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PitchBook Data, Inc.

Nizar Tarhuni Executive Vice President of Research and Market Intelligence

Paul Condra Head of Emerging Technology Research

Institutional Research Group

Analysis

Jonathan Geurkink
Senior Analyst,
Emerging Technology
jonathan.geurkink@pitchbook.com

Data

Harrison Waldock
Data Analyst

pbinstitutionalresearch@pitchbook.com

Publishing

Designed by **Megan Woodard**

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EMERGING TECH RESEARCH

Hybrid Revival

Hybrid technology represents a key step on path to zero emissions

PitchBook is a Morningstar company providing the most comprehensive, most accurate, and hard-to-find data for professionals doing business in the private markets.

Key takeaways

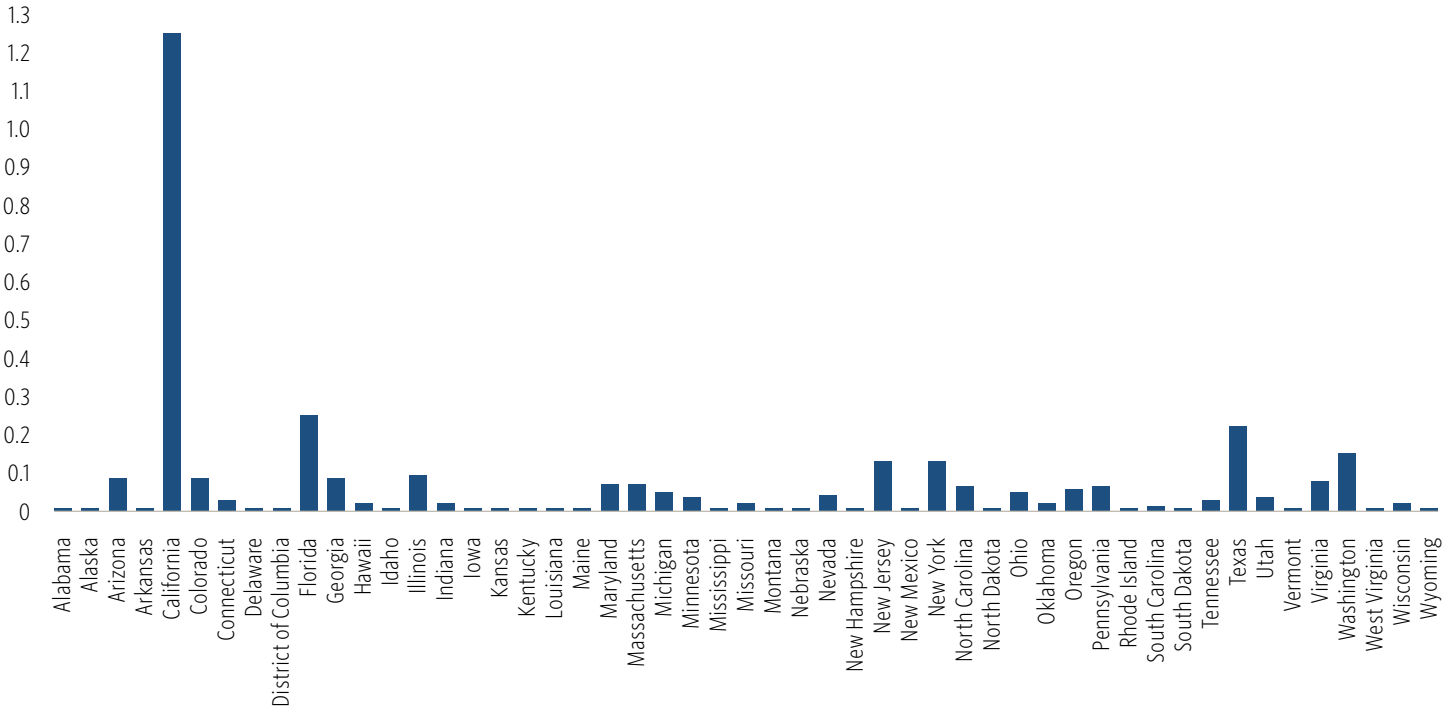
- BEV adoption is slowing as consumers remain anxious about adopting full electric vehicles.
- Hybrid vehicles, by contrast, are flying off dealers' lots as consumers want the benefits of EVs without the risks.
- Extended-range EVs, which have a small combustion engine to generate electricity for the battery, represent one of the fastest-growing categories.
- Hybrids can make a significant impact in carbon emissions compared with traditional gas vehicles—and at a lower cost and using far fewer battery materials.
- Hybrid technology can be improved, thus reducing emissions and enhancing performance.
- Full electrification is a worthy, ideal goal, but more realistic, incremental efforts with hybrid technology can have a big impact on emissions.

