circular carbon economy

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Recycle: Bioenergy.

IRENA
International Renewable Energy Agency

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Abbreviations

AR5	The Fifth Assessment Report of the Intergovernmental Panel on Climate Change
BECCS	bioenergy with carbon capture and storage
BES	Baseline Energy Scenario
CCGT	Combined Cycle Gas Turbine
CCU	carbon capture and utilisation
CDR	carbon dioxide removal
CHP	combined heat and power
CO_2	carbon dioxide
DDP	Deeper Decarbonisation Perspective
DHC	district heating and cooling
DRI	direct reduced iron
EJ	exajoule

Abbreviations

FAO	Food and Agriculture Organisation of the United Nations
FiTs	Feed-in tariffs
G20	Group of Twenty
GBEP	Global Bioenergy Partnership
GHG	greenhouse gas
Gt	gigaton
HEFA	hydroprocessed esters and fatty acids
HVO	Hydrotreated vegetable oils
ILUC	indirect land-use change
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
LBG	liquefied biogas
LNG	liquefied natural gas
LUC	land-use change
Mt	million tonne
PEF	polyethylene furanoate
PES	Planned Energy Scenario
PHAs	polyhydroxyalkanoates
PHB	polyhydroxybutyrate
PUR	polyurethanes
PV	photovoltaic
R&D	research and development
SAF	Sustainable Aviation Fuel
SDG	Sustainable Development Goal
TES	Transforming Energy Scenario
TPES	total primary energy supply
TFEC	total final energy consumption
UNECE	United Nations Economic Commission for Europe
UNFCCC	United Nations Framework Convention on Climate Change
USD	United States dollar

Executive Summary

In an era of accelerating change, the need to create energy systems that guarantee a secure and affordable energy supply globally while protecting the environment is strengthening the momentum for a global energy transformation. That transformation involves moving away from fossil fuels towards renewable sources of energy, supported by increased efficiency and the reduction of total overall energy consumption. Bioenergy will have essential roles in all sectors in this energy transformation and in building a climate-friendly circular carbon economy that delivers economic and social benefits.

Bioenergy is the largest source of renewable energy in use today, globally accounting for 70% of the renewable energy supply and for 10% of the total primary energy supply in 2017. Bioenergy has key roles as a source of energy and as a feedstock that can replace fossil fuels in end-use sectors (industry, transport and buildings), and it can contribute to balancing an electricity grid that has high shares of variable renewables, such as solar PV and wind. **Bioenergy technologies are developing rapidly and have significant potential to scale up by 2050.** The share of primary energy met with modern bioenergy could increase almost five times from 5% to 23% in 2050. Meanwhile, traditional uses of bioenergy, which account for a large share of bioenergy demand today, must be phased out.

In sectors that are particularly challenging to decarbonise, such as long-haul or heavy freight transport and some industrial sectors (i.e. iron and steel, cement and lime, aluminium and chemicals and petrochemicals), **biomass use will be significant.**

Biofuels could play an important role in the transport sectors as an alternative to fossil fuels, complementing the greater use of electrification. IRENA's analysis indicates that a five-fold increase in liquid biofuels use could be needed, rising from 153 billion litres in 2017 to 652 billion litres in 2050. In the **buildings sector**, modern biomass use could play an increasing role in heat production in district heating systems and building-scale furnaces. It could also produce electricity and heat in combined heat and power (CHP) plants. In some **industry sectors**, biomass may need to play an expanded role as feedstocks to replace fossil feedstocks and as a fuel to produce low, medium and high-temperature heat, potentially providing up to one-quarter of the total final energy consumption in the sector.

However, there are some key limiting factors. Barriers include the current high cost of converting biomass into usable fuels and feedstocks and the challenge of providing a sufficient supply of sustainable biomass without causing environmental or social harm.

In the circular carbon economy, bioenergy is just one part of the wider biomass system that supports the basic needs of humans by providing food, feed, fibre, fine chemicals, fertiliser and fuels. Yet bioenergy can strengthen the whole biomass system by creating revenue streams for residues and wastes generated along supply chains that would otherwise be burned onsite, wasted or disposed of. Bioenergy can help prevent environmental problems currently caused by those residues and wastes, such as methane emissions, whilst improving the economics of farming and forest management.

The use of biomass can lower overall atmospheric CO_2 levels if that use is managed and regulated properly. When biomass is used for energy purposes, it generates positive effects from avoided CO_2 emissions when the whole life cycle is considered. Similarly, when biomass is used in bio-based materials (i.e. construction, furniture and plastics), it increases the biogenic carbon stored in materials throughout the products' lifetimes, and in some circumstances, may have the positive effect of sequestering CO_2 for the medium or long term.

If bioenergy is used with carbon capture and storage (BECCS), then the carbon is not returned to the atmosphere, leading to a net reduction of CO_2 (i.e. negative emissions). Although BECCS is currently not deployed at the industrial scale, the technology could be used for applications such as bioethanol production, waste to energy plants, power generation, and industries like pulp and cement.

There is significant potential for biomass to contribute to energy and environmental objectives, but it must be produced in ways that are environmentally, socially and economically sustainable. Biomass use in energy includes a wide range of options, and the environmental, social and economic benefits depend on many factors and can vary by location. Confidence in the sustainability of bioenergy is an important requirement for its widespread use, and sustainability assessments are needed to consider the risks associated with each specific bioenergy route.

Despite strong drivers for the uptake of bioenergy, multiple barriers stand in the path of its further development globally. These vary depending on specific markets and renewable energy technologies. They include challenges such as the high cost of many bioenergy options and the lack of access to finance. There also are policy barriers, including the lack of specific regulations, and cultural and awareness barriers. In particular, the deployment of biofuels is highly affected by global trends in oil prices. The recent abrupt decline in oil prices during the COVID-19 crisis, for example, is threatening the development and use of biofuels. If the current low fossil fuel prices are maintained, biofuels will struggle to compete with conventional fuels.

Addressing these barriers will be fundamental for a successful energy transition in many countries and regions. Governments have important roles to play in providing measures to support deployment and technological innovation. Those measures can include grants, feed-in tariffs and certificate schemes, as well as clear policy and regulatory frameworks, such as ambitious targets to drive markets and regulations for waste and blending. Policies and regulations could also help in ensuring that the appropriate infrastructure is in place for the greater uptake of bioenergy. For example, the availability of district heating systems is a powerful enabler for bioenergy heat supply in urban areas. Other enabling policy interventions include improving awareness of the benefits associated with bioenergy by providing clear and reliable information to consumers and potential investors; creating a level playing field through the removal of subsidies for fossil fuels; and introducing carbon pricing or other taxes, levies and duties to put a price on the environmental impacts of fossil fuel energy use.

G20 member states have a strong economic and political interdependence, with a shared interest in creating a sustainable and stable global environment. As part of the steps needed to achieve the energy transformation, this report argues that G20 countries together can foster the development, deployment and spread of bioenergy technologies. Ultimately, the success of the energy transition in mitigating the climate crisis will depend on the policies adopted, the speed of their implementation and the level of resources committed. In our interconnected world, international cooperation and solidarity are not just desirable, they are vital for addressing climate change, economic inequality and social injustice.

G20 recommendations

This report highlights the central role of biomass in delivering many aspects of the energy transformation and in building a climate-friendly circular carbon economy. It discusses the current and potential roles of biomass as the primary source of renewable hydrocarbons and demonstrates how bioenergy is a well-established and well proven technology for uses in the generation of heat and power and in all end-use sectors. However, there are still many challenges to overcome to maximise the sustainable use of biomass in the energy transition.

Increased use of biomass will be essential for several aspects of the energy transition. For example, key industrial processes and transport modes will not be totally decarbonised without it, and bioenergy with carbon capture and storage (BECCS) is one of only a few viable technologies that could offer negative emissions. Yet biomass is underutilised and undervalued in current energy plans and not sufficiently integrated in either the energy system or the biomass economy.

Increasingly, a major challenge is negative perceptions of biomass use among some policy makers and stakeholders, linked to concerns about the impacts of producing or harvesting biomass for energy. Ensuring sustainable supplies of biomass that do not cause social or environmental harm is an important challenge that must be addressed, but strong and growing evidence shows that the challenge can be met with careful planning and robust processes. Discussion and plans for the use of biomass need therefore to distinguish good practice from bad. Not doing so and not making appropriate use of biomass in energy risks significant harms from unmitigated climate change.

To sustainably deploy biomass sources along a pathway that is beneficial for society and the economy and is climate safe, G20 countries should individually and in partnership with others take action to:

1. Mainstream the circular carbon economy as a foundational pillar of economic policy and embark on the transition toward carbon neutrality

Addressing human needs for food, feed, materials and minerals in a sustainable fashion and tackling climate change require the phasing out of fossil fuel derived energy and materials and substituting the sustainable production and consumption of biomass. However, the far-reaching nature of this goal makes it difficult for countries to make it a high priority in their political agendas, despite the multiple potential benefits, including higher GDP growth compared to business-as-usual pathways.

Action needed: Countries should explicitly cite and adopt the concepts of the circular carbon economy and the goal of carbon neutrality as central guiding principles in national policy documents, including national energy plans, Nationally Determined Contributions (NDCs) and other key strategic plans.

2. Integrate bioenergy in energy system planning and raise awareness of its potential as a key component of an optimised energy system

Modern bioenergy can make a major and essential contribution to transforming the end-use sectors of industry, buildings and transport. Potential users of bioenergy and other actors along the supply chain, however, may be unaware of bioenergy's potential. That potential must be fully explored when developing energy policy and the experience of bioenergy's use should be shared more widely.

Action needed: Countries should explore the full potential of bioenergy, particularly in decarbonising the most challenging end-use sectors – industry and long-haul transport. G20 countries should work together to raise awareness among key actors of uses that go beyond conventional applications and encourage studies and piloting of those new uses.

3. Enhance sustainability governance and proper land use planning

A better understanding of benefits and risks of bioenergy has been developed in recent years and has formed the basis for regulations that seek to prevent unsustainable practices. The regulations, however, must include provisions for monitoring and tracking in the bioeconomy. For example, considering land use change, it is food production rather than bioenergy that is the primary driver of deforestation. An incomplete understanding of both benefits and risk mitigation options can lead to uncertainty amongst policy makers, lack of confidence amongst potential investors and reputational risks for off-takers that hamper progress.

Action needed: Governments and expert groups should improve the understanding of sustainable biomass production and consumption. Sustainability governance schemes should be further strengthened with the implementation of project-based certification mechanisms alongside improved monitoring of carbon stock changes, in order to improve the evidence-based implementation of a carbon-neutral or carbon-negative biomass economy.

4 Take a holistic approach to maximise synergies across the whole biomass industry

Biomass today provides food, feed, fibre, fine chemicals, fertiliser, energy and fuels. Bioenergy currently is only a small part of the biomass industry, but could be expanded in ways that would bring positive synergies with agriculture and forestry.

For instance, materials that now are burned onsite or thrown away, such as residues, by-products and wastes, could create new revenue streams. The sale of woody residues for energy production, for example, would increase the value of timberland and encourage more intensive forest management that, in turn, would increase the amount of carbon stored in forests over time.

Through these and other benefits, the circular carbon economy can turn food vs. fuel trade-offs or conflicts into food and fuel synergies. In many countries however, these synergies are not being considered or exploited because policy development for agriculture and forestry is not closely linked with energy and climate change.

Action needed: Countries should establish cross-departmental policy groups to fully explore how bioenergy and biomass management can be more closely integrated, and how agriculture and forestry policies can be designed to fully tap into the potential of their resources including for energy use.

5. Improve the sustainable biomass value chain through greater use of biorefineries

Building more biorefineries will enable greater use of biomass for a variety of applications and improve the entire biomass value chain in a sustainable fashion. The finite availability of biomass resource means biomass conversion technologies must be highly efficient to maximise the economic and environmental benefits. Enhanced use of biomass residues could improve resource efficiency and economics by co-producing value-added products such as bioenergy and bio-based materials.

Action needed:
Countries should establish multi-stakeholder platforms which include all actors across the full value chain of biomass to improve communication and knowledge sharing and to develop and pilot integrated infrastructure projects, such as biorefineries.

6. Raise bioenergy targets to fully exploit its sustainable potential

IRENA's Global Renewables Outlook report concluded that modern forms of bioenergy can be sustainably deployed at an amount four times larger than today's level. However, the current and planned policies of countries would only marginally grow bioenergy's share of the total energy mix by 2050.

Action needed: Countries should systematically assess the full sustainable potential of biomass use in their energy systems and then increase national bioenergy targets in their energy system plans, including in Nationally Determined Contributions (NDCs). Similarly, bioenergy targets should be included in long-term energy scenarios to support the planning for a renewable energy system.

7. Accelerate the uptake of bioplastics

The G20 has recently raised strong concerns about the severe environmental consequences of plastic waste. While bioplastics can help reduce overall CO_2 emissions, the like-for-like replacement of fossil fuel plastics with bioplastics can simply perpetuate environmental harm. One solution, therefore, may be increased use of biodegradable bioplastics. Bioplastics currently comprise 1% of annual plastics production, so there is significant scope for scale-up.

Action needed: In support of G20 coordinated actions on plastics and to reduce CO_2 emissions and reliance on fossil fuels, countries should include the increased substitution of bioplastics for fossil fuel plastics in national strategies. In addition, tightly controlled recycling and end-of-life management processes for all forms of plastics are needed to reduce negative environmental impacts and the use of fossil derived materials.

8. Integrate novel technologies for carbon capture and utilisation or storage

Bioenergy with carbon capture and utilisation or storage (BECCU or BECCS) may have a role to play in decarbonising some emissions-intensive industries and sectors and in enabling negative emissions. The current lack of large-scale projects means that the cost of BECCS/CCU technology is highly uncertain, but the number of pilot projects has been growing. Collaborations among countries and between the public and private sectors are needed because of the significant costs of pilot projects and the diversity of applications that need to be explored.

Action needed: G20 countries could, together with the private sector, develop strategies to more fully explore BECCS use, especially for industrial process applications. Countries should commit to establishing multiple pilots and should create mechanisms to share learning.

9. Mobilise enabling policy for investment

Supportive policy frameworks are key to scaling up the deployment of bioenergy and other bio-based solutions. Without a predictable investment environment backed up by a stable policy framework, biomass businesses cannot plan investments. A wide array of enabling policies to bridge the gap between the costs of bioenergy and fossil-based solutions should be mobilised. The policies could include regulatory frameworks to address environmental and operational risks, trade policies, policies to enhance sustainability, price incentive mechanisms. Countries could also set a carbon price on fossil fuels and GHG emissions limits for industrial processes.

Action needed: Countries should develop innovative financing and investment strategies aimed at facilitating market access and addressing the financial barriers for bioenergy projects.

10. Promote international cooperation and the transfer of both knowledge and technologies

The greater use of biomass in the energy transformation needs to be considered globally. Limited supplies of biomass and differences in resources between countries will lead to increased international trade in biomass. Relatively few countries are now exploring or expanding the use of biomass, so many more need to scale up their efforts. However building the necessary technical and regulatory awareness and capacity is challenging, especially for emerging and developing economies. More international cooperation is needed to exchange best practices, promote technology transfer and develop cross-border trade mechanisms.

Action needed: More countries should explore biomass use and provide stronger support to multilateral organisations and initiatives working on bioenergy, including through increased senior-level engagement.

Further Actions with IRENA

Discussions about bioenergy often take place only on the margins of the wider energy policy debate, and bioenergy is often not managed by policy teams in energy ministries. IRENA, with its remit to support a renewables-based energy transition, can play a key role in fully integrating bioenergy in energy transitions and can support G20 members and IRENA's wider global membership in addressing the above recommendations. Building on the G20's 2015 Renewable Energy Toolkit and the Plan of Action, the G20 countries could consider supporting work to:

- **Mainstream the use of biomass in energy transition planning.** As part of IRENA's work with a wide range of member countries on energy system roadmaps and plans, IRENA can assist countries in fully exploring their biomass potential.

