Outlook for biogas and biomethane

Prospects for organic growth

World Energy Outlook Special Report

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Introduction

The case for biogas and biomethane lies at the intersection of two critical challenges of modern life: dealing with the increasing amount of organic waste that is produced by modern societies and economies, and the imperative to reduce global greenhouse gas (GHG) emissions.

By turning organic waste into a renewable energy resource, the production of biogas or biomethane offers a window onto a world in which resources are continuously used and reused, and one in which rising demand for energy services can be met while also delivering wider environmental benefits.

In assessing the prospects for "organic growth" of biogas and biomethane, this new report from the International Energy Agency (IEA) explores how big a role these gases can play in the transformation of the global energy system, where the opportunities and potential pitfalls lie, and what policy makers and industry can do to support sustainable growth in this sector.

The answers to these questions rest on a major new IEA analysis of the sustainable potential for biogas and biomethane supply, including a detailed assessment of feedstock availability and production costs across all regions of the world.

This provides a platform to explore the various services that biogas and biomethane can provide in different countries, which vary widely depending on circumstances and policy priorities. Biogas can be a valuable local source of power and heat, as well as a clean cooking fuel to displace reliance on the traditional use of solid biomass in many developing countries. There are also potential co-benefits in terms of agricultural productivity (as a result of using the residual "digestate" from biodigesters as a fertiliser) and reducing deforestation.

When upgraded, biomethane (also known as renewable natural gas) is indistinguishable from natural gas and so can be transported and used in the same way. Biomethane can deliver the energy system benefits of natural gas while being carbon-neutral.

The value of biogas and biomethane is heightened in scenarios such as the IEA Sustainable Development Scenario (SDS), which meet in full the world's goals to tackle climate change, improve air quality and provide access to modern energy. Projections from the SDS provide an essential benchmark for much of the discussion in this report.

Biogas and biomethane have the potential to support all aspects of the SDS, which charts a path fully consistent with the Paris Agreement by holding the rise in global temperatures to "well below 2°C … and pursuing efforts to limit [it] to 1.5°C", and meets objectives related to universal energy access and cleaner air.

The other scenario referenced in the analysis is the Stated Policies Scenario (STEPS), which provides an indication of where today's policy ambitions and plans, including national policy announcements and pledges, would lead the energy sector.

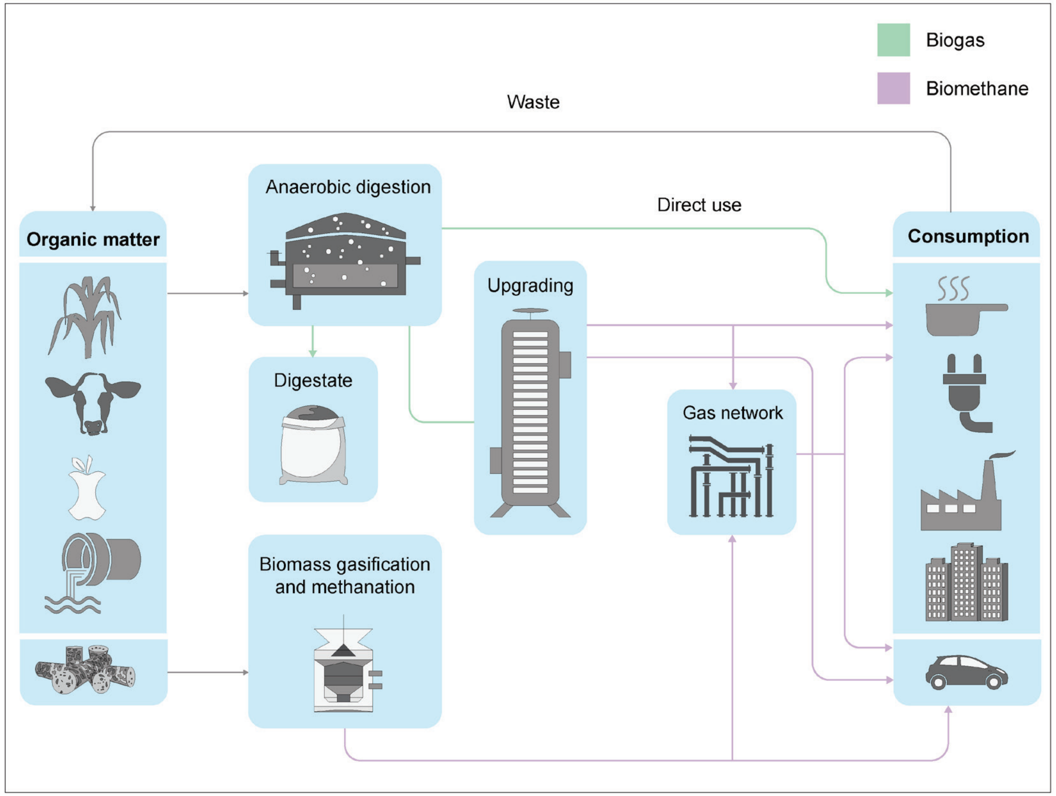
Comparison between the outcomes in these two scenarios provides an indication of the range of possible futures that are open to biogas and biomethane, and the policy and technology levers that will affect which pathway they ultimately follow.

Key findings

1. Biogas and biomethane producers take organic residues and wastes and turn them into a valuable modern source of clean energy

Modern societies and economies produce increasing amounts of organic waste that can be used to produce clean sources of energy, with multiple potential benefits for sustainable development. Biogas and biomethane are different products with different applications, but they both originate from a range of organic feedstocks whose potential is underutilised today. The production and use of these gases embody the idea of a more circular economy, bringing benefits from reduced emissions, improved waste management and greater resource efficiency. Biogas and biomethane also provide a way to integrate rural communities and industries into the transformation of the energy sector.

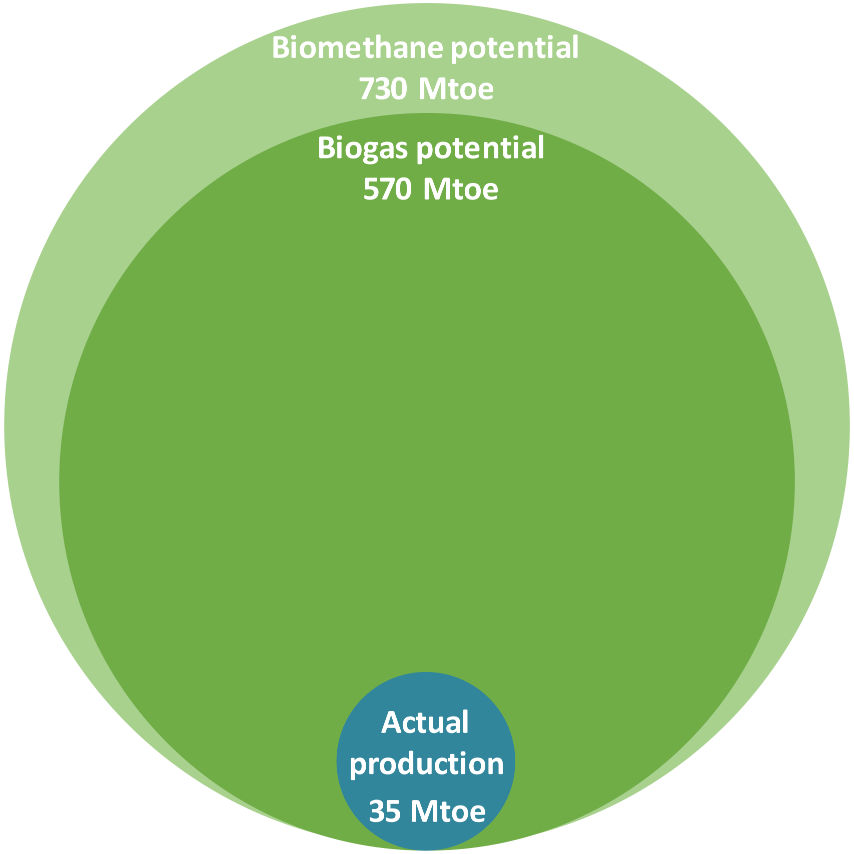
Biogas and biomethane production pathways



2. The feedstocks available for sustainable production of biogas and biomethane are huge, but only a fraction of this potential is used today

A detailed, bottom-up study of the worldwide availability of sustainable feedstocks for biogas and biomethane, conducted for this report, shows that the technical potential to produce these gases is huge and largely untapped. These feedstocks include crop residues, animal manure, municipal solid waste, wastewater and – for direct production of biomethane via gasification – forestry residues. This assessment considers only those feedstocks that do not compete with food for agricultural land. Biogas and biomethane production in 2018 was around 35 million tonnes of oil equivalent (Mtoe), only a fraction of the estimated overall potential. Full utilisation of the sustainable potential could cover some 20% of today's worldwide gas demand.

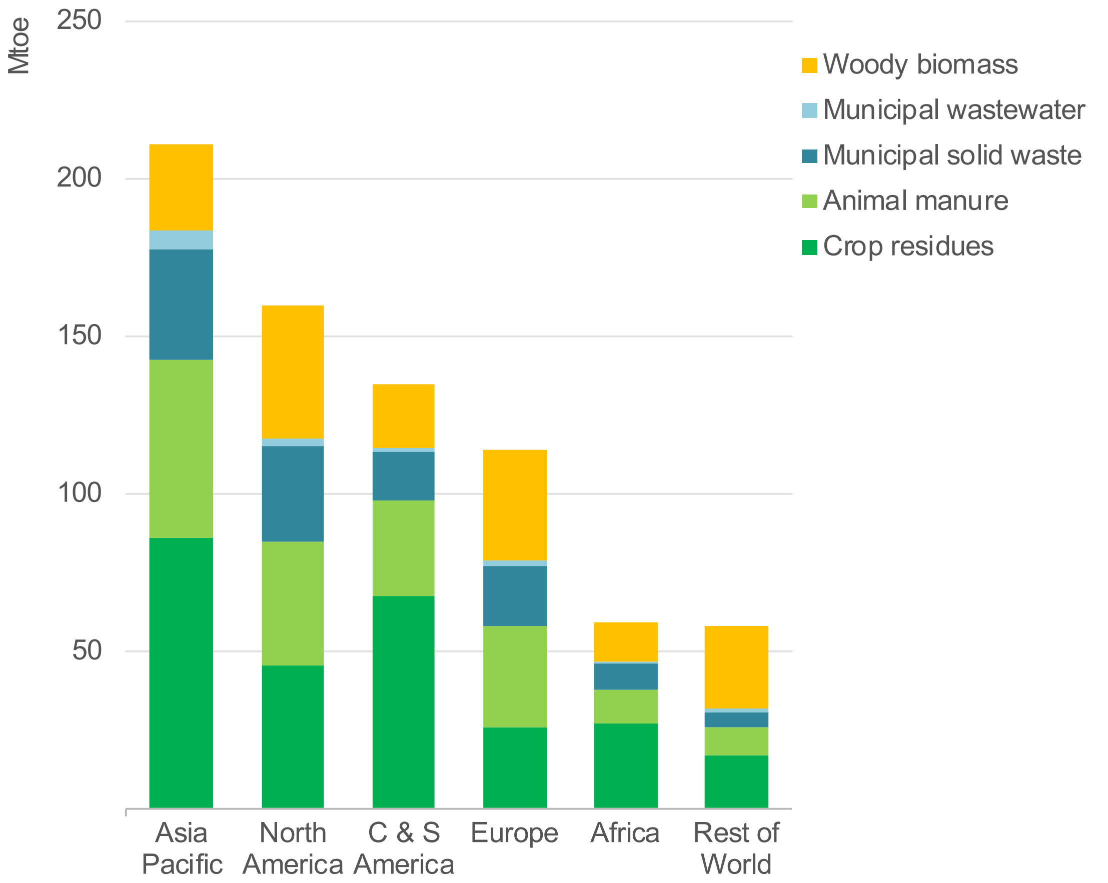
Biogas and biomethane production in 2018 against the sustainable potential today



3. Possibilities to produce biogas and biomethane are widely distributed around the world

Every part of the world has significant scope to produce biogas and/or biomethane, and the availability of sustainable feedstocks for these purposes is set to grow by 40% over the period to 2040. The largest opportunities lie across the Asia Pacific region, where natural gas consumption and imports have been growing rapidly in recent years, and there are also significant possibilities across North and South America, Europe, and Africa. The overall potential is set to grow rapidly over the next two decades, based on increased availability of the various feedstocks in a larger global economy, including the improvement in waste management and collection programmes in many parts of the developing world.

Production potential for biogas or biomethane by feedstock source, 2018



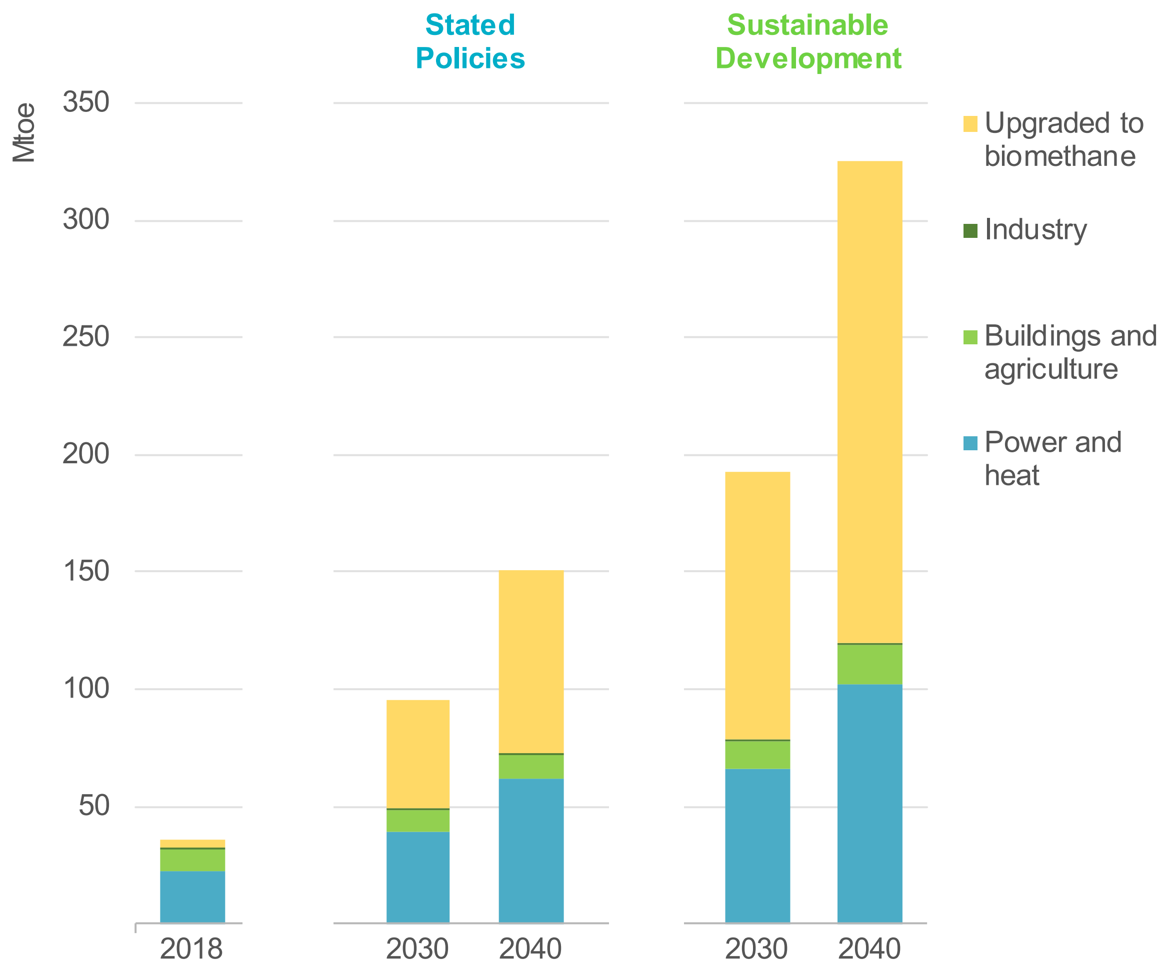
Notes: C&S America = Central and South America. Woody biomass feedstocks are available only for biomethane production.

4. Biogas offers a local source of power and heat, and a clean cooking fuel for households

Biogas is a mixture of methane, CO_2 and small quantities of other gases that can be used to generate power and to meet heating or cooking demand. Its uses and competitiveness depend on local circumstances, but a common element is that biogas offers a sustainable way to meet community energy needs, especially where access to national grids is more challenging or where there is a large requirement for heat that cannot be met by renewable electricity. In developing countries, biogas reduces reliance on solid biomass as a cooking fuel, improving health and economic outcomes. In the SDS, biogas provides a source of clean cooking to an additional 200 million people by 2040, half of which in Africa.

Biogas can also be upgraded to produce biomethane by removing the CO_2 and other impurities.

The outlook for global biogas consumption by sector

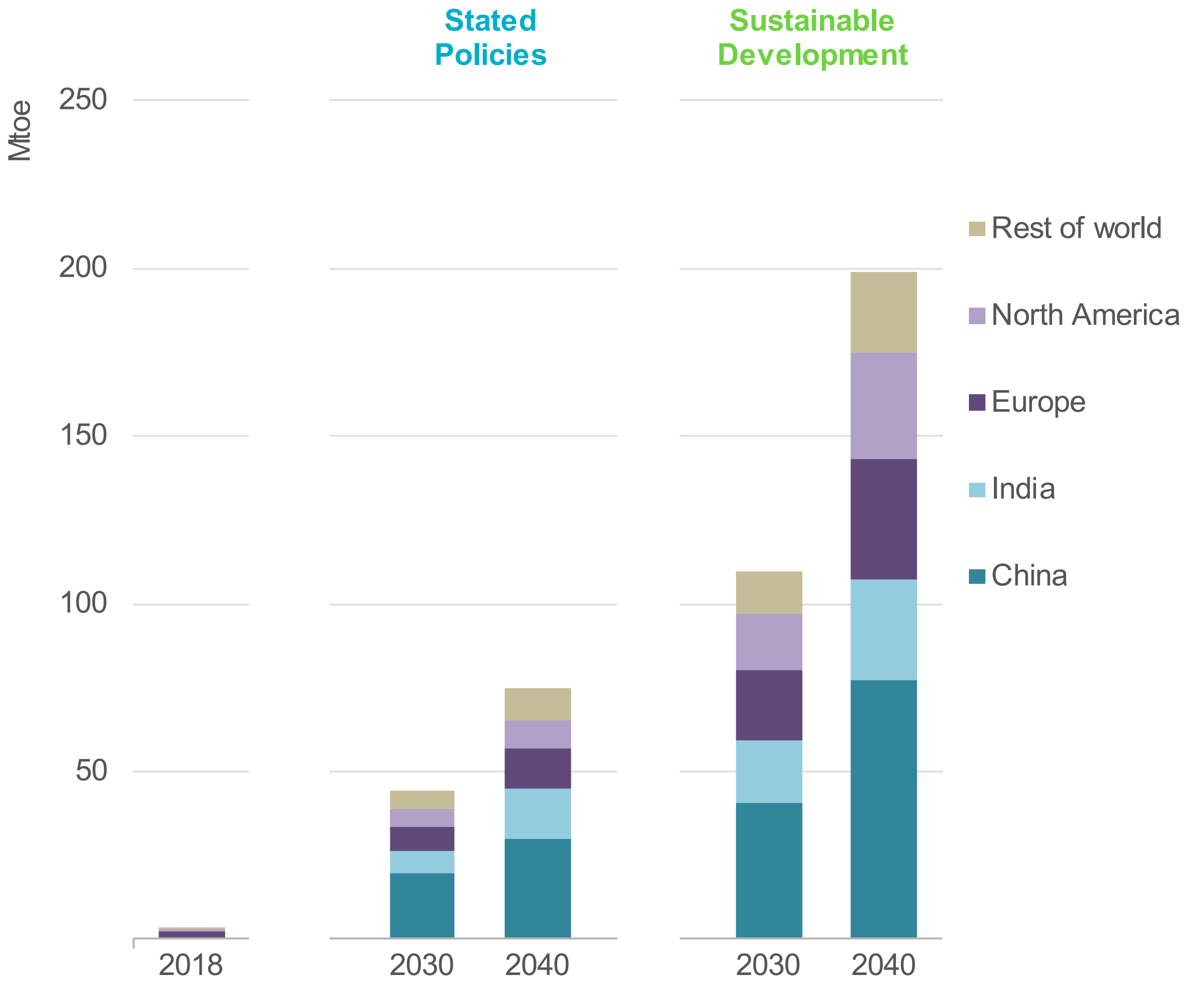


5. When upgraded, biomethane brings all the energy system benefits of natural gas without the associated net emissions

Biomethane is a near-pure source of methane produced either by "upgrading" biogas or through the gasification of solid biomass; since it is indistinguishable from the regular natural gas stream, it can be transported and used wherever gas is consumed, but without adding to emissions. Biomethane grows rapidly in IEA scenarios. It allows countries to reduce emissions in some hard-to-abate sectors, such as heavy industry and freight transport. It also helps to make some existing gas infrastructure more compatible with a low-emissions future, thereby improving the cost-effectiveness and security of energy transitions in many parts of the world.

Biomethane in the SDS avoids around 1 000 million tonnes (Mt) of GHG emissions in 2040. This includes the CO_2 emissions that would have occurred if natural gas had been used instead, as well as the methane emissions that would otherwise have resulted from the decomposition of feedstocks.

The outlook for global biomethane consumption by region



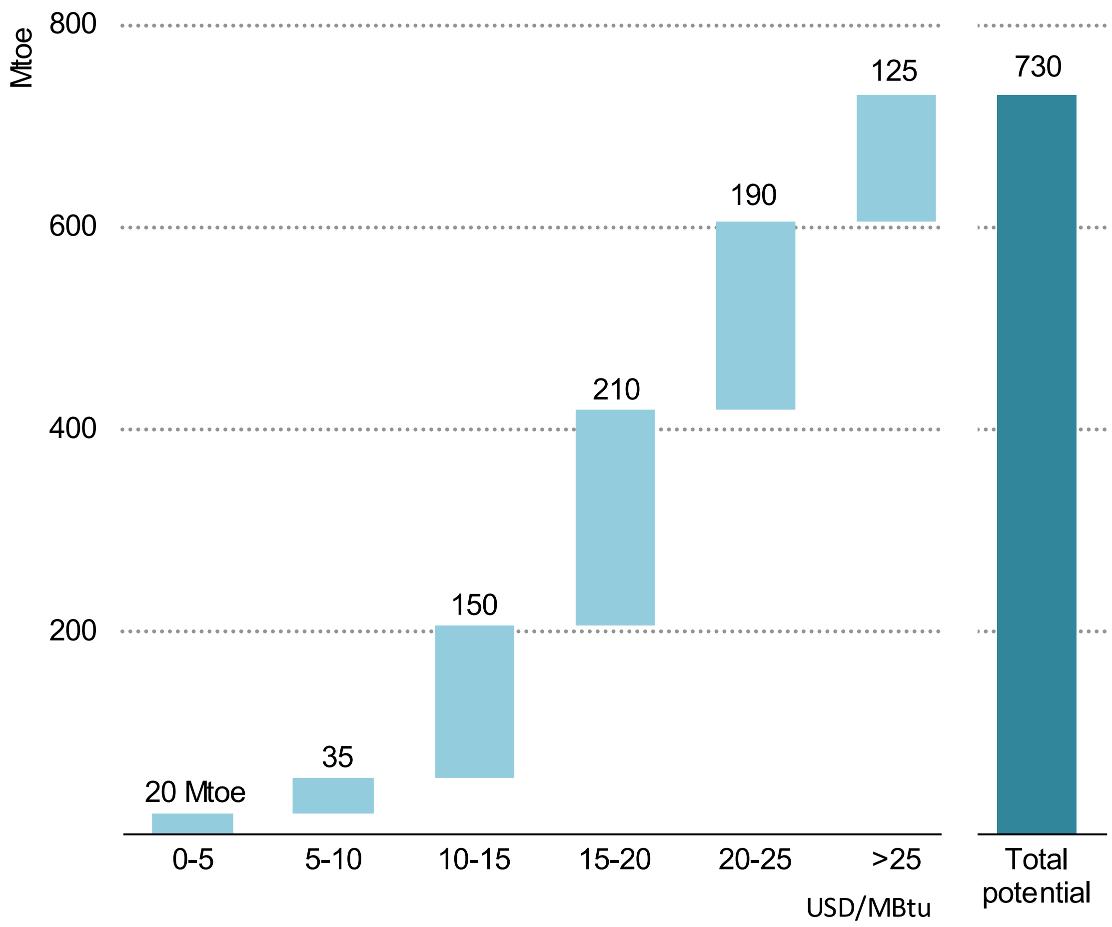
Notes: 1 Mtoe = 11.63 TWh = 1.21 bcm-equivalent to natural gas. China = People's Republic of China.

6. Most of the biomethane potential is more expensive than natural gas, but the cost gap narrows over time

With the exception of some landfill gas, most of the biomethane assessed in this report is more expensive than the prevailing natural gas prices in different regions. The average price for biomethane produced today is around USD 19 per million British thermal units (MBtu), with some additional costs for grid injection. However, this report estimates that around 30 Mtoe (~40 billion cubic metres [bcm]) of biomethane – mostly landfill gas – could be produced today at a price that undercuts the domestic price of natural gas; this is already ten times more than total biomethane consumption today.

The cost gap is projected to narrow over time as biomethane production technologies improve and as carbon pricing in some regions makes natural gas more expensive. Recognition of the value of avoided CO_2 and methane emissions goes a long way towards improving the cost-competitiveness of biomethane.

