Biomass Supply and the Sustainable Development Goals

International Case Studies

IEA Bioenergy

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Abbreviations

Anaerobic Digestion (AD)

Combined Heat and Power (CHP)

Environnemental Non-Governement Organization (ENGO)

European Union (EU)

Food and Agriculture Organization (FAO)

Forest Stewardship Council (FSC)

Global Bioenergy Partnership (GBEP)

Indirect-Land-Use-Change (iLUC)

Non-Governmental Organization (NGO)

Program for the Endorsement of Forest Certification (PEFC)

Renewable Energy Directive (RED)

Sustainable Development Goal (SDG)

United Nations (UN)

Executive Summary

Bioenergy is currently the largest source of renewable energy globally and demand for bioenergy is expected to increase as countries look for sustainable low-carbon energy alternatives as part of national climate change mitigation strategies. Bioenergy is also likely to compete with other end-uses for sustainably-procured biomass, as countries also implement broader bioeconomy policies.

With demand for sustainable biomass expected to increase, an initiative was launched under IEA Bioenergy involving multiple tasks to identify and document best practice case studies from around the world to better understand how biomass supply chains could be implemented to support bioenergy production while simultaneously contributing to the United Nations (UN) Sustainable Development Goals (SDG).

This report is a collection of 37 best practice case studies from around the world highlighting different methods, practices and technologies used across the four most common biomass supply chains (forest biomass, agricultural residues, energy crops and waste biomass) to sustainably grow, harvest, transport, process and use biomass for bioenergy generation, as well as their contributions to the UN's SDGs.

The table below summarizes themes by supply chain type and their contributions to the SDGs[1]:

Forest Biomass

- Biomass sourced from forests that are sustainably managed can ensure the protection of ecosystem services (e.g. water purification, soil stabilization, biodiversity conservation).
- Biomass sourced through stand improvement techniques (e.g. thinning) can simultaneously increase growth rates, improve carbon sequestration, and reduce natural disturbances (e.g. wildfires, pests).
- Use of residues can improve resource-use efficiency if previously discarded as a waste material, and help replace fossil-based energy generation.
- Use of biomass for bioenergy can improve energy security and resiliency, while also improving the share of renewable low-carbon energy.
- Biomass can provide new economic and job opportunities for communities and regions as forest biomass supply chains typically require more labour than those of fossil-based supply chains.

SDGs Contributed To

Agricultural Residues

- Use of residues can improve resource-use efficiency, especially if sourced from waste and by-product streams of primary production while ensuring enough residues are left to maintain soil health and productivity.
- Redirecting residues to bioenergy from disposal piles and open-air burning can improve local air and water quality.
- Residues that would otherwise add to excess fuel loads can help reduce destructive effects of pests and wildfires and support other perennial management goals.
- Use of residues for bioenergy can improve energy security and resiliency, while also improving the share of renewable low-carbon energy.
- Mobilization of residues can support sustainable economic development and job opportunities related to perennial management and biomass collection, transportation, processing, and use.
- Removal of a portion of residues from high-yielding agricultural croplands can enable use of no-till practices which would otherwise be impractical.

SDGs Contributed To

Energy Crops

- Energy crops integrated into good farming practices, or other land management practices such as landscape management, can improve ecosystem function by improving local soil and water quality, reducing and filtering agricultural run off, reducing soil erosion, diversifying land cover, and increasing soil carbon storage.
- Energy crops can help to reclaim degraded land by restoring land and soil by adding nutrients and carbon to soils.
- Energy crops can also provide new sources of incomes for farmers, land owners and land managers, as well as provide new economic and job opportunities in the community as growing, harvesting, transporting and processing energy crops can be labour intensive.
- Use of energy crops can improve energy security and resiliency, while also improving the share of renewable low-carbon energy.

SDGs Contributed To

[1] Case studies for all supply chain types also contributes to SDG 7 (Affordable and Clean Energy).

Waste Biomass	
• Waste biomass used for bioenergy can improve both resource use efficiency and waste management, while providing value-added services and products such as bioenergy generation. • Waste biomass used for bioenergy also creates co-products, such as fertilizer that can be used for agricultural purposes to reduce the use of synthetic fertilizer, improving the overall circularity of supply chains. • Waste biomass used for bioenergy can reduce potential contamination of local/regional water ways. • Waste biomass used for bioenergy can also improve energy security and resiliency in communities and regions, while also improving the share of renewable low-carbon energy in communities and regions.	SDGs Contributed To 

1 Introduction

The United Nations (UN) Sustainable Development Goals (SDGs) were adopted by all UN Member States in 2015 to achieve the UN's 2030 Agenda for Sustainable Development. The SDGs serve as a comprehensive framework to guide national and international development, enshrining the importance of developing holistic policies that address environmental, social and economic priorities. Such an approach is particularly important for the sustainable production of biomass for bioenergy, or any other bio-based product for that matter, as its growth, harvest, collection, storage, transport, processing and use can have significant environmental, socio-economic, and health impacts for people and their communities.

Currently, bioenergy is the largest source of renewable energy, making up 9.6% of the world's total energy supply (55.6 EJ in 2018)[2]. Roughly half of this bioenergy supply comes from traditional use of solid biomass such as wood-burning fires and cook stoves, but this share is expected to decline as *modern* equipment and systems, designed to increase energy efficiency and reduce air pollution, are increasingly being deployed in cooking, heating and transport systems. Modern bioenergy, in its various forms, is also the fastest growing renewable energy source and currently accounts for more than half of all renewable energy generation. For example, bioenergy accounts for 90% of renewable heat in the industrial sector and is expected to provide industry with over 10% of overall heat demand by 2025[3], with hard-to-decarbonize industries such as marine and aviation transportation likely to increase their use of drop-in biofuels to support rapid decarbonisation. In addition, both the International Panel on Climate Change (IPCC) and International Energy Agency (IEA) recognize that bioenergy paired with carbon capture utilization and storage (BECCUS) will be required to limit global warming to 1.5 degrees[4,5].

Given these trends, it is expected that there will be a significant increase in sustainably-procured biomass as bioenergy systems are adopted under national climate change and bioeconomy policies, regulations and frameworks. While it is likely that much of the additional biomass will be sourced from waste and residue streams, biomass sourced from purpose-grown crops are also expected to increase[6].

1.1 OVERVIEW OF CASE STUDIES

In light of this, 37 best practice case studies from 18 nations worldwide were documented to better understand how biomass supply chains could be implemented to support bioenergy production, while simultaneously contributing to the UN's SDGs. The authors, with the support of collaborators, collected the 37 cases from existing literature and reports, primarily three recent IEA Bioenergy/Global Bioenergy Partnership (GBEP) reports [7,8,9]. This material, in addition with direct input from the original authors, was used to prepare two-page summaries on each case study's supply chain.

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[2] International Energy Agency. *Key World Energy Statistics 2020*; IEA: Paris, France, 2020.

[3] International Energy Agency. (2020). *Renewables 2020: Analysis and Forecast to 2025.* https://www.iea.org/reports/renewables-2020.

[4] IPCC 2018: *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels*, https://www.ipcc.ch/sr15/

[5] International Energy Agency. (2021). *Net Zero by 2050*. https://www.iea.org/reports/net-zero-by-2050.

[6] International Energy Agency. (2017). Technology Roadmap: Delivering Sustainable Bioenergy. https://www.ieabioenergy.com/blog/publications/technology-roadmap-delivering-sustainable-bioenergy/.

[7] International Energy Agency Bioenergy and Global Bioenergy Partnership. (2016). *Examples of Positive Bioenergy and Water Relationships*. https://www.ieabioenergy.com/blog/publications/examples-of-positive-bioenergy-and-water-relationships/

[8] Global Bioenergy Partnership. (2020). Examples of Positive Relationships between Sustainable Wood Energy and Forest Landscape Restoration. http://www.globalbioenergy.org/news0/newsletter/newsletter-26/positive-relationships-between-wood-energy-and-forest-landscape-restoration/it/.

[9] International Energy Agency Bioenergy. (2017). Attractive Systems for Bioenergy Feedstock Production in Sustainably Managed Landscapes. https://www.ieabioenergy.com/wp-content/uploads/2019/07/Contributions-to-the-Call_final.pdf.

Case studies were selected from the most common biomass supply chains:

- **Forest biomass**, which includes harvest residues such as treetops, branches, and unmerchantable stems, as well as wood processing residues such as wood chips, sawdust, and shavings (10 cases).
- **Agriculture residues,** which consist primarily of the biomass remaining after crops are harvested (e.g., wheat straw, corn stover) but also include food or feed processing residues such as corn cobs, olive pits, or grape marc (11 cases).
- **Energy crops**, which are purpose-grown for bioenergy production and can also include food crops (e.g., sugar cane, oil palm, corn) redirected to bioenergy production. Emerging energy crops are most often perennial and can be woody (e.g., poplar or willow) or herbaceous (e.g., switchgrass). Annual cover crops can also be used for bioenergy (12 cases).
- **Waste** of biological origin, which includes primarily animal (manure) and household, commercial or municipal organic waste (4 cases).

Of the 37 case studies included, two cases were from Asia, 11 from Europe, 12 from North America, three from Oceania, three from South America, and six from Africa. Nine of the case studies focused on forest-based supply chains, while 11 focused on agricultural residue-based supply chains, 12 on energy crop-based supply chains, and five on waste-based supply chains (Figure 1). It should be noted that the collection of case studies reflects the availability of documented supply chains with sufficient information at the time of collection rather than the actual distribution or number of bioenergy projects globally.

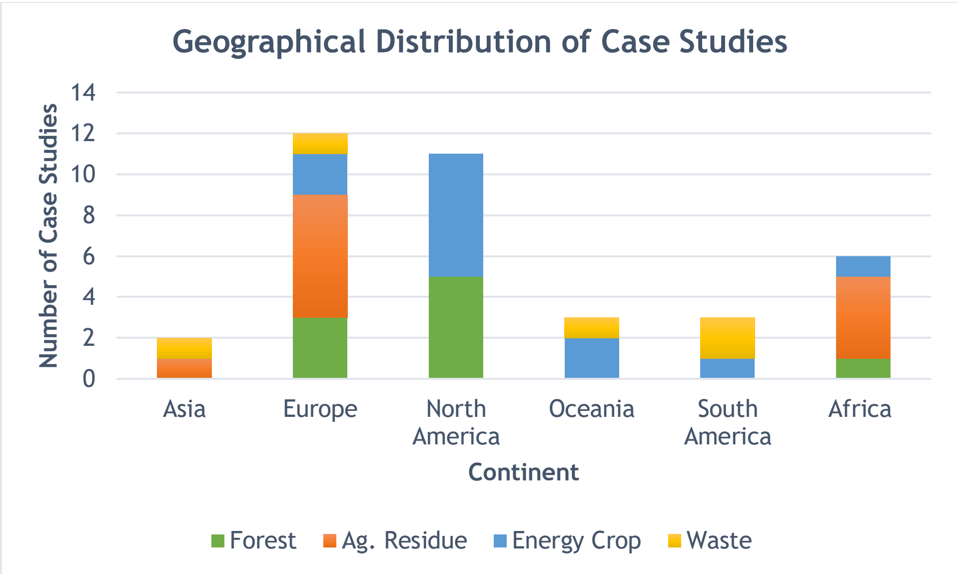


Figure 1: Types of Supply Chain Case Studies Reviewed by Continent.

The majority of the case studies are biomass supply chain projects that have already been implemented (24). Others are projects proposed for the near future (5) and the remaining are studies on increasing the sustainable supply of biomass in a given region, namely lignocellulosic energy crops studied for conversion to biofuels, or an unspecified end use. By far the most common end use for forest biomass and agricultural residues is heat, or combined heat and power (CHP), for building, district energy networks or industry, in line with the most common bioenergy end uses internationally. Most of these case studies have been implemented. Several other implemented case studies produce biogas through anaerobic digestion of wastes and by-product streams from food processing, which in turn is used to generate electricity. Those bioenergy options support the transition towards a low-carbon energy system complimenting other renewable sources of energy and at times contributing to multiple end-uses. Figure 2 gives a summary of bioenergy end use, by supply chain type for all case studies.

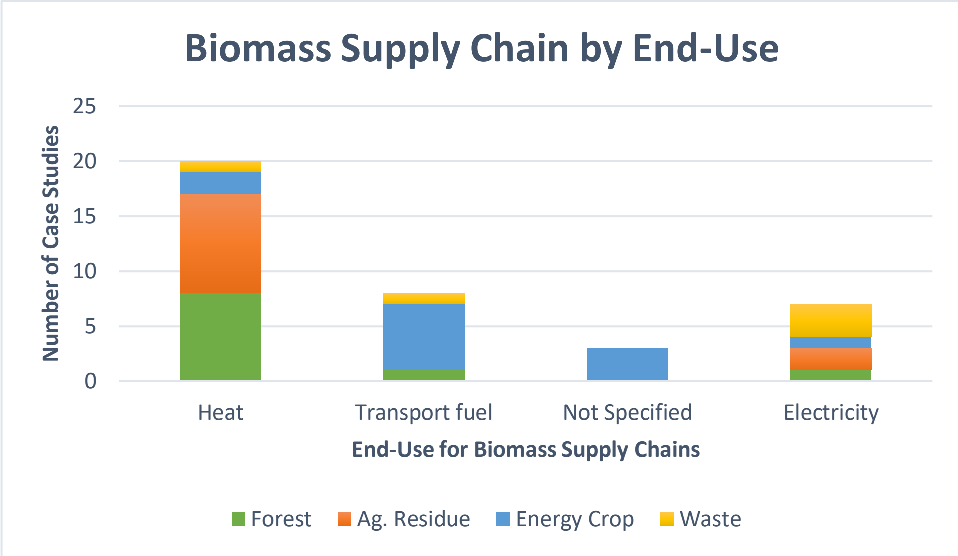


Figure 2: Biomass Supply Chains Reviewed by End-Use.

1.2 SUSTAINABLE DEVELOPMENT GOALS

The 17 SDGs and their 169 associated targets are presented as interlinked and interdependent, with their integration essential to leverage commonalities while managing trade-offs.[10] The SDGs and their descriptions are provided in the table below, while targets and indicators can be accessed on the UN's website.

Table 1: Sustainable Development Goals

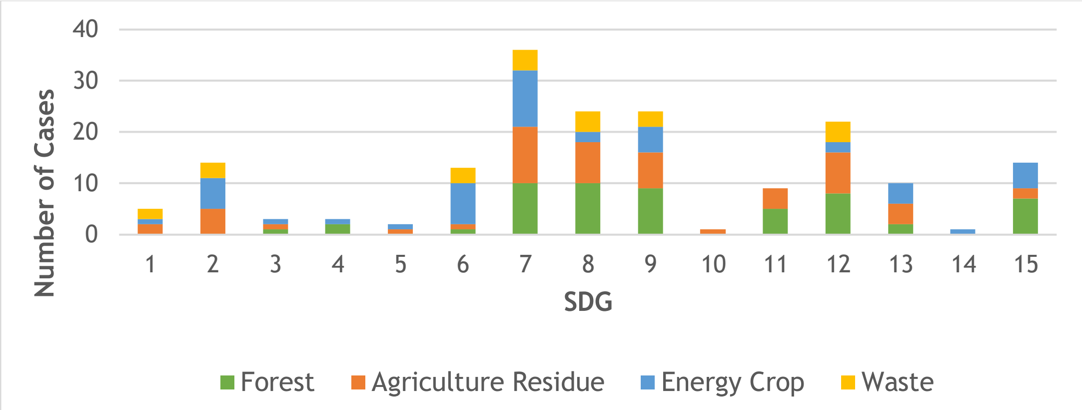
SDG	Description
	End poverty in all its forms everywhere
	End hunger, achieve food security and improved nutrition and promote sustainable agriculture
	Ensure healthy lives and promote well-being for all at all ages
	Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all
	Achieve gender equality and empower all women and girls

[10] United Nations. (2015). Transforming our world: the 2030 Agenda for Sustainable Development. New York.

SDG	Description
6 CLEAN WATER AND SANITATION	Ensure availability and sustainable management of water, sanitation for all
7 AFFORDABLE AND CLEAN ENERGY	Ensure access to affordable, reliable, sustainable and modern energy for all
8 DECENT WORK AND ECONOMIC GROWTH	Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation
10 REDUCED INEQUALITIES	Reduce inequality within and among countries
11 SUSTAINABLE CITIES AND COMMUNITIES	Make cities and human settlements inclusive, safe, resilient and sustainable
12 RESPONSIBLE CONSUMPTION AND PRODUCTION	Ensure sustainable consumption and production patterns
13 CLIMATE ACTION	Take urgent action to combat climate change and its impacts
14 LIFE BELOW WATER	Conserve and sustainably use the oceans, seas and marine resources for sustainable development
15 LIFE ON LAND	Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss
16 PEACE, JUSTICE AND STRONG INSTITUTIONS	Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels
17 PARTNERSHIPS FOR THE GOALS	Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development

For each case study, the relationships between bioenergy, biomass supply activities and the SDGs were recorded and discussed at the target level. Relationships were recorded only if directly referenced in the case study documentation. Figure 3 provides a visual summary of the relationships between case studies and the SDGs. By default, all bioenergy case studies contributed to SDG 7. A total of 24 cases were found to contribute to SDG 8 and SDG 9 through targets related to job creation and resource use efficiency (SDG 8), and CO_2 emission intensity (SDG 9). The next most common contribution was to SDG 12 (22 cases), which also has a target for resource use efficiency (any case related to target 8.4, also related to 12.2 and vice-versa), followed by SDG 2 (14 cases), which has targets related to small farm income and agricultural productivity, and SDG 15 (14 cases), which includes targets regarding sustainable forest management, land degradation and biodiversity. A total of 9 to 13 cases were found to contribute to a combination of SDGs 6, 11, and 13, while all other SDGs were related to fewer than five of the documented bioenergy case studies.

Figure 3: Summary of relationships between bioenergy case studies and SDGs, by biomass type



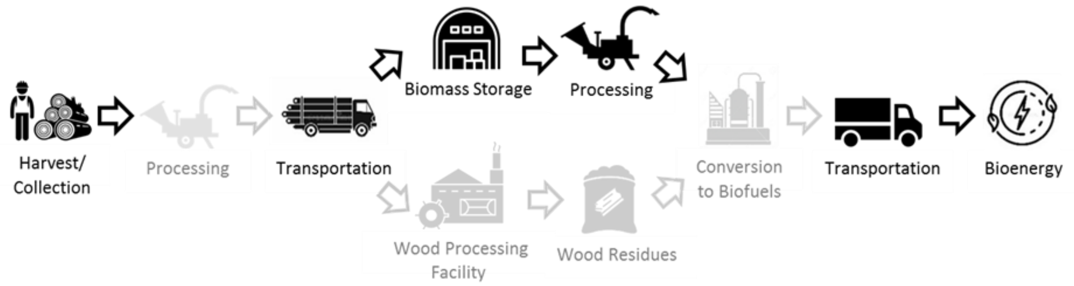
Looking at the relationships between SDGs and bioenergy by biomass supply chain type emphasizes the potential for different development goals to be related to different biomass types. For some SDGs, a contribution is noted regardless of supply chain, though potentially through different targets or mechanisms. For other SDGs, certain biomass types are much more likely to contribution the goal than others. In many cases, differences between biomass types are related to land use and management practices specific to the bioenergy supply chain type. For example, there are no forest bioenergy projects linked to SDG 2 (zero hunger), forest and energy crops are more likely to be linked to SDG 15 (life on land) which includes forest management and land degradation targets, energy crops and waste bioenergy cases are more likely tied to SDG 6 (clean water) with targets related to water availability and quality, while forest and agriculture residue cases may be linked to SDG 11 (sustainable cities) if use of residues for energy reduces open burning and thus particulate emissions.

1.3 CASE STUDY SUMMARIES

All case study summaries include the following sections:

- Case study location and overview
- Details of biomass feedstock supply chain
- Drivers, policies and other support mechanisms
- Relation to SDGs
- Strength, Weakness, Opportunity, and Threat (SWOT) analysis

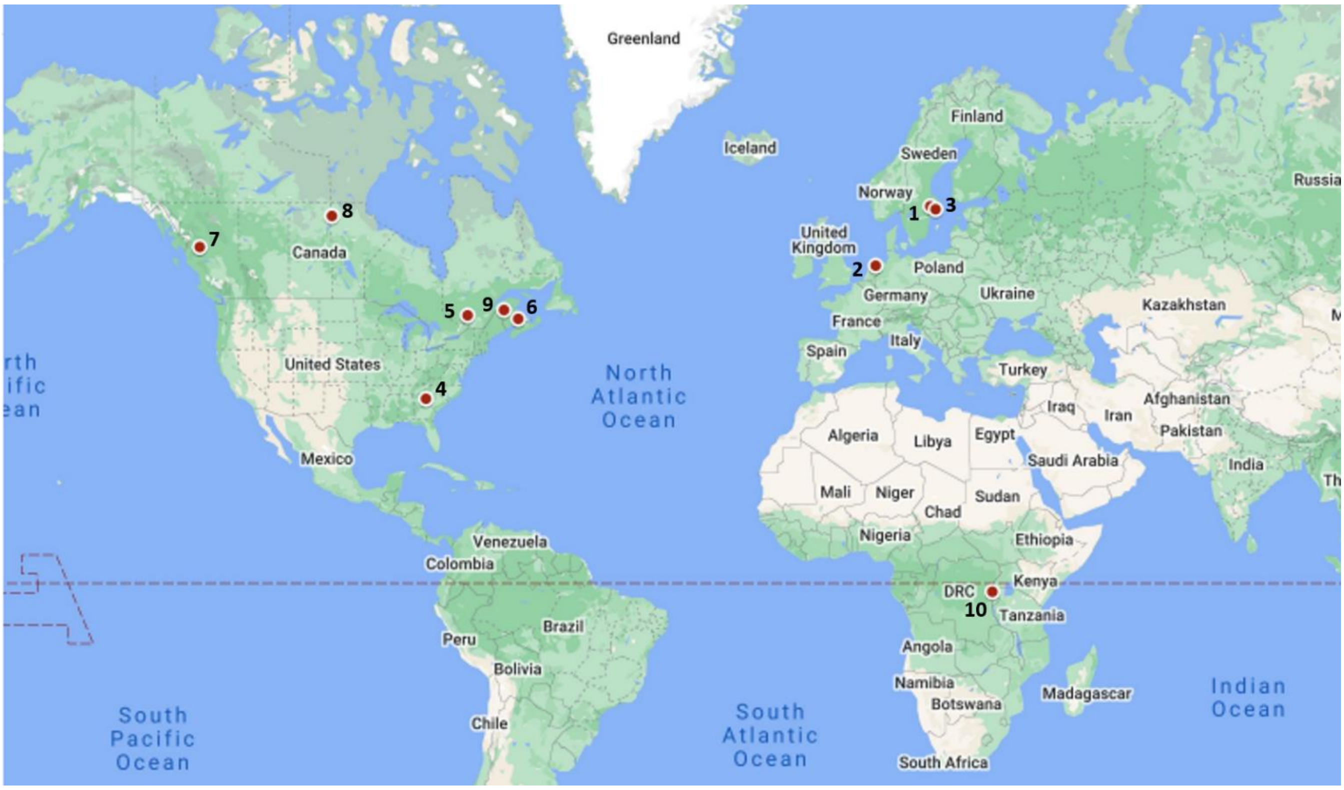
For each case study, a figure describing the supply chain activities is provided, with included steps in black and excluded or non-applicable steps in gray. In the example below, wood is harvested and transported to a storage facility, before being chipped and sent to a boiler for heat generation.



The case studies presented in this report have been organized by supply chain type. The sources have been cited alongside each case study to enable further reading for those who are interested. The case study summaries were reviewed by both IEA Bioenergy colleagues and experts in biomass supply chains and bioenergy systems from around the world to ensure completeness and accuracy.

This report is a contribution to the IEA Bioenergy strategic inter-task project on *The Role of Bioenergy in a WB2/SDG world*, for the activity on the *contribution of bioenergy systems to SDG implementation*.

2 Forest Biomass Supply Chain Case Studies



	Forest Biomass Supply Chain Case Studies' Primary Contributions to SDGs																
	Title	SDG															Status
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
1	Wood Chip Boiler Cascade							x	x	x		x	x				I
2	Wood Chip District Heat							x	x	x		x		x			I
3	Värtaverket Biomass CHP Plant							x	x	x		x	x			x	I
4	Wood Pellet Production in Southeast USA							x	x	x			x			x	I
5	Harvest Residues for Energy							x	x	x			x			x	P
6	Integrated Biomass Supply from Acadian Forests for Bioheat				x			x	x	x		x	x			x	I
7	Gitxsan First Nation Biomass Trade Centre							x	x	x		x	x			x	I
8	Fire Killed Wood for Bioheat				x		x	x	x	x				x			I
9	Wood Pellets from Industrial Residues for Domestic Heat							x	x	x			x			x	I
10	Biomass Pellets and Cookstoves			x				x	x				x			x	I

I = Implemented, P = Proposed

* Supply chains can contribute to multiple SDGs, however SDGs listed were those identified as most relevant.

2.1 WOOD CHIP BOILER CASCADE IN SWITZERLAND

Year of Project: 2012, second plant 2015

Location: Beggingen, Switzerland, Europe

Status: Implemented

Source: Nussbaumer, T. (2018). *Cascade of wood chips for heat supply at variable demand*. IEA Bioenergy.

