IRENA

International Renewable Energy Agency

INNOVATION OUTLOOK

ADVANCED LIQUID BIOFUELS

SUMMARY FOR POLICY MAKERS

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IRENA is an intergovernmental organisation that supports countries in their transition to a sustainable energy future, and serves as the principal platform for international co-operation, a centre of excellence, and a repository of policy, technology, resource and financial knowledge on renewable energy. IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar and wind energy, in the pursuit of sustainable development, energy access, energy security and low carbon economic growth and prosperity. ***www.irena.org***

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SUMMARY FOR POLICY MAKERS

The case for advanced biofuels

Biofuels have a vital role to play in the global transition to sustainable, renewable energy. Together with electric vehicles and the increase of renewables in the power mix, they can help us move away from petroleum use in passenger transport. They also provide the only practical alternative to fossil fuel for aeroplanes, ships and heavy freight trucks. Advanced biofuels using lignocellulosic feedstocks, waste and algae could vastly expand the range of resources for fuelling both light and heavy transport.

Advanced liquid biofuels can be refined from a range of sources. These include agricultural residues associated with food crops, as well as forest residues like sawdust from lumber production. Other sources include non-food energy crops, such as rapidly growing grasses like switchgrass and miscanthus, and short rotation tree species like poplar and eucalyptus. Finally, advanced biofuels are produced from solid biogenic waste (including the biogenic fractions of municipal and industrial waste, as well as garden waste) and algae.

These emerging options open up the range of feedstock available to produce biofuels for transport, while mitigating sustainability risks associated with changing land use and competition over food production. Residues do not compete with crop or lumber production but grow alongside it. High-yielding grasses and trees can grow more energy per unit of land area than conventional biofuel crops, potentially mitigating the impact of any land use change.

Innovation Outlook: Advanced Liquid Biofuels provides a global technology outlook for advanced biofuels between 2015 and 2045, specifically for liquid transport fuels for road, shipping and aviation use. It includes details of the technical and non-technical barriers to commercial deployment and the role of innovation in overcoming these barriers. It provides strategies to support advanced biofuels at all stages of the innovation chain. The potential for advanced biofuels is great but so are the challenges. A competitive advanced biofuels industry will depend on innovative technology and supply chains, market development and policy support.

Economic potential of advanced liquid biofuels

Innovation may reduce the cost of advanced biofuels production by up to a third over the next three decades. Yet they may not become consistently competitive without a price on carbon emissions.

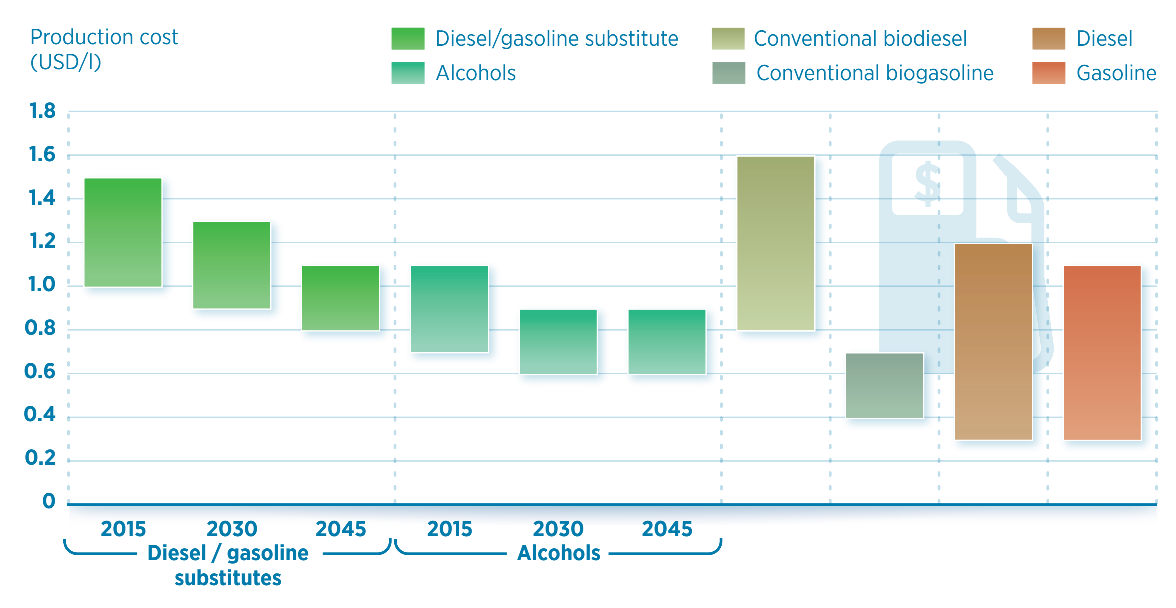
As IRENA's innovation outlook indicates, the production cost of advanced biofuels is likely to amount to USD 0.60-1.10 per litre by 2045. At oil prices below USD 80/bbl, advanced biofuels would have difficulty competing with fossil-based gasoline and diesel. But if oil prices exceed USD 100, most advanced biofuels should be able to compete effectively.

