CHEMICAL REACTIONS

Renewable Energy Transition

Natrium Capital has looked at the pros, cons and main uses / applications of the significant fuel types which will form the transition to renewable energy. This edition of Chemical Reactions provides an overview of fuel types on the subsequent pages.

There has been significant change in renewable technologies in recent years and they have evolved from partially replacing hydrocarbon fuels with renewables to new types of fuels (hydrogen and ammonia) to new engine concepts such as electric vehicles. With a desire for change, the year 2021 is expected to be the first-time renewable energy surpasses oil and gas as the energy industry's largest area of spending. The pandemic has fuelled the renewable energy transition with overall energy demand falling drastically, resulting in a reduction in CO_2 emissions. This was very promising as it showed that the goals of the Paris Agreement were achievable. Companies and researchers took advantage of this reduction and accelerated the development of renewable technologies.

WIDER PORTFOLIO OF RENEWABLE ENERGY

Bioethanol and **biodiesel** as blended alternative fuels have been common since the 1970s. Although, they were not a popular first fuel option, as both petrol and diesel were cheaper and widely available, increasing concerns about the environment, energy security, and agricultural overproduction in the 1980s led to the increasing popularity of using biofuels. This popularity was further accelerated in 2001 when there was an all-time high in oil prices.

One of the main problems with biofuels is land-use conflict; there are concerns regarding using farmland or agricultural land/sourcing from the rainforest for biomass. However, thanks to technological advancements, the renewable energy portfolio now has more variety and has expanded outside of biofuels.

Alternatives have included using water and air as main feedstock to produce fuel types such as **syngas**, **E-diesel** and **ammonia**. Particularly with syngas, waste gas from industrial facilities and methane from landfills can be captured and used as feedstock rather than releasing them into the atmosphere.

Electricity as an energy source has gained popularity over the past few years with cars running solely off electricity. Electricity can also be easily generated from renewable sources such as **solar**, **wind** and **hydropower**. From using biomass to alternatives from renewable sources and waste feedstock, the problem with land use is addressed and avoided.

Using renewable energy, **green hydrogen** can be produced and used in hydrogen fuel cells. Fuels can also be produced from waste plastics through pyrolysis, contributing to a circular economy. **Pyrolytic oils** have been found to have a high heating value close to conventional diesel, so they have the potential to be used as a diesel alternative or as a blend with diesel.

CHALLENGES WITH RENEWABLE FUEL TYPES

Electricity and hydrogen have become the most prevalent fuel alternatives to traditional fuels, with electricity use being more widespread. However, the main problem with these two alternatives is infrastructure, including the availability of the fuel across networks and the refuelling times.

Hydrogen storage has been a recurring challenge due to its requirement for extreme pressures and cryogenic temperature to stabilise it in a liquid state. Hydrogen is currently only an option for heavy-duty vehicles such as lorries and trucks as they are big enough to hold a large amount of onboard hydrogen. The lack of hydrogen storage technology for smaller vehicles makes it difficult for hydrogen-powered commercial / light-duty vehicles to work efficiently, despite hydrogen fuel cells having a short refuelling time. Therefore, electric vehicles are currently preferred as an alternative for personal transport. Many companies are now installing more EV charging ports, so infrastructure is not as big an issue. However, charging times for electric vehicles can be over 30 minutes and to the consumer, can be seen as a nuisance compared to liquid fuels. Especially for long-distance journeys, extra planning must be done beforehand to map out all the EV charging stations along the journey.

