Clearthought

Green Hydrogen

Green hydrogen has a key role to play in the zero-carbon future of the automotive sector

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Market overview

A number of specific properties make hydrogen a particularly viable energy carrier as the world moves towards net zero. According to the EU[1] its benefits include:

- Its use for energy purposes does not cause greenhouse gas (GHG) emissions as water is the only by-product of the process
- It can be stored over long periods
- It can be used for producing other gases, such as methane or ammonia, as well as liquid fuels
- Existing infrastructure (gas transport and gas storage) can be repurposed for hydrogen, and a certain proportion of hydrogen can be blended with natural gas
- It has a higher energy density relative to volume than batteries, making it a suitable fuel for long distance and heavy goods transport.

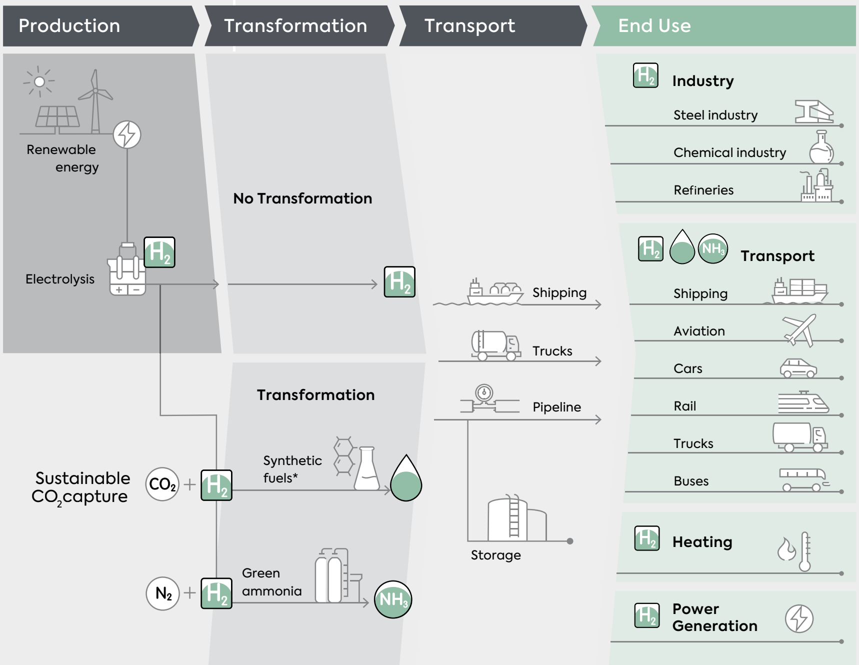
Against this backdrop, interest in green hydrogen policies is soaring across the world with many countries publishing national hydrogen strategies and investors pouring billions into the rapidly evolving sector.

A recent report[2] claimed that green hydrogen was poised to become a "once-in-a-generation opportunity" and could give rise to a €10tn addressable market globally by 2050 for the utilities industry alone. The report stated that in Europe, the green hydrogen industry could attract more than €2tn of investment by that date. Up to €1.4tn of this figure would come from capex in renewables to power electrolysers, €400bn each in both hydrogen power plants and electrolysers, and a further €100bn in gas infrastructure.

Looking ahead to 2050, green hydrogen in Europe has the potential to double power demand while also leading to a profound reconfiguration of the gas grid. Gas power plants could also be converted to burn hydrogen instead to provide backup power in periods of abnormally high demand and/or extremely low production from renewables.

Meanwhile, interest in how green hydrogen can help decarbonise the world has been given added impetus by the conflict in Ukraine which has, in particular, forced European governments to speed up their transitions to renewables and to urgently find ways of reducing their dependence on Russian gas supplies.

Green hydrogen production, conversion and end uses across the energy system



Source: Green Hydrogen, a guide to policy making: International Renewable Energy Agency, 2020

What is 'green' hydrogen?