- **Convene diverse groups of stakeholders for knowledge sharing and joint strategy development.** IRENA can bring together disparate policy makers, such as those from the often-different ministries responsible for agriculture, environment, energy and industrial policy, as well as a diversity of private sector actors.

- **Develop and share evidence to inform strategies.** IRENA's work aims to address misconceptions about bioenergy and to collate and share best practices in the sustainable sourcing and use of biomass in the energy and end-use sectors.

- **Build capacity in countries – particularly in the developing world.** IRENA can support countries in developing policies and projects that can fully and sustainable utilise bioenergy in national energy systems.

01
Introduction

Climate change is one of the greatest threats of our era. Over the past decade, energy-related carbon dioxide (CO_2) emissions have increased by 1% per year on average. If the historical trends were to continue, energy-related emissions would increase by a compound annual rate of 0.7% per year to 43 gigatonnes (Gt) by 2050 (up from 34 Gt in 2019), resulting in a likely temperature rise of 3°C or more in the second half of this century. Meanwhile, a growing world population is increasing the demand for energy. At the same time, large numbers of people have no access to electricity or are forced to spend a large part of their incomes on energy. Indeed, it is becoming increasingly harder to address the three central issues: security of supply, environmental sustainability and energy justice.

This challenging situation calls for a swift and drastic energy transformation, moving away from fossil fuels towards renewable sources of energy, supported by increased efficiency and the reduction of total energy consumption. The goal is to create energy systems that guarantee a secure and affordable energy supply for all populations, while also protecting the environment and the climate.

In support of that energy transition, the King Abdullah Petroleum Studies and Research Center (KAPSARC) has proposed the concept of a "circular carbon economy". Under this approach, all climate mitigation options are included and can be linked together to achieve the climate goals in the Paris Agreement. The key organising principle for carbon management is the "three Rs": reduce, reuse and recycle, with the addition of a fourth R for "remove". The current paper addresses biomass under the "recycle" pillar. Bioenergy is viewed in the context of the "natural carbon cycle, in which natural sinks (e.g. plants, soil and oceans) draw carbon from the atmosphere and then release it again through decomposition and combustion. The carbon is effectively recycled, and the bio-energy subsystem can be considered carbon neutral, as long as an equal amount of biomass grows to replace what is harvested as bio-feedstock (e.g. wood, fuel crops, algae) for bio-energy"(KAPSARC, 2019).

This report describes how biomass has a central role in delivering many aspects of the energy transformation and help build a climate-friendly circular carbon economy. It discusses the current and potential application of bioenergy and renewable carbon, and presents the strong economic case supporting them, including their positive externalities and socio-economic benefits.

The report is structured as follows:

- **Chapter 2** summarises current levels of deployment of bioenergy on a global scale, showing that bioenergy is an established and proven technology with key roles in both power generation and all end-use sectors.
- **Chapter 3** describes how bioenergy technologies are developing and how bioenergy use can be broadened across a range of end-use applications.
- **Chapter 4** details how bioenergy can contribute to reducing carbon emissions to meet the goals of the Paris Agreement.
- **Chapter 5** identifies the barriers (technological, financial, policy, social, etc.) that may inhibit bioenergy in reaching its full potential and outlines the socio-economic aspects of bioenergy.
- **Chapter 6** discusses policies that can enable the fuller use of bioenergy.

The report concludes with a set of recommendations and actions for G20 countries for the development of bioenergy.

02
Current Status

Bioenergy makes up a large share of renewable energy use today and plays a key role as a source of energy and as a fuel in the end-use sectors (industry, transport and buildings), as well as in the power sector. Figure 1 shows key indicators of the current contribution of bioenergy to the energy transition. Bioenergy use has been growing and changing in promising ways, thanks to improvements in the technology, growing acceptance and supportive changes in policy environment, such as the global commitment to reaching the Sustainable Development Goals (SDG), in particular SDG7: ensure access to affordable, reliable, sustainable and modern energy for all.

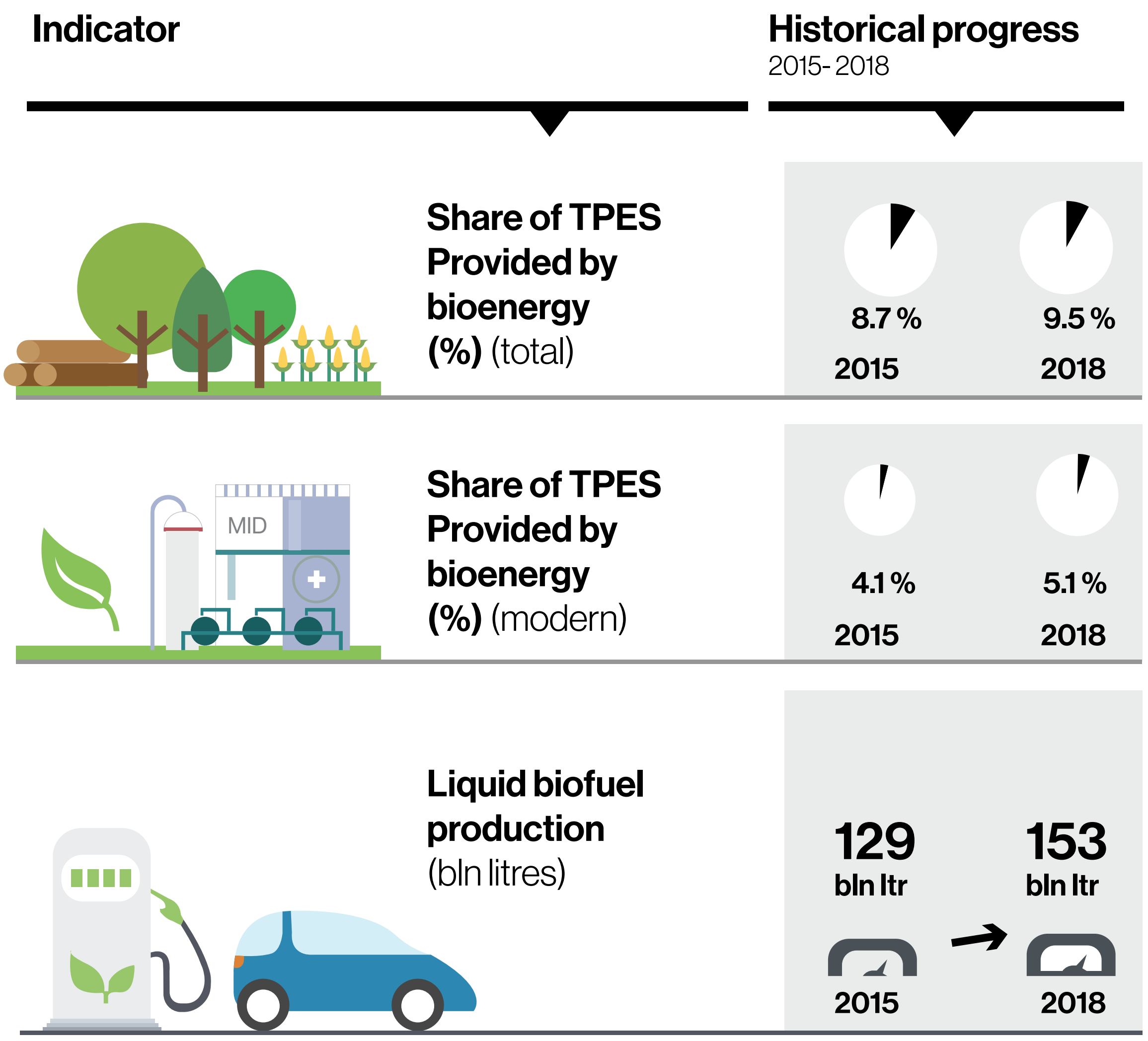

Figure 1. Current bioenergy shares, and liquid biofuel production

Note: "total" refers to traditional and modern

Source: Data extracted from (IRENA, 2020; REN21, 2019)

Bioenergy today accounts for 70% of the global renewable energy supply and 10% of the total primary energy supply. In terms of end uses, the largest share of total bioenergy use (modern and traditional) is in the buildings sector, which includes cooking and space heating (26%). The second largest share is in the industry sector (at 7%), followed by the transport sector (3%), mostly in the form of liquid biofuels from crops such as sugar cane and corn, and the power sector (2%) (IRENA, 2020).

Box 1: Traditional vs. Modern biomass

Biomass is any organic material derived from plants or animals. It includes wood, agricultural crops, herbaceous and woody energy crops, algae, animal fats, livestock manure and municipal organic wastes.

- **Traditional use** refers to the use of wood, charcoal, agricultural residues and animal dung locally collected or from unsustainably produced sources with basic techniques for cooking and heating at very low conversion efficiency (10% to 20%) in open stoves or fires with no chimney or hood. These uses often release flue gases indoors or cause high concentrations of air pollutants.

- **Modern use refers to the direct combustion of commercially produced primary biomass and the indirect use of pre-treated solid biomass with heightened energy density for electricity and/or heat generation.** It includes liquid forms of biomass produced via conventional or advanced conversion routes for transport fuels, cooking and industrial applications; biogas produced through anaerobic digestion of residues and waste; and syngas produced through biomass gasification. Biomass use in improved cookstoves can be categorised as modern use if sustainably sourced.

Source: (IRENA, 2013), IRENA website and GBEP Sustainability Indicators for Bioenergy Implementation Guide combined and further revised

Currently, bioenergy has well-established roles and set of applications in each of the end-use sectors, as well as in the power sector.

Industry sector

The industry sector uses energy for a wide range of purposes, such as for processing and assembly, steam generation, cogeneration, process heating and cooling, lighting, heating, and air conditioning. However, most of the energy consumed in industry is in the form of heat, especially in the most energy-intensive industrial sectors – iron and steel, chemical and petrochemical, non-metallic minerals, pulp and paper, and the food industry. Current direct renewable energy use in industry is predominantly in the form of biofuels and energy from waste. Biomass could play an expanded role for the decarbonisation of the industry sector, as it offers an established renewable energy option to provide low-, medium- and high-temperature heat, as well as a feedstock that can replace fossil fuels. At a regional level, the largest share of biomass in industry's final energy consumption in 2017 was in Latin America and the Caribbean at 32%, followed by Asia and Sub-Saharan Africa, both at 29%.

Biomass is also used for carbon emissions reductions in the industry sector through the production of natural synthetic fibres based on cellulose, and biomaterials to produce bioplastic. Biomass used for bioplastic production mainly comes from corn, sugarcane or cellulose (European Bioplastic, 2020). In 2019, according to the European Bioplastics association, the global production capacity of bioplastics reached 2.11 Mt using 0.79 million hectares of land, representing 0.02% of the global agricultural area of a total of 4.8 billion hectares. Production was concentrated in Asia (45%), followed by Europe (25%), North America (18%) and South America (12%) (IRENA, 2020).

Transport sector

Globally, the share of renewable energy in this sector is very small at just 3% in 2017. In road transport, the use of renewables is dominated by liquid biofuels, mostly bioethanol and biodiesel, which offer an alternative fuel for all types of internal combustion engines in both passenger vehicles and trucks. North America had the largest production of liquid biofuels in 2017, with 64 billion litres, followed by Latin America and the Caribbean with 31 billion litres and the European Union with 25 billion litres.

Liquid biofuels could also help decarbonise the shipping and aviation sectors, which currently are entirely fueled by fossil sources. The decarbonisation of these modes of transport is essential, as they make up 20% of total energy demand from transportation and are the fastest growing segments of the sector. Advanced biofuels offer significant emissions reductions compared to petrol and diesel. They can be made from non-food and non-feed biomass, including waste materials (such as vegetable oils or animal fats) and energy-specific crops grown on marginal or degraded land. They thus have a lower impact on food resources and lower probability of causing Land Use Change (LUC) and Indirect Land Use Change (ILUC). However, despite their advantages, advanced biofuels face significant barriers, such as lack of technological development, high production costs, immature supply chains and dependence on government support schemes (IRENA, 2019b).

Buildings sector

There are two different ways of using biomass in the buildings sector: space heating and cooking. Buildings can currently be heated using biomass through town-scale district heating systems or building-scale furnaces, both of which use feedstocks such as wood chips and pellets very efficiently.

Cooking with biomass is typically one of the traditional uses of biomass in developing countries. Inefficient traditional cookstoves paired with solid fuels and kerosene emit indoor smoke that imperils the health of mainly women and children and causes nearly 4 million premature deaths every year. Unsurprisingly, the largest share of biomass consumption in the buildings sector in 2017 was in Sub-Saharan Africa at 91% (entirely in the form of traditional uses). These detrimental cooking practices must be replaced with clean, efficient, modern systems that use improved cookstoves fueled with sustainably produced bioenergy such as wood, biogas or ethanol (IRENA, 2017).

Power sector

Biomass and waste fuels in solid, liquid and gaseous forms are currently used to generate electricity. The feedstocks and technologies range from mature, low-cost options, like the combustion of agricultural and forestry residues, to less mature and/or expensive options, like biomass gasification or municipal solid waste generators with stringent emissions controls (IRENA, 2019c). However, electricity generation from biomass is most often provided through combined heat and power (CHP) systems. Power production from biomass is relatively flexible, so it can help to balance output over time on electricity grids with high shares of variable wind and solar power. At a regional level, in 2017 the European Union and Asia had the largest bioenergy capacity installed, a total of 34 GW each.

An important niche that has yet to be fully explored is the use of biomass residues and waste generated in bio-based industries such as pulp and paper, lumber and timber, and food processing and biofuels. These sectors usually have large amounts of biomass that can be used for energy production. To a large extent, the modern part of those industries already taps into those resources, mostly for electricity and heat generation, in stand-alone applications or co-generation systems.

03 The technology outlook for bioenergy and bio-based materials

The following chapter describes how bioenergy technologies are developing and how bioenergy use can be broadened across a range of end-use applications.

3.1 Bioenergy in the Industry Sector

Key findings

- In IRENA's estimation, biomass (direct use, bioelectricity and biomass in district heating) could contribute up to one-fourth of total final energy consumption in industry.
- Bioenergy is one of only a small number of possible solutions for those industrial sectors that remain particularly challenging to decarbonise, namely iron and steel, cement and lime, aluminium and the chemical and petrochemical industry.

Biomass, due to its versatility, could play significant roles in the industry sector. Biomass can be used as a feedstock to replace fossil fuels, it can be used to produce low-, medium- and high-temperature heat, and it can be used as a fuel for localised electricity production. The versatility of biomass and its finite supply, however, also result in competition for its use within and between industry sectors, and other sectors of the economy. In IRENA's analysis, renewable energy (including renewable electricity and district heating) could contribute 63% of industry's total final energy consumption by 2050 (89 EJ in absolute terms). Of that total energy, 24% would be sourced from biomass (direct, bioelectricity and biomass in district heating) and the remaining 39% from other renewable sources (Figure 2).

