation, storage and transport of raw materials, SAF conversion and processing, transport of the finished product, and combustion. Accordingly, the actual emissions reductions to be achieved depends on many factors.

The carbon intensity of a given fuel is estimated using life-cycle assessment (LCA) methodology and is typically expressed in gCO_2e/MJ of fuel (i.e., its carbon intensity). The LCA is an operational tool aiming at the evaluation of the potential environmental impacts of a product, a process or a service, on human health, ecosystems and the depletion of natural resources. It is used to calculate the amount of CO_2 released during the whole process from the feedstock production to the tank of the aircraft.

Aircraft operators that intend to claim emissions reductions from the use of SAF will need to determine the life cycle emissions value of such fuels. Work is ongoing in ICAO to determine default LCA values for CORSIA-eligible fuels, including SAF[27]. The current status of this work in ICAO includes a requirement that SAF shall achieve net GHG emissions reductions of at least 10 per cent compared to current aviation fuel on a life cycle basis. Therefore, in addition to other key environmental and social development factors, the GHG balance of a biofuel pathway is a critical metric in determining its overall sustainability characteristics. A recent study published by the MIT LAE confirmed that there is a significant potential for a reduction in life cycle GHG emissions across all of the SAF production pathways under consideration today[28].

The impacts of biofuel production on land use are of particular concern, as in some cases, the resulting emissions from land use change can fully negate the GHG benefits of replacing aviation fuel with a biofuel. Therefore, land-use change effects that may be associated with SAF production needs to be considered. Emissions attributable to indirect land use change (ILUC) can occur, for example, when existing cropland is diverted to meet the increased feedstock demand of additional biofuel production, resulting in the displacement of other agricultural production activities onto land with high carbon stocks or other ecosystem services.

However, in the case of Burkina Faso, none of the analysed feedstock cultivation and related biofuel production scenarios are likely to cause either direct or indirect land-use change that otherwise would have to be accounted for when assessing the GHG implications of substituting conventional fuels with biofuels. ILUC risk is greatly reduced when biofuel feedstock is grown on marginal land and does not displace other activities or cultivation practices.

Provided that land-use change effects are properly considered in feedstock cultivation and biofuel production in Burkina Faso, life-cycle GHG emissions reductions of 60 to 90 per cent could be achieved. The binding constraint of avoiding harmful land-use changes encourages the use of waste biomass (cashew and shea nut shells, waste fat), agricultural residues (rice straw, corn stover) and oil crop (jatropha) cultivation on marginal land, as well as the balanced integration (intercropping) of food and fuel production to the extent possible. Cellulosic crops (elephant grass) generally carry lower risks of land-use change impacts than oilseeds. While no actual GHG intensity values for elephant grass are available from any of the operating demonstration plants, comparable reference data can be derived from the European Renewable Energy Directive. Accordingly, wheat straw-derived ethanol has typical GHG emissions of 11 gCO_2e/MJ, leading to potential GHG savings of 87 per cent.

With regard to HEFA-processed alternative aviation fuel derived from animal waste fats (tallow), the life cycle GHG emissions have been calculated by the MIT LAE. Accordingly, total CO_2e GHG emissions of tallow-derived SAF were found to range between 25.7 to 37.5 gCO_2e/MJ. This corresponds to life cycle GHG emission reductions of 59 to 72 per cent, compared to its conventional counterpart[29].

All of the analysed values for SAF produced from waste and lignocellulosic feedstocks are below the GHG intensities of current aviation fuel.

One of the lessons learnt from international biorefinery projects is that setting high GHG savings thresholds for demonstration plants may not be appropriate as these plants are typically designed to demonstrate the technical viability of the concept, but may not be designed to optimize environmental performance so to limit costs and added complexity.

Another caveat to consider is that different national circumstances will result in different sustainability specifications. Some concerns have been raised that standardization of SAF sustainability without taking into full account the specific interests of developing countries might set up barriers for the sustainable development of developing countries, whch would be contrary to the objectives of the UN SDGs and the ICAO *No Country Left Behind* initiative.

7.4 AVIATION ALTERNATIVE FUEL IMPLEMENTATION-INDEX

The series of feedstock-specific feasibility matrices in the previous chapters summarized the most significant parameters of a domestic feedstock supply chain and potentially matching fuel conversion technologies.

The following *"Aviation Alternative Fuel Implementation-Index"*, as shown in **Figure 48**, intends to add a chronological perspective, providing a concise and streamlined overview.

The segmentation into three parallel but nevertheless distinct streams (i.e., (A) *Feedstock Readiness*, (B) *Technology Readiness* and (C) *Financials/Economics*) may serve as a tool and rough guideline for governments and authorities to identify the right action items in the appropriate context, prioritize implementation measures and define a conducive policy framework within a given set of agro-climatic, social, economic and ecological circumstances in a specific region.

[27] Cf. 191. Wei-Cheng Wang et al., Review of Biojet Fuel Conversion Technologies, National Renewable Energy Laboratory (NREL), July 2016; 199.Erik C. Wormslev et al., Nordic Council of Ministers, Sustainable jet fuel for aviation, Nordic perspectives on the use of advanced sustainable jet fuel for aviation, 2016; 81. International Council on Clean Transportation (ICCT), Sammy El Takriti et al., Mitigating International on Clean Transportation (ICCT), Sammy El Takriti et al., Mitigating International Aviation Emissions - Risks and Opportunities for Alternative Jet Fuels, March 2017.

