Annex 3:
Bioenergy solutions suitable for immediate scale-up

Biomethane from waste and residue feedstocks for use as a transport fuel

**Solution description:** Anaerobic digestion to produce biogas from organic wastes with high moisture content. Before use in natural gas-fuelled vehicles, raw biogas must be upgraded to biomethane, a fuel similar in its physical and chemical quantities to natural gas. Biomethane in transport applications can be used in compressed (Bio-CNG) or higher energy density liquefied (Bio-LNG) form for extended vehicle operation ranges.

**Deployment examples:** Within OECD countries, less than 1.5% of all biogas production in 2015 was used in transport, notably in Germany, Norway and Sweden. By the end of 2015 there were over 450 biomethane plants in Europe (EBA, 2016) (Figure A3.1). However, only a small proportion of output from these is currently destined for transport, with competing uses for electricity, heat and co-generation. Several heavy-duty vehicle manufacturers offer CNG- and LNG-fuelled models compatible with biomethane and the fuel can also be used in municipal bus fleets, as demonstrated in Sweden. In the US Renewable Fuel Standard (RFS2), biomethane consumption grew fivefold between 2014 and 2016 (US EPA, 2017).

**Benefits offered:** Biomethane can offer significantly lower GHG emissions than fossil transport fuels, for example over 80% lower for typical\(^1\) bio-CNG fuels produced from municipal waste and manure feedstocks (European Commission, 2015c), while heavy-duty vehicles fuelled by biomethane can deliver 66-70% lower GHG emissions compared to oil products (EBA, 2016). Biomethane use in transport can also improve air quality as a result of lower hydrocarbons, CO, NO, and PM emissions compared to fossil fuels, particularly diesel. Furthermore, biomethane vehicles also offer reduced noise.

Biogas and biomethane production can incentivise improved waste management practices. If not utilised, the organic feedstocks used to produce biogas could otherwise emit methane directly to the atmosphere, resulting in a far greater climate impact,\(^2\) and can potentially also result in other local environmental impacts. Furthermore, depending on the feedstocks used, the material remaining post anaerobic digestion (digestate) can be used in agriculture as a fertiliser.

**Enabling factors:** Existing natural gas grids provide the most cost-effective means of biomethane transportation to areas of transport fuel demand, as well as lower GHG emissions than other transport modes. Where these are used, systems are needed to record and balance the volumes of biomethane injected to the gas network and subsequently consumed. Twelve such biomethane registries are already established in Europe. Fleet operators also benefit from blending biomethane with natural gas by adjusting consumption according to relative fuel costs.

Captive fleets, e.g. municipal refuse collection vehicles and city buses, that operate on established routes and that are refuelled at specific locations such as depots, provide opportunities for biomethane consumption. For more widespread biomethane consumption, a strategic roll-out of fuelling infrastructure along key transport corridors is needed. In the European Union the Alternative Fuels Infrastructure Directive (AFID) requires public refuelling points every 400 km for LNG and 150 km for CNG by 2025 along the core transport network. Biomethane uptake is also supported by pricing that allows comparison

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1. Emissions from biomethane vary in each supply chain according to factors such as the feedstock used for biogas production, if digestate storage is closed or open, if the fuel is compressed or liquefied, and means of transport to point of use.

2. Methane has a global warming potential 28 times higher than carbon dioxide (CO\(_2\)) over a 100-year timescale, according to the IPCC (UNFCCC, 2016).
with other fuels, for example in the United States units of gasoline or diesel energy content equivalents are used. Technical specifications also support uptake in transport, for example, the draft EN 16723-2 European standard for automotive biomethane use.

Figure A3.1: European biomethane plants 2011-15 (left) and production by feedstock source for selected countries 2015 (right)

Notes: Feedstock share determined on a mass basis; Industrial wastes refers to wastes from the food and beverage industry; Municipal wastes refers to the biomass fraction of MSW; Mixed waste refers to a mix of these two waste types. Source: EBA (2016), European Biogas Association Statistical Report 2016.

Waste and residue HVO in heavy-duty road freight and HEFA in aviation

Solution description: Hydrotreated vegetable oil (HVO), also referred to as renewable diesel, produced from waste and residue lipid feedstocks for use in heavy-duty transport. Hydrotreated esters and fatty acids (HEFA) biojet fuel is certified to industry standards for aviation use in blends of up to 50% with fossil jet kerosene. Examples of suitable feedstocks for both fuels include food processing fats and oils, technical corn oil and tall oil.