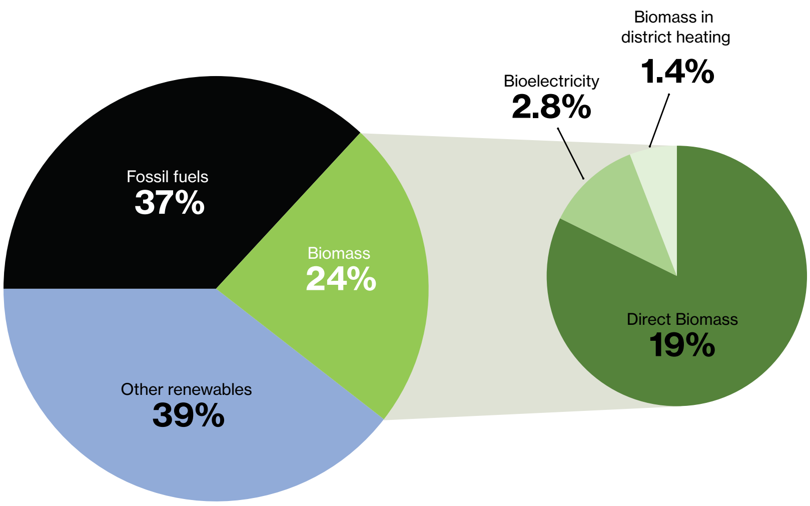

Figure 2. Renewable energy contribution to industry final energy consumption in the Transforming Energy Scenario (TES) in 2050

Note: "Other renewables" also includes renewable electricity

Source: Data extracted from: (IRENA, 2020)

Table 1 illustrates the applications of bioenergy in some industrial sectors that are hard-to-decarbonise

Sectors	IRENA's TES	Bioenergy application
Iron and Steel	In the Transforming Energy Scenario, emissions would decline to 1.2 Gt/yr by 2050	A significant share (about 78%) of the total energy consumed for iron and steel production comes from the use of coal and coke as chemical reducing agents for iron production. The substitution of biomass products for coal and coke can provide carbon and at the same time could be upgraded to have similar characteristics to fossil fuels. Using biomass instead of coal and coke more widely could cut emissions by almost 50%, but it remains costly and its use on a larger scale is only at the research stage.
Cement	In IRENA's Transforming Energy Scenario Cement emissions would fall from 2.8 $GtCO_2$ in 2017 to 1.7 $GtCO_2$ thanks to lower clinker/cement ratio.	The manufacture of clinker is responsible for the bulk of the CO_2 emissions associated with cement production. Biomass could be considered as a clinker substitute (however, its role and potential are still quite limited). In addition to this role, biomass can also be used as an alternative material to cement in the construction industry, where wood materials contribute to reaching zero carbon if produced sustainably.
Aluminum	In IRENA's Transforming Energy Scenario, aluminium production grows from 196 Mt per year in 2019 to 268 Mt per year in 2050. The shift to renewable power generation cuts CO_2 emissions by more than 20% by 2050: from 1.4 $GtCO_2$ in the Planned Energy Scenario to 0.7 $GtCO_2$ in the Transforming Energy Scenario.	Most energy consumed in the aluminium industry is in the form of electricity used for smelting. The use of biofuels and solar heat are among several new technologies emerging in this industry to reduce the electricity needed for smelting, as they can readily replace fossil fuels and low- and medium-temperature alumina production.
Chemicals and Petrochemicals	In 2017, the chemicals and petrochemicals sector emitted around 2.8 Gt of CO_2 (including energy, process, non-energy use and waste). However, under the Transforming Energy Scenario, emissions would fall to 1.4 $GtCO_2$.	Biomass is one of the prime alternatives to fossil fuel use in the sector, either through biomaterials (see section 3.6 below) or using biomass building blocks. Key bio-based feedstocks, which can be used to produce conventional products such as plastics, are bio-ethylene and bio-methanol; others include also biogas or bio-naphtha.

Table 1. Bioenergy applications in the industrial sector
Source: (IRENA, 2020)

Other potential industrial applications include the use of biomass residues generated in biomass-based industries such as pulp and paper, lumber and timber, food and biofuels. In addition, biorefinery systems offer attractive routes for energy generation, in the form of combined heat and power (CHP) and biofuels, alongside chemical production, with great promise for reduced environmental impacts.

3.2 Bioenergy in the Transport Sector

Key findings

- In IRENA's analysis, biofuels and biogas consumption would grow to nearly five times 2017 levels by 2050 and provide 20% of total transport final energy demand.
- Biofuels would play a particularly important role for the decarbonisation of long-haul transport (aviation, marine and long-haul road freight).

Compared to current levels, energy demand in the transport sector is lower under the Transforming Energy Scenario due to efficiency improvements and other measures, such as changes in transport modes and reductions in the need for travel. Fossil fuel consumption (oil, natural gas) is sharply reduced, and there is a major increase in biofuels, which reach 17 EJ in 2050 (over five times 2017 levels) and provide 20% of total transport final energy demand. Electricity use in transport also grows sharply to 37 EJ (of which 2 EJ is bioelectricity, 29 EJ is from other renewable sources and the remaining 5 EJ is from fossil fuels), representing 43% of total transport final energy demand in 2050 (Figure 3).

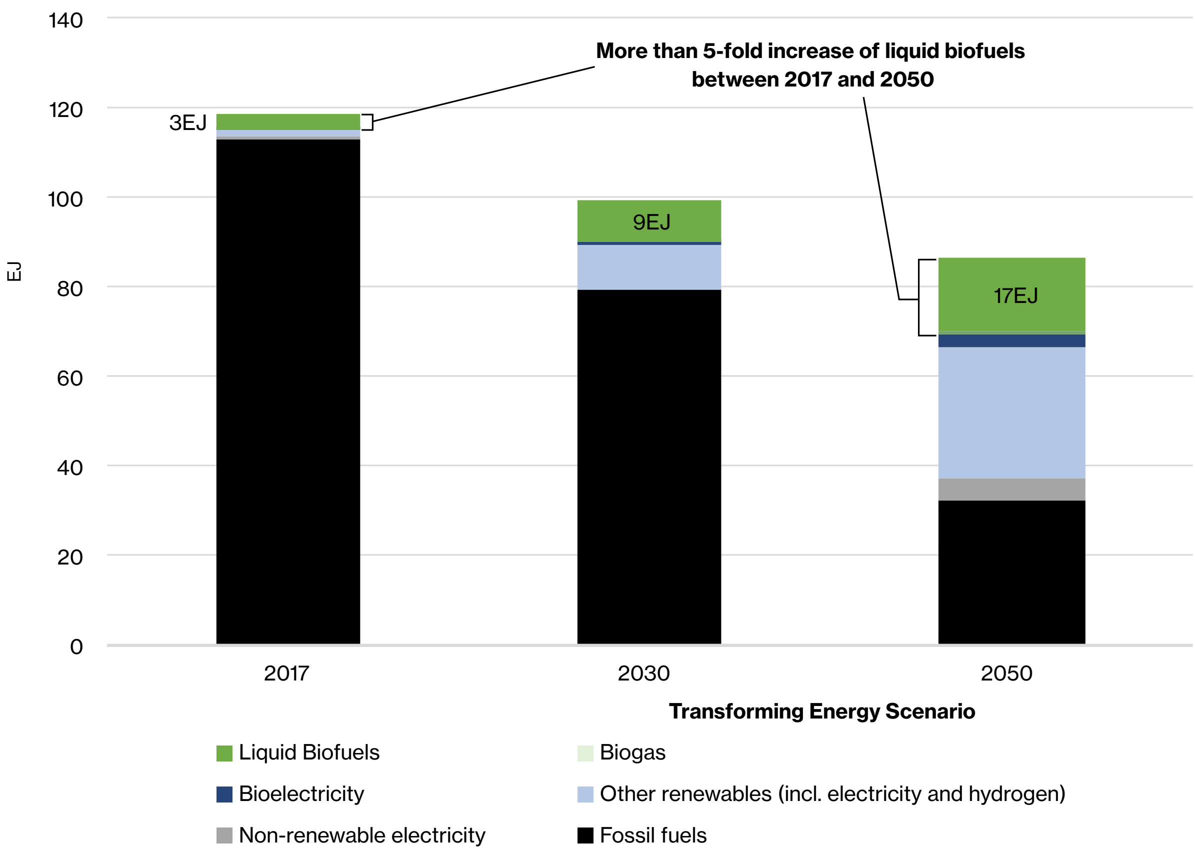

Figure 3. Final energy consumption in the transport sector per energy carrier (2017 and 2030- 2050 TES)
Source: Data extracted from: (IRENA, 2020)

Biofuels are an important alternative to fossil fuels, particularly for long-haul transport (aviation, marine and long-haul road freight), complementing the enhanced role of electrification and other urban measures. Transport will become much more electrified, but not everywhere, not in all sectors and not all at once. While EVs powered by renewable electricity will dominate light vehicle fleets, they can only enter markets with well-developed power grids. Long-haul transport is unlikely to be fully electrified due to the higher energy density it requires. Hence, a mix of oil-based, carbohydrate-based, and lignocellulosic biofuels has to be developed and used. Conventional fuel ethanol production will also have a continuing role where production costs are low. In IRENA's analysis, overall liquid biofuel production could increase five-fold from 130 billion litres in 2016 to 652 billion litres in 2050.

At a regional level, North America would lead in liquid biofuel production, with 183 billion litres in 2020. However, liquid biofuels have a large potential in Asia, with production increasing from 13 billion litres in 2017 to 211 billion litres in 2050. Biogas can replace fossil gas in natural gas vehicles (NGV) or so-called dual fuel vehicles. When biogas is upgraded to natural gas quality, it forms biomethane, which can also be used as a vehicle fuel, with similar properties to natural gas. Biomethane would increase from 0.4 bcm in 2017 to 13 bcm in 2050 (Figure 4) and could be used for public transport, waste collecting vehicles or heavy freight trucks (IRENA, 2020).

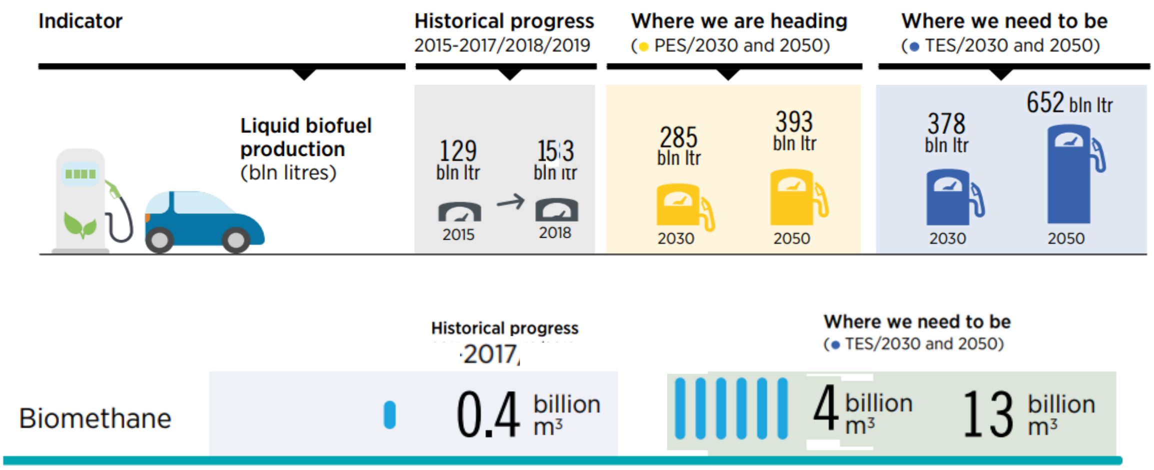

Figure 4. Biofuels production for the transport sector (2015-2017/2018, Planned Energy Scenario and Transforming Energy Scenario in 2030 and 2050) and biomethane production in 2017 and 2030-2050 in the Transforming Energy Scenario

Source: Data extracted from (IRENA, 2020; REN21, 2019)

Table 2 illustrates the applications of bioenergy in some transport sectors that are hard-to-decarbonise

Sectors	Bioenergy application
Aviation	Aviation, and in particular jet fuel use, is one of the fastest-growing sources of greenhouse gas emissions. Biofuel for jet aircraft, known as bio-jet, is the only currently available option for achieving significant reductions in aviation emissions. Despite the large potential, the current market for bio-jet is quite limited, due to high costs and lack of supportive regulatory framework and/or carbon pricing.
Shipping	Liquid biofuels are an option for decarbonising the shipping sector. From a technological perspective, liquid biofuels are mature, require few adjustments to existing ship engines or port infrastructure, and can significantly reduce emissions, even as blends. However, there are three main barriers to wider use: economics, availability and sustainability concerns.
Heavy-duty trucks	Biomethane, biodiesel and renewable diesel can be used in heavy-duty natural-gas-powered or diesel-powered vehicles (as well as in light-duty vehicles) without any specific adaptation. Some truck manufacturers are trying to develop biogas-fueled trucks for heavy and long-haul transport, while biodiesels are already being blended with conventional diesel and used in existing vehicles without any modification.

Table 2. Bioenergy applications in transport sectors
Source: (IRENA, 2020)

3.3 Bioenergy in the Buildings Sector

Key findings

- Traditional uses of biomass in cooking are expected to be phased out in the next decade and be replaced by modern uses of biomass through improved and modern cookstoves.
- Modern bioenergy is expected to play increasing roles in the decarbonisation of the buildings sector for heat production through district heating systems and building-scale furnaces, as well as for electricity and heat production in combined-heat and power (CHP) plants.

Traditionally, biomass has been used for **heating and cooking in open fireplaces or stoves,** and today modern biomass is being used in efficient boilers and furnaces and improved cookstoves. However, more than 3 billion people still rely on inefficient traditional use of biomass, such as fuelwood and charcoal, for cooking. The hazardous emissions released during inefficient cooking cause one of the world's major public health challenges, leading to over 4 million deaths per year (WBA, 2016). The problem is most severe in developing countries, where access to modern forms of energy is limited, and where cooking is typically done with solid fuel like wood logs and twigs, or with agricultural residues such as straw, especially in rural areas. The solution is a systems approach that uses innovative cookstove designs to vastly improve the efficiency of solid biomass combustion, while also replacing traditional charcoal or wood with modern biomass use like pellets, biogas and ethanol.

Modern bioenergy use also is expected to play an increasing role in the decarbonisation of the buildings sector, particularly in areas with high demand for space heating. Buildings can be heated through town-scale **district heating systems** or building-scale furnaces, both of which use feedstocks like wood chips and pellets very efficiently. It is important, therefore, to replace existing low-efficiency heating systems by high efficiency district heating and cooling (DHC) or building-scale furnaces fueled by renewable sources as much as possible.

In some cases, fossil fuel-based boilers can be co-fired with solid biomass, such as wood residues, or converted into biomass-only boilers. Biomass can also be used for both electricity and heat production in **combined-heat and power (CHP)** plants. Using biomass solely for electricity generation is not seen as a good choice because of its low efficiency, at about 30% (Koppejan and van Loo, 2008). However, the overall efficiency of biomass-based CHP plants for industry or district heating can be 70%-90% (IEA-ETSAP and IRENA, 2015). As a result, sustainable bioenergy used to provide heat and power can reduce emissions considerably compared to coal, oil and natural gas-generated heat and power.

In IRENA's Transforming Energy Scenario, by 2050 the final energy consumption of modern biomass (solid, biogas and liquid biomass, bioelectricity and biomass in district heating) grows more than three-fold from the 2017 level in the buildings sector, from 5EJ in 2017 to 16EJ in 2050. (Figure 5).