[28] Laboratory for Aviation and the Environment (LAE), Massachusetts Institute of Technology (MIT), Cassandra Vivian Rosen, Scenario based lifecycle analysis of greenhouse gas emissions from petroleum-derived transportation fuels in 2050, June 2017

[29] Laboratory for Aviation and the Environment (LAE), Massachusetts Institute of Technology (MIT), Gonca Seber, Robert Malina et al., Environmental and economic assessment of producing hydroprocessed jet and diesel fuel from waste oils and tallow, Biomass and Bioenergy, Vol. 67, 108-118, Aug. 2014

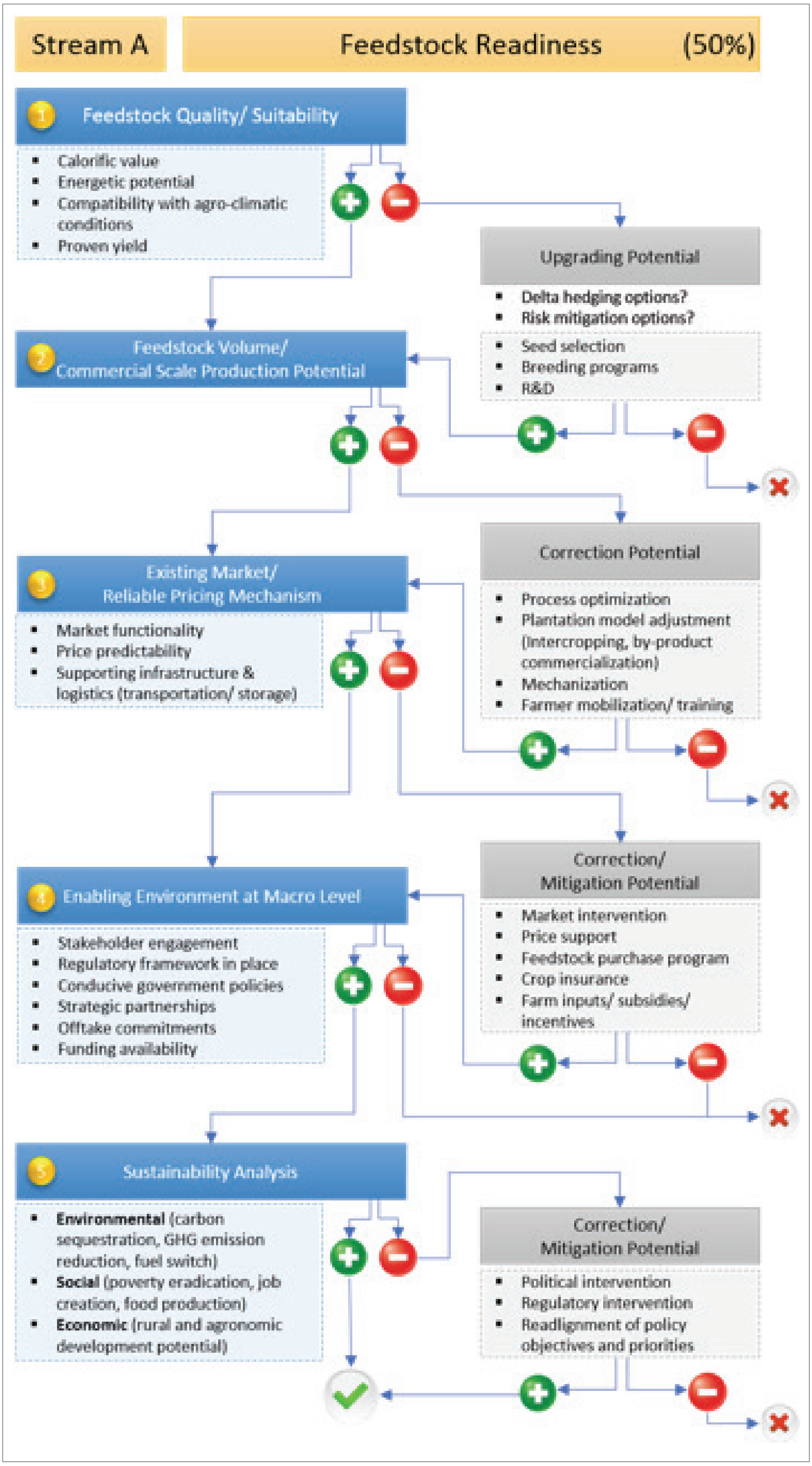
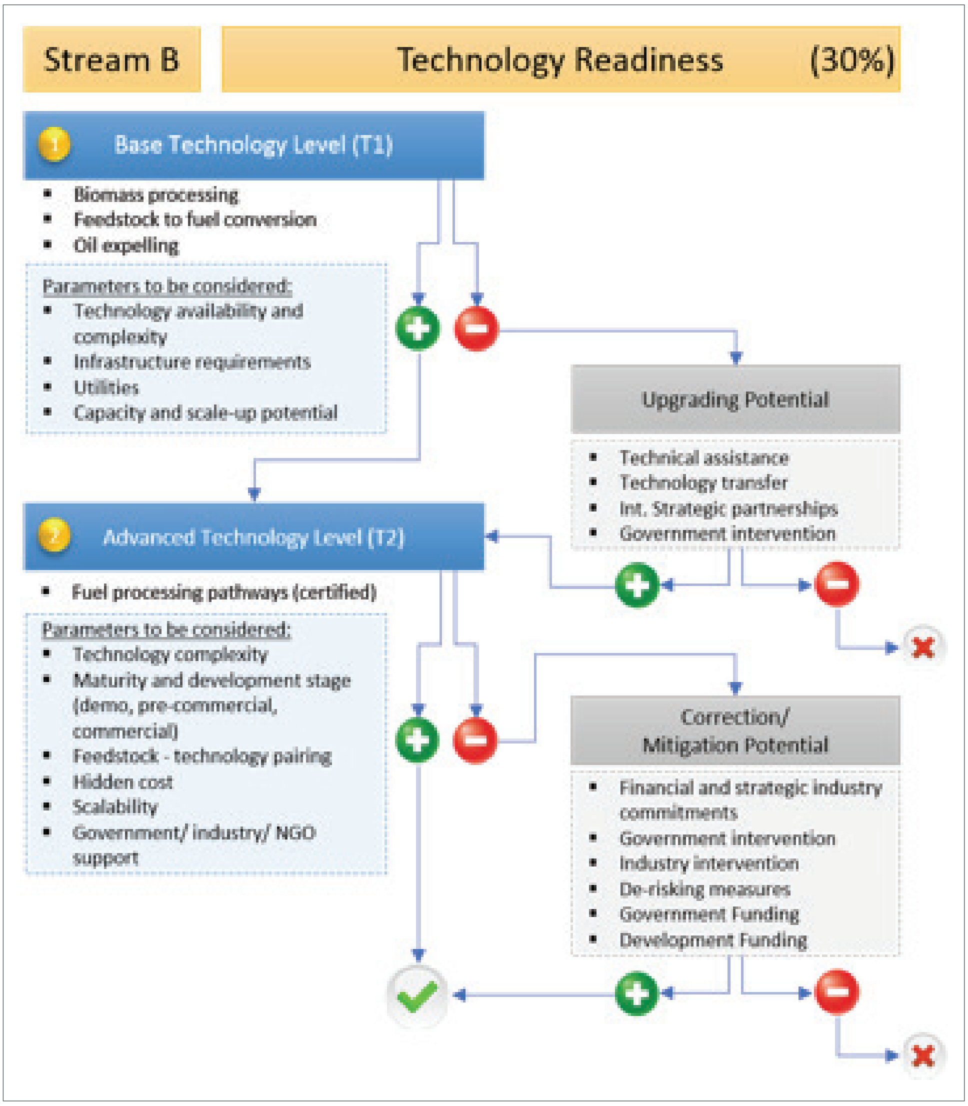
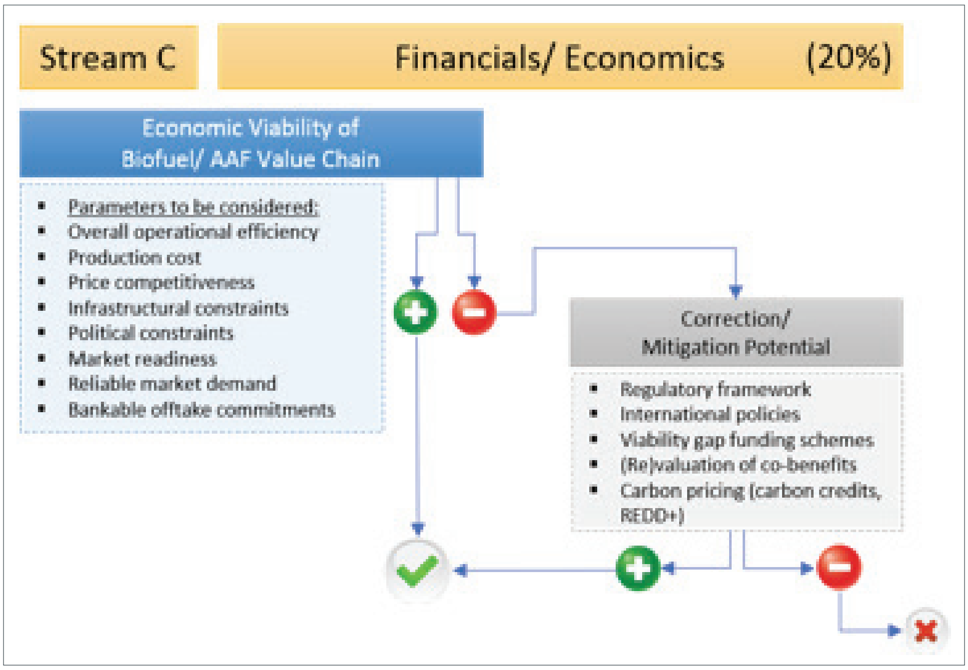