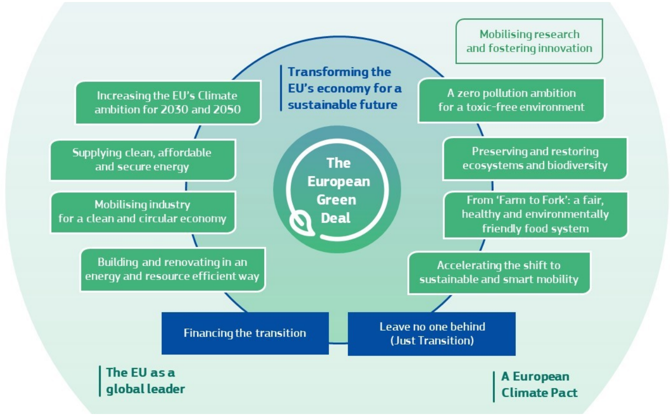
For hydrogen and electricity to become the mainstream fuelling options, there must be further infrastructure developments and technological advancements to make charging vehicles quicker and more efficient. Consumers will be more likely to stray away from purchasing traditionally powered vehicles and be more environmentally wary, ultimately shifting completely away from traditional fuels.

The energy content per litre is less for renewable fuels compared to traditional fuels, making the renewable alternatives more expensive. However, these prices are dropping, and the various carbon taxes on CO_2 emissions is helping to accelerate the shift to using green and low-emission energy sources only.

EU GREEN DEAL

The European Green Deal proposes legislation to tackle the problems from infrastructure to energy poverty. For infrastructure, there are plans to introduce more EV charging points and hydrogen refuelling points along the TEN-T network of Europe to increase accessibility. For energy poverty, there will be a social

Figure 1. *EU Green Deal Infographic*



Source: European Commission

climate fund available. However, these proposed legislations are still under discussion. The longer the discussions take, the shorter amount of time left to act upon the changes to make a difference.

CONCLUSION

The renewable energy transition is gathering pace. However, there are still some key problems deterring consumers from switching from traditional fuels. To be successful there needs to be collaboration between governments and business to improve the supply chain infrastructure for renewable fuels. More developed markets and countries can more easily change their energy habits, but for emerging markets, it will take more time for a significant change to come about.

There is good progress toward greater renewable energy usage, but there should be a constant push towards minimising the effects of climate change and to completely align with the Paris Agreement.

The following tables are intended as a summary and are not an exhaustive list.

CONTACT THE TEAM	ALASDAIR NISBET	LAURA MARSH	SOPHIE BEADSMOORE
Click here	CEO	Director	Analyst
	+44 7767 207 185	+44 7920 473 992	+44 7570 723 639

SUMMARY OF FUEL TYPES

Fuel Type	Most Common Production Method / Description	Advantages	Disadvantages	Main Use
TRADITIONAL				
Diesel / Petrol	**Fractional distillation** of crude oil	Most common fuel used	Many emissions	Transport
GREEN – BIOFUELS				
Biodiesel	**Transesterification** of fats and oils	Carbon neutral	Expensive	Transport
Renewable Fuels / Biofuels	Biochemical and thermochemical **treatment of biomass**	Produces direct, drop-in fuels	Further investment / development needed	Transport
Syngas	**Gasification** of carbon feedstock	Waste gas as feedstock	Inefficient gasification process	Fuels
Ethanol	**Fermentation** of food grains and crops	Produced from sugars/grains	Land use conflict	Transport
GREEN – HYDROGEN				
Green Hydrogen	**Electrolysis** of water	Zero emissions	Very expensive	Power
Blue Hydrogen	**Steam Methane Reforming** - combining high-temperature steam with natural gas	Near-zero emissions	Requires CCUS technology Hydrogen storage is difficult	Power
GREEN – OTHERS				
Electricity	Produced **from a variety of energy sources** (can be renewable or non-renewable sources)	Stored in batteries	Batteries have a finite life – need replacing	Electricity
Fuels from Plastics	**Pyrolysis** (thermal degradation) of plastic waste	Helps circular economy	Energy-intensive process	Transport
Solar Power	**Energy from the sun** converted into thermal or electrical energy	Renewable	Weather dependent	Power
Hydropower	**Water flow** is used to **turn turbines** to generate electricity	Renewable, reliable	Expensive to build dams	Electricity
Wind Power	**Wind** used to **turn turbines** to generate electricity	Renewable, space efficient	Weather dependent	Electricity
OTHER – E-DIESEL				
E-Diesel (Synthetic Fuel)	Produced from **carbon dioxide, water using electricity to create "blue crude"**, which is **then refined** with the Fischer-Tropsch Process	No biomass required, so no land use conflict	Still emissions when burnt	Transport
E-Diesel (Ethanol-Diesel)	Blends of **up to 15% of ethanol in fossil diesel** by volume	Ethanol used can be derived from renewable sources	Needs to be used as a blend with fossil diesel	Transport
OTHERS				
Ammonia	**Reverse fuel cell technology** to produce ammonia from air and water	Can be burnt or be “cracked” into hydrogen	NOx emission problems	Transport

