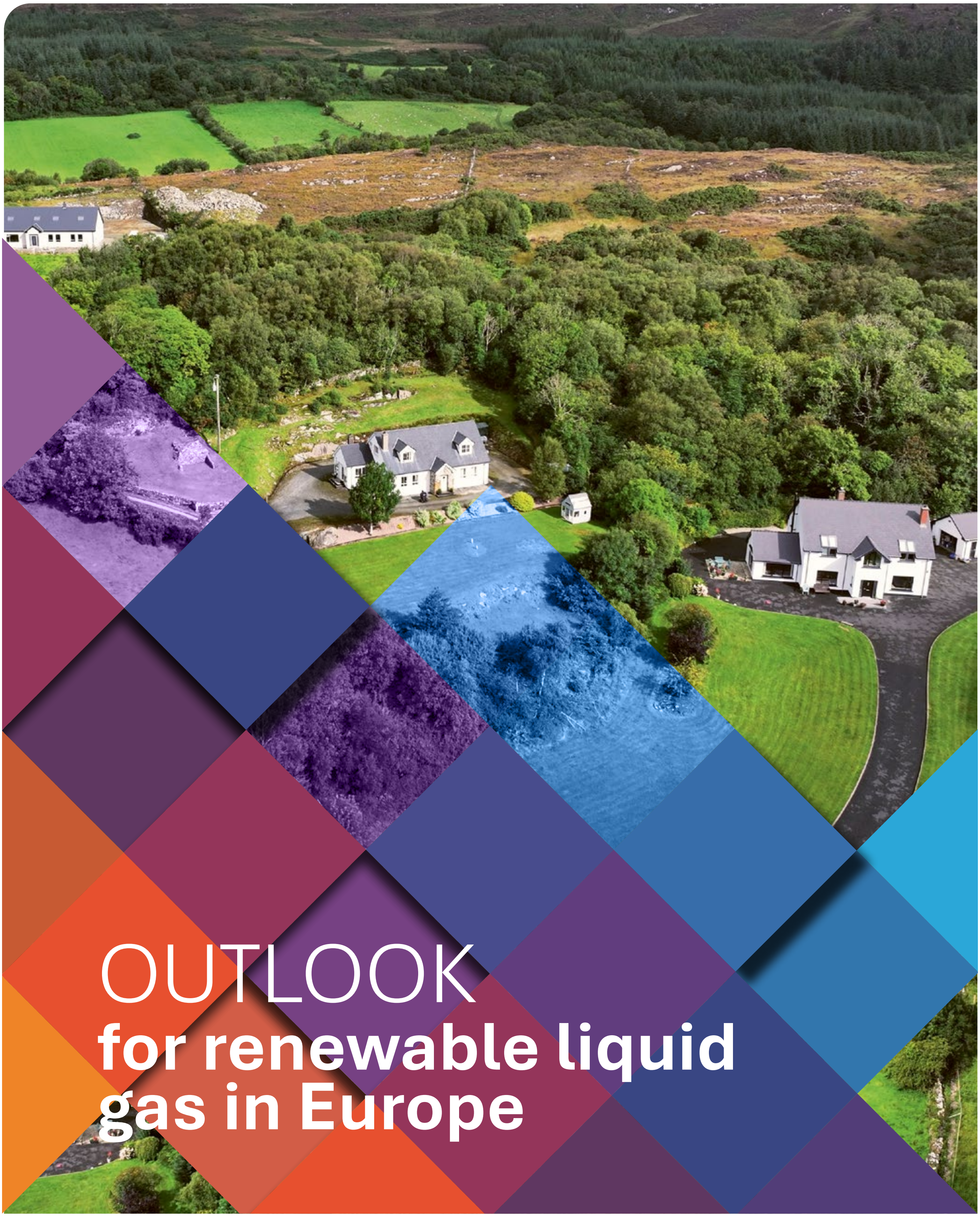
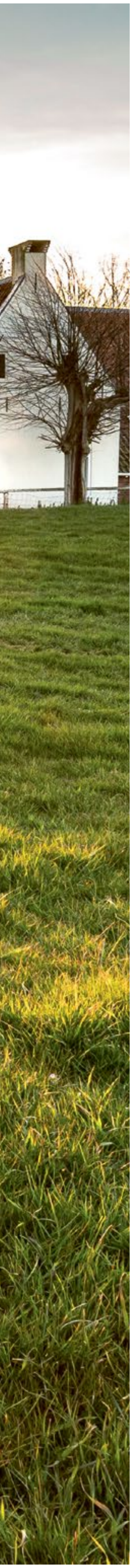


OUTLOOK for renewable liquid gas in Europe

Supply scenarios
for 2040 and 2050

Liquid Gas Europe

Contents



01 Summary

The 2040 and 2050 Renewable Liquid Gas Outlook presents a comprehensive analysis of the potential for renewable liquid gases (rLG), such as renewable LPG and renewable dimethyl ether (renewable DME), to contribute to Europe's decarbonization efforts. Commissioned by Liquid Gas Europe (LGE), the study was conducted by bioeconomy consultants NNFCC in collaboration with modelling experts Frazer-Nash. It focuses on assessing the availability and production potential of rLG in Europe for 2040 and 2050, which aligns with the EU's climate goals.

Using a robust, probabilistic Bayesian network model, the study examines multiple scenarios—baseline, moderate, and high-support—accounting for policy, regulatory factors, and technological developments. The model is designed to handle uncertainty using various inputs, including feedstock availability (without automatic constraints on the rLG outputs), technology efficiencies (that recognize uncertainties related to technology readiness levels), and growth projections for rLG production. This approach ensures realistic and credible forecasts for rLG availability, providing policymakers and industry stakeholders with a dependable outlook.

> Renewable liquid gases can reduce greenhouse gas (GHG) emissions by more than 80% compared to traditional LPG.

The study's key finding is that, with strong policy support and technological advancements, Europe could produce up to 27,389 kt LPG-equivalent (350 TWh) of renewable liquid gas annually by 2050—enough to meet most of Europe's current LPG demand. Feedstock availability, particularly from waste-based sources such as agricultural residues, animal fats, and used cooking oils, will support this production level, even under high-supply scenarios (albeit recognizing uncertainties). The flexibility of production pathways further strengthens the viability of scaling rLG supply.

Renewable liquid gases can reduce greenhouse gas (GHG) emissions by more than 80% compared to traditional LPG, positioning them as a vital solution for decarbonizing off-grid heating, industrial processes, and transport—particularly in rural areas and in industries where electrification is challenging. This makes rLGs critical in achieving Europe's 2040 and 2050 climate targets.

The deployment of renewable liquid gases has the potential to drive Europe's energy transition, particularly in decarbonizing hard-to-abate sectors and supporting innovation across diverse applications, especially in rural areas and transport. However, realizing this potential, as outlined in the High Scenario, requires resolving regulatory complexities and ensuring investment certainty. A coherent and simplified policy framework is essential—one that harmonizes EU legislative definitions, adopts a lifecycle emissions approach, recognizes renewable liquid gases as sustainable investments under EU Taxonomy, reforms energy taxation to align with climate goals, and creates a stable, long-term policy environment. By embracing simplicity and certainty, policymakers can unlock the full potential of renewable liquid gases, ensuring they play a central role in Europe's diverse, resilient, and low-carbon energy future.

02 Introduction

The global energy transition has intensified recently as governments, industries, and consumers seek sustainable alternatives to fossil fuels. Renewable liquid gases (rLG) such as renewable LPG and renewable dimethyl ether (renewable DME) have emerged as essential components in this transition, offering significant greenhouse gas (GHG) emission reductions while providing practical, low-carbon energy solutions. These gases have the potential to play a pivotal role in sectors that are challenging to electrify, particularly in off-grid heating, industrial processes, and transport.