Along with technological innovation, policies and business models are needed to bridge the way, ensuring that plants continue to be built and production costs continue to decline. Different advanced biofuel pathways reduce greenhouse gas (GHG) emissions by 60%-95% compared to the fossil fuel reference value in the European Commission's 2009 Renewable Energy Directive. Carbon pricing in fuel markets, therefore, would promote the emergence of an advanced biofuels industry.

A wide range of feedstocks can be used to produce advanced liquid biofuels. This implies substantial production potential, with different feedstocks presenting different opportunities. In cities, solid municipal waste may be most attractive, since it is cheap and readily available and has few competing non-energy uses. In rural areas, agricultural residues have major potential but also face competing uses such as for animal feed. In countries with substantial wood product industries, forest residues are easy to access and low in cost but also sell into an established and growing market for heat and electricity generation. Dedicated lignocellulosic energy crops have great future potential if more land is made available for a mix of food and fuel. This could be achieved through higher food crop yields and more efficient use of pastureland for livestock, for example.

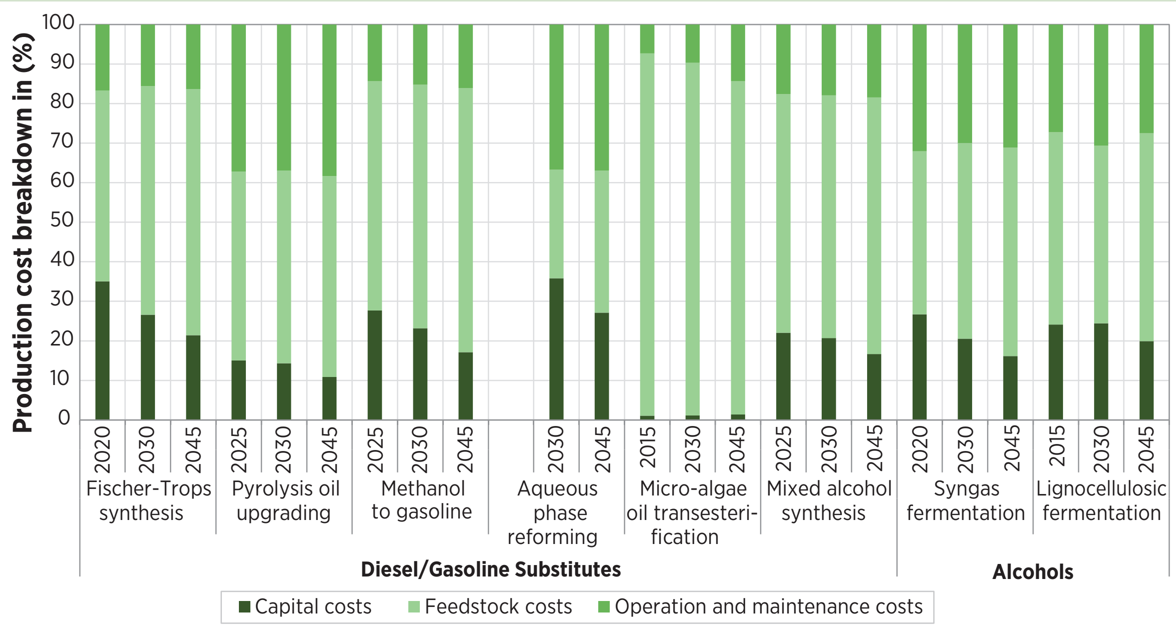
For most advanced biofuels, feedstock costs are the greatest contributor to production costs. Taking into consideration the current costs of wood and agriculture residue, the feedstock cost share is 40%-70% of total production costs. This may grow over time as capital costs decline and technology development makes conversion cheaper and more efficient. Establishing practical, efficient feedstock supply chains at scale, therefore, is crucial for the success of advanced biofuels.