OVERVIEW OF FUEL TYPES

Fuel Type	Description / Method of Production	Advantages	Disadvantages	Main Uses / Applications
TRADITIONAL				
Diesel / Petrol	• **Derived from crude oil** by fractional distillation • Recovered **from oil wells** by drilling	• **Most common transportation fuel used is petrol** and there are many existing and new oil wells to recover more petrol	• Extracting, refining and burning all **release large quantities of greenhouse gases** • A **major contributor** to **climate change** • Many **environmental impacts** of **exploration** and **exploitation** of **petroleum reserves** e.g., oil spills • **Oil** has been a **source of conflict** leading to both state-led-wars and other conflicts • NOx emissions can increase **risk of respiratory conditions**	• Transport • Plants • Machinery
GREEN — BIOFUELS				
Biodiesel	• **Derived from biomass** consisting of long-chain fatty acids esters • Produced by **transesterification of fats and oils into biodiesel** and glycerin • Most typically, a **base-catalysed transesterification** is performed using NaOH – as it requires low temperatures and pressures and has a conversion rate of 98% • The fatty acid biodiesel will depend on the oil/fats used	• **"Carbon neutral"** • Can be **produced from straight vegetable oil**, **animal oil/fats**, **tallow** and **waste oils** • The side product, glycerin can be refined & used for pharma purposes • **Biodegradable** and **non-toxic** – meaning spillages present far less of a risk than fossil diesel spillages • **Higher flash point than fossil diesel** so is safer in a crash	• **Not completely carbon neutral** as CO_2 is released during production of fertilisers used to fertilise oil crop fields • The whole process from transesterification, refining to drying and transporting all **require energy input** – which will **lead to the release of greenhouse gases** • Currently **more expensive** than fossil diesel • **Concerns about B100** (100% biodiesel) and its **impact on engine durability**	• Used in diesel vehicles and engines • Mostly used as a blend with fossil diesel • All manufacturers have approved the use of B5 (5% biodiesel, 95% petroleum diesel) and some approved B20 (20% biodiesel, 80% fossil diesel)
Renewable Fuels / Biofuels	• Derived from **treating biomass through various processes to produce hydrocarbons chemically identical to petroleum -based fuels** ◦ **Hydrotreating** (main route), pyrolysis, gasification, hydrothermal processing, etc. *(cont'd)*	• Can be used "neat", as **drop-in fuels** • **Much of the infrastructure needed is pre-existing** - e.g. oil refineries can be converted with co-processing units • **Compositionally advantageous** - high cetane number, low density, low temp cloud points	• Most common renewable fuel is renewable diesel produced via hydrotreating lipid-based biomass in existing refineries - **little incentive for petroleum companies to transition** • **Investment in other conversion technologies lacking** – various technologies still in R&D or pilot-stage due to this	• Transport • Used without blending

Fuel Type	Description / Method of Production	Advantages	Disadvantages	Main Uses / Applications
		GREEN — BIOFUELS (cont'd)		

Renewable Fuels / Biofuels
 	
(cont'd)
	• Derived from variety of biomasses:
	  ○ **Lipids** (vegetable oils, animal fats, greases)
	  ○ **Cellulosic material** (crop residues, dedicated energy crops & woody (woodland, forest) biomass
		• **2nd gen.** biofuel feed so **no land-use conflict** (unlike 1st gen. feed)		