> At the heart of this study is how much rLG can be produced to meet Europe's decarbonization goals by 2040 and 2050.

Recognizing this potential, Liquid Gas Europe (LGE) commissioned a study to explore the future availability and production of renewable liquid gases in Europe for 2040 and 2050. The study, conducted by bioeconomy experts NNFCC in collaboration with modelling specialists Frazer-Nash, was designed to provide a realistic and adaptable forecast of rLG supply under different policy and technological scenarios.

Building on previous analyses, this study introduces a new probabilistic approach using a Bayesian network model to evaluate factors influencing rLG production, including feedstock availability (but without automatic constraints on the rLG outputs), technology efficiency, and market conditions. By modelling three scenarios—baseline, moderate, and high support—the study reflects the uncertainty and variability in the future policy environment. The model's adaptability allows for continuous refinement as new data and technological advancements emerge, making it a valuable tool for policymakers and industry leaders.

At the heart of this study is how much rLG can be produced to meet Europe's decarbonization goals by 2040 and 2050. With more than 80% lower carbon emissions than conventional LPG, rLG provides an immediate and scalable solution to reduce GHG emissions in rural heating, high-temperature industrial applications, and specific transport modes.

Based on the study, this report examines the production potential of rLG and the availability of critical feedstocks, such as agricultural residues, animal fats, and used cooking oils, which will be essential for scaling rLG production. It also highlights the role of co-production pathways, where rLG is a valuable by-product of processes that produce other fuels, such as renewable diesel and sustainable aviation fuel (SAF).

By providing a detailed outlook on rLG availability, this study aims to inform the development of policies that will unlock the full potential of renewable liquid gases, ensuring they are fully integrated into Europe's broader energy transition strategy. With appropriate policy recognition, financial support, and continued innovation, rLG can substantially contribute to achieving Europe's 2040 and 2050 climate targets.

03 Policy recommendations

Unlocking the high scenario for renewable liquid gases: simplicity and certainty

The future of liquid gases depends on a fundamental revision of the EU regulatory framework, ensuring that fuels are assessed based on their overall emissions reduction potential.

The 2040 and 2050 Renewable Liquid Gas Outlook, commissioned by Liquid Gas Europe and conducted by NNFCC and Frazer-Nash, explores two key scenarios for the future of renewable liquid gases (rLG) in Europe:

- **Baseline Scenario**: Limited policy support leads to slow growth, with rLG remaining a niche fuel. Production reaches 2.3 million tonnes (29.6 TWh) by 2040 but stagnates, failing to meet Europe's full decarbonization potential.
- **High Scenario**: With strong regulatory support and investment certainty, rLG production scales up to 27.4 million tonnes (350 TWh) by 2050, reaching its full potential.

This policy document focuses on unlocking the High Scenario, ensuring renewable liquid gases become a mainstream, cost-effective solution for off-grid heating, transport, and hard-to-electrify industrial processes.

The role of renewable liquid gases in Europe's energy transition

Renewable liquid gases are uniquely positioned to contribute to the EU's most pressing objectives, including:

- Enhancing **European energy production**, reducing import dependency, and supporting a circular economy – especially where waste-to-energy solutions are possible.
- Achieving **decarbonization targets** in hard-to-abate sectors and off-grid areas.
- Fostering **innovation and sustainability** in the energy transition.
- Ensuring an **affordable and fair energy transition for** all by supporting policies that maintain competitiveness—for off-grid households, businesses, transport, and industries that rely on diverse energy solutions.

Addressing regulatory barriers: simplicity and certainty

One of the industry's core challenges is ensuring a regulatory framework that enables the development and use of renewable liquid gases across all sectors, including rural communities, transport, and industry. Strong support from national governments and the EU is crucial to creating a stable policy environment that fosters energy security, innovation, market growth, and a competitive and affordable energy transition.

> Strong support from national governments and the EU is crucial to creating a stable policy environment that fosters energy security, innovation, market growth, and a competitive and affordable energy transition.

However, the solution is not just about new policies—it requires addressing the complexity and uncertainty of the existing climate and energy legislative framework. This framework must recognize the diverse energy needs of off-grid rural areas and businesses relying on flexible energy solutions and transport applications, ensuring they are not disadvantaged in the transition. It should be revised and simplified with a technologically neutral approach to ensure all low-carbon energy solutions, including renewable liquid gases, can compete fairly. Addressing these challenges requires focusing on two foundational principles: **simplicity and certainty**.

The current legislative landscape: a case for simplification

European climate and energy legislation, such as the **Fit For 55 Package**, often lack alignment between targets, definitions, and supported technologies, leading to inconsistencies. Key examples include:

- **Fragmented Definitions**: The revised **Energy Performance of Buildings Directive (EPBD)** recognizes biofuels as "carbon-free energy sources." However, the **CO_2 emission performance standards for cars and vans** limit "carbon-neutral fuels" to e-fuels, excluding biofuels/ biogases like renewable liquid gas. Moreover, the definitions given are not consistent with what is laid down in **the Renewable Energy Directive (RED)**, which should instead be the sole reference also for all other specific dossiers.

- **Unclear End-Use Applications**: While the **RePowerEU Plan** sets a target of 35 billion cubic meters (bcm) of biomethane and biogas production annually by 2030, it lacks clarity on end-use applications for biogases like enewable LPG, creating uncertainty for producers and investors.

- **Inconsistent Taxation Policies**: The ongoing revision of the **Energy Taxation Directive (ETD)** presents both an opportunity and a risk. While reforms are needed to ensure fair and technology-neutral taxation, the current proposal does not fully uphold this principle, failing to provide a level playing field for all energy sources. As it stands, the proposal risks discouraging the adoption of renewable fuels — such as biogases, including renewable liquid gases, which are already recognized under the **Renewable Energy Directive (RED)**— while disproportionately favouring electricity, regardless of its production source. Similarly, carbon-neutral fuels, acknowledged under the revised CO_2 emission performance standards for cars and vans, could face taxation policies that hinder their competitiveness. It is crucial that the **Energy Taxation Directive** ensures consistency across EU policies and supports all renewable energy solutions that contribute to decarbonization.

- **Inequitable Emissions Calculation**: The exclusive reliance on tailpipe emissions in the automotive sector—and a similar methodology in the heating sector—fails to account for the full lifecycle emissions of different fuels. This approach distorts fuel comparisons and risks slowing the EU's progress toward effective emissions reductions and decarbonization.

Call to action: turning the high scenario into reality

Decisive action is needed to achieve the full potential of renewable liquid gases outlined in the High Scenario. Policymakers, industry leaders, and stakeholders have a unique opportunity to collaborate in creating a clear, consistent, and supportive regulatory framework that accelerates progress. By addressing complexity and uncertainty, they can unlock the full potential of diverse energy solutions and ensure a balanced approach to decarbonization that goes beyond electrification alone. The future of renewable liquid gases—and their critical role in Europe's energy transition—depends on clear, bold, and coordinated policy measures built on two core principles: **simplicity and certainty.**