Hybrids make a comeback

Sometimes markets have to take a step back to move forward. In the transition toward electrification of mobility, one of the more surprising trends of the past couple of years has been the surge in sales of hybrid vehicles. A little over two years ago, leading automaker and top hybrid-vehicle producer Toyota was vilified for not moving aggressively enough into battery electric vehicles (BEVs). At the time, long-standing Toyota CEO Akio Toyoda held that the company's read on the market indicated that consumers wanted a variety of power train types. Bowing to investor pressure, in January 2023, the company announced Toyoda was relinquishing the president and CEO roles to become chairman. At nearly the same time, however, Tesla began slashing prices of its BEVs after it missed analysts' estimates for deliveries for 2022.[1] By December 2023, sales of BEVs in the US had slowed. Inventories on dealers' lots had more than doubled from the previous year to a 114-day supply.[2] Average days' supply of passenger cars on dealers lots is typically in the mid-50s. Meanwhile, hybrids (HEVs) from companies such as Honda, Hyundai, and Toyota were selling fast, with days of inventory in the mid-20s.

The distribution of sales of BEVs in the US has been concentrated in just a few states, with California accounting for as much as 35%. Concerns such as range anxiety, cold-weather operation, lack of charging facilities, and higher up-front cost have kept consumers on the sidelines. Rules mandating EV adoption became a political flash point during the 2024 US presidential election.

EV registration count (millions) by state in 2023



Sources: National Renewable Energy Laboratory and Experian Information Solutions • Geography: US • As of September 2024

1: "Tesla Turns Up Heat on Rivals With Global Price Cuts," Reuters, Hyunjoo Jin, Victoria Waldersee, and Zoey Zhang, January 13, 2023.
2: "EV Inventories Hit Record High in US as Cars Pile Up on Dealer Lots," Bloomberg, Keith Naughton, December 14, 2023.

The recent preference for hybrids is not limited to the US. For the first nine months of 2024, European HEV and plug-in hybrids (PHEVs) combined accounted for 37% of new car registrations, eclipsing sales of petrol vehicles (34.4%), while BEVs made up 13.1%.[3] In China in October 2024, BEV sales totaled 842,000 units, reflecting 30.4% YoY growth.[4] At 587,000 units, however, PHEV sales were growing significantly faster, up 89.7% YoY. If the growth rates hold, PHEV sales will eclipse BEV sales in China in one year.

In early 2023, the CEO of the Toyota Research Institute, Gill Pratt, presented on minimizing carbon accumulation on the path to net-zero at the World Economic Forum.[5] He persuasively showed that given the resource constraints on lithium for BEV batteries, when converting a fleet of 100 traditional gas-powered cars using the same amount of battery material for one BEV (100 kilowatt-hours of battery) spread across 90 HEVs (90 x 1.1 kWh batteries), the impact on lifetime carbon emissions significantly favors the HEV route. 90 HEVs would reduce carbon emissions for the fleet by 18% compared with just 0.6% for one BEV. Replacing all 100 cars with BEVs would obviously have a bigger impact but would require 100x the supply of lithium. Until the lithium mining capacity and charging infrastructure is in place, this represents an unrealistic option.

In a surprise to the market, as EV sales slowed through 2023, lithium prices collapsed by 90.8%, reflecting the supply/demand imbalance.[6] For 2024 YTD, they have fallen another 25%. The bubble in lithium prices in 2021 and 2022 drew in many mining companies seeking to expand capacity. The subsequent popping of the price bubble should be good for EV consumers and EV adoption down the road. Meanwhile, the surge in demand for hybrids should further stretch lithium supplies and, if Pratt's calculations are accurate, take a bite out of carbon emissions over the medium term while other factors in the market catch up.