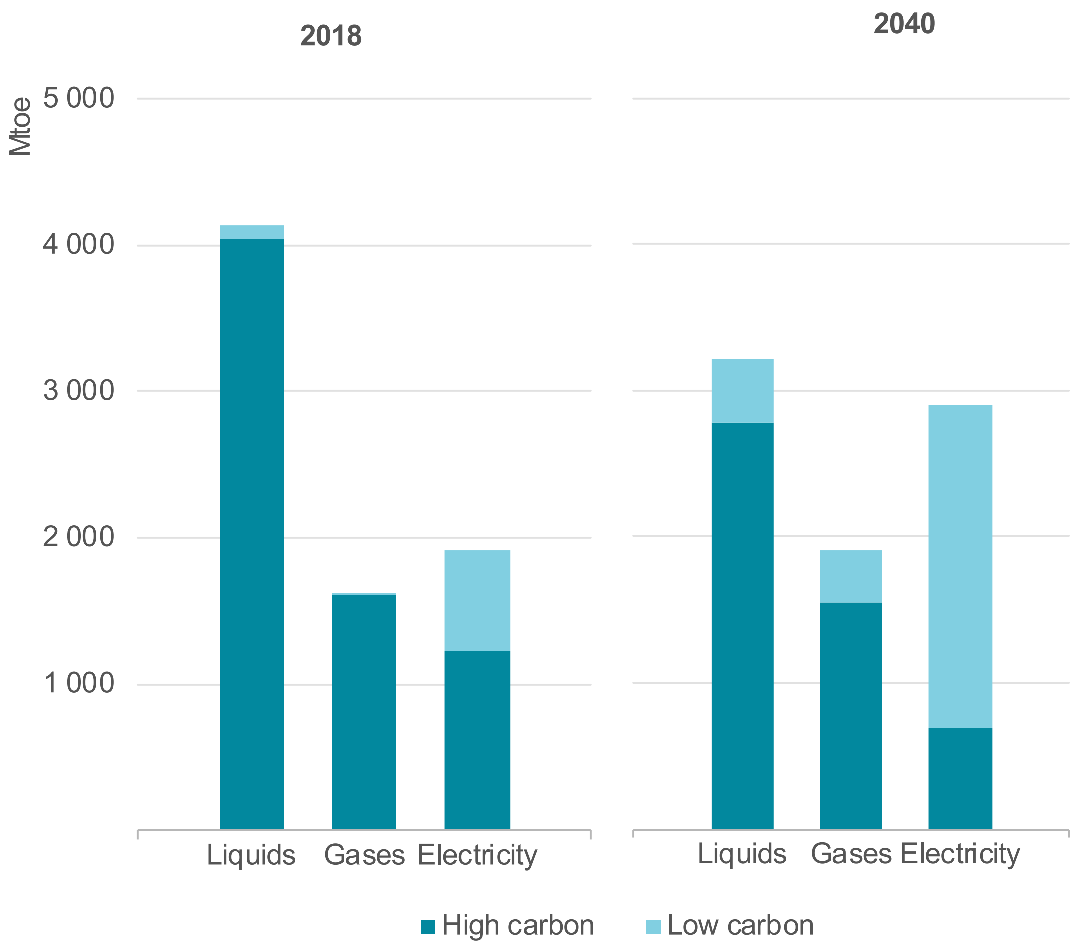
Cost ranges for developing global biomethane potential today



7. Low-carbon gases are essential to energy transitions; supportive policies are required to unlock the potential for biogas and biomethane

Multiple fuels and technologies will be required to accelerate energy transitions, and low-carbon gases – led by biomethane and low-carbon hydrogen – have critical roles to play. The 20% share of electricity in global final consumption is growing, but electricity cannot carry energy transitions on its own against a backdrop of rising demand for energy services. Biomethane is the largest contributor to low-carbon gas supply in the time horizon of the *World Energy Outlook* (*WEO*) Scenarios. How the biogas and biomethane industry evolves will vary by country depending on the sectoral focus, feedstock availability, prevailing market conditions and policy priorities. In all cases, however, realising the multiple benefits of biogas and biomethane requires co-ordinated policy-making across energy, transport, agriculture, environment and waste management.

Final energy consumption by carrier in 2018 and 2040 in the SDS



Note: Low-carbon gases include low-carbon hydrogen, biomethane and low-carbon synthetic methane, along with gas-based carbon capture, utilisation and storage (CCUS) used in large-scale industry.

An introduction to biogas and biomethane

What are biogas and biomethane?

Biogas is a mixture of methane, CO_2 and small quantities of other gases produced by anaerobic digestion of organic matter in an oxygen-free environment. The precise composition of biogas depends on the type of feedstock and the production pathway; these include the following main technologies:

- **Biodigesters**: These are airtight systems (e.g. containers or tanks) in which organic material, diluted in water, is broken down by naturally occurring micro-organisms. Contaminants and moisture are usually removed prior to use of the biogas.
- **Landfill gas recovery systems**: The decomposition of municipal solid waste (MSW) under anaerobic conditions at landfill sites produces biogas. This can be captured using pipes and extraction wells along with compressors to induce flow to a central collection point.
- **Wastewater treatment plants:** These plants can be equipped to recover organic matter, solids, and nutrients such as nitrogen and phosphorus from sewage sludge. With further treatment, the sewage sludge can be used as an input to produce biogas in an anaerobic digester.

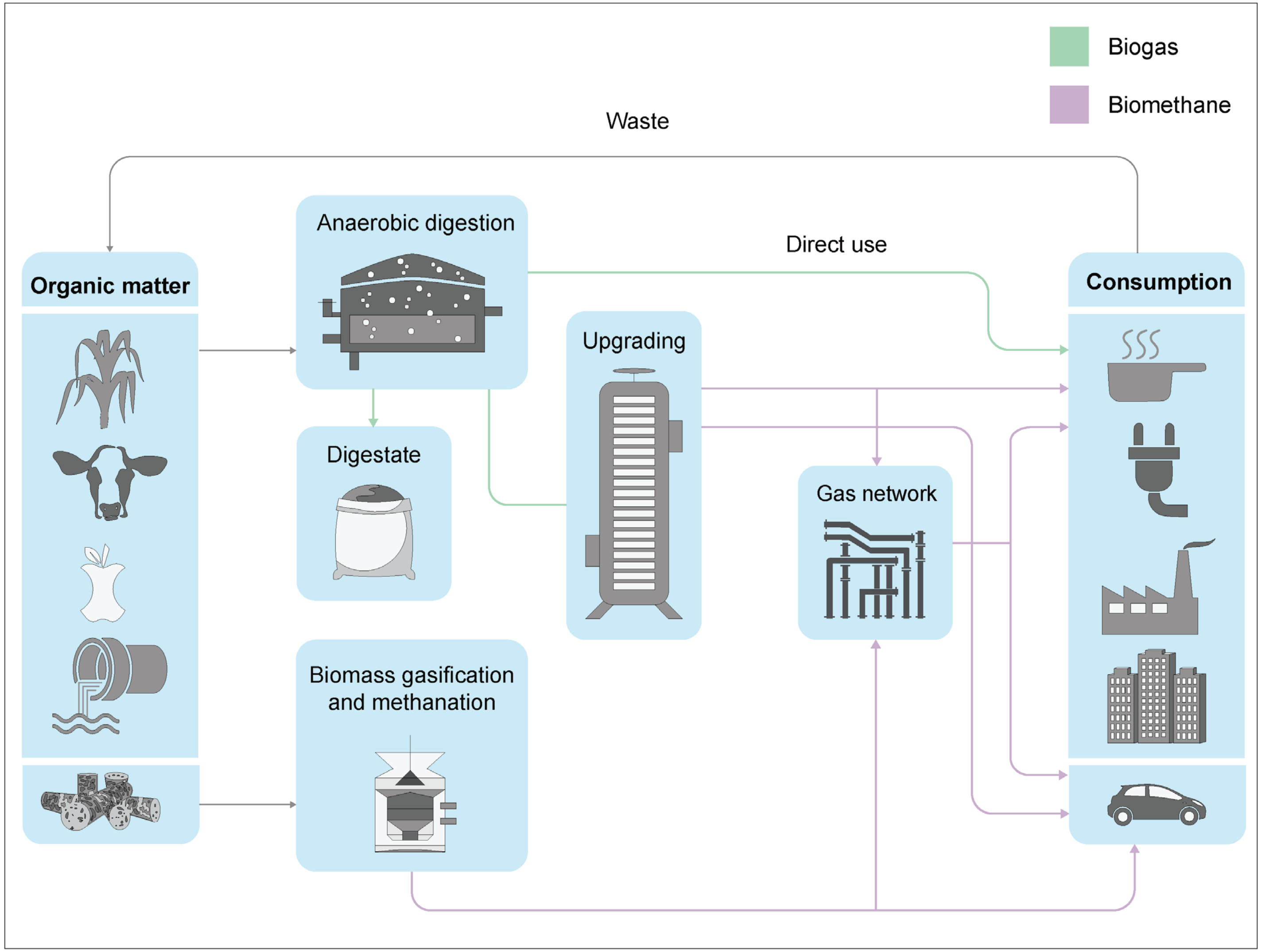
The methane content of biogas typically ranges from 45% to 75% by volume, with most of the remainder being CO_2. This variation means that the energy content of biogas can vary; the lower heating value (LHV) is between 16 megajoules per cubic metre (MJ/m^3) and 28 MJ/m^3. Biogas can be used directly to produce electricity and heat or as an energy source for cooking.

Biomethane (also known as "renewable natural gas") is a near-pure source of methane produced either by "upgrading" biogas (a process that removes any CO_2 and other contaminants present in the biogas) or through the gasification of solid biomass followed by methanation:

- **Upgrading biogas**: This accounts for around 90% of total biomethane produced worldwide today. Upgrading technologies make use of the different properties of the various gases contained within biogas to separate them, with water scrubbing and membrane separation accounting for almost 60% of biomethane production globally today (Cedigaz, 2019).
- **Thermal gasification of solid biomass followed by methanation**: Woody biomass is first broken down at high temperature (between 700-800°C) and high pressure in a low-oxygen environment. Under these conditions, the biomass is converted into a mixture of gases, mainly carbon monoxide, hydrogen and methane (sometimes collectively called syngas). To produce a pure stream of biomethane, this syngas is cleaned to remove any acidic and corrosive components. The methanation process then uses a catalyst to promote a reaction between the hydrogen and carbon monoxide or CO_2 to produce methane. Any remaining CO_2 or water is removed at the end of this process.

Biomethane has an LHV of around 36 MJ/m^3. It is indistinguishable from natural gas and so can be used without the need for any changes in transmission and distribution infrastructure or end-user equipment, and is fully compatible for use in natural gas vehicles.

There are multiple production pathways for biogas and biomethane



Note: Only biomethane is considered suitable for use in the transport sector.

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A range of different feedstocks can be used to produce biogas and biomethane

A wide variety of feedstocks can be used to produce **biogas**. For this report, the different individual types of residue or waste were grouped into four broad feedstock categories: crop residues; animal manure; the organic fraction of MSW, including industrial waste; and wastewater sludge.

- **Crop residues:** Residues from the harvest of wheat, maize, rice, other coarse grains, sugar beet, sugar cane, soybean and other oilseeds. This report included sequential crops, grown between two harvested crops as a soil management solution that helps to preserve the fertility of soil, retain soil carbon and avoid erosion; these do not compete for agricultural land with crops grown for food or feed.
- **Animal manure:** From livestock including cattle, pigs, poultry and sheep.
- **Organic fraction of MSW:** Food and green waste (e.g. leaves and grass), paper and cardboard and wood that is not otherwise utilised (e.g. for composting or recycling). MSW[1] also includes some industrial waste from the food-processing industry.
- **Wastewater sludge:** Semi-solid organic matter recovered in the form of sewage gas from municipal wastewater treatment plants.

Specific energy crops, i.e. low-cost and low-maintenance crops grown solely for energy production rather than food, have played an important part in the rise of biogas production in some parts of the world, notably in Germany. However, they have also generated a vigorous debate about potential land-use impacts, so they are not considered in this report's assessment of the sustainable supply potential.

Using waste and residues as feedstocks avoids the land-use issues associated with energy crops. Energy crops also require fertiliser (typically produced from fossil fuels), which needs to be taken into account when assessing the life-cycle emissions from different biogas production pathways. Using waste and residues as feedstocks can capture methane that could otherwise escape to the atmosphere as they decompose.

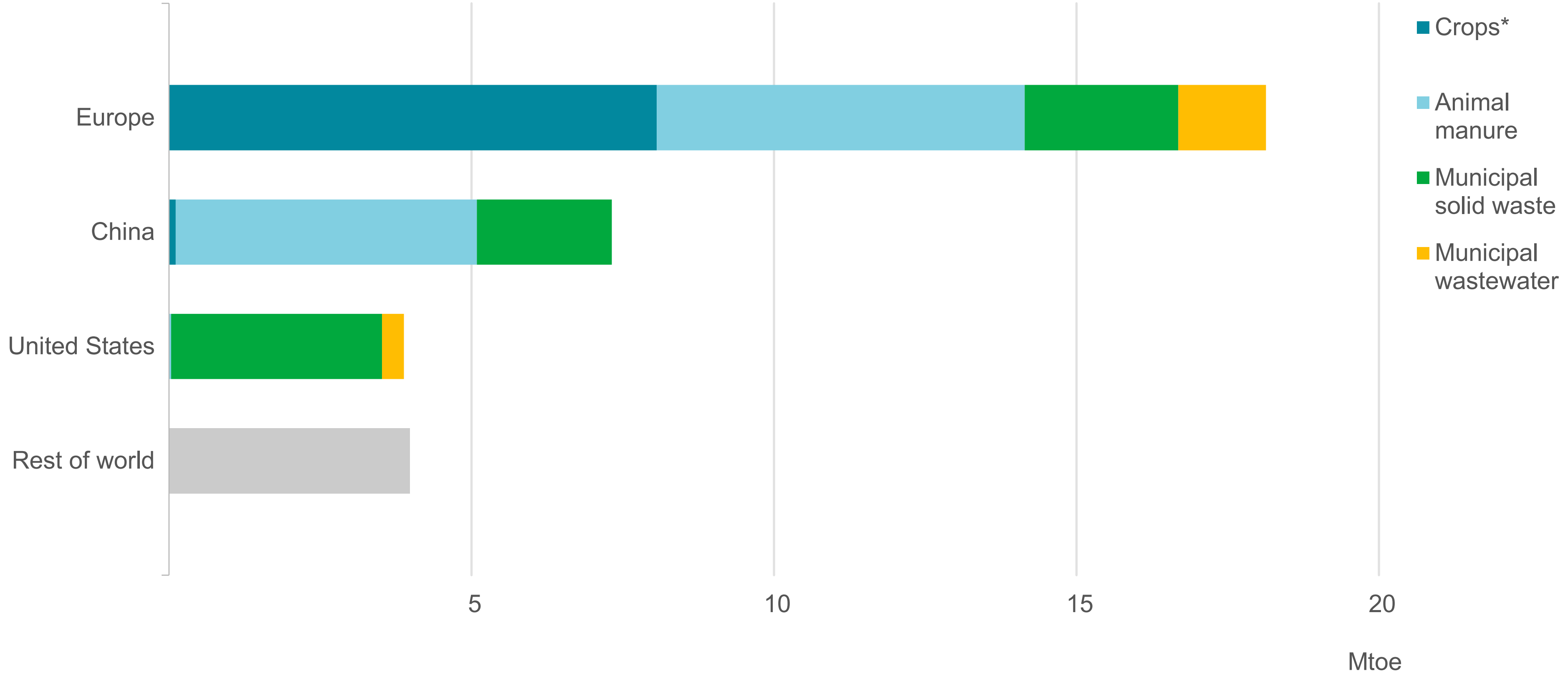
Most **biomethane** production comes from upgrading biogas, so the feedstocks are the same as those described above. However, the gasification route to biomethane can use **woody biomass** (in addition to MSW and agricultural residues) as a feedstock, which consists of residues from forest management and wood processing.

The feedstocks described above were considered in this report's assessment of the sustainable biogas and biomethane supply potential, and are further discussed in Section 3 below.

[1] MSW can either feed a biodigester or be disposed in landfill to produce landfill gas.

Biogas: Most production today comes from crops and animal manure

Biogas production by feedstock type, 2018



* Crops include energy crops, crop residues and sequential crops.
Note: 1 Mtoe = 11.63 terawatt-hours (TWh) = 41.9 petajoules (PJ).

The rise of biogas has been shaped by two main factors: Policy support and feedstock availability

The development of biogas has been uneven across the world, as it depends not only on the availability of feedstocks but also on policies that encourage its production and use. Europe, the People's Republic of China (hereafter, "China") and the United States account for 90% of global production.

Europe is the largest producer of biogas today. Germany is by far the largest market, and home to two-thirds of Europe's biogas plant capacity. Energy crops were the primary choice of feedstock that underpinned the growth of Germany's biogas industry, but policy has recently shifted more towards the use of crop residues, sequential crops, livestock waste and the capture of methane from landfill sites. Other countries such as Denmark, France, Italy and the Netherlands have actively promoted biogas production.

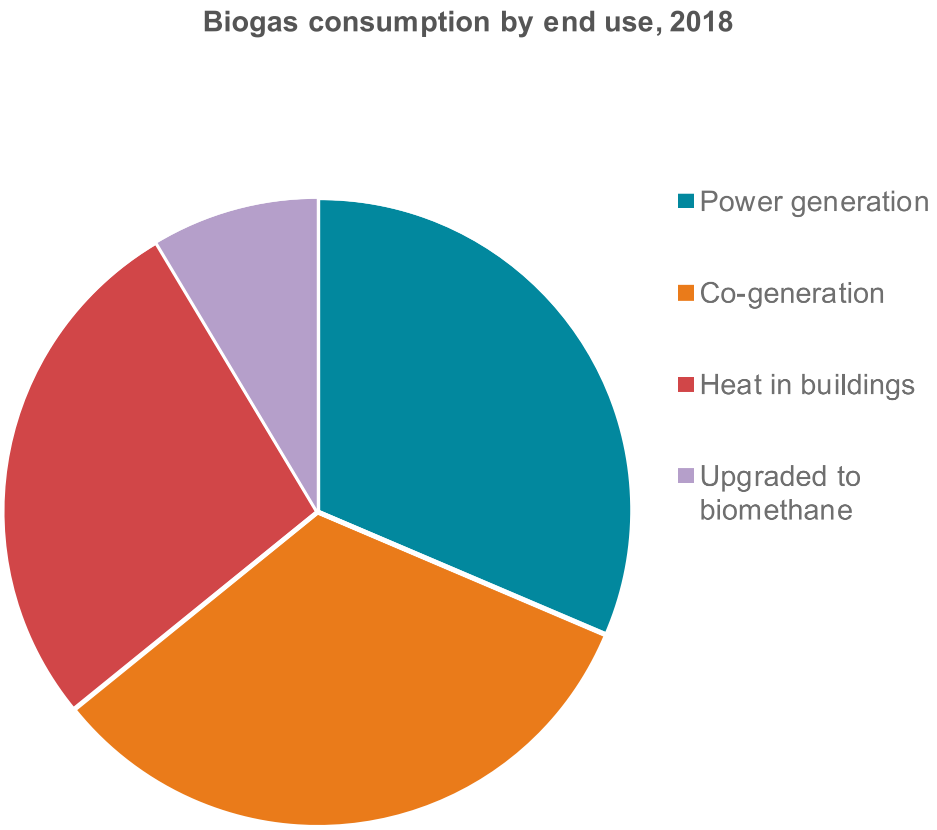
In **China**, policies have supported the installation of household-scale digesters in rural areas with the aim of increasing access to modern energy and clean cooking fuels; these digesters account for around 70% of installed biogas capacity today. Different programmes have been announced to support the installation of larger-scale co-generation plants (i.e. plants producing both heat and power). Moreover, the Chinese National Development and Reform Commission issued a guidance document in late 2019 specifically on biogas industrialisation and upgrading to biomethane, supporting also the use of biomethane in the transport sector.

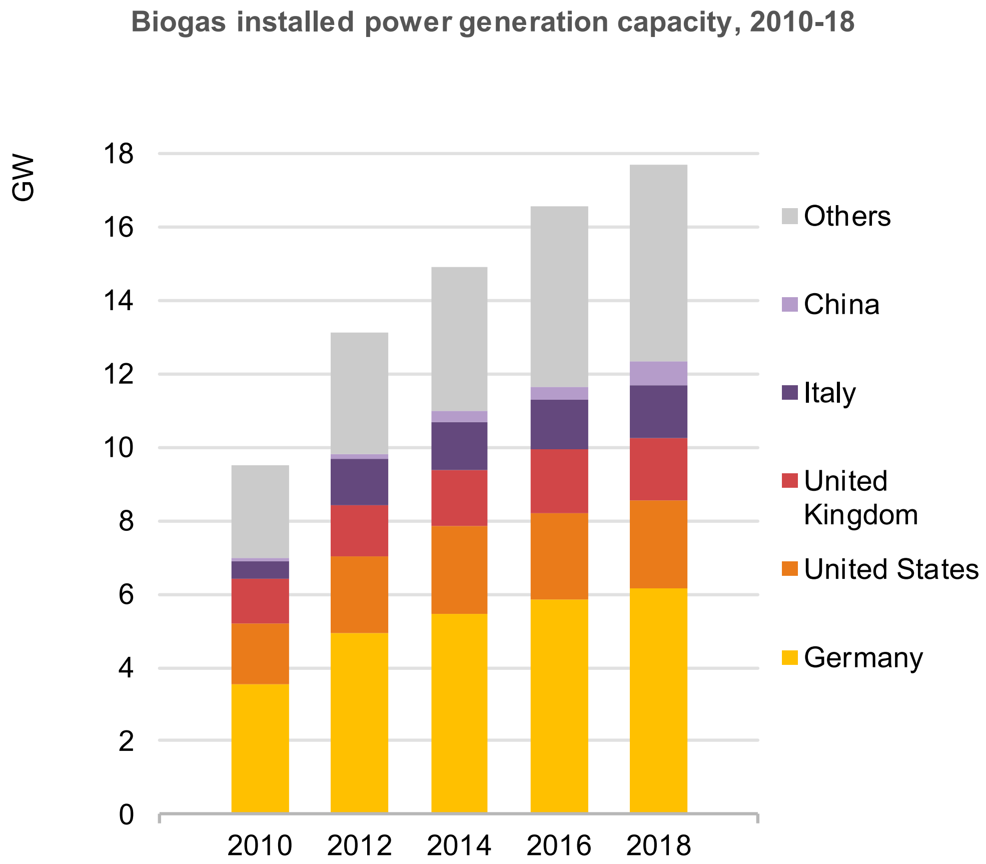
In the **United States**, the primary pathway for biogas has been through landfill gas collection, which today accounts for nearly 90% of its biogas production. There is also growing interest in biogas production from agricultural waste, since domestic livestock markets are responsible for almost one-third of methane emissions in the United States (USDA, 2016). The United States is also leading the way globally in the use of biomethane in the transport sector, as a result of both state and federal support.

Around half of the remaining production comes from developing countries in Asia, notably **Thailand** and **India**. Remuneration via the Clean Development Mechanism (CDM) was a key factor underpinning this growth, particularly between 2007 and 2011. The development of new biogas projects fell sharply after 2011 as the value of emission reduction credits awarded under the CDM dropped. Thailand produces biogas from the waste streams of its cassava starch sector, biofuel industry and pig farms. India aims to develop around 5 000 new compressed biogas plants over the next five years (GMI, 2019). **Argentina** and **Brazil** have also supported biogas through auctions; Brazil has seen the majority of production come from landfills, but there is also potential from vinasse, a by-product from the ethanol industry.

A clear picture of today's consumption of biogas in **Africa** is made more difficult by a lack of data, but its use has been concentrated in countries with specific support programmes. Some governments, such as Benin, Burkina Faso and Ethiopia, provide subsidies that can cover from half to all of the investment, while numerous projects promoted by non-governmental organisations provide practical know-how and subsidies to lower the net investment cost. In addition to these subsidies, credit facilities have made progress in a few countries, notably a recent lease-to-own arrangement in Kenya that financed almost half of the digester installations in 2018 (ter Heegde, 2019)

Most of the biogas produced today goes to the power sector





Note: GW = gigawatt.
Source: IEA, 2019a.

Upgrading biogas to biomethane could be a major source of future growth

Almost two-thirds of biogas production in 2018 was used to generate electricity and heat (with an approximately equal split between electricity-only facilities and co-generation facilities). Around 30% was consumed in buildings, mainly in the residential sector for cooking and heating, with the remainder upgraded to biomethane and blended into the gas networks or used as a transport fuel.

Today there is around 18 GW of installed power generation capacity running on biogas around the world, most of which is in Germany, the United States and the United Kingdom. Capacity increased on average by 4% per year between 2010 and 2018. In recent years, deployment in the United States and some European countries has slowed, mainly because of changes in policy support, although growth has started to pick up in other markets such as China and Turkey.

The levelised cost of generating electricity from biogas varies according to the feedstocks used and the sophistication of the plant, and ranges from USD 50 per megawatt-hour (MWh) to USD 190/MWh. A substantial part of this range lies above the cost of generation from wind and utility-scale solar photovoltaic (PV), which have come down sharply in recent years.

The relatively high costs of biogas power generation mean that the transition from feed-in tariffs to technology-neutral renewable electricity auction frameworks (such as power purchase agreements) in many countries could limit the future prospects for electricity-only biogas plants. However, unlike wind and solar PV, biogas plants can operate in a flexible manner and so provide balancing and other ancillary services to the electricity network. Recognising the value of these services would help to spur future deployment prospects for biogas plants.