1. **Harmonize Definitions Across EU Legislation**: Since biogases and renewable liquid gases are recognized in the Renewable Energy Directive (RED), subsequent legislation—such as the Energy Performance of Buildings Directive (EPBD)—should align with these definitions to ensure consistency. A more coherent approach across policies will eliminate unnecessary inconsistencies, provide regulatory clarity, and send a strong, unified signal to market actors. In this context, an urgent revision of the EPBD is necessary to enhance alignment and consistency.
2. **Revise Emissions Calculation Schemes**: Implement a life-cycle emissions approach to assess the real impact of all energy solutions accurately. This methodology would enhance competitiveness, promote recycling and reuse, and strengthen European industry. Adopting this approach should start with an urgent revision of the Regulation on CO_2 emission performance standards for cars and vans.
3. **Promote Renewable Fuels as Sustainable Investments**: Ensure that renewable liquid gases, irrespective of end use, are classified as sustainable investments under EU Taxonomy. This includes recognizing their role in reducing emissions across heating, transport, and industry sectors with a global approach to emission calculation criteria. Producers need clear business cases to market renewable liquid gases to decarbonize off-grid areas, rather than using it in their internal production processes.
4. **Create a Predictable Investment Environment**: Establish stable policies that provide long-term certainty for investors and producers of renewable liquid gases. Simplified tax frameworks, realistic decarbonization targets, fair calculation models, and streamlined project approvals are crucial to fostering growth.
5. **Align Taxation Policies with Climate Goals**: Reform the Energy Taxation Directive to ensure renewable fuels like bioLPG and other biogases benefit from fair excise duties that reflect their role in achieving EU decarbonization objectives. Ensure that the implementation of EU ETS 2 supports a technology-neutral approach, enabling renewable liquid gases (rLG) to compete fairly as a decarbonization solution.
6. **Enable Demand Across Key Sectors**: Simplified legislation should embrace technology neutrality by enabling consumers to choose renewable liquid gases, ensuring their recognition and fair consideration across diverse applications such as heating, light and heavy-duty transport, maritime transport, industrial applications, and cogeneration.

A simplified and harmonized way forward

We are convinced that achieving the challenging EU de-carbonisation targets cannot be achieved without the contribution of all energy sources, including renewable liquid gases.

Therefore, EU policymakers must embrace a simplified and harmonized approach to technologically neutral climate and energy legislation to unlock the High Scenario for renewable liquid gas. By harmonizing definitions, promoting renewable fuels as sustainable investments, unlocking their decarbonization potential across all sectors—including transport, industry, and off-grid rural areas—and aligning taxation policies with climate goals, Europe can accelerate the deployment of renewable liquid gases and ensure their role in a cleaner and more secure energy future.

Through these actions, the industry will be empowered to deliver on its full potential, providing essential energy solutions for businesses and consumers alike—whether through low-carbon transport options, industrial applications, or heating in rural and off-grid areas. This will drive forward the EU's objectives for energy independence, decarbonization, and economic resilience, ensuring a just and inclusive transition for all.

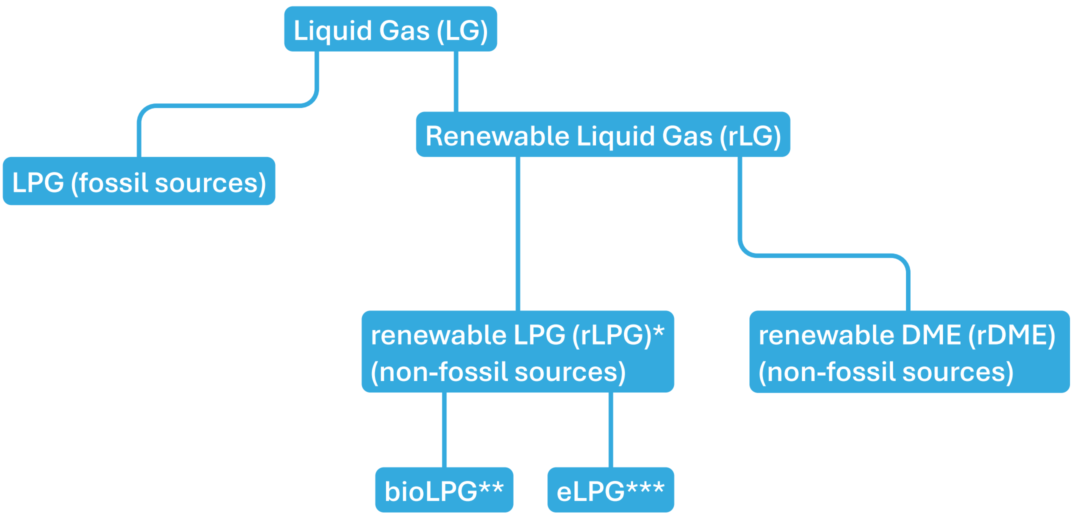
04 What is liquid gas?

About liquid gas

Liquid gas is the generic name for (conventional) LPG, renewable LPG and renewable DME. LPG is a versatile and cleaner-burning fuel made up of propane (C_3H_8) and/or butane (C_4H_{10}). It earns its name because it remains liquid under moderate pressure (6-8 bar at 20°C) and quickly transforms into a flammable gas when released at atmospheric pressure. This makes it far more energy-dense and easier to store and transport than conventional gaseous fuels like natural gas, which require much higher pressures or cryogenic temperatures to liquefy.

LPG burns cleaner, producing a lower impact on air quality than similar fuels used for heating, such as heating oil and biomass, and fuels used for transportation, like diesel and petrol. Additionally, LPG burns with minimal residue and produces fewer harmful emissions, such as Particulate Matter (PM).

LPG's portability is one of its key advantages, as it can be easily transported and stored in cylinders of varying sizes. This makes it ideal for use in off-grid locations, remote areas, and situations where access to traditional energy infrastructure, like natural gas pipelines, is unavailable. LPG cylinders can be delivered to homes, businesses, and industries, ensuring a reliable energy supply in regions with limited connectivity.



* may also be referred to as renewable propane or renewable butane
** may also be referred to as biopropane or biobutane
*** may also be referred to as ePropane or eButane

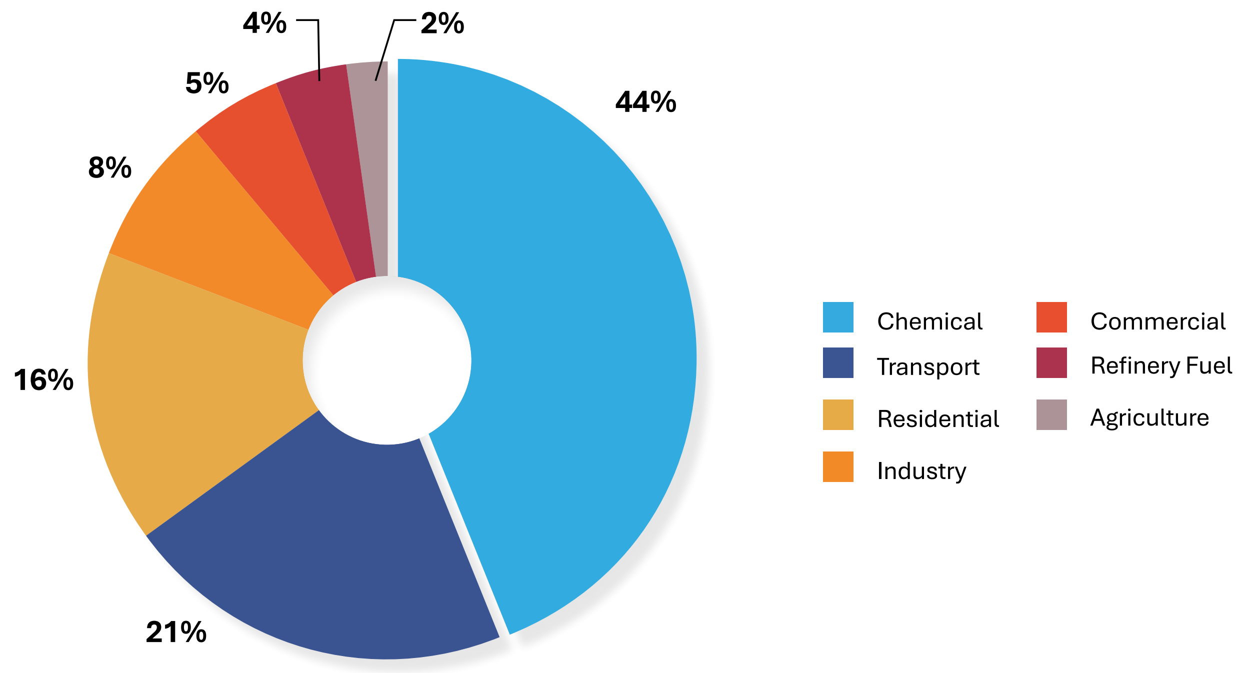


Chart 1: Consumption of LPG by sector in 2023; source: Argus media, Annual LPG Statistical Report 2024

The EU's logistical system for LPG delivery is a well-established and complex network designed to ensure efficient distribution to urban and rural areas. This system includes a mix of rail, road, and sea transport to move LPG from production facilities or import terminals to distribution hubs. Trucks that carry bulk LPG or cylinders from these hubs deliver LPG to end-users such as households, businesses, and industries.