Syngas	• A gas fuel that consists of **hydrogen** and **carbon monoxide**, with **trace carbon dioxide** • **Gasification of carbon** containing feedstock produces syngas • Syngas can be **manipulated** in many ways **to form different compounds/fuels**	• **Waste gas** from industrial facilities such as steel milling and petroleum refining, **can be captured** and **used to produce syngas**, rather than releasing them into atmosphere • **Methane from landfills** can also be **used as feedstock** • Fuels produced from syngas are **compatible with existing engines** and infrastructure	• **Inefficient gasification process** if by oxygen/air as large portions of inert nitrogen in air that will lead to low quality syngas • **Syngas storage is not common**, and syngas is **usually fed directly for use**, but if to be stored, there are **potential hazards** associated with the failure of proper syngas storage as syngas **contains toxic** and **flammable gases**	• Using Fischer-Tropsch (FT) process to convert syngas to liquid hydrocarbons. Then hydrocracking to break down long hydrocarbons to produce synthetic fuels e.g. jet fuel and diesel • Syngas can be fermented to produce ethanol, methane and acetic acid • Novel use – refining syngas to obtain hydrogen to power hydrogen fuel cells
Ethanol	• Using **food grains and crops** with high starch and sugar content as feedstocks to **produce ethanol** • Most common method is **fermentation** • **Corn** is the **most common feedstock** in **US** • **Sugar beet** and **sugar cane** are the **most common feedstock** in the **rest of the world**	• Produced from **sugars** and **grains** • Great **potential** with **cellulosic ethanol** which is **derived from trees**, **grasses** and **agricultural residues**. They require **less cultivation**, **fertilisers** and **water** to grow than grains so they can be grown on lands that are not suitable for growing food crops	• May be **using farmland or agricultural land/sourcing from rainforest** • **Forest fires** happening recently – which has also become a challenge for carbon offset • The **fermentation process involves burning coal/nat. gas** for heat sources • **Lower energy content**/gas mileage • If **ethanol demand increases**, **prices of food**, e.g. corn, will follow with an **increase** (many animal feeds rely on corn) • **Cellulosic ethanol waste** has **potential environmental consequences** as microorganisms are used	• Used in car engines • Used as a blend with petrol/ diesel • All vehicles made since 2011 in the UK are compatible with E10 (petrol with 10% ethanol) • Not compatible with boats, petrol-powered garden equipment or machinery

Fuel Type	Description / Method of Production	Advantages	Disadvantages	Main Uses / Applications
GREEN — HYDROGEN				
Green Hydrogen	• Production of **hydrogen from renewable energy**, mainly through **electrolysis**	• Generates **zero emissions** • Only **water** and **heat** as **byproducts**	• **Most expensive way to produce hydrogen**	• Transport ∘ Fuel cell vehicles (FCVs) that turn hydrogen and oxygen from the air into electricity to power an electric motor ∘ For some boats and submarines – even use onboard solar panels and wind turbines to generate their own hydrogen for a fuel cell system ∘ Hydrogen can be burnt in internal combustion engines (ICEs) • Domestic use ∘ Stationary, Portable, and Emergency backup power (grid independent) • Commercial and Industrial use – plants
Blue Hydrogen	• Hydrogen that is **derived from natural gas through the process of Steam Methane Reforming** (SMR) or **Auto Thermal Reforming** (ATR) • SMR involves combining **high-temperature steam** with **natural gas**, in the presence of a catalyst, to extract hydrogen • **Carbon monoxide** is also produced but **converted into CO_2** by adding water – producing more hydrogen • **CO_2 emissions are captured** and stored using **Carbon Capture, Utilization and Storage** (CCUS) technology – resulting in nearly pure hydrogen	• **Most economical way to produce hydrogen** • **Nearly zero emissions** when used **with CCUS** • Only **water** and **heat** as **byproducts** **For both…** • Hydrogen fuel cells have **fast filling time** and are **highly efficient**	• **If no CCUS technology is used, CO_2 will be released** – instead of Blue Hydrogen, it will be **Grey Hydrogen** **For both...** • **Highly flammable gas** • Large scale adoption of hydrogen fuel cell technology for automotive applications will **require new refuelling infrastructures** to support it • **Difficult to store and transport hydrogen** – requires high pressures and cryogenic temperatures • **Low energy density by volume** so large quantities must be stored	
GREEN — OTHERS				
Electricity	• Can be **produced from a variety of energy sources**: **natural gas**, **coal**, **nuclear energy**, **wind energy**, **hydropower** and **solar energy** • **Stored in batteries**	• **No emissions**, if the electricity is generated **from renewable sources** • **Reduce fuel costs** • **Infrastructure available** for flexible charging for electric vehicles	• **Hybrid** and **plug-in electric vehicles** are **usually more expensive** • **Batteries** have a **finite life** – needs replacing	• Transport • Domestic use • Commercial and Industrial use – plants • Machinery • Electronics