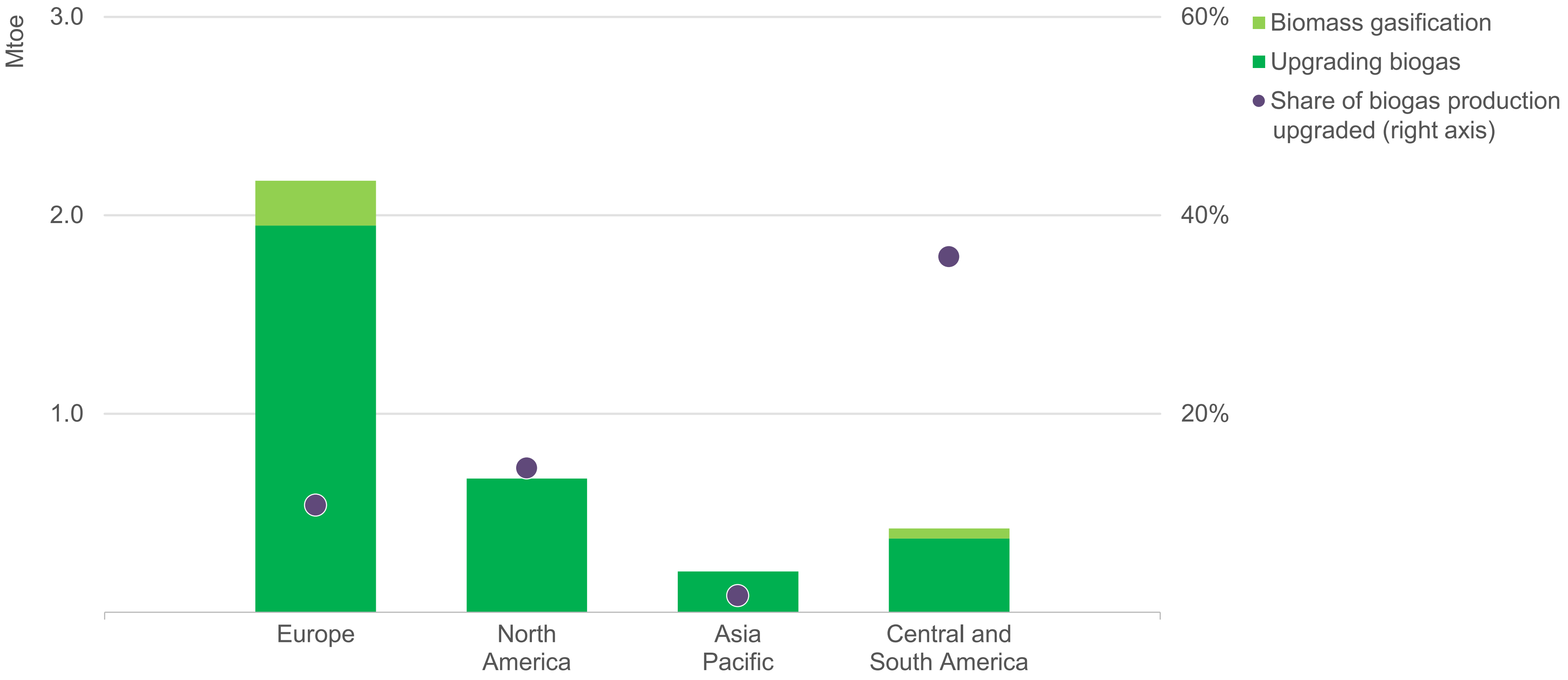
Where local heat off-take is available, the economic case for biogas co-generation is stronger than for an electricity-only plant. This is because co-generation can provide a higher level of energy efficiency, with around 35% of the energy from biogas used to generate electricity and an additional 40-50% of the waste heat put to productive use.

Certain industrial subsectors, such as the food and drink and chemicals, produce wet waste with a high organic content, which is a suitable feedstock for anaerobic digestion. In such industries, biogas production can also have the co-benefit of providing treatment for waste while also supplying on-site heat and electricity.

For the moment, a relatively small but growing share of the biogas produced worldwide is upgraded to biomethane. This area has significant potential for further growth, although – as outlined in subsequent sections of this report – this is heavily contingent on the strength and design of policies aimed at decarbonising gas supply in different parts of the world.

Biomethane: Around 90% of today's production is from upgrading biogas

Biomethane production and share of total biogas production that is upgraded in selected regions, 2018



Note: 1 Mtoe = 11.63 TWh = 1.21 bcm-equivalent to natural gas.
Sources: Analysis based on IEA data and CEDIGAZ (2019).

Most biomethane production today is in Europe and North America, although these regions upgrade only a small share of their overall biogas output

The biomethane industry is currently very small, although it is generating growing amounts of interest in several countries for its potential to deliver clean energy to a wide array of end users, especially when this can be done using existing infrastructure.

Currently around 3.5 Mtoe of biomethane are produced worldwide. The vast majority of production lies in European and North American markets, with some countries such as Denmark and Sweden boasting more than 10% shares of biogas/biomethane in total gas sales. Countries outside Europe and North America are catching up quickly, with the number of upgrading facilities in Brazil, China and India tripling since 2015.

Biomethane represents about 0.1% of natural gas demand today; however, an increasing number of government policies are supporting its injection into natural gas grids and for decarbonising transport. For example, Germany, Italy, the Netherlands and the United Kingdom have all introduced support for biomethane in transport. Brazil's RenovaBio programme has a target of reducing the carbon intensity of fuels in the transport sector by 10% by 2028. Subnational schemes are also emerging, such as low-carbon fuel standards in the US state of California and in British Columbia, Canada.

The percentage of biogas produced that is upgraded varies widely between regions: in North America it is around 15% while in South America it is over 35%; in Europe, the region that produces the most biogas and biomethane, around 10% of biogas production is upgraded (although in countries such as Denmark and Sweden the percentages are much higher); in Asia, the figure is 2%.

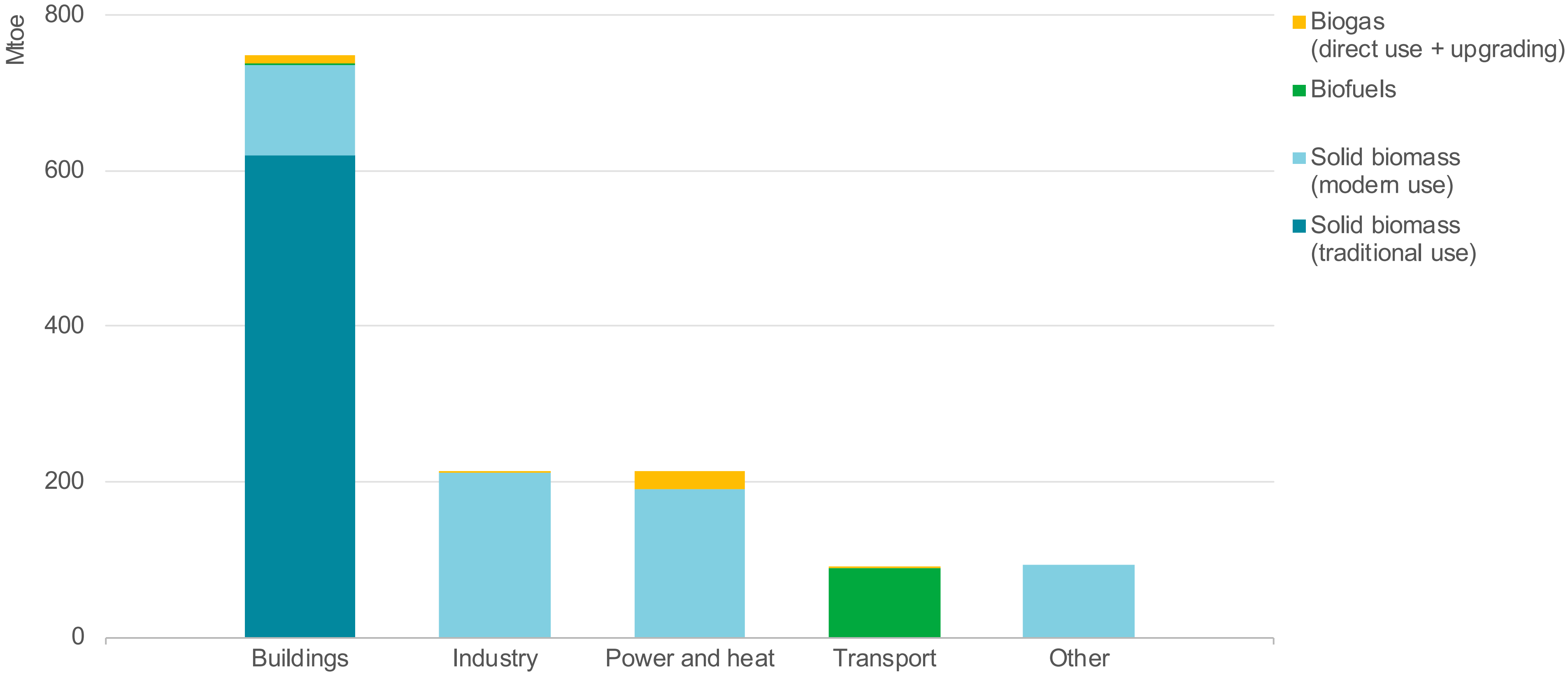
The main co-product of biogas upgrading is CO_2, which is produced in a relatively concentrated form and therefore could be used for industrial or agricultural purposes or combined with hydrogen to yield an additional stream of methane. Another option would be to store it underground, in which case the biomethane would be a CO_2-negative source of energy.

As noted above, the alternative method to produce biomethane is through thermal gasification of biomass. There are several biomass gasification plants currently in operation, but these are mostly at demonstration scale producing relatively small volumes. Some of these plants have struggled to achieve stable operation, as a result of the variable quality and quantity of feedstock. Since this is a less mature technology than anaerobic digestion, thermal gasification arguably offers greater potential for technological innovation and cost reductions. Prospects would be enhanced if incumbent gas producers were to commit resources to its development, as it would appear a better fit with their knowledge and technical expertise.

The rising interest in biomethane means that the number of operating plants worldwide (both biogas upgrading and biomass gasification facilities) is expected to exceed 1 000 in the course of 2020. Around 60% of plants currently online and in development inject biomethane into the gas distribution network, with a further 20% providing vehicle fuel. The remainder provides methane for a variety of local end uses.

For the moment, biogas and biomethane are only a small part of overall bioenergy consumption

Global bioenergy consumption by type of source and sector, 2018



Notes: "Traditional use" of solid biomass refers to the use of solid biomass with basic technologies, such as a three-stone fire, often with no or poorly operating chimneys. "Modern use" of solid biomass in buildings refers to the use of improved cook stoves and in other sectors modern technologies using processed biomass such as woodchips and pellets.
1 Mtoe = 11.63 TWh = 41.9 PJ.

However, there is a strong potential role for biogas and biomethane in the transformation of the global energy system

Bioenergy accounts for around 10% of the world's primary energy demand today. It can be consumed either in solid, liquid or gaseous form, and by far the most prevalent use of bioenergy today is solid biomass (around 90%).

The use of solid biomass is typically categorised as either "traditional" or "modern", and currently demand is split roughly equally between the two. Modern biomass relies on more advanced technologies, mainly in electricity generation and industrial applications, which use upgraded fuels such as woodchips and pellets. Traditional use refers to the burning of solid biomass, such as wood, charcoal, agricultural residues and animal dung, for cooking or heating using basic technologies such as three-stone fires. With low conversion efficiencies and significant negative health impacts from indoor air pollution, many developing economies are trying to shift consumption away from traditional use.

The differentiation between traditional and modern does not apply for liquid and gaseous bioenergy, since both are produced using advanced technologies. Liquid biofuels make up around 7% of total bioenergy demand today. Biofuels are the main renewable energy source used directly in the transport sector, with around 90 Mtoe or almost 2 million barrels of oil equivalent per day consumed in 2018. About 70% of biofuels consumed today is bioethanol, which is usually blended with gasoline; most of the remainder is biodiesel.

Biogas and biomethane today account for less than 3% of total bioenergy demand, and represent an even smaller 0.3% share of total primary energy. But there are reasons to believe that these low-carbon gases could gain a firmer foothold in the future.

- They can provide the system benefits of natural gas (storage, flexibility, high-temperature heat) without the net carbon emissions. As economies decarbonise, this becomes a crucial attribute.
- Biogas provides a sustainable supply of heat and power that can serve communities seeking local, decentralised sources of energy, as well as a valuable cooking fuel for developing countries.
- The GHG reduction benefit is amplified by the processing and use of methane (a potent GHG) that could otherwise be released to the atmosphere from the decomposition of organic by-products and waste.
- Biogas and biomethane can also play an important part in waste management, improving overall resource efficiency.
- Where it displaces gas transported or imported over long distances, biogas and biomethane also yield energy security benefits.
- There are also broader non-energy considerations, such as nutrient recycling, rural job creation or reductions in the time spent in low-income communities collecting firewood. Both biogas and biomethane can also be developed at scale through partnerships between the energy and agricultural industries. By transforming a range of organic wastes into higher-value products, biogas and biomethane fit well into the concept of the circular economy.

Policies can help to unlock these benefits, but much will depend on how much biogas and biomethane is available and at what cost. These are the questions addressed in the next section.

Sustainable supply potential and costs

The backbone of the *Outlook* is a detailed global assessment of the sustainable technical potential and costs of biogas and biomethane supply

This report uses a new IEA estimate of the sustainable technical potential of biogas and biomethane supply, based on a detailed assessment of the availability of 19 types of feedstocks across the 25 regions modelled in the World Energy Model. The assessment used detailed cost, feedstock and technology data to derive supply cost curves illustrating the potential scale and commercial viability of different biogas and biomethane production pathways around the world. This section considers first the potential and costs for biogas, followed by those for biomethane.

For biogas, this report considered 17 individual types of residue or waste, grouped into the four feedstock categories described in Section I, namely crop residues, animal manure, the organic fraction of MSW and wastewater sludge. Biogas production pathways vary by feedstock and region and rely on the following main technologies: biodigesters (including centralised digesters at small, medium or large scale and decentralised digesters at household scale), landfill gas recovery systems, and wastewater treatment municipal plants.

For biomethane this report considered two main production pathways: upgrading biogas and the gasification of biomass. For biogas upgrading, the same feedstocks assessed for biogas have been considered, on the assumption that these can be used either for biogas production or for upgrading biogas to biomethane. The alternative route to biomethane production – gasification – opens up the possibility of using two additional sources of solid biomass feedstock: forestry residues and wood processing residues.

This analysis focuses primarily on the opportunities and costs of biogas and biomethane, thereby excluding technologies to convert electricity to gas (also known as power-to-gas) and methanation using the CO_2 extracted during the biogas upgrading process.

As noted in Section I, this analysis includes only the technical potential of feedstock that can broadly be considered sustainable. This is defined as feedstocks that can be processed with existing technologies, which do not compete with food for agricultural land and that do not have any other adverse sustainability impacts (e.g. reducing biodiversity). Although energy crop residues are included, energy crop feedstocks grown specifically to produce biogas and biomethane are not included on the basis that their sustainability warrants further in-depth analysis outside the scope of this study.

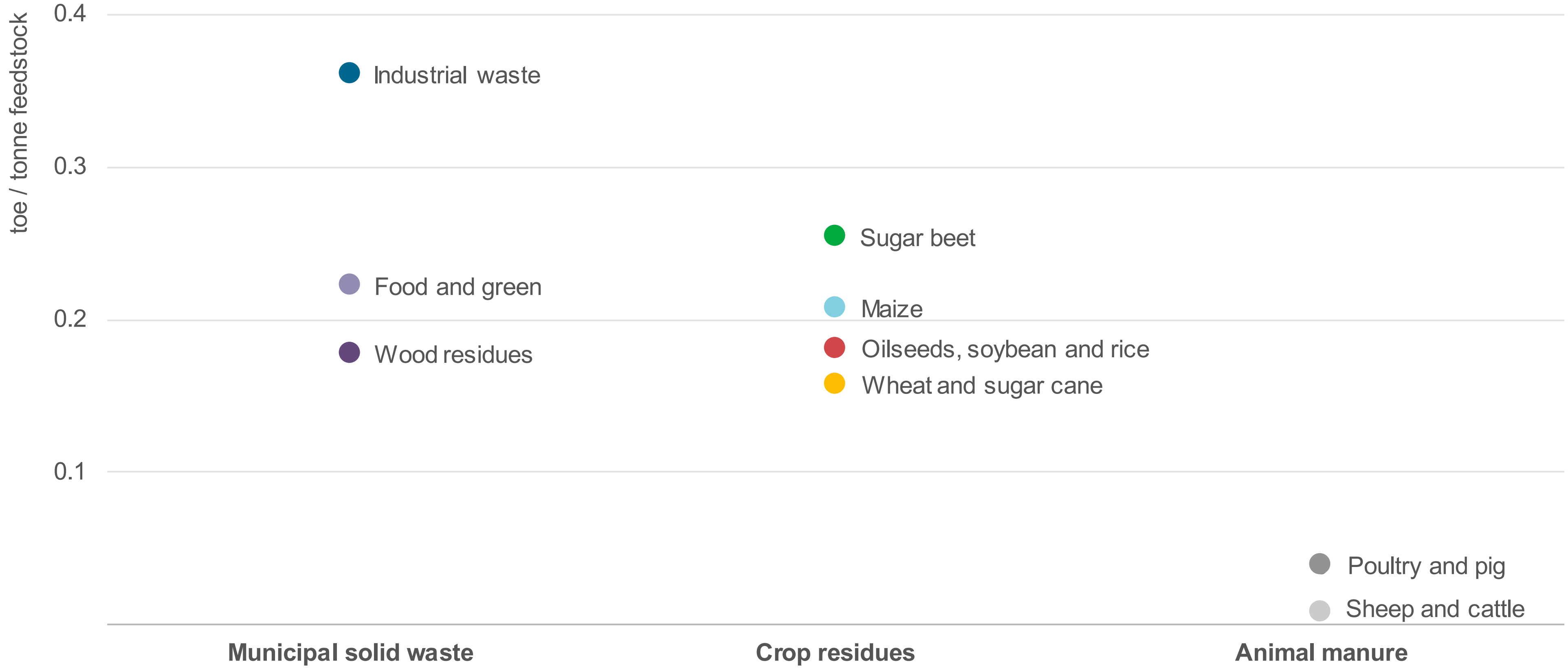
The estimates of the sustainable technical potential of biogas and biomethane evolve over time, and are affected by gross domestic product (GDP) and population growth, urbanisation trends, changes in waste management, and anticipated rates of technology evolution.

This report's assessment of supply costs matches feedstock availability with the appropriate production technologies, and draws on a number of case studies of the unit costs of biogas and biomethane production around the world. The costs presented here differ slightly from those in the *World Energy Outlook 2019* (IEA, 2019b). This is mainly due to the adoption of a more comprehensive data set for biogas upgrading technologies, separate consideration of the costs of connecting upgrading facilities to the gas grid, and inclusion of the latest published data and information.

Biogas supply potential and costs

The energy content of the various feedstocks is a key factor in the productivity of biogas production facilities

Average biogas production yield by tonne of feedstock type



Note: "Food and green" represents food and garden waste (e.g. leaves and grass) disposed as MSW. Many plants use more than one feedstock for biogas production. Wastewater is excluded due to the high variability of yields, depending on wastewater and treatment technologies in different regions. toe = tonne of oil equivalent.
1 toe = 11.63 MWh = 41.9 gigajoules.

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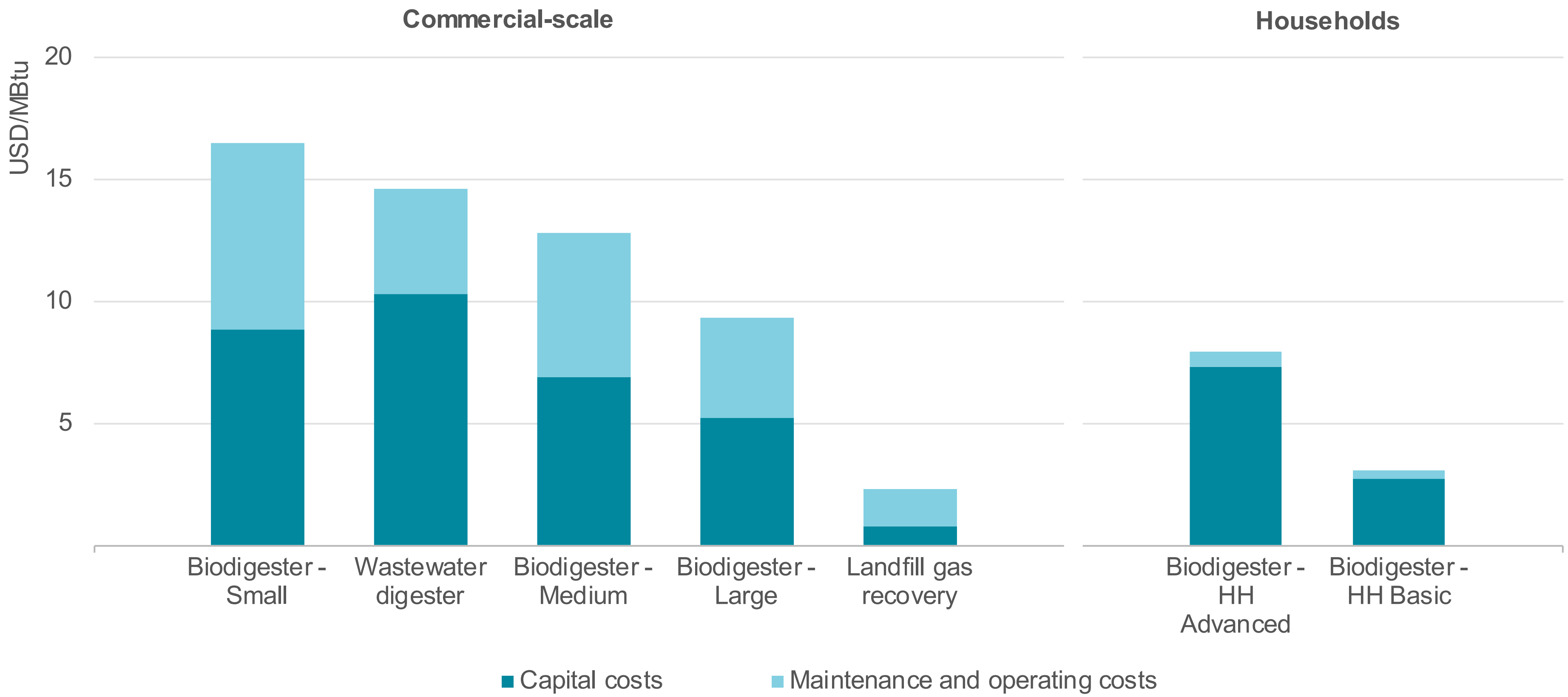
A range of technologies are available to produce biogas from different waste streams

Average costs of biogas production technologies per unit of energy produced (excluding feedstock), 2018



Notes: HH = household; "HH Basic" includes biodigesters constructed in place using traditional construction materials such as sand, gravel and cement; "HH Advanced" includes pre-manufactured biodigesters made of more expensive composite material. Maintenance and operating costs include ordinary and extraordinary maintenance, labour costs, and energy required to operate the system. Capital costs have been levelised for the production lifetime of each technology: 25 years for landfill gas recovery and advanced household biodigesters; 20 years for centralised biodigesters (small, medium and large) and wastewater digesters; 15 years for basic household biodigesters. 1 MBtu = 0.29 MWh.
Sources: IEA analysis based on different sources (Dennehy et al., 2017; ETSAP, 2013; and others).

Each biogas technology is adapted for different types of user and use, and comes with distinctive advantages and challenges

There are many different pathways for biogas production, involving different feedstocks and biogas technologies. Livestock manure is the most common feedstock, but the biogas production yield is significantly lower than what could be obtained from crop residues. Industrial waste is the highest-yielding feedstock, able to provide around 0.40 toe of energy per tonne. Besides yields, there is variation in the cost and effort required for collecting different volumes of feedstock. Technologies also vary; this report assessed the following:

- Decentralised biodigesters at household scale, categorised into either basic or advanced technologies
- Centralised biodigesters systems categorised by small (100 cubic metres per hour [m^3/h]), medium (250 m^3/h) and large scale output flow rates (750 m^3/h)
- Existing wastewater treatment plants adapted to process sludge produced at the municipal level (1 000 m^3/h)
- Landfill gas recovery systems to recover biogas produced from closed landfill sites (2 000 m^3/h).

Household-scale biogas systems can provide heating and cooking fuels in developing countries, as an alternative to the traditional use of solid biomass. The output of these units are typically around 1 m^3 per day, providing two to three hours of gas-fired stove cooking time for every 20 to 30 kg of animal manure (SNV, 2019). The capital costs of these basic technologies lie in a range of USD 3-8/MBtu (USD 10-30/MWh) and generally have shorter lifetimes and variable production yields. Feedstocks are usually available locally at zero cost, and in many cases the deployment of these systems has been supported through development programmes.

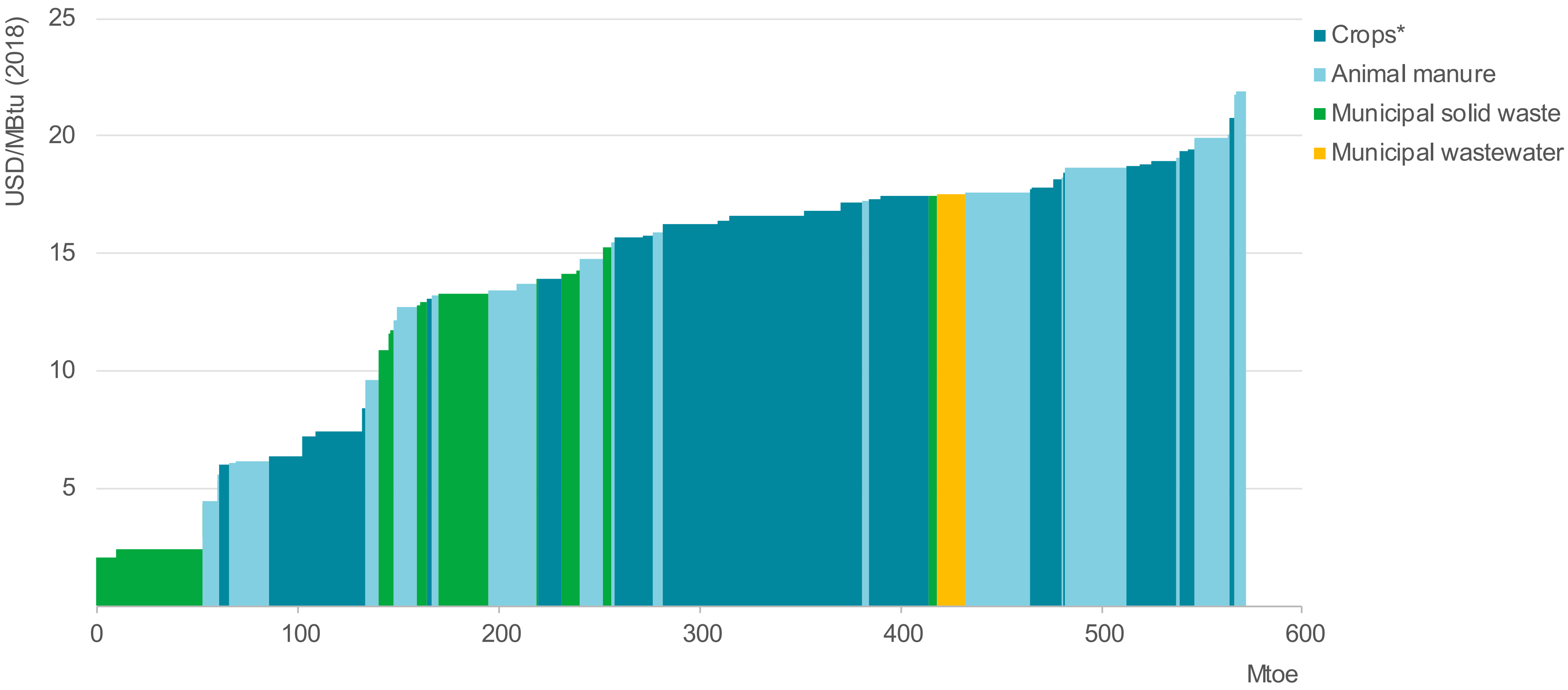
The picture changes when biodigesters scale up. Providing a continuous flow of organic material in significant quantities requires a more structured system to collect industrial quantities of feedstock. The biogas output is then typically connected to a captive power or co-generation plant involving additional investments. To ensure efficient operation, temperatures need to be maintained generally in the range of 30-45°C, and the feedstock must be continuously moved. For these reasons, centralised commercial and industrial biogas plants are more technologically sophisticated and their capital and operating costs per unit of energy produced are higher, although they also offer higher levels of efficiency and automation.