New hybrid technologies

While hybrid technology has been around for decades, it still has opportunities for new technology. Emissions control is one area for potential improvement. As hybrids move down the road, in and out of traffic, stopping and starting, the internal combustion engine (ICE) cycles on and off to power the wheels and/or charge the battery. The erratic cycling back and forth of the ICE in a hybrid and the resulting temperature swings create challenges for catalytic converters, which moderate and manage emissions. The normal operating temperature for catalytic converters ranges from 500 to 800 degrees Fahrenheit.[7] At a cold start, an ICE produces much more pollution. Researchers have suggested that as much as 80% of pollution generated by vehicles today stems from cold-start emissions.[8] When hybrids shift to battery power, exhaust temperatures drop out of the optimal range, and when the ICE switches back on, it takes time to warm up, similar to start-up. As a

3: "New Car Registrations: -6.1% in September 2024; Year-to-Date Battery-Electric Market Sales -5.8%," European Automobile Manufacturers' Association, October 22, 2024.
4: "China NEV Sales Rise to New Record of 1.43 Million in Oct, CAAM Data Show," CnEVPost, Lei Kang, November 11, 2024.
5: "Reinventing the Wheel," WeForum, Gill Pratt, Jennifer Vescio, and Jamie Heller, January 18, 2023.
6: "Lithium," Trading Economics, November 1, 2024.
7: "Common Catalytic Converter Q&A," Walker, 2022, accessed November 11, 2024.
8: "Canadians Revolutionizing the Catalytic Converter," YouTube, Motoring TV, November 30, 2015.

result, catalytic converters in hybrids tend to need 10% to 15% more catalysts to effectively manage emissions.[9] PHEVs and extended-range EVs (EREVs) require even greater amounts of catalysts as the vehicles travel greater distances on battery power alone, resulting in colder engines. The catalysts used in catalytic converters are precious platinum group metals (PGMs), including platinum, palladium, and rhodium. Platinum and palladium are currently trading at close to $1,000 per troy ounce, and rhodium is trading at greater than $4,500, so any increase in catalyst required can impact overall vehicle cost.

Another impact is theft. In fact, for a time, certain vintages of Toyota Prius hybrids were at the top of thieves' lists for harvesting PGMs by stealing catalytic converters.[10]

New approaches provide an opportunity to develop catalytic converters that use fewer PGMs while maintaining emissions standards. Emissol, based in Mill Creek, US, has developed catalytic converters that dramatically reduce the need for expensive PGMs. The company's uniquely designed monoliths, where exhaust gases pass through, allow catalytic converters to function with 30% to 40% fewer PGMs. The company has also developed direct air capture solutions with the potential for onboard carbon capture. Aether Catalyst Solutions, based in Burnaby, US, has also developed catalytic converter technology to dramatically reduce the use of PGMs. CATAGEN, based in Belfast, Northern Ireland, offers a variety of testing and other engineering services, including PGM optimization for catalytic converters. QuantumCat, based in Daejeon, South Korea, has developed innovative catalyst materials for automobiles, industrial facilities, and other industries. The catalysts are active at room temperature all the way down to sub-zero temperatures, enabling emissions reduction at start-up and cold cycling. Advanced Technology Emissions Solutions (ATES), based in Toronto, has developed the Smart Induction Catalyst (SI-CAT), which actively manages the temperature of the ceramic catalyst substrate to maintain optimum efficiency. The induction heating circuit is controlled directly by the vehicle's engine control unit. Many of these companies are small, but their technologies could have a big impact on emissions. Unfortunately for US-based companies, funding from sources such as Small Business Innovation Research grants has mostly dried up, with funding activity almost exclusively targeting BEV technology and solutions to the detriment of technologies that are trying to clean up ICE systems.

9: "WPIC: Hybrid Vehicles Boosts Platinum Amid Electric Shift," Mining Review Africa, April 11, 2024.
10: "Thefts of Older Toyota Prius Models Surge as Thieves Target Precious Metals in Catalytic Converters," Forbes, Tanya Mohn, November 19, 2021.