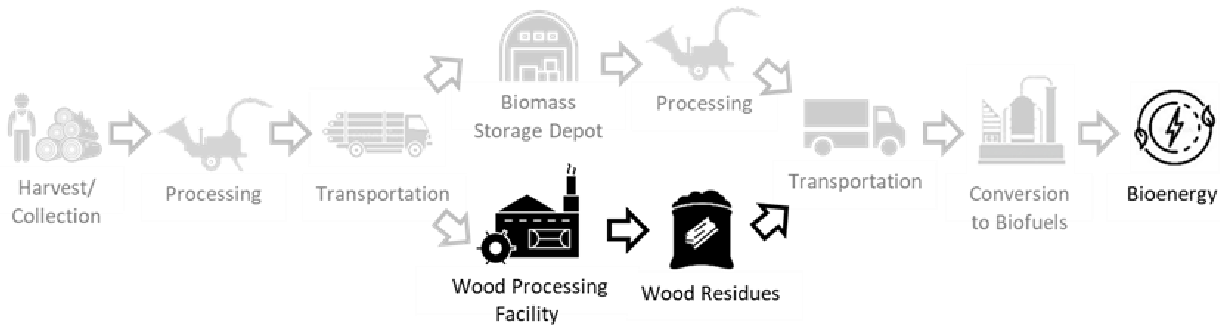
Bioenergy Supply Chain Summary
Biomass Type: Forest
Biomass Origin: Wood processing residual
Biomass Format: Chips
Biomass Amount: 1,000 oven dry tonnes/yr
Supply Chain Length: local
Bioenergy Product: District heat
Stakeholders: Plant 1: Hübscher Holzbau AG (Investor and Operator)
Plant 2: Lutz Bodenmüller AG, Beggingen (Investor)
Feedstock supplier: Heitzmann AG, Schachen

Overview of Case Study

A heating plant and district heat network were constructed by a local timber company in 2012 to supply their facility, as well as buildings in the village, with wood-based heat. The plant uses a cascade of six 200 kW wood chip boilers to provide a peak heat output of 1,200 kW to the district network. The cascade design, with several small-scale boilers, eliminates the need for a fossil fuel boiler for partial heat loads, making the district heat network 100% wood fuelled. After several years of successful operation, a second heat plant was constructed in 2015 in a neighbouring village using a similar design.

Details of Biomass Feedstock Supply Chain

Wood chips are supplied to the wood chip boiler by the local timber company itself. The wood chips are stored in a purpose-built bunker where they are dried to achieve a moisture content below 35% to ensure optimal combustion in the boilers. The chips are then fed automatically into the adjacent boiler system as required to supply heat to the district heat network.



Drivers, Policies, Support Mechanisms

Primary drivers for this project were 1) increasing competitiveness of the primary production at the timber mill through the valorisation of wood residues and 2) reducing fossil fuel dependency in the local community. Close cooperation between local entrepreneurs and the local wood industry enabled successful implementation of the biomass plants.

Relation to Sustainable Development Goals

SDG		Target, Explanation	Evidence
7	Affordable & clean energy	7.2, Renewable energy share increased due to displacement of fossil fuels for heat with biomass disctrict heat in village.	District network is 100% biomass-fuelled
9	Industry, innovation, infrastructure	9.4, CO_2 emissions reduced relative to heating with fossil fuels; value added for timber company through creation of market for residues.	Described qualitatively in case study
11	Sustainable cities & communities	11.6, Cascade design and advanced emissions controls limits emissions of fine particulate matter in the village.	Described qualitatively in case study
12	Responsible consumption & production	12.2 (also 8.4), Material footprint improved due to use of previous waste product for energy resulting in more efficient use of wood resource.	Described qualitatively in case study

Other Strengths, Weaknesses, Opportunities, Threats

Strengths

- Cascade of small boilers allows for high efficiency and low emissions.
- Cooperation between local entrepreneurs and local wood industry enabled success.

Opportunities

- Use of standard equipment, relatively small scale, and simple supply chain makes the system easily replicable in other communities.

Weaknesses

- Installation cost increases for several small boilers compared to one large boiler.

Threats

- If wood processing facility closes, fibre supply and important heat customer disappear.

2.2 WOOD CHIP DISTRICT HEAT IN THE NETHERLANDS

Year of Project: 2012 and expanded upon in 2018 and 2021

Location: Marum, Netherlands, Europe

Status: Implemented

Source: Koppejan, J. (2018). *Wood chips fired district heating plant in Marum, Netherlands*. IEA Bioenergy.

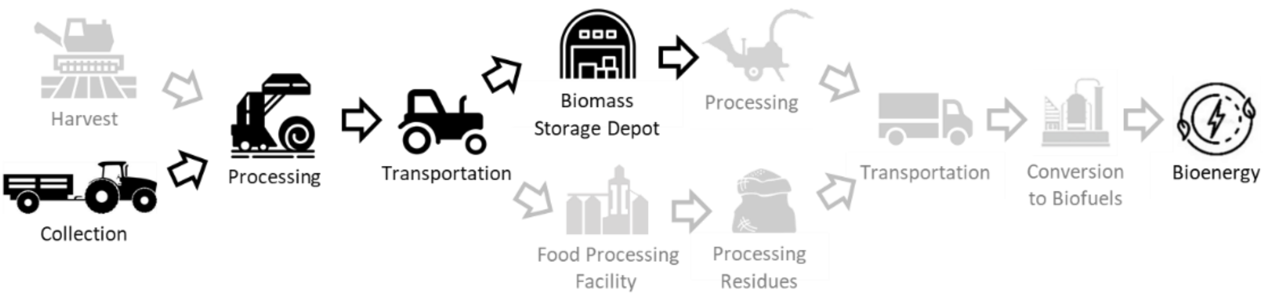
Bioenergy Supply Chain Summary
Biomass Type: Woody residues
Biomass Origin: Co-productive system (wood from landscape maintenance on farms)
Biomass Format: Chips
Biomass Amount: 800 tonnes/yr
Supply Chain Length: Local
Bioenergy Product: District Heat
Stakeholders: Bio Forte BV (Investor & operator), Municipality of Marum, Local farmers' association

Overview of Case Study

A 500 kW biomass heating plant and district network heat plant was constructed in the Dutch community of Marum in 2012, and expanded in 2018 and 2021. The heating network supplies heat to 12 customers in the community for heating in the winter season and also supplies heat to the open air swimming pool in the summer. High demand has resulted in the heating network operating at full capacity, or near full-capacity, consistently. The bioheat plant uses wood chips derived from landscape maintenance residuals that were previously burned. In addition, the initiative has created ten jobs for local residents with disadvantaged backgrounds in managing and operating the heat system's supply chain.

Details of Biomass Feedstock Supply Chain

Farmers are paid to deliver wood chips, derived from landscape maintenance residuals, by tractor to a covered long-term storage facility that was specifically constructed by the local municipality. The wood chips are stored and dried in the storage facility for eight months. The fuel bunker at the bioheat plant is fed remotely by a municipal employee to reduce operation costs.



Drivers, Policies, Support Mechanisms

Primary drivers for this project were 1) to stop open air burning of wood waste and 2) to generate renewable energy at an affordable price reducing energy costs for customers. The project benefitted from involvement by Bio Forte BV, an energy service company specialised in biomass combustion plants, who saw economic value in the proposed project supporting the design, financing, construction and operation of the installation. The bioheat plant also received financial subsidies from two different programs designed to support innovation and local development projects, as well as 500,000 Euro's from the Netherland's Renewable Heat Subsidy Scheme.

Relation to Sustainable Development Goals

SDG	Target, Explanation	Evidence
Affordable & clean energy	7.2, Renewable energy share increased due to displacement of fossil fuels for heat with biomass disctrict heat in village.	7000 GJ/yr of bioheat dispaces 250,000 m^3 of natural gas consumption
Decent work & economic growth	8.5, The municipality provided incentives to hire people from marginalized communities to manage the heat network's supply chain.	10 locals with disadvantaged backgrounds employed in supply chain
Industry, innovation, infrastructure	9.4, CO_2 emissions reduced relative to heating with natural gas; value-added for developer, municipality and customers.	450 tonnes/yr CO_2 avoided, as stated in reference
Sustainable cities & communities	11.6, Project stopped the burning of wood residues which are now burned under controlled conditions in a boiler with flue gas cleaning.	Particulate emissions from open burning have been eliminated; emissions from biomass boiler very low
Climate action	13.1, Local government banned open-air burning of wood residues after heating plant constructed.	Described qualitatively in case study

Other Strengths, Weaknesses, Opportunities, Threats

Strengths

- Local collaboration between municipality, developer, local farmers, local residents, led to overall success of project.

Opportunities

- Potential for integrating other renewables into the district heating network in the future.
- Simple, efficient technology, relatively small scale and local supply chain make project easily replicable in other communities.

Weaknesses

- High investment cost.

Threats

- Project not economically feasible without initial subsidies.

2.3 VÄRTAVERKET BIOMASS COMBINED HEAT AND POWER PLANT (SWEDEN)

Year of Project: 2016
Location: Stockholm, Sweden, Europe
Status: Implemented
Source: Strömberg, M. (2018). *Large biomass CHP plant in Stockholm*. IEA Bioenergy.

Bioenergy Supply Chain Summary

Biomass Type: Forest

Biomass Origin: Forest harvest residues and wood processing residuals

Biomass Format: Chips

Biomass Amount: 1.2 million green tonnes/yr

Supply Chain Length: National

Bioenergy Product: Combined Heat and Power

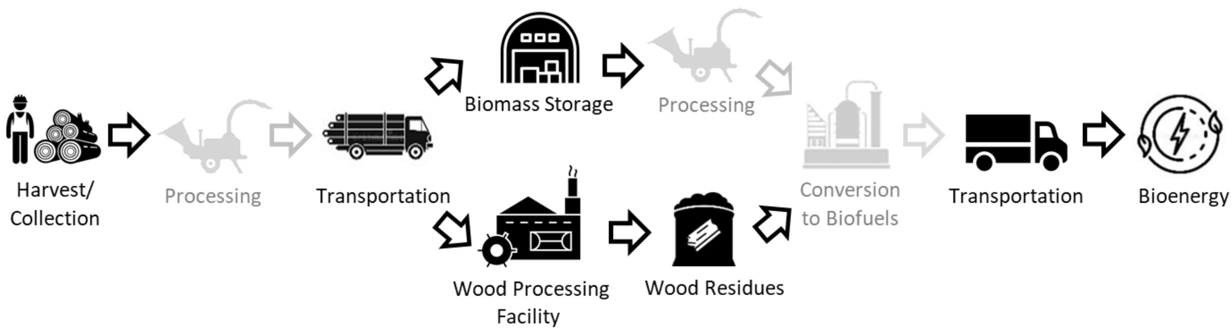
Stakeholders: Stockholm Exergi

Overview of Case Study

Värtaverket is the largest biomass Combined Heat and Power (CHP) plant in the world providing electricity to customers and heat to buildings by a district network heating system. The plant can produce 130 megawatts (MW) of electricity and 280 MW of heat, generating enough electricity to charge 150,000 electrical vehicles and heat 190,000 apartments. The plant is located in central Stockholm and is designed as a closed-loop system to process fuel and ash, reducing the noise, smell, and dust associated with biomass combustion.

Details of Biomass Feedstock Supply Chain

Waste wood and residues from the forest sector are transported to the port of Värtahamnen via marine transport from countries surrounding the Baltic Sea (60%), while domestic feedstock is transported by train (40%). The waste wood and residues are supplied from Forest Stewardship Council (FSC) and/or Programme for the Endorsement of Forest Certification (PEFC) certified suppliers. Once wood residues arrive at the port they are stored in an underground rock cavern previously used to store oil. This rock cavern can store about five days' worth of biomass (60,000 m^3), as the plant uses about 12,000 m^3 a day (3 million m^3/year). Wood chips are fed into the boiler from a dedicated conveyor system 40 meters below sea level that connects the boiler to the wood chips stored in the rock cavern. Ash from the plant is transported back through the same tunnels to silos at the harbour.



Drivers, Policies, Support Mechanisms

The city of Stockholm has a goal of being fossil fuel-free and climate positive by 2040. The Värtaverket plant was contructed to advance this goal and its constuction replaced coal-fired electricty plants that previously provided heat for the district heating network.

Relation to Sustainable Development Goals

SDG	Target, Explanation	Evidence
Affordable & clean energy	7.1 & 7.2 Renewable energy share increased replacing expensive petroleum-based heating fuels in city-wide district heat system.	Plant runs on 100% biomass and replaces previous coal-fired plant
Industry, innovation, infrastructure	9.4, CO_2 emissions from heating reduced in Stockholm and national emissions reduced due to replacing high-carbon electricty production with low-carbon production.	Heating emissions reduced by 126,000 t/yr, global emissions by 650,000 t/yr
Sustainable cities & communities	11.6 (also 8.4), Modernized district heat plant located in an urban area and achieves very low particulate matter emissions.	Described qualitatively in case study
Decent work & economic growth	12.2 (also 8.4), Fuel sourced from waste streams and residues improves material use-efficiency.	Described qualitatively in case study
Life on land	15.2, Using FSC and PEFC-certified forest residues for bioenergy production supports sustainable forest management.	Stockholm Exergi is the first energy company in the EU to have FSC Chain of Custody certification

Other Strengths, Weaknesses, Opportunities, Threats

Strengths

- CHP plant designed within urban space and urban energy system and has received support from residents.
- Makes use of the city's existing district heating network.

Opportunities

- Provides large market for residues from Sweden and neighbouring countries and opportunities for more sustainable forest management.
- Demonstrates the feasibility of large biomass CHP plants in cities, opportunity for others to follow suit where biomass is available.

Weaknesses

- The plant has high fuel demand (12,000 m^3/day) requiring constant shipments of wood residues.
- District heating networks are required to support feasibility of biomass CHP of this size for which most large cities do not have.

Threats

- Very large fuel demand could lead to overexploiting forests to meet demand.
- Disruptions to supply chain could impact heating and electricity supply for residents.

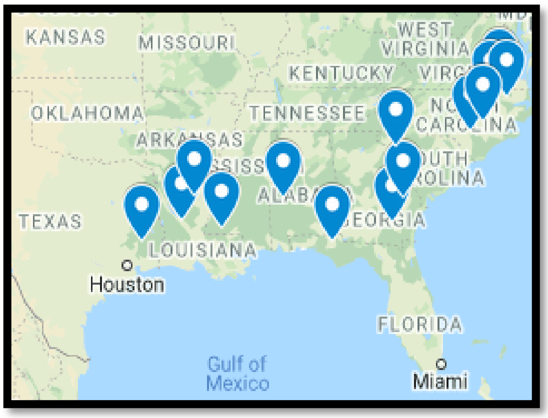
2.4 WOOD PELLETS PRODUCTION IN SOUTHEAST USA

Year of Project: 2020

Location: Southeastern United States, North America

Status: Operational

Source: Kline, K., Dale, V., Rose, E., & Tonn, B. (2021). Effects of Production of Woody Pellets in the Southeastern United States on the Sustainable Development Goals. *Sustainability*, 13(2), 821-840.



Bioenergy Supply Chain Summary

Biomass Type: Forest

Biomass Origin: Forest and wood processing residues

Biomass Format: Utility-grade biomass pellets

Biomass Amount: 7 million tonnes/yr

Supply Chain Length: Regional and International

Bioenergy Product: Electricity and heat

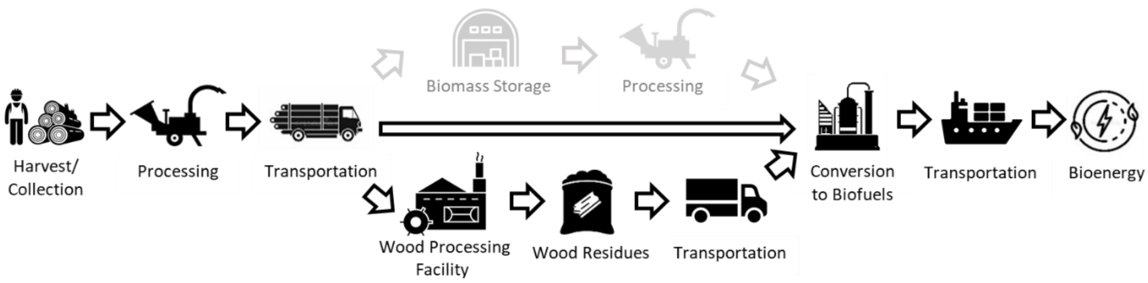
Stakeholders: Private forest landowners, foresters, pellet mill owners, shipping industry, utilities in the United Kingdom (UK) and European Union (EU), forest certification groups, environmental non-governmental organizations (ENGOs).

Overview of Case Study

Wood pellets made from harvesting and wood product residues are produced in the Southeastern (SE) United States (US) and shipped to the United Kingdom (UK) and Europe for heat and power generation. These wood pellets are produced only if market conditions make it impossible to sell the woody biomass for higher-value products (i.e., lumber, pulp, composites). Almost all woody biomass used in pellet manufacturing in the SE US is sourced from private forests, and 60% of those lands are owned by families where harvesting operations are typically conducted by professional harvesters. In 2019, woody biomass used in wood pellet manufacturing made up less than 5% of total harvest removals in the SE US.

Details of Biomass Feedstock Supply Chain

Wood is harvested from privately-owned forests for high-value wood products (i.e., lumber, pulp, paper) and harvesting and manufacturing residuals are sent to pellet mills. While about 80% of feedstock for pellets comes from secondary sources and other forestry industries, some unmerchantable timber is collected during the forest harvest and transported to a pellet mill. The mill processes (i.e., grinds and densifies) the feedstock into pellet form. From there, pellets are transported to a port facility and then shipped to clients primarily in the UK and the European Union (EU).



Drivers, Policies, Support Mechanisms

Primary drivers for this project were 1) sustainable development of a forest product and 2) reducing fossil fuel dependency in the UK and EU (Renewable Energy Directive). Close cooperation between regional and local industry partners, including small forest operations, and reliable chain of custody for biomass, is critical for achieving sustainability goals.

Relation to Sustainable Development Goals

SDG		Target, Explanation	Evidence
7	Affordable & clean energy	7.2, Renewable energy share increased in the EU with bioenergy as the largest renewable energy source.	19% of EU energy consumption is from renewable sources; 59% of that is from biomass
8	Decent work & economic growth	8.4, Improved forest management while using wastes to produce pellets encourages economic growth without environmental degradation.	More growth in sustainable green economy jobs relative to non-renewable alternatives
9	Industry, innovation & infrastructure	9.3, Small-scale industries play important role in providing feedstock for wood pellet industry.	60% of SE US timberland is family-owned
		9.4 (also SDG 13), CO_2 emissions reduced relative to electricity from fossil fuels; value-added for timber company through creation of market for residues.	GHG emissions are reduced when wood pellets replace fossil fuel (coal)
12	Responsible consumption & production	12.2 (also 8.4), Bioenergy allows for more efficient use of forest resources.	Feedstock collected at the forest harvest
15	Life on land	15.2, Forest area as a proportion of total land area is retained through the production of wood pellets, sustainable management, and ecosystem conservation.	Demand for forest products helps retain land in forests and promotes sustainable management

Other Strengths, Weaknesses, Opportunities, Threats

Strengths	Opportunities
• Displacing fossil coal with bioenergy supports renewable energy goals. • Conservation of forests paired with green jobs using waste material for bioenergy.	• Socioeconomic opportunities supporting transition to low carbon economy industries. • Sustainable forest management in SE US can improve soil, water and wildlife habitat quality and reduce wildfires and pest infestations.
Weaknesses	**Threats**
• Accounts for only a small portion of forest industry products. • Local impacts of pellet mills (air, noise, traffic) and inefficiency related to exporting versus opportunities for local utilization.	• Policies that exclude wood-based bioenergy from renewable energy and climate programs. • Public perceptions of forest bioenergy.

Other Sources

Dale, V. H., Parish, E. S., Kline, K. L., & Tobin, E. (2017). How is wood-based pellet production affecting forest conditions in the southeastern United States? *Forest Ecology and Management*, 396, 143-149.

Kittler, B., Stupak, I., & Smith, C. T. (2020). Assessing the wood sourcing practices of the U.S. industrial wood pellet industry supplying European energy demand. *Sustainability and Society*, 10, 23-40.

2.5 HARVEST RESIDUES FOR ENERGY IN CANADA

Year of Project: 2018-2021

Location: Quebec, Canada, North America

Status: Studied

Source: Thiffault, E. (2020, May 20). *Forest Biomass procurement as a silvicultural tool for management in Quebec Canada* [PowerPoint]. Presented at Positive Relationships between Sustainable Wood Energy and Forest Landscape Restoration Webinar.

Bioenergy Supply Chain Summary

Biomass Type: Forest

Biomass Origin: Harvest residue

Biomass Format: Chips

Biomass Amount: N/A

Supply Chain Length: Regional

Bioenergy Product: N/A

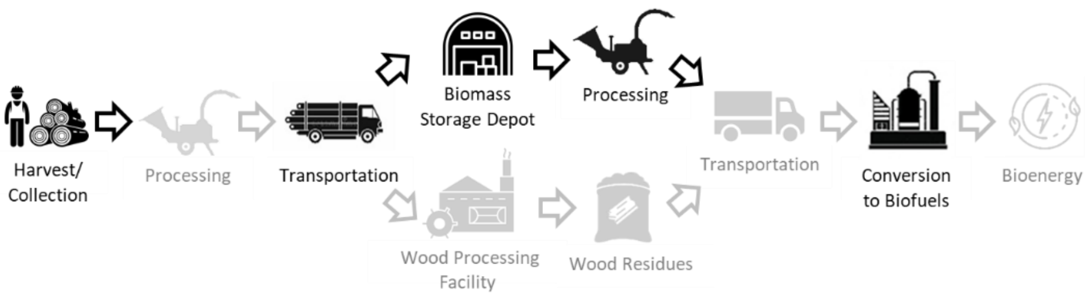
Stakeholders: Canadian Wood Fibre Centre, Université Laval

Overview of Case Study

The aim of this project was to compare the cost of procuring wood for timber and biomass for bioenergy, and the costs of site preparation. The analyses will make it possible to assess whether biomass procurement provides benefits in terms of costs of regeneration after harvest, and whether differences in regeneration patterns translate into carbon sequestration differences. When considering the entire forest silvicultural system, there is an increasing recognition that the recovery of forest biomass can play a positive role in reducing the cost and effort to properly prepare harvested sites for effective planting or natural re-establishment which in turn influences the net carbon balance of implementing bioenergy and may reduce overall silvicultural costs for forest operators.

Details of Biomass Feedstock Supply Chain

The study examines a network of experimental sites that include fir and spruce-dominated stands of the northeastern boreal forest of Quebec affected by cyclic spruce budworm outbreaks, wet boreal fir stands of the Laurentian Highlands of central Quebec, hardwood dominated forests typical of southeastern Quebec, and two contrasting forest types of low quality conifer-dominated mixedwood typical of the Gaspesie peninsula in eastern Quebec. At each site, woody biomass (i.e., branches, tree tops, discarded log pieces and trees) was removed and the impact on regeneration in different microsites was assessed. Currently, no specific end-use has been identified but could include thermal energy, biofuels or electricity.



Drivers, Policies, Support Mechanisms

The primary driver for this study was to help contribute to a broader understanding of available forest biomass in Canada as levels of forest biomass mobilization for bioenergy production in Canada are well below levels observed in other countries of the boreal and temperate biomes. This is of strategic importance for Canada, as part of national efforts to fight climate change, and to accelerate the deployment of Canada's bioeconomy to ensure its competitiveness in the world markets. Understanding the silvicultural and carbon sequestration impacts, as well as costs, are also important components for future policy decisions.

Relation to Sustainable Development Goals

SDG		Target, Explanation	Evidence
7 AFFORDABLE AND CLEAN ENERGY	Affordable & clean energy	7.2, Energy produced from forest biomass would displace fossil energy.	Energy indicated as likely end-use but amount and form not specified
8 DECENT WORK AND ECONOMIC GROWTH	Decent work & economic growth	8.2 & 8.4, Anticipated job creation and maintenance associated with the collection and processing of harvest residues.	Up to 500 jobs created or maintained in forest operations
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	Industry, innovation & infrastructure	9.4 (also 13), Displacement of fossil fuels with forest bioenergy would reduce emissions; potential to increase carbon sequestration in the forest.	Potential for CO_2 reductions, sequestration, results not available
12 RESPONSIBLE CONSUMPTION AND PRODUCTION	Responsible consumption & production	12.2, Material footprint improved due to use of previous waste product for bioenergy resulting in efficient use of wood waste.	Harvest residues re-directed to bioenergy
15 LIFE ON LAND	Life on land	15.2, Harvest residues collection as a silivicultural tool has potential to increase health of forests and improve sustainable forest management.	Described qualitatively in case study

Other Strengths, Weaknesses, Opportunities, Threats

Strengths

- Several sites and microsites studied, with different ownership, harvest practices and ecosystem types.

Opportunities

- Could provide additional economic opportunities for forest operators and cooperatives.
- Increase value-added products from wood waste.

Weaknesses

- Study results not yet available, unsure if costs of biomass collection when considered within silviculture value chain will be lower than status quo.

Threats

- Lack of current market for residues.

2.6 INTEGRATED BIOMASS SUPPLY FROM ACADIAN FORESTS FOR BIOHEAT (CANADA)

Year of Project: 2019

Location: New Brunswick, Canada, North America

Status: Implemented

Source: Gagnon, B, & Laganière, J. (2020). Unpublished site visit.