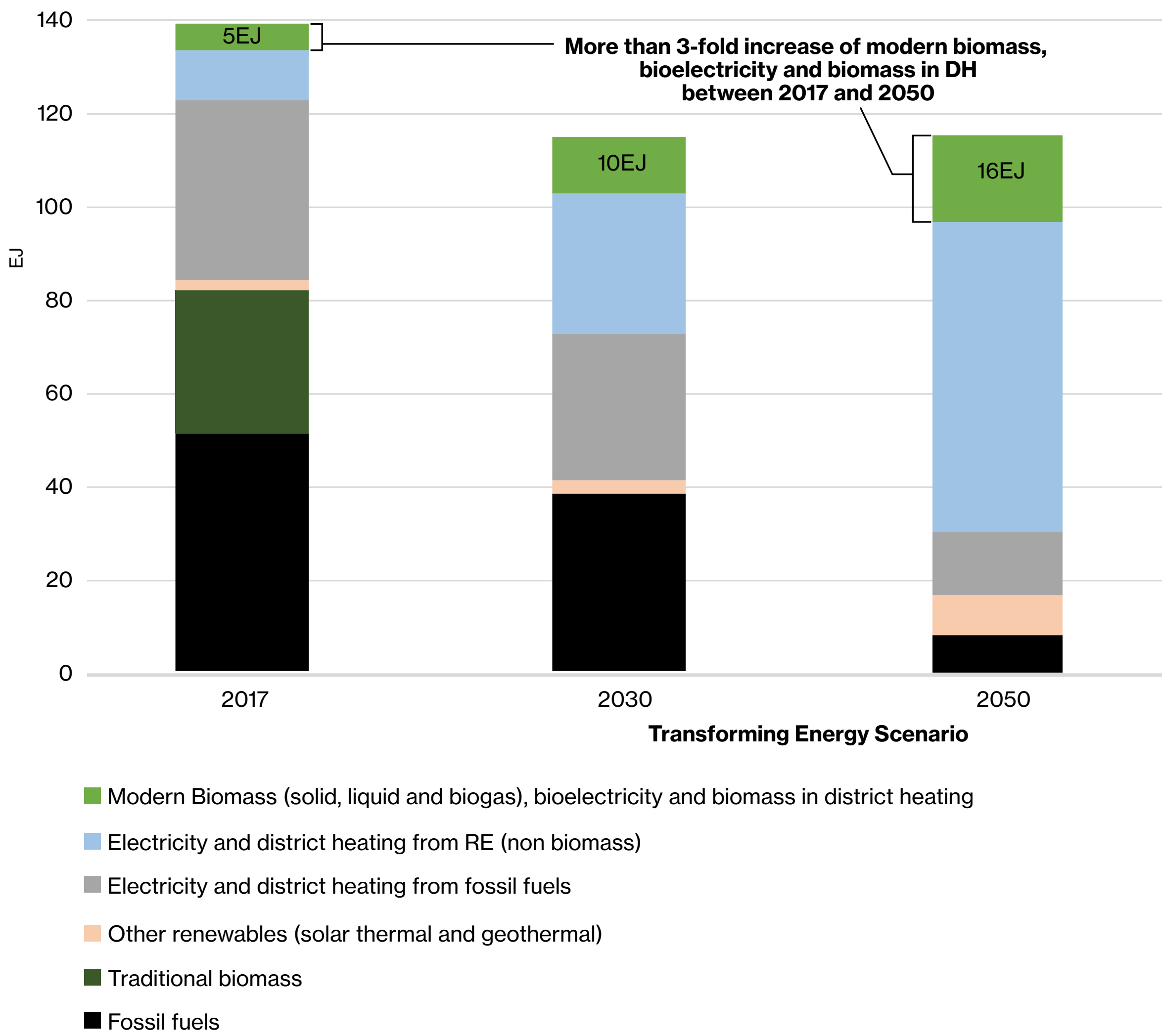

Figure 5. Final energy consumption in the buildings sector by energy carrier (2017-2030 and 2050 under the Transforming Energy Scenario)
Source: Data extracted from: (IRENA, 2020)

3.4 Bioenergy in the Power Sector

Key findings

- Bioenergy will play an important supporting role in renewable electricity generation to 2050.
- Bioenergy-based electricity has relatively high generation costs compared to other renewable technologies, but there are still several situations where it can have an important role.

Under the Transforming Energy Scenario, the power sector would be transformed. The total amount of electricity generated would more than double by 2050 – to over 55 000 TWh (up from around 24 000 TWh today). The share of electricity in total final energy use would increase from just 20% today to 49% by 2050, and 86% of that electricity would be generated by renewable sources, mostly wind (35% of renewable electricity), solar PV (25%) and some hydro (14%) (Figure 6). Biomass would be the fourth largest renewable power source, generating 7% of electricity. To produce that much power, bioenergy installed capacity would increase six-fold from 108 GW in 2017 to 685 GW in 2050. Asia would lead in bioenergy installed capacity, with 318 GW, followed by the European Union with 107 GW and Latin America and the Caribbean with 94 GW. In addition, biomass can be used for co-firing coal power plants as an intermediate measure to reduce CO_2 emissions.

Bioenergy-based electricity can play a particularly important role when: i) its generation costs are lower than other sources (i.e. where biomass feedstock costs are low or where heat can be used in co-generation systems); ii) it helps to balance output over time on electricity grids with high shares of variable wind and solar power; and iii) it is possible to use BECCS (IEA, 2017; IRENA, 2019a).

Total installed costs for bioenergy vary significantly. Projects using bagasse and rice husks tend to have lower installed costs than those using landfill gas, wood waste, other vegetal and agricultural waste and renewable municipal waste (IRENA, 2019c). Overall, however, bioelectricity's relatively high costs and limited options for lowering them are the main constraining factors to faster deployment.

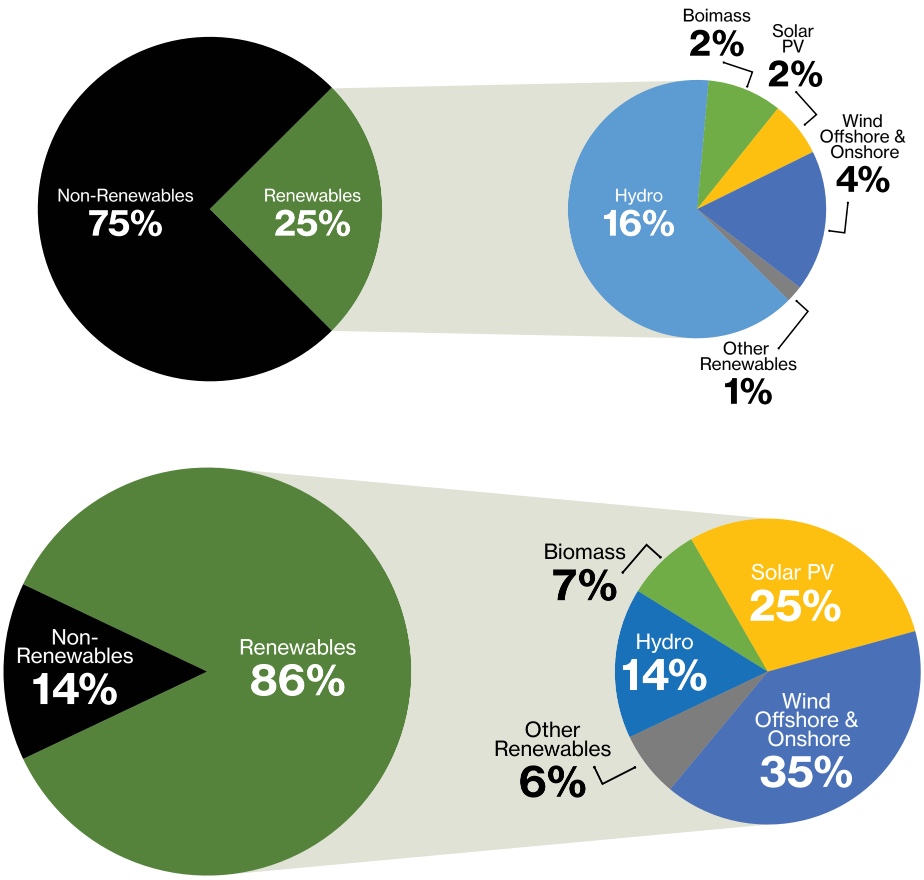

Figure 6. Electricity generation mix in 2017 and in the Transforming Energy Scenario in 2050
Source: Data extracted from: (IRENA, 2020)

Box 2: Biogas and biomethane applications

Biogas can be burned directly for cooking and lighting or indirectly in combustion engines to generate electricity or motive power. Biogas for cooking is particularly relevant for many developing countries, where it can reduce traditional use of solid biomass, offering a sustainable way to meet community energy needs, especially in areas without good grid access or where heat requirements cannot be met only by electricity. Biomethane is a versatile energy carrier produced from biomass via gasification or upgraded from biogas. It is sometimes also known as renewable natural gas, as it possesses compatible properties to natural gas.

In the transport sector, biomethane can be used as a drop-in substitute for natural gas in existing light- and heavy-duty natural-gas-powered vehicles, such as commercial vehicles, city buses and urban service fleets for delivery and refuse collection (IRENA, 2020). Some truck manufacturers are looking to develop biogas fuelled trucks for heavy and long-haul transport operations, and there already are examples of biogas use in commercial freight transport.

For example, in 2018, the grocery store chain Lidl started using trucks fuelled with liquefied biogas (LBG) in Finland. The LBG was produced from their stores' own wastes. These trucks are expected to cut CO_2 emissions by up to 85% compared with traditional fossil fueled trucks.

Biogas and biomethane can also be used for greening the gas system. Reusing gas infrastructure for green gas would avoid stranding assets while also reducing greenhouse gas emissions. Biomethane production via anaerobic digestion (AD, biogas), thermal gasification of biomass, or power-to-gas from hydrogen and carbon dioxide represents a clean and feasible solution for cleaning the gas system. However, currently, its production route is not mature and faces significant cost-related, logistical and infrastructure challenges.

In 2019, the World Biomass Association estimated that there were about 700 biogas upgrading plants, with more than 75% of them in Europe. Germany is the world's largest producer of biomethane with 220 plants, nearly half of the global installations. As of 2019, Denmark injects 10% biogas into its natural gas network, and the Danish gas industry has set a goal of reaching 100% by 2035.

Source: (IRENA, 2020)

3.5 Bio-based Materials

Key findings

- Bioplastic is a sustainable and carbon neutral alternative to plastic derived from fossil fuels.
- There are two main pathways to produce bioplastics: bio-based building blocks, such as olefins and aromatics, and dedicated bio-based polymers.

Because petrochemicals require hydrocarbon feedstocks, the only ways to produce these sustainably are by using biomass feedstocks or by using CO_2 captured from the air or from biomass combustion. The use of biomass feedstocks for plastics may result in the CO_2 being stored in products for decades and can, therefore, provide either carbon neutrality or negative carbon emissions, depending the products' eventual fate.

Bioplastics can be produced from bio-based building blocks or from dedicated bio-based polymers.

Bio-based building blocks

Chemicals produced from biomass can directly replace their fossil-fuel counterparts as building blocks for other chemicals and chemical derived products such as plastics. Key building blocks include olefins, aromatics and ethylene.

One pathway to produce olefins for bioplastics is converting methanol to olefins (MTO), which is a well-established production route in China. Producing biomethanol for this pathway can be done by steam reforming of raw glycerine, using residues from vegetable oil and animal fat processing; by biomass gasification from woody biomass or wastes; and by the anaerobic digestion of organic matters. Biomethanol, however, costs USD 1.00 to USD 2.50 more per gallon to produce than conventional natural gas methanol, according to one study (Biofuels Digest, 2017).

Another pathway is dehydrating bioethanol to form ethylene (an olefin). The production of bio-based ethylene has been underway on a commercial scale in Brazil and India for some years now although volumes are relatively small (less than 0.5% of total global ethylene production). The costs of production are currently higher than for petrochemical ethylene (Mello et al. 2019), so more work is needed to demonstrate cost-effective production at scale.

Aromatics are also important chemical building blocks, in addition to being used as solvents and as components of transportation fuels. It may be viable to produce aromatics from biomass using catalytic direct conversion, since biomass is already chemically similar to functional aromatics.

Bio-aromatics production is mostly in the early development stages, however, and commercial scale is a few years away. Higher production capacities for bio-aromatics of 150 kilotonnes (kt) can be expected for 2025 or after, with a few middle-scale industrial plants beginning operations. Less uncertainty about supply and technological improvements, along with higher fossil energy prices, may lead to an increase by 2030 in the range of 450 kilotonnes, or a 0.2% bio share (European Commission, Directorate-General for Research and Innovation, Fraunhofer ISI and Università di Bologna, 2019).

Dedicated bio-based polymers

In contrast to bio-based building blocks, dedicated bio-based polymers cannot be obtained through traditional chemical reactions (Carus, Dammer, Puente, Raschka and Arendt, 2017). Instead, there are range of promising bio-polymers being explored:

- Polyhydroxyalkanoates (PHAs) are a group of polymers that are of particular interest due to their thermoplastic behaviour (their ability to be melted and shaped). They can in principle be used directly as plastics without modification. Polyhydroxybutyrate (PHB), the first discovered polymer from this group, occurs naturally in low amounts in the cells of some microorganisms and can be obtained through fermentation (Voevodina and Kržan, Andrej, 2013).

- PEF (polyethylene furanoate) is comparable to PET but is 100 percent bio-based. It is claimed to feature superior barrier and thermal properties, potentially making it an ideal material for the packaging of drinks, food and non-food products.

- Bio-based PUR (polyurethanes) are a group of polymers that are expected to grow faster than conventional polyurethanes due to their versatility (European Bioplastics, 2019).

- PLA is a thermoplastic aliphatic polyester that can be produced through the fermentation of sugars and starch (Voevodina and Kržan, Andrej, 2013). With similar properties as classical thermoplastics (e.g. polystyrene), PLA could be used for packaging materials (films, bottles), disposable dishes, sheets and fibres.

04
Carbon management potential of biomass

IRENA's analysis is centered around the need to accelerate the global energy transformation, driven by the dual imperatives of limiting climate change and fostering sustainable growth. Renewable energy (including biomass), electrification and energy efficiency have emerged as key solutions for emissions reductions and achievement of the Paris Agreement goals.

The global energy transformation requires significant changes in the global energy sector and IRENA has developed an extensive and data-rich energy scenario database and analytical framework, which highlights immediately deployable, cost-effective options for countries to fulfil climate commitments and assesses the projected impacts of policy and technology change. IRENA's latest report: Global Renewables Outlook: Energy Transformation 2050, presents four scenarios representing possible paths of the global energy transformation as outlined in Box 3.

Box 3: IRENA's scenarios and perspectives

- **The "Planned Energy Scenario (PES)"** is IRENA's primary reference case providing a perspective on energy system developments based on governments' current energy plans and other planned targets and policies (as of 2019), including Nationally Determined Contributions under the Paris Agreement unless a country has more recent climate and energy targets or plans.

- **The "Transforming Energy Scenario (TES)"** describes an ambitious, yet realistic, energy transformation pathway based largely on renewable energy sources and steadily improved energy efficiency (though not limited exclusively to these technologies). This would set the energy system on the path needed to keep the rise in global temperatures to well below 2°C and towards 1.5°C during this century.

- **The "Deeper Decarbonisation Perspective (DDP)"** provides views on additional options to further reduce energy-related and industrial process CO_2 emissions beyond the Transforming Energy Scenario. It suggests possibilities for accelerated action in specific areas to reduce energy and process-related CO_2 emissions to zero in 2050-2060.

- **The "Baseline Energy Scenario (BES)"** reflects policies that were in place around the time of the Paris Agreement in 2015, adding a recent historical view on energy developments where needed.

Source: (IRENA, 2020)

The Transforming Energy Scenario outlined in this report offers a sustainable, low-carbon climate-safe foundation for stable, long-term economic development. A key element of the scenario is the synergy between increasingly affordable renewable power technologies, such as wind and solar PV, and the widespread electrification of end-use applications. Biomass, however, will have important roles in the end-use sectors, especially in industry for process heat and feedstocks and in transport as fuel.

This chapter outlines how bioenergy can be part of the global transformation of energy systems to renewables by making a major contribution to transforming the end-use sectors of industry, transport and buildings, particularly those applications that cannot be easily electrified.

4.1 Key drivers for the energy transformation

There are multiple drivers of the global energy transformation, as shown below in Figure 7.