Hydrogen requires other sources of energy, such as natural gas or electricity and water, to be generated. As such there are a number of different types of hydrogen that can be produced:

Green hydrogen: produced from renewable energy. The most established technology option for producing green hydrogen is water electrolysis fuelled by renewable electricity. Electrolysis creates green hydrogen by separating water into hydrogen and oxygen.

Grey hydrogen: produced with fossil fuels, either from methane using steam methane reforming (SMR) or coal gasification. This is the current dominant technology. The use of grey hydrogen entails substantial CO_2 emissions.

Blue hydrogen: refers to grey hydrogen with carbon capture and storage (CCS). Around three-quarters of hydrogen is currently produced from natural gas. Retrofitting with CCS would allow the continued use of existing assets while still achieving lower greenhouse gas emissions.

Turquoise hydrogen: combines the use of natural gas as feedstock with no CO_2 production. Through the process of pyrolysis, the carbon in the methane becomes solid carbon black.

Until now hydrogen that meets certain sustainability criteria has been termed 'green', but there is no universally agreed definition and no international green hydrogen standard.

For green hydrogen to have a role in future low-carbon energy systems it is critical that it demonstrates that it has sufficiently low carbon emissions. Molecules of green hydrogen are identical to those of grey hydrogen, so once hydrogen has been produced a certification system is needed that allows end users and governments to know its origin and quality. As such, guarantees of origin are essential for hydrogen to become a tradeable commodity.

One study[3] says international standards are now starting to be discussed by national and international standardisation organisations and policy makers, while a range of approaches have been taken to defining green hydrogen and guarantees of origin. These vary on whether green hydrogen must be produced from renewable energy, on the boundaries of the carbon accounting system, on the emission thresholds at which hydrogen is considered green, and on the extent to which feedstocks and production technologies are included in the scheme.

Selected shades of hydrogen

Colour	Grey Hydrogen	Blue Hydrogen	Turqoise Hydrogen	Green Hydrogen
Pyrolysis	SMR or gasification	SMR or gasification with carbon capture (85–95%)	Pyrolysis	Electrolysis
Source	Methane or coal	Methane or coal	Methane	Renewable electricity

Note: SMR = steam methane reforming.
* Turquoise hydrogen is an emerging decarbonisation option.

Source: Green Hydrogen, a guide to policy making: International Renewable Energy Agency, 2020

1: EU Hydrogen Policy: Hydrogen as an energy carrier for a climate-neutral economy. European Parliament, 2021
2: Green Hydrogen: The next transformational driver of the utilities industry. Goldman Sachs, 2020
3: Green Hydrogen characterisation initiatives: Definitions, standards, guarantees of origin, and challenges (Velazques Abad and Dodds, 2020)

Energy transition

The International Renewable Energy Agency (IRENA) say[4] that green hydrogen is still only at the technology readiness stage in most sectors, so its transition from niche to widespread energy carrier requires an integrated policy approach in terms of technology readiness, market penetration and market growth. It cites a number of specific challenges that need to be overcome:

High production costs
Green hydrogen produced using electricity from a variable renewable energy plant is two to three times more expensive than grey hydrogen and adopting green hydrogen technologies for end uses can be expensive. For instance, vehicles with fuel cells and hydrogen tanks cost at least one and a half to two times more than their fossil fuel counterparts.

Lack of infrastructure
Hydrogen has to date been produced close to where it is used, with limited dedicated transport infrastructure. Natural gas infrastructure could be repurposed for hydrogen, but not all regions of the world have existing infrastructure.

Energy losses
Green hydrogen incurs significant energy losses at each stage of the value chain. For instance, about 30-35% of the energy used to produce hydrogen through electrolysis is lost. The total energy loss will depend on the final use of hydrogen and the higher the energy losses, the more renewable electricity capacity will be needed to produce green hydrogen. One of the key issues is whether the pace of development of renewables will be fast enough to meet the needs of both the electrification of end-uses and the development of a global supply chain in green hydrogen.