Anaerobic digestion systems can be installed at water treatment plants (through the processing of sewage sludge with high moisture content). Adapting a wastewater treatment plant entails high upfront investment costs averaging around USD 15/MBtu, but can significantly improve the longer-term economics of the plant. However, treatment capacities must generally be higher than 5 000 m^3 per day in order for the facility to be cost-effective. Landfill gas extraction is possible for closed landfill facilities containing MSW. This technology is best positioned to benefit from economies of scale, with production costs below USD 3/MBtu.

The suitability of these various technologies depend on factors such as location, feedstock availability and end-use applications. In this analysis each type of feedstock is allocated to the most suitable technology, resulting in the supply cost curves, presented below, which combine technology and feedstock costs.

Today's sustainable biogas potential could deliver nearly 600 Mtoe of low-carbon energy across a range of sectors

Cost curve of potential global biogas supply by feedstock, 2018



* *Crops* includes only crop residues and sequential crops (not dedicated energy crops).
Notes: The curve integrates technology and feedstock costs. Technology costs include the biodigester only, i.e. excluding any costs for equipment to transform biogas into power and heat. 1 MBtu = 0.29 MWh.

Crop residues provide around half of the global biogas potential today, but landfill gas is the lowest-cost source

This report estimates that nearly 600 Mtoe of biogas could be produced sustainably today. Developing economies currently account for two-thirds of the global potential, with developing countries in Asia holding around 30% and Central and South America another 20%. The sustainable feedstock in Africa is smaller, but would nonetheless be sufficient to meet the needs of the 600 million people in sub-Saharan Africa who remain without access to electricity.

Crop residues together with animal manure are the largest sources of feedstock, particularly in developing economies where the agricultural sector often plays a prominent role in the economy. In India, where the agricultural sector contributes 17% of GDP and around half of overall employment, the vast majority of biogas potential comes from sugar cane, rice and wheat crop residues. In Brazil, there are large volumes of maize and sugar cane residues coming from its sugar and ethanol industries, while the scale of the meat industry in China means that it is well-positioned to use animal manure for biogas production.

One-third of the total potential is in advanced economies and over half of this is in North America, with a further 30% in the European Union. The biogas supply potential in the United States is divided equally among crop residues (mainly corn residues from the ethanol industry), animal manure and MSW. In the European Union the potential contribution of MSW to biogas production is much lower due to regulations that have drastically reduced the fraction of organic matter flowing into landfills.

Globally, the costs of producing biogas today lie in a relatively wide range between USD 2/MBtu to USD 20/MBtu. There are also significant variations between regions; in Europe, the average cost is around 16/MBtu, while in Southeast Asia it is USD 9/MBtu. Around 70-95% of the total biogas costs are for installing biodigesters, with the remainder involving feedstock collection and processing costs. There is huge variability, as feedstocks can be zero-cost or even negative in cases where producers of waste are obliged to pay to dispose of their waste, whereas in other cases “gate fees” for certain agricultural feedstocks may be as high as USD 100/tonne in some regions.

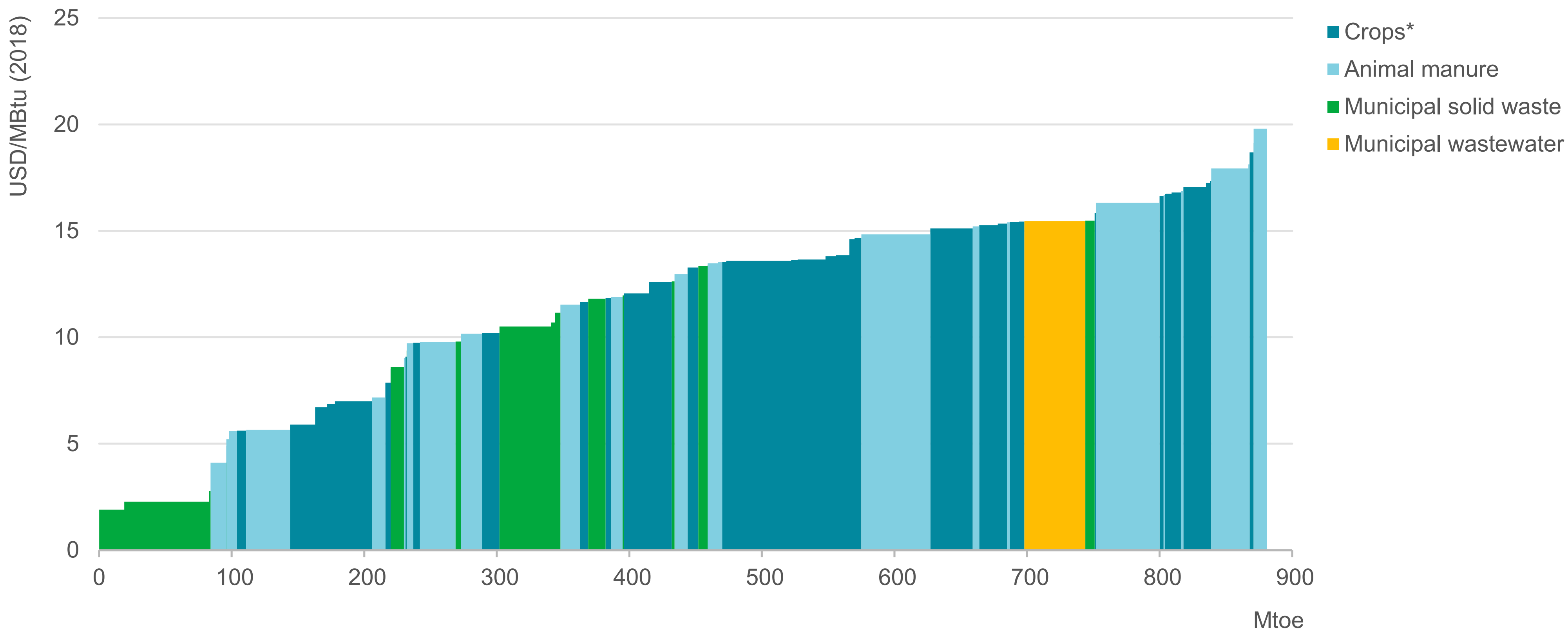
Biogas is produced and consumed locally, meaning transportation costs are negligible. However, these estimates exclude the investments required to transform biogas into electricity or heat, and this can be considerable in some cases; for example, adding a co-generation unit and including power grid connection and heat recovery distribution can add an additional 70% to the costs of an integrated project.

While constructing larger and more industrialised facilities could provide some economies of scale, in general there is only modest scope for cost reductions as the main production technologies are already mature. Cost-competitive production routes do, however, exist: in all regions, landfills equipped with a gas recovery system could provide biogas for less than USD 3/MBtu (about USD 10/kWh); this represents around 8% of the global supply potential.

In total, this report estimates that around 100 Mtoe of today’s biogas potential could be exploited in different parts of the world at a cost equal to or lower than prevailing natural gas prices. This is already three and a half times the current level of biogas production globally.

In 2040, biogas potential is more than 50% larger than today, around 40% of which would cost less than USD 10/MBtu

Cost curve of potential global biogas supply by feedstock, 2040



* *Crops* includes only crop residues and sequential crops (not dedicated energy crops).

Notes: The curve integrates technology and feedstock costs. Technology costs include the biodigester only, i.e. excluding any costs for equipment to transform biogas into power and heat. 1 MBtu = 0.29 MWh.

Biogas production costs fall slightly over time, narrowing the cost gap with projected natural gas prices

This report's assessment of the sustainable potential for biogas production in 2040 is 50% higher than today, based on increased availability of the various feedstocks in a larger global economy. The projected costs of production also fall modestly over time.

There are significant variations in dynamics across different regions, with the biogas supply potential in developing economies growing at around twice the rate of advanced economies. This is mainly due to the increased availability of animal manure and MSW along with the rising potential to produce biogas from wastewater treatment plants.

Changes in dietary habits, with a growing number of people consuming more protein-rich diets, increases the size and scale of the meat industry and therefore the availability of animal manure. Increased urbanisation and waste collection also increase the availability of MSW in some developing economies; In India and Southeast Asia, for example, the improvement of waste management and collection programmes leads to significant growth in the availability of MSW (reaching 36 Mtoe in 2040, three times the current assessment). The level of wastewater available for biogas production also increases by around 6% per year over the period to 2040.

More sophisticated and sustainable waste management practices could in some cases reroute feedstock away from certain biogas production technologies. For example, the availability of landfill gas could be reduced if organic waste is collected separately and used for other purposes, such as composting or transport biofuel production.

In 2040, the agricultural sector remains the largest contributor to global biogas supply potential, with crop residues accounting for over 40% and animal manure for 35% of the total. Availability of animal manure as a feedstock is projected to increase by around 2.5% on average each year, double the rate of increase for crop residues. MSW provides a much smaller fraction of total potential in 2040 than today. Nonetheless, there is still scope to produce more than 80 Mtoe in 2040, with landfill gas remaining the lowest-cost source of supply.

Overall, biogas production costs are projected to decrease slightly while natural gas prices tend to increase. Countries and regions where projected natural gas prices are relatively high, such as China and Southeast Asia, and regions with ambitious climate targets could therefore have strong incentives to increase their biogas production.

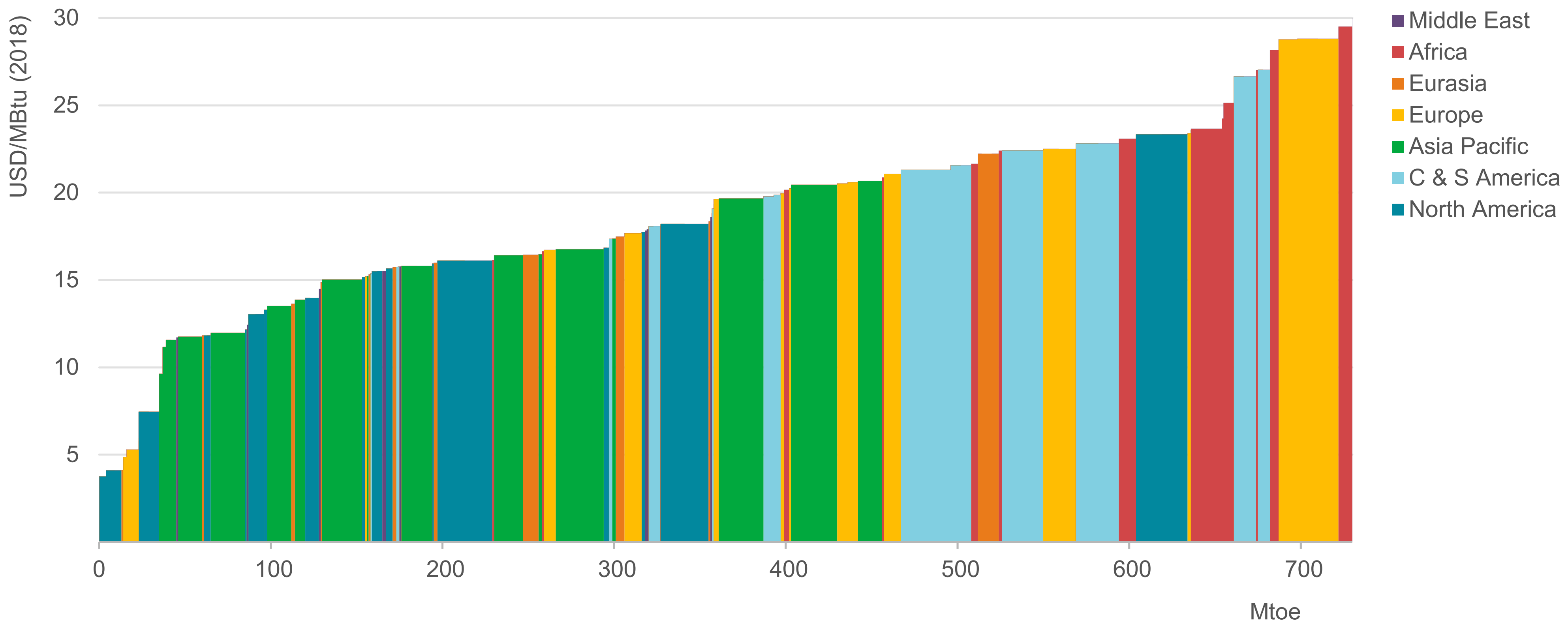
In total, this report estimates that in 2040 over 260 Mtoe of biogas could be produced worldwide for less than prevailing regional natural gas prices in STEPS, which average around USD 9/MBtu in importing regions such as Europe and most developing Asian economies, USD 7/MBtu in Africa, and around USD 4.5/MBtu in North America.

One option to increase the competitiveness of biogas is to monetise the by-products from its production. Producing biogas leaves a residue of fluids and fibrous materials called “digestate”. The handling and disposal of digestate can be costly and as a result it is often considered a waste rather than a useful by-product. However, in certain locations and applications, digestate can be sold as a natural fertiliser, helping to offset a part of the production cost. European regulations have recently recognised the role organic materials play in the production of digestate (EBA, 2019).

Biomethane supply potential and costs

More than 700 Mtoe of biomethane could be produced sustainably today, equivalent to more than 20% of global natural gas demand

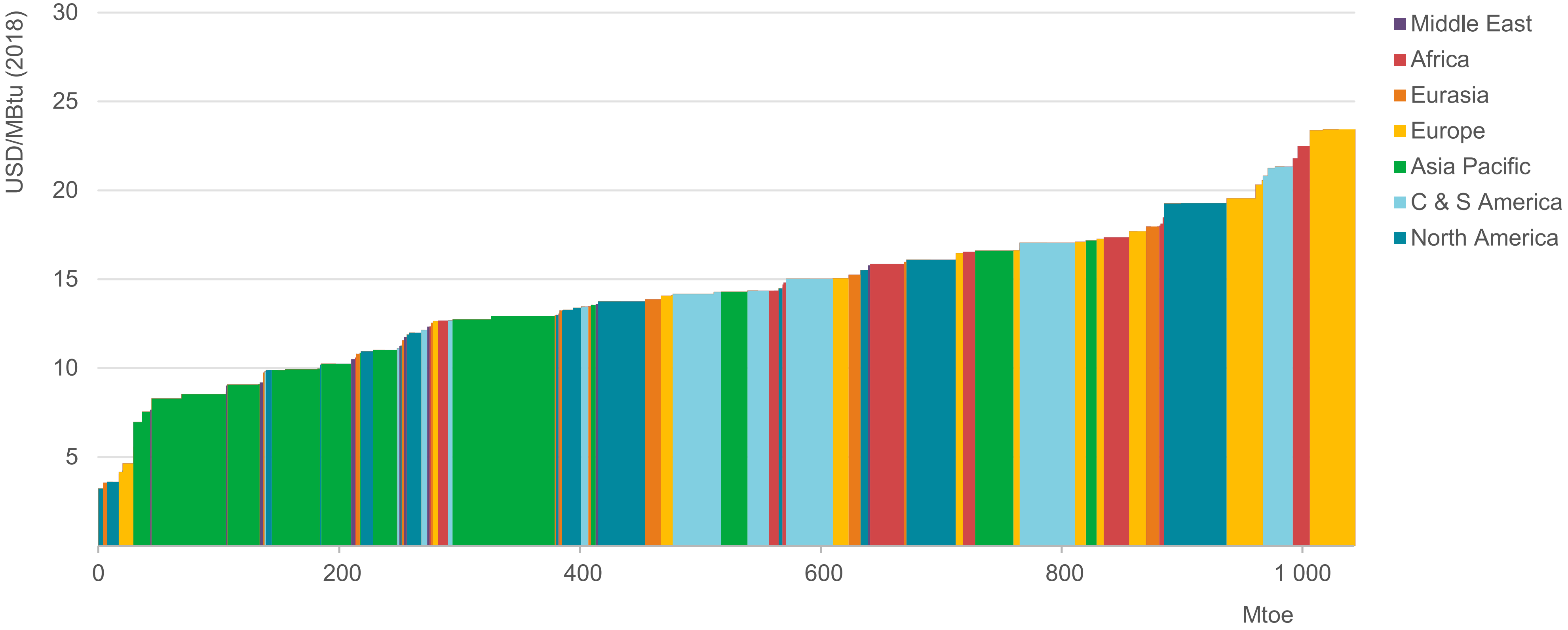
Cost curve of potential global biomethane supply by region, 2018



Notes: C & S America = Central and South America. The curve integrates technology and feedstock costs; injection costs are not included. The chart incorporates all the biogas potential that can be upgraded to biomethane.1 MBtu = 0.29 MWh.

By 2040, this potential grows to more than 1 000 Mtoe with a global average production cost of less than USD 15/MBtu

Cost curve of potential global biomethane supply by region, 2040



Notes: C & S America = Central and South America. The curve integrates technology and feedstock costs; injection costs are not included. The chart incorporates all the biogas potential that can be upgraded to biomethane. 1 MBtu = 0.29 MWh.

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Upgrading biogas is by far the most common biomethane production route today. Biomass gasification remains a relatively niche industry

The potential for biomethane production today is over 700 Mtoe, which is higher than biogas because of the inclusion of woody biomass as a feedstock for thermal gasification; this increases the total possible resource base by a fifth. However, the vast majority of global biomethane potential today is linked to the upgrading of biogas.

This potential has a wide geographic spread: at a regional level, the United States and Europe each hold a 16% share in the global total, but there is also major potential in China and Brazil (each with 12%) and India (8%). As with biogas, the potential could be even larger if energy crops were to be included, but classifying them as "sustainable" would require case-specific consideration of possible competition between biomethane and food production. This does not mean, however, that the feedstocks included in this assessment do not compete with one another for alternative uses: for example, forestry residues can be a sustainable source of direct heat, while crop residues can be used for animal feed or to produce advanced biofuels.

Cost curves for biomethane equal the biogas production costs plus the additional costs required for upgrading. An assessment of woody biomass that can be processed via gasification is also included. This report estimates that the global average cost of producing biomethane through biogas upgrading today is around USD 19/MBtu. Most of this cost is attributable to the production of the biogas, with the upgrading process costing around USD 2/MBtu to USD 4/MBtu for a facility that upgrades around 3.5 million m^3 of biogas per year. The cost of the upgrading process can vary significantly for different facility sizes and across different regions: for example, in North America, upgrading costs are at the lower end of this range due to economies of scale captured by larger unit sizes.

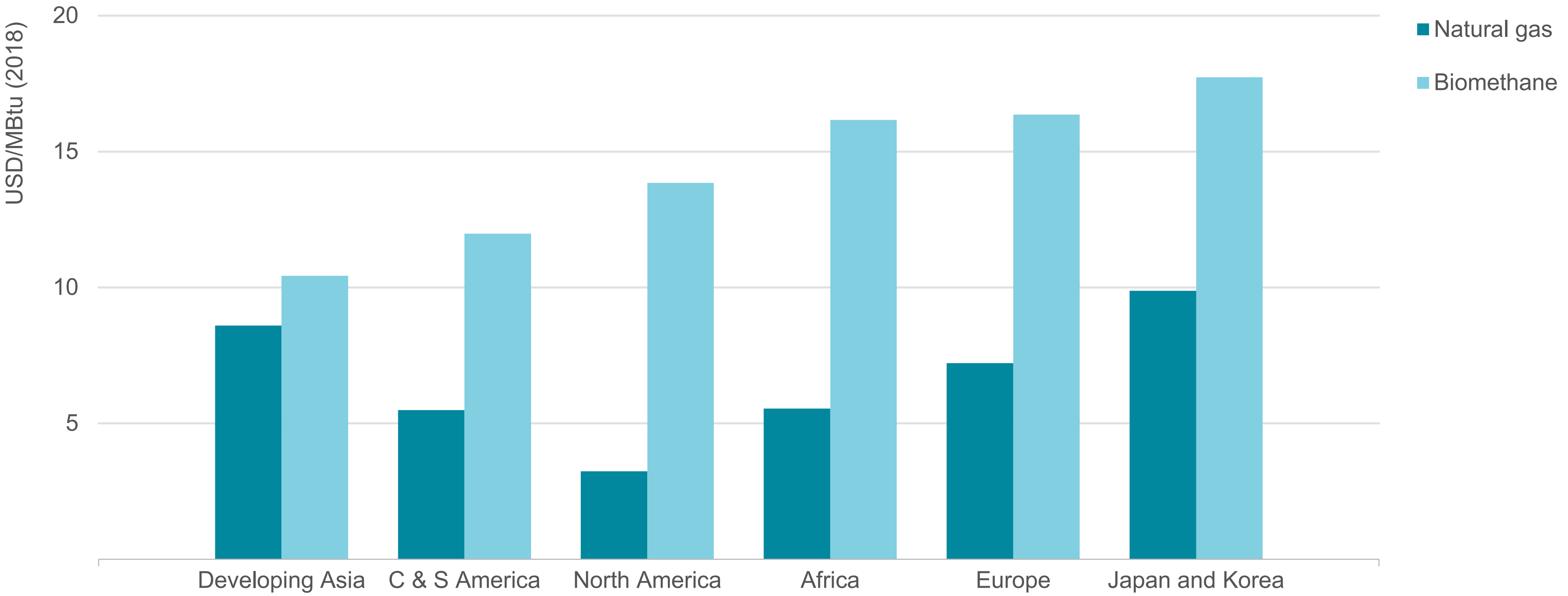
Grid connection represents a potential additional cost (if the biomethane is to be injected into gas networks rather than used locally). Proximity to the gas network is a significant cost factor, and to be cost-effective plants must generally be located very near to gas grids. Typical network connection costs are around USD 3/MBtu, split roughly equally between pipeline infrastructure and grid injection and connection costs (Navigant, 2019). In developing economies in Asia a significant buildout of the gas network is assumed, concurrent with the projected increase in natural gas demand, meaning a greater amount of feedstock is geographically proximate to the gas grid.

There is growing interest in biomass gasification as a way to produce biomethane at a larger scale. However, very few plants have been successfully developed thus far (OIES, 2019). Gasification is currently the more expensive method of production in all regions with average costs around USD 25/MBtu globally. The potential is also limited by the availability of cost-effective feedstock such as forestry management and wood processing residues. Other possible feedstock sources for biomass gasification would be MSWs and agricultural residues.

Looking ahead to 2040, this report estimates that the global biomethane potential increases by more than 40% compared with today. Most of this stems from increased availability of biogas (as described above); the potential for biomass gasification grows at a much slower pace.

The gap between today's natural gas price and the cost of biomethane varies widely by region

Cost of using the least expensive biomethane to meet 10% of gas demand and natural gas prices in selected regions, 2018



Notes: C & S America = Central and South America; Developing Asia = People's Republic of China, India, the Association of Southeast Asian Nations (ASEAN) and other developing economies in Asia Pacific. 1 MBtu = 0.29 MWh.

Upgrading biogas captured from landfill sites is typically the cheapest option to produce cost-competitive biomethane

There are limited prospects for major reductions in the cost of producing biomethane. The technologies for biogas production and upgrading are relatively mature although there may be higher potential to bring down the cost of biomass gasification. Larger facilities could also provide some economies of scale for both production routes. Overall, by 2040, this report estimates that the average cost of producing biomethane globally is set to be around 25% lower than today, at around USD 14/MBtu.

Natural gas prices in several regions are very low today, a consequence of ample supplies of gas and of liquefied natural gas (LNG). However, there are still commercially viable opportunities for biomethane in some markets. Taking into account biomethane costs and natural gas prices across different regions, this report estimates that around 30 Mtoe of biomethane could be produced today for less than the domestic price of natural gas in the relevant regions, most of which involves fitting landfill sites with gas capture technologies. If this were to be fully exploited, this would represent around 1% of today’s natural gas demand.

Whereas most sources of biomethane in advanced economies are significantly more expensive to produce than today’s natural gas prices, this is not necessarily the case in parts of the developing world. This is particularly visible in parts of Asia, where natural gas is imported and therefore relatively expensive, and where biogas feedstock is available at a very low cost; in India for example, the share of today’s natural gas demand that can be met cost-effectively by biomethane is 10%. By 2040 this rises to almost two thirds.

A key reason for the relatively low uptake of biomethane in developing countries is the lack of specific policies encouraging its development. The relatively high cost of capital is also a barrier to investment. There are also non-economic barriers, such as the lack of awareness and information, and the scarcity of expertise in the design, installation and maintenance of biomethane production plants.

Monetising some of the by-products from biomethane production could improve its cost-competitiveness. In addition to the potential use of digestate as fertiliser, biogas upgrading also results in a pure stream of CO_2 that could be used by other industries. The revenues that can be achieved through selling digestate or the pure CO_2 stream, however, are likely to be relatively modest and in most cases would not be sufficient to close the cost gap entirely with natural gas.

Ultimately, the cost-competitiveness of biomethane in most markets relies on pricing externalities. If CO_2 prices are applied to the combustion of natural gas, then biomethane becomes a more attractive proposition. If policy recognises the value of avoided methane emissions that would otherwise take place from the decomposition of feedstocks, then an even larger quantity would be cost-competitive. Methane is such a potent GHG that attaching a value to these avoided emissions makes a dramatic difference to its overall supply cost profile.

The outlook for biogas and biomethane to 2040

Scenarios for the future of energy

The future of biogas and biomethane cannot be considered separately from the broader context of the global energy system. There is a huge range of possible futures for global energy, depending on the pace of technological innovation, the ambition of energy policies, market dynamics, societal trends and many other factors. The analysis below refers to two scenarios included in the IEA *WEO*, the Stated Policies Scenario (STEPS) and the Sustainable Development Scenario (SDS).