Bioenergy Supply Chain Summary

Biomass Type: Forest

Biomass Origin: Harvest residue

Biomass Format: Roundwood (stand improvement cuts)

Biomass Amount: Approximately 5,000 tonnes/yr

Supply Chain Length: Regional

Bioenergy Product: Individual building heat

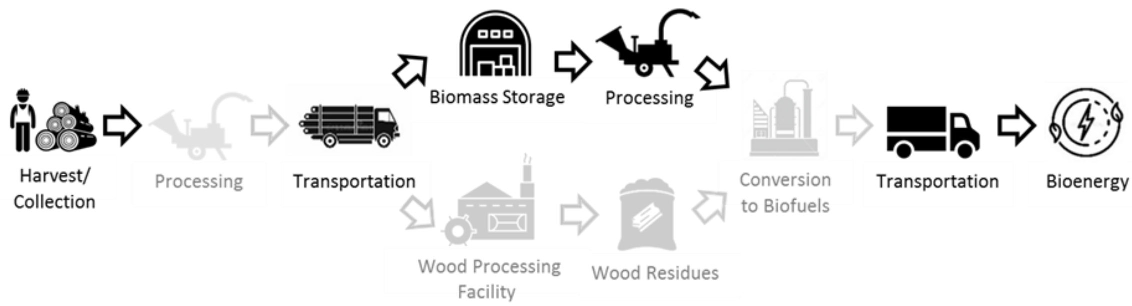
Stakeholders: ACFOR, Municipality of Riverview, Municipality of Moncton, Government of Prince Edward Island, Private woodlot owners

Overview of Case Study

ACFOR works with private woodlot owners, with lots ranging in size from 20 to 500 hectares, to harvest trees using selective harvesting and commercial thinning. This silviculture practice leaves higher-value trees such as white pine and red maple, to continue growing, while harvesting intolerant or low-value trees such as balsam fir and aspen for lumber, pulp, oriented strand board (OSB) and bioenergy production. The company harvests approximately 50,000 m^3 of trees annually. Softwood trees (predominantly balsam fir) make up roughly two thirds of the harvest and the remaining third is hardwood. Parts of the harvested trees dedicated for wood chip production are either chipped and used in boilers, or split for firewood and used in wood stoves.

Details of Biomass Feedstock Supply Chain

Low quality logs destined to become wood chips are transported to ACFOR's storage and chipping facility near the city of Moncton, New Brunswick, where they are stored and dried before being chipped. A portion of the hardwood logs harvested are also sold to a firewood producer. When harvested, wood has a moisture content of around 50% and reaches 25-30% moisture content after passive drying. Chips are transported and delivered to ACFOR's clients using a customized delivery truck capable of transferring them into storage silos. Wood chips are automatically fed into biomass boilers to supply heat to schools, hospitals and municipal buildings in Prince Edward Island and New Brunswick.



Drivers, Policies, Support Mechanisms

Primary drivers for this project were 1) finding an outlet for lower value wood coming from forest management operations and 2) reducing fossil fuel dependency in the local community. ACFOR's ownership of the supply chain also contributed to the successful implementation of the bioheat systems.

Relation to sustainable development goals

SDG		Target, Explanation	Evidence
4 Quality Education	Quality education	4.4, Training provided by ACFOR to operators on selective harvest techniques.	Described qualitatively in case study
7 Affordable and Clean Energy	Affordable & clean energy	7.2, Renewable energy share increased due to displacement of fuel oil in public and commercial buildings.	Historical supply of fuel oil and deliveries of wood chips
8 Decent Work and Economic Growth	Decent work & economic growth	8.4 (also 12.2), Bioenergy provides an outlet for low quality wood species following declining demand for pulp wood, ensuring efficient resource use.	Described qualitatively in case study
9 Industry, Innovation and Infrastructure	Industry, innovation & infrastructure	9.4 (also 13), Displacement of high carbon intensity fuel oil with forest biomass reduces GHG emissions related to heating buildings.	GHG quantification for avoided fuel oil combustion and wood chip combustion
11 Sustainable Cities and Communities	Sustainable cities & communities	11.6, Modern boilers have very low atmospheric emissions and achieve better performance than conventional wood stoves.	Particulate emissions testing for EN 303-5 certified boilers
15 Life on Land	Life on land	15.2, Commercial thinning allows the removal of intolerant species and upgrading of wood stands by leaving higher-value species specific to Acadian forests.	Described qualitatively in case study

Other Strengths, Weaknesses, Opportunities, Threats

Strengths

- Control over the entire supply chain and operation of boilers, ensuring high quality wood chips match requirements for boilers.
- Ability to shift between end-uses for low-grade wood (pulp vs energy) because of integrated harvest.

Opportunities

- High electricity prices and limited access to natural gas in the Canadian Atlantic provinces, making biomass heating cost-competitive.
- Increasing demand for selective harvest from private woodlot owners in the region.

Weaknesses

- Underutilization of equipment and infrastructure (chipper, delivery truck, storage).

Threats

- Lack of familiarity with biomass heating from institutional/commercial building owners and engineering firms, resulting in few installed systems and higher construction costs.

Other Sources

ACFOR. (2020). *Our Work*. http://www.acfor.ca/ourwork.

2.7 GITXSAN FIRST NATION BIOMASS TRADE CENTRE (CANADA)

Year of Project: 2019

Location: Gitxsan Traditional Territory, Canada, North America

Status: Partially Implemented (Biomass trade centre in operation but planned pellet plant not yet constructed)

Source: Harmse, K. (2020). Gitxsan Bioeconomy Strategy. In B. Gagnon (Ed). *Bio-hubs as Keys to Successful Biomass Supply for the Bioeconomy* (pp. 3). IEA Bioenergy.

Bioenergy Supply Chain Summary

Biomass Type: Forest

Biomass Origin: Harvest residue

Biomass Format: Bulk woody biomass

Biomass Amount: N/A

Supply Chain Length: Regional with planned expansion to international

Bioenergy Product: Individual building heat

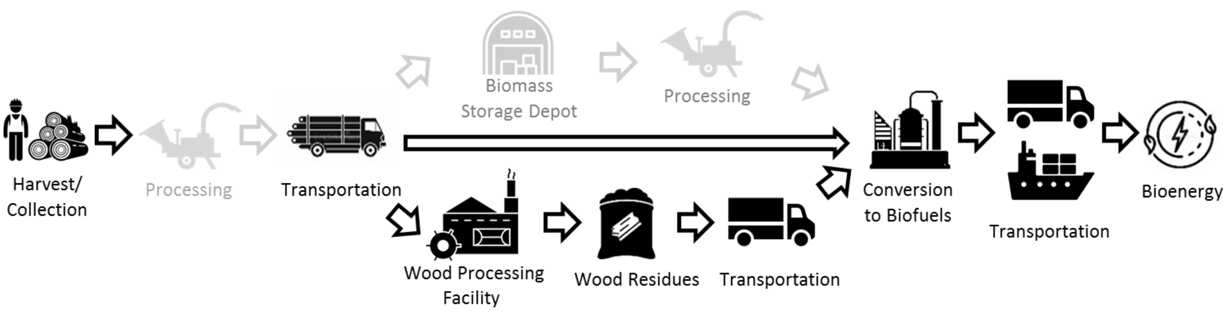
Stakeholders: Gitxsan Development Corporation, Gitxsan First Nation, Skeena Bioenergy

Overview of Case Study

The Gitxsan First Nation community is moving away from fossil fuels, using wood pellet boilers to provide heat in community buildings. The boilers were installed by a local supplier and are maintained by trained community members. The Gitxsan Development Corporation (GDC) purchased its own pellet delivery vehicle and is delivering pellets to community members in large reusable drums as a more sustainable practice instead of using plastic bags. A proposed pellet plant, jointly owned by the GDC and Airex Energy, is expected to start operating in 2022. Pellets are expected to be distributed both domestically and internationally.

Details of Biomass Feedstock Supply Chain

Bulk pellets are currently sourced through Skeena Bioenergy, a supplier in Terrace, British Columbia. Pellets are made from a combination of hardwoods and softwoods. Wood pellets are produced from a blend of sawdust and bark supplied by a neighbouring facility: Skeena Sawmills. In the future, both "white" wood pellets and torrefied wood pellets will be produced at the proposed wood pellet plant, using a variety of feedstocks (e.g., sawmill residues, harvest residues and non-merchantable wood).



Drivers, Policies, Support Mechanisms

Primary drivers for this project were 1) reducing fossil fuel dependency in the local community and 2) increasing energy self-reliance. Close cooperation between local entrepreneurs and the local wood industry enabled successful implementation of the bioheat system and future implementation of wood pellet production capacity.

Relation to Sustainable Development Goals

SDG	Target, Explanation	Evidence
Affordable & clean energy	7.2, Renewable energy share increased due to displacement of fossil fuels for heat with biomass disctrict heat in community.	Buildings are 100% biomass-fuelled
Decent work & economic growth	8.5, Project has created employment and capacity building opportunities through training for community members of the First Nation.	3 full time jobs with Gitxsan Energy, several more in biomass supply
Industry, innovation & infrastructure	9.4 (also 13), CO_2 emissions reduced relative to heating with fossil fuels; value added for timber company through creation of market for residues.	Described qualitatively in case study
Sustainable cities & communities	11.6, Cascade design of boiler system and advanced emissions controls limits emissions of fine particulate matter in the community.	Described qualitatively in case study
Responsible consumption & production	12.2 (also 8.4), Material footprint improved due to use of previous waste product for energy resulting in more efficient use of wood resource.	Described qualitatively in case study
 Life on land	15.2, Forest is managed for lumber, bioenergy adds value and allows for improved management practices.	Forest Stewardship Plan prepared

Other Strengths, Weaknesses, Opportunities, Threats

Strengths

- Cascade of small boilers allows for high efficiency and low emissions.
- Cooperation between local entrepreneurs and local wood industry enabled success.

Opportunities

- Use of standard equipment, relatively small scale, and simple supply chain makes the system easily replicable in other communities.

Weaknesses

- Installation cost increases for several small boilers compared to one large boiler connected to a district heat network.

Threats

- If wood processing facility closes, a significant portion of fibre supply and important heat customer disappears.

Other Sources

Gitxsan Development Corporation. (2020). *Energy*. https://gitxsanbusiness.com/pages/energy.

Hazelton Bioenergy. (2020). *Frequently Asked Questions*. http://hazeltonbioenergy.com/index.php/torrefied-pellets/.

2.8 FIRE KILLED WOOD FOR BIOHEAT IN CANADA

Year of Project: 2020

Location: Northland Denesuline First Nation, Manitoba, Canada, North America

Status: Implemented

Source: Blair, J. (2020). Interviews with community members through Natural Resources Canada's CanmetENERGY Research facility.

Bioenergy Supply Chain Summary

Biomass Type: Forest

Biomass Origin: Primary production

Biomass Format: Roundwood

Biomass Amount: 700 green tonnes/yr

Supply Chain Length: Local

Bioenergy Product: District heating

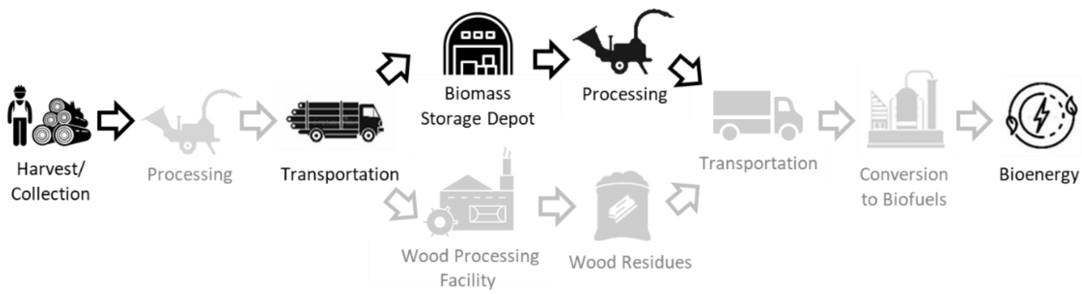
Stakeholders: Northland Denesuline First Nation, Indigenous and Northern Affairs Canada (INAC)

Overview of Case Study

In 2017 the Northlands Dënesųłiné First Nation's community developed the Environmental Remediation and Alternative Energy Systems (ERAAES) project to reduce, and eventually eliminate, the community's dependence on diesel fuel imports. The community previously relied on two million litres of diesel fuel per year to provide heat and electricity to the local community and could only be transported to the community in the winter via the community's ice road. The project has several features which include remediating and cleaning up two contaminated diesel sites in the community, constructing a 1.5 megawatts (MW) biomass district heating system, developing a log-yard and logging operations to harvest wood from previous forest fire locations to be used in the district heating system, installing a 140kW geothermal district heating and cooling system and installing 282kW of solar panels. As of 2020, the community has been able to replace one-third of its diesel consumption with renewable energy sources, reducing the community's carbon emissions by 800 tonnes, providing new permanent jobs for community members while improving the community's energy security.

Details of Biomass Feedstock Supply Chain

Employees harvest wood from previous forest fire-affected locations in the surrounding region. Harvested wood is transported to the log-yard and chipped as needed to be used in wood boilers connected to the community's district heating network.



Drivers, Policies, Support Mechanisms

Primary drivers for this project were 1) reducing fossil fuel dependency and the associated soil contamination risks and 2) using local resources. The biomass system was installed as part of a project funded by the Government of Canada's Contaminated Sites on Reserve (CSOR) to clean up and reduce future risk of diesel contamination in remote Indigenous communities.

Relation to Sustainable Development Goals

SDG	Target, Explanation	Evidence
4 Quality education	4.3, Training provided for community members on forest management, biomass supply, boiler operation, safety, operation of machinery, management and accounting.	Several community members received training
6 Clean water & sanitation	6.3, One of the project's goal was to clean up diesel contamintation that polluted the water table and prevent further contamination.	Described qualitatively in case study
7 Affordable & clean energy	7.2, Renewable energy share increased due to displacement of fossil fuels for heat with biomass disctrict heat in community.	District network is 30% biomass-fuelled
8 Decent work & economic growth	8.5, Over 50 people in a community of around 1000 people have employment as a result of the biomass heating project, most of whom were not previously employed.	Employment records
9 Industry, innovation & infrastructure	9.1, The biomass district heating system is reliable, sustainable, and resilient infrastructure owned by the community.	Described qualitatively in case study
13 Climate action	13.1, Primary motivation for community was to reduce environmental and supply risks associated with diesel fuel imports.	Described qualitatively in case study

Other Strengths, Weaknesses, Opportunities, Threats

Strengths

- Community members had existing skill set required for biomass supply but were not previously paid for those skills.
- Demonstrates integration, and viability, of bioenergy with renewable energy systems.

Opportunities

- Created opportunities for community members to be involved in planning, operation and management.

Weaknesses

- High cost to purchase equipment and establish local supply chain.

Threats

- Long term viability of biomass supply given the use of wood from previous forest fire locations and no other forestry operations in the region.

Other Sources

Boke Consulting. (2020). *Northlands Dënesųłiné Renewable Energy & Remediation*. http://bokeconsulting.com/northlands-denesuline-renewable-energy-remediation/.

2.9 WOOD PELLETS FROM INDUSTRIAL RESIDUES FOR BUILDING HEAT (CANADA)

Year of Project: 2010

Location: Saint Quentin, New Brunswick, Canada, North America

Status: Implemented

Source: Häfele, S. (2015). *SCS Global Services Evaluation of Groupe Savoie Inc Compliance with the SBP Framework: Public Summary Report*. Sustainable Biomass Partnership.

Bioenergy Supply Chain Summary

Biomass Type: Forest

Biomass Origin: Wood processing and harvest/thinning residues

Biomass Format: Non-standardised (shavings)

Biomass Amount: 90,000 tonnes of pellets/yr

Supply Chain Length: Regional

Bioenergy Product: Wood pellets for heat

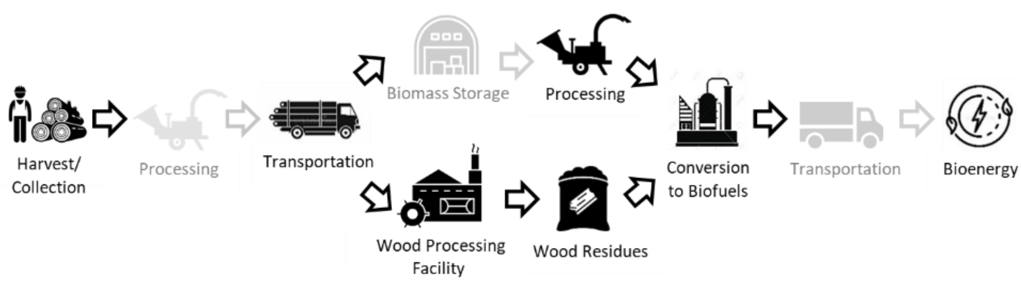
Stakeholders: Groupe Savoie, Biomass Solutions Biomasse

Overview of Case Study

Groupe Savoie Inc. is a vertically integrated forest products manufacturing company in Eastern Canada with the pellet mill utilizing residues generated along the lumber and pallet manufacturing supply chain. The company produces 90,000 tonnes of pellets for both industrial and residential customers, all of which are certified under the Sustainable Biomass Program (SBP) standards. Of this, around 50,000 tonnes are sold domestically for residential, commercial and institutional heat. Groupe Savoie also has a subsidiary company that offers bulk pellet delivery and distributes high end wood pellet boilers.

Details of Biomass Feedstock Supply Chain

Feedstock for the pellet mill is sourced primarily from Groupe Savoie's sawmill residuals as well as forest operations in the province of New Brunswick (NB), other Canadian provinces in Eastern Canada, and the state of New England in the United States. Wood fibre is loaded into a de-stoner to separate the fibre from any unwanted objects (i.e. rocks) that may have been collected during collection prior to being dried. Wood fibre is dried using a bark-fuelled drier, then sent to a hammer mill and pressed into pellets. Industrial grade pellets are exported, while premium grade pellets are bagged and distributed to retailers or stored onsite in 100 tonne silos to be delivered to commercial and institutional customers in bulk using a vacuum truck.



Drivers, Policies, Support Mechanisms

Primary drivers for this project were 1) maximizing unused sawmill residues to provide solid wood fuels 2) generate new revenue opportunities for Groupe Savoie and 3) support economic diversification and job creation in the province of New Brunswick after the 2008 financial crisis. The construction of the pellet plant was supported by a $2 million dollar investment from the Canadian government, as well as a $5 million dollar investment from the New Brunswick provincial government.

Relation to Sustainable Development Goals

SDG		Target, Explanation	Evidence
7 AFFORDABLE AND CLEAN ENERGY	Affordable & clean energy	7.2, Renewable energy share increased due to displacement of fossil fuels for space and water heating in buildings. Heating costs also reduced for customers.	Fuel oil displaced in >20 large public buildings in NB, plus residential buildings
8 DECENT WORK AND ECONOMIC GROWTH	Decent work & economic growth	8.4, (also 12.2), Previously unused wood residues are used to generate heat, displacing fossil fuels and improving resource- use efficiency.	Described qualitatively in case study
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	Industry, innovation & infrastructure	9.2 (also 8.5) Manufacturing job creation at the wood pellet plant, which supports hundreds of indirect forest sector jobs.	17 jobs at pellet plant help maintain up to 500 indirect jobs in forest sector
		9.4, Reduced carbon emissions when wood pellets displace fuel oil for heat.	Lifecycle emissions reported to SBP
15 LIFE ON LAND	Life on land	15.2, Bioenergy provides market for thinning/stand improvement cuts in the mixed hardwood forests of Eastern Canada as a part of sustainable forestry.	Described qualitatively in case study

Other Strengths, Weaknesses, Opportunities, Threats

Strengths

- Bulk pellet delivery enables smaller scale boiler installations which are not large enough to use chips or unable to source their own bulk pellets directly from mills.
- Pellet production and bulk delivery integrated within business model.

Opportunities

- More buildings and houses can install pellet stoves or boilers in the region to take advantage of the bulk delivery service currently in place.
- Support energy diversification in a region of Canada that is heavily dependent on heating oil fuel.

Weaknesses

- Fuel cost is high (compared to wood chips) for larger installations.

Threats

- Customers could be left without solid wood fuels if pellet plant were to close.

Other Sources

Canadian Biomass Magazine. (2019, November 11). *$7 million in funding for Groupe Savoie pellet*. https://www.canadianbiomassmagazine.ca/7-million-in-funding-for-groupe-savoie-pellets-1317/

Personal communication (2020). With Theo Losier (BSB) and Jean Francois Martel (Groupe Savoie).

2.10 BIOMASS PELLETS AND COOKSTOVES IN RWANDA

Year of Project: 2018

Location: Gisenyi, Rubavu, Western Province, Rwanda, Africa

Status: Implemented

Source: Jagger, P., & Das, I. (2018). Implementation and scale-up of a biomass pellet and improved cookstove enterprise in Rwanda. *Energy for Sustainable Development*, 46, 32-41.

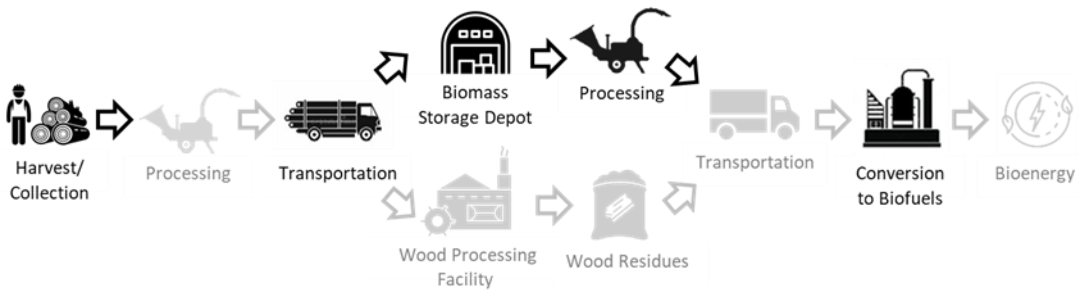
Bioenergy Supply Chain Summary
Biomass Type: Forest
Biomass Origin: Post-industrial residue or waste
Biomass Format: Woody biomass of different quality
Biomass Amount: 800 tonnes/yr
Supply Chain Length: Local
Bioenergy Product: Heat
Stakeholders: Inyenyeri, Government of Rwanda

Overview of Case Study

Inyenyeri is a Rwanda-based company that leases biomass cooking stoves and sells locally produced wood pellets made from eucalyptus trees and other woody residues. Customers sign a contract to lease a biomass stove and purchase wood pellets from the company. Inyenyeri primarily sells wood pellets as the *Mimi Moto* cook stoves leased by the company to customers are generally too expensive for customers to buy outright. Leasing the cook stoves and selling the wood pellets on a contractual basis also allows the company to price the pellets competitively with charcoal, the regions primary fuel source for cooking, so households can adopt more efficient and cleaner burning cooking systems. The company also provides free delivery, repairs and replacement of cook stoves, as well as training for customers on how to use the cook stove. The company has had 1000 customers as of 2016.

Details of Biomass Feedstock Supply Chain

The company sources sustainably sourced woody biomass (i.e., eucalyptus stems and branches) from government-owned plantations. This feedstock is transported to Inyenyeri's factory in Rubavu where it is made into pellets. The wood pellets are sometimes dried depending on their moisture content given the variability in moisture from the woody biomass. The wood pellets are then distributed to customers in the region.



Drivers, Policies, Support Mechanisms

Primary drivers for this project were 1) to provide access to clean cook stoves for residents and 2) make modern fuels and cooking systems affordable for residents.

Relation to Sustainable Development Goals

SDG	Target, Explanation	Evidence
Good Health & Well-Being	**3.9,** The cook stoves use clean modern fuels and reduce emissions and smoke during cooking.	Described qualitatively in case study
Affordable & clean energy	**7.1**, The company provides modern, affordable and efficient cook stoves and fuel for residents, decreasing their dependence on charcoal.	1000 customers and 800 tonnes of pellets a year
Responsible consumption & protection	**12.2** (also **8.4**), Wood pellets made from eucalyptus tree residues.	Described qualitatively in case study
Life on land	**15.1,** Woody biomass sourced from sustainable government-owned eucalyptus plantations.	Described qualitatively in case study

Other Strengths, Weaknesses, Opportunities, Threats

Strengths	Opportunities
• Innovative business model and a high level of customer service. • Improving access to clean and renewable fuels that improve cooking conditions for customers	• Large market as Rwanda's population is growing and urbanizing; in addition, over 81% of households in sub-Saharan Africa use solid fuels for cooking.
Weaknesses	**Threats**
• Importing and maintaining all the company's equipment is expensive and difficult. • Cooking systems require customer training.	• Complexity and vulnerability of supply chain could limit company's growth. • Limited awareness of technology by customers and small markets.

3 Agricultural Residue Supply Chain Case Studies

Agricultural Residue Supply Chain Case Studies' Primary Contributions to SDGs																	
	Title	SDG															Status
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
1	Assessment of Straw from Energy		x					x	x	x		x					S
2	District Heating with Straw							x	x	x		x	x				I
3	Tschiggerl Agrar Bio-Hub Logistic Centre		x					x	x	x			x				I
4	Gasification of Agricultural Residues in Distillery							x	x	x			x	x			I
5	Fuel Pellets from Feed Residues							x	x	x			x	x			P
6	Valorisation of Agro-prunings							x	x				x	x		x	P
7	Biogas Powers Grass Biorefinery						x	x	x			x	x	x			I
8	Crop Residue CHP	x	x					x		x			x				I
9	Bioenergy from Sugarcane Residues		x					x	x	x	x						S
10	Briquettes from Rice Husks		x					x					x			x	I
11	Women-led Bioenergy in Agro-industries	x		x		x		x				x					I

I = Implemented, P = Proposed, S = Studied

* Supply chains can contribute to multiple SDGs, however SDGs listed were those identified as most relevant.

3.1 ASSESSMENT OF STRAW FOR ENERGY IN CHINA

Year of Project: 2015

Location: Jilin, China, Asia

Status: Studied

Source: Wang, X., Li, K., Song, J., Haiyan, D., & Wang, S. (2018). Integrated assessment of straw utilization for energy production from views of regional energy, environmental and socioeconomic benefits. *Journal of Cleaner Production*, 190, 787-798.