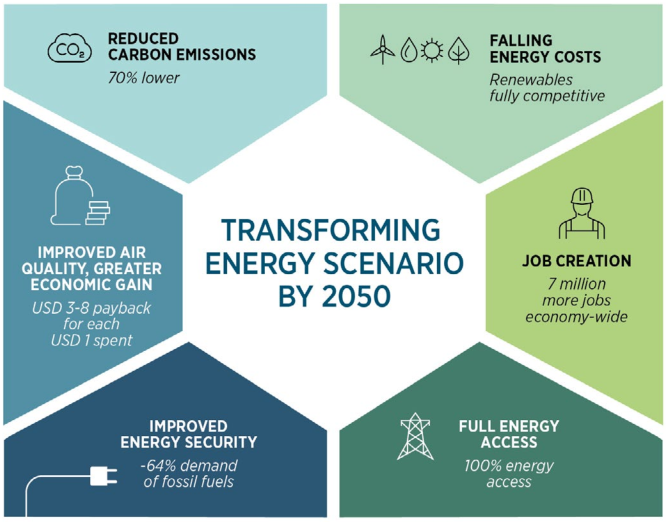

Figure 7. Key drivers for the energy transformation
Source: (IRENA, 2020)

However, the reduction of carbon emissions is at the heart of IRENA's analysis, given the urgent need to swiftly reduce the emissions that cause climate change.

The Paris Agreement establishes a clear goal to limit the increase of global temperature to "well below" 2°C, and ideally to 1.5 °C, compared to pre-industrial levels, during this century. To realise this climate target, a profound transformation of the global energy landscape is essential. The world must urgently shift away from the consumption of fossil fuels and towards cleaner renewable forms of energy by rapidly replacing conventional fossil fuel generation and uses with low-carbon technologies. IRENA's roadmaps offer an ambitious yet technically and economically feasible pathway for accomplishing this energy transformation and creating a more sustainable clean energy future.

To meet the aims of the Paris Agreement, energy-related carbon dioxide (CO_2) emissions need to be reduced by a minimum of 3.8% per year from now until 2050, with continued reductions thereafter. However, trends over the past five years show annual growth in CO_2 emissions of 1.3%. If this pace were maintained, the planet's carbon budget would be largely exhausted by 2030, setting the planet on track for a temperature increase of more than 3°C above pre-industrial levels with potentially catastrophic consequences. This case also would mean that governments were failing to meet the commitments they made in signing the Paris Agreement.

4.2 Global pathway and the role of bioenergy

4.2.1 Emissions reductions and the role of bioenergy

IRENA's Transforming Energy Scenario outlines a climate-friendly pathway with energy-related CO_2 emissions reductions of 70% by 2050 compared to current levels. About 9.5 Gt energy-related CO_2 emissions would remain by 2050. Of that, just under one-quarter would be emitted in electricity generation, just under another one-quarter in transport, one-third in industry, 5% in buildings and the remaining 15% in other sectors (agriculture and district energy). The Transforming Energy Scenario is focused on energy-related CO_2 emissions reductions, which make up around two-thirds of global greenhouse gas emissions. Of the 23.6 Gt of CO_2 reductions achieved in 2050 relative to the Planned Energy Scenario, 11% (or 2.6 $GtCO_2$) would come from bioenergy. Of that 0.6 $GtCO_2$ is from biomass power generation, 0.7 $GtCO_2$ from displacing liquid fossil fuel with liquid biofuels, 1.1 $GtCO_2$ from solid biofuels and 0.2 $GtCO_2$ from biogas/biomethane use in end-use sectors including district heating.

Figure 8 shows the annual energy-related CO_2 emissions in the Planned Energy Scenario (indicated by the grey line) and in IRENA's Transforming Energy Scenario (indicated by the blue line).

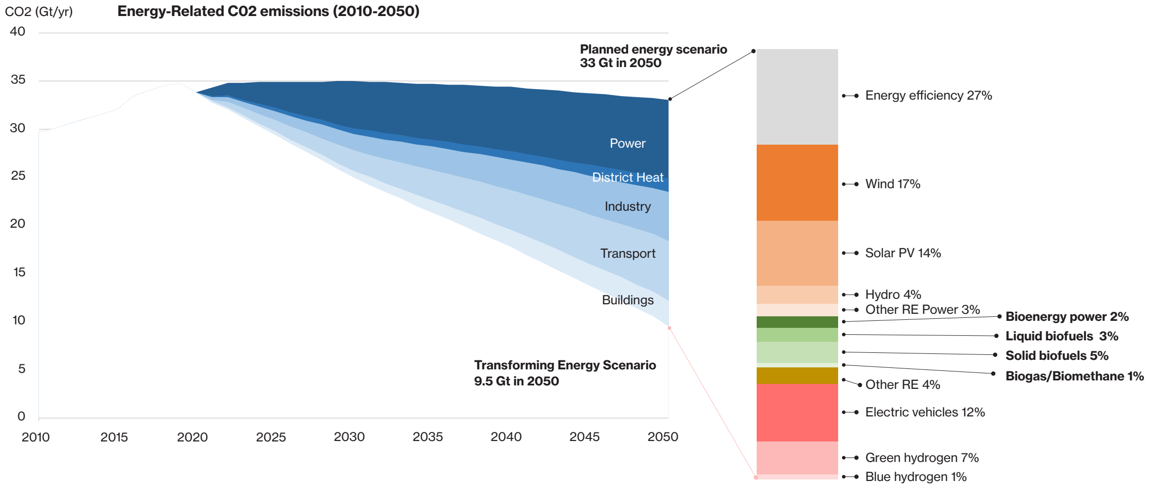

Figure 8. Annual energy-related CO_2 emissions in the Planned Energy Scenario and the Transforming Energy Scenario, and mitigation contributions by technology in the scenarios, 2010-2050

Source: Data extracted from: (IRENA, 2020)

In the Planned Energy Scenario, there also would be 3.6 Gt of process-related CO_2 emissions remaining in 2050. In the Transforming Energy Scenario, these are reduced to 0.9 Gt through carbon capture and storage (CCS), which accounts for 2 Gt of the 2.7 Gt reduction, and forms of carbon management. Those include offsetting using carbon dioxide removal (CDR) or reducing through material efficiency. The result would be 10.4 Gt of remaining net CO_2 emissions in 2050 (Figure 9).

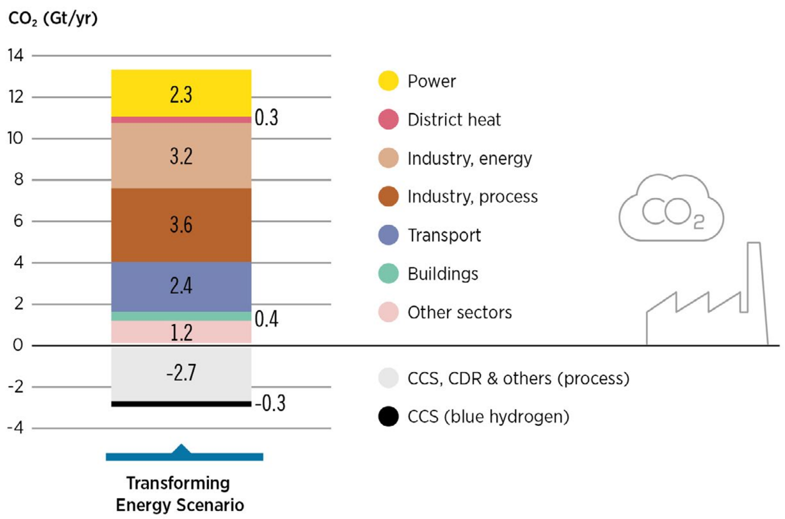

Figure 9. CO_2 emissions in 2050 from energy and process
Source: (IRENA, 2020)

Achieving net zero or zero greenhouse gas emissions to be in line with a 1.5°C scenario requires a step further to achieve a deeper decarbonisation and will very likely involve the development and use of carbon-negative solutions (Figure 10). The latest IRENA analysis discusses additional mitigation measures in its Deeper Decarbonisation Perspective (DDP), which offers a pathway to reduce the 10.4 Gt of annual CO_2 emissions remaining in the Transforming Energy Scenario to net zero by 2050. About two-thirds of the reductions would come from additional renewables, including additional bioenergy, and greater energy efficiencies. But the pathway also requires the annual removal of 3.4 Gt of carbon dioxide from the atmosphere, or 3.4 Gt of "negative emissions." Examples of CDR measures include reforestation, afforestation, direct air capture, enhanced weathering and bioenergy carbon capture and storage (BECCS) as well as carbon capture and utilisation (CCU) (IRENA, 2020).

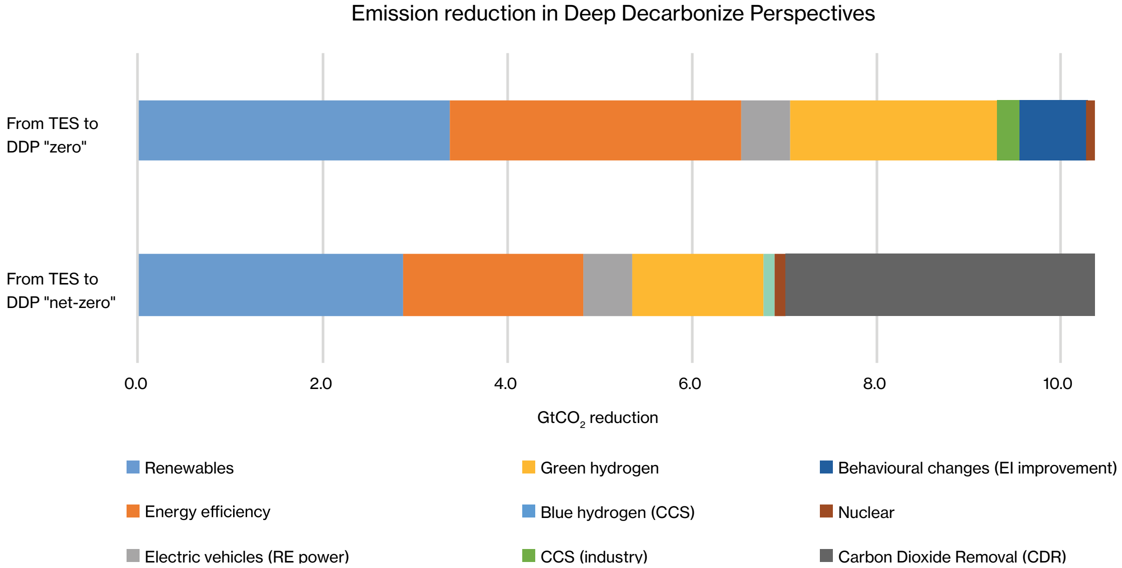

Figure 10. Additional mitigation measures (CO_2) in the Deeper Decarbonisation Perspective (DDP)
Source: Data extracted from: (IRENA, 2020)

4.2.2 Energy outlook for biomass

Under current and planned policies in the Planned Energy Scenario, the share of biomass in total primary energy supply (TPES) would remain at similar levels as today, rising slightly from 9.4% in 2017 (4.8% from traditional uses and 4.6% from modern uses) to 10% in 2050, while under the Transforming Energy Scenario, it increases to 23% (IRENA, 2020) (Figure 11) by 2050.

Biomass in absolute terms would increase from 52 exajoules (EJ) in 2017 to 70 EJ in 2050 in the Planned Energy Scenario and to 125 EJ in 2050 in the Transforming Energy Scenario. TPES would also have to fall slightly below 2017 levels, despite significant population and economic growth. In the period from 2010 to 2017, global primary energy demand grew 1.1% per year. In the Planned Energy Scenario, the growth in energy demand would be lower, at 0.6% per year to 2050, whereas in the Transforming Energy Scenario, energy demand would decline by 0.2% per year to 2050.

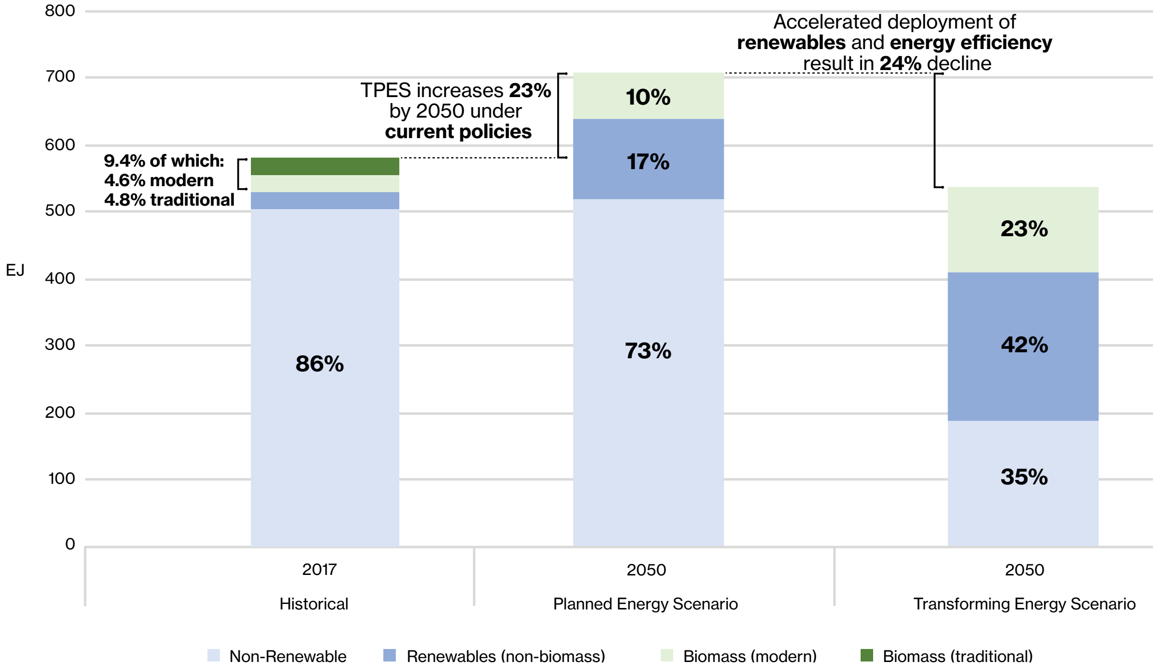

Figure 11. The global energy supply must become more efficient and more renewable
Source: Data extracted from: (IRENA, 2020)

4.2.3 Bioenergy with carbon capture and utilisation (BECCS)

Key findings

- Bioenergy with carbon capture and storage (BECCS) may have a role in decarbonising some emissions-intensive industries and sectors and enabling negative emissions.
- The cost of BECCS/CCU technology depends on the costs of biomass feedstock, CCS components, infrastructure, operation and fuel.
- BECCS/CCU is currently not deployed at scale due to several large uncertainties. However, potential applications include bioethanol production, waste to energy, power generation, and use in the pulp and cement industries.

The overarching purpose of all types of CDR measures is removing CO_2 from the atmosphere and then storing that CO_2 in some other carbon reservoir. The CO_2 can be stored in solid, liquid or gaseous state, either as CO_2 or in the form of other carbon-containing materials, such as char. The key aspect for “net removal” is that the storage must be permanent.

Many of the decarbonisation scenarios assessed by the Intergovernmental Panel on Climate Change (IPCC) in its Fifth Assessment Report (IPCC, 2014) and its special report on the impacts of global warming of 1.5°C (IPCC, 2018) rely heavily upon negative emissions, especially using BECCS. The Fifth Assessment Report (AR5) includes 116 scenarios that are consistent with a greater than 66% probability of limiting warming below 2°C, in which atmospheric concentrations of CO_2 would be 430–480 ppm in 2100. Eighty-seven percent of these scenarios apply global CDRs in the second half of this century, using BECCS to remove between 2 and 10 $GtCO_2$ annually in 2050 (Smith et al., 2016). (Fuss et al., 2014) and (Fuss et al., 2018) confirm that BECCS is the negative emissions technology most widely selected by integrated assessment models to keep temperatures at 2°C or below, and BECCS could remove up to 5 $GtCO_2$/yr by 2050, assuming biomass sustainability and adequate supply chains.