Value recognition
There is currently no green hydrogen market and no valuation of the lower GHG emissions that green hydrogen can deliver. There are also no internationally recognised ways of differentiating green from grey hydrogen.

Goldman Sachs[2] add there are other potential bottlenecks and risks such as supply constraints in electrolysis given that the industry is in its early stages. Despite strong policy support by the EU and central governments, local authorities may – at least temporarily – also be overwhelmed by the strong acceleration in requests to develop renewables, install new equipment (such as electrolysers and hydrogen turbine power plants), and upgrade gas pipelines.

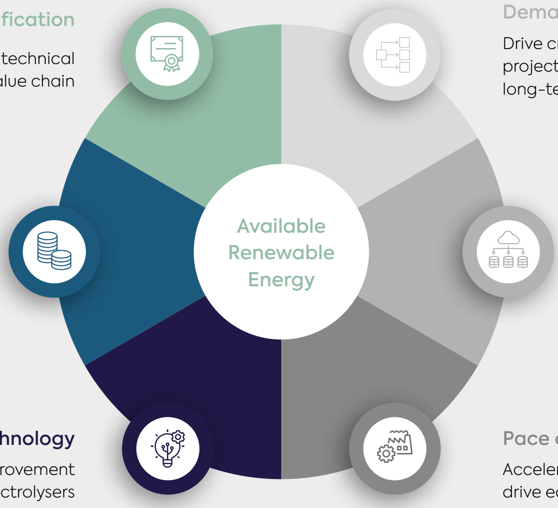
IRENA and the World Economic Forum recently produced a roadmap[5] which identifies the key actions required to reach a scaled and traded green hydrogen market. The document stresses that in order to accelerate the market, key enabling measures for international/regionally traded markets must be brought forward and accelerated over the next five to ten years. As we can see below, these enabling measures will specifically direct a number of objectives to accelerate the hydrogen market.

Key objectives per barrier

Standards & Certification
Ensure clarity on carbon intensity, safety and technical standards for projects across the value chain

Demand
Drive critical mass demand through major hydrogen projects leveraging efficient allocation of capital, long-term certainty and sectoral targets

Cost
Remove cost and regulatory barriers for production and deploy mechanisms to accelerate demand in hard-to-abate sectors



Infrastructure
Ensure early ramp up of 'no regret' infrastructure, including transport, storage, conversion and trade facilities

Tehnology
Focus on innovation and R&D to enable improvement on cost, efficiency and durability of electrolysers

Pace of development
Accelerate scale-up of elecrolyser manufacturing to drive economies of scale

Source: World Economic Forum/IRENA

Outlook

In Europe much hope on the growth of the industry is pinned on the European Commission's 2030 Hydrogen Strategy which details the central role that hydrogen is to play in the European economy.

The strategy identifies a phase between 2024 and 2030 where infrastructure will be increasingly deployed and where hydrogen would be used not only for renewable energy balancing but also in industry and transport applications, and for residential and commercial heating.

This phase also envisages developing the EU-wide logistical infrastructure (initially networks of refuelling stations), establishing larger-scale storage facilities, and planning a pan-European hydrogen network, possibly including the repurposing of existing gas infrastructure.

Research and innovation funding will play a significant role in the coming decade to boost efficiency and scale, help deliver cost-effective electrolysers in gigawatt (GW) scale, and reach cost-competitiveness of renewable hydrogen by 2030. Beyond 2030, renewable hydrogen technologies would reach maturity with large-scale deployment and demand expected.

Meanwhile, in the transport sector the rapidly declining cost and technological improvement of batteries have already made electric vehicles a very attractive solution. But, while batteries are a suitable technology for light-duty road vehicles or urban buses, their lower energy density – compared to fossil fuels – limits their use for long distance road transport, shipping or aviation.