FIGURE 48
Aviation Alternative Fuel Implementation Index

FIGURE 48
Aviation Alternative Fuel Implementation Index





8. ROADMAP GOING FORWARD

A. STRUCTURAL ORGANIZATION

Recommendations/Action items What needs to be done	Potential stakeholders to be involved	Electricity Priority & Timing Target
1. NATIONAL STEERING COMMITTEE/PROGRAMME OFFICE • Bold and transformative action requires a neutral party that combines competency and authority without being dependent on any particular government agency or ministry. Potentially paralyzing bureaucracy, sectoral interests and internal issues risk slowing down momentum and international stakeholder and investor commitment. • It is therefore recommended to set up a National Steering Committee (NSC)/Programme Office with budget authority that enjoys a central role in formulating and coordinating policy instruments under the chairmanship (reporting line) of either the Prime Minister or the President. • Given the multi-sectoral specificity of biofuels, this independent central coordinating platform needs to be equipped with operational autonomy, ideally under the technical oversight of the Ministry of Finance. • The NSC will provide strategic orientation for the project; approve annual work plans and budgets; review project progress and evaluation reports; monitor implementation of the NSC recommendations; and ensure synergy with other projects; **The NSC/Programme Office** would be supported by two governing bodies, a project **Coordination & Cooperation Office (CCO)** and a project **Implementation & Execution Office (IEO)** • The IEO is responsible for overseeing all operational implementation aspects. It will take stock of project progress, implementation of action plans, and financial performance. • The IEO will also oversee the execution of activities which fall under the areas of responsibility of relevant ministries. • Following the identification and prioritization of individual tasks, a clear assignment of responsibilities will allow for effective monitoring of performance and prevent the break-down of accountability mechanisms. • It is critical that those team members assigned responsibility for certain tasks are made fully aware of both their own responsibilities and how these inter-relate with other tasks. • The CCO will coordinate all project activities at the central level; ensure day-to-day coordination of relevant stakeholders; and consolidate information on project progress. • Given its pioneering role in climate protection and international coordination, the National Civil Aviation Agency (ANAC) could potentially become the nucleus of the CCO. • Additional national high-level strategic partners to include ANEREE and SP-CONEDD.	- Ministry of Finance - Ministry of Energy - ANAC - ANEREE - SP/CONEDD - CIRAD - CNRST	Short Term