Deployment examples: Global HVO production capacity exceeds 5 billion L with commercial-scale plants in Singapore, the United States and Europe (Figure A3.2). Capacity is anticipated to grow as a result of the expansion of existing plants, and projects to convert conventional oil refineries to HVO production. Currently most HVO consumption occurs in Europe and North America, primarily in blends with fossil diesel (e.g. 30-50% HVO by volume), although there is growing demand for HVO100 in private vehicles, heavy-duty vehicles and city fleets. In Europe, HVO consumption reached around one-fifth of combined HVO and biodiesel demand in 2016. In the United States, just over 2 billion L of HVO was used for RFS2 compliance in 2016, with demand for waste and residue HVO also arising from California’s LCFS. Blends of HEFA with fossil jet kerosene are used in a growing number of commercial flights by US and European airlines from a number of airports, e.g. Oslo and Los Angeles.

Benefits offered: HVO is technically a drop-in fuel with properties almost identical to fossil diesel. This means that where certified to industry standards and approved by vehicle OEMs, it can be used unblended without modifications to diesel engines, maintenance regimes or fuelling infrastructure. A number of major heavy-duty vehicle OEMs have approved unblended HVO (HVO100) use in various engine families. Where waste and residue feedstocks are utilised, HVO can deliver very low life-cycle GHG emissions compared with fossil diesel, as well as good operational properties in cold climates.
The aviation industry has adopted ambitious targets to reduce the climate impact of air transport, including carbon-neutral growth from 2020 and a reduction in net aviation CO₂ emissions of 50% (on 2005 levels) by 2050 (IATA, 2016). Meeting these targets will necessitate a move to lower-carbon fuels. HEFA is currently the most commercialised aviation biofuel and will play a key role in establishing aviation biofuel supply chains and markets. Other benefits to the aviation industry from aviation biofuels include supply diversification and hedging against potential regulatory and carbon taxation costs in the future.

**Enabling factors:** Scaling up HVO consumption in heavy-duty transport requires an increase in production capacity, more widespread OEM vehicle approvals, and fuel quality standard development covering HVO use in a wider number of markets and applications. Market and policy measures to increase HVO fuel availability at service stations, for example either blended or as HVO100, and its cost competitiveness against fossil transport fuels are also needed. The conversion of existing oil refineries to HVO offers a lower investment cost means to grow production capacity compared to new build plants.

Waste and residue feedstocks present additional challenges in processing due to their variable composition and the presence of impurities. Therefore, development of pre-treatment processes to expand the range of lipids suitable for HVO production supports increased output of HVO fuels with highest decarbonisation potential. While availability of these feedstocks is ultimately finite, industry assessments indicate sufficient availability to allow for a scale-up on current production levels, provided supply chains can be mobilised. However, the potential for competing uses for these resources also needs to be considered.

The availability of HEFA aviation biofuel remains limited and airline fuel off-take agreements will be essential in providing the investor confidence to deliver new biojet refinery projects. For aviation biofuels, supply chain development and measures to reduce cost premiums over fossil jet fuels are also needed. Building regional supply chains will require clustering airlines and aviation biofuel suppliers, as well as the integration of HEFA biojet fuel into existing aviation fuel supply logistics, for example airport fuel storage and distribution infrastructure. Reducing aviation biofuel cost premiums is likely to require a combination of lowering production costs in combination with policy support and financial innovation e.g. the SkyNRG Fly Green Fund.

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*Figure A3.2: Global biodiesel and HVO production 2010-16 (left) and feedstock use for HVO production by Neste 2008-16 (right)*

Notes: Mt = million tonnes of feedstock; Wastes and residues includes food processing fats and oils and corn oil; other raw materials includes virgin vegetable oils.

Higher ethanol blends and unblended ethanol in road transport

Solution description: The consumption of fuel ethanol, either in mid- (E20-E40) or high-level (E85) blends with gasoline, or as pure hydrous ethanol (E100) for light-duty vehicles, as well as ED95 in heavy-duty transport. Consumption of these fuels should be linked to ongoing efforts to increase GHG emissions reduction from fuel ethanol compared to fossil fuels, and ensure environmental, social and economic sustainability considerations are respected.