Fuel Type	Description / Method of Prod.	Advantages	Disadvantages	Main Uses / Applications
GREEN — OTHERS (cont'd)				
Fuels from Plastics (through pyrolysis)	• Derived from the **thermal degradation** of **plastic waste** at different temperatures (300 –900°C) in the absence of oxygen, to produce liquid oil • Using plastic bags, disposable cups and plates, and water bottles (polyethylene (PE), polypropylene (PP), polystyrene (PS) and polyethylene terephthalate (PET) plastics, respectively)	• Can help **achieve a circular economy** in any country • **Pyrolysis oil holds more energy** than coal and some other fuels • Pyrolysis oil has a **high heating value** close to conventional diesel – potential to be used as an alternative source of energy and as transportation fuel after refining/blending with conventional fuels • Pyrolysis oils have **high aromatic content**, such as benzene, toluene and styrene – which can be refined and sold in already established markets	• Pyrolysis is an **energy-intensive process**, and the **oil product requires more energy to be refined before use** • **GHG emissions** are still **released**, and the process **may not be any better than using conventional diesel** • **Emissions/gases** produced from pyrolysis **of some plastic waste** such as PVC are **toxic** and therefore the **pyrolysis emission treatment** technology must be further refined to achieve maximum environmental benefits • **Some produced aromatic hydrocarbons** are known **carcinogens** and can cause serious human health and environmental damage • Need **new catalyst development** to **optimize** the **pyrolysis technology**	• Fuels, power, heat and other valuable chemicals and materials • Produced aromatic compounds can be used as raw material for polymerization in various chemical industries • Pyrolytic liquid oil can be used as an alternative to conventional diesel as a blend – 20:80% blend ratio of pyrolysis oil and conventional diesel, respectively has shown to give similar engine performance to 100% conventional diesel
Solar	• Using **energy from the sun** that is converted into **thermal or electrical energy**	• **Cannot run out of solar energy** • **Reduces Electricity Bills** • **Low Maintenance Costs** • **Solar battery storage systems** to store excess energy – more efficient	• **Weather dependent** • **Expensive to install** solar panels • **Uses a lot of space**	• Converted into electricity using photovoltaics panels • Used to generate thermal energy
Hydro	• Flow of **water** is used to turn **turbines** to **generate electricity**	• **Low emissions** • **Renewable** and water flow is usually **reliable** – generation at any time of day • **Output of electricity can be adjusted** according to demand • **Pumped storage method** uses electricity to pump water back to the reservoir in off peak periods	• **Expensive to build dams** • **Environmental consequences** ◦ Natural flow of river is affected; Affects fish migration patterns; Electricity can be **severely reduced** if there is a **drought** • Difficult to finding **suitable locations** with a large year-round water supply and is close enough to existing power lines	• Generating electricity