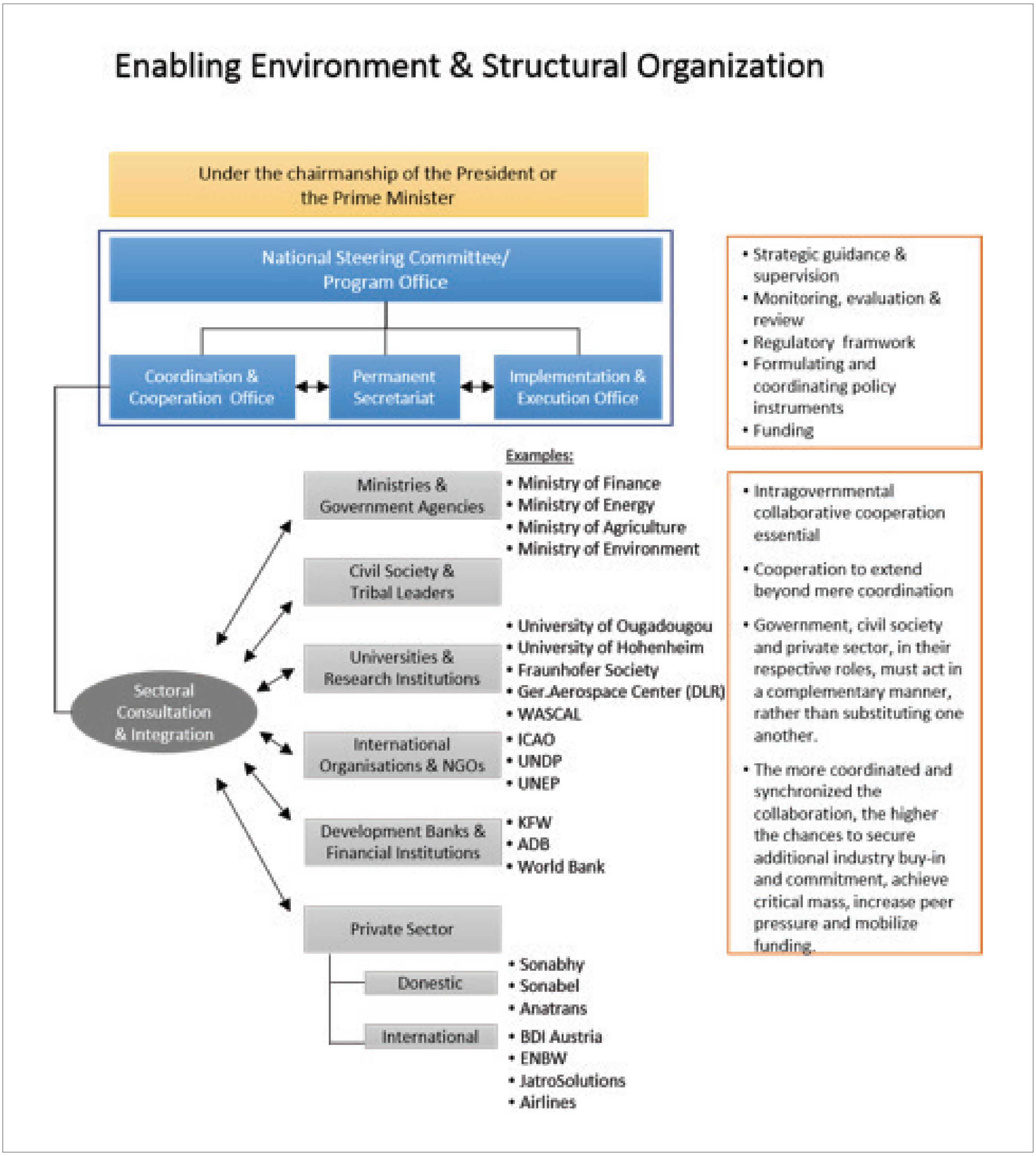


FIGURE 49
Enabling Environment and Structural Organization

B. BUSINESS PLAN & IMPLEMENTATION

Recommendations/Action items What needs to be done	Potential stakeholders to be involved	Electricity Priority & Timing Target
2. BUSINESS WHITE PAPER Draft a business plan that allows to secure public climate finance and international development funding.	- Hanns-Seidel Foundation	Imme-diately
3. UNITY OF EFFORT Develop a concrete business plan for a national biofuel supply chain, incl. all relevant aspects, recommendations, interdependent factors, sequence of decisions, implementation of Master Plan etc. To ensure unity of effort and reduce/prevent costly inefficiencies, it is vital to integrate any and all willing project partners into joint planning as early as possible, so an integrated, comprehensive and achievable execution plan can be developed.		Short Term
4. Promote technology transfer and forge technology and energy partnerships.		Mid- Term
5. JOINT MARKET DEVELOPMENT EFFORTS • To reach economies of scale for the envisaged installation of high tech feedstock processing equipment it is recommended to also identify suitable biomass potential in Ghana, Togo and Côte d'Ivoire. • Depending on the specific feedstock, the concentration of production capacity at select strategic locations would potentially allow for more cost-efficient processing plants with a higher throughput. • Efforts made by individual States on policies affecting feedstock production, social development and international aviation are less effective than regionally coordinated options. • In addition, the national civil aviation, air transport and energy industries would be much more motivated to implement SAF policies if a long-term policy framework based on regional policy agendas would be established and such policies would be part of regionally coordinated and harmonized efforts to tackle both, sustainable development goals and international aviation emissions. • Chances are that regional coordination by ECOWAS could be helpful.	- ECOWAS - UEMOA	Mid- Term
6. Support alternative aviation fuel demonstration programme and early on commercial use (local centres of excellence)	- ANAC	Short Term