BECCS and BECCU processes are described in Figure 12 below. BECCS involves the permanent storage of captured CO_2, while bioenergy with carbon capture and utilisation (BECCU) utilises captured CO_2 as a carbon feedstock in the production of energy carriers, chemicals and materials. BECCU can be carbon neutral but can only provide negative emissions in some limited circumstances, depending on the lifetimes and final disposal of the products produced[1]. BECCU has started to attract attention because the use of CO_2 could be a profitable activity that produces valuable products. BECCU also avoids the need for geological carbon storage capability, which may be limited or not possible depending on location or high transportation, injection and monitoring costs (Cuéllar-Franca and Azapagic, 2015).

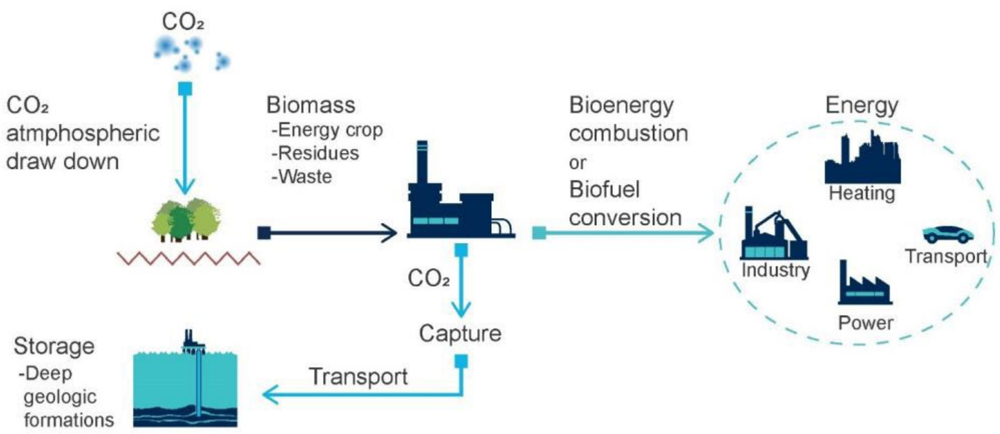

Figure 12. Process schematic of BECCS and BECCU
Source: Based on : (Global CCS Institute, 2019)

[1] CCU technologies bind the CO_2 molecule in a multitude of different products for different periods of time. The lifetime in which CO_2 is removed from the carbon cycle will vary: some uses, such as the use of CO_2 as a fuel precursor are very short term (days to months); whilst others, such as its use as a precursor for plastics, have a longer term. (Boot-Handford et al., 2014).

The current lack of real-world projects means that the cost of BECCS/CCU technology is highly uncertain. Calculated potential costs vary significantly depending on the costs of biomass feedstock, CCS components, infrastructure, operation and fuel. Biomass feedstock costs vary geographically owing to different kinds of biomass and its availability. The energy demand for carbon capture and storage is also important part of the cost, and the cost of CO_2 transport and storage depends on geological carbon storage capability.

A literature review found a cost range of USD 15/tCO_2 to USD 400/tCO_2 (Fuss et al., 2018) for different sectors. BECCS costs from ethanol fermentation were USD 20/tCO_2 to USD 175/tCO_2. From Fischer-Tropsch diesel and BioSNG, costs were USD 20-40/tCO_2. BECCS applied in pulp and paper mills could have a cost range of USD 20-70/tCO_2 in the case of utilising black liquor to produce heat. Biomass gasification coupled with BECCS has been estimated to cost between USD 30/tCO_2 and USD 76/t CO_2 (Global CCS Institute, 2019). The cost of capturing CO_2 is typically lower in biofuel routes than in power routes, because of the higher CO_2 purity in the biomass-to-fuel routes (Fajardy, KÖBERLE, MAC DOWELL and FANTUZZI, 2019). BECCS in biomass combustion shows generally a higher cost range of USD 88-288/tCO_2 (Fuss et al., 2018).

Despite the potential of BECCS/CCU, it is currently not deployed at scale due to a lack of incentives as well as uncertainties, such as the effective potential, technical viability and economic feasibility. However, projects piloting or deploying BECCS/CCU have been growing in recent years, coupled with different applications such as bioethanol production, waste incineration, biomass power generation and pulp and paper manufacturing (Global CCS Institute, 2019). Key applications and current projects are summarised in table 3 below.

Application	Discussion
BECCS in bioethanol production	• The only large-scale BECCS facility in use today is for bioethanol production. The Illinois Industrial CCS facility owned by Archer Daniels Midland captures up to 1 million tons of CO_2 per year. This facility produces ethanol from corn with CO_2 produced during the fermentation in an oxygen deprived environment. The CO_2 is captured and stored in porous sandstone in the Illinois Basin deep underneath the facility. • Four small-scale ethanol production plants with BECCU are operational in the US and Canada and they use most of the CO_2 for enhanced oil recovery (EOR). Together they capture around 1 million tons of CO_2 per year (Global CCS Institute, 2019; US.DOE, 2017)

Application	Discussion
BECCS/CCU in waste to energy	• CCS or CCU with biomass waste incineration poses challenges due to the greater mix of chemicals in the CO_2 stream than in normal ethanol or power production. Those chemicals can be corrosive to the metal pipes normally used in carbon capture. • In Japan, the world's first application of CCU to a biomass fired waste incineration plant has been in operation since 2016. This facility in Saga city is capable of capturing about 3 000 tonnes of CO_2 per year with the captured carbon used to cultivate crops at a nearby algae farm (Global CCS Institute, 2019; Toshiba energy, 2018). • A waste-to-energy power plant with CCU is being developed in Duiven in the Netherlands, with a plan to capture up to 50 KtCO_2 per year (AVR, 2020). In 2019, AVR-Duiven captured its first 7.5 KtCO_2 and supplied it to buyers in the greenhouse horticulture sector (AVR, 2019; TNO, 2019). • A waste-to-energy system with CCS is part of the Klemetsrud facility in Oslo, Norway. The facility aims to capture up to 400 000 tonnes of CO_2 per year when it is operating at full scale and plans to transport the captured CO_2 by ship to western Norway, and to inject it several thousand meters below sea level. 58% of the waste incinerated at the plant is of biological origin and the rest is coming from non-recyclable waste. This project is part of a wider portfolio of Norwegian full-scale CCS efforts (Fortum, 2018; Oslo, 2019).
BECCS in biomass power	• The Mikawa power plant on the Fukuoka Prefecture in Japan is a biomass-fired power generation plant using palm kernel shells (PKS). The 50 MW power station successfully piloted carbon capture in 2009 using coal as fuel, but is being retrofitted as a 100% biomass boiler with PKS for operations to begin in 2020. The system is designed to capture more than 50% of the biomass plant's CO_2 emissions, or up to 180 000 tonnes per year (500 tons per day)(Global CCS Institute, 2019; Toshiba, 2017; Toshiba energy, 2019). • In Europe, the Drax Power Station in the United Kingdom started a BECCS project on a pilot scale in 2019. This pilot project captures one tonne of CO_2 a day, but does not currently store the CO_2. The project is intended to pave the way for a large-scale rollout of the technology, which could eventually capture 16 Mt a year of CO_2 (Drax, 2019).
BECCS/CCU in the paper and pulp industry	• Between 75% to 100% of the CO_2 emissions from the pulp and paper industry originate from the combustion of biomass in generating power for their sites (Onarheim, Santos, Kangas and Hankalin, 2017). • In Saint-Felicien, Quebec, the BECCU project in a pulp mill run by Resolute Forest Products captured its first carbon in 2019. It expects to scale up to capture 30 tonnes of CO_2 per day. The carbon will be used by the adjacent Toundra Greenhouse for growing cucumbers (PaperAge, 2019).
BECCS in the cement industry	• Cement production is well suited for CO_2 capture; it involves high concentrations of CO_2 and generates excess heat which can be utilised in the capturing process. • There are currently no large-scale operational facilities equipped with CCS/CCU technologies, but there is a least one plant under development. The Norcem cement plant plans to capture 400 000 tonnes of CO_2 per year and send the CO_2 to a multi-user storage site in the Norwegian North Sea. Operation is scheduled to start in 2024 (Global CCS Institute, 2019).

Table 3. BECCS applications and projects
Source: (IRENA, 2020)

05 Barriers to the deployment of biomass for energy and material use

Barriers to the deployment of biomass for energy and material use

As is the case with other renewable energy and low-carbon technologies, several barriers inhibit the more widespread deployment of bioenergy and prevent this part of the circular carbon economy from reaching its carbon management potential.

Some of these barriers are generic and apply more broadly to renewable and other low-carbon energy sources, while others apply to bioenergy supply chains or specifically to particular end-use sectors. There are different issues surrounding the “traditional” use of biomass and the more “modern” and efficient uses of bioenergy. In the following sections, these subsectors are considered separately.

5.1 Barriers to transitioning from traditional to modern uses of biomass

The inefficient traditional use of biomass leads to significant indoor and outdoor air pollution with severe health consequences along with other negative environmental and social impacts. One of the UN's Sustainable Development Goals (SDG) is to ensure universal access to clean cooking solutions by 2030, and that goal has stimulated a global effort to reduce or improve the traditional use of biomass. Solutions include the use of fossil-based LPG as well as renewable solutions, such as solar based electricity. More sustainable biomass-based solutions also can provide energy for cooking and heating in developing economies, but there are still barriers to their adoption. The principal barriers include:

5.1.1 Financial barriers

One major barrier is the higher cost of the improved equipment and fuels which replace what is essentially a "free" resource of wood fuels and other residues (although their collection requires considerable time and effort) (World Bank, 2017). In addition, many potential users are living outside the cash economy and do not have the means to pay for fuels.

This cost barrier is reinforced by the lack of access to capital to finance the purchase of clean equipment and fuels, or to provide for investment and working capital for fuel or equipment production systems. When loans are available, they are generally only for small amounts, which disincentivises potential lenders from accepting the administrative costs to offer the financial products in the first place (Winrock International, 2017). Micro-finance can play an important role here[2].

5.1.2 Technological barriers

Many proposed cookstove solutions do not have the technical characteristics to meet appropriate efficiency and environmental performance standards and also do not provide culturally acceptable solutions which reflect the needs of consumers, particularly in rural areas.

Improved bioenergy cookstoves still have low efficiencies and often fail to meet health guidelines, unless associated with improved fuels (such as briquettes and pellets, or ethanol-based fuels) (World Bank, 2017).

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[2] In addition to the cost issue, people might be reluctant to buy fuels because it is a market transaction and most rural people are living in the informal economy. Entering the cash economy can be risky for rural people, so they may prefer to stay as subsistence farmers and gatherers. This is a fundamental rural development issue that applies to many situations including fuelwood collection.

5.1.3 Policy barriers

“Clean” cooking fuels, such as biomass briquettes, and suitable cooking stoves have immature distribution channels, which can lead to supply concerns for clean cooking fuels or to higher prices. Distribution to remote rural areas is especially challenging.

Fuel supply chains are often based on unsustainable patterns of biomass production which negatively affect forest cover. Programmes for improved biomass solutions often do not address the needs for sustainable fuel supply and for user solutions.

5.1.4 Supply chain barriers

The lack of a coherent strategic approach to clean cooking has been a major impediment to progress in many countries. The issues relating to clean cooking cut across many government actors, including ministries responsible for energy, social, financial, environmental and forestry issues, who may not give this issue priority, making coordination difficult (FAO, 2017).

The inclusion of the clean cooking goal in the SDGs has stimulated greater international efforts to address the issue. The development community has paid increasing attention and made significant investments in clean cooking over the past five years, under the leadership of the Global Alliance for Clean Cookstoves, with the support of various stakeholders. However, national and international funding is not sufficient to meet the SDG goals (IEA, IRENA, UNSD, World Bank, WHO, 2020).

5.1.5 Awareness and cultural barriers

A lack of knowledge and understanding of the economic, social, and health benefits of clean cooking is a barrier to the adoption of clean household energy. There is also perceived misinformation – for example, the mistaken belief that wood smoke repels insects and so protects against malaria.

Clean cooking solutions often do not reflect user requirements, such as cooking preferences or solutions that reduce the time spent cooking so that the (mostly women) users can perform household and childcare duties. It is therefore critical to consider various factors, particularly consumer preferences and needs, to ensure the long-term adoption of clean cooking solutions. Although women are usually responsible for cooking, they are often disadvantaged in household investment decision making and in gaining access to finance for clean cooking.

The principal barriers to adoption of modern bioenergy systems are as follows.

5.2 Barriers for modern bioenergy in the developed context

5.2.1 Cost barriers

In many cases, the costs of producing bioenergy are higher than the costs of fossil fuel equivalents, in the absence of measures which internalise the negative environmental impacts of fossil fuel use.

Bioenergy electricity generation options span from mature, low-cost options, like the combustion of agricultural and forestry residues, to less mature and/or expensive options, like biomass gasification. Lower unit capital costs and higher efficiencies favour large-scale biomass power generation systems. Economies of scale are evident in China and India, where large numbers of plants have been deployed. Power generation efficiency using steam turbines at low scale can be as low as 10-15%, rising at larger scale to over 30% (compared to gas efficiencies of over 45% for modern CCGT plants and 40% for modern coal plants). Generation costs are lower when the heat can be used effectively in CHP plants.

When low-cost feedstocks are available as by-products from agricultural or forestry processes, bioenergy electricity can be competitive with fossil fuel solutions. In 2018, when about 5.7 GW of new bioenergy electricity projects were commissioned, the global weighted average LCOE of the new power plants was USD 0.062/kWh. This is a decrease of 14% from 2017. However, bioenergy power generation costs are often higher than those of other renewable generation technologies such as wind and solar PV, where costs have fallen dramatically in recent years.

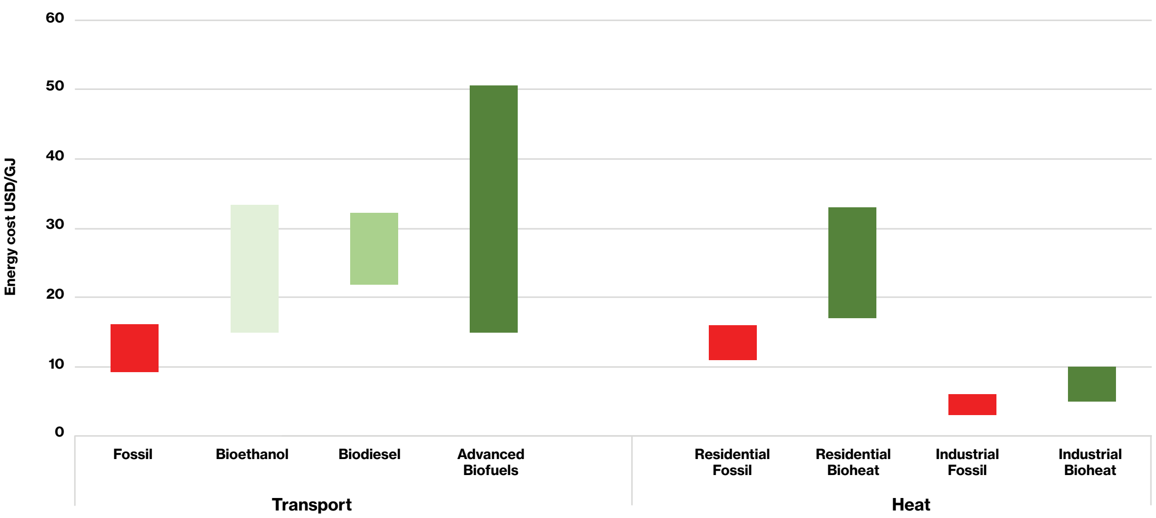

Figure 13. Comparison of costs of bioenergy and other options

Source: (IEA Bioenergy, 2020; UK Renewable Energy Association, 2019)

Bioenergy heat costs are strongly influenced by the utilisation rate of the heat producing system, which favours industrial and larger-scale applications such as district heating. The relatively high cost of biomass fuels compared to low-cost coke and coal used in many high-temperature industry applications and in power production is a major impediment to fuel switching. (In the cement industry, low-cost waste fuels are used rather than wood-based fuels for cost reasons.)