Fuel Type	Description / Method of Production	Advantages	Disadvantages	Main Uses / Applications
		GREEN — OTHERS (cont'd)		
Wind	• **Wind** used to turn **turbines** to **generate electricity**	• **Renewable, clean energy** • **Space efficient** – space in between each turbine can be used as farmland	• **Weather dependent** • Manufacturing, transportation and installation of wind turbines releases emissions • **Environmental impact** ◦ A threat to flying wildlife • **Limited locations** – area with strong, reliable wind are usually distanced from infrastructure so there must be new infrastructure to connect the wind farm to the power grid	• Generating electricity
		GREEN — E-DIESEL		

E-diesel
(Synthetic fuel)
	• Produced from **carbon dioxide, water, and electricity** (from renewable energy sources) to **create "blue crude"**, which is then **refined with the Fischer-Tropsch Process** to generate E-diesel
	  ◦ Electrolysis of water
	  ◦ Reaction of hydrogen and carbon dioxide to form syngas
	  ◦ Syngas reaction to produce blue crude
	• About 80% of blue crude can be converted into e-diesel
		• **Carbon neutral** fuel – if the energy sources to drive the process are from carbon-neutral sources
		• **No biomass required** – so no problems with land use
		• **Cleaner energy** than fossil fuels – **less NOx emissions**
		• E-diesel contains no sulfur or aromatics
		• Has a **high cetane number** so it burns readily and completely
			• **Still emissions** as they are used in internal combustion engines	• Suitable for some aircrafts with diesel engines
				• Compatible with all diesel engines – can be used as a blend with typical fossil diesel or as a replacement fuel in automobiles

Fuel Type	Description / Method of Production	Advantages	Disadvantages	Main Uses / Applications
GREEN — E-DIESEL (cont'd)				
E-diesel **(Ethanol-Diesel)**	• Blends of **up to 15% of ethanol in fossil diesel** by volume • Ethanol can be derived from renewable sources	• **Less PM** (particulate matter) **emissions** compared to using just fossil diesel • **Improves engine power** and specific fuel consumption (SFC)	• Needs to be **used as a blend** with fossil diesel **Requires an additive package** to help **maintain blend stability and other properties** (cetane number and lubricity) • **Effects on NOx, CO and HC emissions are unknown** and contradicting in various reports	• Compatible with most diesel engines
OTHERS				

Ammonia	• Using **reverse fuel cells** to **produce ammonia from air and water** with **renewable energy** – a far more environmentally friendly technique than the **Haber-Bosch process**
	• Water reacts at the anode to make **hydrogen ions** (H+), which migrate to the cathode where they **react with nitrogen** (N_2) to **form ammonia** – this reaction is efficient, but slow
		• Ammonia is a **flammable gas**, but the **risk of fire is low compared to other fuels**
		• Ammonia liquefies easily under light pressure and chilling (compared to hydrogen) – **easy to transport to power plants**
		• **Can also be "cracked" into hydrogen** and used for fuel cell vehicles
			• Ammonia is **toxic**, therefore using ammonia fuel requires a **suitable sensing system** and **additional safety systems** such as ventilation and water sprays **to dissolve ammonia**
			• If used in **internal combustion engines**, there will be **NOx emission problems** – a requirement for **extra engine design** and systematic tuning to **reduce NOx emissions**
			• Ammonia has the **tendency to dissolve fuel cell membrane** – **need advancements in fuel cell technology** – currently solid-oxide fuel cells (SOFC) and polymer electrolyte membrane fuel cells (PEMFC) are proving ammonia to be a viable fuel for fuel cells
				• Ammonia power plants
				  ◦ Converted into electricity in a power plant customized to burn ammonia
				• Cracked to form hydrogen to use in traditional fuel cells
				  ◦ The energy penalty for converting the hydrogen to ammonia and back is roughly the same as chilling hydrogen
				  ◦ Far more already existing infrastructure for handling and transporting ammonia than hydrogen
				• Ammonia driven marine operations
				• Used in internal combustion (IC) engines
				• Fertilizer