Clean hydrogen is therefore a promising fuel for transport applications because it offers a higher driving range than batteries and quick refuelling.

Beyond 2030 renewable hydrogen technologies would reach maturity with large-scale deployment and demand expected.

2: Green Hydrogen: The next transformational driver of the utilities industry. Goldman Sachs, 2020
4: Green Hydrogen, a guide to policy making: International Renewable Energy Agency, 2020
5: Enabling measures roadmap for green hydrogen, World Economic Forum/IRENA

The technology

Fuel cells

Electricity is generated in a fuel cell through a chemical reaction between the hydrogen fuel and oxygen. Though a fuel cell can use almost any hydrocarbon as its fuel, hydrogen's advantage is its high energy efficiency. As it can produce electricity without energy-wasting combustion, it is possible to convert 83% of the energy in a hydrogen molecule[1] into electricity – more than double the energy efficiency of a petrol engine.

In fuel-cell hydrogen cars[2] the hydrogen is stored in tanks and compressed to an extremely high pressure. It is then converted into electricity through a PEM fuel cell which powers an electrical motor. A rechargeable battery is added to provide additional power for the engine, mainly for braking and accelerating.

Hydrogen cars offer multiple benefits, such as no pollutant emissions, lower noise, and operability at low temperatures. However, as discussed above, infrastructure will be key as large-scale deployment will require refuelling infrastructure and compliance with local regulations, especially on tank safety.

Likewise, vans, buses and trucks can be equipped with the same combination of a hydrogen tank, PEM fuel cell, battery, and electric motor. The use of such technology in towns and cities by the likes of parcel delivery companies, waste disposal trucks, and buses is a particularly fascinating prospect. Because of the cyclical nature of many trips a refuelling station could be centralised and potentially shared between many different vehicles.

As such many analysts believe that heavy-duty trucks and buses could be the most obvious application for initial widespread deployment of hydrogen vehicles.

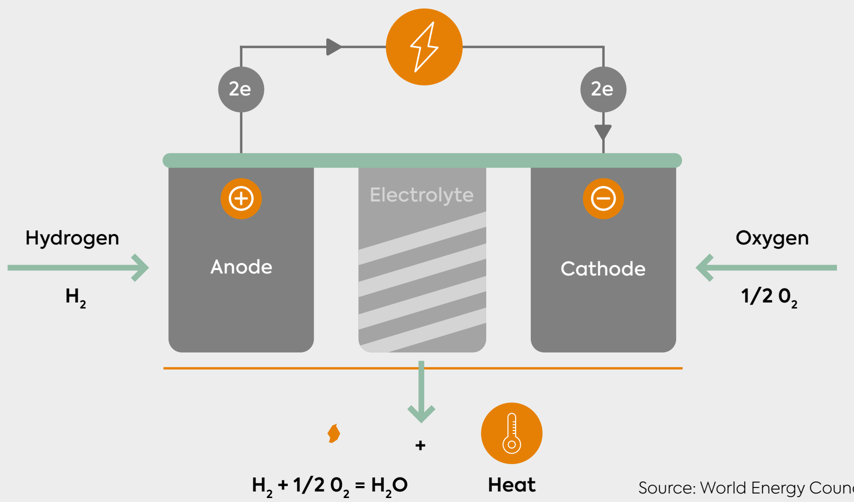
Impact on automotive industry
While some OEMs such as Tesla are focusing solely on Battery Electric Vehicles (BEVs), many OEMs are adopting a dual strategy and developing capabilities in BEVs as well as Fuel-cell Electric Vehicles (FCEVs) powered by hydrogen.

One report[3] states the rapid charging of large batteries needed for trucks is an even bigger challenge than high-performance charging for cars in terms of the infrastructure, parking space and time required. With the decarbonisation of electricity generation, electricity costs are also likely to increase substantially, potentially turning the current operating cost advantage of BEVs into a disadvantage.