LPG's ability to be stored and transported in liquid form under moderate pressure makes it an ideal energy source for areas not connected to the natural gas grid. This flexibility is significant in rural or remote regions and during disaster relief operations where centralized infrastructure might be compromised. In Europe, suppliers often rely on time-phased planning to optimize deliveries, ensuring that demand is met efficiently while minimizing traffic and congestion at warehouses and distribution centres.

Furthermore, dedicated fleets of LPG delivery trucks play a critical role in maintaining supply, often equipped with the latest technology to ensure safety and accuracy in fuel delivery. Some companies also use rail transport to handle large volumes, especially for industrial customers who require consistent bulk deliveries.

This robust and flexible logistics network ensures that LPG is a reliable energy source for millions of Europeans, providing fuel for heating, industrial processes, and transportation even in the most challenging circumstances.

In Europe, LPG is used in residential heating and cooking, transport (where it is know as Autogas), industrial processes, agriculture, known commercial applications, off-grid power generation, and as a chemical feedstock. LPG plays a crucial role in Europe's energy mix, especially in rural and off-grid areas where access to natural gas infrastructure is limited, providing a reliable, clean, and easily transportable energy source that ensures energy security and reduces reliance on more polluting fuels like coal or oil.

Uses of liquid gas

In 2023 Europe consumed 26 million tonnes of LPG, distributed across various sectors. The chemical industry, where LPG is used as the building block for chemical products, at 43.7% (11.2 million tonnes), was the largest consumer, followed by the transport sector, accounting for 20.8% (5.3 million tonnes). The residential sector represented 16.4%

of the total consumption (4.2 million tonnes), while industry accounted for 7.8% (2 million tonnes). Other significant uses included commercial applications at 4.9% (1.2 million tonnes), refinery fuel at 3.7% (0.9 million tonnes), and agriculture at 2.6% (0.68 million tonnes).

LPG's role in the energy mix in off-grid and rural areas

In the European Union, over 137 million people live in rural areas[1] , many of whom rely on LPG for heating due to a lack of connection to the natural gas grid. Additionally, approximately 700,000 businesses in industries and manufacturing use LPG for heating and process heat. Beyond heating, LPG also plays a crucial role in transport, with around 8.2 million vehicles running on Autogas, supported by a robust network of 32,000 filling stations[2].

LPG's versatility extends beyond heating and transport, supporting various applications across multiple sectors. In the industrial sector, LPG is used for metal processing, including cutting, welding, and brazing, as well as in glass and ceramic production due to its ability to provide high-temperature heat. In the hospitality industry, LPG is commonly used for cooking and heating in restaurants and hotels. It also powers commercial laundries and provides efficient energy solutions for large-scale food production.

In the agricultural sector, in addition to crop drying and frost protection, LPG is employed in grain drying, weed control, and poultry brooding. Its reliability and portability also make it a preferred fuel for power generation, especially in remote or off-grid areas. LPG even has applications in leisure activities, such as outdoor cooking and caravanning, ensuring energy is available wherever needed.

LPG cylinders and equipment can be quickly transported to evacuation centres, hospitals, and other vital locations to restore energy needs. This offers a reliable solution when natural gas or electricity networks are disrupted. LPG also powers essential vehicles and mobile units in recovery efforts, ensuring a swift emergency response[3].

[1] European Commission: A long-term Vision for the EU's Rural Areas - Towards stronger, connected, resilient and prosperous rural areas by 2040
[2] Liquid Gas Europe – Argus Annual Statistical Report 2023
[3] LPG Apps - An overview of the innumerable applications of LPG (lpg-apps.org)

Key benefits of liquid gas

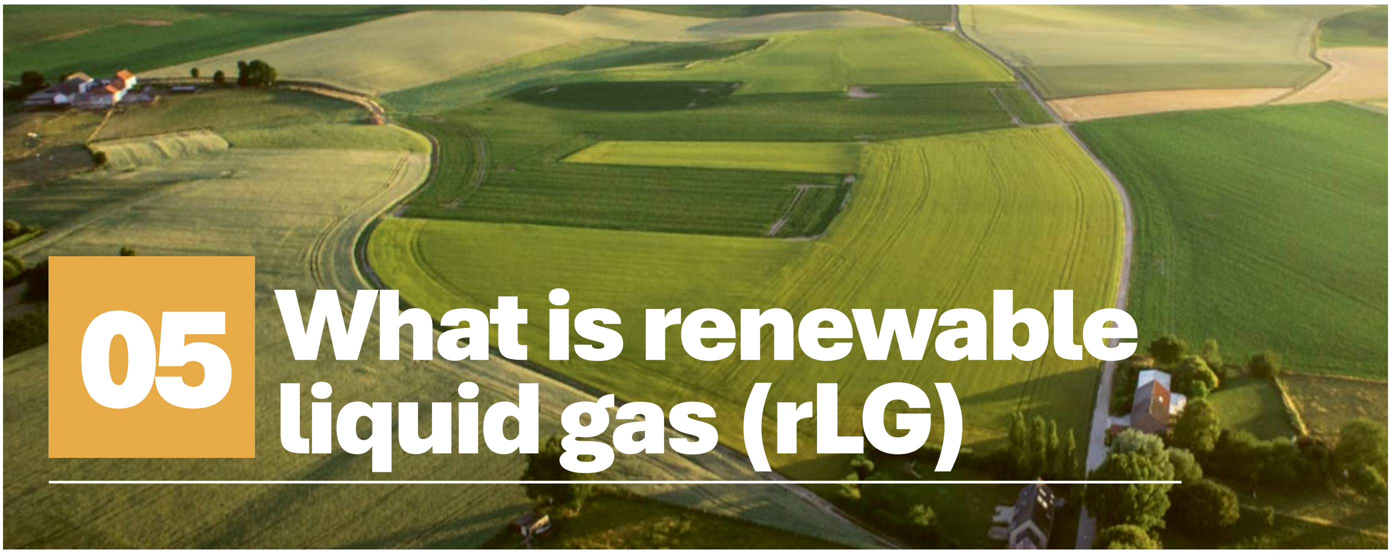
Portability: LPG can be easily transported and stored in cylinders, making it ideal for off-grid locations and remote areas.

Cleaner Burning: Compared to other fossil fuels, it produces lower levels of harmful emissions (NOx, SOx, PM), contributing to better air quality.

Versatility: LPG has many applications, from residential heating and cooking to industrial processes and transport.

Energy Security: It provides a reliable energy source in disaster relief and during disruptions to centralized energy grids.

Cost-Effectiveness: It offers an affordable alternative to other energy sources, especially in rural areas.