Bioenergy Supply Chain Summary

Biomass Type: Agriculture residue

Biomass Origin: Crop straw

Biomass Format: Bales

Biomass Amount: 47 million tonnes/yr (potential in 2030)

Supply Chain Length: Regional

Bioenergy Product: Electricity

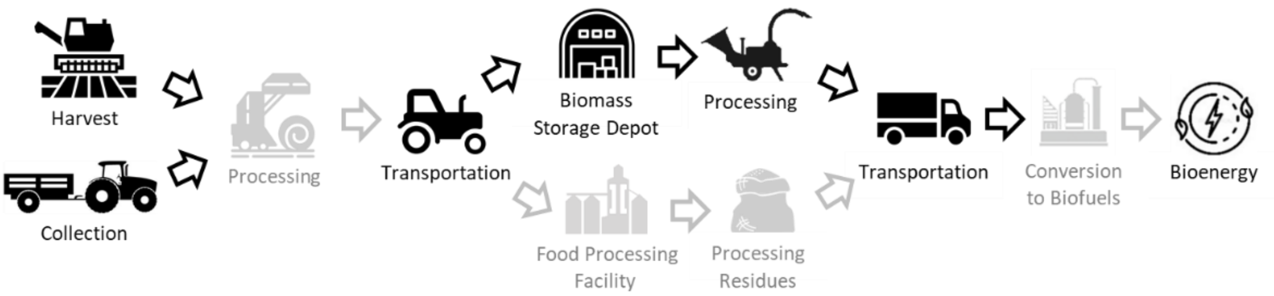
Stakeholders: Key Laboratory of Groundwater Resources and Environment, Jilin University, College of New Energy and Environment

Overview of Case Study

The study develops a model for predicting the energy production from straw resources and assessing regional energy, environmental, and socioeconomic benefits of this model in Jilin Province, China. The benefits of using straw as a feedstock for direct-combustion power generation are quantitatively evaluated based on the Global Bioenergy Partnership's (GBEP) sustainability indicators.

Details of Biomass Feedstock Supply Chain

In the modelled biomass supply chain, straw would be harvested from crops (several types) annually from several different locations (referred to as *resource islands*) within a fixed radius of the combustion facility. Straw would be collected and transported to the center of the island, where it would be bound and compressed. The bound and compressed straw would then be transported to the combustion facility.



Drivers, policies, support mechanisms

Primary drivers for this project were 1) replacing greenhouse gas intensive energy sources with lower emitting options and 2) reducing the open-air burning of straw and associated particulate matter ($PM_{2.5}$) emissions that impact air quality in the region. This project has not been implemented with the study citing a need to improve policy to support biomass energy development in the region.

Relation to Sustainable Development Goals

SDG	Target, Explanation	Evidence
Zero hunger	**2.3,** Farmers across Jilin would benefit from additional income from the sale of straw.	Additional farm income estimated to be 14 USD/GJ of electricity from straw
Affordable & clean energy	**7.2,** Renewable energy share would be increased due to displacement of coal-fired electricity with biomass electricity.	Estimated fossil fuel substitution rate of 79 kgce[11]/t straw
Decent work & economic growth	**8.5,** Employment opportunities would be generated in fibre supply and at the energy plant, mostly in rural areas where employment opportunities are scarce.	An estimated 246 jobs would be created per kJ of electricity generated
 Industry, innovation, infrastructure	**9.4,** CO_2 emissions per unit of energy generated would be reduced relative to coal-generated electricity.	An estimated 992 kg of CO_{2eq} emissions would be mitigated per GJ of electricity
Sustainable cities & communities	**11.6,** $PM_{2.5}$ emissions from open burning of straw would be significantly reduced if straw instead combusted to produce electricity in a plant with emissions controls.	Approximately 5 kg of $PM_{2.5}$ emissions would be eliminated per GJ of electricity produced

Other Strengths, Weaknesses, Opportunities, Threats

Strengths

- Availability of straw is high and currently there is a limited market for straw, with much being disposed of through open-air burning.
- Rural development would positively impact many rural residents.

Opportunities

- Existing and potential opportunities for significant job creation, farmer income and improvement in air quality.
- Opportunity for region to be a leader in bioenergy.

Weaknesses

- Straw supply network of the scale studied would require coordination between many farmers and other stakeholders.

Threats

- Farmers may not be willing to sell straw as many currently use straw for household energy production and additional income from selling straw would need to cover the cost of an alternate heating/cooking fuel.

[11] Kg of coal equivalent.

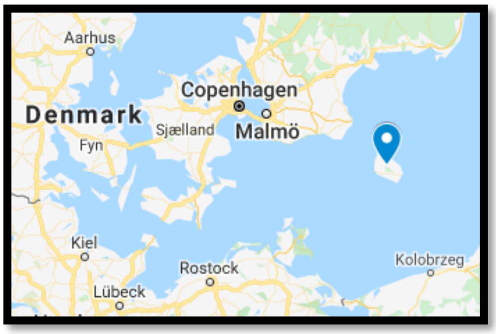
3.2 DISTRICT HEATING WITH STRAW IN DENMARK

Year of Project: 1990, upgraded in 2016

Location: Bornholm, Denmark, Europe

Status: Implemented

Source: Depenau, J., Pedersen, A.S., Nielsen, S., Neergaard, T. F. B., & Hansen, M. T. (2018). *Straw Fired District Heating in Nexø*. IEA Bioenergy.



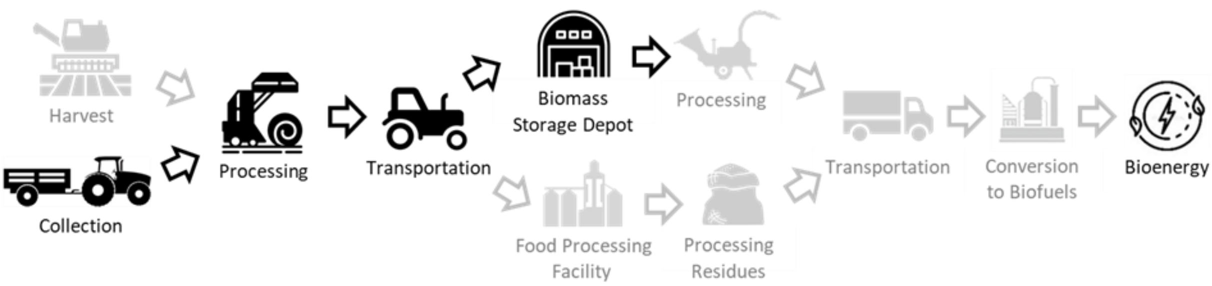
Bioenergy Supply Chain Summary
Biomass Type: Agriculture residue
Biomass Origin: Crop harvest residue
Biomass Format: Bales
Biomass Amount: 15,000 tonnes/yr
Supply Chain Length: Local
Bioenergy Product: District heat
Stakeholders: Bornholms Energi, Forsyning

Overview of Case Study

The Nexø straw-fired heating plant was established in 1990 to supply district heating to the community. The district heating distribution grid was later expanded to include three neighbouring towns to the north of Nexø. To service the expanded distribution grid without significantly increasing the heating plant's fuel consumption, Nexø Halmvarmeværk invested in a new, more efficient straw-fired biomass plant, capable of generating 12.5 megawatts (MW) of heat and was installed in 2016. The upgraded heating plant can now generate 15 MW of heat and runs entirely on biomass.

Details of Biomass Feedstock Supply Chain

Wheat straw and other crop residuals are harvested and bailed by farmers across the small Danish island of Bornholm and transported to the Nexø heat plant, where it is stored in a warehouse until needed. Bales are fed automatically into the boiler using an automatic fuel crane that was installed alongside the new boiler in 2016. Due to the small size of the island, straw supply is periodically limited, therefore the new boiler system was optimized with flue gas condensation and absorption heat pump technology to fully utilize the energy of the consumed fuel.



Drivers, Policies, Support Mechanisms

Primary drivers for this project were 1) to reduce dependency on imported oil using local sources and 2) to provide a use for crop residues which cannot be burned on the small island under Danish regulations. Other supporting factors were straw's exemption from Danish energy taxes that apply to petroleum-based heating fuels, as well as improvements in bioheat technologies that have been used in Denmark for several decades.

Relation to Sustainable Development Goals

SDG		Target, Explanation	Evidence
	Affordable & clean energy	7.2, Contributes to renewable energy share in the plant's final energy demand given 100% of heat demand for the district network is met with biomass, displacing oil and coal.	District network is 100% biomass-fuelled
	Decent work & economic growth	8.5, Local jobs created in biomass supply and management as well as benefits for local economy with lower heating costs by reducing dependency on imported heating fuels.	Described qualitatively in case study
	Industry, innovation, infrastructure	9.4, CO_2 emissions reduced relative to heating with oil and coal. The project has also led to local economic development.	Described qualitatively in case study
	Sustainable cities & communities	11.6, Limited emission of fine particulate matter and improved waste management practices by using straw for local energy production.	Described qualitatively in case study
	Decent work & economic growth	12.2 (also 8.4), Reducing waste and improving material-use efficiency by re-directing agriculture residues streams to replace carbon intensive heating fuels.	Described qualitatively in case study

Other Strengths, Weaknesses, Opportunities, Threats

Strengths

- Able to renovate pre-existing heating plant with state-of-the-art high efficiency biomass boiler technology.
- More than half of the island of Bornholm is heated with biomass in several district heat systems.

Opportunities

- Potential for integrating other renewables into the district heating network in the future.
- Simple, efficient technology, relatively small scale and local supply chain make project easily replicable in other communities.

Weaknesses

- Straw supplies may be periodically limited due to limited number of farms on the island.
- Variation in moisture content from year to year can impact quality of straw as feedstock.

Threats

- Removing too much of the crop residue from the land could lead to soil degradation over time impacting agricultural activities.

3.3 TSCHIGGERL AGRAR BIO-HUB LOGISTIC CENTRE (AUSTRIA)

Year of Project: 2014

Location: Styria, Austria, Europe

Status: Implemented

Source: Kindler, A. (2019, October 10). "*Tschiggerl Agrar bio-hub*": *Logistic and Trade Centre for non-woody biomass*. Presented at IEA Bioenergy Task 43 & BioEast Initiative Workshop, Hungary.

Bioenergy Supply Chain Summary

Biomass Type: Agriculture residue

Biomass Origin: Crop harvest and feed processing residues

Biomass Format: Not standardised (corn cobs)

Biomass Amount: 2,000 wet tonnes/yr

Supply Chain Length: Local

Bioenergy Product: Pellet for internal heat (corn drying) and residential/district heat

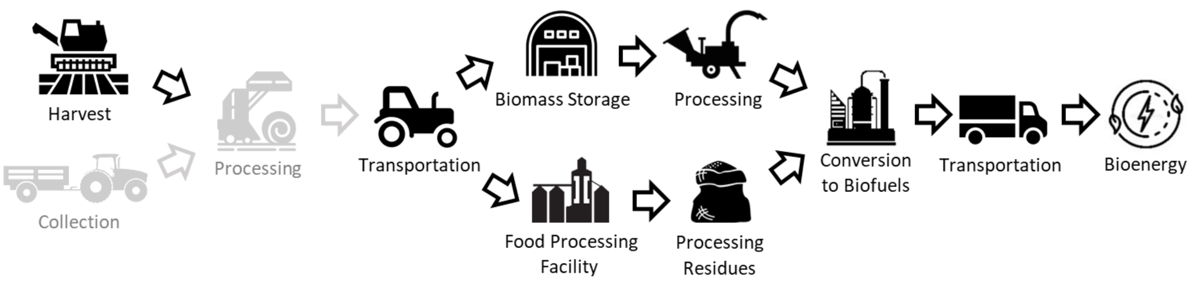
Stakeholders: Tschiggerl Agrar GmbH (corn harvest, drying), Alwera AG (crop growing, harvest, drying), two local energy service companies

Overview of Case Study

Agricultural stakeholders that grew, harvested, dried and sold corn grains, collaborated to develop a use for corn cobs, which were previously considered waste. An innovative addition to a harvester was designed that could harvest corn grain and cobs simultaneously. The corn cobs replaced heavy oil to fuel a 2 megawatt (MW) boiler to dry the corn grain. The remaining corn cobs were grinded and pelletized as a locally available solid biofuel. A biomass logistics centre, or "bio-hub" was established to produce pellets as a service to the corn growing farmers. The agro-pellets are used in nearby residential pellet boilers and district heating plants.

Details of Biomass Feedstock Supply Chain

Corn cobs are harvested along with the corn using a modified harvester. Corn cobs are delivered to the corn feed facility, where approximately 500 tonnes of wet cobs per year are used to dry corn. Remaining corn cobs and grits, about 1,500 tonnes, are delivered to the biomass logistics centre where they are pelleted then distributed for use as heating. All corn cobs are sourced within 30 km of the bio-hub.



Drivers, Policies, Support Mechanisms

Primary drivers for this project were 1) increasing competitiveness of the primary production at the feed mill through valorisation of production and crop harvest residues and 2) increasing energy self-sufficiency and reducing fossil fuel dependency both at the processing facility and in local communities. The project was implemented with the support of two energy service company loans and participation between several stakeholders.

Relation to Sustainable Development Goals

SDG	Target, Explanation	Evidence
Zero hunger	2.4, Incomes of farmers and feed producer increased due to additional revenue from production of fuel pellets from corn cobs and feed producer saves money on heating fuel.	Feed producer saves about €35,000 annually on fuel oil
Affordable & clean energy	7.2, & 7.3, Renewable energy share increased due to displacement of fossil fuels for internal heat production and district heat. Energy efficiency improved with adjustment of harvester to also collect cobs.	250,000 litres heating oil displaced for corn drying, improvements to harvester as described in case study
 Industry, innovation, infrastructure	9.4 (also SDG 13), CO_2 emissions reduced through displacement of heating oil for drying and other fossil fuels in district networks using biomass that was previously a waste stream.	Cobs from 1 ha of corn save ~2 t CO_2 emissions or~780 t CO_2/yr when oil displaced to dry corn
Responsible consumption & production	12.2 (also 8.4), Material footprint improved due to use of previous waste stream for energy, resulting in more efficient use of crops and displacing imported fossil fuels.	Described qualitatively in case study

Other Strengths, Weaknesses, Opportunities, Threats

Strengths

- Non-controversial source of biomass with a simple and local supply chain, and little additional labour required for biomass supply.
- Corn farmers are earning additional revenue from corn cobs.

Opportunities

- Supply chain and technology have low complexity and high potential for replicability wherever corn is grown and processed.
- Opportunities for new local employment in biohub.

Weaknesses

- Harvesting machinery needs adaptation.
- Solid biofuels are an unknown market for grain farmers and could be seen as high risk.

Threats

- Corn cobs pellets might not be standardized and therefore not recognized as a solid biofuel.
- Lack of local or regional demand for agropellets.

Other Sources

Engelmann, K. (2017, February 2017). *Successful implementation of the SUCELLOG concept based on corn cobs in Austria* [PowerPoint]. Presentation at the mobilisation of agricultural solid biomass for local energy, Brussels.

3.4 GASIFICATION OF AGRICULTURE RESIDUES IN DISTILLERY (FRANCE)

Year of Project: 2022

Location: Limoux, Occitanie, France, Europe

Status: Implemented

Source: Poutrin, C. (2017, February 15). *Triggering a national awareness about the use of agricultural residues for the production of solid biomass in France*. Presented at The mobilisation of agricultural solid biomass for local energy.

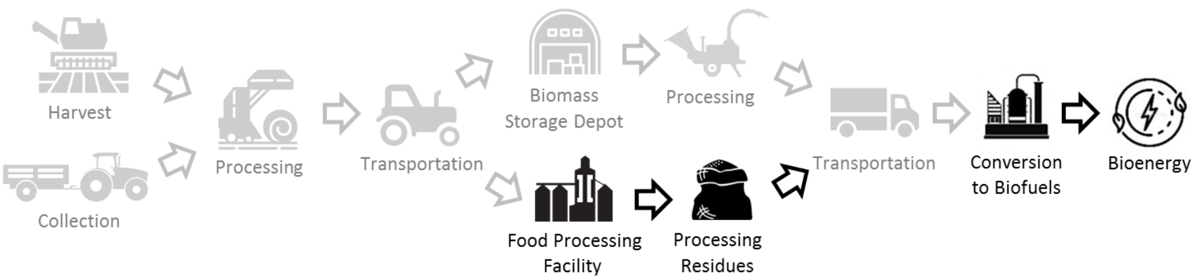
Bioenergy Supply Chain Summary
Biomass Type: Agriculture residue
Biomass Origin: Post-industrial residue (distillery)
Biomass Format: Non-standardised (spent marc)
Biomass Amount: 1,500 tonnes/yr of marc
Supply Chain Length: Local
Bioenergy Product: Industrial heat (internal)
Stakeholders: La CAVALE (The Cooperative Agricole des Viticulteurs et Agriculteurs de Limoux et des Environs)

Overview of Case Study

La CAVALE operates a distillery in Limoux, France that collects 10,000 tonnes of grape marc (residue from the wine industry) annually to produce alcohol and other co-products. In 2016, the cooperative decided to invest in a project at the distillery to valorise spent grape marc. A 1 megawatt (MW) gasification unit will be installed to produce syngas used to heat the pome dryer used in the distillation process.

Details of Biomass Feedstock Supply Chain

Spent grape marc is used to fuel a gasifier located in the distillery. The syngas produced is combusted in a burner to generate heat, which is used internally in the distillation process.



Drivers, Policies, Support Mechanisms

Primary drivers for this project were 1) increasing competitivness of the primary production at the distillery through the valorisation of residues from the distilling process and 2) to become energy self-sufficient. The project was co-funded (pre-feasibiliy and feasibility studies) by the European Union's (EU) Intelligent-Energy Europe (IEE) programme and the French Environmental and Energy Agency. A partnership was formed with a pellet-producing company to explore the possibility of producing agro-pellets from residues.

Relation to Sustainable Development Goals

SDG		Target, Explanation	Evidence
	Affordable & clean energy	7.2, Renewable energy share increased due to displacement of fossil fuels for industrial heat.	Gasifier with 1 MW capacity
	Industry, innovation, infrastructure	9.4 (also SDG 13), CO_2 emissions reduced through displacement of fossil fuels with syngas.	Described qualitatively in case study
	Responsible consumption & production	12.2 (also 8.4) & 12.5, Material footprint improved due to use of previous waste residue for energy, spent grape marc no longer landfilled reducing waste generated.	Described qualitatively in case study
	Climate action	13.2 Project supported by European and national programs that established to achieve climate change and energy targets set by the EU's Renewable Energy Directive.	Described qualitatively in case study

Other Strengths, Weaknesses, Opportunities, Threats

<u>Strengths</u>

- Elimination of landfilling fee for spent marc.
- Sustainability of distilling process improved using a non-controversial source of biomass.

<u>Opportunities</u>

- Potential for replicability given simple supply chain and technology available.

<u>Weaknesses</u>

- Gasification technology is expensive and requires a dry biomass feedstock.
- Grape marc is usually not standardised or certified as a solid biofuel; amounts used for bioenergy are limited by internal demand.

<u>Threats</u>

- The entire quantity of marc generated is too large for internal use only and too small for supplementary wholesale under the form of pellets.
- Alternative use of spent marc for novel bio-based products in bioeconomy.

3.5 FUEL PELLETS FROM FEED RESIDUES (FRANCE)

Year of Project: 2014 - 2017

Location: Varambon, Auvergne-Rhône-Alpes, France, Europe

Status: Proposed Project (implemented at small scale, capacity increase proposed)

Source: Poutrin, C. (2017, February 15). *Triggering a national awareness about the use of agricultural residues for the production of solid biomass in France*. Presented at The mobilisation of agricultural solid biomass for local energy.

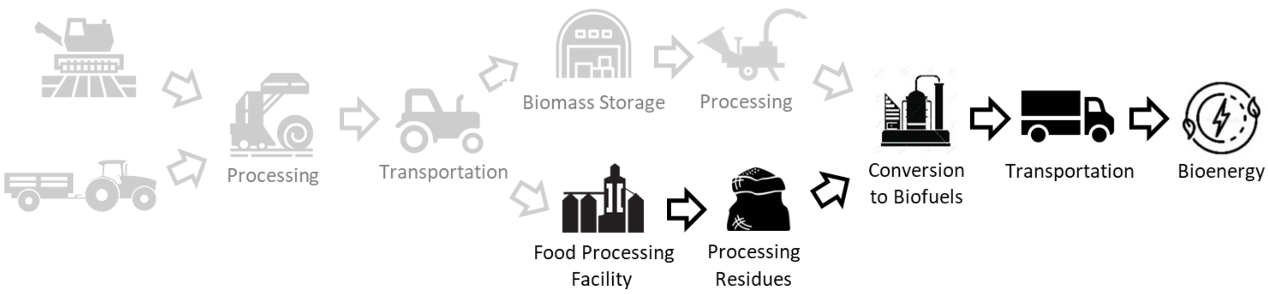
Bioenergy Supply Chain Summary
Biomass Type: Agriculture residue
Biomass Origin: Post-industrial residue
Biomass Format: Not standardised (silo and maize dust)
Biomass Amount: 200 tonnes/yr (to increase to 5,000)
Supply Chain Length: Local
Bioenergy Product: Pellets for heat
Stakeholders: SOFRAGRAIN animal feed company, Energy Service Company (ESCO) Agronergy

Overview of Case Study

In 2014 SOFRAGRAIN, an animal feed manufacturer, wanted to increase its production of energy pellets made from silo dust and animal feed residues. The company already owned a pellet production line for animal feed pellets but wanted to use it to produce energy pellets from residues during winter months when the equipment sat idle. A € 5,000 investment was required to increase capacity, production capabilities, and maximize company storage facilities for storing residues during 'off peak' times in their agriculture activities. By investing in production capacity and leveraging underutilized storage facilities the company hopes to increase pellet production from agriculture residues from 200 to 5,000 tonnes a year.

Details of Biomass Feedstock Supply Chain

Silo dust and animal feed residue (maize dust) are sourced from SOFRAGRAIN's animal feed production facility,with the potential of sourcing residues from other agro-industrial companies in the region in the future. These residues are stored in SOFARGRAIN's storage facilities and then pelletized using the company's feed pelletizer. Pellets are sold to an Energy Service Company (ESCO) as heating fuel with the intent of using pellets internally for process heat once the required equipment is purchased.



Drivers, Policies, Support Mechanisms

Primary drivers for this project were 1) increasing the competitiveness of the primary product through valorising residue streams and maximizing underutilized storage space and processing equipment, and 2) improving waste management practices by utilizing residues from the feed production process. The project was identified by the European Union's (EU) Intelligent-Energy Europe (IEE) programme that provided information on the opportunities to participate in the biofuels market and was supported by the EU’s Renewable Energy Directive (RED) which provided a framework for promoting the use of biofuels (liquid, solid, gaseous) in electricity and heat production.

Relation to Sustainable Development Goals

SDG		Target, Explanation	Evidence
7 AFFORDABLE AND CLEAN ENERGY	Affordable & clean energy	7.2, Renewable energy share increased due to displacement of fossil fuels with pellets for bioenergy systems.	5,000 tonnes of energy pellets to be produced per year, displacing fossil heating fuels.
	Industry, innovation, infrastructure	9.4, Reduced CO_2 emissions per tonne of pellets manufactured relative to fossil fuel production.	Described qualitatively in study; biomass residue displaces fossil fuel.
12 RESPONSIBLE CONSUMPTION AND PRODUCTION	Responsible consumption & production	12.2 (also 8.4) Waste streams used for energy instead of imported fuels; resource use efficiency increased, and overall material extraction/use decreased.	Hope to divert at least 5,000 tonnes per year of unused residues to pellet production
	Climate action	13.2 Project supported by European and national programs established to achieve climate change and energy targets set by the EU’s RED.	Described qualitatively in case study

Other Strengths, Weaknesses, Opportunities, Threats

Strengths

- Small investment required for diversifying business.
- Improving resource efficiency as the facilities and equipment (storage, pelletizing line) used for solid biofuel production were underutilized.

Opportunities

- Potential for new employment and revenue.
- Improve availability of low carbon fuel sources.

Weaknesses

- Limited demand for agropellets in the region.
- Agropellets might not be standardised or certified as a solid biofuel in some countries.

Threats

- Other grain producers might not consider grain entering the biofuels market as an attractive business diversification option.
- There may be other higher value pathways for feedstock in the bioeconomy.

Other Sources

Poutrin, Camille. (2017). *Report on individual auditing studies and diagnosis in France*. Succelog. https://www.sucellog.eu/images/Publications_and_Reports/SUCELLOG_D6.5b_Individual_auditing_studies_and_diagnosis_in_France_EN.pdf.

3.6 VALORISATION OF AGRO-PRUNINGS IN ITALY

Year of Project: 2013-2016
Location: Puglia, Italy, Europe
Status: Proposed Project
Source: Chiostrini, C. (2017, February 15). *Promoting enterprise network and local supply chains for the energy valorisation of agro-prunings in Italy*. Presented at The Mobilisation of Agricultural Solid Biomass for Local Energy, Brussels.

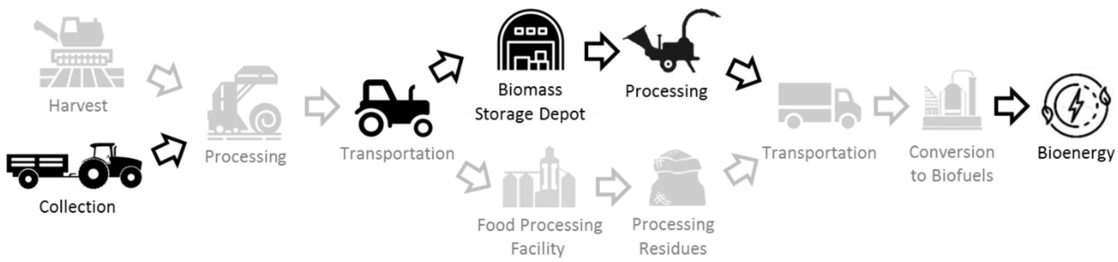
Bioenergy Supply Chain Summary
Biomass Type: Agriculture residue
Biomass Origin: Harvest residue/waste
Biomass Format: Chips
Biomass Amount: 3,500 oven dry tonnes/yr
Supply Chain Length: Local
Bioenergy Product: Combined Heat and Power
Stakeholders: Oleificio Cooperative Produttori Agricoli Molfetta

Overview of Case Study

In 2013, the Oleificio Cooperative Produttori Agricoli Molfetta, an olive oil cooperative, commissioned a study to assess the feasibility of producing wood chips from olive tree prunings to fuel a new Combined Heat and Power (CHP) plant that would supply electricity to the cooperative with any remaining surplus to be sold to the grid. The study found that cooperative members could provide upwards of 3,500 tonnes per year of olive tree prunings to the cooperative. The cooperative would also need to invest €75,000 in a wood chipper and €1,000,000 in the development of a cogeneration plant.