Figure 1: Current and projected fossil-fuel and biofuel production costs



Note: All data have been converted from gigajoules to litres based on lower heating values. Production costs are given in United States dollars (USD) per litre.

Figure 2: Declining capital-cost shares in advanced biofuels production



Note: All data have been converted from gigajoules to litres based on lower heating values. Production costs are given in USD per litre.

Advanced biofuel types and innovation opportunities

Bioethanol (via fermented feedstock) and biomethanol (via gasification) are both ready for commercialisation. Other production pathways are at early stages of development.

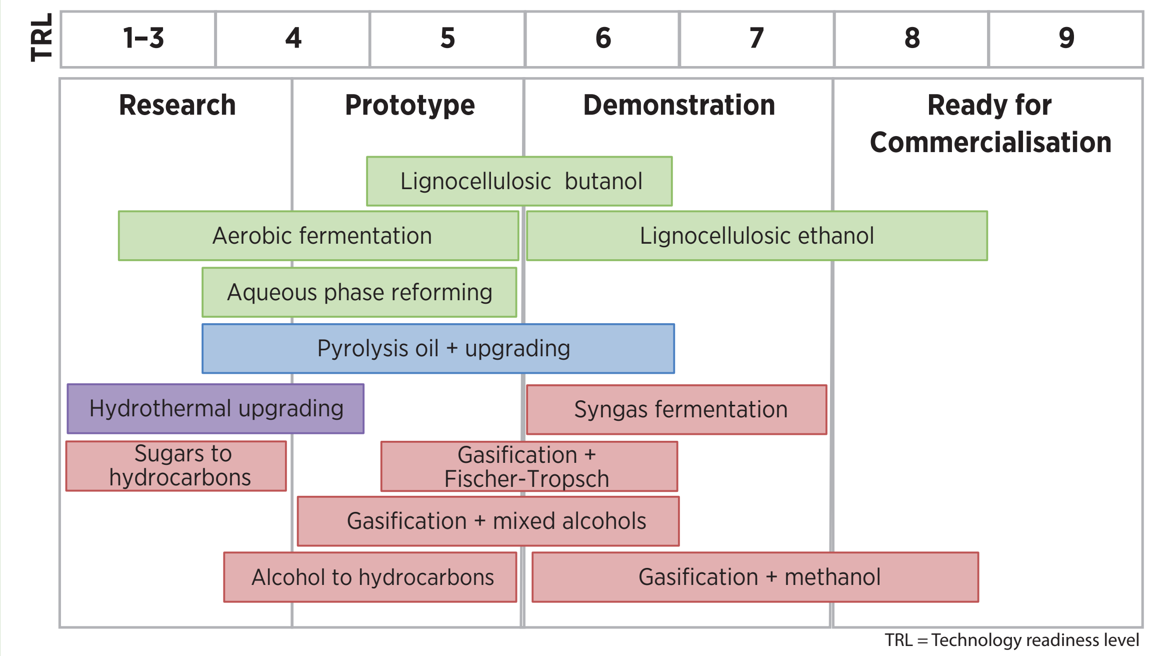
Many technologies can convert lignocellulosic feedstocks into liquid transport fuels:

- **Hydrolysis and fermentation** of lignocellulosic feedstock to produce bioethanol has reached an early commercial phase. In October 2015 DuPont opened the largest such plant in the world with a capacity of 114 million litres per year (DuPont, 2015). Plants using woody biomass are still at an early demonstration stage. Fermentation of ethanol from municipal solid waste is still under development.
- **Gasification** can be applied to a variety of feedstocks to produce a variety of fuels. Many demonstration projects based on gasification with catalytic synthesis have used forestry residues. However, the first commercial plant has been started using municipal solid waste. Enerkem Alberta began producing methanol in 2015 using municipal solid waste from the city of Edmonton, with a capacity of 38 million litres per year (Enerkem, 2015). Gasification followed by syngas fermentation to ethanol is being demonstrated at near-commercial scale using garden waste.
- **Fast pyrolysis and upgrading** can also be applied to a variety of feedstocks to produce a variety of fuels. Agricultural and wood residues and wastes are being used in pilot and demonstration plants. Ensyn has converted its plant in Renfrew, Ontario, to produce around 12 million litres of biofuel per year through fast pyrolysis. It is developing other fast pyrolysis plants in Brazil and Malaysia (Ensyn, 2012).