Deployment examples: With global production around 100 billion L in 2016, fuel ethanol is the most established transport biofuel. In most markets ethanol consumption is at blend levels up to E10, due to limits on use of higher ethanol blends or hydrous ethanol associated with compatible vehicles, fuel availability at service stations and climatic temperatures which can impact upon fuel suitability. The notable exception is Brazil, where hydrous ethanol competes directly with E27 gasoline in a light vehicle fleet composed of over 70% ethanol and flex-fuel vehicles (Figure A3.3).

In the United States, E85 was available at more than 3,000 service stations by the end of 2016 and an estimated 20 million flex-fuel vehicles are on the road (US DOE, 2017). Sweden has widespread availability for E85 at over 1,800 service stations, while in Thailand E20 and E85 consumption is growing with the aspiration to reach an average blend share of 24% by 2026, specified within the country’s Alternative Energy Development Plan. In heavy-duty vehicles, ED95 consumption has been successfully demonstrated in Sweden and Brazil, with one major OEM offering adapted diesel engines suitable for the fuel.

Benefits offered: Higher blend shares of the best-performing conventional fuel ethanol can maximise GHG reduction potential versus petroleum products. Typical GHG emissions stated within the EU FQD for ethanol vary by feedstock and process fuel, but indicate between 32% and 71% reductions on fossil gasoline. This is in line with an average 64% GHG savings from European fuel ethanol compared to fossil gasoline for 2015, as reported by the ethanol industry (EPure, 2016). Sugar cane ethanol is also able to offer significant emission reduction compared to fossil gasoline, aided by the use of bagasse residues as a process fuel. Current GHG emission levels from the ethanol industry are not static, as improvements in crop yields, switching to lower-carbon or renewable process fuels, maximising the use of co-products and efficiency gains in logistics offer scope to lower fuel carbon intensity.

The use of domestically produced fuel ethanol at higher blends supports diversification of transport fuel supply. For example, in Brazil, India and Thailand, domestically produced ethanol increases security of supply compared to imported petroleum products. In addition, the high octane rating of ethanol can result in improved engine efficiency and fuel economy, and lower GHG emissions where mid-level (E20-E40) ethanol blends are used in high-compression engines. ED95 in heavy-duty vehicles offers air quality benefits compared to fossil diesel, particularly in terms of reduced PM and NOx emissions. A recent study highlighted reduced PM emissions when pricing dynamics resulted in drivers switching from gasoline (with a 27% ethanol blend) to hydrous ethanol in São Paolo (CETESB, 2016). Wider benefits include supporting agricultural employment and the co-production of high-protein animal feed.

Enabling factors: Policies to expand flex-fuel vehicle fleets and OEM approvals are favourable for ethanol consumption at higher levels than E10; however, parallel steps to raise the awareness of flex-fuel vehicle drivers as to the range of fuels suitable for their vehicles are also needed. Exploiting the potential of ED95 in heavy-duty road freight transport will also require a wider offering of suitable vehicles from OEMs. This would be supported by the development of fuel specifications from recognised bodies, e.g. ASTM in the United States or CEN in Europe.

5. EU FQD figures exclude net carbon emissions from land use change where there is scope for additional research to reach consensus on suitable emissions values applicable for crop-based biofuels. Research by Valin et al. (2015) indicated that sugar and starch ethanol feedstocks in the European Union have land use change emission impacts of 14 gCO2e/MJ biofuel consumed for maize, 34 gCO2e/MJ for wheat, 17 gCO2e/MJ for sugar cane and 13 gCO2e/MJ for sugar beet.

6. An indication of gasoline’s anti-knock performance in vehicle engines, the ability to resist engine “knocking” is required for proper operation of spark-knock engines.

3. E20 equates to a blend of 20% ethanol by volume with gasoline; similarly references to E10, E27, E40 and E85 refer to the volume share of ethanol blended with gasoline.

4. A fuel composed of 95% ethanol alongside lubricants and additives to improve ignition and protect against corrosion.

Annex 3:

Bioenergy solutions suitable for immediate scale-up
The expansion of fuel distribution infrastructure for ethanol fuels can be supported by specific programmes, such as the USDA Biofuels Infrastructure Partnership to expand availability of higher blends of ethanol in the United States. Strategic roll-out of fuelling infrastructure for fuels such as ED95 along key road freight transport corridors would also accelerate uptake, and complement the use of the fuel in public-sector captive bus and truck fleets.