Recommendations/Action items What needs to be done	Potential stakeholders to be involved	Electricity Priority & Timing Target
7. Identify quick wins to promote awareness and understanding for environmental and related technical issues. • Climate change mitigation affects harvests and livelihoods. Aviation which doesn't play a role in the daily life of impoverished farmers therefore just acts as a "door opener". Apart from sector-specific environmental goals (GHG emission reductions, carbon neutral growth) aviation is ideally used as a very suitable and vivid medium to help convey the key messages in order to win broad public support for necessary mobilization efforts and recommended changes in agronomic practices. • Practical applications on the community level could raise awareness and facilitate necessary mobilization on a large scale. • Recommendations for practical examples that allow straightforward implementation include domestic biodiesel production for Ouagadougou airport GSE and select rural electrification (water pumps).	- RACGAE - ANAC - Ministry of Transport.	Short Term
8. THINK SMALL • As time to market is critical, it is advisable to consider exporting feedstock first for conversion overseas (and re-import of upgraded end-product). • Lacking any petrochemical infrastructure, it is unlikely that SAF will play any noticeable role in reducing aviation emissions in Burkina Faso the near term. One remaining option would be to export domestically produced feedstock to Europe for fuel conversion and SAF upgrading at existing petrochemical complexes and refineries. • While this may incur significant cost and logistical challenges, another more pragmatic option would be to focus initially on technologically less complex feedstock and biomass processing (incl. transesterification) which requires less capital-intensive infrastructure. • While any domestically produced biodiesel cannot replace jet fuel, it could nevertheless be used by the ground support handling agency of Ouagadougou airport (RACGAE) which operates the truck and trailer fleet of diesel-powered GSE.	- BDI Austria - GEA - Fraunhofer - RACGAE - ANAC - Ministry of Transport	Short Term
9. To unleash the larger potential with regard to SAF production it might be advisable to concede -at least temporarily- feedstock use for decentralized rural electrification, environmental protection, reforestation and other urgent socio-economic activities and local needs first. Such holistic strategic approach would integrate public actors who otherwise found themselves marginalized. Securing critical buy-in among public stakeholders from across the political and sectoral spectrum at an early stage would help to formulate a shared vision and also facilitate necessary mobilization for later production scale-up.	- ANEREE - SP/CONEDD - CIRAD - CNRST	Mid- Term
10. Identify, prioritize and install **demonstration facilities** for • biofuel use (e.g. airport trucks/ ground support equipment); • decentralized, rural (off-grid) electricity generation (e.g. powering of water pumps); • efficient use of heat and power (e.g. in the cashew nut industry in Bobo-Dioulasso)	- ANEREE - Anatrans	Short Term

Recommendations/Action items What needs to be done	Potential stakeholders to be involved	Electricity Priority & Timing Target
11. To avoid costly duplication of uncoordinated renewable energy activities, it is strongly recommended to align project conceptualization and agree on synchronized implementation efforts. Pragmatism, focus, critical reflection and time to market are fundamental to success.	- UNDP	Short Term
12. Consider collaboration with the West African Science Service Centre on Climate Change and Adapted Land Use (WASCAL), a large-scale research-focused programme initiated to develop effective adaptation and mitigation measures to climate change. Funded by the German Federal Ministry of Education and Research, the geographical focus of WASCAL is on West Africa in general and Burkina Faso in particular. The University of Ouagadougou recently launched a Master's programme (Oct. 2017) in this subject matter.	- WASCAL - Univ. of Ouagadougou	Mid Term
C. FUNDING		
13. Mobilize public funding and private investments: • encourage and incentivize strategic investments into the feedstock and SAF supply chain. • market participants and stakeholders to be called upon as investors should include public and private entities, such as development banks, NGOs, airport authorities, oil majors, fuel suppliers and other established actors in the biofuel production value chain. • it is essential to significantly expand the funds available to domestic feedstock producers.	- Ministry of Finance - Ministry of Energy - Ministry of Agriculture - Ministry of Transport	Short Term
14. • The full range of identified risks and sensitivities requires public funding sources as a precursor to private finance • Use official development assistance funds to leverage private investment and matching funding - Germany, together with the European Union, made 2017 a year with a special focus on Africa. The German Government campaigned for renewed cooperation efforts with African States on various political, social, economic and technological levels. Launched in February 2017, the "Marshall plan with Africa" intended to offer stable conditions for inclusive growth and sustainable economic development. One of the cornerstones of the Plan concerned the mobilization of private investment through government guarantees. The recent German initiative offers an opportunity to identify and mobilize additional sources of international public and private funding, especially for investments involving technology transfer, biomass processing facilities and mechanization of the farming sector.	- German Ministry of Finance - German Ministry for Economic Cooperation and Development	Short Term
15. Mobilize financial resources in Burkina Faso and strengthen the country's capacity to generate own revenues (e.g. reallocation of revenues from mining operations)	- Ministry of Energy - Ministry of Finance	Short Term