Advanced biofuels conversion pathways are at different stages of technological maturity. Opportunities for innovation exist across the entire spectrum. Significant improvements to all advanced biofuels pathways will come from process integration.

- **Hydrolysis and fermentation** could be greatly reduced in cost by integrating the two steps to reduce enzyme loading, modifying fermentation organisms and applying membrane separation. In the ButaNexT project, Green Biologics is scaling up its fermentation process and integrating the *in-situ* removal of butanol with a membrane separation process developed by VITO (ButaNexT, 2016).
- **Pyrolysis** is highly efficient and has potentially low processing costs but more effective catalytic upgrading processes are needed. Petrobras and Ensyn have demonstrated co-cracking for pyrolysis oil production in the fluid catalytic cracking process of a conventional refinery.
- **Gasification** needs to prove reliable long-term operation in view of feedstock contaminants. Alter-NRG is working on enhanced pre-treatment and ash removal using plasma gasification or plasma torches. Process optimisation is also needed to achieve target syngas composition.
- **Fischer-Tropsch processes** need to be proved at commercial scale for biomass use. Velocys is one of the companies developing modular units, which may enable reactors to operate at smaller scales to match local feedstock supplies.
- **Alcohol fermentation from syngas** could benefit from modification of fermentation organisms to improve tolerance to contaminants, raise yields and boost selectivity.

Figure 3: Commercialisation status of various advanced biofuels-conversion technologies



Note: Colours represent the principal conversion process, hydrolysis (green), pyrolysis (blue), hydrothermal upgrading (purple) and gasification (red).

Growing needs, slowing deployment

A lack of regulatory clarity and stability, combined with externalities like oil price volatility, hinders investment in advanced biofuel production.

Transport accounts for about a third the world's energy use, half its oil consumption and a fifth of its GHG emissions. There will be around two billion vehicles on the road by 2020. Aviation alone causes nearly 3% of global carbon emissions, a share that is likely to grow. Against this background, further development of sustainable, renewable biofuel options is essential. IRENA's REmap analysis to double the global share of renewable energy by 2030 shows that advanced biofuels production has the potential to grow more than hundredfold over a 15-year period (IRENA, 2016). However, investments have stagnated over the last few years due to lower oil price expectations and a perceived weakening in policy support.

Demonstration and commercial plants at present add 1 billion litres per year of advanced biofuels production capacity, which would meet just 0.04% of the current liquid transport fuel demand. Plants planned or under construction would add another 2 billion litres per year of capacity. These include plants producing ethanol, methanol, mixed alcohols, diesel and jet fuel. Most are in Europe and North America. Clearly, the pace will have to increase exponentially, and projects develop further afield, if advanced liquid biofuels are to fulfil their practical and economic potential for displacing fossil fuels.

Performance prospects over the next three decades

Innovation drives improvements in performance and cuts production costs. This will eliminate the gap in costs between advanced biofuel conversion and today's first-generation biofuels.

Eight advanced biofuels pathways have been compared in terms of potential technical, economic, and environmental performance over the next three decades:

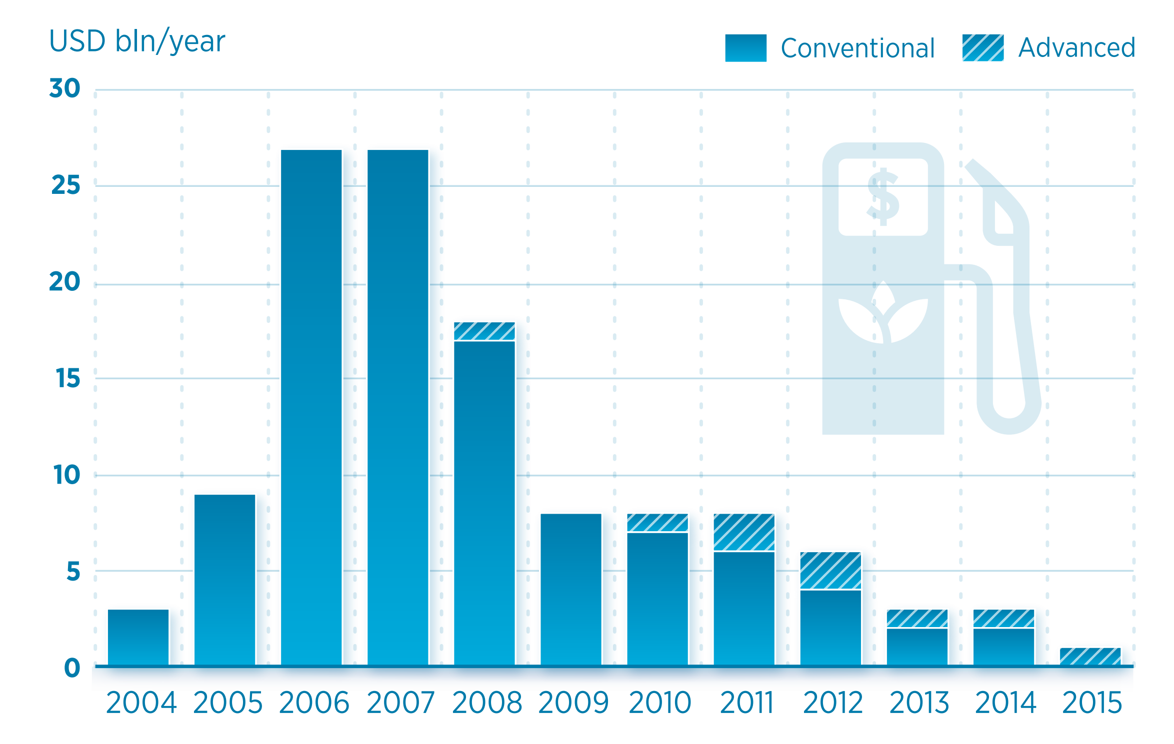
- Forest-residue feedstocks:
  - for gasification and Fischer-Tropsch synthesis to produce diesel and jet fuel
  - in fast pyrolysis and pyrolysis oil upgrading to produce diesel
  - for gasification and methanol synthesis followed by conversion of methanol to gasoline (MTG)
  - in gasification and mixed alcohol synthesis to produce ethanol
  - for gasification and syngas fermentation to produce ethanol
- Agricultural residue conversion to ethanol via hydrolysis and fermentation
- Agricultural residue conversion to diesel via hydrolysis and aqueous phase reforming of sugars
- Micro-algae use for fatty acid methyl ester (FAME) production via oil extraction and transesterification

Processes based on gasification and pyrolysis could produce the highest fuel conversion efficiencies, especially upgraded pyrolysis oil and MTG pathways. Biological conversion processes employed to produce fuel have lower conversion efficiencies, producing lignin as a co-product.

The specific capital investment costs for the first commercial-scale plants up until 2025 are expected to amount to USD 2 000-7 000 per kilowatt $(kW)_{biofuel.}$ Learning rate effects mean all pathways are capable of reducing capital investment costs in the next three decades. Pathways achieving full commercialisation are expected to reduce specific capital investment costs down to USD 700-2000/$kW_{biofuel}$. Between 2035 and 2045 specific capital investment costs for certain advanced biofuels could be similar to the current costs of conventional (corn-based) ethanol. They include lignocellulosic fermentation to ethanol, syngas fermentation, mixed alcohol synthesis, Fischer-Tropsch synthesis, pyrolysis oil upgrading and MTG.