The **STEPS** represents the IEA's assessment of the implications of today's energy and climate policies, including those policies that have been announced (for example, as part of the nationally determined contributions under the Paris Agreement). This gives a sense of the direction in which the global energy system is heading, based on the latest available market and technology data and a defined set of starting conditions and assumptions.

The **SDS** takes the opposite approach. It fixes the end point, in this case full achievement of various energy-related sustainable development goals, and then works out a feasible pathway to reach them. Most significantly, it charts a pathway for the global energy sector to be fully aligned with the Paris Agreement by holding the rise in global temperatures to "well below 2°C … and pursuing efforts to limit [it] to 1.5°C". It also meets goals relating to universal access to modern energy, including access to both electricity and clean cooking fuels, as well as a dramatic reduction in emissions of the pollutants that cause poor air quality.

Achieving the SDS would require rapid and widespread changes across all parts of the energy system, but there is a large gap between this scenario and the direction outlined in STEPS. While the SDS requires an early peak and a rapid decline in energy-related CO_2 emissions, in the STEPS there is no such peak in sight before 2040. And while the SDS sees universal access to modern energy achieved by 2030, in the STEPS there are still more than 600 million people remaining without electricity in 2030, and well over 2 billion still reliant upon the traditional use of solid biomass as a cooking fuel.

This disparity between the direction in which the world appears to be heading, on the one hand, and what would be required to hit crucial energy-related sustainable development goals, on the other, is a crucial fault line in global energy. The production and use of biogas and biomethane grow in both of these scenarios, but the STEPS and SDS also provide divergent visions of the opportunities that might lie ahead.

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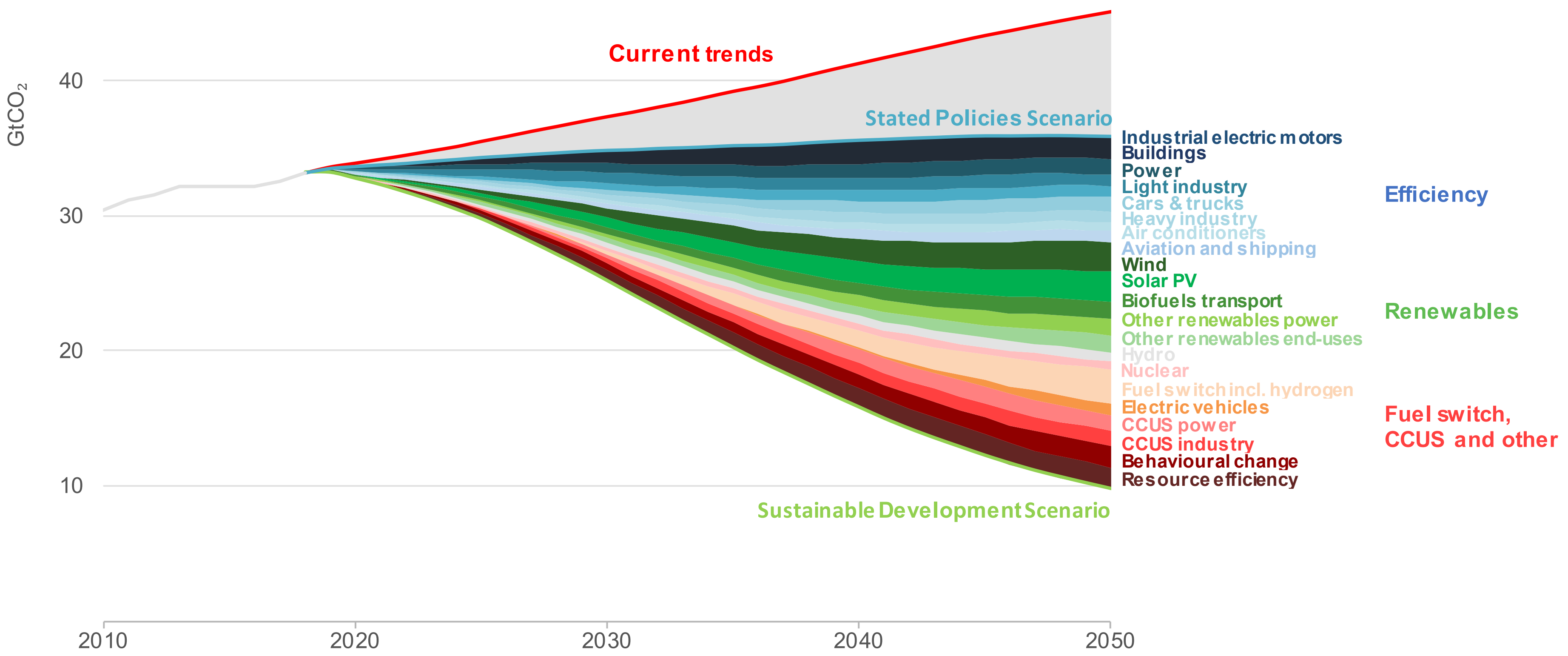
A wide range of approaches and technologies are required to achieve the SDS

Energy-related CO_2 emissions and CO_2 emissions reductions by measure in the SDS



Notes: $GtCO_2$ = gigatonnes of carbon dioxide. Biogas and biomethane appear under the categories “other renewables power” and “other renewables end uses”.

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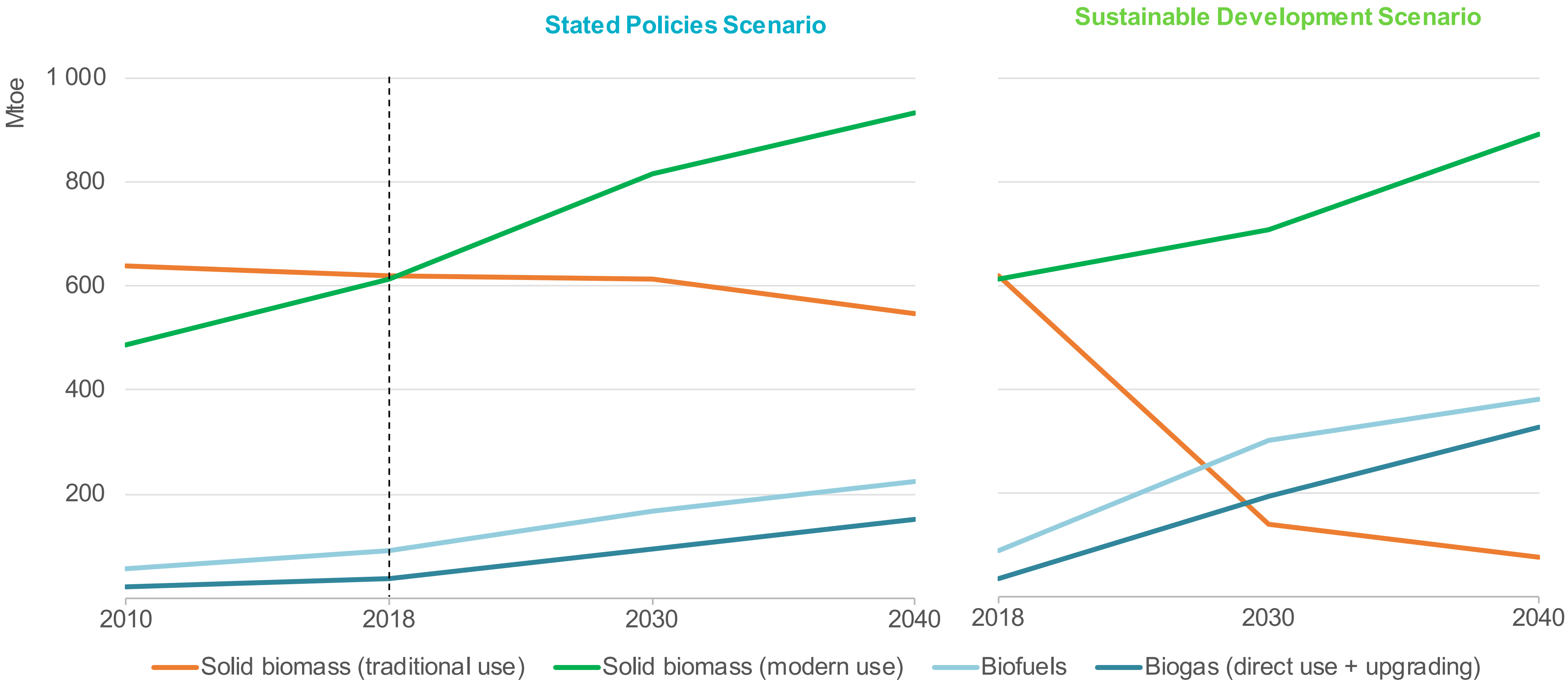
Modern bioenergy technologies grow in both scenarios, but take on particular importance in the SDS

Breakdown of global bioenergy demand by scenario



Note: 1 Mtoe = 11.63 TWh = 41.9 PJ.

Energy transitions give biogas and biomethane the opportunity to gain a firmer foothold in global energy consumption

A wide range of technologies and policies are required to bring down emissions and ensure universal access.

In the SDS, alongside widespread improvements in energy efficiency, there is also a step change in the pace at which renewable technologies are deployed. This is most visible in the power sector, where renewables provide two-thirds of electricity supply worldwide by 2040 (up from one-quarter today). Of this, solar PV and wind power together provide 40%, with a further 25% from dispatchable renewables including hydro and bioenergy.

The growth in low-carbon electricity is accompanied by the rising importance of electricity as an energy carrier. The share of electricity in global final consumption rises from 19% today to more than 30% by 2040. The increase in electricity demand in the SDS comes from a variety of sources; the largest is electric vehicles.

However, even with rapid growth in low-carbon electricity, more than two-thirds of final consumption in 2040 in the SDS comes from other sources, mainly from liquids and gases.

And even if electricity use were to grow even faster and the complete technical potential for electrification were deployed, there would still be sectors requiring other energy sources (given today's technologies), with most of the world's shipping, aviation and certain industrial processes not yet "electric-ready".

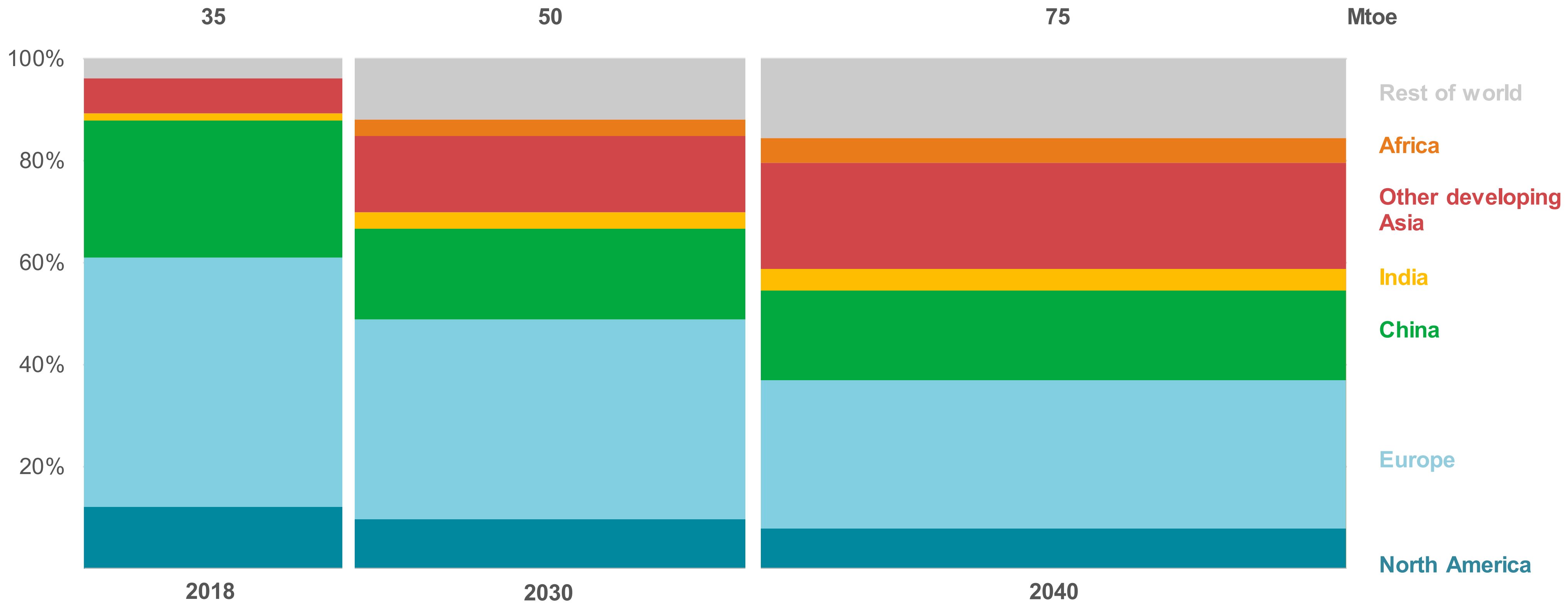
These trends open up significant possibilities for biogas and biomethane. These gases can help to decarbonise parts of the energy system that low-carbon electricity cannot reach. By enhancing the flexible operation of power systems, they can facilitate the rise of wind and solar. By displacing the traditional use of biomass, they can provide clean cooking fuels as part of the drive for universal access to modern energy. As a local, sustainable source of power and heat, they offer communities and municipalities a way to meet clean energy commitments in tandem with renewable electricity.

Biogas and biomethane start from a low base, but are the fastest-growing forms of bioenergy in both the STEPS and the SDS. Their combined market share in total modern bioenergy demand grows from 5% today to 12% by 2040 in STEPS and to 20% in SDS.

Outlook for biogas

Developing countries in Asia lead the growth in direct biogas use in the STEPS

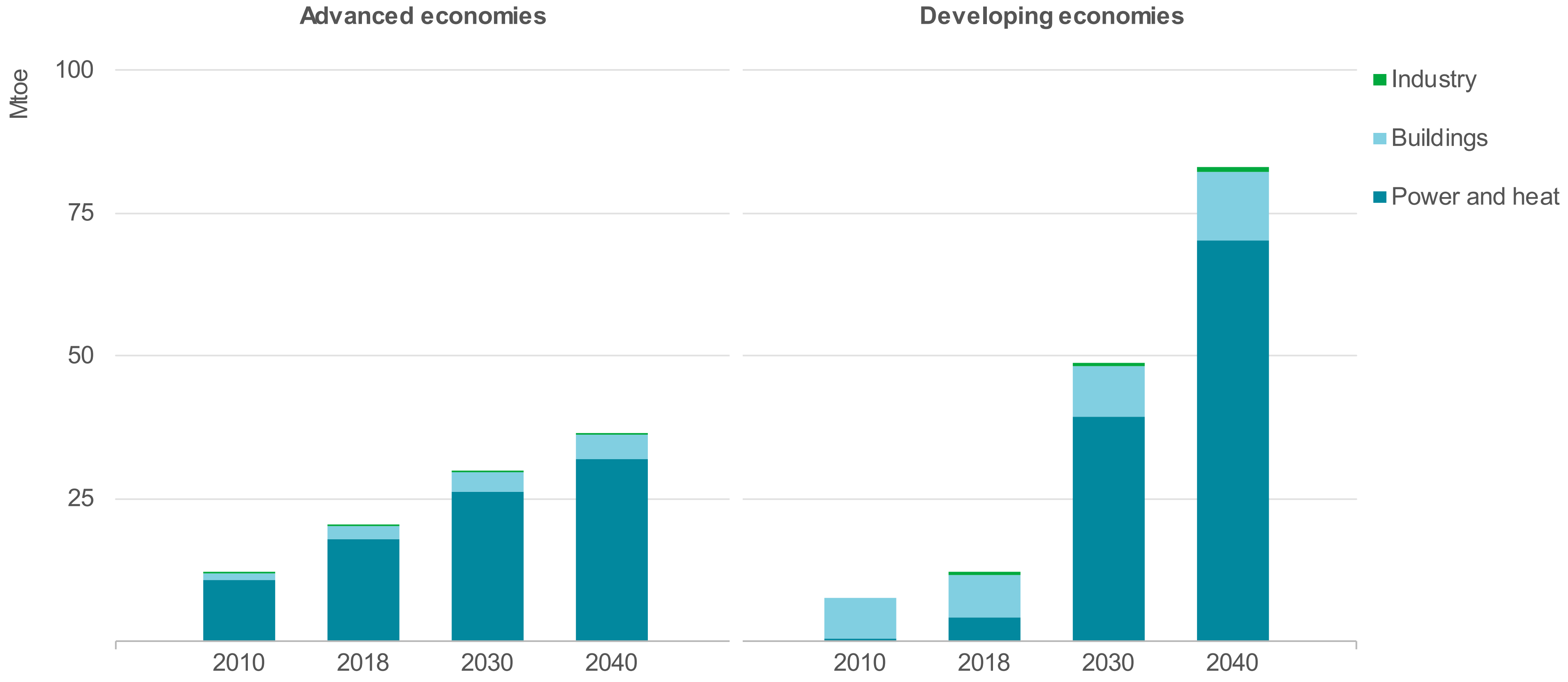
Global biogas demand for direct use in the STEPS



Notes: Excludes biogas production used for upgrading to biomethane. “Other developing Asia” includes Southeast Asia and other developing economies in Asia Pacific.
1 Mtoe = 11.63 TWh = 41.9 PJ.

Biogas picks up quickly in the SDS and is widely used as a local source of renewable power and heat, and for ensuring clean cooking access

Global demand for direct use of biogas in the SDS



Notes: "Power and heat" includes power generation as well as co-generation. "Buildings" includes the direct use of biogas for cooking and heating.
1 Mtoe = 11.63 TWh = 41.9 PJ.

Low-cost feedstocks, supportive policies and relatively high natural gas prices underpin biogas growth, led by the developing world

Global direct consumption of biogas was around 35 Mtoe in 2018. Currently, over 60% of biogas production capacity lies in Europe and North America. As the leading biogas-producing region, Europe has around 20 000 biogas plants, with the majority situated in Germany. Most are built for on-site electricity generation and co-generation, with around 500 plants dedicated to the upgrading of biogas (OIES, 2019).

In the STEPS, projected production of biogas for direct consumption more than doubles, reaching around 75 Mtoe in 2040. Most of this growth comes from centralised plants that are fed by agricultural and municipal solid waste sources in order to meet local power and heating demand. The share of biogas used for power and heat rises from around 70% today to 85% by 2040.

Providing a renewable and reliable source of power has typically been the easiest route to market for biogas, given incentives such as feed-in-tariffs, subsidy grants and tax relief schemes that can also support the development of rural areas. The economic case for biogas improves when biodigesters are favourably located – e.g. close to feedstock sources, electricity networks and local heat offtake – or where co-benefits, such as the ability of biogas plants to treat wastewater with high levels of organic pollutants, are recognised and remunerated.

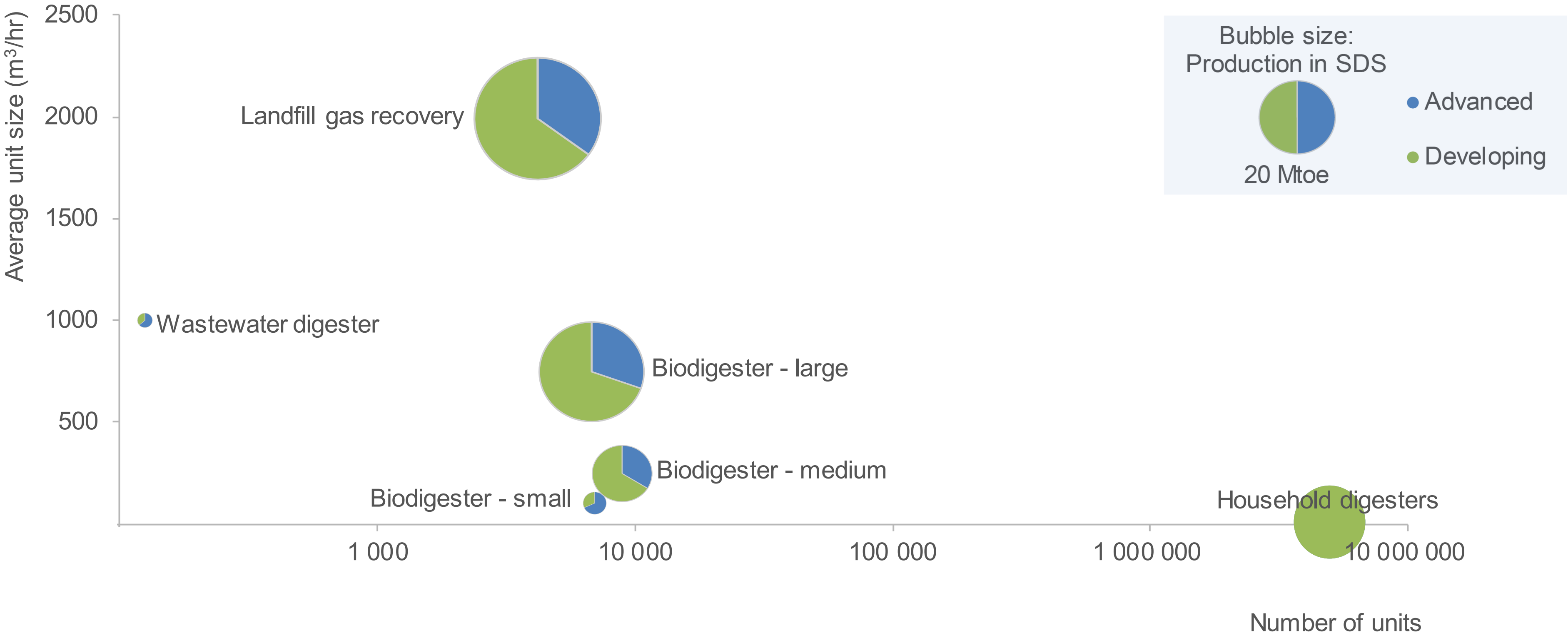
Such co-benefits from biogas production can address a suite of sustainability priorities in developing economies, which are set to capture three-quarters of the growth in global biogas production. China, already producing almost a third of the global total, is seeking to expand rural biogas production to reduce air pollution from coal use while improving waste management practices, with plans to reach a level of nearly 17 Mtoe (20 bcm) by 2030 (from around 7 Mtoe today). India has offered to provide financial support to local biogas co-generation plants and has overseen the deployment of more than 5 million household biogas units for clean cooking. The prospects for biogas are further galvanised by wider bioenergy targets in countries such as Indonesia, Malaysia and Thailand. These countries are seeking to develop a biogas market by leveraging vast quantities of available residues produced from certain industry sectors, such as the palm oil industry.

In the SDS, robust policy support for biogas development translates into nearly double the production level of the STEPS by 2040, along with a wholesale shift towards the use of sustainable feedstocks. Over 80 Mtoe of biogas is produced in developing economies alone, which exploit their vast potential from agricultural residues and MSW. Growth is underpinned by the use of biogas as a relatively stable source of renewable electricity generation; this becomes more valuable as developing economies increase the share of variable wind and solar in their electricity generation mix.

Biogas also provides an important option to support clean energy commitments at community level, especially where access to national electricity grids is more challenging, or where there is a large requirement for heat that cannot be met by renewable electricity. There is also a considerable push to develop biogas for clean cooking. By 2030, around 200 million people move away from the traditional use of biomass through biogas, half of whom are in Africa.

Biogas development in the SDS means scaling up a range of production technologies

Global biogas production for direct use in the SDS by technology, units installed and average flow rate, 2040



Notes: Bubble size indicates production level in 2040 in the SDS. Household digesters are considered only in developing economies, and are primarily deployed to ensure access to clean cooking.

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The choice of biogas production technologies is conditioned by policy priorities and local circumstances

The development of a biogas industry ultimately depends on the policy framework in different countries and regions, which is itself informed by broader renewable energy goals and targets. In Europe most biogas plants to date have been built to capture feed-in tariffs and other forms of support for renewable power generation. In developing economies, development funding has driven the deployment of biodigesters at household and community levels to help ensure rural energy access.

In the SDS, there is an acceleration in the production of biogas in several regions. The installation of household biogas digesters is part of a concerted policy drive to ensure access to clean cooking solutions in developing economies, particularly for geographically dispersed populations located in rural areas far from cities or not connected to gas or electricity grids. Scaling up the use of household biogas in the SDS requires annual additions of over 5 million biodigesters in developing economies over the period to 2040.

A range of medium- and large-scale centralised biodigesters are also deployed in this scenario to capture agricultural wastes across a larger number of sources. These centralised units form around clusters of agricultural feedstock sources (e.g. a dense set of industrial farming facilities) and produce in the range of 500 m^3/hour to 1 000 m^3/hour of biogas; economies of scale mean lower per-unit capital and operating costs compared with smaller-scale commercial units. Such facilities could provide heat to local, captive distribution systems as well as power to national grids.

With low marginal costs of installing capture equipment, closed landfill facilities make the largest contribution to the growth in total biogas production in the SDS, as emerging economies increasingly adopt more comprehensive and efficient waste management practices.

Biogas production in the SDS ultimately comes from thousands of local, small-scale facilities, compared with the traditional large-scale centralised infrastructure that meets most energy service demand today. While this has several co-benefits for rural communities, it also creates challenges for scaling up output, as larger plants require more sophisticated co-operative models and are also more exposed to the variability of different waste streams. It is also less certain that biogas digesters can undergo the type of factory-style modular fabrication that has driven down the manufacturing costs of other renewable technologies, such as solar PV.

Policy frameworks need to value the co-benefits of biogas, including reduced air pollution, avoided emissions, and rural and agricultural development, and to consider its contribution in these areas relative to other bioenergy pathways (i.e. biofuels or solid biomass). Tailoring support schemes to local conditions could also ensure that a biogas industry develops as a partner, rather than competitor, to food production.

Below, this report considers the role of biogas as a way to provide clean cooking in Africa, to illustrate how well-designed policies can overcome some of the barriers to larger-scale deployment.

Focus: The role of biogas as a clean cooking fuel

The direct use of biogas can be crucial to accessing clean cooking while improving waste management, especially in developing economies

The world has made considerable progress towards achieving universal access to electricity in recent years, but increasing access to clean cooking facilities remains challenging. In sub-Saharan Africa, around 900 million people lack access to clean cooking facilities (or, five out of six people), accounting for a third of the global total. Almost 95% of them use solid biomass, in the form of fuelwood, charcoal or dung in open fires, while the remainder use kerosene (especially in Nigeria) or coal (mostly in Southern Africa).