Figure A3.3: Brazilian light vehicle fleet by fuel type 2007-16 (left) and reference well-to-wheel CO₂ emissions from ethanol and fossil transport fuels (right)

Notes: Ethanol CO₂ emissions value includes estimated of land use change emissions; gCO₂/km = grams of carbon dioxide per kilometre.


Bioenergy based district heating networks in urban areas

Solution description: Biomass fuelled district heating networks in urban areas, serving heat demand from buildings and industry. Most deployment utilises forestry residues (wood chips and pellets); however, agricultural residues and MSW fuels are also used.

Deployment examples: High shares of biomass within district heating are evident in Nordic and Baltic countries (Figure A3.4), where district heating is widespread and serves between 50-65% of the population (Euroheat and Power, 2017). While biomass district heating has been established for a long period of time in these countries, new projects are still being delivered. A 280 megawatt thermal (MWₜₚ) biomass co-generation plant came on line in Stockholm in 2016 and a >200 MWₚ biomass and waste co-generation plant in Vilnius plans to commission in 2018.

In Sweden and Lithuania, over 60% of heat generation in district heating is sourced from biomass, with around 50% in Denmark, 45% in Estonia, and 32% in Finland. While heat-only biomass boilers can be utilised, co-generation is

7. The exception is Norway, where district heating is not widely used.
8. Values for Denmark (Lauersen, 2017) and Estonia (IEA, 2016b) are for 2015; Finland is 2016 (Fyhr, 2017).
9. Co-generation refers to the combined production of heat and power. It should be noted that in many large-scale district heating networks a variety of fuels are commonly used to cover different load profiles, e.g. base-load and peaking operation.
the principal technology choice in Nordic countries in cases where high heat demand (e.g. tens of megawatts) is required for extended periods.

**Benefits offered:** District heating infrastructure facilitates economies of scale in the investment costs of biomass plants compared to installations in individual buildings. In addition, higher-volume procurement generally lowers fuel costs. Barriers associated with sufficient space for biomass heating systems and potential for disruption during installation, which occur in the residential market, are also negated via district heating.

Where fossil fuels are replaced by biomass, lower CO₂ emissions per unit of heat supplied are delivered. In addition, where coal-fired systems are replaced by biomass boilers fitted with emission control equipment, significant air quality benefits are also realised. Biomass fuel prices can also be competitive versus fossil fuels, although this depends on the fuel and country in question. A key driver in the Nordic and Baltic markets highlighted is diversification of heating fuel supply to reduce reliance on imported fossil heating fuels by replacing these with domestically produced biomass.

**Enabling factors:** Globally most district heating systems remain fossil fuelled, and the most promising initial opportunities should arise from converting these networks to renewable fuels and therefore avoiding the initial investment cost of heat distribution pipe infrastructure. In Lithuania, the transition to biomass has been supported by the introduction of the Baltpool biomass exchange. This has facilitated the market entry of new fuel suppliers, enhancing fuel price competition and supply liquidity.

Where new district heating infrastructure is required, municipal governments can support deployment through urban heat mapping and planning exercises. Policies that allow municipalities to mandate connection in certain areas can reduce off-taker risk and facilitate investment, with such approaches employed in Copenhagen and Hamburg. However, where these are used, connection agreements that ensure consumer protection are required. A diverse customer base comprising industrial facilities, commercial and public buildings can ensure year-round demand and increase asset utilisation compared to supplying the residential sector alone.

**Figure A3.4: Heating and cooling renewable energy consumption by sector and share of renewables for selected EU countries (left) and composition of fuels used in district heating in Denmark 1980-2015**

- **Note:** District heating share based on derived heat produced in main activity producer plants and heat sold produced in auto producer plants. The majority of the renewable energy consumed within district heating in Denmark is in the form of biomass.
Medium-scale biomass heating systems in commercial and public buildings

Solution description: Biomass wood chip or pellet heat or co-generation systems, within public and commercial buildings e.g. schools, hospitals and hotels. These can also be used in large residential buildings with communal heating systems.

Deployment examples: Medium-scale biomass heating is most widespread in Europe, driven by renewable energy targets for 2020 within the EU RED, with deployment most evident in Germany and Sweden. However, its market share is smaller than residential biomass boilers and stoves. Commercial-scale heat-only and co-generation heating accounted for around 22% of wood pellet consumption in the European Union in 2015, compared to 42% for individual residential heating systems (AEBIOM, 2016). However, the deployment of medium-scale systems in Europe is increasing and holds considerable scale-up potential.