The rapidly growing demand for hydrogen will also drive a global green hydrogen supply economy that will be sufficient to meet both industrial and automotive needs over the long term, while pricing levels for green hydrogen will be such that its use in the automotive sector will still be relatively attractive versus other industries.

It concludes that hydrogen has a key role to play in the zero-carbon automotive sector of the future. There will be sufficient supply, pricing levels should not be prohibitive, and in many situations the real "source-to-wheel" efficiencies will be attractive versus BEVs.

The science behind fuel cells



Source: World Energy Council

1: Toyota UK magazine
2: Hydrogen applications and business models, Kearney Energy Transition Institute, 2020
3: The role of hydrogen in building a sustainable future for automotive mobility, Prism 2021

Active players
A number of OEMs and Tier 1 suppliers are already very active in the market.

Weifu, a Chinese state-owned and listed automotive components manufacturer, is investing very heavily in the sector as it builds an Asian-Pacific base for hydrogen fuel cell components. Earlier this year it announced a JV around hydrogen fuel cell parts with various businesses, one of which was **RBINT**, a subsidiary of industrial giant Bosch. Weifu also recently acquired **Borit,** the world's largest independent one-stop-shop supplier of metal bipolar plates and assemblies used in fuel cells and electrolysers. Weifu also bought **IRD**, a specialist in fuel cell membrane and graphite bi-polar plate products.

General Motors recently announced that it would supply its Hydrotec fuel cell power cubes to truck maker **Navistar** for use in its FCEV. Each Hydrotec power cube contains more than 300 hydrogen fuel cells along with thermal and power management systems. The power cubes are compact, easy to package and can be used in a wide range of applications, including marine, earth-moving and mining equipment, locomotives and power generators.

Ford and powertrain testing specialist **AVL UK** have teamed up to build a FCEV prototype which will be used to research the suitability of hydrogen powertrains in the commercial vehicle sector. AVL is leading research into the integration of the fuel cell and hydrogen systems into the vehicle.

Ecosystem

What is striking is how many players are investing across the complete hydrogen value chain to accelerate the clean energy transition.

Renault and fuel cell system specialist **Plug Power** have launched a JV called **Hyvia** to manufacture hydrogen fuel cell systems for light commercial vehicles. Hyvia is working on an entire hydrogen ecosystem as it develops electrolysis solutions, mobile storage solutions, and hydrogen refuelling stations too.

A number of stock-listed players that operate in the general hydrogen industry also now have a very strong focus on green hydrogen.

Ireland-based **Linde**, a manufacturer of atmospheric gases, has announced plans to invest more than $1bn in decarbonisation initiatives and triple the amount of clean hydrogen production by 2028. It is also investing heavily in hydrogen refuelling stations, such as a specific facility for passenger trains in Germany which is expected to be operational later this year and which will have a capacity of around 1,600kg of hydrogen per day.

Canada-based **Ballard** develops and manufactures hydrogen fuel cells for automobiles and engineering services. It also has a strategic partnership with **Audi** to focus on automotive fuel cells which are designed for light, medium and heavy duty vehicles.

What is striking is how many players are investing across the complete hydrogen value chain.

M&A activity

The rapid development of the hydrogen economy is now beginning to drive significant M&A activity as new entrants seek to acquire the necessary skills, technologies, products, and systems they need in order to be future key players in the green hydrogen value chain.

Any developer of water electrolysis systems – and especially technologies that improve their operating efficiency – are now coming under the spotlight. Likewise, any company involved in the design, development and manufacture of fuel cell systems (and technologies for refuelling stations) is now on the radar, as are those which specialise in hydrogen storage solutions and energy transportation.

Clearwater International's experience and knowledge of the market tells us that these are markets which are rapidly consolidating and those players interested in the market will need to move fast in the months and years to come. Market-enticing factors such as strong government support will also further drive M&A activity, especially in Europe which – until recently – had not seen the levels of M&A witnessed in North America in the sector.