05 What is renewable liquid gas (rLG)

Renewable liquid gases (rLG), derived from organic materials or waste products, are more sustainable alternatives to conventional fossil fuels. These include renewable propane, renewable butane, bioLPG, and e-LPG, known collectively as rLPG, and renewable DME (rDME). Renewable propane and butane are typically produced from biomass feedstocks, such as agricultural residues, animal fats, or used cooking oil, and renewable DME is also created using renewable sources (e.g., agricultural residues, forest biomass, and waste streams, etc.), thus all contribute to a circular economy.

The environmental benefits of renewable LPG and renewable DME are substantial. Compared to traditional fossil fuels, they significantly reduce carbon emissions and air pollutants. Moreover, these renewable gases enhance energy security by diversifying the energy supply and harnessing local waste resources, making the energy system more resilient to market fluctuations.

Key benefits of renewable liquid gas

Renewable Source: Renewable liquid gases are derived from renewable biological materials, such as waste oils, fats, and other organic feedstocks, and also, in the case of e-LPG, from renewable power and CO_2, making them a sustainable energy alternative to fossil-derived LPG.

Lower Carbon Footprint: rLG significantly reduces greenhouse gas emissions. Depending on the feedstock used, it can provide more than 80% lower CO_2 emissions than conventional LPG.

Clean Combustion: When combusted, LPG and rLPG produce very low levels of nitrogen oxides (NOx), sulphur oxides (SOx), and particulate matter (PM). This contributes to improved air quality and reduces emissions of harmful pollutants that affect health and the environment.

Drop-In Replacement: renewable LPG can be seamlessly integrated into existing LPG systems without requiring any infrastructure changes, offering a straightforward transition to a cleaner energy option.

Current production of renewable liquid gas in Europe

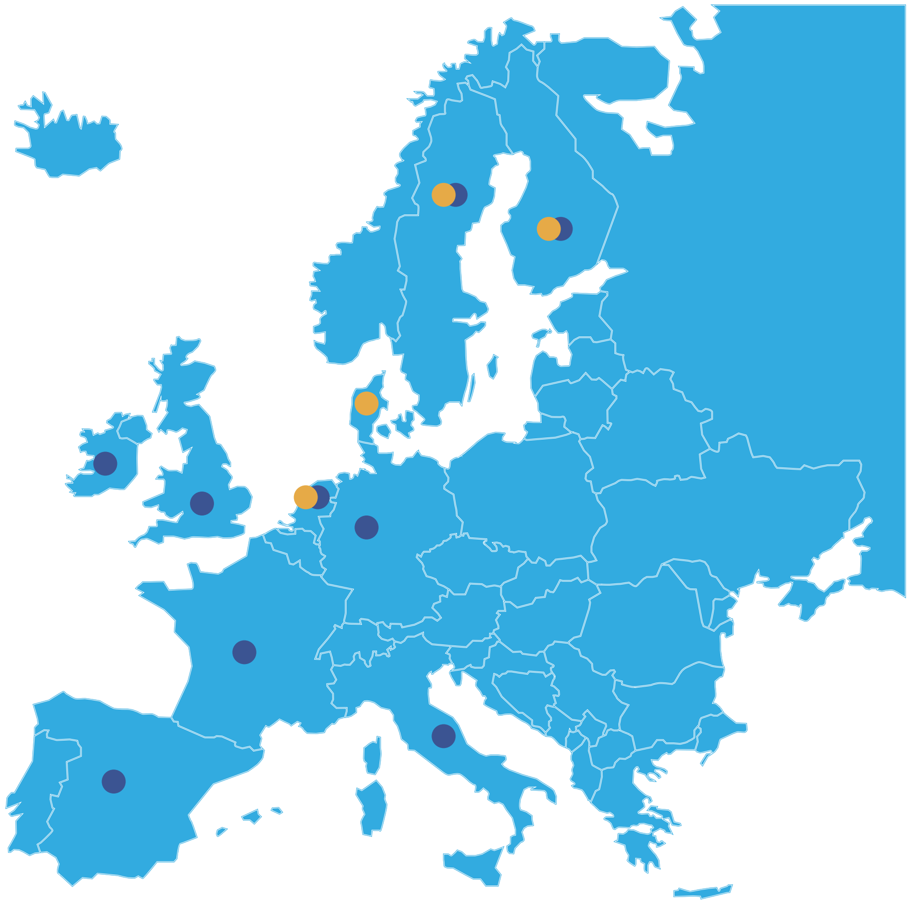
The table and map below show Europe's 2024 distribution and pathway type of operational plant. The table shows the target fuel, the expected capacity in 2030, and the associated rLG (with the rLG being a by-product of the target fuel production).

BioLPG

Chemically identical to conventional LPG, bioLPG is a drop-in solution which can be produced from **sustainable feedstocks** such as plant and animal waste materials, vegetable oils, and biogas, and can be used in existing LPG infrastructure and appliances.

Pathway	No. of facilities	Target fuel	Capacity Target Fuel (tonnes)	Capacity rLG (tonnes)
Pyrolysis	5	Pyrolysis oil	132,000	3,300
HVO & HEFA	18	SAF & renewable diesel	6,605,000	528,400

Table 1: 2024 distribution and pathway type of operational plants in Europe, source NNFCC and Frazer Nash



Map: Operational plant producing renewable liquid gas in Europe today

Renewable liquid gas production pathways

The process of identifying and selecting pathways for renewable liquid gas (rLG) production was led by NNFCC, starting with an extensive literature review and a series of interviews with key stakeholders in the sustainable fuel sector. These stakeholders included representatives from R&D institutes, technology providers, project developers, fuel producers, and potential off-takers involved in pathway innovation and technology development. The review mapped out current and planned rLG projects across Europe, assessing feedstock types and availability, national policies, carbon intensity of the pathways, and market demand for rLG.

Building on this, NNFCC conducted a multicriteria analysis to evaluate the potential of each pathway based on three key factors: feedstock availability (from a literature review), technology development, and commercial viability (based upon a commercial readiness index). From an analysis of twenty-two pathways, a short list of nine were selected for inclusion in the model.

Pathway	Product or co-product	Feedstock used
Alcohol to Fuel (LPG)	Renewable LPG	Ethanol
■ Biogas (LPG)	Renewable LPG	Biogas
■ Biogas (DME)	Renewable DME	Biogas
CO_2 and H2 to fuel (DME)	Renewable DME	CO_2 Hydrogen
CO_2 and H2 to fuel (LPG)	Renewable LPG	CO_2 Hydrogen
Gasification with FT (LPG)	Renewable LPG	MSW Waste wood and residues
■ Gasification (DME)	Renewable DME	MSW Waste wood and residues
HVO & HEFA (LPG)	Renewable LPG	Tallow UCO Virgin Oils
Pyrolysis (LPG)	Renewable LPG	MSW Waste wood and residues Waste tyres

Table 2: Selection of pathways for renewable liquid gas (rLG). All pathways marked with a red dot are dedicated solely to producing rLG; in all other cases, rLG is a by-product of the process. It should be noted, however, that it is possible to modify a process so that the by-product becomes the primary target fuel. Source: NFCC and Frazer Nash.

06 Modelling of renewable liquid gases supply scenarios

Scenarios

The future supply of renewable and recycled carbon[1] liquid gases in Europe depends on various socioeconomic, technological, political, and other factors, each introducing uncertainty into forecasts for 2040 and 2050. The model incorporates qualitative and quantitative assumptions to address this uncertainty to create three distinct market outlooks. These scenarios form the foundation of the model and are defined as follows:

1. **Baseline scenario**: Business as usual, with existing government and industry action
2. **Moderate supply scenario**: Limited government support and technology development
3. **High supply scenario**: Supportive policy frameworks and technology advancement

Assumptions & limitations of the model

This model focuses solely on the domestic and regional production potential for renewable liquid gases and does not account for any imports or exports of fuel. Additionally, the import and export of feedstocks (as opposed to fuels) are not included in the study. The model calculates the feedstock required to meet production outputs such that any feedstock availability constraint can be assessed from the outputs. The proportions of local feedstock needed to achieve the outputs are detailed in the outputs section below.