Recommendations/Action items What needs to be done	Potential stakeholders to be involved	Electricity Priority & Timing Target
16. Apply for KfW Development Bank project finance in the form of non-repayable grants and development finance. • KfW is the world's leading financier of renewable energies in developing countries. Key strategic focus perfectly matches the situation in Burkina Faso, i.e. providing a route out of poverty in combination with reforestation and environmental and climate protection. • To be eligible for KfW funding, development policy criteria must be met including the partner country's commitment as well as the performance capacity of the project partner.	- KfW Development Bank	Short Term
17. MARKET INTERVENTION • The government should consider direct market intervention and offer price guarantees (price floors) to domestic feedstock producers/farmers. • To improve overall market functionality for identified sources of feedstock and to balance/reduce production and market risks for farmers and feedstock suppliers, specific measures should include: - the establishment of a central purchasing counterparty (Centrale d'achat des intrants et du matériel agricoles, cf. PNDES No. 186); - the establishment of an agricultural seed production company (société de production de semences agricoles, cf. PNDES No.197);	- Ministry of Finance - Ministry of Agriculture	Mid-Term
18. FARM INPUT SUBSIDIES • Provide input subsidies for high yielding seeds/seedlings and fertilizer (payments made to feedstock farmers aimed at incentivizing production). • Biofuel subsidies could potentially take the form of a subsidy equivalent to the government's financial support granted to Sonabel. • Provide subsidies for basic equipment and mechanization	- Ministry of Finance - Ministry of Agriculture	Mid-Term
19. PUBLIC-PRIVATE RISK HEDGING • To encourage investments into large-scale feedstock production, it is recommended to introduce an effective public-private risk hedging system. • The absence of a policy for financing agriculture — aside from ad hoc fertilizer subsidies — remains one of the main barriers to scaling up production. • Domestic financial services and incentives need to be adapted to better reflect production, market and price risks and to suit the diversity of the agricultural sector as a whole. • The establishment of a dedicated bank for agricultural finance which is explicitly foreseen in the PNDES (item No. 250) is certainly a step in the right direction. • Investigate the potential for PPP and opportunities for cooperation between the Government of Burkina Faso and the private sector, including industry, NGOs and academia.		Mid-Term

Recommendations/Action items What needs to be done	Potential stakeholders to be involved	Electricity Priority & Timing Target
20. MICRO-FINANCE • Smallholders need easy access to agricultural financial services (e.g. loans for agricultural inputs and insurance). • To spur investment into a Burkinabe biofuel value chain it is important to enlist and engage local (micro-)finance institutions that are well informed about local market conditions just as well as international institutions, such as multilateral and bilateral donors. • Potential international financing partners and programmes may include, inter alia the Renewable Energy and Energy Efficiency Partnership (REEEP), the European Union Energy Initiative (EUEI),	- KfW - REEEP - EUEI	Mid-Term
21. CARBON FINANCE • The role for carbon financing should be further explored. • Emission reductions can be certified and traded as credits in the carbon markets, providing additional revenue that can mitigate investment cost and facilitate the deployment of SAF projects. • Consider setting up a dedicated Biofuel Agroforestry Fund which provides upfront financing to project developers for the implementation of select feedstock cultivation and production projects in Burkina Faso. In return for the risk taken, the fund would receive carbon credits from the projects over a period of [x] years. The carbon credits could then be distributed to private companies which have invested in the fund and they use them to offset some of the emissions they cannot avoid. This investment model is made possible through the long-term commitment of the investors who rely on the fund to generate carbon credits with high value for them, be it for social, marketing or regulatory compliance reasons. In order to gain airlines as partners and potential investors, it would be necessary to identify qualifying offsetting requirements • In close coordination with the General Directorate on Green Economy and Climate Change of the Ministry of Environment develop dedicated REDD+ project for marketing of voluntary carbon credits to international airlines.	- Ministry of Environment - Directory on Green Economy andClimate Change - UN-REDD - UNEP	Short Term
• Support the quantification and monetization of avoided climate damages and ancillary environmental, economic and societal benefits.	- Ministry of Environment - DGECC	Mid-Term
22. GLOBAL GREEN GROWTH INSTITUTE (GGGI) Investigate collaboration and co-funding potential with the Global Green Growth Institute (GGGI) - an international organization dedicated to supporting and promoting sustainable economic growth in developing countries and emerging economies. The GGGI was formed in 2012, at the Rio+20 United Nations Conference on Sustainable Development. According to GGGI, and in contrast to conventional development models that rely on the unsustainable depletion and destruction of natural resources, green growth is a coordinated advancement of economic growth, environmental sustainability, poverty reduction and social inclusion driven by the sustainable development and use of global resources.	- GGGI	Long Term

Recommendations/Action items What needs to be done	Potential stakeholders to be involved	Electricity Priority & Timing Target
23. SUSTAINABLE ENERGY FUND FOR AFRICA (SEFA) Investigate collaboration and co-funding potential with AfDB which has taken the lead in establishing the Sustainable Energy Fund for Africa (SEFA) to facilitate access to financing and private risk guarantees for the implementation of renewable energy projects. SEFA provides the initial phase financing for small and medium-sized renewable energy projects and technical and skills empowerment for entrepreneurs and developers.	- AfDB	Mid-Term
24. ENVIRONMENTAL INTERVENTION FUND (EIF) • Consider setting up an Environmental Intervention Fund (EIF). • Funding missions are to: - mobilize national and international financing for the environment in Burkina Faso; - allocate financing (subsidies) or facilitate financial incentives (interest rate subsidies, loan guarantees) for the various national stakeholders in line with their skills in environmental management and protection; and - monitor and report on the use of funds received and allocated.	- ANEREE - Ministry of Environment - Directory on Green Economy and Climate Change	Long Term
25. Other alternative forms of financing may include national tax systems, the issuance of government securities, voluntary contributions and lotteries, methods of mobilizing Burkinabe funds from abroad, bonds guaranteed by donor countries sold on the financial market, allocations from funds generated by the sale of emission quotas, public private partnerships, subsidized loans, crowd-funding, and popular shareholding, among others.	- Ministry of Finance - German Ministry for EconomicCooperation and Development	Long Term
D. FEEDSTOCK		
26. Promote agricultural yield improvement (productivity, energy and water use, fertilizer use, land use changes). Promote innovative agricultural practices to enable large-scale feedstock and biofuel production.	- ENBW	Mid- Term
27. If jatropha in Burkina Faso stands any chance to succeed on a commercial scale, high quality performing hybrid plants are needed to prevent unnecessary and costly disappointments. Certified high-yielding jatropha hybrids from special breeding sites in Cameroon under German operation are potentially available for planting trials and mass propagation in Burkina Faso.		Short Term
28. Develop genomic and marker-aided selection capacities • set up/leverage sub-commercial-scale test sites to perform R&D with existing genotypes/residuals; • train regional extension/technology transfer specialists who will interface with producers (farmers/landowners), processors, and communities; • accelerate improvement of crop yields by expanding capacity building and extension services to promote modern farming techniques; Potential collaboration partner to include ENBW and JatroSolutions.	- ENBW - Jatro Solutions - University of Hohenheim - University of Ouagadougou	Short Term