Providers of fuel cell technology have also generated substantial liquidity through IPOs in recent years in order to finance their strategic plans and growth opportunities. For instance, Canadian-based fuel cell company **Loop** launched a $100m IPO in 2021, while other stock-listed pure play hydrogen players include Power Cell, Cell Impact, Impact Coatings, Ceres and Ballard.

Examples

A recent example of a deal in the green hydrogen sector was **HydrogenPro's** acquisition of **Advanced Surface Plating**, a Danish provider of advanced electrode technology that improves the operating efficiency of electrolysers. This is the type of technology that is needed to make green hydrogen fully competitive, with hydrogen produced from fossil sources. HydrogenPro, a Norwegian electrolyser manufacturer, aims to become a leading provider of electrolysers for renewable energy projects globally.

Another interesting deal saw **Gaztransport & Technigaz** (GTT) acquire **Areva H2Gen**, a French manufacturer of electrolysers. GTT say the green hydrogen market is now expanding rapidly, notably driven by energy companies which want to make their energy production greener, and by numerous national development plans.

Trilantic North America and **Climate Adaptive Infrastructure** acquired a stake in **Intersect Power**, one of North America's largest developers of utility-scale renewable energy.

Recent transactions

TDL Partners, a US developer of green hydrogen and ammonia production, storage facilities, and associated transportation assets, is to acquire through its subsidiary **EverWind Fuels**, a terminal in Nova Scotia, Canada, from **NuStar Energy**.

BioHEP Technologies acquired **Next Hydrogen**, a Canadian developer of water electrolysis technology and provider of green hydrogen solutions.

Trilantic North America and **Climate Adaptive Infrastructure** acquired an undisclosed stake in **Intersect Power**. The deal allows Intersect to scale its core solar and energy storage business in North America and will expand is business further into green hydrogen.

South Korea-based **SK Holdings** acquired a 10.2% stake in **Plug Power Inc.**, the US-based company engaged in providing alternative energy technology that focuses on the design, development, commercialisation, and manufacture of fuel cell systems for the industrial off-road market.

Xebec Adsorption acquired **HyGear Technology and Services**, a Dutch developer of on-site hydrogen generators, from **Oost NL**.

Gaztransport & Technigaz acquired **Areva H2Gen**, a French manufacturer of electrolyzers using Proton Exchange Membrane (PEM) technology, from **AREVA, ADEME** and **Smart Energies.**

Plug Power acquired **Giner ELX**, a US renewable energy storage solutions company that provides PEM hydrogen generators, grid-level renewable energy storage solutions and hydrogen generation systems for fuel cell vehicle refuelling stations.

HL Acquisitions Corporation acquired **Fusion Welcome-Fuel**, a Portuguese company engaged in producing green hydrogen using concentrated photovoltaics.