The potential for renewable liquid gas supply in Europe could be higher than the calculated figures, especially if imports from other regions, such as Asia, were considered. Furthermore, new pathways to the production of rLG will likely emerge, in the future. Still, the output forecasts have included no estimation of the possible increase in availability from these pathways.

Model inputs and parameters

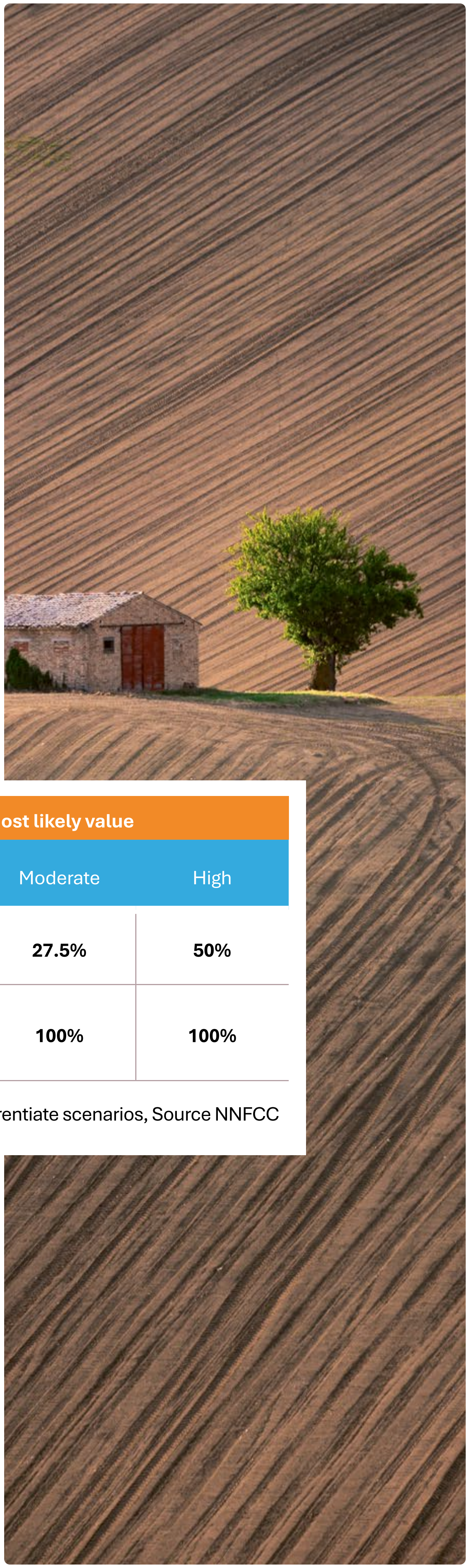
The scenarios are differentiated by adjusting key input parameters to estimate renewable liquid gas production. The model inputs include:

- **Feedstock competition**: Accounts for the alternative uses of available feedstock, thus reducing the feedstock available (see below) for rLG production.
- **Feedstock availability**: Total expected feedstock available in Europe by type.
- **Feedstock conversion efficiency**: The percentage of target fuel output relative to feedstock input for each production pathway.
- **Yield of renewable liquid gases**: The percentage of renewable liquid gas output in relation to the target fuel output for each pathway.

[1] If the feedstock for the pathway is not 100% renewable, for example where fossil carbon waste material is included in municipal solid waste, the resulting fuel is referred to as renewable and recycled carbon.

- **Announced numbers and capacities**: Operational facilities' capacities (target fuel) expected by 2030.
- **Facility and capacity growth rate**: Growth multipliers for 2030-2040 and 2040-2050 have been estimated based on several factors, including the historic growth seen in the production of other biofuels, the technology and commercial readiness of each pathway, and other pathway-specific considerations.
- **Energy densities**: The energy density of liquid gas and feedstock (MJ/kg).
- **Market competition factors**: Adjustments for other uses of renewable liquid gas that reduce the output available for traditional LPG consumers (i.e., exclude chemicals demand).
- **Carbon intensities**: Feasible values for the carbon intensity of renewable liquid gas (in gCO_2e/MJ) have been used purely to compute carbon savings associated with the forecast volumes

An example of varying the model input parameter to differentiate scenarios is as follows:



		Most likely value		
Pathway	Renewable liquid gas as a % of output	Baseline	Moderate	High
Alcohol or fuel (LPG)	**5 - 50%**	**5%**	**27.5%**	**50%**
Biogas (LPG)	**100%**	**100%**	**100%**	**100%**

Table 3: Yield of renewable liquid gases input from each pathway to differentiate scenarios, Source NNFCC and Frazer Nash

Outputs

The model is a custom-built probabilistic Bayesian network, which evaluates the probabilities and conditional dependencies between input variables to forecast potential outcomes. As a result, the outputs are probabilistic rather than deterministic, providing a range of values with a median for each. This approach is more realistic and credible for long-term forecasts, as it accounts for the inherent uncertainty in projections for 2040 and 2050.

07 Outlook on European production of rLG in 2040 and 2050

In the high-supply scenario for 2040, the model forecasts that a median annual production of 7,543 LPG-eq kt (96.4 TWh) of renewable liquid gas (rLG) is achievable, with a range from 4,992 LPG-eq kt (low) to 9,718 LPG-eq kt (high). In 2050, this figure could increase to 27,389 LPG-eq kt (350 TWh) annually under the high-supply scenario, with a range from 16,998 LPG-eq kt (low) to 38,428 LPG-eq kt (high).

The chart's columns represent these values' central estimate (median). At the same time, the lines indicate the full range of potential outcomes (95% confidence interval), showing the minimum to maximum values expected.

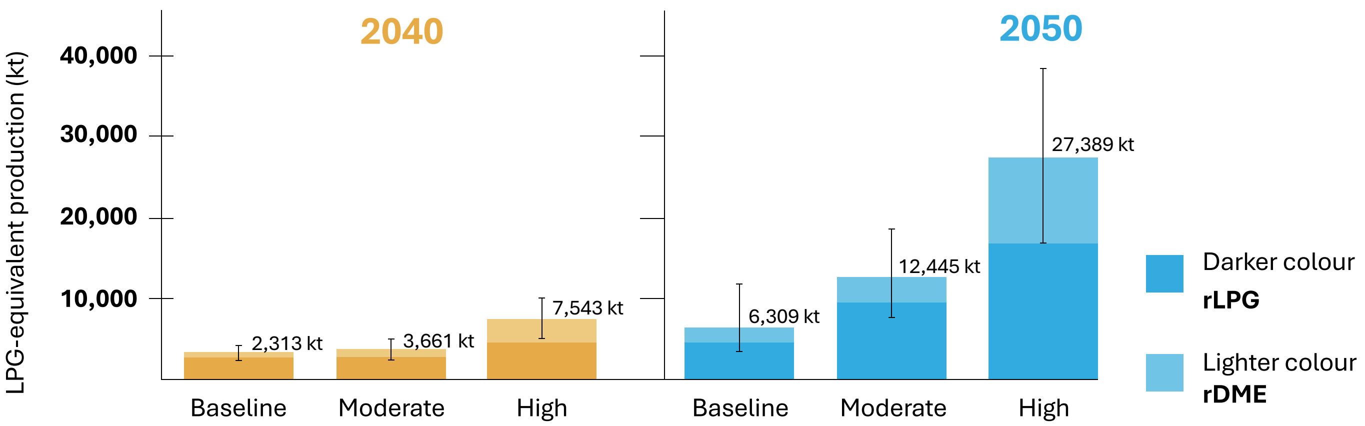


Chart 2: Production scenarios for renewable liquid gas production in 2040 and 2050, Source, NFCC and Frazer Nash