Catalytic converter technology companies

Company	Last financing date	Last financing size ($M)	Last financing deal type	Year founded	HQ location
Klarius Products	October 17, 2024	N/A	Buyout/LBO	2013	Cheadle, UK
MIRATECH	August 20, 2024	N/A	Buyout/LBO	1992	Tulsa, US
Aether Catalyst Solutions	July 22, 2024	$0.1	PIPE	2011	Burnaby, Canada
Activated Research Company	February 28, 2024	N/A	M&A	N/A	Eden Prairie, US
Regenx Tech	December 14, 2023	$1.1	PIPE	1986	Saint Albert, Canada
QuantumCat	June 1, 2023	N/A	Accelerator/incubator	2019	Daejeon, South Korea
ATES	April 1, 2023	N/A	Private secondary transaction	2015	Toronto, Canada
Powertherm	February 16, 2023	N/A	Buyout/LBO	1969	Houston, US
AP Exhaust Technologies	January 1, 2023	N/A	M&A	1927	Goldsboro, US
Carbon Capture Enviro Tech	September 1, 2022	N/A	Accelerator/incubator	2021	Mumbai, India
Association for Emissions Control by Catalyst	January 1, 2021	N/A	Grant	1978	Brussels, Belgium
MONOLITHOS	January 31, 2020	$1.1	Grant	2000	Athens, Greece
3DFS	May 3, 2018	N/A	Accelerator/incubator	2010	Pittsboro, US
Interkat	October 31, 2016	$4.7	M&A	2008	Königswinter, Germany
GT Exhaust	December 18, 2015	N/A	Buyout/LBO	1978	Lincoln, US
Catalon Chemical	October 26, 2015	$16.9	M&A	1990	Winston-Salem, US
Eastern Manufacturing	September 29, 2015	N/A	Buyout/LBO	1976	Langhorne, US
Exhaust Systems	October 20, 2014	N/A	Joint venture	2014	Pune, India
SGS Advanced Testing & Engineering	June 2, 2014	N/A	M&A	2001	Taylor, US
International Muffler	September 13, 2013	N/A	M&A	1968	Loudon, US
Dinex Ecocat	June 28, 2013	N/A	M&A	1985	Vihtavuori, Finland
Sharda Motor Industries	May 22, 2013	N/A	IPO	1986	New Delhi, India
Lori Products	January 28, 2011	N/A	M&A	1977	Phoenix, US
EMCON Technologies	February 8, 2010	$464.3	M&A	N/A	Troy, US

Source: PitchBook • Geography: Global • As of October 31, 2024

Catalytic converter technology companies (continued)

Company	Last financing date	Last financing size ($M)	Last financing deal type	Year founded	HQ location
Delphi Automotive	May 1, 2009	$17.0	M&A	N/A	Troy, US
The Automotive Edge/Hermoff	May 20, 2008	N/A	M&A	N/A	Hagerville, Canada
Automotive Components	January 23, 2008	N/A	M&A	1929	Monroe, US
Metpela	January 1, 2008	N/A	M&A	1964	Laitila, Finland
MTS	January 1, 2007	N/A	M&A	N/A	Italy
Guilin Reecat Environment Industry	December 12, 2006	N/A	M&A	1991	Guilin, China
Sejong Industrial	September 25, 2002	N/A	IPO	1976	Ulsan, South Korea
Hydrocarbon Technologies	August 1, 2001	$17.0	M&A	1943	Lawrence Township, US
Yutaka Giken	October 14, 1997	N/A	IPO	1954	Hamamatsu, Japan
Park N Protect	N/A	N/A	Accelerator/incubator	N/A	US

Source: PitchBook • Geography: Global • As of October 31, 2024

Technologies focused on the efficiency and optimization of the ICE power train can boost the effectiveness of hybrids as well. Toyota, in a refresh of its SUVs and trucks, is pushing hybrid technology hard. It is abandoning thirsty V-8 engines in its larger vehicles and the V-6 for midsize trucks and SUVs. The hybrid i-FORCE MAX power train incorporates turbocharging for V-6 and four-cylinder gas engines and a 48-horsepower electric motor.[11] In most cases, the combination results in a significant increase in torque and horsepower compared with previous gas-only versions. The new Tacoma model, for example, sees a 75% increase in torque to 465 pound-feet.[12] Miles per gallon also goes up across the lineup. Combining turbocharging and electric motors with diesel engines offers promise as well with diesel's inherent advantage over gasoline in both efficiency and power. Unfortunately, diesel engines for passenger cars have never been popular in the US, but overseas markets could see broader adoption. One area hybrid technology does not offer much benefit is long-range trucking. The lack of frequent stopping and starting associated with urban driving means a hybrid system would not benefit from regeneration. However, hybrid turbodiesels look promising for shorter commercial routes.