Details of Biomass Feedstock Supply Chain

Olive tree prunings would be sold to the cooperative by its members. The cooperative would store, process, and chip the olive tree prunings. The wood chips would then be used in the cooperative's CHP plant to produce electricity for the cooperative with any surplus fed to the electricity grid.



Drivers, Policies, Support Mechanisms

Primary drivers for this project were 1) creating value-added products from agricultural by-product, 2) using biomass without a competing use to provide energy to the cooperative and 3) supporting a rural development plan for the region. Successful implementation would require a significant amount of capital to construct a CHP plant and purchase a chipper, as well as coordination and collaboration between the cooperative and its members. The project concept was enabled through the European Union's (EU) Intelligent-Energy Europe (IEE) program.

Relation to Sustainable Development Goals

SDG	Target, Explanation	Evidence
Affordable & clean energy	7.2, Renewable energy share increased by replacing electricty produced from fossil fuels with development of cogeneration plant fueled by wood chips.	Tonnes of wood chips produced per year
Resposible consumption & production	12.2 (also 8.4), Waste streams used for energy instead of imported fuels. Resource-use efficiency increased, and overall material extraction/use decreased.	Tonnes of wood chips produced per year
Climate action	13.2, Project co-funded by the EU's IEE. Further investment made by DREAM Italia.	Funding agreement
Life on land	15.9, Replacing pile burning of prunings with use for biofuels supportsinclusion of olive groves with forest fire prevention practices in the Mediterannean ecosystem thereby improving other ecosystem and biodiversity meausures in national and local planning.	Described qualitatively in case study

Other Strengths, Weaknesses, Opportunities, Threats

Strengths

- Bioenergy produced from agricultural by-product with no indirect land use change while supporting wildfire mitigation in region.
- Providing revenue to local farmers from agricultural by-product.

Opportunities

- Reduce air pollution by burning olive tree branches for energy capture.
- Replication rate could improve if economically feasible across supply chain.

Weaknesses

- Little demand for heat from CHP and expertise to implement and manage system required.
- Requires cooperation from coop members across supply chain.

Threats

- Competition on wood fuel market is high, which may reduce the price of pruning fuel.
- Traditional practice of pile burning is hard to change.

3.7 BIOGAS POWERS GRASS BIOREFINERY IN GERMANY

Year of Project: 2007

Location: Brensbach, Hesse, Germany, Europe

Status: Implemented

Source: IEA Bioenergy. (2019). *Biowert Grass Biorefinery: Biobased Plastics, Germany*. IEA Bioenergy.

Bioenergy Supply Chain Summary
Biomass Type: Agriculture residue
Biomass Origin: Industrial and post-consumer waste
Biomass Format: Non-standardised (grass juice, food waste)
Biomass Amount: 1,942 tonnes/yr grass juice; 15,260 tonnes/yr co-substrates
Supply Chain Length: Local
Bioenergy Product: Biogas for Combined Heat and Power
Stakeholders: Biowert Industrie

Overview of Case Study

The Biowert grass refinery was constructed in 2007 and uses grass from surrounding crops and pastureland to manufacture bioproducts (e.g., grass fibre insulation and bioplastic). The grass juice remaining from pre-treatment of grass silage is used as substrate in the biogas plant. The biogas plant produces about 1,340,000 m^3 of biogas annually to fuel a Combined Heat and Power (CHP) plant. Digestate from the biogas plant is further processed to a concentrated and a liquid biofertilizer used by local farmers. The Biowert grass refinery utilizes waste streams from their own facility, and local manure and food waste that would otherwise be disposed.

Details of Biomass Feedstock Supply Chain

Grass is sourced from local pasture and crop lands and stored in bunker silos as silage. The grass fibres are processed into bioproducts while the remaining juice from the grass is used as substrate, along with local food waste, for the biogas plant to produce heat and electricity. The heat and electricity derived from the CHP is used to satisfy the energy requirements in the biorefinery and excess electricity is exported to the grid.

Drivers, Policies, Support Mechanisms

Primary drivers for this project were 1) increasing the competitiveness of the primary products by reducing energy costs and deriving additional income from digestate and 2) responsible waste management. The project was supported by the European Union's (EU) Renewable Energy Directive (RED) which provided a legal framework for promoting the use of biofuels in electricity and heat production. Key factors for the successful implementation of the biorefinery project include product diversity which allows the biorefinery to sell multiple products in different markets, achieve high sales prices, and rising electricity prices in the region making electricity produced from the refinery an affordable energy option.

Relation to Sustainable Development Goals

SDG	Target, Explanation	Evidence
Clean water & sanitation	6.3 Waste water re-used in processing grass; biogas digestate processed into liquid fertilizer and used on local fields instead of synthetic fertilizers.	Described qualitatively; 11,000 t/yr liquid digestate produced
Affordable & clean energy	7.2, Renewable energy share increased due to displacement of fossil fuels used for electricty production and process heat.	Amount of electricty generated from biogas (~5 GWh/yr)
Industry, innovation, infrastructure	11.6, Local food waste re-directed to biogas production (prior treatment of food wate unknown).	Described qualitatively in case study
Resposible consumption & production	12.2 (also 8.4) Waste streams used for energy displaces fossil fuels and digestate displaces synthetic fertilizer, improving resource-use efficiency and reducing material footprint.	Annual contribution: 11,362 tonnes of biofertilizer and 1.34 Mm^3 of biogas
 Climate action	13.2 Project supported by European and national programs established to achieve climate change and energy targets set by the EU's RED.	Described qualitatively in case study

Other Strengths, Weaknesses, Opportunities, Threats

<u>Strengths</u>

- Maximizing resource efficiency with product and power production.
- Re-use of wastewater from biogas plant in biorefinery and digestate as fertilizer closes the nutrient cycle in the circular economy.

<u>Opportunities</u>

- Potential to replicate model to areas with available grass feedstock and waste streams.

<u>Weaknesses</u>

- Significant capital and expertise in bioeconomy and bioenergy required.
- Finding markets for all the products produced.

<u>Threats</u>

- Availability of large volumes of grass feedstock may be limited in many regions and there is potential for competition with other land uses (e.g., crops for food/feed, forests).
- Large capital investment requirement

3.8 CROP RESIDUE COMBINED HEAT AND POWER IN KENYA

Year of Project: 2016

Location: Kenya, Africa

Status: Implemented

Source: International Renewable Energy Agency. (2018). *Sustainable Rural Bioenergy Solutions in Sub-Saharan Africa: A Collection of Good Practices*.

Bioenergy Supply Chain Summary
Biomass Type: Agriculture Residue
Biomass Origin: Crop or processing residues
Biomass Format: Non-standardised
Biomass Amount: Two tonnes per week
Supply Chain Length: Local
Bioenergy Product: Combined Heat and Power
Stakeholders: Village Industrial Power (VIP), Social Enterprise

Overview of Case Study

Village Industrial Power's (VIP) technology is a modernised steam engine that produces three phase electricity (10 kW), mechanical power (12 kW) and thermal energy (40 kW) using crop waste. It has a 60% energy conversion rate and is easily operated, repaired, and maintained in a small village setting. The engine can be combined with ancillary equipment like irrigation pumps, grain mills, dryers, and pasteurisers that allow rural businesses to increase revenues, primarily using heat to dry crops and allowing farmers to sell goods year-round. The power generated can also be used to charge batteries for other household uses. The technology was introduced in Kenya in 2016, where a maize processing unit was set up for local farmers.

Details of Biomass Feedstock Supply Chain

The system is fuel-flexible, using farm residues such as maize cobs, coffee parchment, mango pits, or bagasse. Residues may be from a crop, or crop processing, but generally are collected and brought directly to the drying unit where they are manually fed into the burner. In some cases, the system may be set up by a farmers group, allowing several farms from a region to access the crop dryer.

Drivers, Policies, Support Mechanisms

The primary drivers for adoption of technology were 1) to alleviate energy poverty for agro-processors by providing farmers with clean and reliable energy solutions and 2) increase the competitiveness of their farms by significantly reducing crop losses and increasing revenues. VIP also established a pilot partnership with Musoni, a Kenyan lending institution, to provide asset financing to farmers to lease a facility.

Relation to Sustainable Development Goals

SDG		Target, Explanation	Evidence
	No poverty	1.4, Farms and households now have access to electricity and heat for farming operations and households.	Described qualitatively in case study
	Zero hunger	2.3, Farm incomes increased from reducing post-harvest crop losses and adding preserved crops that can be sold out of season at a higher price.	Report states losses reduced up to 80%; incomes increased up to ten-fold
	Affordable & clean energy	7.1, and 7.2, Renewable energy share increased due to displacement of diesel generators with power from engine; power is provided to some households/farms that did not have it, increasing proportion of population with access to electricity.	Described qualitatively in case study
	Industry, innovation & infrastructure	9.4 (also SDG 13), CO_2 emissions reduced relative to heating with fossil fuels in the case where diesel is displaced; crop residues no longer burned openly.	Described qualitatively in case study
	Responsible consumption & production	12.3, Food waste reduced due to minimization of crop losses as it can be preserved for use throughout the year.	Report states crop losses reduced up to 80%

Other Strengths, Weaknesses, Opportunities, Threats

Strengths

- Simple design that is easily operated, repaired, and maintained in small village.
- Low cost operation using crop residues as fuel that previously had no value.

Opportunities

- Applicable to other developing countries (Company has plans to expand to Uganda, Tanzania and India).

Weaknesses

- Initial cost may be high as VIP partnered with a lending institution to offer leases and farm groups can lease a system together.

Threats

- Availability of crop residues; requires high-density agricultural production.
- Applicable only for farmers groups or SMEs; larger availability of residues and energy demand needed.

Other Sources

Mung'ata, M. (2017). *Rural communities access energy for income generating ventures*. Kenya Climate Innovation Center. https://www.kenyacic.org/2017/12/rural-communities-access-energy-for-income-generating-ventures/.

Flanagan, M. (2017). *Village Industrial Power offering innovative clean energy for rural farmers*. Farmbiz Africa. https://farmbizafrica.com/machinery/304-village-industrial-power-offering-innovative-clean-energy-for-rural-farmers.

3.9 BIOENERGY FROM SUGARCANE RESIDUES IN SOUTH AFRICA

Year of Project: 2015

Location: Nkomazi, South Africa, Africa

Status: Studied

Source: Röder, M., Stolz, N., & Thornley, P. (2017). Sweet energy – bioenergy integration pathways for sugarcane residues. A case study of Nkomazi, District of Mpumalanga, South Africa. *Renewable Energy,* 113, 1302 – 1310.

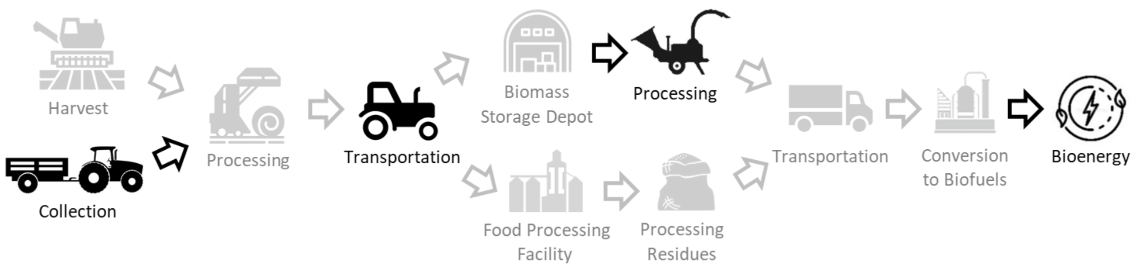
Bioenergy Supply Chain Summary
Biomass Type: Agriculture Residue
Biomass Origin: Crop harvest residue
Biomass Format: Non-standardised
Biomass Amount: N/A
Supply Chain Length: Local
Bioenergy Product: Electricity (potentially heat)
Stakeholders: Farmers, co-operatives, communities

Overview of Case Study

The study examined the potential socio-economic and environmental impacts of integrating bioenergy into the sugar cane value chain in South Africa amid rising electricity costs. Seeking input from local farmers and industry associations, the study examined four pathways to achieve sustainable land management practices while using sugar cane leaf residues to generate energy. Pathway (B): 'Field to community', by which sugar cane residues would be collected from small-scale farms and used to fuel a biomass power generator providing energy for the local community, was found to be the most supportive of local energy security and economic development. Other organic household wastes, farm and commercial activities could have been included as feedstocks but are not explicitly considered in this study.

Details of Biomass Feedstock Supply Chain

Sugarcane would be harvested manually with the tops of the stock, and the green and the brown leaves removed. Half of these residues would be left in the field to decompose, returning nutrients to the soil, with the other half, primarily brown leaves, collected and transported to the bioenergy facility to be shredded before being used as a fuel source. While the conversion technology and end-use were not specified, the energy derived from combusting these residuals would be distributed through decentralized infrastructure to the local community.



Drivers, Policies, Support Mechanisms

Primary drivers for this project were 1) to improve the reliability, affordability and security of energy supply in rural communities and 2) to reduce the net GHG emissions of energy production. Studying potential economic development opportunities for communities, empowering small-scale farmers, and supporting community resilience was another driver for studying the impacts of bioenergy deployment. In addition, national interest in reducing carbon emissions may further support bioenergy projects.

Relation to Sustainable Development Goals

SDG		Target, Explanation	Evidence
	Zero hunger	2.3, Re-directing sugar cane residues for bioenergy generation could provide new economic opportunities for farmers.	Identified as likely impact by stakeholders interviewed
	Affordable & clean energy	7.1 & 7.2, Increasing share of renewable energy would increase and reduce community dependence on fossil fuels providing reliable and affordable energy.	Described qualitatively in case study
	Decent work & economic growth	8.5, Community-scale bioenergy generation would likely lead to economic development and generate employment opportunities.	Identified as likely impact by stakeholders interviewed
	Industry, innovation & infrastructure	9.4, CO_2 emissions would be reduced relative to fossil-generated electricity and traditional cooking and heating fuels; pre-harvest crop burning practices would be replaced with controlled combustion.	Identified as likely impact by stakeholders interviewed
	Reducing inequality	10.3, Local energy generation and distribution may reduce inequalities in access to resources, services, and empower rural communities where electricity is unreliable and costly.	Identified as likely impact by stakeholders interviewed

Other Strengths, Weaknesses, Opportunities, Threats

Strengths

- Green cane harvest, instead of pre-harvest burning, generates additional employment opportunities and improves soil quality.
- Adding value to residues infers income resilience to farmers.

Opportunities

- Improve use of sugarcane residues.
- Improve energy security as power supply in region is inconsistent, expensive and increasing, and most power is produced by state-owned supplier.

Weaknesses

- Increased demand in labour and transport, associated with green harvest would increase post-harvest cost by about 20%.
- Consistency of feedstock supply will be limited by timing and season of harvest.

Threats

- The lacking regulatory and policy framework regarding bioenergy generation.
- Challenges protecting facilities from crime.

3.10 BRIQUETTES FROM RICE HUSKS IN TANZANIA

Year of Project: 2013 - ongoing

Location: United Republic of Tanzania, Africa

Status: Implemented

Source: International Renewable Energy Agency. (2018). *Sustainable Rural Bioenergy Solutions in Sub-Saharan Africa: A Collection of Good Practices.*

Bioenergy Supply Chain Summary

Biomass Type: Agriculture residue

Biomass Origin: Post-industrial residue or waste

Biomass Format: Not-standardised (rice, peanut husks)

Biomass Amount:300,000 green tonnes/yr

Supply Chain Length: Local/Regional/National/International

Bioenergy Product: Briquettes

Stakeholders: Tromso Co. Ltd., DEMACO Co. Ltd.,Rice processors

Overview of Case Study

To address deforestation caused by the increased use of woody biomass for energy production in the country, the government of Tanzania procured Tromso Co. Ltd's briquette-producing machine from Japan in 2013 to manufacture briquettes made primarily from rice husks. Four types of briquettes can be made by the machine: 1) only rice husks 2) a combination of rice husks, coal and Allanblackia powder 3) 50% rice husk and 50% sawdust, and 4) carbonated rice husk briquettes (i.e., charcoal from already-used rice briquettes). Charcoal produced from burning rice briquettes can also be transformed into activated charcoal useable for purifying water. Pilot projects producing and using the briquettes have been successful and Tromso is looking at ways to reduce costs to replicate in other locations.

Details of Biomass Feedstock Supply Chain

Rice husks are sourced from local rice mills as a waste product after they have been removed from grains of rice during processing. Depending on the type of briquette that is being made, these husks are either made into briquettes on their own or are combined with either sawdust, Allablackia powder and coal powder, or a combination of all, and then made into briquettes. The briquettes are then used as a cooking fuel alternative to coal or solid biofuel from traditional wood resources which are being rapidly depleted in the region.

Drivers, Policies, Support Mechanisms

Primary drivers for this project are 1) providing alternative biomass for bioenergy production to reduce woody biomass consumption leading to deforestation 2) maximize resource efficiency and 3) create value-added products from agriculture waste.

Relation to Sustainable Development Goals

SDG	Target, Explanation	Evidence
Zero hunger	**2.3**, Briquettes from food processing residues generate new and diversified residues for producers.	Desire to create value-added products from waste was a project driver
Affordable & clean energy	**7.2**, Renewable energy share increased through briquette production.	Number of briquettes produced a year that displace traditional cooking fuels
Responsible consumption & protection	**12.2,** Briquette production from agriculture residue that were previously unused (often burned) improves resource-use efficiency.	Tonnes of rice husks per year used to produce briquettes
Life on land	**15.2,** Reducing deforestation by providing alternative biomass feedstocks for bioenergy production.	Reduction in deforestation per year; described qualitatively in case study

Other Strengths, Weaknesses, Opportunities, Threats

Strengths

- Partially sourcing parts for, and assembling, briquette machine in Tanzania leads to lower costs and easier uptake.
- Variety of briquettes can be used, with charcoal produced from briquettes recycled for other uses.

Opportunities

- Reducing agriculture waste that would traditionally be burned without energy capture.
- Briquette machines can be used for other agriculture residues (e.g., peanut husks).

Weaknesses

- Quality of briquettes.

Threats

- Consumers not familiar with briquettes.

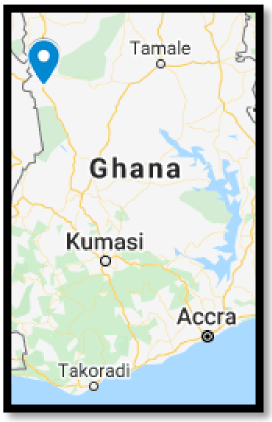
3.11 WOMEN-LED BIOENERGY IN AGRO-INDUSTRIES IN GHANA

Year of Project: 2015

Location: Ghana, Africa

Status: Implemented

Source: International Renewable Energy Agency. (2018). *Sustainable Rural Bioenergy Solutions in Sub-Saharan Africa: A Collection of Good Practices.*



Bioenergy Supply Chain Summary

Biomass Type: Agriculture residue

Biomass Origin: Post-industrial residue or waste

Biomass Format: Not-standardised

Biomass Amount: N/A

Supply Chain Length: Local

Bioenergy Product: Heat and electricity

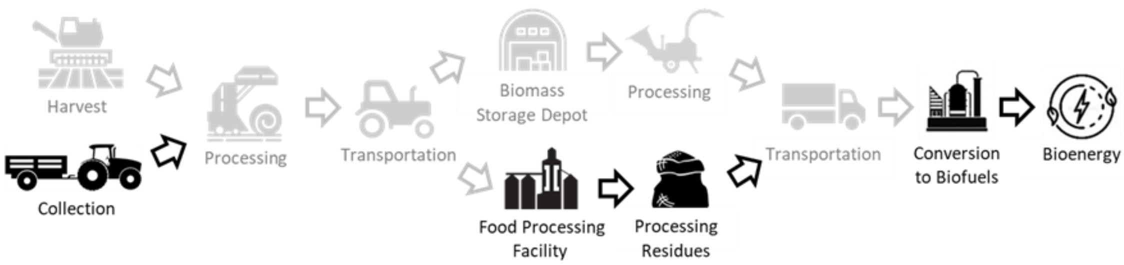
Stakeholders: Institute for Sustainable Energy and Environmental Solutions (ISEES), local Womens' Organizations

Overview of Case Study

The Institute for Sustainable Energy and Environmental Solutions (ISEES) is a Ghanaian-based non-governmental organization (NGO) that supports the deployment of climate-smart and renewable technologies to low-income households and small-scale agro-processing businesses led by women. Rural food processing industries in Ghana rely primarily on women's labour and ISEES supports these small businesses by consulting them on their needs and providing solutions to improve working conditions. ISEES has supported the implementation and use of biogas stoves for food processing. These stoves improve the sterilisation and longevity of the food being processed (i.e., cassava, mushrooms, and fish). The biogas is also used to provide electricity required for food processing. The biogas stoves rely on agriculture residues and reduce the emissions and smoke from food processing improving both health and working conditions for women.

Details of Biomass Feedstock Supply Chain

One example of the successful implementation of these biogas stoves systems is in Bole, Northern Ghana. Shea nuts are collected and processed by employees, with the shea butter processing effluent transported to a 50m^3 fixed dome biogas digester for anaerobic digestion. The biogas digester can produce upwards of 12m^3 of biogas daily and is used to power the shea nut kernel-grinding mill.



Drivers, Policies, Support Mechanisms

Primary drivers for this project were 1) to improve access to efficient, renewable, and safe energy sources for female-led small-scale agro-processing businesses, 2) reduce greenhouse gas emissions associated with agro-processing in Ghana and 3) improve economic development in low-income rural areas of Ghana.

Relation to Sustainable Development Goals

SDG	Target, Explanation	Evidence
No poverty	**1.1 & 1.2,** Project supplies affordable biogas to agro-processing businesses.	Described qualitatively in case study
Good health & well-being	**3.9,** Project reduces emission and smoke pollution in the workplace improving health conditions for employees.	Described qualitatively in case study
Gender equality	**5.a,** Project supports women-led businesses by providing access to clean, safe, and renewable energy.	Described qualitatively in case study
Affordable & clean energy	**7.1**, Project increased the share of renewable heat and electricity and reduces dependence on fossil fuels.	Its 50 m^3 fixed dome biogas digester capable of generating 12 m^3 of biogas daily
 Reducing inequality	**10.1,** Renewable energy production in rural areas of Ghana may reduce inequalities between rural-urban areas and improve economic opportunities.	Described qualitatively in case study

Other Strengths, Weaknesses, Opportunities, Threats

Strengths

- The ISEES supports women-led businesses in improving working conditions and provides opportunities to rurally-located businesses.
- Different technologies provided by ISEES to optimize support of different business contexts.

Opportunities

- Opportunity to replicate easily with many small scale agro-processors.

Weaknesses

- Limited financial capacity can impair uptake and management of biogas systems.

Threats

- Maintaining biogas systems in rural areas.

4 Energy Crop Supply Chain Case Studies

Energy Crop Supply Chain Case Studies' Primary Contributions to SDGs																	
	Title	SDG															Status
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
1	BiogasDoneRight®	x	x					x		x				x		x	I
2	Willow for Energy and Water Treatment						x		x							x	I
3	Algae Cultivation for Biofuel Production						x	x		x							S
4	Switchgrass Intercropped in Pine Forests						x	x						x			S
5	Perennial Grass in Buffer Zones		x				x	x									S
6	Water Quality and Switchgrass in Agriculture		x				x	x	x	x							P
7	Willows in Buffer Zones		x				x	x		x							S
8	Living Snow Fences			x				x		x			x	x			S
9	Integrated Bioenergy Tree Crop Systems		x				x	x								x	S
10	The Emerald Plan							x						x		x	S
11	Reduced Water Use in Sugarcane Industry						x	x					x		x		I
12	Bioenergy and Food Security		x		x	x		x								x	I

I = Implemented, P = Proposed, S = Studied

* Supply chains can contribute to multiple SDGs, however SDGs listed were those identified as most relevant.

4.1 BiogasDoneRight® (ITALY)

Year of Project: 2009

Location: Po River Valley, Italy, Europe

Status: Implemented

Source: Bezzi, G., & Rossi, L. (2016). Biogas done right. In B. Kulišić, G. Berndes, I. Dimitriou & M. Brown (Eds.), *Attractive Systems for Bioenergy Feedstock in Sustainably Managed Landscapes* (pp.21-23). International Energy Agency Bioenergy.