At the global level, 80% of those without access to clean cooking are located in rural areas, and they make up 60% of the world's rural population. Less than 15% of the urban population globally lacks access to clean cooking, thanks to wider access to cleaner options.

There are a range of modern fuels and technologies that can provide clean cooking, including natural gas, LPG, electricity, bioethanol and biogas, or improved biomass cook stoves which deliver significant improvements compared with basic biomass cook stoves or three-stone fires. The choice among these options is a consequence of the interactions among policy, geography, demographics and socio-economic factors.

Rural areas face a unique array of challenges in transitioning towards clean cooking, with the lack of availability of modern fuels being one of the principal barriers to change:

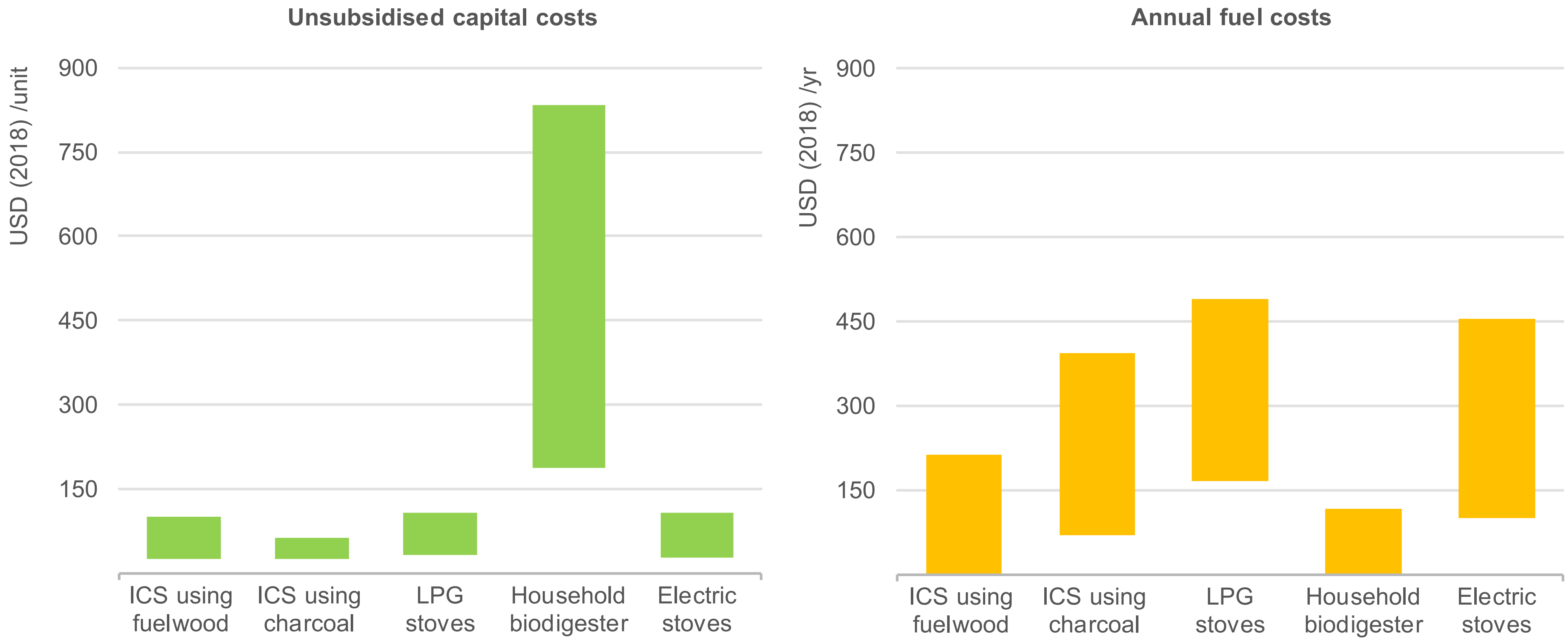
- LPG is not always available due to long distances and poor transport links between distribution centres and households. Moreover, there can also be competition for supply from urban areas.
- A move to electric cooking is impeded by very low rates of electricity access in rural areas in Africa, the unreliability of electricity supply in many places where it does exist, the prioritisation of electricity for uses such as lighting and appliances, and a cultural preference in many countries for cooking over a flame.
- Other modern fuels such as ethanol and processed biomass pellets or briquettes often face similar barriers to access.

Household air pollution resulting from reliance on inefficient and polluting cook stoves is directly linked to nearly 500 000 premature deaths in sub-Saharan Africa in 2018, and 2.5 million globally. There are also around 3 million deaths attributable to outdoor air pollution, half of which are in China and India. Stubble burning, the practice of intentional burning of the stubble that remains after grains have been harvested, is a major contributor to air pollution. There have been attempts to restrict this practice, but it remains common in many developing economies (in India, stubble burning can account in certain peak days for up to 40% of air pollution in Delhi).

Turning organic waste such as animal manure or crop residues into biogas via a simple household biodigester offers a way to support rural development and to alleviate these health impacts. In China, for example, subsidy support was based on the diversion of household sewage towards biodigesters, with major positive health impacts.

Household biodigesters have higher upfront costs but much lower fuel and operating costs than other clean cooking options

Global ranges of spending for different clean cooking technologies in developing economies, 2018



Notes: ICS = Improved cook stoves. Electric stoves are considered for households connected to the centralised grid or minigrid.
Sources: IEA analysis based on data from Politecnico di Milano (2016), World Bank (2014) and Hivos (2019).

The upfront costs of installing a biodigester are the main economic barrier today to their use, despite payback periods as little as two years

Research in East Africa shows that families with access to biogas see benefits in terms of ease of cooking and a reduction in the time spent collecting fuelwood, as well as a lower incidence of health and respiratory problems. There are also potential co-benefits in terms of agricultural productivity (as a result of using the digestate as fertiliser) and reducing deforestation (Clemens et al., 2018).

The main economic challenge is the relatively high upfront cost of the biodigester. In Africa, upfront costs for an average-size household biodigester with a technical lifetime of over 20 years can range between USD 500 and USD 800 (ter Heegde, 2019). Installation costs for other clean cooking technologies are much lower. However, on a total cost-of-ownership basis, biodigesters have a corresponding advantage by having low or non-existent fuel costs, and basic digesters can prove their relative worth once they surpass two years of continuous use.

A part of the capital cost can be reduced by using traditional and locally available construction materials such as sand and gravel, and by relying on local labour. For the remainder, financing help is often needed. There are also significant non-economic barriers. Biogas systems have been in use as early as the 1980s to provide clean cooking in rural parts of Africa and Asia. However, their wide-scale diffusion has been limited by a number of deployment challenges, such as difficulties with providing a continuous availability of feedstock and ensuring proper maintenance of biodigesters. These barriers can be even more pronounced for a biodigester at the community scale or larger. The same research in East Africa showed that more than a quarter of biodigesters installed between 2009 and 2013 were out of operation by 2016 because of a lack of readily available maintenance expertise (Clemens et al., 2018).

While there are no fuel costs for running household biodigesters, producing and gathering sufficient feedstock cannot be taken for granted. For example, in order to generate enough biogas to cook for two to three hours per day and prepare one family meal, 20 to 30 kg of fresh dung has to be available on a daily basis, along with an equivalent quantity of water. Feeding a household biodigester regularly with animal manure requires at least two mature cattle, so any deterioration in household circumstances quickly affects biogas production, while local communities need to develop and maintain a system to collect waste and residues for centralised biodigesters.

Well-designed development assistance programmes could help overcome these barriers and thereby encourage the wider diffusion of household biodigesters. Training a local workforce and involving local communities in the construction of biogas production plants can create durable employment opportunities while ensuring the optimal use of biodigesters over their full technical lifetimes.

Local entrepreneurs and government partnerships with the private sector also have a crucial role to play in overcoming these barriers, with governments promoting investment through a range of subsidy programmes, community grants and favourable financing facilities. This is crucial for attracting private-sector participation, particularly independent energy companies, private equity and infrastructure funds, which can help scale up the supply chain while benefiting from lower-cost financing afforded by government-backed investment programmes.

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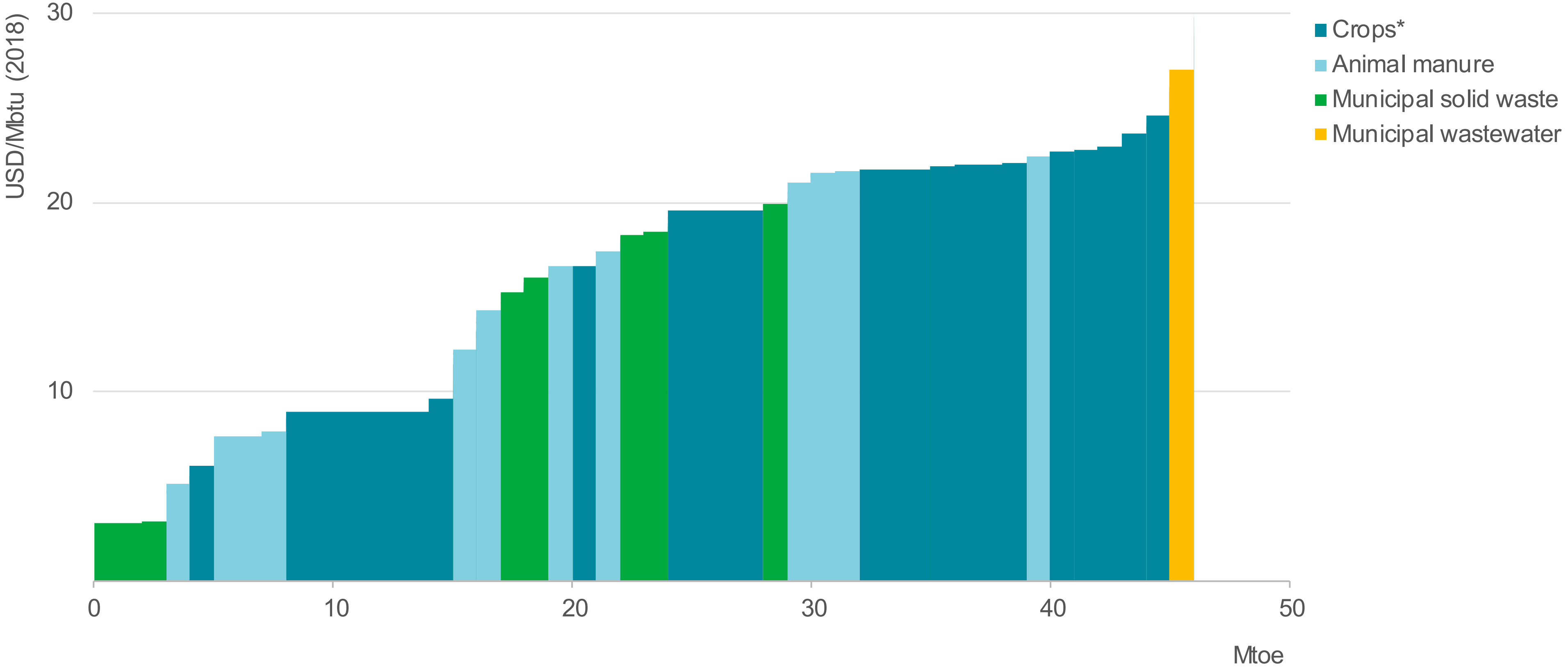
Today there is enough sustainable feedstock to satisfy the entire energy demand for clean cooking in Africa

Cost curve of potential biogas supply by feedstock in Africa, 2018



Notes: "Crops" includes crops residues only; energy crops are excluded given concerns about their sustainability.
1 MBtu = 0.29 MWh.

By 2030, an additional 200 million people, half of whom are in Africa, use biogas in SDS to move away from reliance on traditional use of solid biomass

The agricultural sector employs around half of the labour force in Africa, meaning biogas is a strong contender for large-scale diffusion across the population. However, a clear picture of today's consumption of biogas in Africa is not available due to lack of data. This report estimates that current biogas use is around 5 000 toe (6 million m^3 of natural gas equivalent), and its use is concentrated in countries with specific support programmes for this fuel.

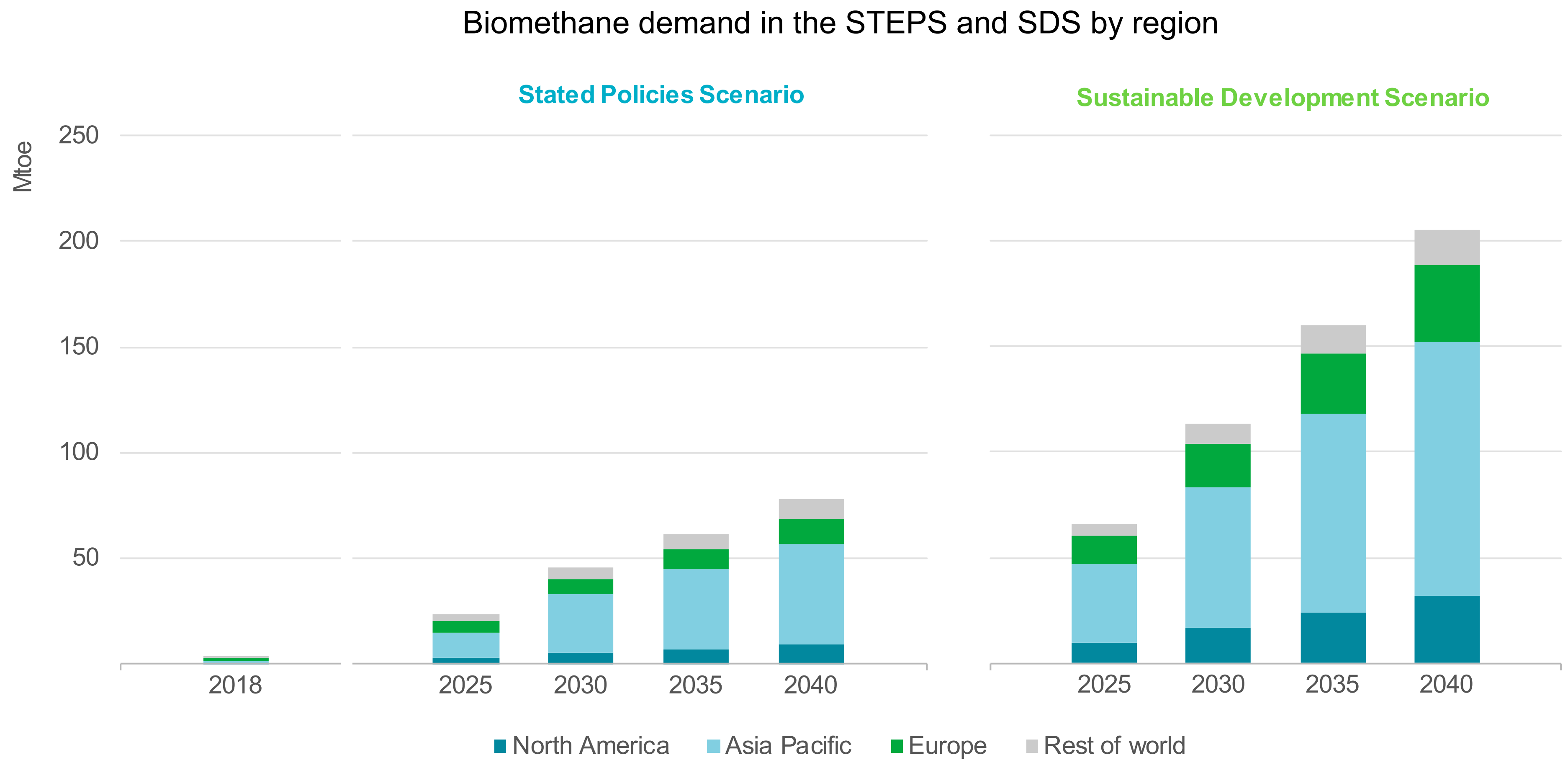
Some governments, such as Benin, Burkina Faso and Ethiopia, provide subsidies that can cover anywhere from half to the full cost of investment, while numerous projects promoted by non-governmental organisations provide practical know-how and subsidies to lower the net investment cost. In addition to these subsidies, credit facilities have made progress in a few countries. A limited number of companies in Kenya have recently developed a new lease-to-own (LtO) arrangement, and around 45% of the households in Kenya that installed a digester in 2018 financed their unit through an LtO arrangement (ter Heegde, 2019).

Based on this new bottom-up assessment, this report estimates that Africa has the potential to provide nearly 50 Mtoe of locally produced low-carbon biogas, largely via household-scale biodigesters; this potential doubles to almost 100 Mtoe by 2040, at an average cost of around USD 15/MBtu. The case for developing biogas in Africa is strongest for rural areas with large agricultural sectors. Crop residues, especially cereals, account for almost 60% of the total potential, animal manure for close to 25%, and MSW for most of the remainder. At the end of the outlook period, the picture changes slightly as further urbanisation increases the availability of MSW and as anticipated changes in diet underpin an increase in livestock and therefore of animal manure.

Projected consumption of biogas rises to more than 3 Mtoe in Africa by 2040 in STEPS. However, this is only a fraction of the potential. Africa's rural electrification needs and the achievement of universal access to clean cooking could push biogas demand three times higher, at 9 Mtoe by 2040 (over half of this would be used as a clean cooking fuel, the remainder for power generation). In such a scenario, more than 100 million people in Africa use biogas to move away from reliance on traditional use of solid biomass.

Outlook for biomethane

Developing countries in Asia lead the way for biomethane



Note: 1 Mtoe = 11.63 TWh = 41.9 PJ.

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The policy environment shapes the biomethane outlook

Whichever way the energy system evolves over the coming decades, biomethane is on a growth trajectory. But the extent of that growth varies substantially between STEPS and SDS, responding to the different market and policy environment that each scenario describes.

Since biomethane is indistinguishable from natural gas, it can reach any grid-connected residential or commercial building, industrial facility, or power plant and can provide energy services to a broad spectrum of sectors and end users. To be injected, biomethane has to comply with the gas grid specifications originally planned for natural gas.

Viewed through the lens of decarbonisation, the optimal uses of biomethane are in end-use sectors where there are fewer low-carbon alternatives, such as high-temperature heating, petrochemical feedstocks, heavy-duty transport and maritime shipping. But there are other motivations that can play into the uses of biomethane, including rural development, energy security (where biomethane is used instead of natural gas transported over long distances or imported, or where it is used flexibly to complement electricity from variable wind and solar PV), and urban air quality.

This range of motivations is visible in IEA scenarios, notably in developing economies in Asia (including China, India, Southeast Asia and other developing economies in Asia Pacific) that account for the bulk of the growth. China produces over 30 Mtoe of biomethane by 2040 in the STEPS, which is injected into its expanding natural gas grid, while India's consumption grows to 15 Mtoe, in part to support the expansion of gas use in the transport sector.

In the case of China, biomethane largely substitutes for domestic coal and imported natural gas (biomethane provides a much greater reduction in CO_2 emissions than switching from coal to natural gas). In India, it substitutes for the traditional use of solid biomass and for oil products, where import dependence stands at around 80% of total demand.

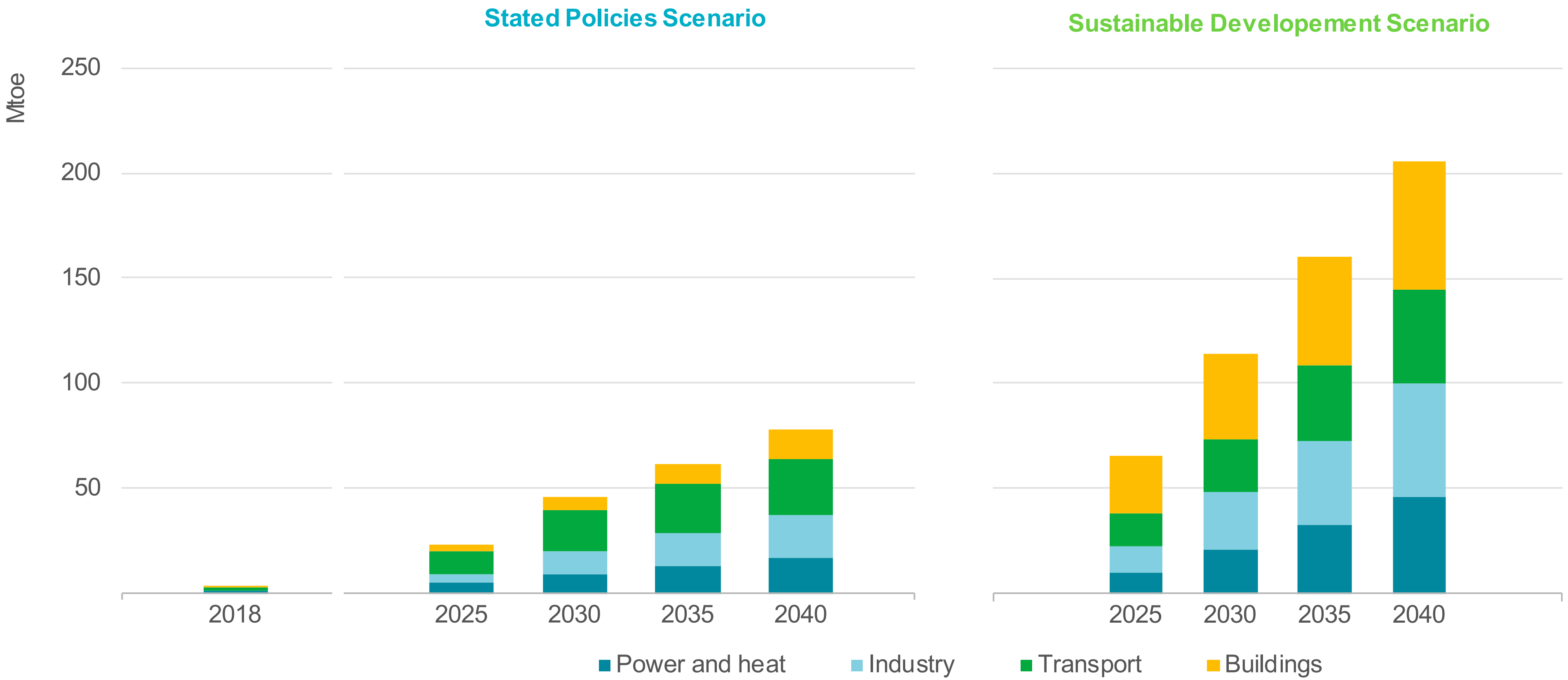
Projected consumption growth in STEPS is more limited in countries with mature gas markets. Consumption in North America increases to just under 10 Mtoe. European biomethane use reaches 12 Mtoe in 2040, accounting for 2.5% of the gas used in natural gas grids.

At the moment, 70% of the biomethane used in Europe comes from energy crops. The share of waste and residue feedstocks is set to rise, though, as policies seek to encourage bioenergy that avoids competition with food or feed production, and industry initiatives (such as the Biogas Done Right concept developed by the Italian Biogas Association) gain traction.

In the SDS, the production and use of biomethane accelerates in all regions, a consequence of strengthened efforts to lower the carbon footprint of gas and ensure energy access across the developing world. The Asia Pacific region sees by far the largest growth, driven in large part by China and India, but gains are also visible elsewhere: by 2040, there is a 10% blend of biomethane in gas grids in Europe and a 5% blend in North America. This represents a step change in the role of biomethane in global energy.

Biomethane sees broad-based growth across all sectors, reflecting existing uses of natural gas …

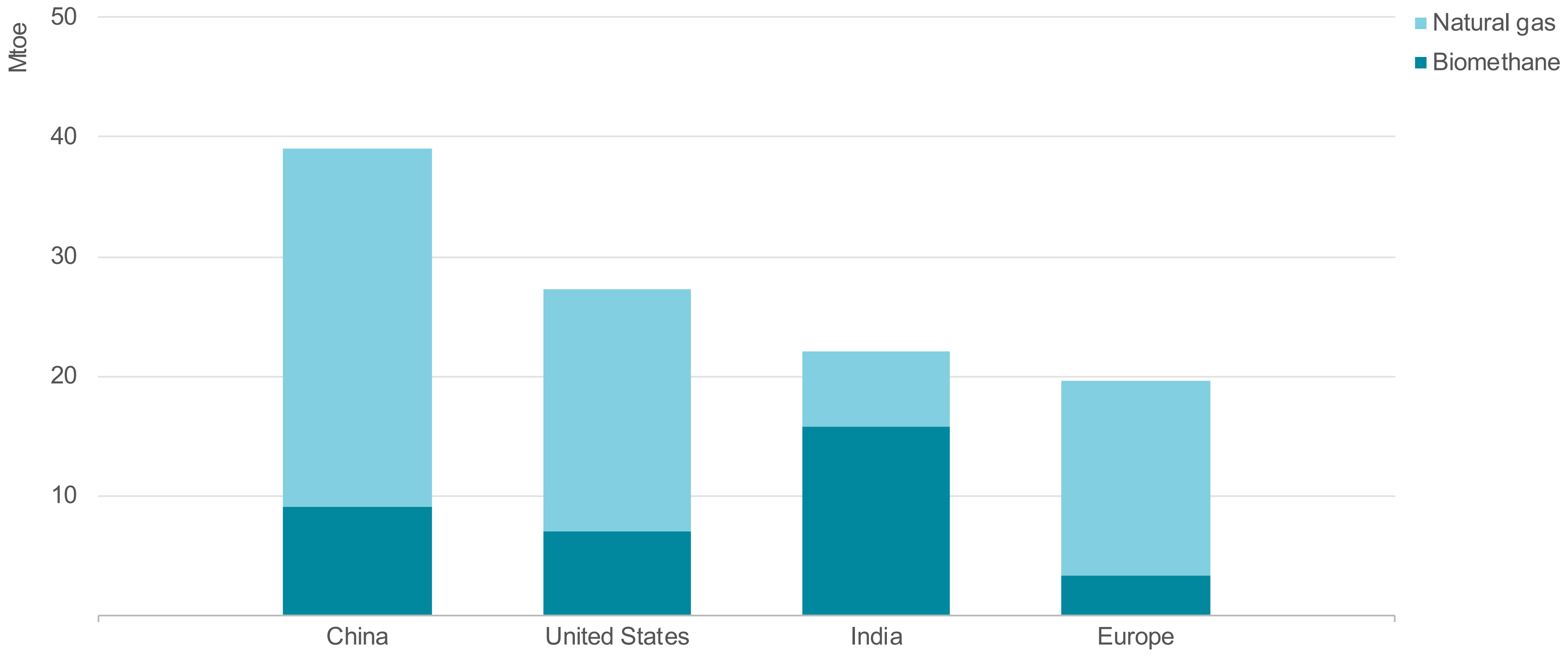
Global biomethane demand in the STEPS and SDS by sector



Note: 1 Mtoe = 11.63 TWh = 41.9 PJ.