Recommendations/Action items What needs to be done	Potential stakeholders to be involved	Electricity Priority & Timing Target
29. Expand local trials of the most promising new biomass varieties.	- UNDP	Mid- Term
30. Establish two decentralized jatropha nurseries for superior quality and high yielding seedling production from improved planting material.	- ENBW - Jatro Solutions	Mid- Term
31. Support the establishment of a 1 000 ha jatropha demo plantation, intercropped with mango, beans, cashews, maize, ginger, sesame, and peanuts.		Mid-Term
32. Scale-up next generation improved feedstock for deployment.	- UNDP	Long Term
33. To stop the process of degradation and to improve agricultural productivity per hectare, the use of organic fertilizers is needed; • given its proven properties, the use of available jatropha seedcake should be actively encouraged; • government recognition of the jatropha seed cake as organic fertilizer would facilitate valorization of this product and encourage domestic use.	- Ministry of Agriculture	Mid- Term
34. Given the positive impact on climate change mitigation and carbon sequestration, the development and expansion of cashew tree plantations is to be encouraged and incentivized.	- Ministry of Agriculture - Ministry of Environment	Mid- Term
35. Conduct in-depth research on practices for cultivating fast growing trees and grasses on pastureland that could sequester carbon and enhance biodiversity.		Long Term
36. Accelerate afforestation through incentives to cultivate trees on degraded lands and through sharing best practices for sustainable forest management.	- Ministry of Environment	Long Term
E. PROCESSING & TECHNOLOGY		
37. Increase the processing rate of agricultural products in the country. Improve jatropha, cashew and shea processing capacities.	- Harburg Freuden-berger - GEA	Mid- Term
38. Assess the most promising locations for sustainable feedstock processing capacity.		Mid- Term
39. To improve oil extraction rates and process economics, domestic oil expelling and milling operations need to be upgraded to latest technology standards. • This includes innovative aqueous oil extraction methods and optimization of dehusking. • Potential industry partners are Harburg-Freudenberger Group and GEA Group, Germany.	- Harburg Freuden-berger - GEA	Mid- Term
40. Considering the domestic portfolio of identified feedstock sources, it would make economic sense to opt for a multi-feedstock processing plant. BioEnergy International (BDI) AG, Austria has developed a proven concept even for a small-scale multi-feedstock biofuel plant.	- BDI Austria	Long Term

Recommendations/Action items What needs to be done	Potential stakeholders to be involved	Electricity Priority & Timing Target
41. Investigate potential for a catalytic cracking micro-refinery solution (greenfield), potentially in partnership with the German Fraunhofer Society, the German Ministry for Economic Cooperation and Development and the German Aerospace Center (DLR).	- Fraunhofer - German Ministry for Economic Cooperation and Development - German Aerospace Center (DLR)	Long Term
F. MARKET STRUCTURE & LOGISTICS		
42. • Strong governmental initiatives on infrastructure and logistics, contributing to decrease the feedstock costs, are inevitable if aviation biofuel production based on identified domestic feedstock resources should be established in Burkina Faso.	- Ministry of Finance - Ministry of Agriculture	
43. Key factors in the development of an alternative aviation fuel supply chain are the logistical considerations of where the relevant biomass is cultivated and how it is collected, stored and processed. The logistical considerations are heavily reliant on the locality. • Improve understanding of logistics for cost-effective harvesting of farm and agricultural residues; • Improve harvesting, collection, storage, densification, pre-treatment, and transportation of physical biomass to the conversion facility; • Increase storage capacities (building storage warehouses, store-keeper training, etc.) to avoid losses from insects and other pests; Best practices on logistics for cost-effective, sustainable residue collection should be disseminated.	- Sonabhy - SEGAS-BF	Mid- Term
44. Negotiate logistics Joint Venture with Sonabhy • Even if feedstock processing and biofuel production in Burkina Faso were successfully launched, transportation and logistics still pose a major challenge since the "nearest" petrochemical facilities capable of converting biofuels into alternative aviation fuels are all located in Europe. However, state-owned hydrocarbon company Sonabhy has put in place a logistics infrastructure that might offer a cost-efficient opportunity worth investigating. Petroleum fuel supply is ensured by a large fleet of tank trucks that are continuously covering the 1 000 km to the maritime ports of Lomé (Togo), Cotonou (Benin), or Abidjan (Côte d'Ivoire) by land. While Sonabhy's fleet delivers fossil fuels to Burkina Faso, the trucks return empty. Should domestic biofuel production in Burkina Faso exceed a certain (high) volume, the feedstock could theoretically be loaded onto the circulating trucks and potentially be transported overland to a tank farm at one of the three seaports,without incurring extra costs.	- Sonabhy - SEGAS-BF - Total	Mid- Term
45. The Société d'Entreposage, de Gestion de Garantie et de Sûretés Burkina Faso (SEGAS-BF) is the only privately operating market intermediary that offers market access and product marketing assistance, storage and warehousing facilities, trade financing, crop insurance and transparent price-finding services to farmers and producers. A large-scale mobilization of farmers and the establishment of a domestic biofuel supply chain is	- SEGAS-BF - Allianz	Mid- Term