The United States and Canada account for around half of global wood pellet production capacity; however, domestic consumption is minimal compared to exports. Both countries have significant potential to increase the utilisation of medium-scale biomass heating systems in areas without access to natural gas, e.g. in the north-eastern United States and Canadian provinces of Quebec and Ontario. The potential for medium-scale biomass heating systems also remains largely untapped in emerging economies and developing countries.

Benefits offered: Due to their larger size and engineering complexity, biomass boilers generally have higher investment costs compared with liquid and gaseous fossil fuel heating systems. However, medium-scale biomass systems facilitate reduced specific investment costs. For biomass boilers, these drop significantly up to 50 KW, with economies of scale levelling off after 100 kW (Figure A3.5). In addition, biomass fuel prices are influenced by quantity supplied, with low-volume purchases (e.g. bagged pellets) more expensive than bulk procurement via negotiated contracts or ESCO heat provision applicable to medium-scale systems.

Fuel costs for biomass wood chips and pellets can be competitive versus a range of fossil heating fuels. However, competitiveness against natural gas can be challenging in certain countries. Where this is the case, key opportunities for biomass deployment exist in the off-natural gas grid market sector. Since the launch of the UK Renewable Heat Incentive (RHI) scheme, 57% of installed non-domestic biomass systems replaced heating oil boilers, compared to 5% for natural gas systems (BEIS, 2017). In addition, the price stability of wood pellets provides a degree of fuel cost certainty over the operational life of a heating system. By contrast, heating oil costs are aligned with crude oil prices and more variable over the operational life of a heating system (Figure A3.5).

Enabling factors: For existing buildings, renovation programmes that include the upgrade of outdated heating plant create opportunities for integrating biomass heating. For new buildings, planning requirements and buildings codes which stipulate the utilisation of renewable heat systems can be applied, for example policies that specify a certain percentage of building energy demand is met from renewables. Other relevant policy measures to stimulate the uptake of biomass heating include fiscal measures (exemption from CO₂ and energy tax in Sweden), inclusion within Renewable Portfolio Standards (US states of Massachusetts and New Hampshire) and generation-based subsidisation for renewable heat (the United Kingdom). Commercial biomass systems account for over three-quarters of all heat generated within the UK RHI scheme since its inception (BEIS, 2017).

With regard to biomass fuels, the development of fuel quality standards to assure uniform characteristics (e.g. ISO 17225 standard for solid biofuels, ENplus certification for pellets), new market mechanisms to hedge price risk (e.g. futures contracts) and the more widespread application of ESCO business models, all support the use of medium-scale biomass heating. These need to be complemented by steps to raise awareness of biomass technologies, alongside training and certification programmes to expand the skilled workforce to undertake design/specification, installation and system O&M. Emissions control equipment can be more easily implemented for medium-scale biomass heating systems, ensuring that the transition to biomass from (non-coal) fossil fuels does not increase PM emissions.

10. Categorised by AEBIOM as having a capacity above 50 kilowatt thermal.
11. The remainder is attributable to electricity generation in electricity-only and co-generation plants.
Maximising the efficiency of bagasse co-generation in the sugar and ethanol industry

**Solution description:** The utilisation of bagasse\(^\text{12}\) secondary residues by cane sugar and ethanol mills for process energy needs is established. However, there is scope to increase the efficiency of heat and electricity generation at many facilities in sugar cane producing countries. An accelerated transition from outdated generation plants and high steam consumption sugar recovery processes to more modern processes, including co-generation systems with higher-pressure boilers\(^\text{13}\) that offer greater efficiency and reliability, can maximise the quantity of steam and electricity generated for a given input of bagasse. Furthermore, increased mechanical harvesting, instead of the field burning that is still commonplace in many countries, can be used to obtain additional residues suitable for energy purposes.

**Deployment examples:** Globally bagasse-fuelled power generation capacity stood at around 22 GW in 2016 (IRENA, 2017), representing around 20% of global bioenergy electricity capacity. Brazil, India, Pakistan and Thailand have introduced measures to improve the efficiency of bagasse co-generation in their sugar and ethanol industries. However, there remains scope for more widespread upgrading of bagasse co-generation plants in these countries (Figure A3.6). Significant unexploited potential also exists in other sugar cane cultivating countries. For example, in Mexico 43 of the country’s 51 sugar mills are suitable for investment in higher-efficiency co-generation (NAMA facility, 2017).