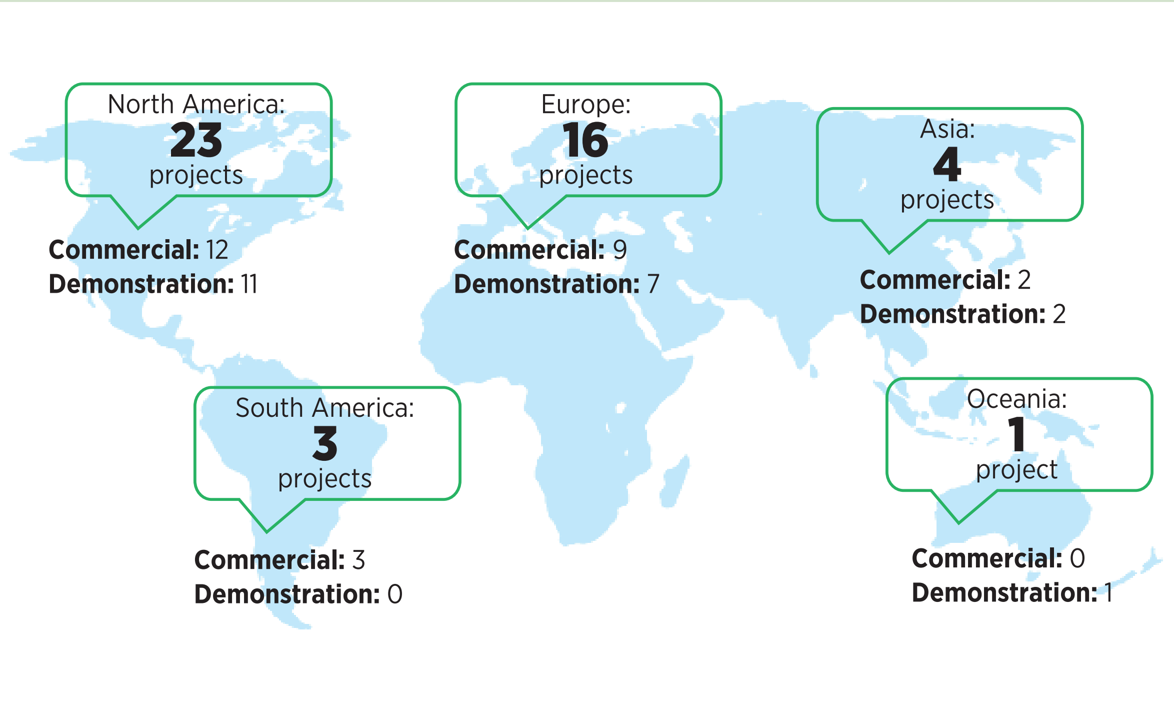
Advanced biofuels pathways produce low GHG, achieving GHG emissions savings of 60%-95% compared to the fossil fuel reference. The exception is micro-algae oil to FAME.

Figure 4: Declining global investment in advanced and conventional biofuels



Note: IRENA analysis based on Bloomberg New Energy Finance (2015), Global Trends in Clean Energy Investment. Investments are given in USD billion per year.

Figure 5: Commercial and demonstration plants for advanced biofuels by region



Supporting advanced liquid biofuels commercialisation

To keep boosting competitiveness, technological development must continue. But other kinds of innovation – related to regulatory frameworks, business models and risk-mitigation instruments – are also vital in order to deploy advanced biofuels at the scale needed.

Speeding up advanced liquid biofuels deployment will require a range of policy support related to energy markets, technology development and enterprise formation.

Technology development: Promising technology pathways need some kind of investment support for early plants to get to the cost-competitive n^{th} plant. First-of-a-kind commercial-scale demonstration plants are essential to progress in advanced biofuels technologies because scaling up laboratory conditions creates many problems. These include, for instance, feedstock impurities and logistical requirements and the need for offtake arrangements. But commercial-scale demonstration plants have a high risk profile and will not usually get built if support is not in place. Grants to build prototypes and pilot plants are needed to test and evaluate technical concepts and claims. Loan guarantees and other risk management tools can be an efficient way to stimulate private debt funding for such projects. They allow governments to reduce the credit risk to financial institutions lending to advanced biofuel projects.

Market formation: Policy incentives, targets or mandates are probably needed to overcome barriers such as insufficient operational experience, immature supply chains and uncertain market size. Co-production of fuel additives, chemicals, plastics and cosmetics in biorefineries can compensate biofuel production costs. Internalising carbon costs in the market would encourage lignocellulosic feedstock production and conversion. Niche markets like as shipping and aviation – which attracts strong industry engagement – can nurture technology progress that may enable the future deployment of advanced biofuels in other markets. New applications for ethanol may expand its potential market as octane booster for highly efficient gasoline engine cars, for example.

Enterprise formation: Advanced biofuels projects can be stimulated by facilitating equity investments in start-up companies. Strategic partnerships and joint ventures could allow companies to share expertise and financial risk. Effective business models coupling agricultural and energy sectors can be documented and shared to help expand advanced biofuels markets. The potential for job and income creation can be highlighted to attract local support.

There is clear political commitment to decarbonise the global economy. However, this has yet to be transformed into action to promote clean and competitive energy alternatives for transport. Industry will remain cautious about making the large-scale investments required to scale up the advanced biofuels production until cost-effective technologies are available and an attractive market exists.

The potential for advanced biofuels is great, but so are the challenges. A competitive industry will depend on innovative technology and supply chains, market development and policy support.

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