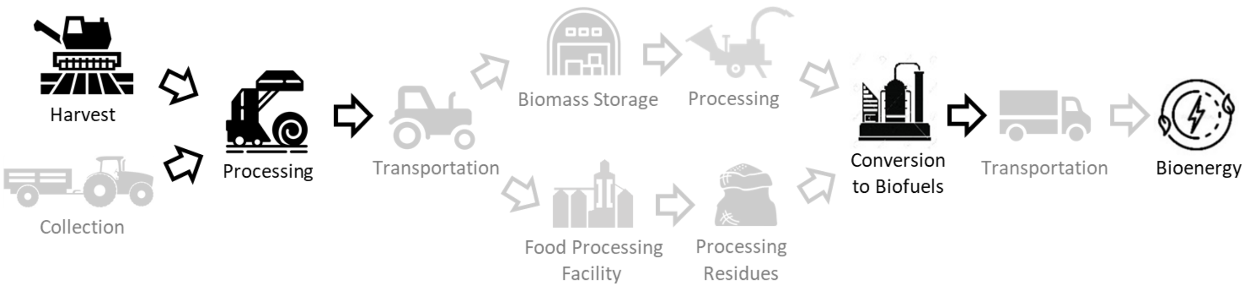
Bioenergy Supply Chain Summary
Biomass Type: Energy crop
Biomass Origin: Co-productive system
Biomass Format: Non-standardized
Biomass Amount: Variable from site to site
Supply Chain Length: Local
Bioenergy Product: Biomethane (co-product fertilizer)
Stakeholders: Italian Biogas Consortium (CIB)

Overview of Case Study

Consorzio Italiano Biogas (CIB) brings together more than 730 Italian owners of on-farm biogas plants with industries, operators and technicians. The BiogasDoneRight® model has been developed to improve the resilience and sustainability of farming. The concept is a bottom-up approach focused on intercropping annual energy crops with crops grown for food and feed. The biomass crops are harvested to produce biogas and have a low risk of indirect land use change (iLUC). Digestate from biogas production is used as fertilizer by farmers to restore minerals in the soil. In 2019, 20 biomethane liquefaction plants were constructed on farms to produce liquid fuel from the biogas. Currently 72% of Italian biogas-producing farms have used the "Biogas Done Right" concept to produce biogas.

Details of Biomass Feedstock Supply Chain

Biomass crops are planted between cash crops in areas that are underutilized. Biomass crops are grown, harvested, ensiled, and then fed to the anaerobic digestion (AD) units, along with other on-farm feedstocks such as manure and other crop residues. The raw biogas is used in a Combined Heat and Power (CHP) plant to produce electricity that is supplied to the electricity grid or will be upgraded to biomethane. In addition, excess waste from the AD process, digestate, is collected and used as fertilizer in local farm fields.



Drivers, Policies, Support Mechanisms

The primary driver for the BiogasDoneRight® model was 1) to improve the resiliency of farming practices and increase farmer income in the region as crop land was bare for 45% of the year and farmers were reliant on food crops for income and 2) to displace fossil fuels through the generation of renewable electricity (slowly shifting towards biomethane for transport). A feed-in-tariff system for renewable electricity or biomethane enabled the establishment of on-farm AD systems.

Relation to Sustainable Development Goals

SDG	Target, Explanation	Evidence
No poverty	1.5, Additional income stream from biomass reduces impacts from harvest yield or damaged crops.	Qualitative: "Additional crop hedges against crop losses, builds resilience of farms"
Zero hunger	2.3, Farm incomes increased due to reduced fertilizer costs, electricity sales. 2.4, Productivity of crop land improved due to reduced use of synthetic fertilizer.	21/43% cost reduction for feed/biogas silage Average 30 to 35 t/ha additional biomass
Affordable & clean energy	7.2, Renewable energy share increased in the national electricity grid, reducing the need for fossil-fuel generated electricity.	Total electricity from biogas in Italy is >8,000 GWh/year
 Industry, innovation, infrastructure	9.4 (also SDG 13), GHG emissions significantly reduced relative to fossil electricity and can be carbon negative.	GHG intensity of electricity reduced by 86% compared to fossil fuel
Climate action	13.2 Project supported by European and national programs established to achieve climate change and energy targets set by the European Union Renewable Energy Directive.	Funding provided by EU and Italy
Life on land	15.3, Double-cropping shown to improve soil quality compared to traditional crop; potential to remediate degraded land.	0.5% increase in soil organic matter and improved nitrogen stability

Other Strengths, Weaknesses, Opportunities, Threats

<u>Strengths</u>

- Does not result in land use change due to integration with existing crop system.
- Farmer benefits from improved soil quality while sequestering CO_2 in the soil.

<u>Opportunities</u>

- High replicability in intensive agriculture areas with developed/developing biogas market.
- Reduced use of mineral fertilizers due to the nutrients from digestate and double-cropping preventing soil erosion.

<u>Weaknesses</u>

- Agriculture development requires investment costs.
- Lack of legal framework or local leader to implement the overall concept.

<u>Threats</u>

- System may no longer be viable in the absence of a feed-in-tariff for renewable energy.
- Concept may be overwhelming for the farmer (I.e., growing additional crop; managing facility).

4.2 WILLOW FOR ENERGY AND WATER TREATMENT IN SWEDEN

Year of Project: 2000

Location: Enköping, Sweden, Europe

Status: Implemented

Source: Sööder, F., Nilson, M., Olevik, J., Forsberg, J., Jacobsson, A., Holm, L., Svensson, I., Uebel, C., Haglun, J., & Ekman, O. (2013). *Industrial Symbiosis in Enköping*. Linköping University.

Bioenergy Supply Chain Summary

Biomass Type: Energy crop

Biomass Origin: Primary production

Biomass Format: Chips

Biomass Amount: 3,000 dry tonnes/yr

Supply Chain Length: Regional

Bioenergy Product: District heat and electricity (co-product fertilizer and water treatment)

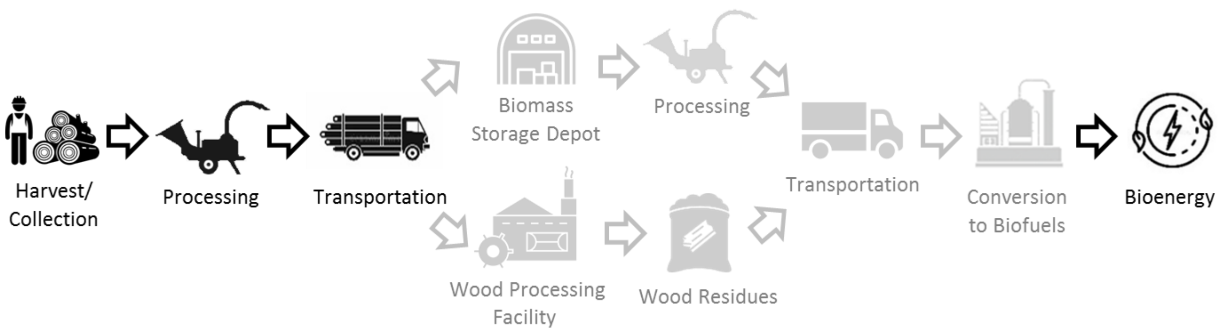
Stakeholders: ENA Energi, Wastewater treatment plant (owned by Enköping municipality), Willow farmers

Overview of Case Study

The municipality of Enköping has been generating heat and electricity with biomass since the 1980s. In the early 2000s, the local wastewater treatment plant (WWTP) faced costly upgrades. Instead of investing in upgrades, an arrangement was made with local farmers to establish short rotation willow plantations on existing agricultural land. The plantations receive wastewater and sludge as fertilizer that would otherwise need to be handled by the WWTP, and ENA Energi purchases willow chips from farmers to use as fuel at its biomass CHP plant, which is connected to a district heating network.

Details of Biomass Feedstock Supply Chain

Several farms surrounding Enköping grow willow crops to supply chips to ENA Energi and receive wastewater and sludge from the WWTP to fertilize the crops. Thanks to the use of wastewater and sludge as fertilizer, willow crops can be harvested every three years instead of four. Willow crops are harvested with a specially designed harvester that produces chips, which are transported directly to the Combined Heat and Power (CHP) plant for use as fuel. Other biomass fuels used in the power plant include wood residues and pellets; willow typically displaces higher cost pellets and makes up 10-20% of the fuel used.



Drivers, Policies, Support Mechanisms

The primary driver for this project was to improve the management of wastewater and sludge from the WWTP in order to avoid investment in costly upgrades, necessary due to stricter regulations on nitrogen emissions issued by the European Union (EU) in the 1990s. Close cooperation between stakeholders was also key to the success of this project. A planting subsidy covered about half of the establishment costs.

Relation to Sustainable Development Goals

SDG	Target, Explanation	Evidence
Clean water & sanitation	6.3, Wastewater applied to willows was previously discharged to environment. Application of sludge to willows increases proportion of wastewater safely treated and minimizes leaching to waterways.	>20,000 m3 of untreated wastewater diverted from local waterways; >1 ton of phosphorus recovered
Affordable & clean energy	7.2, Renewable energy share increased by using woodchips from short rotation willows as feedstock in CHP plant.	3,000 dry tonnes/year of willow chips
Decent work & economic growth	8.2, Higher levels of economic productivity were achieved by the WWTP (reduced infrastructure investment) and ENA Energi (reduced fuel cost if pellets displaced).	WWT plant saved ~15 million Swedish Korna (MSEK), fuel cost reduced by ~2.5 MSEK/year
Life on land	15.3, Willow crops improve soil quality and absorb cadmium therefore purifying the soil. Contaminated land, after growing willow, might be suitable for food crop.	Described qualitatively in case study

Other Strengths, Weaknesses, Opportunities, Threats

<u>Strengths</u>

- Guaranteed market for willow trees, along with planting subsidy, reduced risk for farmers and improved economic feasibility.

<u>Opportunities</u>

- Excellent opportunity for landowners that are not active in farm management to become active.
- Prevents non-utilised agriculture land degradation and afforestation.

<u>Weaknesses</u>

- Limited opportunity to replicate model as many factors must align, including established market for willow and removal of restrictions on use of sludge as fertilizer.
- Willow chips are a small income source for which other crops or land use might represent a better income opportunity for farmers.

<u>Threats</u>

- Potential for iLUC if willow is planted on crop land.
- Requires agriculture, environmental and renewable energy stakeholder coordination and policy agreement.

Other Sources

Dimitriou, I., & Aronsson, P. (2005). Willows for energy and phytoremediation in Sweden. *Unasylva* 56 (221), 47-50.

4.3 ALGAE CULTIVATION FOR BIOFUEL PRODUCTION (USA)

Year of Project: 2013-2015

Location: Tampa Bay, Florida, United States, North America

Status: Studied

Source: Philippidis, G. (2016). Development of a scalable algae cultivation system that enhances water sustainability in algal biofuel production in the United States. In *Examples of Positive Bioenergy and Water Relationships* (pp. 71-73). *Global Bioenergy Partnership and International Energy Agency Bioenergy.*

Bioenergy Supply Chain Summary

Biomass Type: Energy Crop

Biomass Origin: Primary production

Biomass Format: Not standardised

Biomass Amount: N/A

Supply Chain Length: Local

Bioenergy Product: Liquid Biofuel

Stakeholders: University of South Florida (Patel College of Global Sustainability), Culture Fuels Inc.

Overview of Case Study

A floating horizontal bioreactor (HBR) was developed to study the production, cost and sustainability of algae cultivation for biofuel production. The bioreactor was an enclosed system made from low-density polyethylene with a working volume of 150 litres and a depth of five centimetres. This setup increased the exposure to light, increasing algae growth, while minimizing water usage. The HBR is being scaled-up for pre-commercial testing and is intended to be used on pieces of land and bodies of water that have no use for human activities.

Details of Biomass Feedstock Supply Chain

Algae was grown in the HBR, with the use of a built-in paddle wheel to mix the algae and water, both indoors and outdoors. This algae is then harvested and converted into biofuels to be used as bioenergy.

Drivers, Policies, Support Mechanisms

Primary drivers for this project were 1) reducing the cost of algae cultivation for biofuel production and 2) reducing the amount of energy and water used in algae cultivation.

Relation to Sustainable Development Goals

SDG	Target, Explanation	Evidence
Clean water & sanitation	6.4, Horizontal bioreactor designed with inexpensive plastic film to minimize contamination and evaporation of water.	Described qualitatively in study
Affordable & clean energy	7.1 & 7.2, Horizontal bioreactor will reduce the cost of sustainably cultivating algae in turn reducing biofuel production costs and will increase sustainable cultivation of algae for biofuel production.	Described qualitatively in study
Industry, innovation, infrastructure	9.4, Horizontal bioreactor reduces energy consumption reducing CO_2 emissions associated with algae cultivation; increase biofuel feedstock availability for low-carbon fuel production.	Described qualitatively in study

Other Strengths, Weaknesses, Opportunities, Threats

<u>Strengths</u>

- Inexpensive technology.
- Able to cultivate algae year-round.

<u>Opportunities</u>

- Easy to manufacture.
- Does not require a lot of space, maximizing biomass feedstock growth per acre.

<u>Weaknesses</u>

- Unknown efficiency at larger scale.
- Not commercialized yet.

<u>Threats</u>

- Cost competitiveness of biofuel from algae compared to others biofuels.

Other Sources

Dogaris, I., Welch, M., Meiser, A., Walmsley, L., & Philippidis, G. (2015) A novel horizontal photobioreactor for high-density cultivation of microalgae. *Bioresource Technology*, 198, 316-324.

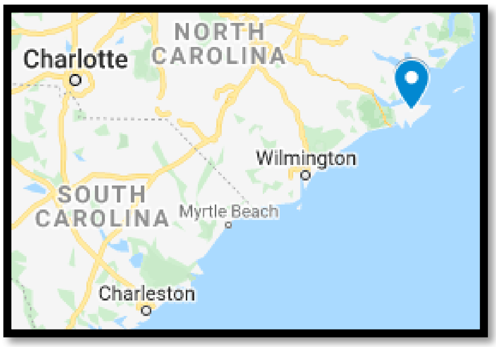
4.4 SWITCHGRASS INTERCROPPING IN PINE FORESTS (USA)

Year of Project: 2010-2016

Location: Carteret County, North Carolina, United States, North America

Status: Studied

Source: Amatya, D. (2016). Impacts of switchgrass intercropping in traditional pine forests on hydrology and water quality in the southeastern United States. In *Examples of Positive Bioenergy and Water Relationships* (pp. 75-79). *Global Bioenergy Partnership and International Energy Agency Bioenergy*.



Bioenergy Supply Chain Summary

Biomass Type: Energy Crop

Biomass Origin: Co-productive System

Biomass Format: Bales

Biomass Amount: N/A

Supply Chain Length: Regional

Bioenergy Product: Liquid Biofuel

Stakeholders: United States Department of Agriculture, Forest Service Southern Research Station, Centre for Forested Wetlands Research, Cordesville, South Carolina

Overview of Case Study

A study examining the environmental effects of intercropping switchgrass for biomass cultivation in pine plantations was conducted from 2010-2016. The main objectives of the study were to characterize temporal effects of management to predict impacts on downstream water quantity and quality. Measures were taken to minimize erosion and other impacts during site preparation. The study found no significant effect of switchgrass intercropping on daily water table elevations, water flows or nutrient runoff. The study is being replicated at two other sites in the States of Mississippi and Alabama to examine the impacts on a larger scale and assess the potential of the intercrop system to serve as a biofuel feedstock.

Details of Biomass Feedstock Supply Chain

Switchgrass was planted from seed between pine tree rows, two years after pine plantation establishment, and left to grow for four years. It was then harvested, collected, and baled using modified agricultural equipment. The future intent is for the bales to be transported to biofuel processing facilities though only the biomass production aspect was studied.

Drivers, Policies, Support Mechanisms

The primary driver for this project was to assess the environmental impacts and overall feasibility of intercropping switchgrass in pine forests with the intention of increasing cellulosic feedstock for biofuel production as demand for low-carbon fuels continues to increase.

Relation to Sustainable Development Goals

SDG	Target, Explanation	Evidence
Clean water & sanitation	6.3, No change in water quality or nutrient runoff before and after intercropping; temporary nutrient level increase post harvesting.	Nitrogen levels of local watershed before and after study
	6.4, No change in water table or water flow. Switchgrass may use slightly less water than the pine they replace, based on early result.	Water table levels and flow data (m) before and after study
Affordable & clean energy	7.2, Potential area that could be intercropped with switchgrass for biomass cultivation for biofuel production.	Amount of switchgrass harvested per hectare (Kg/Ha-1).
Climate action	13.2, Multi-collaborative research partnership with government, academia, and industry.	USD

Other Strengths, Weaknesses, Opportunities, Threats

Strengths

- Value-added product/land-use efficiency.
- Potential for increased profits for farmers.

Opportunities

- Switchgrass can also be used as cattle feed.

Weaknesses

- Expensive and time consuming planting process; the need to modify agricultural equipment led to bale costs nearly double than in agricultural field.
- Upfront investment in storage and pre-processing of switchgrass.

Threats

- Competition from potential commercial-scale cellulosic biorefinery.

Other Sources

Muwamba, A., Amaty, D. M., Ssegane, H., Chescheir, G.M., Appelboom, T., Nettles, J. E., Tollner, E. W., Youssef, M A., Walega, A., & Birgand, F. (2020). Response of Nutrients and Sediment to Hydrologic Variables in Switchgrass Intercropped Pine Forest Ecosystems on Poorly Drained Soil. *Water, Air and Soil*, 231:458.

Muwamba, A., Amatya, D. M., Chescheir, G. M., Nettles, J. E., Appelboom, T., Tollner, Ernest W., Ssegane, H., Youssef, M. A., Birgand, F., & Callhan, T. (2020). Response of Drainage Water Quality to Fertilizer Applications on a Switchgrass Intercropped Coastal Pine Forest. *Water*, 12(5): 1265.

Muwamba, A., Amatya, D. M., Chescheir, G. M., Nettles, J. E., Appelboom, T., Ssegane, H., Tollner, E. W., Youssefy, M. A., Birgand, F., Skaggs, R. W., & Tian, s. 2017. Water Quality Effects of Switchgrass Intercropping on Pine Forests in Coastal North Carolina. *American Society of Agricultural and Biological Engineers*, 60(5):1607.

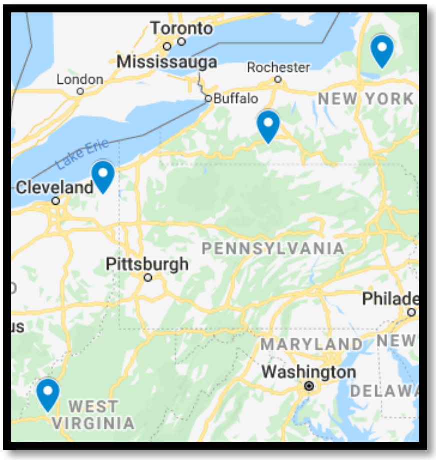
4.5 PERRENIAL GRASS IN BUFFER ZONES (USA)

Year of Project: 2011-2015

Location: Chesapeake Bay watershed, North Central/Northeast regions, United States, North America

Status: Studied

Source: Goldner, W. (2016). Integrating perennial bioenergy crops to enhance agricultural water quality in the north central and northeastern United States. In *Examples of Positive Bioenergy and Water Relationships* (pp. 91-95). *Global Bioenergy Partnership and International Energy Agency Bioenergy.*



Bioenergy Supply Chain Summary

Biomass Type: Energy Crop

Biomass Origin: Co-productive System

Biomass Format: Bales

Biomass Amount: 3-5 million tonnes/yr

Supply Chain Length: Regional

Bioenergy Product: Liquid Biofuel

Stakeholders: Institute of Bioenergy, Climate, and Environment, United States Department of Agriculture

Overview of Case Study

A five-year project was commissioned between 2011 and 2015 to study perennial grass growth in the north-central and north-eastern region of the United States for advanced transportation fuel production. The study found that three to five million tonnes of biomass feedstock could be harvested annually from perennial grasses while dramatically improving water quality by reducing nitrogen runoff into the Chesapeake watershed. The study also found that perennial grasses grown as biomass feedstock could reduce nutrient and sediment loss in the region without substantial conflicts with food or fibre production. The project was part of a larger strategy to develop a regional biomass feedstock supply for advanced biofuels and bioproducts using land either unsuitable for row crop production or with low productivity rates for row cropping.

Details of Biomass Feedstock Supply Chain

Perennial grasses were planted in fields that were either unsuitable for row crop production or had low productivity rates for row cropping. Once fully grown the grass was harvested, collected and baled using conventional agriculture equipment. The future intent is for the bales to be transported to biofuel processing facilities though this study is focussed on biomass production.

Drivers, Policies, Support Mechanisms

The primary driver was to grow biomass on unused land for biofuel and bioproduct production. Supporting policies include the United States' Federal Renewable Fuel Standard which requires transportation fuels to contain a minimum amount of renewable fuel, and the state of Pennsylvania's Nutrient Trading Program, a credit system for reducing effluent waste among farmers to help restore the Chesapeake Bay watershed.

Relation to Sustainable Development Goals

SDG		Target, Explanation	Evidence
2	Zero Hunger	2.4, Potential to improve soil quality and arable land quantity through bioenergy crop production based on unused, unproductive, or available agricultural land.	Qualitative, described as a co-benefit of perennial grasses
6	Clean water & sanitation	6.3, Improving water quality; modelled potential for removal of nitrogen from local/regional watershed.	Estimate nitrogen loading reduced by 24-38 kg/ha/yr
		6.5, Establishment of NEWBio (Consortium of academia, industry, government laboratories); Chesapeake Bay Commission.	Described qualitatively in case study
7	Affordable & clean energy	7.2, Potential bioenergy crop production based on unused, unproductive, or available agricultural land.	Potential hectares of land

Other Strengths, Weaknesses, Opportunities, Threats

Strengths

- Maximizing marginal land for biomass feedstock production (i.e., land-use efficiency).
- Improving local water quality and soil.

Opportunities

- Diversify and possibly increase income for farmers.

Weaknesses

- Feedstock costs of environmentally beneficial perennials and cover crops.

Threats

- Current market conditions and agricultural policy.
- Cost to establish perennial crops and payback time on investment.

4.6 WATER QUALITY AND SWITCHGRASS IN AGRICULTURE LANDSCAPES (USA)

Year of Project: 2007-2012

Location: Lower Little Tennessee watershed and 10-county supply shed area in east Tennessee, United States, North America

Status: Studied

Source: Negri, C. M. (2016). Introduction of switchgrass in agriculture landscapes to reduce stream nutrient and sediment concentrations in the southeastern United States. In *Examples of Positive Bioenergy and Water Relationships* (pp. 96-100). GBEP and IEA.

Bioenergy Supply Chain Summary

Biomass Type: Energy Crop

Biomass Origin: Primary production

Biomass Format: Bales

Biomass Amount: N/A

Supply Chain Length: Regional

Bioenergy Product: Liquid Biofuel

Stakeholders: State of Tennessee, University of Tennessee Institute of Agriculture and AgExtension agents, DuPont, Genera Energy, Tennessee farmers, University of Tennessee, Oak Ridge National Laboratory

Overview of Case Study

A Biomass Location for Optimal Sustainability Model (BLOSM) was developed by Oak Ridge National Laboratory (ORNL) and five scenarios were modelled using an assumed production of 50,000 mega tonnes of switchgrass from the Lower Little Tennessee watershed region to supply a commercial biorefinery. All five models suggested an increase in water quality, zero change in water availability and only minor impacts on overall economic profits for farmers if they converted portions of their land to switchgrass. Beginning in 2008, farmers throughout a 10-county area surrounding a demonstration-scale biorefinery in Vonore, Tennessee were contracted to grow switchgrass, and a total of 2,064 hectares of corn/soy row crops and pasture were converted to switchgrass. Empirical measurements taken at 12 fields showed reductions in sediment and nutrient export, and SWAT modelling of nearby streams calibrated with local flow measurements showed water quality improvements following the perennial grass plantings.

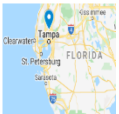
Details of Biomass Feedstock Supply Chain

A local supply chain was developed for a pilot scale (1 million litres) cellulosic biorefinery from 2007-2012. Farmers were contracted to grow switchgrass three years in advance of construction for the biorefinery. The perennial grasses were harvested and baled using conventional agricultural equipment and then transported to the biorefinery. A combination of switchgrass and corn cobs was used to generate ethanol that went into E85 fuel for vehicles in the University of Tennessee’s Motor Pool fleet. The biorefinery has since closed.

Drivers, Policies, Support Mechanisms

The primary driver for the BLOSM modelling was to assess environmental impacts of switchgrass production for biofuel production prior to the selection of planting locations. The BLOSM modelling work was funded by ORNL through its internal Lab Directed Research and Development program. From 2007 to 2012, the Tennessee Biofuels Initiative invested $70.5 million in the construction of a pilot-scale biorefinery and contracts with farmers in surrounding counties. Subsequent ORNL sustainability analysis of the five-year case study was funded through the United States (US) Department of Energy's BioEnergy Technologies Office.

Relation to Sustainable Development Goals

SDG		Target, Explanation	Evidence
	Zero hunger	2.1, Modelled impacts of integration of energy crops on food security and found no change in food price volatility due to switchgrass production.	Percent change in food price volatility (no change found)
	Clean water & sanitation	6.3, Soil and Water Assessment Tool (SWAT) and Multi-Attribute Decision Support System (MADDS) are used to assess water indicators.	SWAT: seven soil/land measurements MADDS: 12 ecological indicators
7 AFFORDABLE AND CLEAN ENERGY	Affordable & clean energy	7.2, Amount of switchgrass that could be grown for bioenergy production.	107 - 1640 ha of non-agricultural land, 1,477 - 3,344 ha agricultural land
8 DECENT WORK AND ECONOMIC GROWTH	Decent work	8.5, Harvesting and baling switch grass would provide additional jobs for labourers year- round.	60-90 full-time jobs were created during the study
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	Industry, innovation & infrastructure	9.5, Funding for innovative cellulosic biofuel project from several sources including US Department of Energy, State of Tennessee, DuPont, and others.	70$ million USD for switchgrass/biorefinery pilot

Other Strengths, Weaknesses, Opportunities, Threats

Strengths

- Switchgrass can be harvested off-season for farmers maximizing land, equipment, and labourers.
- Switchgrass has potential for greater profit than corn in region since it is native to the area and needs fewer chemical inputs.

Opportunities

- Complementary uses for switchgrass such as cattle feed.
- Improvement in local biodiversity (e.g., switchgrass farmers observed quail returning to their fields).

Weaknesses

- Upfront investment in storage and pre-processing equipment can be expensive.
- More than 1400 stored bales were burned through arson.

Threats

- Commercial-scale cellulosic biorefinery was expected to move to the region but was built in the state of Iowa instead despite a successful demonstration-scale experiment.