**Benefits offered:** The move to higher-efficiency bagasse co-generation supports sugar mill energy self-sufficiency and can offset fossil fuel consumption for process energy demand. Consequentially, this can lower operational costs for sugar and ethanol production, as well as CO\(_2\) emissions. In addition, increased energy production offers scope for the export of surplus electricity to the grid, as well as heat and steam sales in cases where a viable offtake is available in the vicinity. These additional revenue streams further diversify mill income, which otherwise depends on fluctuating sugar and ethanol prices. Fuel ethanol energy production can be awarded co-product credits within carbon intensity based...
policy frameworks. These lower lifecycle GHG emission values enhance competitiveness against alternative fuels.

Bagasse represents a relatively low-cost form of electricity generation, for example in Brazil government auctions have awarded PPAs to bagasse electricity projects in the region of USD 60/MWh. If all bagasse produced globally in 2014 was utilised in high-efficiency co-generation, approximately 130 TWh of electricity would have been produced; this corresponds to almost 30% of global electricity from all forms of bioenergy in the same year. The export of surplus electricity generation provides a financial incentive for higher and more efficient sugar cane straw collection rates, e.g. through mechanised harvesting. This in turn can result in air quality benefits by reducing in-field sugarcane residue burning.

Enabling factors: Mechanisms to extend affordable finance to both public and privately owned sugar mills are likely to be required to facilitate the investment required to increase the efficiency of bagasse co-generation plants and obtain grid connections. Where these mechanisms are complemented with policies that valorise renewable electricity generation, the economic case for investment to increase surplus electricity export is strengthened. Wider measures can also be considered, for example India has established a capital subsidy for the upgrade of sugar mill cogeneration plants with support levels based on boiler pressure rating.

Sugar mills are typically located in rural areas where the electricity networks are weak and generation capacity is lacking. Therefore exporting excess electricity generation can support local electricity grids. However, steps to remove grid access barriers for sugar and ethanol mills will be required for this to occur. Prospects are best for those mills in close proximity to electricity networks, which consequentially benefit from lower capital investment for grid connection. The potential to group mills in the same vicinity on a shared grid connection may also facilitate lower-cost grid connection through economies of scale. For example, the Mexican energy law specifically allows for this approach to grid connection.

International co-operation programmes to facilitate knowledge transfer and best practice between key sugar cane cultivating countries would also be valuable. Year-round generation potential is enhanced by multi-fuel technologies, which can access alternative fuels available outside the sugar cane harvest season. Energy cane, which creates more bagasse residues with comparable sugar content to other sugar cane varieties, can also enhance bioenergy generation.

Figure A3.6: Bagasse production, co-generation potential and electrical capacity (2014), selected countries

Notes: Theoretical generation assumes co-generation with an overall 80% efficiency, split between two-thirds thermal and one-third electrical generation and 80% capacity factor; GWh = gigawatt hour.


14. A certain percentage of sugar cane residues will need to remain in the field to maintain soil condition.
Energy recovery from municipal waste solutions

Solution description: The application, within the wider context of the waste management hierarchy, of thermal EFW and landfill gas technologies for energy recovery from MSW. While applicable globally, future potential for such solutions is particularly significant in areas where trends of rapid urbanisation, population growth and rising living standards combine to increase per-capita waste production and energy demand.

Deployment examples: Total primary energy supply of renewable municipal waste reached 0.7 EJ globally in 2014, supporting 35 TWh of electricity and 36 TWh of heat generation. Spurred by urban waste management challenges, EFW is growing in China, with 5 GW of EFW accounting for around half of national bioenergy electricity generation capacity in 2015. Japan and the United Kingdom also possess significant EFW electrical capacity, while RDF has been widely used in municipal co-generation plants in Sweden. The deployment of landfill gas plants is prominent in the United States and United Kingdom.

However, significant volumes of municipal waste are still subject to landfill in many countries. In the European Union, around nine times more waste was subject to disposal than energy recovery in 2014 (Eurostat, 2017a); while in the United States over half of municipal waste production was landfilled in 2014, compared to 13% subject to energy recovery (OECD, 2017).