… while also tapping into markets such as transport, where biomethane demand rises in line with the growing gas-fuelled fleet in some countries and regions

Change in gas use in transport in the SDS, 2040 versus 2018



Note: 1 Mtoe = 11.63 TWh = 41.9 PJ.

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Electricity and liquid biofuels are the main vectors for decarbonising transport, but biomethane finds a niche in some countries and sectors

Reducing emissions from the transport sector is a central challenge of energy transitions. Efficiency, electrification and alternative fuels are the key vectors for reducing reliance on oil, with biofuels currently displacing around 2 million barrels per day of oil demand. Natural gas is also playing a role in some sectors and countries; there are some 28 million natural gas-fuelled vehicles on the road today, representing around 1% of the global road fleet. This also opens up opportunities for biomethane.

The case for using compressed natural gas (CNG) or LNG for transport is strongest in transport segments where electrification is a more challenging prospect, such as long-haul road freight and shipping. Although the provision of gas fuelling infrastructure adds expense and complexity, there are possibilities to build infrastructure along established routes (for example those used by captive fleets such as municipal buses, refuse collection vehicles, or ferries and cruise ships) or along key transport corridors sustaining a significant portion of tonne- or passenger-kilometre activity.

The environmental case for natural gas in these applications rests on much lower air pollutant emissions, allied to an appreciable reduction in CO_2 compared with combustion of oil. The counterargument points to the risk of fugitive methane emissions along the natural gas supply chain as well as at the vehicle tailpipe.

The use of biomethane as a transport fuel bolsters the environmental case for gas-based vehicles. It also has a distinctive advantage over bioethanol and biodiesel, which can often be subject to blend share limitations (since they are not identical to gasoline and diesel); biomethane, by contrast, can fully replace natural gas as a source of fuel without any changes required to the engine.

Around one-fifth of existing biomethane plants produce either CNG (bio-CNG) or more energy-dense liquefied gas (bio-LNG) for the transport sector, but their use in transport is currently very small. How far and fast this niche role expands depends to a large degree on policy design and the buildout of infrastructure.

The United States is the current leader in this area, due to incentives from the federal Renewable Fuel Standard and California's Low Carbon Fuel Standard. Several countries in Europe are also developing gas-based transport infrastructure; most of Sweden's biomethane production is used in vehicles, giving it the highest share of biomethane use in transport demand. Italy has a well-established natural gas vehicle fleet and an expanding fuelling network, and has recently introduced biomethane blending obligations. India also has ambitious plans to expand the use of biomethane in transport, targeting the buildout of 5 000 bio-CNG stations by 2025. Most of the small quantities of biomethane produced in China today are used in gas-fired vehicles – primarily buses and heavy-duty trucks.

The use of biomethane in transport reaches more than 25 Mtoe in STEPS by 2040, or around 30% of total biomethane consumption; a lack of policy commitments elsewhere limits overall growth. In the SDS, biomethane consumption in the transport sector is nearly twice as high, with India accounting for the largest share of vehicles running on biomethane by 2040.

Focus: Biomethane and the future of gas infrastructure

What role for gas infrastructure in a low-emissions future?

In many respects, the prospects for biomethane and other low-carbon gases are tied up with wider questions about the future role of gas infrastructure in energy transitions. Long-term strategies need to consider the potential for existing and new infrastructure to deliver different types of gases in a low-emissions future, as well as their role in ensuring energy security. There is a concurrent need to consider interactions and possible synergies between the delivery systems for liquids, gases and electricity.

WEO analysis has consistently highlighted the enormous potential for electricity to play a bigger direct role in the energy system in the future (IEA, 2018). Indeed, all deep decarbonisation pathways envisage a low-carbon energy system in which an expansion of low-carbon electricity generation is accompanied by widespread electrification of industrial processes, electric heating takes over market share from natural gas in buildings, and electric transport is ubiquitous.

Since 2000, global electricity demand has grown two-thirds faster than total final consumption. Worldwide investment in electricity generation, networks and storage in 2018 exceeded USD 750 billion, more than combined investment in oil and gas supply.

However, there are limits to how quickly and extensively electrification can occur, as electricity is not well suited to deliver all types of energy services. Even if the complete technical potential for electrification were deployed, there would still be sectors requiring other energy sources (given today's technologies).

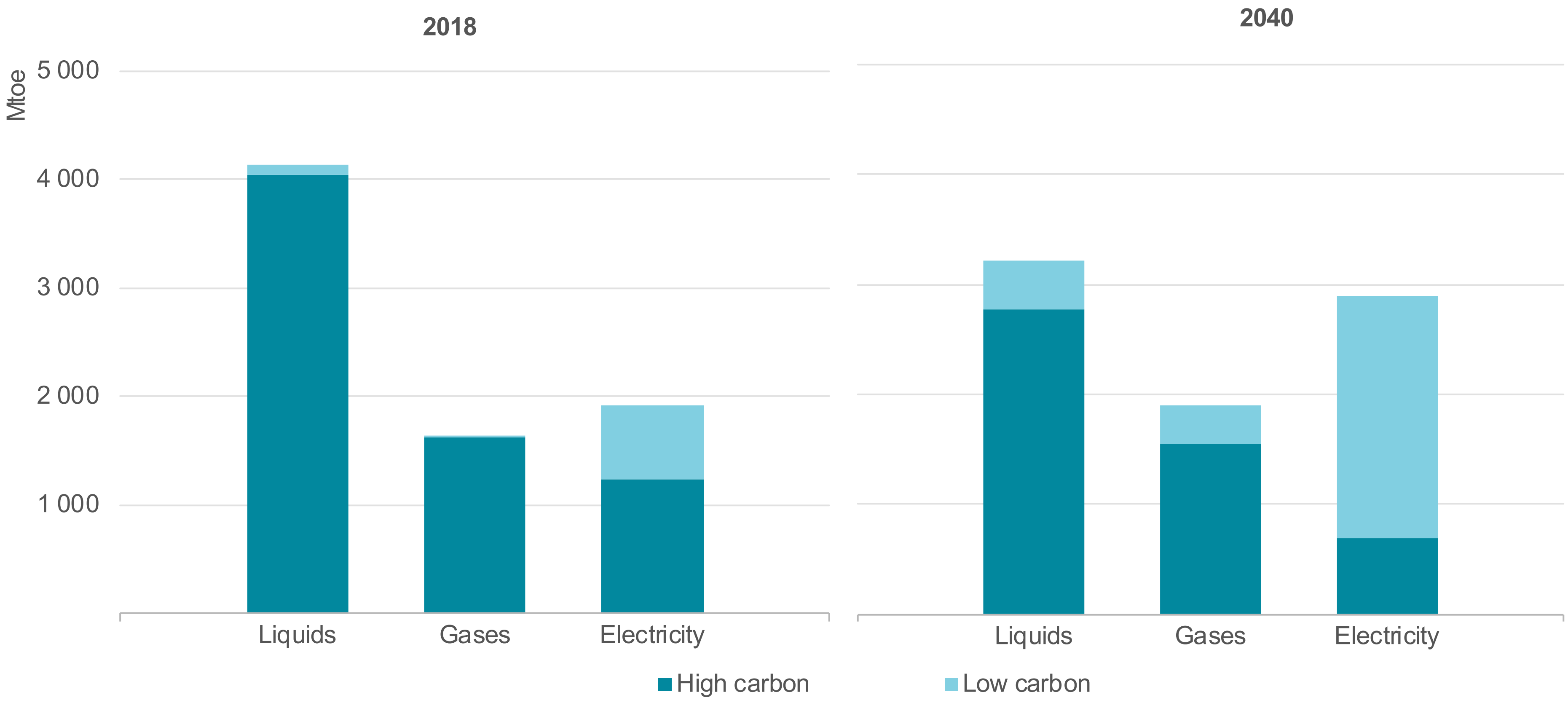
For example, most of the world's shipping, aviation, heavy-freight trucks and certain industrial processes are not yet "electric-ready". While in the future these sectors could use fuels that have been generated using electricity (such as hydrogen or synthetic fuels), some of these fuels would need a separate delivery infrastructure.

The energy security value of overlapping infrastructure can also be an important consideration for policy makers. Maintaining a parallel gas infrastructure system adds a layer of resilience compared with an approach that relies exclusively on electricity. This was visible, for example, in Japan when gas-fired generation stepped in to provide power following the shutdown of its nuclear reactors from 2011. It also provides a useful hedge against the risks that electrification and the development of new electricity networks do not increase at the pace needed to displace existing fuels while meeting energy service demands.

However, if gas infrastructure is to secure its role in a low-emissions system, it will ultimately need to deliver truly low-carbon energy sources.

Electricity cannot be the only vector for the energy sector's transformation …

Final energy consumption by carrier in 2018 and 2040 in the SDS



Notes: Figure excludes the direct use of renewables and coal for generating heat and the traditional use of solid biomass.
1 Mtoe = 11.63 TWh = 41.9 PJ.

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… but can gas infrastructure be repurposed to deliver low-carbon energy?

In the SDS, the share of electricity in final consumption rises from 19% today to 30% by 2040, and there is a simultaneous decarbonisation of supply through a significant expansion of renewables, particularly wind and solar PV but also bioenergy, hydropower and nuclear. Still, half of final energy consumption in 2040 remains served by liquids and gases; the share of low-carbon sources in liquids supply also rises to 14%, and in gas supply to 18%.

Replicating the services that gas grids provide via low-carbon electricity may be possible in some parts of the world, in particular areas that have ample resources to generate renewable electricity, relatively limited winter heating requirements, and an economic base (services and certain industrial subsectors) that is amenable to electrification. However, elsewhere, substituting electricity for gas as a way to provide services to end consumers is likely to be much more challenging and expensive.

There are practical issues with deploying electric heating at scale in both industry and residential sectors. The scale of infrastructure investments required to balance peak loads with variable supply present a significant barrier to full electrification. Batteries are becoming cheaper and are well suited to manage short-term variations in electricity supply and demand, but they are unlikely to provide a cost-effective way to cope with large seasonal swings.

If there is, instead, an option to use some existing infrastructure to deliver decarbonised gases, then these networks could be used through energy transitions and beyond. As things stand, gas networks are the primary delivery mechanism for energy to consumers in many countries; in Europe and the United States, for example, they provide far more energy to end users than electricity networks. Allied to gas storage facilities, they also provide a valuable source of flexibility, scaling up deliveries as necessary to meet peaks in demand.

The two main options to decarbonise gas supply are biomethane and low-carbon hydrogen.

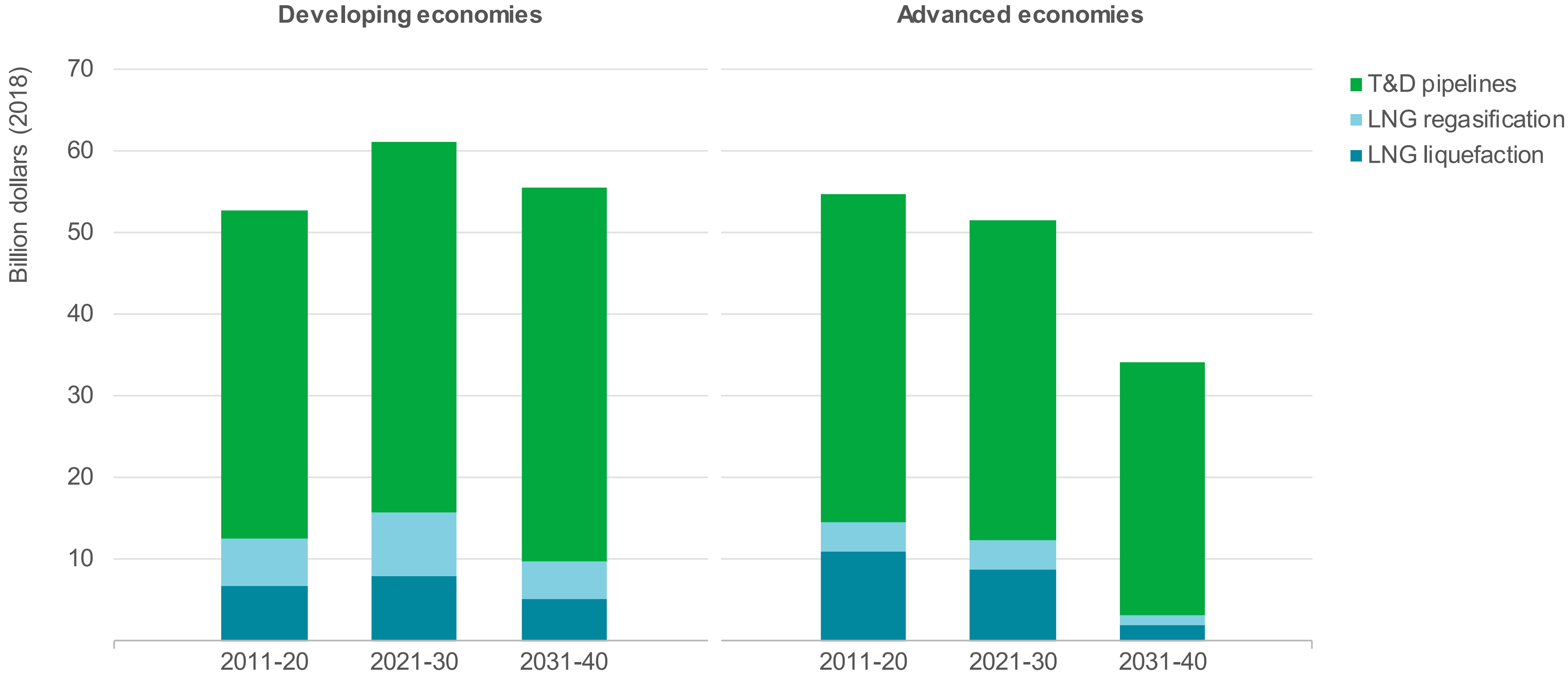
There has been a surge of interest in low-carbon hydrogen in recent years, although for the moment it is relatively expensive to produce. Blending low-carbon hydrogen into gas grids would not only mean lower CO_2 emissions, but also help scale up production of hydrogen and so reduce its costs (IEA, 2019b). Further, since there is no widespread infrastructure today for dedicated hydrogen transport, the existing natural gas grid in many countries could be used to transport hydrogen at much lower unit costs than would be the case if new dedicated hydrogen pipelines had to be built.

With minor modifications, transmission networks could probably cope with hydrogen blends of up to 15-20%, depending on the local context. However, regulations on hydrogen blending today are generally based on natural gas supply specifications or the tolerance of the most sensitive piece of equipment on the grid. As a result, only very low levels of blending are allowed: in many countries, no more than 2% hydrogen blending is currently permitted (IEA, 2019b).

Unlike hydrogen, biomethane, a near-pure source of methane, is indistinguishable from natural gas and so can be used without the need for any changes in transmission and distribution infrastructure or end-user equipment.

Maintaining viable and well-functioning gas infrastructure is a feature of the SDS …

Average annual investment in LNG and gas pipeline infrastructure in the SDS



Notes: T&D = transmission and distribution. Investments show maintenance costs.

… but this scenario is far from business-as-usual for the gas industry and for the owners of gas infrastructure

The trajectory of gas demand in the SDS means a reduced requirement for spending on gas infrastructure, especially after 2030. There is an increasing divergence in trends between advanced economies, where investment levels fall more sharply, and developing economies. In all cases, an increasing share of total spending is for the maintenance of existing networks: investment in new assets continues in some places to meet rising gas demand in the near term, but this also has to take adequate account of longer-term trends.

The growth in biomethane, along with low-carbon hydrogen, provides a way to future-proof continued investment in gas infrastructure in the SDS. However, there are uncertainties about the optimal configuration of the gas grid, including the costs involved in maintaining its role as a flexible delivery mechanism for large quantities of energy.

The chosen pathway to deliver low-carbon gases has major implications for investment in storage and delivery capacity, processing and separation requirements, blending tolerances, and choices about end-user equipment. The uptake of technologies that create interdependences between gas and electricity networks (for example, electrolysers or hybrid heat pumps) will also determine the scale of investments required for gas grids

The location and size of biomethane and hydrogen production facilities are also crucial variables for the scale and types of infrastructure investments. There are many uncertainties over the way this might play out in practice, but in general biomethane production is likely to be more dispersed than hydrogen, requiring (if it is not consumed locally) thousands of new grid connections. By contrast, hydrogen is likely to be done at scale and, in most cases, as close as possible to concentrations of end users (such as industrial clusters).

On the regulatory side, gas quality specifications are an essential step in scaling up production from a variety of different feedstocks and technologies. Blending levels and injected volumes also need to be properly tracked in order to support certification schemes (such as guarantees of origin or the development of national registries), which are required for policies that remunerate consumption of low-carbon gases. There may also be a need to incentivise low-carbon gas production through the socialisation of grid connection charges.

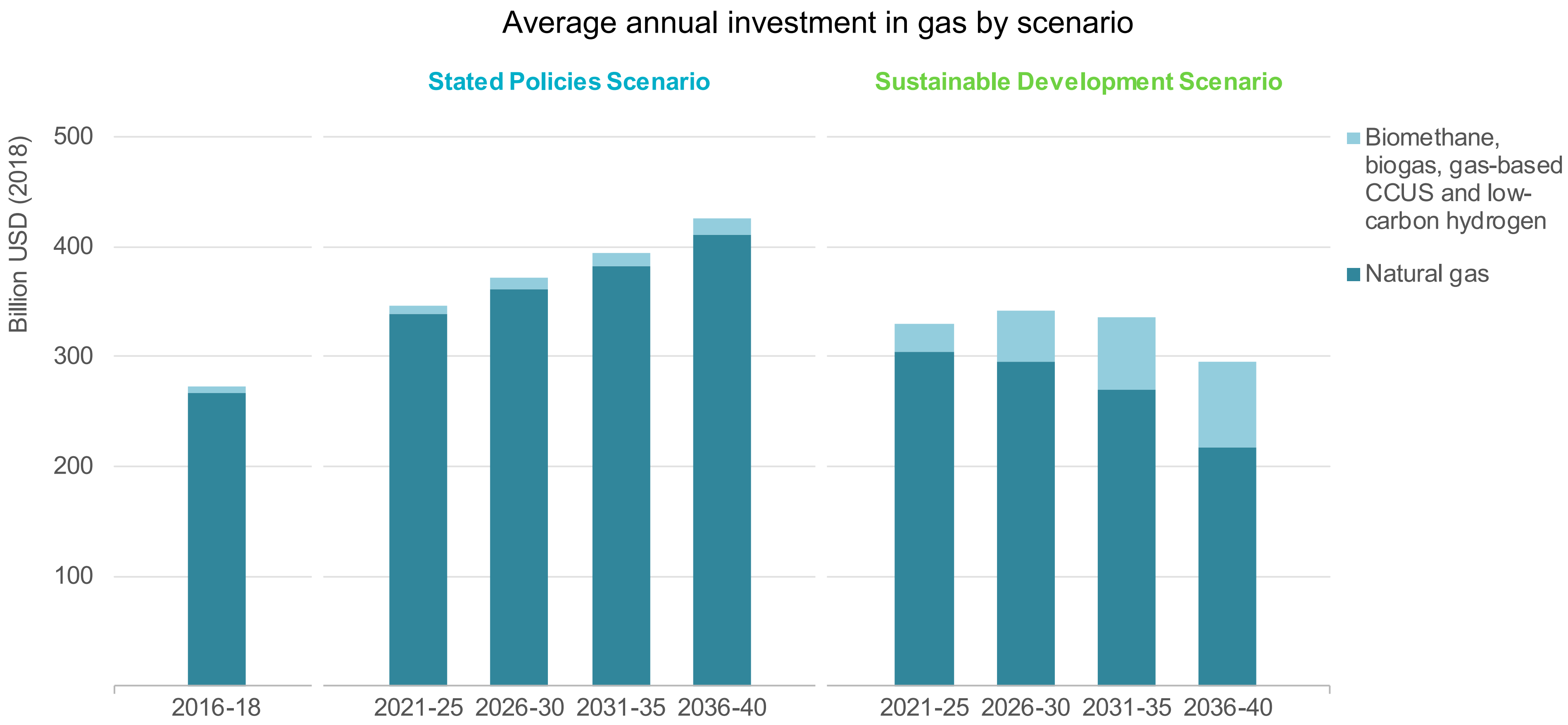
Another important consideration, particularly in the context of ambitions to reach net-zero emissions, is whether low-carbon gases, on their own, can eventually provide for a fully carbon-neutral gas system. The volumes of low-carbon gases delivered to consumers are on a sharp upward trajectory in the SDS by 2040, but whether they can be scaled up to provide 100% decarbonised gases depends on numerous factors, including relative technology costs, supply availability and the trajectory for gas demand (including seasonality).

In the case of the European Union, maximising the full sustainable technical potential of biomethane would allow it to reach a 40% share of total gas demand in 2040. Options to tackle emissions from the remaining share would include accelerated investments in low-carbon hydrogen, CCUS or carbon offsetting mechanisms, alongside efficiency measures and fuel switching to reduce further gas consumption.

Implications for policy makers and industry

Investment

In energy transitions, gas investment has to shift towards low-carbon supply …



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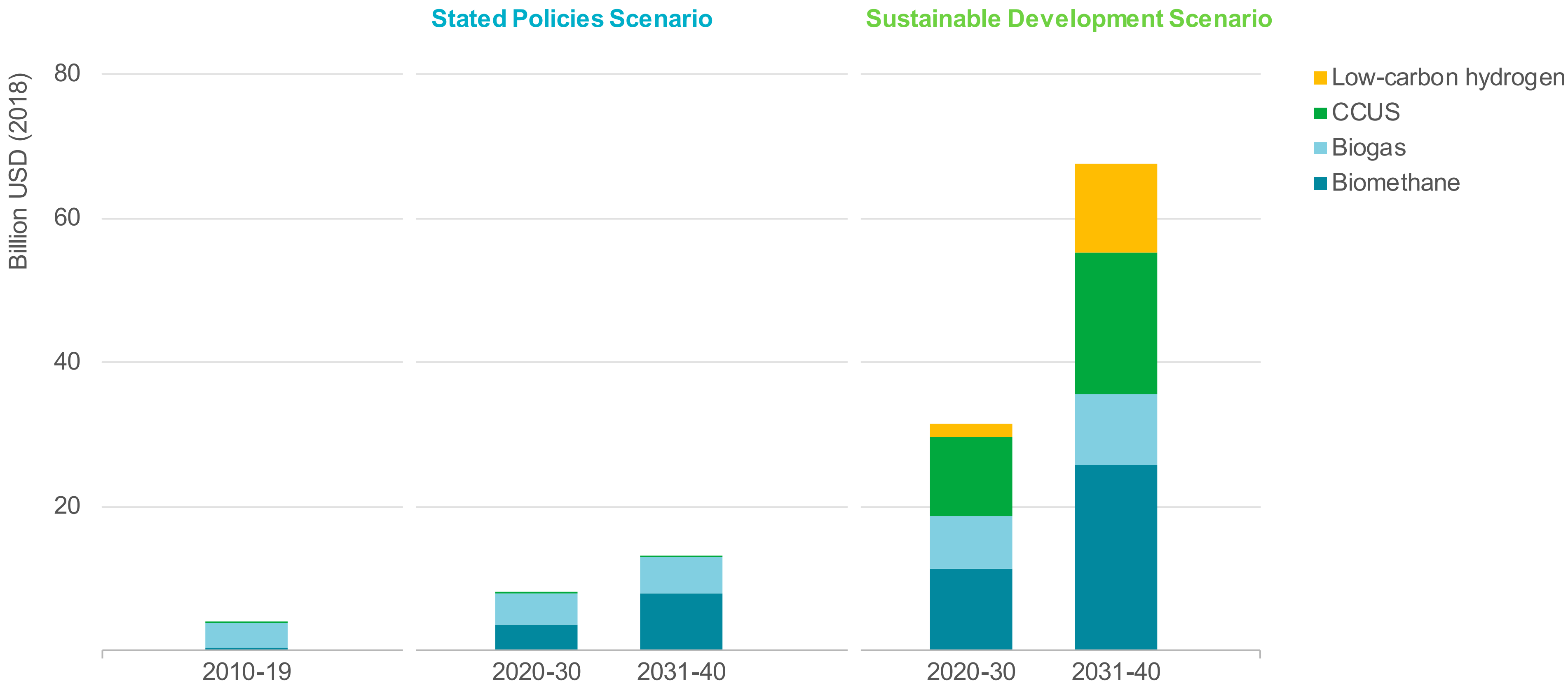
… and spending on biogas and biomethane picks up sharply

Average annual investment in low-carbon gas by scenario



Notes: CCUS is gas-based, and includes investments in power and industry. Values exclude cost of feedstock. Biomethane costs include the cost of developing biogas production capacity, as well as the upgrading cost.

New business models and improved access to financing are critical to the prospects for biogas and biomethane

Currently, biogas and biomethane projects represent only a small fraction of total global spending on gas. Investments have averaged less than USD 4 billion per year over the last decade, the same amount the natural gas industry typically spends every week.

In the STEPS, annual spending on biogas and biomethane rises more than threefold to reach around USD 14 billion by 2040. Rising spending on biomethane eclipses the amount invested in the direct use of biogas by the late 2020s. However, the share of biomethane and biogas in total investment spending on gas remains well below 5%.

The SDS sees a significant upside to this trend. As investment in natural gas declines, total capital spending on low-carbon gases rises to capture over a quarter of total investment in global gas supply, as biogas and biomethane are scaled up and hydrogen and CCUS are added to the mix of low-carbon gases. Biomethane and biogas projects remain the largest destination for low-carbon gas investment, capturing 40% of the total; by 2040, around USD 30 billion is spent on biomethane injected into gas grids every year, around the same level of investment being made in shale gas development in the United States today. These investments are made primarily in developing economies in Asia, particularly China and India, which together make up nearly 40% of total global spending.

The investments made in the SDS assume that several financing barriers are overcome. At the moment, biogas and biomethane projects encounter some of the same financing challenges as other small-scale, distributed renewable projects (especially in developing economies). Local banks often serve as a first port of call for raising the capital necessary for a biogas project; however, the loan requirements are often too small to attract project finance, and also potentially too large for individual investors (e.g. farmers) to raise the required equity. The latter is usually around 20-25% of the initial capital costs (which, for a medium-sized biogas plant producing around 2 million cubic metres per year [1.7 kilotonnes of oil equivalent], would be in the range of USD 1.5 million to USD 2 million).