Going a step further, it is possible to dispense with the reciprocating ICE in favor of turbine for some applications. The turbine offers several advantages, including greater power density, multifuel potential, and greater efficiency under specific circumstances. A turbine engine in a car is not a new concept. In 1954, Chrysler put a gas turbine engine in a Plymouth sport coupe.[13] From 1963 to 1964, the company

11: "2024 Toyota Tacoma i-FORCE MAX," Toyota, n.d., accessed November 11, 2024.
12: "Legendary Performance, Modern Power: 2024 Toyota Tacoma With i-FORCE MAX," Toyota, April 23, 2024.
13: "A Brief History of the 1963 Chrysler Turbine Car," Motor Cities, Robert Tate, May 20, 2020.

produced 50 examples of the Chrysler Turbine as a consumer research project. It kept its Turbine Lab open until 1981.[14] The 1963 effort never went beyond the research phase. The Chrysler Turbine sounded like a vacuum cleaner, had a slow zero-to-60 mph time of 13.2 seconds, and consumed a lot of whatever fuel was fed into it, which could include gasoline, diesel, jet fuel, alcohol, and even vegetable oil. Gas turbines can be extremely efficient but only in a narrow band of optimal RPMs. Throttling up and down for everyday driving proved inefficient. The key successful example of gas turbines used in land vehicles is the M1 Abrams tank, which has been powered by a 1,500-horsepower Honeywell AGT1500 gas turbine since the early 1980s for its superior power/weight ratio.[15] Over 10,000 examples have been produced.

A recent trend in the hybrid vehicle market may provide an opening for gas turbine technology, however. In China, growth in PHEV sales has outstripped that of BEVs. PHEVs can typically run 40 miles on battery power alone, with gasoline power kicking in to augment range. The fastest-growing category within PHEVs is EREVs, where the gasoline engine acts only as a generator and does not directly drive the wheels. Many of these drivetrains in China use a small 1.5-liter engine for generating electricity. Li Auto, which has been the key proponent of EREVs in China, saw sales jump 182% in 2023.[16] The rate of growth attracted attention, and now all major EV manufacturers in China, with the exception of Nio with its swappable battery vehicles, are making EREVs or have announced plans to do so. Volkswagen recently announced the return of the Scout brand, with an EREV option under the Harvester name. The Harvester EREV will have a range of more than 500 miles, compared with 350 miles for the BEV versions.

The notion of a turbine hybrid is not new either. In 2009, Capstone Turbine unveiled the CMT-380, which it developed in partnership with Electronic Arts' Chief Creative Director Richard Hilleman. Built on a Ford GT kit car body, the vehicle had some impressive statistics. It could accelerate from zero to 60 mph in 3.9 seconds and travel 500 miles on a tank of diesel or biodiesel. Its battery-only range was 80 miles. It utilized a 30-kilowatt Capstone C30 microturbine run in series (not mechanically connected to the wheels) and had a relatively small lithium-polymer (LiPo) battery that weighed only 450 pounds. The battery was likely 20 kWh—smaller than the battery in an electric MINI Cooper. Its combustion system generated such low emissions there was no need for exhaust after treatment to meet the California Air Resources Board and Environmental Protection Agency requirements at the time.[17] Capstone also partnered with UK-based Langford Performance Engineering to integrate the technology into a Ford S-Max minivan demonstration vehicle. Neither vehicle was planned for production, and costs were likely high. Capstone did provide hybrid-turbine technology for several passenger buses worldwide, but cost remained an issue for broader adoption. Despite impressive air-bearing turbine technology and marquee investors, such as Sevin Rosen Fund, Bill Gates, and Paul Allen, Capstone struggled through its decades-long history to generate cash. The company filed for bankruptcy in 2023. UK-based microturbine developer Bladon

14: "Revisiting the Future With the 1963 Chrysler Turbine Car," Car and Driver, Patrick Bedard, May 1989.
15: "M1 Abrams Still Going Strong With Honeywell Jet Engine," Honeywell, n.d., accessed November 11, 2024.
16: "The Extended-Range Electric Car Is Red Hot in China," Clean Technica, Steve Hanley, October 2024.
17: "Hybrid-Electric Supercar With Microturbine Technology Debuts at Los Angeles Auto Show Dec. 2-13," Capstone Green Energy, November 30, 2009.