Benefits offered: As indicated by its higher position in the waste management hierarchy, thermal energy recovery from municipal wastes offers multiple benefits compared to landfill disposal. EFW facilities deliver significant waste volume reduction and require a smaller land area than landfill sites. From a sanitary and environmental perspective, polluting emissions to groundwater and soil, as well as odour issues and GHG emissions are reduced by energy recovery compared to landfilling. EFW solutions also offer a means to meet electricity and heat demand using locally produced waste resources, increasing the diversification of energy supply. In addition, the electricity and heat generated are close to urban demand centres. There is a correlation between waste disposal costs and the proportion of waste which is used for energy purposes (Figure A3.7).

The potential for EFW facilities to receive gate fees for waste received can result in negative fuel costs, and consequently lower electricity and heat generation costs. Lower-end cost estimates for EFW plants indicate that LCOE generation costs in the region of USD 50/MWh are achievable in diverse markets. Furthermore, bottom ash produced post-combustion can be utilised as an aggregate or for road construction.

For landfill sites, landfill gas collection and utilisation offers the dual benefits of energy production and avoiding direct methane emissions to the atmosphere that result in a far greater climate impact than CO₂. In addition, landfill gas plants entail no fuel purchase costs, and as a result global generation costs for landfill gas are relatively uniform at around USD 40-90/MWh.

Enabling factors: Municipal governments have a key role to play in designing waste management strategies and implementing practices that reflect national and supranational waste management legislation. These define the framework in which municipal waste energy recovery facilities operate. To ensure public confidence in EFW plants, comprehensive consultation should be undertaken. In addition, the application of best available pollution control technologies and monitoring is essential to ensure emissions to air and water, noise and odour remain within regulatory limits.

The production of RDF should form one constituent of a wider waste management strategy, ensuring improved collection and source separation of waste to maximise the potential for re-use and recycling of materials prior to energy recovery. In addition, advanced waste separation practices improve RDF energy content and waste combustion efficiency, which is important from an air quality perspective. The classification of RDFs to defined standards, such as solid recovered fuel (SRF) in the

15. Composed of the following steps: prevention, preparing for re-use, recycling, recovery and disposal.
16. A fuel obtained from municipal and industrial wastes post separation and recycling of materials.
17. A gate fee (or tipping fee) is the charge levied upon a given quantity of waste received at a waste processing facility. These can be adjusted according to technology costs to ensure adequate remuneration.
European Union, can ensure uniform fuel characteristics.18

Landfill bans have been demonstrated to correlate with higher rates of thermal recovery in several European countries; for example, in Germany almost a quarter of municipal waste in 2014 was subject to energy recovery. These bans have been applied in different forms depending on waste composition, e.g. for unsorted waste, organic wastes or wastes above certain caloriific or total organic carbon values. Landfill taxation increases the cost of disposal and consequently supports the economic case for recycling and EfW facilities.19

The move towards more sophisticated and sustainable waste management practices that limit waste disposal to land is likely to mean landfill gas is primarily a transition technology. However, landfill disposal practices are still in evidence in many countries. Where this is the case, the application of landfill gas technologies represents a viable revenue-generating option to offset the cost of installing and operating a methane collection system.

Figure A3.7: Waste disposal costs and share of energy recovery (2015) for selected countries

Notes: Actual gate fee values vary; value stated is assessed average; percentage energy recovery assumes no incineration takes place without energy recovery and as such may be lower; aside from the cost of waste disposal, landfill ban policies will also influence the share of energy recovery.


18. Covered within the European CEN standard EN 15359; an ISO standard is being developed by ISO TC300.
19. Landfill taxation is in addition to overall landfill costs and forms a proportion of a higher gate fee that can be charged for waste receipt.
The conversion of existing fossil fuel infrastructure for bioenergy use

Solution description: Several options are available to convert existing fossil-fuelled infrastructure to biomass consumption; these include districting heating networks, power generation assets, the addition of biomass powder burners20 to boilers and the conversion of fossil fuel refineries to HVO and HEFA fuel production.

Deployment examples: The conversion of fossil fuel district heating systems to biomass is prominent in Nordic and Baltic countries (Figure A3.8). Coal-to-biomass power plant conversions have been delivered in Canada, Denmark and the United Kingdom, and conversions are underway in other countries, such as Korea. Numerous wood burner installations have been delivered with a wide geographical spread. Two HVO refinery conversion projects are in development in France and Italy, with a further completed in the United States to produce HEFA biojet fuel. Co-processing of biomass feedstocks in fossil refineries is also undertaken in Ireland, Spain and Sweden.