Other Sources

Parish, E. S., Hilliard, M. R., Baskaran L. M., Dale, V. H., Griffiths, N. A., Mulholland, P. J., Sorokine, A., Thomas, N. A., Downing, M. E., & Middleton, R. (2012). Multimetric Spatial Optimization of Switchgrass Plantings Across a Watershed. *Biofuels, Bioproducts & Biorefining* 6(1), 58-72.

Parish, E.S., Dale, V.H., English, B.C., Jackson, S.W., & Tyler, D. (2016). Assessing multimetric aspects of sustainability: Application to a bioenergy crop production system in East Tennessee. *Ecosphere* 7(6):1-18.

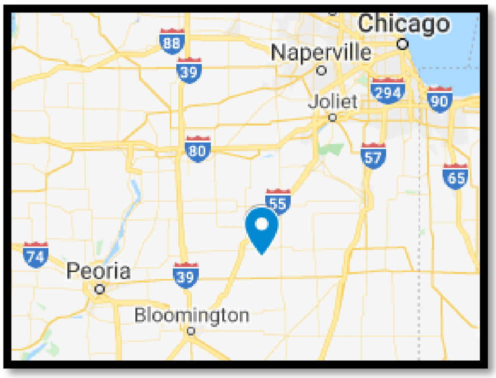
4.7 WILLOWS IN BUFFER ZONES (USA)

Year of Project: 2011-Present

Location: Livingston County, Illinois, United States, North America

Status: Studied (field trial)

Source: Negri, C. M. (2016). Lignocellulosic plants as buffer zones in the Indian Creek watershed of the United States. In *Examples of Positive Bioenergy and Water Relationships* (pp. 105-111). Global Bioenergy Partnership and International Energy Agency Bioenergy.



Bioenergy Supply Chain Summary

Biomass Type: Energy Crop

Biomass Origin: Co-productive System

Biomass Format: Bulky woody biomass

Biomass Amount: 70 tonnes/yr (7.3 ha, 9.7 t/ha)

Supply Chain Length: Local

Bioenergy Product: Liquid Biofuel

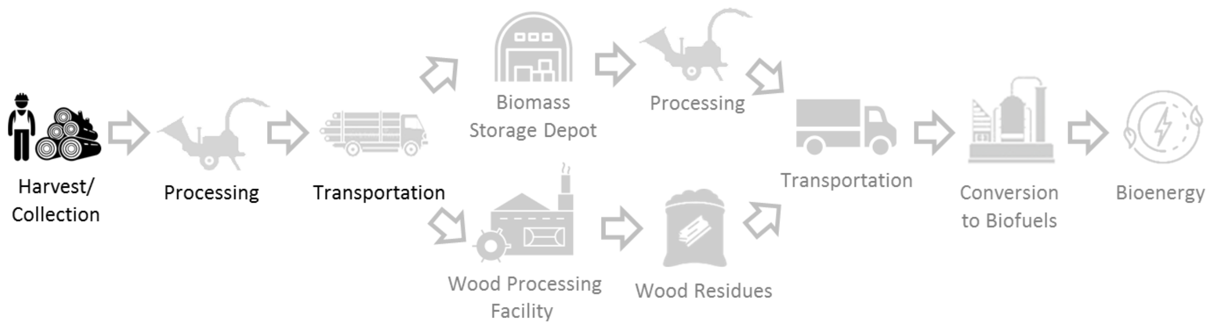
Stakeholders: United States Department of Agriculture, Forest Service Southern Research Station, Centre for Forested Wetlands Research, Cordesville, South Carolina

Overview of Case Study

Shrub willows were established in buffer zones to assess the feasibility of growing biomass for bioenergy production while simultaneously using the willows as a filtration system to reduce nitrate from agricultural activities leaching into local water bodies. The willows would replace 6.7 tonne/ha of harvested corn with 9.7 tonne/ha of willow biomass for bioenergy production while also reducing GHG emissions in the form of nitrous oxide (N_2O) by 10.8%. Furthermore, if the willows were planted in similar marginal land throughout the watershed, the annual nitrate load from agricultural lands could be reduced by 18%.

Details of Biomass Feedstock Supply Chain

Shrub willows were planted as marginal land buffers (in-field and riparian buffers) totalling 0.8 ha of a 6.5-ha corn/soybean field. Willows were coppiced after one year of establishment and harvested on three to four year intervals. The intended future use of the willow was for biofuels.



Drivers, Policies, Support Mechanisms

The primary driver was to assess innovative approaches to growing biomass for bioenergy production that could also provide environmental benefits such as restoring or conserving ecosystems.

Relation to Sustainable Development Goals

SDG	Target, Explanation	Evidence
Zero hunger	2.4, Sustainability of crop production would improve due to positive impacts on water, soil, and ecosystems provided by willows when planted in buffer zones in marginal lands around crops.	Nutrients and sediments tracked in water; soil samples taken, measured soil biodiversity
Clean water & sanitation	6.3, Reduction of nitrate losses in agricultural watersheds.	Nitrate concentrations in local watershed
	6.4, Possible increase in water consumption from perennials.	Reduction in water yield
Affordable & clean energy	7.2, Potential yield of biomass for bioenergy production.	Hectares of shrub willow grown; tonnes harvested per harvest
Industry, innovation & infrastructure	9.4, Perennials on marginal land maximizes value from land, while minimizing environmental impacts, including emissions.	Reduction in nitrous oxide (N_2O) emissions, a GHG

Other Strengths, Weaknesses, Opportunities, Threats

Strengths

- Easy to implement without land use change and maximizes land productivity while improving local and regional water, soil health and biodiversity.
- Supports GHG emission reduction.

Opportunities

- Improving local ecosystem, especially if land is susceptible to leaching nutrients or erosion.
- Upscaling easy given the marginal soil areas cultivated for corn in the studied region.

Weaknesses

- May increase water consumption and reduce size of primary crop harvest.
- Adoption dependent on biorefinery demand and/or ecosystem services payments.

Threats

- Lack of understanding of expected economic returns and market for grown biomass.
- Lack of existing and widely accepted platform(s) for accurate and rapid verification of generated ecosystem services.

Other Sources

Mishra, S. K., Negri, M. C., Kozak, J., Cacho, J., Quinn, J., Secchi. S., & Ssegane, H. (2019). Valuation of Ecosystem Services in Alternative Bioenergy Landscape Scenarios. *Global Change Biology Bioenergy*, 11, 748–762.

Zumpf, C., Ssegane, H., Negri, M. C., Campbell, P., & Cacho, J. (2017). Yield and water quality impacts of field-scale integration of willow into a continuous corn rotation system. *Journal of Environmental Quality*, 46, 811–818.

Ssegane, H., & Negri, M. C. (2016). An integrated landscape designed for commodity and bioenergy crops for a tile-drained agricultural watershed. *Journal of environmental quality*, *45*(5), 1588-1596.

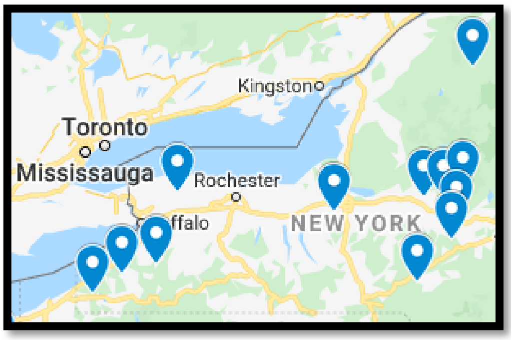
4.8 LIVING SNOW FENCES (USA)

Year of Project: 2013

Location: New York State, United States, North America

Status: Studied

Source: Heavey, J., & Volk, T. (2019). Living snow fences (LSF) from willow stop blowing and drifting snow from reaching roadways. In B. Kulišić, G. Berndes, I. Dimitriou & M. Brown (Eds.), *Attractive Systems for Bioenergy Feedstock in Sustainably Managed Landscapes* (pp.33-34) . International Energy Agency Bioenergy.



Bioenergy Supply Chain Summary
Biomass Type: Energy Crop
Biomass Origin: Co-productive system
Biomass Format: Bulk woody biomass
Biomass Amount: N/A
Supply Chain Length: Local
Bioenergy Product: Combined heat and power
Stakeholders: College of Environmental Science and Forestry, State University of New York

Overview of Case Study

Shrub willow, were planted alongside New York interstate highways and roads as living snow fences (LSF) to assess their capacity to reduce snow drift. Willow LSF were compared to established plantings of spruce, cedar, and Douglas fir trees, along with corn and honey suckle. The study found that three years after planting, willow LSF were able to capture up to 19 metric tons of snow per linear meter, reducing the cost of snow removal and improving driver safety. Other species of trees were also effective but take longer to grow and have higher costs. LSF's also provided co-benefits for local ecosystems, such as soil improvement and act as early season food supply for pollinators. Though not studied specifically, biomass from shrub willow snow fences could be used for energy, as the willows quickly regrows once harvested.

Details of Biomass Feedstock Supply Chain

Shrub willow were planted alongside interstate highways as LSFs and left to grow for a minimum of four years until reaching their maximum height. The shrub willow's capacity to re-grow (i.e., coppice) after repeated harvests indicates that the willow can be used as living snow fences or harvested as woody biomass after four years and then repeatedly every three years after the initial harvest.

Drivers, Policies, Support Mechanisms

The primary driver was to address current living snow fence design protocols which use designs for structural snow fences but do not make adjustments for the dynamics of plant growth, such as growth rate among tree and plants species or snow drift reduction differential between trees and plants.

Relation to Sustainable Development Goals

SDG		Target, Explanation	Evidence
3 Good health and well-being	Good health & well being	3.6, Establishment of willows as snow fences protects highways from blowing snow, improving driver safety.	LSF captured up to 19 metric tons of snow per linear meter
7 Affordable and clean energy	Affordable & clean energy	7.2, Potential woody biomass that could be harvested for bioenergy production.	Described qualitatively in case study
9 Industry, innovation and infrastructure	Industry, innovation & infrastructure	9.4, Fewer vehicles required for snow removal.	Potential for reduced emissions from snow plows
12 Responsible consumption and production	Responsible consumption & production	12.2, Reduced use of structural fences made from non-renewable material.	Described qualitatively in case study
13 Climate action	Climate action	13.1 & 13.2, Project funded by New York State Department of Transportation.	Research grant/USD

Other Strengths, Weaknesses, Opportunities, Threats

Strengths

- Multiple social, economic and safety benefits.
- Cost-effective and not complex compared to other infrastructure.

Opportunities

- Easy to scale up, given the large amount or roads and highways in New York State.
- ‘Greening’, highways could provide environmental, mental and physical health benefits for drivers and nearby residents.

Weaknesses

- Living snow fences may be more easily damaged in severe weather.
- Improper selection of plants could harm local ecosystems.

Threats

- Improper selection of plants and management could affect perceived viability of snow reduction.

Other Sources

Heavey, J. P., Volk, T.A., Abrahamson, L.P., Castellano, P., & Williams, R. (2015). *Designing, Developing and Implementing a Living Snow Fence Program for New York State*. State University of New York, New York State Department of Transportation, Federal Highways Administration. https://trid.trb.org/view/1360909.

State University of New York College of Environmental Sciences and Forestry. (2020). *Willow Living Snow Fences*. https://www.esf.edu/willow/lsf/.

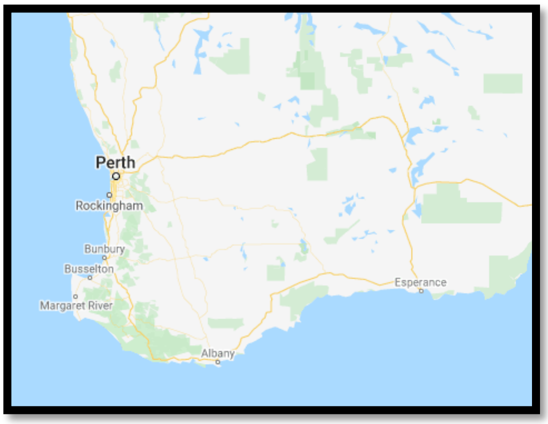
4.9 INTEGRATED BIOENERGY TREE CROP SYSTEMS (AUSTRALIA)

Year of Project: 2016

Location: Western Australia, Australia, Oceania

Status: Studied

Source: McGrath, J., Goss, K., Bartle, J., & Harper, R. (2016). *Integrated bioenergy tree crops in south-western Australia enhance water quality and environmental outcomes* [PowerPoint].



Bioenergy Supply Chain Summary

Biomass Type: Energy crop

Biomass Origin: Primary production

Biomass Format: Chips

Biomass Amount: 130,000 - 300,000 green tonnes/yr (potential)

Supply Chain Length: Regional

Bioenergy Product: Not specified

Stakeholders: Murdoch University, Western Australia Department of Parks and Wildlife

Overview of Case Study

Dryland salinity and water quality in South-West Western Australia were investigated in this study where tree-crops were integrated into farm landscapes. The integrated biomass production systems were proposed to deliver economic bioenergy and to improve water quality by reducing runoff and increasing water table recharge. Test crops were planted, impacts were monitored and a process for biomass harvesting and processing was established. The intent was to use biomass for energy but the specific end use was not defined; the study focused on the potential impacts of the integrated cropping system.

Details of Biomass Feedstock Supply Chain

Mallee, a low-growing eucalyptus, plantations were established and integrated into existing farmland. Mallee trees were harvested using a feller-buncher and a loader and skidder were used to transport logs to the roadside where they were chipped using a mobile chipper. The project also developed a proto-type machine called the Mallee Harvester which cut and chipped whole trees into its purpose-built bin. While no end-use was established for the study, in practice the chips would then be loaded into trucks to be delivered to end-users.

Drivers, Policies, Support Mechanisms

Primary drivers for this project were 1) environmental remediation of soils with high salinity through integration of tree crops into farmland to mitigate hydrologic imbalance, and 2) greenhouse gas (GHG) emissions reduction as mitigation of climate change is a key driver for Australian bioenergy programs.

Relation to Sustainable Development Goals

SDG		Target, Explanation	Evidence
2 ZERO HUNGER	Zero Hunger	2.3, Tree crops provide additional income for rural farmers and hedge against crop losses.	Described qualitatively as a driver for the study
6 CLEAN WATER AND SANITATION	Clean water & sanitation	6.3 and 6.4, Mallee plantations reduce salinity by diverting saline inflows and keeping groundwater suppressed. It also increases water availability by reducing runoff and increasing groundwater recharge.	Salinity and groundwater measurements throughout the study area
7 AFFORDABLE AND CLEAN ENERGY	Affordable & clean energy	7.2, Mallee biomass identified as a prospective feedstock for regional industries (i.e., Combined Heat and Power).	Potential for up to 10 million tonnes annually of biomass for bioenergy
15 LIFE ON LAND	Life on land	15.5, Areas at risk from salinity are biodiversity hotspots and reducing salinity protects ecosystems and biodiversity.	Selection of land for intercropping is aimed at protecting biodiversity

Other Strengths, Weaknesses, Opportunities, Threats

Strengths	Opportunities
• Addresses dryland salinity which is now a broadly recognized problem in Western Australia.	• Potential to combine woody biomass with cropping residue for energy in Western Australia.
Weaknesses	**Threats**
• Lower yield of biomass per hectare due to the nature of integrating trees with agricultural land resulting in higher cost of biomass recovery.	• Unstable funding from policy changes resulting in uncertainty for farmers and environmental programs.

Other Sources

Ghaffariyan, M. R., Brown, M., Acuna, M., & McGrath, J. (2016). Optimized harvesting cost for Mallee supply chain in Western Australia. *Croatian Journal of Forest Engineering*, 37(1), 17-25.

4.10 THE EMERALD PLAN (AUSTRALIA)

Year of Project: 2016

Location: Victoria, Australia, Oceania

Status: Studied

Source: Feltrin, M. (2019). The Emerald Plan: Concepts of fitting production landscapes with modern energy production possibilities via merging better biodiversity outcomes in agricultural landscapes at large scale. In B. Kulišić, G. Berndes, I. Dimitriou & M. Brown (Eds.), *Attractive Systems for Bioenergy Feedstock in Sustainably Managed Landscapes* (pp.7-12) . IEA Bioenergy.

Bioenergy Supply Chain Summary

Biomass Type: Energy crop

Biomass Origin: Co-productive system

Biomass Format: Chips

Biomass Amount: 2,160 green tonnes

Supply Chain Length: Regional

Bioenergy Product: Industrial process heat

Stakeholders: Gasification Australia Pty Ltd, Emerald Plan Foundation

Overview of Case Study

In 2007, the Emerald Plan was developed as a conceptual tool to help inform future policy decisions on restoring degraded land using a combination of conservation and farming practices to grow biomass for bioenergy production in Australia. In 2010, a series of field studies were established to demonstrate how different combinations of practices such as conservation, intercropping, and plant growth, could contribute to improving degraded land across the country. In the decade since, this holistic approach has been recognized at the national and international level, with the development of Integrated Landscape Management being actively supported by large organizations such as the United Nations (UN) and the Food and Agriculture Organization (FAO).

Details of Biomass Feedstock Supply Chain

The Emerald Plan used a theoretical scenario to demonstrate how planting different combinations of plant species and trees, rotation length of crops and harvesting regimes could help restore the productivity of the soil and increase carbon sequestration. Mixed species would be planted manually and later harvested using mechanized harvesters. Planted trees would be processed at the stump to short logs and moved to the closest road to be chipped at roadside or transported to a centralised yard to be chipped.

Drivers, Policies, Support Mechanisms

Primary drivers for this project were 1) remediating degraded land and 2) improving energy security by enhancing agricultural and ecosystem functions. In addition, the national and state governments in Australia committed to address natural resources management (NRM) problems arising from agriculture. This project aimed to implement biodiversity-focused agricultural production systems alongside Integrated Land Managment processes and community/farmer based NRM to achieve multilpe SDGs.

Relation to Sustainable Development Goals

SDG		Target, Explanation	Evidence
	Affordable & clean energy	7.1, The biomass generated would be used to displace fossil fuels.	Described qualitatively in case study
	Climate action	13.2, The Emerald Plan proposed a holistic approach to land management and agricultural practices that could restore degraded land while growing biomass for low-carbon bioenergy production.	Aim to inform policy described qualitatively in case study
	Life on land	15.3 and 15.5, The case study found that tree intercropping could restore degraded land and improve biodiversity.	“Relatively high” biodiversity score acheived

Other Strengths, Weaknesses, Opportunities, Threats

Strengths

- Growing biomass could achieve multiple objectives.
- Could combine biomass growth with reintegrating Indigenous ecosystems.

Opportunities

- Opportunities to achieve multiple sustainability objectives in future land management policy decisions using model.

Weaknesses

- Unknown impacts of proposed management model and intercropping on broader landscape.
- Not economically modelled.

Threats

- Misconceptions about the sustainability of forest bioenergy (i.e., clear cutting, deforestation) could prevent policy makers from using this land management approach.
- Lack of ongoing support from private farmers.

4.11 REDUCED WATER USE IN SUGARCANE INDUSTRY IN BRAZIL

Year of Project: 2016

Location: Multiple Regions, Brazil, South America

Status: Implemented

Source: Neto, A.E. (2016). Management of water resources in the sugarcane agro-industry in Brazil. In *Examples of Positive Bioenergy and Water Relationships* (pp. 51-54). Global Bioenergy Partnership and International Energy Agency Bioenergy.

Bioenergy Supply Chain Summary

Biomass Type: Energy Crop

Biomass Origin: Agriculture and crop residue

Biomass Format: Non-standardised (stems and bagasse)

Biomass Amount: 31.8 million tonnes/yr of sugar cane stems and 8.9 million tonnes/yr of bagasse

Supply Chain Length: International

Bioenergy Product: Transport fuel and electricity

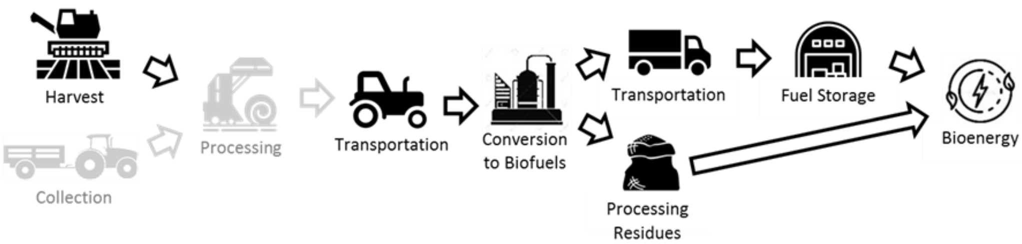
Stakeholders: Brazilian Sugarcane Industry Association (UNICA), Bonsucro, Green Ethanol

Overview of Case Study

Brazil is the world's largest producer of sugarcane with a planted area of 10.5 million hectares. The two sugarcane-producing areas in Brazil are the north/northeast (12%), relying partly on irrigation, and the centre-south (88%) relying primarily on rainfall. Within the past four decades, water extraction used in the processing sugarcane has reached as high as 20 m^3/t. This case study addressed reduction and re-use of water in the Brazilian sugarcane industry, implemented to varying degrees across the country. Advances in water-use efficiency (e.g., water re-utilization and closed water systems) can reduce water use to 2 m^3/t of sugarcane. These water use reduction strategies are reflected in certifications such as Bonsucro.

Details of Biomass Feedstock Supply Chain

Only the Brazilian Bonsucro-certified sugarcane plantations destined for ethanol production were considered (373,520 ha) in this case study. Sugarcane is grown primarily for sugar and ethanol with energy as a by-product. Most sugarcane-processing plants also produce ethanol and bagasse for internal energy demands. Larger plants can also sell surplus energy to the grid. Approximately 46% of the sugarcane production goes to ethanol production, which is used to run the country's "flex fuel" vehicles (70% of its fleet). Most of the sugarcane processed is sourced within a 50 km radius and is self-supplied. Around one third is supplied by third parties ranging from small-scale farmers to large landowners.



Drivers, Policies, Support Mechanisms

Primary drivers for this project were 1) water management requirements in international environmental certifications and 2) profit through cost savings from the reutilization of residues. Environmental legislation under the Federal Constitution of 1988 and the implmentation of a system charging for the use of water resources has also driven increased efficienct water water use practices.

Relation to Sustainable Development Goals

SDG		Target, Explanation	Evidence
6 CLEAN WATER AND SANITATION	Clean water & sanitation	6.4, Reduction of water extraction by sugar cane mills over the past four decades since water reduction efforts began.	Water extraction reduced from 20 m^3/t to 2 m^3/t
7 AFFORDABLE AND CLEAN ENERGY	Affordable & clean energy	7.2, Ethanol exports to markets with blending mandates for substitution of fossil fuels; electricity from bagasse used internally and exported to grid.	Ethanol displaced fossil transportation fuel
12 RESPONSIBLE CONSUMPTION AND PRODUCTION	Responsible consumption & production	12.2 (also 8.4), Material footprint improved due to use of waste product for electricity and heat generation.	6% of Brazil's energy production is from bagasse combustion
14 LIFE BELOW WATER	Life below water	14.1, Fertilisation using vinasse under higher organic material concentrations prevents leaching the nutrients and organic material to water resources and consequently oceans.	Described qualitatively in case study

Other Strengths, Weaknesses, Opportunities, Threats

Strengths

- Effluents from the mills used in the sugar cane plantations promote irrigation and fertilization.
- Extraction and water-use industry goals meet international certification standards (e.g., Bonsucro) allowing access to external markets.

Opportunities

- Opportunity to further reduce water through re-use of water contained in the sugarcane with a tertiary treatment; R&D needed.

Weaknesses

- Meeting international certifications increases the investment costs for new sugarcane ethanol plants.

Threats

- Technologies needed for the reutilization of water in the sugarcane are much more costly than status quo.

Other Sources

Willer, H., Sampson, G., Voora, V., Dang, D., & Lernoud, J. (2019). *The State of Sustainable Markets 2019 - Statistics and Emerging Trends*. International Trade Centre.

Brazilian Institute of Geography and Statistics. A Geografia da Cana-de-Açúcar. Rio de Janeiro: IBGE, 2017.

Brazilian Institute of Geography and Statistics. Pesquisa Industrial 2017. Rio de Janeiro: IBGE, 2017.

4.12 BIOENERGY AND FOOD SECURITY IN ZAMBIA

Year of Project: 2003 - ongoing

Location: The Luangwa Valley, Eastern/Central/Northern Provinces, Zambia, Africa

Status: Implemented

Source: Armitage, C., & Skeer, J. (2015). A set of integrated practices: a multi-faceted market-led approach to improving food and energy security and adaptation to climate change. In B. Kulišić, G. Berndes, I. Dimitriou & M. Brown (Eds.), *Attractive Systems for Bioenergy Feedstock in Sustainably Managed Landscapes* (pp.3-6) . IEA Bioenergy.

Bioenergy Supply Chain Summary

Biomass Type: Energy crop

Biomass Origin: Co-productive system

Biomass Format: Bulky woody biomass

Biomass Amount: N/A

Supply Chain Length: Local/Regional/National/International

Bioenergy Product: Cooking fuel

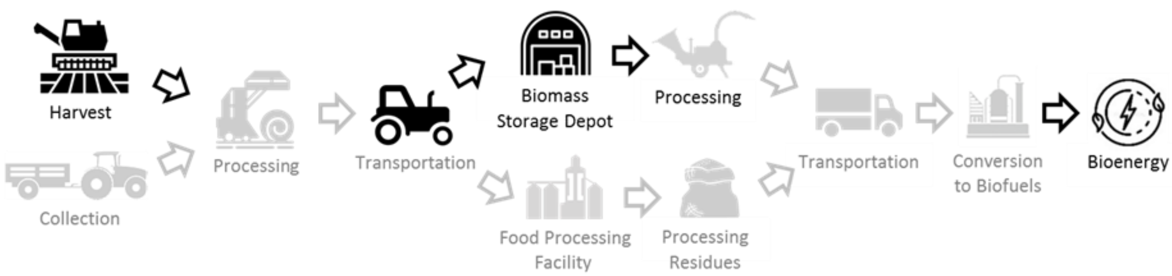
Stakeholders: Community Markets for Conservation (COMACO), local citizens

Overview of Case Study

Community Markets for Conservation (COMACO) is a social enterprise that aims to support the transition of illegal wildlife poachers in Zambia into small-scale farmers by training them in sustainable agricultural practices and in turn purchasing their agricultural products which are then made into value-added food products (e.g., peanut butter, cereals). Sustainable farming practises taught to farmers include intercropping techniques that use the *Gliricidia sepium* tree to restore soil fertility and improve farmers' yields to levels comparable with farmers who use organic fertilizer. This tree, a high-quality wood fuel source, is also harvested by local farmers to meet personal cooking and heating needs. There is also significant opportunity to use excess harvested wood for power generation in the future.