Micro Turbine, which helped develop the Jaguar C-X75 hybrid concept car in 2010, has struggled as well.

Surging consumer interest in EREVs, combined with the dramatic decline in lithium battery prices over the past decade, could set the stage for renewed interest in a turbine EREV. Research shows the potential for a 23.6% fuel savings compared with a reciprocating engine EREV when the turbine is coupled with a reheat system.[18] The advantages of the turbine system include higher efficiency and power density, fewer moving parts, no vibration, low maintenance, high durability, and multifuel capability. UK-based Cosworth has developed a 35-kW microturbine generator for EREV applications.

VC-backed turbine technology companies

Company	Last financing date	Last financing size ($M)	Last financing deal type	Year founded	HQ location
Gravity Industries	November 8, 2024	$19.8	Late-stage VC	2017	Salisbury, UK
Turbotech	August 30, 2024	$1.4	Early-stage VC	2017	Toussus-le-Noble, France
Limatech	July 17, 2024	$0.8	Equity crowdfunding	2016	Toulouse, France
Peregrine Turbine Technologies	May 7, 2024	$0.8	Late-stage VC	2012	Wiscasset, US
Azad Engineering	December 28, 2023	$88.9	IPO	1983	Hyderabad, India
Hyphen Innovations	June 13, 2023	$0.7	Debt - general	2022	Dayton, US
Frontline Aerospace	June 1, 2023	N/A	Private secondary transaction	2007	Lafayette, US
Aero Development Japan	February 1, 2023	N/A	Late-stage VC	2018	Tokyo, Japan
ICR Turbine Engine	December 1, 2022	N/A	Private secondary transaction	2010	Hampton, US
Hana ITM	April 27, 2022	N/A	M&A	2003	Gimhae-si, South Korea
Candent Technologies	August 1, 2021	$0.4	Grant	2001	Greenfield, US
Mechanical Solutions	January 1, 2021	$0.6	Grant	1996	Whippany, US
TurbAero	January 15, 2020	$2.1	Seed round	2008	Mile End South, Australia

Source: PitchBook • Geography: Global • As of October 31, 2024

18: "Combined Cycle Gas Turbine System Optimization for Extended Range Electric Vehicles," ScienceDirect, Energy Conversion and Management, Aya A. Barakat, et al., December 15, 2020.

Looking ahead

BEV adoption has slowed. Consumers remain beset by range anxiety when considering BEVs. Inadequate charging infrastructure, whether through lack of locations or maintenance, continues to fan these fears. Cost remains an issue despite industry price cuts during the past couple of years. Tariffs and trade barriers to keep inexpensive Chinese-built BEVs out of Western markets have allowed Western (and Japanese) auto original equipment manufacturers to pause efforts to roll out BEVs. Tesla has pivoted away from its long-standing strategy to produce an affordable EV for the masses. All of this will likely slow the transition to electric mobility, but surging demand for hybrids across major markets shows consumers want the benefits of electric vehicles but remain ambivalent to commit with both feet. The realistic response from the industry should be to meet this surging demand. Hybrids can be improved. Fossil fuels such as gasoline and diesel remain unbeatable in energy density. Hybrid technology can be advanced to sip onboard fossil fuels to provide significant extension in range. Emissions are a factor, but here, too, technology that optimizes emission abatement systems can result in significant reduction. As Toyota's chief scientist exhorts, echoing Voltaire, "Don't let perfect be the enemy of good."[19]

19: "'Don't Let Perfect be the Enemy of Good'--Toyota's Chief Scientist on Decarbonization," Toyota Times, March 15, 2023.

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