Benefits offered: The principal benefit from the conversion of existing fossil fuel assets to biomass use is reduced investment costs. Other benefits include quicker project completion compared to delivering an equivalent capacity of new-build projects, GHG emissions reduction from the direct substitution of fossil fuels, and potential to conserve jobs within potentially stranded assets. The typically larger scale of these projects can also stimulate biomass supply chain development.

For district heating systems, the heat distribution pipework represents a major component of total investment costs. This infrastructure typically has a longer operational life than the associated heat generation plant; therefore, using existing pipework while substituting fossil fuel boilers for biomass systems entails a lower investment cost than new-build networks.

Coal-to-biomass power station conversions can be delivered for significantly lower investment costs than dedicated biomass electricity projects. Conversion projects have been undertaken in Europe for less than USD 500 per kilowatt electrical (kWe) of capacity, and as low as USD 50/kWe, for a Canadian project using steam exploded pellets.21 Converting coal power stations to biomass also retains system flexibility (e.g. back-up and balancing-at-unit capacities with an impact on the grid), using a renewable fuel. Converted power stations have participated in the United Kingdom balancing mechanism; and two Canadian plants provide back-up to hydropower and variable renewable generation in Ontario. In addition, due to the scale of converted power stations compared to dedicated biomass power plants, higher electricity generation efficiency is achievable.

Fitting wood burners entails a far lower investment cost than purchasing a new biomass boiler and, apart from the addition of fuel storage, usually does not require building modifications. Wood fuel burners can also provide similar load response to gas and oil burners. The investment costs for delivered HVO refinery conversions were reduced by a half to two-thirds compared to new build facilities, while co-processing biomass feedstocks and crude oil in refineries entails low investment costs.

Enabling factors: The application of carbon pricing initiatives can challenge the economics of operating fossil fuel facilities. For example, the carbon price floor increases coal generation costs in the United Kingdom and carbon taxation of heating fuels was pivotal in significantly reducing fossil fuel use for district heating in Nordic Countries. Within the context of the COP21 global climate agreement, more widespread carbon pricing initiatives can be anticipated. As a consequence, stranded fossil fuel assets suitable for conversion to biomass fuels may arise.

The capacity of coal-to-biomass power plant and HVO refinery conversions requires the mobilisation of biomass fuel and feedstock supply chains at scale. Scaling up the supply of wood pellets will require the development of production capacity and logistics infrastructure. Given the volumes of biomass fuel involved, in order to ensure policy maker and public acceptance, this should be undertaken in the context of appropriate sustainability governance. Where possible, the use of co-generation, such as is the case for conversion projects in Denmark, offers higher efficiency use of these biomass

20. These utilise milled biomass, commonly from wood pellets, although wood chips and biomass briquettes are also used.

21. Steam exploded pellets have more similar physical and combustion properties to coal than conventional wood pellets. This consequently lowers the capital expenditure required for plant conversion.
resources. For HVO refinery conversions, locations which provide good logistics connections support the building up of waste and residue feedstock supply chains at scale. Given the distributed nature of these feedstock resources, aggregators and traders can play a role in ensuring biofuel producers do not need to move beyond their core business to obtain supply.

Figure A3.8: Global fossil fuel-to-bioenergy conversion projects
References


Annex 3:

Bioenergy solutions suitable for immediate scale-up


The International Energy Agency (IEA), an autonomous agency, was established in November 1974. Its primary mandate was – and is – two-fold: to promote energy security amongst its member countries through collective response to physical disruptions in oil supply, and provide authoritative research and analysis on ways to ensure reliable, affordable and clean energy for its 29 member countries and beyond. The IEA carries out a comprehensive programme of energy co-operation among its member countries, each of which is obliged to hold oil stocks equivalent to 90 days of its net imports. The Agency’s aims include the following objectives:

- Secure member countries’ access to reliable and ample supplies of all forms of energy; in particular, through maintaining effective emergency response capabilities in case of oil supply disruptions.
- Promote sustainable energy policies that spur economic growth and environmental protection in a global context – particularly in terms of reducing greenhouse-gas emissions that contribute to climate change.
- Improve transparency of international markets through collection and analysis of energy data.
- Support global collaboration on energy technology to secure future energy supplies and mitigate their environmental impact, including through improved energy efficiency and development and deployment of low-carbon technologies.
- Find solutions to global energy challenges through engagement and dialogue with non-member countries, industry, international organisations and other stakeholders.