Funding rounds in hydrogen economy

Date	Transaction name	Funding type	Money raised ($m)	Lead investor	Number of investors	Deal description
Feb-2022	Verdagy	Series A	**25**	TDK Ventures	7	Verdagy is innovating water electrolysis technology for the very large-scale production of green hydrogen
Feb-2022	Lhyfe	Unknown	**17**	Andera Partners	3	Lhyfe is a developer, investor, and supplier of 100% green hydrogen for mobility and industry
Feb-2022	P2X	Corporate Round	**13**	n/a	1	P2X Solutions is a producer of green hydrogen and a pioneer in power-to-x technology
Jan-2022	H2pro	Series B	**75**	n/a	2	H2Pro is a renewable energy company that is working on an efficient green hydrogen production method
Dec-2021	H2pro	Series A	**22**	Bill Gates, IN Ventures	7	H2Pro is a renewable energy company that is working on an efficient green hydrogen production method
Oct-2021	Lhyfe	Unknown	**50**	Swen Capital Partners	6	Lhyfe is a developer, investor, and supplier of 100% green hydrogen for mobility and industry
May-2021	Grant - Hydrogen Optimized	Grant	**4.8**	Sustainable Development Technology Canada	1	Hydrogen Optimized develops and commercialises innovative large-scale green hydrogen production
May-2021	P2X	Seed	**2**	n/a	2	P2X Solutions is a producer of green hydrogen and a pioneer in power-to-x technology
Apr-2021	Raven	Seed	**20**	n/a	4	Raven is a producer of green hydrogen and synthetic fuels using organic waste
Jan-2021	Perpetual Next	Seed	**200**	Momentum Capital	1	Producer of renewable carbon, biochar, green gases and green hydrogen from organic residues
Dec-2020	Green Hydrogen Systems	Debt Financing	**20**	AP Moller Holding	1	Green Hydrogen Systems believes that electrolysers have a great potential to become a core technology
Dec-2020	Green Hydrogen Systems	Unknown	**8**	Nordic Alpha Partners	2	Green Hydrogen Systems believes that electrolysers have a great potential to become a core technology
Dec-2020	Fusion Fuel	Post-IPO Equity	**25**	n/a	n/a	Fusion Fuel is a producer of green hydrogen
Oct-2020	H2-Greenforce	Series A	**12**	n/a	n/a	H2-Greenforce is green hydrogen production, distribution, and storage technology
Apr-2020	H2pro	Series A	**10.2**	IN Venture	2	H2Pro is a renewable energy company that is working on an efficient green hydrogen production method
Jan-2020	Perpetual Next	Seed	**150**	Momentum Capital	1	Producer of renewable carbon, biochar, green gases and green hydrogen from organic residues
Oct-2019	G4 Insights	Grant	**2.8**	n/a	6	Renewable natural gas, power to gas, RNG, green hydrogen, blue hydrogen, biomass energy, biofuel
Jan-2019	Perpetual Next	Seed	**8**	Momentum Capital	1	Producer of renewable carbon, biochar, green gases and green hydrogen from organic residues
Mar-2017	G4 Insights	Grant	**2.15**	n/a	8	Renewable natural gas, power to gas, RNG, green hydrogen, blue hydrogen, biomass energy, biofuel

Source: Clearwater International Research

Our recent automotive transactions

Working for many years with leading suppliers and OEMs, and more recently with new digital players, we have built up an extensive network and knowledge of the sector, becoming a trusted adviser for many of the world's leading automotive players. With more than 290 successfully completed automotive deals, our unique automotive transaction experience covers virtually every system and component of a vehicle, all relevant materials and process technologies.

ROLEC
on the sale to
SDIPTECH
Sell-side
Undisclosed

Finindus PMV
sold
borit
to
威孚集团 WEIFU GROUP
Sell-side
€42.7m

VMI jokon
raised banking facilities to refinance its existing debts
Refinancing
Undisclosed

MAGENWIRTH
sold
bebro eSYSTEMS
to
KATEK
Sell-side
Undisclosed

ARDIAN
sold
AIXAM
to
POLARIS
Sell-side
Undisclosed

KOPERNIKUS AUTOMOTIVE
received investment from
Continental
Sell-side
Undisclosed

BRIDGES Fund Management
on its investment in
matrix TELEMATICS
Buy-side
Undisclosed

WATERLAND
raised finance to support the acquisition of
DUVENBECK THE CULTURE OF LOGISTICS
Acquisition finance
Undisclosed

GRUPO ANTOLIN
completed the automotive electronics transaction with
N
Buy-side
Undisclosed

Our international automotive team

With offices in Europe, the US and Asia, our automotive team can deliver seamless, integrated global advice to SME/owner-managed, corporate and private equity clients. Our team is supported by a number of high-profile senior advisers who are all former top tier executives with relevant product knowledge and a far-reaching network of contacts.

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