From a banking perspective, there is often a lack of technical expertise in this area and relatively few benchmarks to assess adequately the risk/return profile for individual projects. There are also some risks that can be difficult to assess, e.g. the ability to secure reliable feedstock of consistent quality or, in the case of biomethane, to meet the rigorous gas quality specifications for injection into national distribution networks. These issues can increase risk perceptions and raise the cost of debt or reduce the loan tenure available to potential investors.

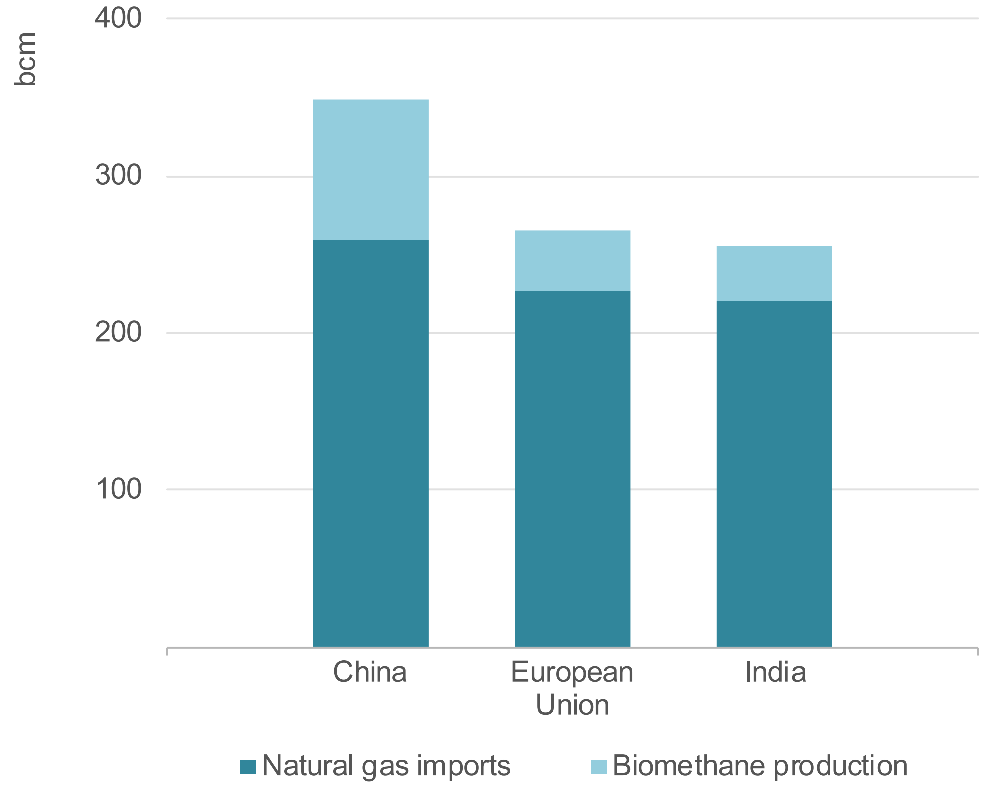
Various models are being tested to overcome these hurdles; for example, project sponsors such as energy companies or larger-scale agricultural firms can offer an integrated business model to farming communities, in order to take advantage of fixed feed-in tariffs or other forms of subsidy, which typically yield a lower risk for securing finance. Farming co-operatives or other models that aggregate feedstock sources are also viable routes to scale up production.

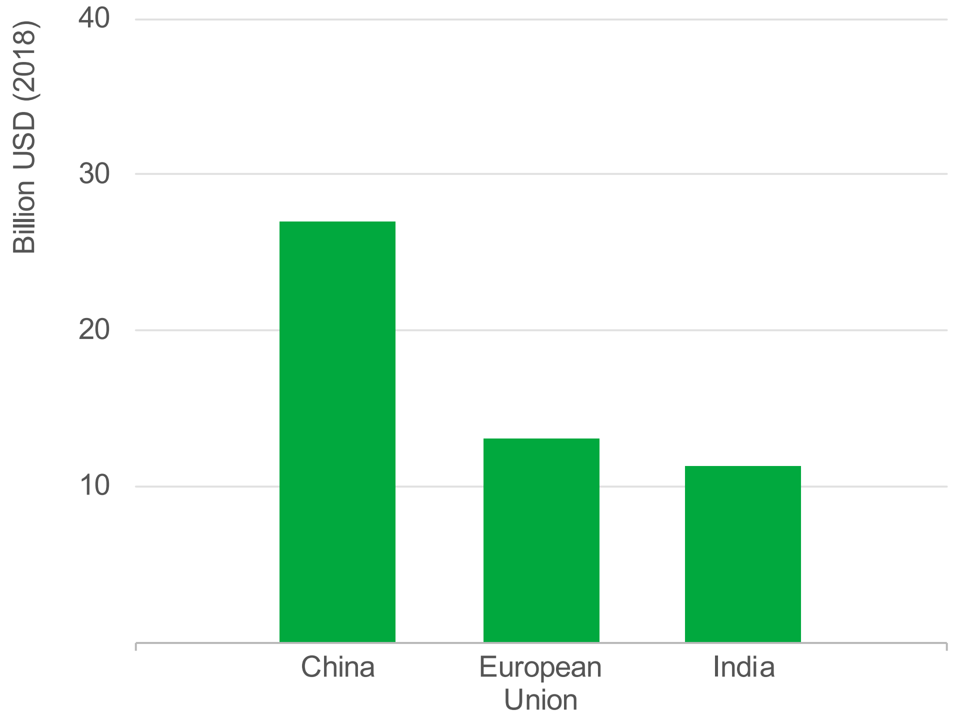
Both biogas and biomethane projects might also benefit from the growing accessibility of financial instruments focused on renewable projects, such as green bonds or targeted institutional investor funds.

Energy security

As a domestic source of gas, biomethane can help to mitigate dependence on imported fuels

Natural gas imports and biomethane production in the SDS, 2040 (left) and import bill savings from biomethane (right)





Note: 1 bcm = 0.83 Mtoe.

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Storage helps to reap the full energy security benefits of biomethane

For import-dependent countries, investment in biomethane supply can displace the need for fuel imports. Natural gas imports in India, for example, increase from 30 bcm in 2018 to 220 bcm in 2040 in the SDS, while in China natural gas imports double from today's levels to reach 260 bcm in 2040.

There is widespread biomethane potential in both of these countries, a significant proportion of which is available at relatively low cost. In India, biomethane consumption in 2040 in this scenario is around 35 bcm, and in China, 90 bcm. If this energy demand were to be met instead by natural gas, imports would be around 15% higher in India and 35% in China. Moreover, every additional billion cubic metres of biomethane produced in China or India could save over USD 300 million on fuel import costs; by 2040, both countries would see tens of billions in import bill savings in the SDS, which could help offset the costs of developing a domestic biomethane industry.

The security-of-supply implications of biomethane production on gas networks require careful evaluation. Scaling up biomethane production means gas supply becomes more decentralised. This reduces excessive reliance on the operation of a limited number of large-scale production, storage and import nodes. However, as with electricity distribution, gas grids would need to accommodate the growth of supply at the distribution level; impacts might be felt in grid balancing, while changes to tariff structures and capacity charges might be needed to incentivise injection at the distribution level while avoiding penalising other grid-connected customers.

Most biomethane projects today require a high and relatively constant level of plant utilisation to recoup their initial investment costs, meaning that (in the absence of storage) the seasonal "swing" capabilities of biomethane plants – the ability to ramp up and down – could be limited in some cases. This could have implications for countries with high winter heating loads, where the ratio of average-to-peak demand for biomethane may be an order of magnitude higher than the ratio of average-to-peak supply. For those countries that have it, gas storage capacity would be able to manage this issue. The spare capacity within gas transmission pipelines could also be leveraged to meet short-term peak periods of demand, whether for electricity or heat. Countries looking to replace seasonal LNG or pipeline imports with biomethane would need to assess feedstock types and their productive cycles to understand the energy security implications of this switch.

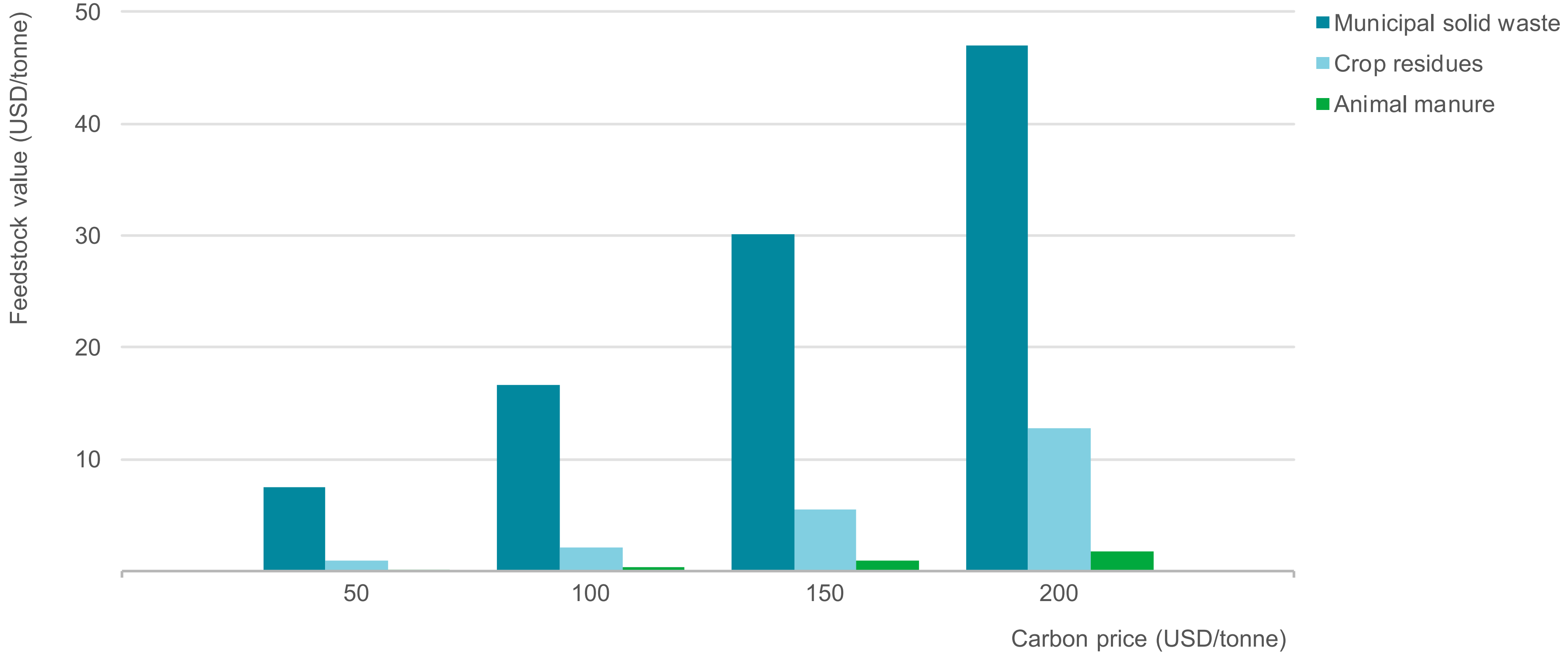
In the power sector, plants running on biogas and biomethane can provide an important complement to the rising shares of variable renewables such as wind and solar. By leveraging the energy storage potential from gas infrastructure, these renewable gases could also be used to flexibly meet peak electricity demand.

Biogas and biomethane also have co-benefits in terms of food security, as the by-product from production – digestate – can be used as a fertiliser and so obviate the need for imports (for example, the European Union must import 30% of its nitrogen consumption, 60% of its phosphorus and 75% of its potassium (European Commission, 2019).

Reductions in CO_2 and methane

A carbon price enhances the economic value of organic waste

Average value of feedstock sources for biomethane production according to different carbon prices, 2018



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Biogas and biomethane help to avoid CO_2 emissions by displacing the use of more polluting fuels and by enabling the rise of other renewables

The potential to realise CO_2 emissions reduction from using biogas or biomethane depends on how these gases are produced and where they are used in the value chain. From a policy perspective, it is essential that the production of biogases (and all other forms of bioenergy) actually deliver net life-cycle CO_2 emissions reduction.

For example, a 10% volume blend of biomethane in a natural gas pipeline would in theory reduce CO_2 emissions in the gas consumed by 10%. However, there are emissions from the collection, processing and transport of the biogas feedstock that need to be weighed against the CO_2 emissions that arise during the production, processing and transport of natural gas (GRDF, 2018) (Giuntoli et al., 2015). These indirect emissions can vary considerably between sources of biomethane and natural gas and, unless minimised, they could reduce the CO_2 emissions savings from the use of biomethane.

The same is true of low-carbon hydrogen: a 10% volume blend in a natural gas pipeline would reduce CO_2 emissions by 3-4% (for a given level of energy). However, the different potential energy inputs and conversion technologies to produce hydrogen mean a careful life-cycle emissions approach is needed to ensure that it is truly low-carbon (McDonagh et al., 2019).

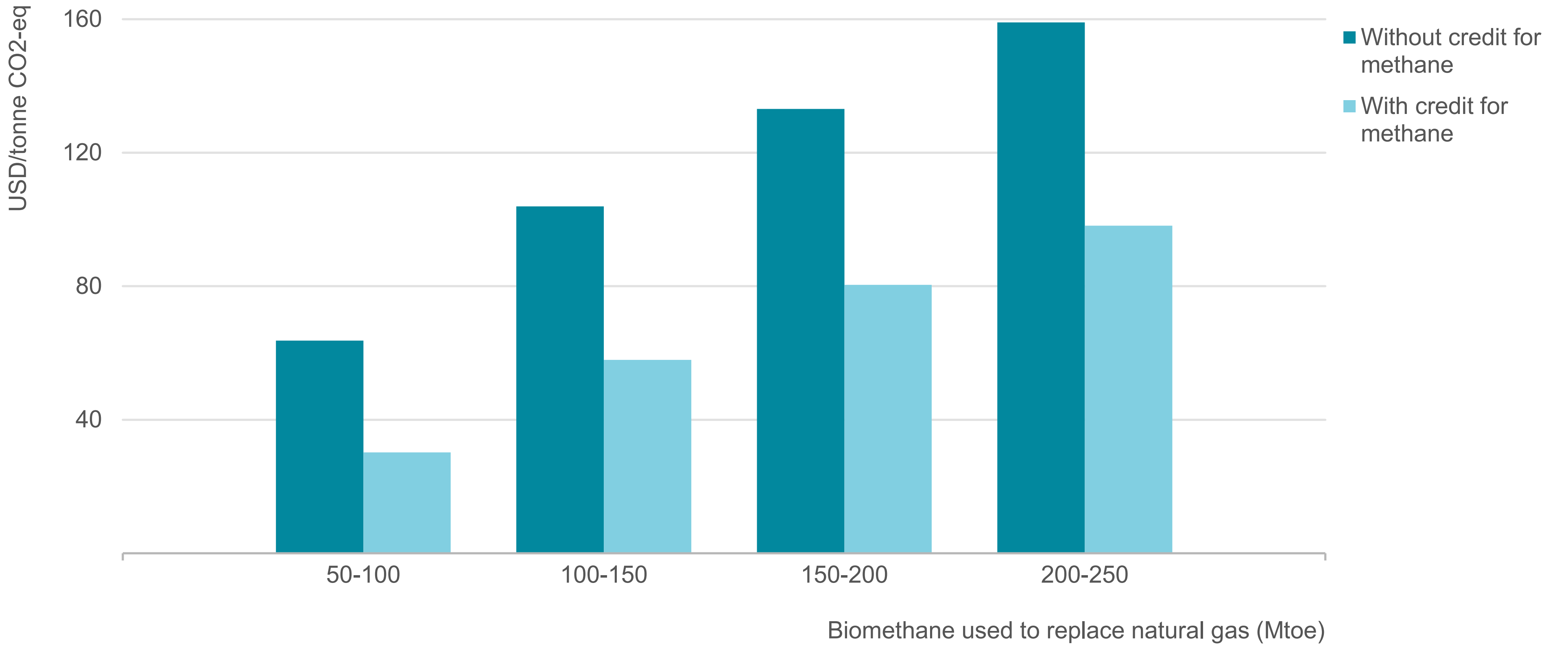
There is an additional opportunity for CO_2 emissions reductions from biomethane production. Biogas upgrading generates a highly concentrated by-product stream of CO_2 that could be captured for as little as USD 20 per tonne of CO_2 (tCO_2) (Koornneef J. et al., 2013).

Carbon prices enhance the economic case for biomethane consumption, supporting the development of plants in areas of feedstock availability and in many cases providing additional sources of income to rural communities. The value of each feedstock type ultimately depends on the production yield of each tonne of collected waste, and also on the costs of collecting and processing the waste. At carbon prices of USD 50/tCO_2, for example, a tonne of MSW used for biomethane production would be worth nearly USD 10, as it could be used to deliver carbon-neutral electricity and heat. However, carbon prices would need to more than triple to unlock the same value from a tonne of crop residue.

Globally, low-carbon hydrogen and biomethane blended into the gas grid in the SDS avoid around 500 Mt of annual CO_2 emissions that would have occurred in 2040 if natural gas were used instead.

Putting a value on avoided methane can dramatically tilt the cost equation in favour of biomethane …

Global marginal abatement costs for biomethane to replace natural gas, with and without credit for avoided methane emissions, 2018



Note: Chart shows the biomethane potential starting from the cheapest production options that would require a GHG price; the first 30 Mtoe of the global biomethane potential costs less than regional natural gas prices (and so should not require a GHG price to be cheaper than natural gas).

… but finding a way to account for methane-related savings is not simple

There is around 30 Mtoe of biomethane potential today that can be developed cost-effectively at a cost lower than the regional gas price. As discussed, if CO_2 prices are applied to the combustion of natural gas, then a much larger quantity of biomethane becomes an attractive proposition. If policy also recognises the value of avoided methane emissions that would otherwise take place from the decomposition of feedstocks, then an even larger quantity would be cost-competitive. Methane is such a potent GHG that attaching a value to these avoided emissions makes a dramatic difference to its overall supply cost profile.

Some of the feedstocks that are used to produce biomethane would decompose and produce methane emissions if not carefully managed. This applies in particular to animal manure and the organic fraction of MSW at landfill sites. In both cases, anaerobic digestion can happen spontaneously, generating methane emissions. All other potential biomethane feedstock types, such as crop residues, generally degrade in the presence of oxygen (not under anaerobic conditions) and so do not commonly result in methane emissions.

Biomethane production can avoid methane emissions from certain organic waste by capturing and processing them instead. Even if these emissions occur outside the energy sector, they should be credited to biomethane. This is already the case within California's Low Carbon Fuel Standard, which considers the full life-cycle GHG emissions for biomethane and gives credit to avoided methane.

Yet estimating the size of this credit is not straightforward, as it depends on a reasonable "counterfactual" case for what level of methane emissions would have occurred if the feedstock had not been converted into biomethane, which can vary according to region and over time. For example, there is wide regional variation in how methane produced within landfill sites is currently handled. In Europe, most sites have capture facilities, with the captured methane (known as "landfill gas") either flared or used for power generation. In the United States, around 55% of the methane that is generated in landfill sites across the country is captured. Around 20% of the remainder breaks down before reaching the atmosphere, meaning that close to 35% of the methane generated in landfills is emitted to the atmosphere. There is a lack of reliable data on landfills in most developing economies, but the percentage of methane that is captured is likely to be considerably lower than in advanced economies.

There are a number of policy frameworks for how "avoided" methane emissions should be handled or credited (e.g. the Clean Development Mechanism (UNFCCC, 2019), but there is currently no globally agreed or universally accepted framework. Different ways of handling these emissions can have a major impact on the apparent cost-effectiveness of using biomethane to reduce global GHG emissions.

For example, if no credit were to be awarded for avoiding methane emissions, but a credit were to be given for the CO_2 that is avoided from displacing natural gas, then around 60 Mtoe of biomethane potential would be economic at a USD 50/tonne GHG price. If avoided methane emissions were to be additionally included, then more than 120 Mtoe would be economic at a USD 50/tonne GHG price.

Considerations for policy makers

Realising the potential of biogas and biomethane will depend on policies that recognise the benefit of low-carbon gases in energy transitions

Biogas and biomethane both have enormous potential to contribute to clean energy transitions and help achieve a number of energy-related Sustainable Development Goals. There have been previous waves of enthusiasm for these gases but today they meet only a fraction of total energy demand. This is because they are generally more expensive than natural gas and they have not enjoyed the same level of policy support as renewable sources of electricity such as wind and solar PV.

If biogas and biomethane are to play a more prominent role in the future energy mix, it will be critical to recognise both the benefits that they provide over natural gases and the enduring importance of gaseous energy carriers.

This report outlines some possible approaches for consideration by governments and other stakeholders seeking to facilitate biogas and biomethane market development. Two key features of any policy framework are to:

- Support the competitiveness of biogas and biomethane against oil, natural gas and coal via CO_2 or GHG pricing mechanisms. This should include recognising the significant GHG emissions abatement potential of biogas/biomethane from avoiding direct methane emissions from feedstock decomposition to the environment. There are many examples of existing and planned policies that do this globally, including the Low Carbon Fuel Standard in California and the forthcoming Netherlands SDE++ policy.
- Ensure co-ordinated policy-making across agriculture, waste management, energy and transport to deliver an integrated approach to developing the biogas and biomethane sector. There are several co-benefits of developing a biogas industry, including employment and income for rural communities, improved gender equality, health benefits from avoided air pollution and proper waste management, reduced risk of deforestation, and greater resource efficiency. These benefits cut across the competencies and jurisdictions of different government departments, and ultimately a holistic approach is required that adequately values these benefits, and hence incentivises public and private investment in their development.

This report concludes with possible policy considerations and approaches in three areas:

- Availability of sustainable biogas and biomethane feedstocks.
- Support for biogas and biomethane consumption.
- Support for biogas and biomethane supply.

1. Availability of sustainable biogas and biomethane feedstocks

Specific ways to support the availability of sustainable feedstocks for biogas and biomethane production could include:

- Introduce comprehensive waste management policies and regulations to enhance the collection, sorting and pre-treatment of MSW, creating suitable biomass feedstock for biogas production in urban areas.
- Enhance the collection of unavoidable food waste by banning landfill disposal and introducing segregated collection.
- Promote sequential cropping trials and programmes to maximise feedstock resources from a given area of agricultural land, without affecting food production.
- Apply appropriate and harmonised sustainability criteria to ensure only sustainable feedstocks are used for biogas and biomethane production.
- Introduce GHG monitoring and reporting requirements for large-scale biogas and biomethane production units.
- Undertake comprehensive national and regional assessments of feedstock availability and cost, including a screening of optimal locations for biogas and biomethane plants, and assessing the potential at municipal level.
- Conduct feasibility assessments at existing landfill and water treatment plants to assess potential for landfill/sewage gas production.

2. Support for biogas and biomethane consumption

Policy measures or approaches that could lead to greater consumption of biogas and biomethane include:

- Consider the wider positive externalities when developing biogas/biomethane policy support, as the benefits from biogas and biomethane extend beyond the provision of renewable heat, electricity and transport fuels.
- Encourage the creation of biogas and biomethane industry jobs in rural locations, through promotional campaigns and training programmes.
- Support the adoption of biogas installations in rural areas of developing countries for clean cooking through subsidy programmes covering a certain percentage of the capital cost or microcredit schemes that would allow households to pay off the capital costs over time using the economic savings produced by the biogas plant.
- Design renewable electricity auction frameworks for power purchase agreements that recognise and reward the flexible generation potential of biogas systems.
- Develop registries to track and balance the volumes of biomethane injected to the gas network and subsequently consumed. These are an essential component in the application of policy support and are already in place in 14 European countries.
- Introduce quotas for renewable energy in transport that include sub-targets for advanced bioenergy production from waste and residues, for example the European Union (EU) Renewable Energy Directive sub-target of 3.5% of transport energy demand from such fuels by 2030.
- Roll out natural gas/biomethane fuelling infrastructure along key road freight corridors to enable biomethane consumption, a relevant example being the EU Alternative Fuels Infrastructure Directive.
- Promote public procurement of biomethane-fuelled vehicles that operate as captive fleets, e.g. municipal refuse collection vehicles and city buses.
- Utilise pricing units that allow comparison with other transport fuels, e.g. units of gasoline or diesel equivalents.
- Develop a framework for the use of digestate as a soil improver/fertiliser, e.g. through appropriate regulations, standards and certifications.
- Consider setting binding targets for renewable gases, based on quotas linked to total gas consumption.
- Develop more targeted incentives for renewable sources of power generation which can provide baseload and load-following services.

3. Support for biogas and biomethane supply

Policy measures or approaches that could lead to greater supply of biogas and biomethane include

- Introduce low-carbon and renewable gas standards and incentives for their use, considering the appropriateness of feed-in tariffs, feed-in premiums or auction-based support schemes for renewable gases.
- Establish targets for biogas electricity capacity, biomethane production or injection into natural gas networks based on realistic assessments of feedstock availability and the status of the industry.
- Introduce fiscal benefits, for example accelerated depreciation for the purchase of equipment/accessories for biogas production, and exemptions from excise duty for imported equipment and biomethane fuels.
- Develop relevant technical specifications, for example the European EN 16723-1 (2016) standard for the injection of biomethane in the gas grid and EN 16723-2 (2017) standard for biomethane use in transport.
- Stimulate innovation in solid biomass gasification to accelerate its commercialisation.
- Develop frameworks for co-operative infrastructure deployment for biomethane upgrading and gas network injection, reducing the investment and operational costs for multiple biogas producers in the same geographical location, e.g. multiple farm digester units.
- Establish a shared understanding about the path to minimise the risk of conflicts between the strategies of market participants with differing commercial interests.
- Utilise nationally appropriate mitigation actions in developing countries to facilitate technology transfer, financing and capacity building from developed countries
- Harness overseas development assistance to co-fund the market-based provision of household and community-scale biogas systems in developing countries.
- Raise awareness of biogas's potential in key industry subsectors such as food and drink, and chemicals.
- Clarify and harmonise Guarantee of Origin schemes and regulations in collaboration with other governments to encourage virtual cross-border trade of low-carbon gas.

Annex

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