N.B. The LPG industry measures its operations in terms of volume in tonnes (t), kilo tonnes (kt), or megatonnes (Mt). The chart above displays the total production of rLG, which includes both rLG and rDME, but rDME has a slightly lower energy intensity than rLPG, so the chart has been configured to show the total production of rLG in LPG-equivalent volume (LPG-equivalent volume being less than rLG volume)

08 Projected European production of renewable liquid gases by pathway

The charts below show the contribution of each pathway to the production outlook volumes of rLG. The first chart shows the central estimate volume contribution by pathway (e.g., light blue, dark blue and purple columns represent the expected production (in kt) of renewable DME from three pathways), whilst the second chart illustrates the percentage share of the central estimate total by pathway (e.g. in the high scenario, in 2050, approximately 40% of the expected production will be renewable DME from three pathways).

Access to oily feedstocks will probably constrain the continued growth of HVO from 2030-2040.

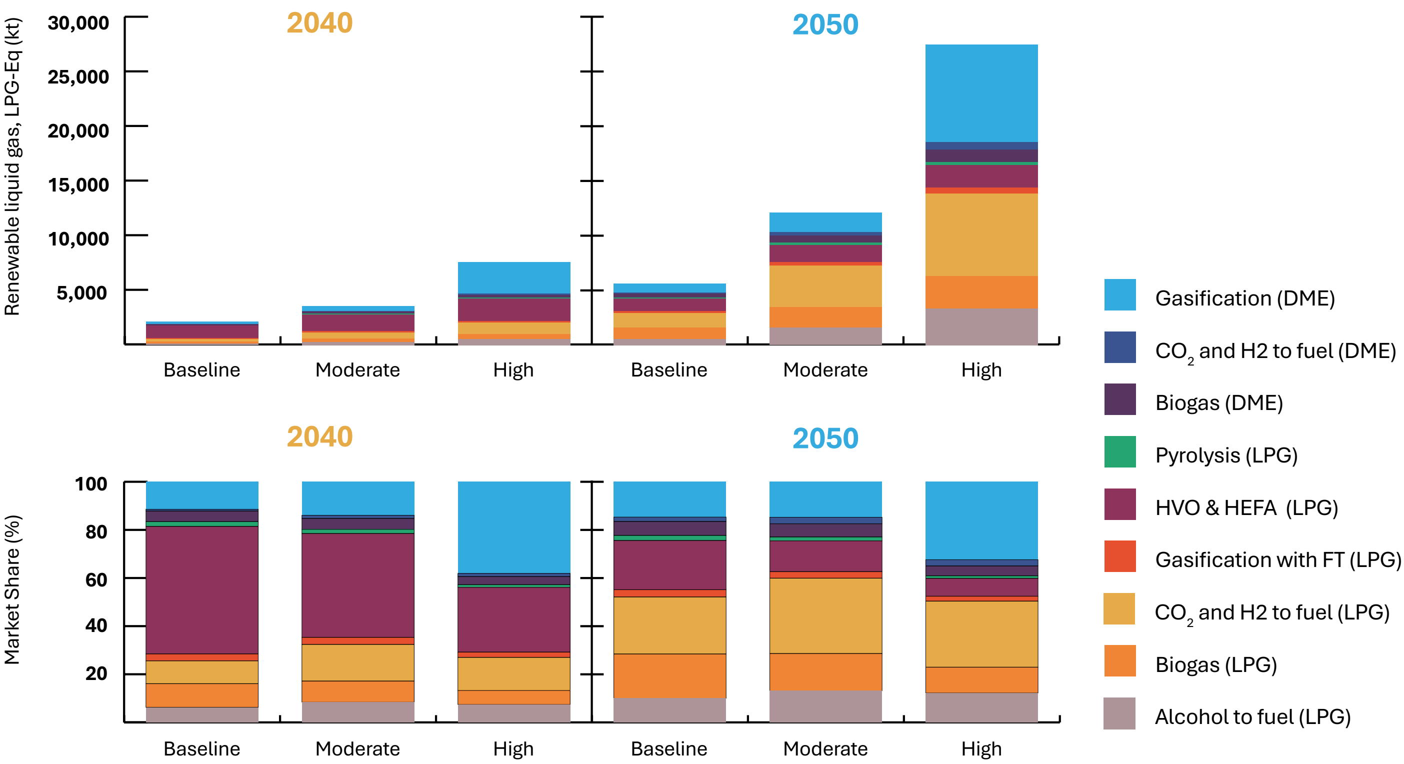


Chart 3: Contribution of each pathway to the production outlook volumes of rLG, source NFCC and Frazer Nash

As the electrification of road transport increases, the availability of ethanol and increased SAF mandates may lead to the increased deployment of Alcohol-to-Jet and other SAF technologies. It is likely that due to SAF mandates from 2030-2040, the supply of rLG as a co-product of SAF production will ramp up with multiple pathways to SAF, including Alcohol-to-Jet. Power-to-liquid (e-fuel), and biomass gasification processes will become commercially crucial due to feedstock availability. Technologies such as pyrolysis may also play an essential role due to feedstock availability with dedicated DME production pathways potentially providing a sizeable part of the renewable liquid gas mix. Towards 2040, Power-to-liquid technologies will start to mature. They may begin to be commercially deployed at scale (depending on the availability of low-cost renewable energy) with renewable and recycled carbon LG produced as a co-product or renewable and recycled carbon DME as a dedicated product.

Projections become more uncertain as the time frame increases, and this must be kept in mind as these forecasts approach 2050. From 2040-2050 it is expected that whilst many of the other technologies will remain relevant for producing renewable and recycled carbon LG including HVO and co-production of rLG alongside SAF (gasification-to-SAF / Alcohol-to-Jet), the deployment of power-to-liquid SAF is likely to expand significantly due to confidence in feedstock availability (CO_2) and access to low-cost renewable electricity which is likely to become more readily available towards 2050 and with barriers to technology costs reducing significantly through economies of scale.

Feedstock requirements

Based on the feedstock conversion efficiency for each pathway, the model calculates the required feedstock volumes to meet the production outlook (excluding Carbon Dioxide and Hydrogen). The table below outlines the feedstock requirements for the high-supply scenario. The “Consumed” figure (in kilo tonnes) represents the amount of feedstock needed to produce both the target fuel and the associated renewable liquid gas (rLG) in by-production pathways (or needed to produce just the rLG in the case of direct pathways). In these cases, the actual feedstock footprint for rLG is lower than the value shown, as it is a by-product of the primary fuel production process (for example for lipids use in HVO pathway rLPG fraction is only 5-10% of the total fuel output).