Details of Biomass Feedstock Supply Chain

G. sepium is planted as an intercrop by local farmers to improve soil fertility and improve agricultural yields. When mature, the trees are sustainably harvested by local farmers and stored until required for use as a clean cooking fuel or alternative heating fuel.



Drivers, Policies, Support Mechanisms

Primary drivers for this project are 1) providing former illegal animal poachers with the necessary skills to earn a living wage, 2) reducing illegal animal poaching and 3) improving food security in poor and rural regions of Zambia.

Relation to Sustainable Development Goals

SDG		Target, Explanation	Evidence
	Zero hunger	2.1, 2.4 Local food security has improved since the program was implemented, imcomes of small farmers and households have also increased.	Food security improved from 34% to 80%; annual incomes increased USD$79 - $348 from 2001 – 2016
	Quality education	4.3, Education and training provided to residents to build knowledge and skills for sustainable farming.	"Train-the-Trainer" model: Lead participants trained who then train other local farmers
	Gender equality	5.a, Active participation and empowerment of women through the program including decision making and teaching.	52% of program participants were women
	Affordable & clean energy	7.2, Renewable energy share increased through sustainably harvesting woody biomass for cooking and heating.	40 GJ/yr/household energy potential from woody biomass
		7.3, Increased supply and use of high-quality wood source; distribution of fuel-efficienct cookstoves to member households.	2 t/yr/household of *G. sepium*; 70,000 cookstoves distributed
	Life on land	15.1, Intercropping techniques to restore soil fertility.	Described qualitatively in case study
		15.2, Sustainably harvesting planted trees for woody biomass reduces need for fuel wood collection from forests, reducing local deforestation.	Planted trees under management

Other Strengths, Weaknesses, Opportunities, Threats

<u>Strengths</u>

- Sustainable co-production of food and energy crops.
- Improving quality-of-life, food security, and energy security.

<u>Opportunities</u>

- Addresses root causes of poverty, food insecurity, and energy insecurity.
- Could be replicated globally to conserve wildlife while providing an alternative way to reduce food insecurity and earn a living wage.

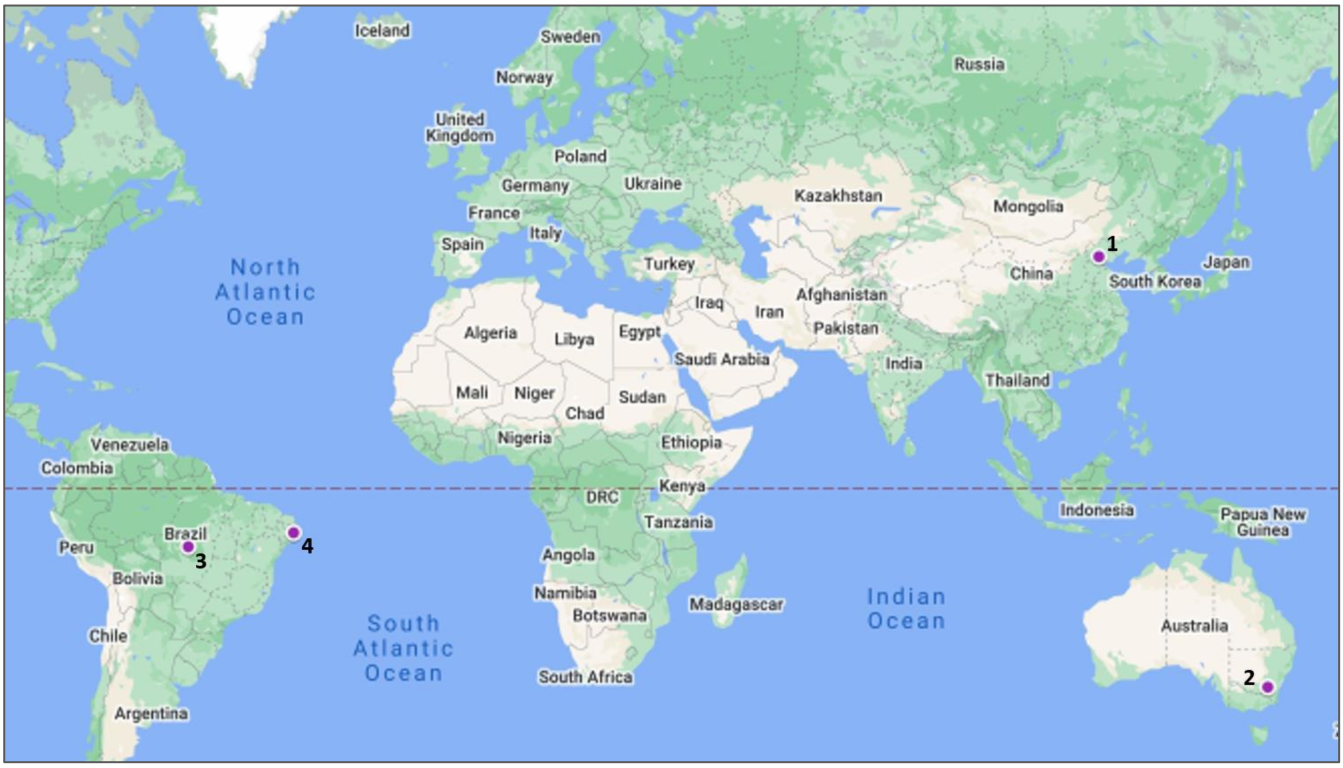
<u>Weaknesses</u>

- Initial results may be slow, disenfranchising farmers to continue practicing sustainable agriculture.
- Geographic isolation for some communities makes training difficult.

<u>Threats</u>

- Lack of accessible, equitable, and reliable markets for food products grown by farmers.

5 Waste Biomass Supply Chain Case Studies



Waste Biomass Supply Chain Case Studies' Primary Contributions to SDGs																
	Title	**SDG**														**Status**
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	
1	Sustainable Biogas in China	x	x				x	x	x	x			x				I
2	On-farm Biogas Production		x					x	x	x			x				I
3	Biogas to Transportation Fuel	x	x				x	x	x				x				I
4	Vinasse for Biogas Production						x	x	x	x			x				I

I = Implemented

* Supply chains can contribute to multiple SDGs, however SDGs listed were those identified as most relevant.

5.1 SUSTAINABLE BIOGAS IN CHINA

Year of Project: 2009

Location: Beijing, China, Asia

Status: Implemented

Source: Chen, L., Cong, R.G., Shu, B., & Mi, Z.F. (2017). A sustainable biogas model in China: The case study of Beijing Deqingyuan biogas project. *Renewable and Sustainable Energy Reviews*, 78, 773-779.

Bioenergy Supply Chain Summary

Biomass Type: Waste

Biomass Origin: Post-industrial residue or waste

Biomass Format: Liquid

Biomass Amount: 80,000 tonnes chicken manure/yr; 100,000 tonnes sewage/yr

Supply Chain Length: Local

Bioenergy Product: Electricity (co-product fertilizer)

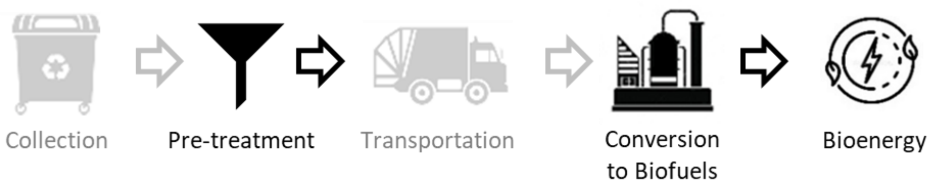
Stakeholders: Beijing Deqingyuan Agriculture Technology Co. Ltd.

Overview of Case Study

Deqingyuan (DQY) Ecological Farm has a comprehensive resource utilization model that integrates poultry farming, biogas, agricultural crops and fertilizer production. DQY was the first egg producer in China to sell green-branded eggs. Central to DQY's farming is a large-scale biogas plant producing 14 million kWh of electricity annually from 80,000 tonnes of manure and 100,000 tonnes of sewage (wastewater from poultry production) annually which is used by the farm with surplus electricity sold to local residents. In addition, the anaerobic digestion process used by DQY generates organic fertilizer that is used on-farm but also sold to other local farmers. The DQY biogas project connects livestock and crop farming with surrounding households and markets, establishing a demonstrative model of a sustainable circular economy.

Details of Biomass Feedstock Supply Chain

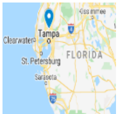
The biogas plant runs off chicken manure and wastewater from poultry production sources entirely from the DQY farm. The chicken manure is pre-treated to remove sand to prevent the pipeline from becoming plugged before being deposited in the anaerobic tank. The methane produced from the fermentation process is also treated to remove sulphur before being combusted in the generator or distributed to nearby households.



Drivers, policies, support mechanisms

Primary drivers for this project were 1) improving waste management and reducing pollution from poultry production and 2) reducing greenhouse gas emission, subsequently leading to new revenue streams through the production of low-carbon energy for DQY. The DQY biogas project generates 8 million Yuan in revenue annually through the Clean Development Mechanism (CDM) for reductions in greenhouse gas (GHG) emissions, equivalent to 84,000 tonnes of CO_2 per year. The CDM is a flexible mechanism introduced as part of the Kyoto Protocol, an international treaty committing countries to reduce their GHG emissions, through which, developed countries provide funding to developing countries to support GHG reduction projects.

Relation to Sustainable Development Goals

SDG		Target, Explanation	Evidence
	No poverty	**1.4**, Project supplies affordable biogas to rural households who would otherwise not have access to cooking and heating fuel.	Plant supplies 730,000 m3/year of biogas to adjacent households
2 ZERO HUNGER	Zero hunger	**2.3**, DQY has contracts with local farmers to purchase organic maize for chicken feed, providing a source of steady income for small-scale producers.	Farm has contracts worth 56 million Yaun/ year with local farmers
	Clean water & sanitation	**6.3**, Anaerobic digestion process improves the quality of discharged water from the chicken farm reducing the discharge penalties for producers.	Chemical/biochemical oxygen demand (COD/BOD) reduced by 64/70% respectively
7 AFFORDABLE AND CLEAN ENERGY	Affordable & clean energy	**7.2**, Renewable energy share increased due to displacement of fossil fuels for heat and electricity generation.	14 million KWh of power generated and 730,000 m3 of biogas supplied to households
8 DECENT WORK AND ECONOMIC GROWTH	Decent work & economic growth	**8.5**, Operating the advanced biogas plant requires a large number of skilled workers in a job market where university graduates have difficulty finding employment.	10 skilled workers employed full-time by biogas project
	Industry, innovation, infrastructure	**9.4**, Project generates revenue for DQY Farm and reduces CO_2 emissions through dispacing grid electricity and reducing use of synthetic fertilizer.	CO_2 emissions reduced by 84,000 tonnes annually (as per CDM contract)
12 RESPONSIBLE CONSUMPTION AND PRODUCTION	Responsible consumption & production	**12.4**, Project treats large quantities of agricultural waste that are pollutants when generated in large quantities.	180,000 tonnes/year of agricultural waste treated

Other Strengths, Weaknesses, Opportunities, Threats

Strengths

- Integrates poultry farming, local energy security, sustainable farming, and demonstrates circular economy.
- Uses advanced technologies to improve performance of biogas plant and maximize GHG reduction.

Opportunities

- Potential to replicate on other large-scale farms and create positive impacts and contribute to circular economy.

Weaknesses

- Very large-scale farm; sustainability and animal welfare challenges even with investments in ecological model.

Threats

- Need many factors in place to replicate model – e.g., sale of biogas to locals, sale of digestate as fertilizer and sale of electricity to grid makes replication complex.

5.2 ON-FARM BIOGAS PRODUCTION IN AUSTRALIA

Year of Project: 2018

Location: Several regions, Australia, Oceania

Status: Implemented

Source: McCabe, B. (2018). *Profitable on-farm biogas in the Australian pork industry*. IEA Bioenergy.

Bioenergy Supply Chain Summary

Biomass Type: Waste

Biomass Origin: Animal production

Biomass Format: Liquid

Biomass Amount: 5,112 to 12,692 Standard Pig Units/yr (*standard waste output of 40kg pig)

Supply Chain Length: Local

Bioenergy Product: Electricity with heat recovery

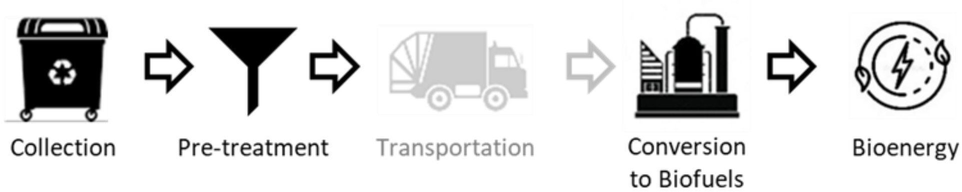
Stakeholders: Australia's Pork Cooperative Research Centre, University of Southern Queensland

Overview of Case Study

Twenty pork farms in Australia, representing about 14% of total Australian pork production, collect and treat effluent (predominately manure and waste feed) in anaerobic digesters to capture methane released from this waste stream. These waste streams accounts for 60-80% of on-farm greenhouse gas emissions in the Australian pork industry. Once captured, this biogas is used to produce electricity for each farm. Capturing methane from effluent and converting it into biogas also reduces on-farm energy costs and reduces dependence on fossil fuels by providing heat and electricity for farming operations. Australia's Emissions Reduction Fund (ERF), which provides carbon credits to farms for emissions reductions, and the Renewable Energy Certificates (RECs), which also provides farms credits for renewable energy production, also improve the economic feasibility of these on-farm biogas facilities resulting in a two to five year payback period for farms and substantial energy savings for over 10 years.

Details of Biomass Feedstock Supply Chain

The effluent, primarily manure and waste feed, is captured and transported from piggeries to a wet well and then transferred to a covered anaerobic pond. A fan blows the biogas to a scrubber tank typically containing iron oxide to remove corrosive hydrogen sulphide from the methane and then is used on-farm to generate heat and electricity as needed.



Drivers, Policies, Support Mechanisms

Primary drivers for this project were 1) increasing competitiveness of the piggeries through energy cost reductions and 2) GHG reductions from displacing high carbon intensity electricity or fuels. The Australian ERF and RECs have assisted pork producers to adopt biogas projects by making them more financially feasible.

Relation to Sustainable Development Goals

SDG		Target, Explanation	Evidence
	No hunger	2.3, New revenue streams for farms selling excess electricity from biogas system to local energy grids and from Australia's carbon credit and renewable energy credit systems.	Between 2013 and 2018, piggery biogas projects generated $4M in carbon credits
	Affordable & clean energy	7.2, Renewable energy share increased by displacing fossil fuel-based electricity and heat.	Described qualitatively in case study
	Industry, innovation & infrastructure	9.4, Using electricity and heat derived from biogas reduces farms CO_2 emissions in comparison to using power and heat generated by fossil fuels.	372,143 carbon credits have been issued between 2013 and 2018 to piggery biogas projects
	Responsible consumption & production	12.2 (also 8.4), Managing and using effluent from pork farms as a biogas feedstock reduces air and water pollution while generating low-carbon energy that can replace fossil fuel.	In 2018, 20 piggeries in Australia (14% of total Australian pork production) capturing and using biogas

Other Strengths, Weaknesses, Opportunities, Threats

Strengths

- Relatively short period of payback from two to five years with savings over ten years.
- Uses waste effluent to capture and convert methane into heat and electricity reducing dependence on fossil fuels.

Opportunities

- Upgrading excess biogas into biomethane for vehicle fuel use or for injection in natural gas grid.
- High potential to centralise biogas generation and combine multiple organic wastes.

Weaknesses

- Lacking consistent guidelines for digestate use.

Threats

- Limited markets for biogas.

Other Sources

Australian Department of Industry, Innovation and Science. (2018). *Annual Report 2017-2018.* http://porkcrc.com.au/wp-content/uploads/2017/11/PorkCRC-Annual-Report-2018_web.pdf.

McCabe, B., Kroebel, R., Pezzaglia, M., Lukehurst, C., Lalonde, C., Wellisch, M., M& urphy, J.D. (2020). Integration of Anaerobic Digestion into Farming Systems in Australia, Canada, Italy, and the UK. In Lalonde, L., Wellisch, M., Murphy, J.D (Ed.), *Integration of Anaerobic Digestion into Farming Systems in Australia, Canada, Italy and the UK* (pp. 6). IEA Bioenergy.

5.3 BIOGAS TO TRANSPORTATION FUEL IN BRAZIL

Year of Project: 2013

Location: Santa Helena, Brazil, South America

Status: Implemented

Source: de Sousa, M.A. (2016). Sustainability in movement: Water energy nexus in southern Brazil. In *Examples of Positive Bioenergy and Water Relationships* (pp. 55-60). Global Bioenergy Partnership and IEA Bioenergy.

Bioenergy Supply Chain Summary

Biomass Type: Waste

Biomass Origin: Animal production waste

Biomass Format: Liquid

Biomass Amount: Approximately 13,000 tonnes of liquid effluents (35 cubic meter per day) (m^3/day)

Supply Chain Length: Local

Bioenergy Product: Transport fuel and electricity

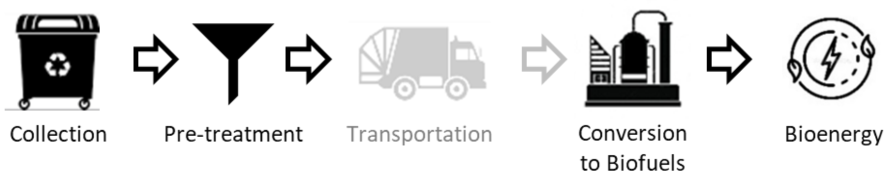
Stakeholders: International Center on Renewable Energy-Biogas (CIBiogás), ITAIPU Binacional, Scania do Brasil, Haacke Farm, Itaipu Technology Park Foundation

Overview of Case Study

The Haacke Farm in Santa Helena has 80,000 egg-laying hens and 750 cattle. Waste from these animals is collected and co-digested in a horizontal type biodigester. The biodigester produces biogas which is primarily used to produce biomethane. This biomethane is sold directly to Itaipu Technology Park and used to fuel a fleet of 43 vehicles. This biomethane is as efficient as diesel previously used to fuel these vehicles (average of fuel consumption 1.92 km/m^3) and reduces the fleet's CO_2 emissions by 20 tonnes. A portion of the biogas is kept to produce electricity and heat for farm operations.

Details of Biomass Feedstock Supply Chain

Around 35 cubic meters per day (m^3/day) of liquid effluents from both the farm's hens and cattles are directed to a covered lagoon biodigester for anaerobic digestion, producing 1,000 m^3 of biogas a day. Of this daily yield, 64% is methane, but is refined and converted into biomethane which can be used in vehicles. The biomethane is put into cylinders and transported 120 kilometers to a biomethane station in Itaipu Technology Park. The remaining biogas is used for electriticy and heat at the farm.



Drivers, Policies, Support Mechanisms

Primary drivers for this project were 1) reducing fossil fuel dependency in the region and 2) improving enviornmental protection by reducing animal waste runoff. Demand will increase as well, as the Itaipu Technology Park intends to increase its fleet of vehicles that run on biomethane.

Relation to Sustainable Development Goals

SDG	Target, Explanation	Evidence
No poverty	1.1, Creates new revenue opportunity in rural communities and could support farmers living below the poverty line.	Rural exodus has slowed, suggesting reduced poverty
 No hunger	2.4, Use of digestate as fertilizer will reduce need for synthetic fertilizer and may improve sustainable land use.	Described qualitatively in case study
Clean water & sanitation	6.3, Removal of manure from land for biogas production improved groundwater quality.	Qualitative observation by participant in case study
Affordable & clean energy	7.2, Renewable energy share increased from replacing fossil fuels for electricity, heat, and transportation with biogas.	1,000 m^3 of biogas produced daily
Decent work & economic growth	8.5, Biogas facility provides revenue streams for farm and more jobs.	Described qualitatively in case study
Responsible consumption & production	12.4, 12.2 (also 8.4), Potentially hazardous waste diverted; material footprint reduced due to reduced need for synthetic fertilizer.	35 m^3/d manure used for biogas production

Other Strengths, Weaknesses, Opportunities, Threats

Strengths

- Biomethane is simpler to produce than fossil fuels and becomes cost competitive for those who can produce their own fuel.

Opportunities

- Brazil has lots of agricultural and livestock production, producing lots of organic waste.
- Sustainable increase in farming operations with water treatment.

Weaknesses

- Training required to compress biomethane.
- Specialized analysis required to test biomethane quality.

Threats

- Biomethane market depends on fleet operators purchasing natural gas vehicles.

Other Sources

CIBIOGÁS. (2019.) *Market research: N° P125/2019 - Biogas and biomethane current stage and opportunities for dutch companies in Brazil*. Foz do Iguaçu, October 2019. https://www.rvo.nl/sites/default/files/2019/12/Market_Study_Report_NBSO_EN_20191202.pdf

Sousa, M.A. (2015, May 23-29). *Biogas for domestic and industrial uses: the experience of CIBiogás-ER and ITAIPU in Brazil* [PowerPoint]. Presented at Global Bioenergy partnership 3rd Bioenergy, Medan. http://www.globalbioenergy.org/fileadmin/user_upload/gbep/docs/2015_events/3rd_Bioenergy_Week_25-29_May_Indonesia/26_5_6_DE_SOUSA.pdf

5.4 VINASSE FOR BIOGAS PRODUCTION IN BRAZIL

Year of Project: 2012

Location: Vitória de Santo Antão, Brazil, South America

Status: Implemented

Source: de Melo Sales Santos, A.F., Alcoforado de Moraes, M. M. G., & Julia Torreão Pecly. (2016). Use of vinasse in biogas production through anaerobic digestion in the Brazilian sugar-cane industry. In *Examples of Positive Bioenergy and Water Relationships* (pp. 66-70). Global Bioenergy Partnership and International Energy Agency Bioenergy.

Bioenergy Supply Chain Summary

Biomass Type: Waste

Biomass Origin: Industrial residue

Biomass Format: Liquid

Biomass Amount: Approximately 300,000 tonnes of vinasse/yr

Supply Chain Length: Local

Bioenergy Product: Electricity

Stakeholders: Cetrel Bioenergia, Federal Rural University of Pernambuco

Overview of Case Study

Enterprise Cetrel Bioenergia (Cetrel) produces biogas from a sugarcane distillation by-product known as vinasse. Vinasse is traditionally used for soil fertigation, however if used too much, can negatively impact local soil and waterways. To address some of this surplus waste, Cetrel's biogas facility was built in 2012 and can produce upwards of 1,000 m^3 of biogas a day which is converted into 0.85 megawatts (MW) of electricity. Cetrel is expected to expand its production to upwards of 4.5 MW, which can be sold as low-carbon electricity on the regional electricity grid. The facility sources its feedstock from a local sugarcane farmer in the city of Vitoria de Santo Antão.

Details of Biomass Feedstock Supply Chain

Cetrel treats raw vinasse to remove its organic compounds and converts it into biogas by using bacteria in the anaerobic biodigestion process. The treated vinasse can also be used for soil fertigation by farmers, since the process does not alter nutrients present in the vinasse. The biogas captured in the biodigestion process contains more than 70% of methane that can be used to generate electricity and heat.

Drivers, Policies, Support Mechanisms

Primary drivers for this project were 1) to improve vinasse waste management and 2) to recover the energetic potential of the vinasse for self-sufficiency. Two Brazilian government entities, the Funding Authority for Studies and Projects (Finep) and Brazilian Development Bank (BNDES) provided financial resources for this project, including financing part of the demonstration-scale stage.

Relation to Sustainable Development Goals

SDG		Target, Explanation	Evidence
	Clean water & sanitation	6.3, Treating vinasse prior to fertigation reduces surface and groundwater pollution.	Described qualitatively in case study
	Affordable & clean energy	7.2, Project increases the share of low-carbon renewable electricty from biogas.	0.87 MW of installed electric generation capacity
	Industry, innovation & infrastructure	9.4 (also 13), Treating vinasse as part of the biogas process reduces the amount of uncaptured methane released by vinasse in fertigation.	Described qualitatively in case study
	Responsible consumption & production	12.2 (also 8.4), Using vinasse to generate renewable low-carbon electricity and reduce pollution of vinasse used for fertigation.	Described qualitatively in case study

Other Strengths, Weaknesses, Opportunities, Threats

Strengths	Opportunities
• Clean and de-centralized energy in Brazil's deregulated and unstable electricity market. • Using waste feedstocks to add value to the sugarcane supply chain while improving environmental sustainability.	• Further treatment of vinasse would allow reuse in industrial processes and reduce surface water use. • Medium to large distilleries and sugar mill plants in Brazil eligible for technology.
Weaknesses	**Threats**
• Enterprise scale is still semi-industrial (or demonstration). • Sugarcane industry in Brazil slow to adopt new technologies and innovations.	• Lacking support for sustainable technology in sugarcane industry. • Lack of public policies, long-term planning, and entrepreneur-friendly lines of investment for technology adoption.

Other Sources

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