The prices of conventional biofuels used in transport (bioethanol, biodiesel, biomethane and HVO) are consistently higher than those of the gasoline or diesel that they can replace (IEA, 2020). The current costs of advanced biofuels under development are significantly higher still. Since these advanced fuels are still at the earlier stages of development and commercialisation, there is significant potential for cost reduction, but the costs are unlikely to approach those of fossil fuels in the absence of substantial financial support or high carbon prices.

In the longer term, solutions involving bioenergy with carbon capture and storage or carbon capture and use are likely to be required to meet very low emissions objectives. This will only be viable with a significant incentive for GHG removed from the atmosphere in the form of a "negative" carbon tax.

The availability and cost of financing for projects involving bioenergy depend on the perceived risk profile. Similar criteria apply as for other renewable energy projects. The availability of long-term power purchase agreements with reputable counterparties facilitates financing for bio-electricity projects, while such firm long-term off-take agreements are less available for bio-heat or biofuels projects.

Investors often consider the risks associated with bioenergy projects to be higher than for other renewable technologies. This is because of increased risks associated with ensuring a reliable fuel supply and concerns about technology complexity and meeting sustainability criteria. In contrast to wind and solar projects, the risk profile of nearly every project is different, given different feedstock and technology combinations. Financing for large-scale demonstration for new technologies such as advanced biofuels is particularly challenging, especially since bioenergy systems need to be tested at large and therefore costly scales, unlike technologies based on modular units like wind and solar PV.

5.2.2 Technological barriers

Many of the bioenergy technologies are fully developed and there is extensive experience of their use. For example:

- Nearly 600 GW of bio-electricity generation capacity is already in operation (IEA, 2020).
- Technologies for producing low-temperature heat for use in buildings and for industrial use are well known.
- Large-scale biofuels production of ethanol from corn and sugar and biodiesel from vegetable oil and fats to produce biodiesel and HVO/HEFA are fully commercialised.
- Production of biogas and biomethane uses well-established technologies.

However, even for these existing technologies, successful project development and operation is demanding and requires skilled and experienced professional expertise.

A number of new technologies and feedstock sources are being developed and commercialised but are not yet widely deployed. They include the production of advanced biofuels, including fuels for aviation; systems for integrating bioenergy with high-temperature industrial processes, such as iron and steel manufacturing; the integrated production of chemicals and energy products in biorefineries; and bio-electricity production systems with high efficiencies (e.g. those using gasification and solid fuel cell technologies). For all of these, technology readiness is a major constraint on deployment in the short term.

5.2.3 Policy barriers

The deployment of bioenergy depends on a strong and supportive policy and regulatory regime that provides for investor certainty over the income streams that projects will receive and also clearly establishes the regulatory requirements that projects must satisfy. For example, regulations must specify levels of emissions to air and water that are permitted and what other sustainability criteria must be achieved. Policy certainty is particularly important for bioenergy projects, where project lead times tend to be long, given the needs to plan technical aspects of projects, to negotiate other energy off-take agreements (sometimes for more than one energy product – e.g. heat and power), and to build up the necessary supply chain.

Biofuels policy and regulation tends to be complex given the many issues involved, including sustainability governance. This requires sufficient resources and qualified institutional capacity to develop, implement, monitor and enforce appropriate regulations. Such policy and regulatory capacity may not be available, especially in emerging and developing economies where many important bioenergy opportunities may lie.

5.2.4 Infrastructural barriers

Since bioenergy can provide dispatchable power, it does not pose the same problems of integration into the grid-based electricity supply as do renewable power sources that are variable, such as wind or solar PV. In fact, bioenergy can contribute to grid flexibility and provide a range of other systems services if it is allowed and incentivised to do so.

For the direct production and supply of heat, no special infrastructure provisions are needed, although bio-heat installations require considerable space for fuel storage and handling. This space may not be convenient in urban situations, constraining deployment. The availability of district heating systems is a major enabling factor for bio-heating, since the larger-scale operation and potential to increase the utilisation rate improves the cost competitiveness. It is also easier to satisfy air emissions requirements at larger scales. Converting existing district heating systems to biomass firing is generally not difficult, but when existing systems are not available, there are a number of commercial and organisational barriers which need to be overcome.

In the transport sector, when fuel regulations allow, bioethanol and biodiesel are widely blended into gasoline and diesel fuel up to certain blend limits (typically 10% by volume for ethanol and 7% for biodiesel). These blends avoid problems in fuel distribution and are also compatible with nearly all road vehicle engines, and higher blend levels can be accommodated in some regions, depending on the vehicle fleet and climate. Much higher levels (including E95 and pure ethanol) can be accommodated, but this may require separate distribution channels and pumps at fuel stations, along with vehicle modifications. It is possible to adapt vehicles to use higher blend levels and neat alcohols, such as "flex-fuel" vehicles capable of using any mix of gasoline and ethanol, but there needs to be coordination between the availability of vehicles and fuel. Alternatively, "drop-in" fuels which mimic the fossil fuels they replace can be developed and used, although some infrastructure is still needed. For example, only a small number of airports have so far established bio-jet fuelling infrastructure.

Biogas can be upgraded by removing the CO_2 and other gases to produce pipeline quality biomethane that can be injected into natural gas grids. It then can replace fossil gas for heating and for transport purposes. However, regulations must first be developed that allow this injection, setting clear quality criteria that need to be achieved (in terms of methane and other gas concentrations). Gas producers also need to be able to secure connections at reasonable costs.

The widespread deployment of BECCS will require extensive CO_2 transport and storage systems.

5.2.5 Lack of a skilled labour force

Developing successful bioenergy projects is complex and requires skilled and experienced people to plan, design and execute projects and to provide continuing operation and maintenance. In some cases, the lack of skilled personnel can be a rate limiting barrier to deployment. For example, a lack of qualified biomass boiler installers in Germany is currently considered an impediment to faster development of the sector, given the strong policy drivers and incentives that are in place.

5.2.6 Supply chain issues

Bioenergy systems require reliable and consistent supplies of feedstocks. While in many cases, supplies can be provided locally (for example, within a site where wood products are handled or in a sugar mill), many other projects require more extensive supply chains. Developing these supply chains may involve many actors in the forestry, agriculture and waste management sectors who have not been engaged in the energy industry before, and who may be reluctant to change their current practices until they see successful examples of stable and profitable outlets for their resources. Similarly, energy producers may be unfamiliar with these upstream bio-industry players.

These problems are most acute when there is a need to produce specific new energy crops, which may require significant changes in crop production and rotation patterns, including a shift from annual crop production to perennial crops such as miscanthus and other grasses or short rotation forestry (e.g. coppiced willow or poplar), along with the use of novel planting and harvesting machinery. In the absence of confidence in a sustained and profitable market, a sufficient supply chain may not emerge.

5.2.7 Insufficient technical, regulatory and administrative capacity

Meeting long-term objectives for bioenergy will require the deployment of the technologies globally, whereas at the moment, activities are highly concentrated. About 79% of deployment of bioethanol and biodiesel is concentrated in the United States, Brazil and the European Union (REN21, 2019). Expansion in other countries will only happen if they can develop the necessary technical and regulatory capacity needed to successfully develop and execute projects and to put in place the necessary policy and regulatory frameworks.

A number of different international platforms and initiatives to promote bioenergy already exist (including the FAO, the Global Bioenergy Partnership (GBEP), the Biofuture Platform, IEA Bioenergy and Mission Innovation IC4 (Sustainable Biofuels)). Aid agencies, development and other multilateral banks and other international agencies can also play key roles in providing advice on best practice policy guidance and institutional capacity building for bioenergy. However, bioenergy is not currently given priority within many of these organisations.

5.2.8 Cultural barriers

Given the wide range of bioenergy technologies, the potential users of bioenergy and other actors along the supply chain may be unaware of the potential solutions. For example, householders (especially in regions without a history of using wood fuels) may not consider using wood fuels and may be unaware of "clean" solutions such as pellet boilers and stoves. Industrial players may either be unaware of potential bioenergy opportunities or lack reliable information on the benefits and risks of the specific bioenergy options.

5.3 Sustainability of bioenergy

Concerns about the sustainability of bioenergy – the extent to which bioenergy contributes to GHG emissions reduction targets and whether its widespread development would have positive or negative environmental, social or economic impacts – has made bioenergy a controversial subject, with poor public understanding of its benefits and uncertainty among policy makers. Confidence in the sustainability of bioenergy is an important requirement for its widespread development. Without this confidence, politicians are wary of including bioenergy in national GHG reduction programmes. Policy uncertainty and risks of reputational damage also discourage investment by industry.

Bioenergy encompasses a very wide range of options – feedstock sources, conversion routes and energy products – and the environmental, social and economic benefits depend on many factors and can vary depending on location. Therefore, sustainability assessments need to consider both the benefits and risks associated with specific bioenergy routes in some detail and general statements are generally unhelpful (Fritsche, Eppler, Fehrenbach and Giegrich, 2018).

Some of the key issues which need to be considered for specific bioenergy supply chains include:

GHG benefits. The production and use of bioenergy are often considered to be "carbon neutral" since the growth and decay of biomass are part of a natural cycle, in contrast to fossil-based systems which transfer CO_2 from geological reservoirs to the atmosphere (Global Bioenergy Partnership 2020). Life cycle assessments show that many bioenergy pathways can have much lower emissions (often 80-85% lower) than their fossil fuel equivalents (IEA, 2017). However, greenhouse gas emissions reductions from displacing fossil fuels with bioenergy can be negated if bioenergy feedstocks are produced in unsustainable ways.

Land use issues. When the production of bioenergy involves changes in land use (for example, where land used for other purposes is planted for energy crop production), there are a number of potential sustainability risks that must be considered and if necessary managed. Such land use change could lead to GHG emissions that reduce or even negate the benefits of using bioenergy – for example, where a forest with high amounts of stored carbon is felled to make way for energy crops. There are also potential indirect effects on land use if energy crops grown on former cropland cause the conversion of land with high-carbon stocks elsewhere to cropland in order to maintain food supplies. A large-scale switch to dedicated bioenergy production could also have negative impacts on the availability of food, and could compromise biodiversity if lands with high conservation value are converted. However, there is considerable potential to improve the efficiency of land use by increasing productivity and bringing underused and abandoned land back into productive use, with positive environmental benefits. In addition, using harvest residues for bioenergy feedstocks can improve resource efficiency and increase GHG emissions reductions without land use change.

Bioenergy and air quality. Inefficient combustion of biomass fuels can lead to significant emissions of unburnt gases and carbon particles. These emissions can cause local air pollution and negative health impacts. This is a particular issue for the "traditional" use of biomass for cooking and heating using simple fires or stoves. But poorly controlled combustion of solid biomass can also be a problem in more developed economies when open grates and simple stoves are used for heating, or when poor quality fuels are used (DEFRA, 2017). This is particularly an issue for residential scale systems, although more modern systems can meet stringent air quality standards even at this scale (Environment Agency Austria, 2018). At a larger scale – for heating commercial and public buildings, industrial systems and district heating, and electricity production – it is easier to meet air quality requirements economically (Thornley et al., 2009).

Other environmental and social Issues. The production and use of bioenergy can also have other environmental and social implications. These include the impacts of bioenergy on soil and on water quality and availability, on land use tenure and on labour rights, including effects on child labour and safe working conditions (GBEP, 2011).

06

Policies to support biomass use in energy

A wide range of policies and regulatory instruments can reduce barriers to bioenergy development and help create a positive enabling environment, ensuring that its development optimises carbon savings and avoids negative environmental, social or economic impacts.

Bioenergy can benefit from measures that impact the whole energy economy – for example, measures that constrain fossil fuel-based energy or increase its costs – or that generally promote renewable energy. Some measures tackle generic issues associated with bioenergy while others can be targeted at issues affecting specific technologies (for example, biogas and biomethane) or specific sectors, such as heat, transport and electricity production. Addressing all of the barriers described earlier requires a portfolio of policy and regulatory measures.

The following discussion is organised according to the IRENA policy classification system that distinguishes between three types of policies:

- **Direct policies,** which are normally used to support the development and deployment of technologies and are typically classified as push or pull, and as fiscal and financial.
- **Integrating policies,** which promote planning and coordination, such as R&D policies and infrastructure policies.
- **Enabling policies,** which focus on reforming the broader institutional architecture to enable systemic effects between the energy sector and the broader economy and which link four crucial national policies: industrial policy, labour market and social protection policy, education and skills policy, and financial policy.

6.1. From traditional to modern uses of biomass

6.1.1 Direct Policies

Direct policies can address the barriers to the deployment of clean cooking solutions by giving policy and budget priority to this sector. Policies can directly offset the cost differences between traditional and cleaner solutions, for example, or provide financial options that make the new solutions affordable. Such policies include providing free or subsidised access to clean cooking solutions and assisting users through the use of microfinance facilities or by establishing leasing or "pay as you go" (PAYG) systems. These policies allow users to pay for the equipment in instalments, improving access to clean cooking in rural, low-income communities by mitigating the high upfront capital costs. National cookstove programs are being launched or scaled up in many Sub-Saharan countries, including Ethiopia, Ghana, Malawi, Nigeria, Rwanda, Senegal and Uganda (World Bank, 2017).

International and national programmes and strategies can have an important catalytic effect on efforts to deploy clean cooking solutions, including intermediate solutions such as improved bioenergy options. Some examples include the World Bank Clean Cooking Fund and the West African Clean Cooking Alliance.

Direct financial measures can improve the sustainability of the wood fuel supply. For example, in Burkina Faso, Chad and Niger, taxes are levied on wood extracted from the forest, but a lower rate is applied to wood extracted from managed forestry. The revenue is shared between communities and local treasuries, an important factor in securing local buy-in (FAO, 2017).

6.1.2 Enabling Policies

Education and awareness programmes can encourage the uptake of clean cooking solutions. Kenya has several initiatives underway to raise awareness about the benefits of clean cooking in the general population. Likewise, the Rwandan and Ethiopian governments are working to increase the uptake of efficient and cleaner renewable fuels like biogas and processed biomass fuels.

Training programmes are also important. In Vietnam, the successful National Biogas Programme supported by the Netherlands Government provides training for manufacturers and government technicians. Manufacturers must be certified before they are able to build digesters, and trained officials provide quality assurance and training for users (SNV, 2020). In Senegal, Sudan, Mali, Niger and Kenya, there is support for sustainable biomass fuel supply demonstration projects, training and market development along with support for cooperatives and producer associations (FAO, 2017).

6.2 Modern bioenergy in the developed context

6.2.1 Direct policies

Direct policies are particularly aimed at facilitating market access and addressing the financial barriers to deployment discussed earlier. A wide range of measures can be used to bridge the gap between the costs of bioenergy and fossil-based solutions, including capital grants, feed-in tariffs or premiums which guarantee a firm price for energy supplied, tax reductions, tradeable certificate schemes which put a value on the GHG emissions reductions and other benefits associated with bioenergy, and tax credits. These can be used to support the production and use of bioenergy in all three end-use sectors – heat, transport and electricity.

Heat for buildings

Capital grants are often seen as a way of supporting bioenergy heating solutions by reducing the upfront investment. They have the benefit of simplicity, especially for small-scale projects such as those in residences. But there is also experience of using grant-based systems for larger-scale systems, including those associated with district heating schemes. For example:

- France's Fond Chaleur (Heat Fund), in place since 2009, offers subsidies for residential, commercial and industrial renewable heat, including small-scale biomass applications (EU Ovserv'er, 2019). The subsidy aims to increase the uptake of renewable heat by lowering the price of renewable heat 5% compared to fossil-fuel alternatives.
- In Italy, the uptake of pellet boilers has been supported by the Conto Termico (Heat Account), a grant scheme that supports renewable heat and thermal efficiency improvements in buildings. The incentive has an annual budget of EUR 900 million and provides grants of up to EUR 5 000 depending on technology capacity, GHG emissions and PM reductions, and heating degree days in the region (Thran, Peetz and Schaubach, 2017).