	2040			2050		
Group	Consumed (kt)	Total (kt)	Proportion (%)	Consumed (kt)	Total (kt)	Proportion (%)
Wastes	27,671	642,843	4.3	90,660	638,854	14.2
Lipids	29,876	44,008	67.9	29,876	44,582	67.0
Ethanol	2,768	20,294	13.6	16,764	21,901	76.5
Biogas	2,372	216,841	1.1	13,379	287,250	4.7

Table 4: ”Total” means total feedstock available in Europe. Whilst the proportions of the total feedstock available for Lipids and Ethanol are high, it should be noted that the pathways that use these feedstocks are those designed to produce another biofuel (e.g., SAF), with the rLG being produced as a by-product of the process. The Total (kt) for each feedstock group is the total available before any feedstock competition factor is applied. Source NFCC and Frazer Nash

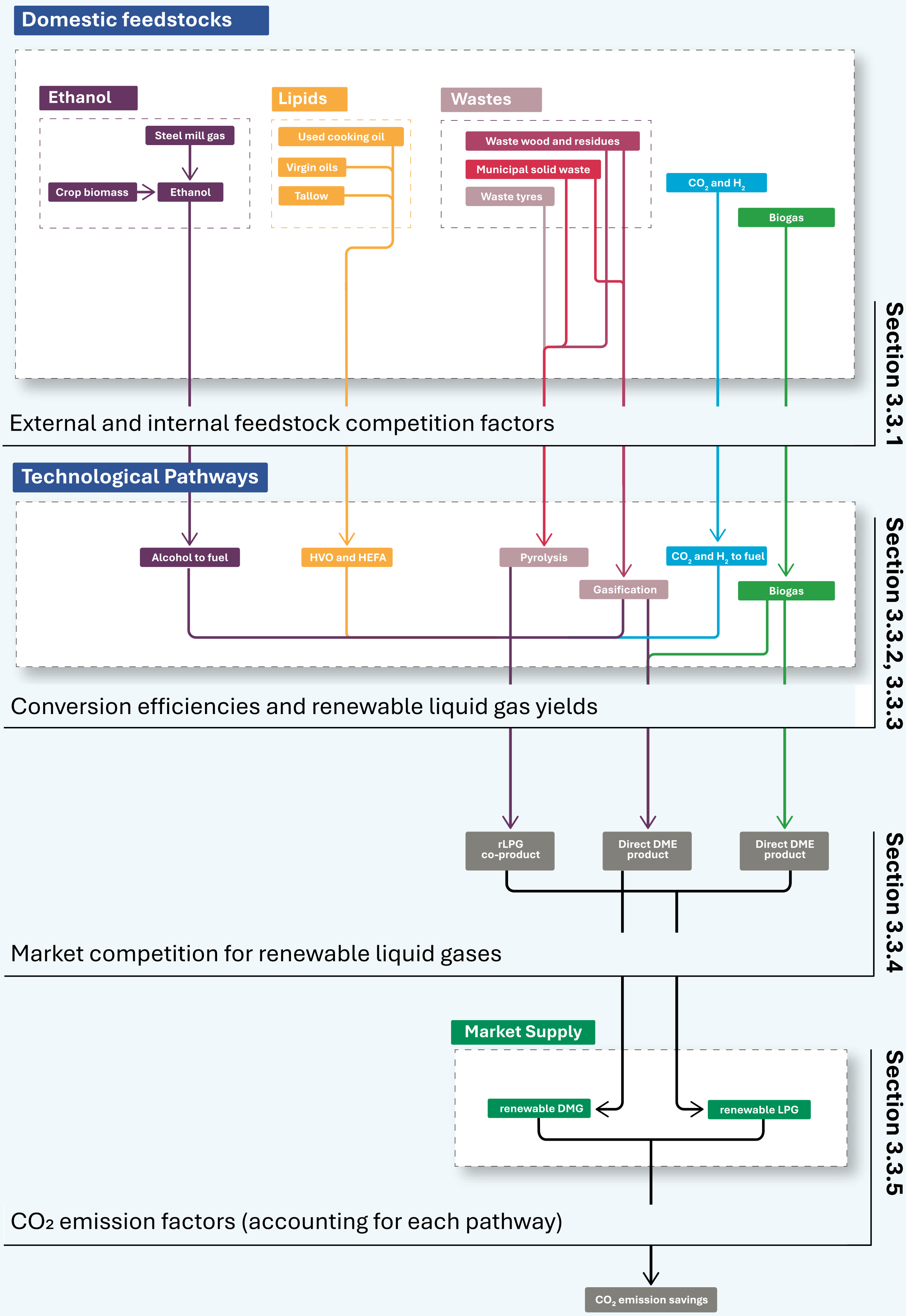


Chart 5: How wastes have been grouped in the model, Source Frazer Nash and NFCC

09 Scenarios for carbon dioxide savings from renewable liquid gases in 2040 and 2050

The CO_2 equivalent emissions savings that can be attained through using renewable liquid gases produced within Europe instead of fossil alternatives are illustrated in the table below:

Table 5: Higher and lower savings against Renewable Energy Directive thresholds. The lower bound was calculated using the heating threshold (80% saving against a comparator of 80 g CO_2e/MJ, so a saving of 64 g CO_2e/MJ), and the higher bound was calculated using the transport threshold (70% saving against a comparator of 94 g CO_2e/MJ, so a saving of 65.8 g CO_2e/MJ). It has been established, by the consultants, via their literature review, that in the case of each pathway (feedstock and technology combination), the resulting fuel can meet these RED saving thresholds.

	2040		2050	
Scenario	**Estimate (kt)**	**Bounds (kt)**	**Estimate (kt)**	**Bounds (kt)**
Baseline	**3,018**	**[2,976, 3,060]**	**9,352**	**[9,222, 9,482]**
Moderate	**7,672**	**[7,565, 7,778]**	**26,915**	**[26,542, 27,289]**
High	**20,467**	**[20,183, 20,751]**	**74,005**	**[72,979, 75,032]**

10 Conclusions

LPG plays a crucial role in Europe's current energy landscape, especially in rural and off-grid areas, serving as a reliable energy source across various sectors. In industry, LPG powers operations such as heating, welding, and machinery, while in agriculture, it is used for irrigation pumps and heating systems. In the transport sector, LPG—via Autogas—is Europe's leading alternative fuel, reducing emissions and air pollution in cities, with further applications in mobile units like food trucks and portable heaters.

These examples underscore LPG's adaptability with a beneficial effect related to its lower carbon footprint. Hence, its widespread use would boost decarbonization of the EU with a consistent transition to renewables. Fortunately, this transition to renewable liquid gases (rLG), such as renewable LPG (rLPG) and renewable dimethyl ether (rDME), offers a clear path forward. With the ability to reduce carbon emissions by more than 80% compared to conventional LPG (and with 100% achievable by leveraging off-setting), rLG represents a near-term solution for deep emissions cuts with minimal disruption to existing systems. As rLPG is chemically identical to LPG, consumers can seamlessly switch to rLG without changing their appliances, benefiting from immediate emission reductions.

The challenge lies in scaling up rLG production to meet growing demand. Currently, not enough rLG is available to serve all users. While alternative solutions such as deep building renovations and installing electric heat pumps are possible, they are costly, disruptive, and slow to implement, especially for regions dependent on LPG for off-grid energy.

This 2040–2050 outlook demonstrates that with existing technologies and available feedstocks, it is feasible to produce a relevant share of the demand of liquid gas in Europe in 2050. However, this can only be achieved with the necessary policy support outlined in this report. Without such backing, consumers may turn to unsustainable alternatives.

Achieving the production of renewable liquid gases at scale, as outlined in the High Scenario, depends on removing regulatory barriers and creating a predictable investment environment. A simplified and technology-neutral legislative framework is essential to unlocking their full potential in Europe's energy transition. This requires harmonizing definitions across EU legislation, adopting a lifecycle emissions approach, recognizing renewable liquid gases as sustainable investments under the EU Taxonomy, reforming energy taxation to align with climate objectives, and establishing long-term policy certainty. By implementing these measures, policymakers can strengthen Europe's energy security, decarbonize hard-to-abate sectors, and ensure a fair transition for rural communities and industries, making renewable liquid gases an integral part of a diverse, resilient, and low-carbon energy system.

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