Recommendations/Action items What needs to be done	Potential stakeholders to be involved	Electricity Priority & Timing Target
likely to require the services and build upon the agro-sector expertise of SEGAS-BF. Given the company's close links with market participants, financial institutions and insurance companies, it could potentially play a crucial role with regard to agricultural credits and micro-finance for small farmers and outgrowers.		
G. REGULATORY FRAMEWORK & SUPPORT POLICIES		
46. Policy support has been instrumental in the global development and commercialization of road transportation biofuels, such as in Brazil, the U.S. and the EU. The two main policy drivers in those cases were energy security and climate-change mitigation. A wide variety of policy instruments and measures is available to achieve the desired goal of reducing GHG emissions and hence influence the gradual market introduction of SAF. This portfolio of policy instruments includes, for example, raising awareness, research and development support, governance and coordination, voluntary agreements, market based measures, private and public financing schemes, tradeable permits, tax credits, blending quota, subsidies and incentives, and new regulations and standards. • While the majority of instruments are either directly or indirectly targeted towards alternative fuels and fuel uses, it may seem advisable to focus on an earlier stage in the alternative aviation fuel supply chain, as emission savings and economic benefits of sustainable fuels can only be realized if steps are taken to actively promote and support their development. • Taking the global demand for SAF as a given, the main stimulus package for Burkina Faso therefore preferably relates to all measures that incentivize large-scale feedstock production in combination with reforestation and agroforestry mandates and in accordance with national circumstances. • Such measures could foster, for example, a sustainable increase in agricultural yields, feedstock production efficiency, and agricultural residue removal and utilization. • The availability of biomass feedstock is expected to ultimately attract technology-related investments.	- Hanns-Seidel Foundation	Mid- Term
47. The revival of the energy crop sector calls for the mobilization of the authorities at the highest level, as it cannot be the result of one single agricultural policy. Addressing agricultural and renewable energy challenges requires policies in numerous areas (agriculture, renewables, trade, infrastructure, environment, social protection, etc.), which must be driven with a high degree of coherence.		
48. As the challenges are siginifcant, and the available resources limited, successfully countering the adverse impacts of climate change will require the involvement of all national actors, from the government down to local communities. It will also require adequate assistance from the international community, to support the country's own efforts. For the protection of the remaining natural reserves, the local communities have to be involved in order to prevent them from exploiting the remaining forests for firewood or expansion of agricultural areas.		

Recommendations/Action items What needs to be done	Potential stakeholders to be involved	Electricity Priority & Timing Target
49. Facilitate international cooperation and coordination in three primary areas: • capacity building, technical assistance and technology transfer; and • scientific and technical R&D conducted under multilateral and bilateral agreements to mutually share risks, minimize duplication of effort, and benefit from international best practices;	- BDI Austria - Harburg-Freudenberger - GEA - Fraunhofer	Mid- to Long Term
50. Securing political commitment and putting in place effective policy and regulatory frameworks are crucial elements that can improve the overall investment climate for bioenergy. • The Burkinabe government has a role to play at all levels and across a range of ministries (all sectors) in effective policy design. • To encourage investment in biofuel technologies and projects, incentivizing policies need to be clear and long-term in nature. • Policies could also address barriers to the development of small-scale activities, e.g. biofuel operated water pumps.		Short to Mid- Term
51. A key issue for delivering biofuels for the aviation sector is the development of an appropriate support mechanism. • To achieve economies of scale and cost reduction, a stable, long term policy framework to build investor confidence and induce demand is necessary. This could be achieved, for example, by announcing aspirational targets, blending mandates or higher carbon taxes – provided there is sufficient supply of feedstock.		Short to Mid- Term
52. PNDES • In July 2016, Burkina Faso adopted its national economic and social development plan (PNDES) as the main instrument defining the strategic guidelines for economic and social development for the period 2016-20. The PNDES identifies strategic objectives and implementation measures to support growth and resilience and improve, inter alia, economic and environmental governance effectiveness. • Based on the findings and conclusions presented above, it is recommended to amend and modify the PNDES accordingly.	- Ministry of Energy - Ministry of Finance - Ministry of Environment	Short Term
53. Amend and modify the framework of the Rural Development Strategy (SDR)	- Hanns-Seidel Foundation	Mid- Term
54. To alleviate burdens on investment and in the absence of regulation, domestic operators and producers should be assured that the domestic fuel tax (taxe sur les produits pétroliers (TPP)) does not apply to the jatropha agrofuel sector.		Long Term

Recommendations/Action items What needs to be done	Potential stakeholders to be involved	Electricity Priority & Timing Target
55. Develop risk management tools such as crop insurance to promote dedicated bioenergy crop production. The insurance provider agrees to indemnify (i.e., to protect) the insured farmer against losses that occur during the crop year.	- Allianz	Short Term
56. The country's weak legal framework doesn't protect farmers from the appropriation or destruction of their efforts, threatening the agricultural gains they've made thus far. For example, farmers in Burkina Faso don't have legal rights to the trees that grow on their property. • Policy changes could provide for this ownership, allowing climate-smart agriculture to expand. • Strengthen land tenure and improve land governance to provide incentives for more intensive land management. • Evaluate gaps and mechanisms to allow farmers and producers to legalize land tenure situations		Mid- to Long Term

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