The adaptation of feed-in tariff (FIT) schemes for heating is less common, but in the United Kingdom, the Renewable Heat Incentive (RHI) has led to significant biomass heat uptake in commercial and residential buildings and in industry by providing a guaranteed tariff for every unit of heat produced, with a 20-year price guarantee. While open to a range of renewable heating options, biomass-based systems are those most widely supported (UK Renewable Energy Association, 2019). The scheme also supports biomethane production with a guaranteed tariff for gas injected into the gas grid.

Renewable heat support is also sometimes included in schemes designed to promote renewable electricity generation, such as renewable portfolio standards. Obligations are now also being considered as ways to increase the role of bioenergy (and other low-carbon solutions) in heat supply and especially to promote inclusion of biomethane and other low-carbon gases in the natural gas grid.

Building codes are widely used as a way of improving the energy performance of buildings (especially for new or refurbished buildings). When these are performance based, they can provide a powerful push for renewable solutions including bioenergy, complementing energy efficiency measures. These can either be based on energy performance or increasingly on GHG emissions levels.

In some cases, renewable measures are specifically mandated as a planning condition for new buildings, which have to meet a specific proportion of their energy supply with renewables. First applied in Merton (UK), such regulations have since been more widely adopted (Climate Works, 2012). Bioenergy solutions for heating or CHP are often a cost-effective solution in these cases.

Heat in industry

Projects providing heat for industry can qualify under the schemes supporting renewable heat discussed above, but there are few schemes specifically aimed at industry use and especially at high temperature applications such as in iron and steel, where the cost differential between low-cost coal and coke currently used and biomass fuels is very significant.
Potential measures include imposing a significant carbon price on the fossil fuels currently used, which would help to bridge the cost gap. Other potential measures could include setting GHG emissions limits for industrial processes or setting an emissions reduction obligation on specific industries.

Transport

In the transport sector, the most widely used measures to promote the uptake of biofuels are requirements for certain levels of blending with fossil fuels, which are in place in at least 70 different countries with the blending limit depending on the vehicle fleet and other local conditions (REN21, 2019). Typical blend levels are 5-15% for ethanol and 5-30% for biodiesel. Such measures are simple to put in place and can be effective, as long as the blending requirements are enforced, and penalties are handed out for non-compliance.

Specific obligations are being used to promote the production and use of new "advanced biofuels". The European Union's revised Renewable Energy Directive for 2020 to 2030 makes explicit provision for increasing the volume of such fuels with a target of 3.5% by 2030, and six EU countries have set specific obligations for such fuels. There are separate obligations in US renewable fuel standards (RFS) for ethanol and for advanced fuels such as biomethane, renewable diesel and ethanol produced from cellulosic materials.
Most such schemes set a volume obligation, but increasingly the target relates to the GHG impact of the fuels being used, incentivising fuels with a higher GHG-saving potential. Such schemes are in place in California (the Low Carbon Fuel Standard) and a few other US states. A similar scheme, RenovaBio, is now in place in Brazil.

Most biofuels support schemes focus on fuels for road transport rather than for aviation or marine use. However, biofuels for these purposes are sometimes allowed to generate credits under the main biofuels support schemes. For example, bio-jet fuels can qualify under the US RFS system, and in the UK, biofuels for aviation and marine purposes can earn Renewable Transport Fuel certificates.

Electricity

Bioenergy power production is often included within renewable generation support schemes such as:

- feed-in tariffs (FITs), which offer a long-term guaranteed price per unit of output, and feed-in premiums, which offer a premium tariff in addition to wholesale electricity prices
- renewable obligations such as Renewable Portfolio Standards (common in the United States) and other renewable obligations, where the generator can earn additional income from the value of traded certificates
- schemes based on auctions for renewable electricity power purchase agreements which offer firm long-term prices for generation that qualifies.

These schemes all allow for separate tranches of support for bioenergy, or for sub-technologies to reflect the differences in generation cost or technology maturity. Differential support can also be used to encourage specific technologies, such as the deployment of systems involving CHP or the use of certain feedstocks (such as energy crops).

Financing novel bioenergy technology can be especially challenging due to potential technology risks and market uncertainties. The provision of loan guarantees can be an effective way of offsetting some of these risks and make projects more palatable to investors. In the United States, the Departments of Energy and Agriculture have both operated loan guarantee programmes which provide guarantees for loans of up to 80% of a project's total cost and are targeted at projects that avoid, reduce or sequester greenhouse gas emissions and employ "new or significantly improved technologies as compared to commercial technologies in service in the United States," including a number of advanced biofuels production plants (Renewable Energy Focus, 2011). The creation of specific funds for projects may facilitate additional funding from commercial lenders. For example, the Brazilian Development Bank (BNDES) provides loan support to expand biomass cogeneration capacity, typically fuelled by renewable biomass, such as bagasse or wood chips (Renewbles Now, 2019).

6.2.2 Integrating policies

Integration of bioenergy into the energy system is relatively simple, since bioenergy can produce dispatchable electricity and heat, and can produce fuels which can either be blended with conventional transport fuels or replace them for use in existing engines and vehicles.

However, there are a number of areas where widespread deployment of biofuels depends on having appropriate infrastructure in place. Policies and regulation can help with this. The availability of district heating systems is a powerful enabler for bioenergy heat supply in urban areas, where space restrictions and the need for very high air quality standards militate against small-scale appliances in homes or commercial properties. District heating at a larger scale mitigates these issues, and the larger scale and associated longer operating periods also improve the economy of operation. Where district heating is not in place, financial support for feasibility studies (to establish heat load profiles and optimum heat pipe routes) and for the costs of network installation can promote new installations.

Governments will have to play key roles in establishing the infrastructure needed to transport and store carbon from BECCS projects at scale, since individual projects are unlikely to be able to bear the costs. Governments aiming to promote this technology will need to help establish transport and storage infrastructure (Zero Carbon Humber Partnership, 2019). For example, the UK government has announced funding of at least GBP 800 million to support the development of two CCS clusters during the 2020s, which may include a large BECCS project

6.2.3 Enabling policies

A range of enabling polices are necessary to provide a policy and regulatory context which encourages bioenergy deployment.

Create a level playing field

Measures to create a level playing field and to aid the transition to a low GHG energy economy include:

- Removal of subsidies for production and use of fossil fuels, including the removal of low rates of VAT for fossil fuels. In some countries, subsidised, low-cost fuels (especially for residential use) are a measure used to offset energy poverty. However, such measures are generally not well targeted and much of the subsidy tends to go to higher income groups that tend to be higher energy users. More targeted social support directed specifically at low-income families can be more effective.
- Use of carbon pricing and other taxes, levies and duties to put a price on the environmental impacts of fossil fuel energy use. That would reduce the gap between renewable and fossil-based sources, including bioenergy and fossil fuels.

Existing tax regimes vary widely between countries and have big impacts on the relevant economics of fossil fuel and bioenergy costs. Figure 14 shows the difference in fossil gas prices for countries within the European Union for residential and industrial customers (UK BEIS, 2020). There is a three-fold difference between Sweden and Luxembourg for residential prices and a 2.5-fold range for industry prices between Finland and Sweden, with the differences being largely due to the differences in taxes and environmental levies.

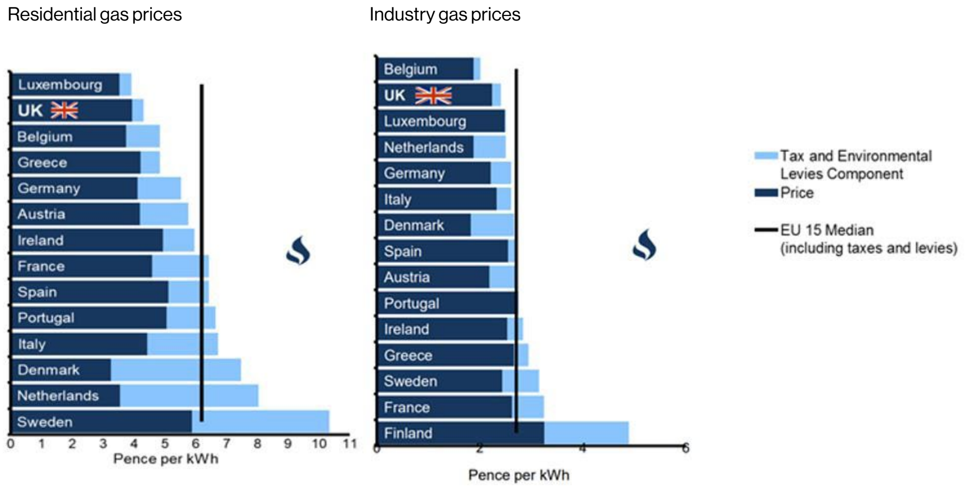

Figure 14. Comparison of EU gas prices
Source: UK BEIS, 20

This wide spread of prices changes the perception of consumers that bioenergy is a cost-effective heat supply option only in the higher-price cases, while requiring significant support when taxes are low. It also influences the perception of officials and politicians who in the first case see bioenergy as a cost-effective option, and in the other as a very expensive technology.

Tax policy relating to bioenergy systems – for example, VAT rates on biomass boilers and other low-carbon energy systems for residential customers – can also significantly influence consumer choice. The regime for capital allowances, such as allowing more rapid depreciation for low-carbon systems, can have an important impact on industrial investments.

Bans or constraints on fossil fuel use also open up the market opportunity for low-carbon fuels. A number of countries have either announced or implemented bans on coal-fired power generation or imposed strict emissions control limits, which make coal generation without CCS effectively impossible. The announcement of these measures, coupled to increasing carbon prices, has had important impacts on generation and investment patterns. In the United Kingdom, for example, the proportion of electricity from coal generation has dropped from 40% in 2012 to less than 5% in 2019, and is expected to reach zero by 2025.

Such bans are also being increasingly used to discourage the use of high-carbon fuels for heating, with new oil-fired boilers in residential properties banned in several European countries, including Denmark, Norway and Sweden (IRENA, IEA, REN21, 2018). Restrictions on gas connections for new properties and developments have been announced or implemented in the Netherlands. In the United Kingdom, new homes will have to be built with low-carbon heating sources starting in 2025 (Committee on Climate Change, 2019).

Provide a clear policy and regulatory framework

Bioenergy developments impinge on a number of policy areas in addition to energy, including environment, agriculture, forestry and the economy, and a successful bioenergy policy has to be consistent across all of these areas.

A consistent and long-term policy approach to bioenergy within overall renewable energy or low-carbon strategies would provide confidence to investors and project developers. The approach should coordinate the different policy areas and be developed with a wide range of stakeholder input, including from industry. It should include targets for bioenergy as a whole and for contributions in specific sectors, helping to provide certainty about future direction. Such plans and targets must be backed up by concrete policies addressing the barriers to bioenergy deployment, including those requiring funding to support bioenergy developments.

Projects are also subject to many planning requirements and other regulations. A clear set of regulations which establish the criteria that projects must meet to achieve permitting and for ongoing operations sets clear design parameters for projects and reduces developer risks (and thus costs). Publishing guidance on the permitting regime explaining the necessary steps is very helpful and can be handled by "one-stop-shops" to reduce permitting time and cost. The areas for regulation include emission limits and other air requirements, regulations concerning gas connections, transport fuel specifications and blending regulations, and waste regulation.
Trade policies, including import and export tariffs, can have a strong influence on biomass trade flows and the relative costs of imported fuels. For example, import tariffs on biodiesel imports to the United States and to Europe from major producing countries such as Argentina and Indonesia, and for ethanol trade between the United States and China, have perturbed production and trade patterns in recent years. This has perturbed fuel production in both receiving and exporting countries and such changes undermine investor confidence.

Policies to enhance sustainability

A better understanding of the potential benefits and risks of bioenergy has been developed in recent years and has formed the basis for regulations to prevent unsustainable practices and to incentivise improved performance[3]. National schemes for bioenergy stipulate sustainability conditions that must be met to qualify for support, and a number of certification bodies provide detailed sustainability audits which show whether or not the conditions have been met.
There are many issues that need to be considered in assessing the overall sustainability of specific bioenergy routes, with specific risks depending on the feedstock, technology and end use. The risks also vary based on the location, since risks vary depending on the climate (for example, if water is in short supply), on social conditions (for example, if there are poor labour practices or food poverty) and on the political and regulatory capacity (for example, if a regulatory framework is in place and is effectively enforced). Bioenergy certification schemes are often aligned with systems already in use in other bio-based industries. For example, serious attention has already been given to the sustainability of forest products, with the development of internationally recognised certification schemes.

Many bioenergy support systems build in minimum GHG savings criteria as a condition for support, calculated according to a prescribed methodology, often with the limit tightening over time. For example, the European Union's RED2 regulations have limits for biomass heat and electricity generation for biofuels. Some schemes, such as California's Low Carbon Fuel Standard (CLCFS) and Brazil's RenovaBio system, provide incentives for fuels with higher levels of GHG emissions savings.

Bioenergy governance regimes exclude from support schemes the use of materials associated with "direct land-use emissions" or with negative impacts on biodiversity or food security. For example, the EU RED II programme excludes support for bioenergy produced from raw materials grown on land which had high carbon stocks (or land with high biodiversity value) (European Commission, 2018). To reduce risks of ILUC, the EU RED II introduced an overall limit on biofuels produced from cereal and other starch-rich crops, sugars and oil crops, and from plants grown as main crops primarily for energy purposes on agricultural land that can be counted towards targets (European Commission, 2015). Other systems (including the CLCFS) include a calculation of ILUC emissions within the LCA calculation.

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[3] For a review of developments in this area see for example IEA Bioenergy Workshop Report – Governing sustainability in biomass supply chains for the bioeconomy, 2019, https://www.ieabioenergy.com/wp-content/uploads/2019/10/ExCo83-Governing-sustainability-in-biomass-supply-chains-for-the-bioeconomy-Summary-and-Conclusions.pdf

Energy crop production now increasingly concentrates on the production of fuels with low ILUC potential – for example, fuels produced on land which is otherwise unproductive, or on fuels which can be produced without impacting food production (by increasing crop productivity, by using crops which complement crop rotation or by using residues) (IEA, 2017).

Other environmental and social implications, including the impacts of bioenergy on air quality and water, can be managed by relevant national legislation which usually sets conditions that have to be met as part of the permitting process, with post-project monitoring to ensure continuing compliance.

IRENA has identified a number of measures that could be promoted to increase the potential for food production, to improve the prospects for bioenergy or biomaterial production, and to ensure that resources are used as efficiently as possible (IRENA, 2016). These include improving food crop yields through improved crop varieties and management practices; improving the land efficiency of animal husbandry; improving the efficiency of food production, notably by reducing food waste and losses (during production, distribution or after purchase); and growing trees on derelict and abandoned land, which could provide significant resources for local food and energy use.

Institutional capacity building

Putting in place effective policy and regulatory portfolios requires significant institutional capacity. Resources and expertise are particularly needed in the agencies which issue permits for projects and monitor long-term performance.
Bioenergy needs to be developed globally if the long-term objectives for bioenergy are to be achieved, but currently deployment is limited to relatively few countries, with over 80% of deployment in developed countries. Building the necessary technical and regulatory capacity is particularly challenging for emerging and developing economies, and more priority should be given to sustainable bioenergy production and use by aid agencies and development banks.

6.2.4 Information policies

Governments at both the national and regional levels have important roles to play in providing **clear and reliable information** on bioenergy to consumers and potential investors. This can help improve awareness of the benefits and challenges associated with bioenergy and encourage adoption of the technologies.

Governments and other public bodies can also assist project developers by providing information needed to locate and develop projects. These can include:

- the availability and location of bioenergy resources, including wastes, residues and the actual production and potential of energy crops
- fuel trading platforms that can improve the liquidity of fuel supply and improve confidence
- mapping of heat loads
- locations on the gas grid where biomethane can most easily be accommodated.

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