



# Notre Dame Venture Capital: LiDAR Technology Thesis

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## **Executive Summary**

Notre Dame Venture Capital sees LiDAR technology as an attractive investment opportunity for growth equity funds, due to the opportunity to invest in mid-to-late-stage technology companies applying the technology in the autonomous vehicle, voluntary carbon market, asset performance management, smart city technology, and augmented reality industries.

The technology faces headwinds, namely its technical limitations, regulatory headwinds for its applications, and the presence of compelling substitute technologies. However, these are outweighed by numerous, strong tailwinds, including rising demand for LiDAR's applications in the autonomous vehicle and smart city technology industries.

## **Technology Overview**

### ***LiDAR***

LiDAR technology uses light in the form of a pulsed laser to measure variable distances from objects surrounding a system. These light pulses— combined with other data recorded by the system— generate precise, three-dimensional information about the shape of the sensor's surroundings and its surface characteristics. A LiDAR instrument principally consists of a laser, a scanner, and a specialized GPS receiver.

Two classes of LiDAR sensors are topographic and bathymetric. Topographic LiDAR uses a near-infrared laser to map dry surface areas, whereas bathymetric LiDAR uses water-penetrating green light to measure seafloor and riverbed elevations. LiDAR systems allow users to examine both natural and manmade environments with accuracy, precision, and flexibility.

### ***Market Size***

The global Light Detection and Ranging (LiDAR) technology market is valued at USD \$3.2 billion in 2023, with a projected 5-year CAGR of 16.5%<sup>1</sup>. Anticipated to reach \$7 billion by the end of 2028, LiDAR technologies find applications across various industries. Notably, the autonomous vehicles sector dominates the market, boasting a 9-year CAGR of 35.2%<sup>2</sup>. Industry leaders are continually exploring innovative implementations of LiDAR technology, driving transformative changes in everyday business operations.

North America dominated the LiDAR market, contributing more than 40 percent of the overall revenue<sup>3</sup>. Following closely are Europe and Asia-Pacific, both witnessing growth in accordance with the industry's overall revenue trajectory. Experts suspect Asia-Pacific to witness a significant market growth due to LiDAR technology expansion as these locations move towards more modern technologies. Additionally, LiDAR adoption is on the rise and as more are exposed to the benefits of its applications. Noteworthy companies shaping the LiDAR landscape include Leica Geosystems AG, Trimble Inc., Teledyne Optech, Faro Technologies Inc., among others. While these key players specialize in diverse industries, the market experiences heightened competition, with an anticipated rise in returns.

**Sources:**

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2. <https://www.acumenresearchandconsulting.com/automotive-lidar-market>
3. <https://www.nextmsc.com/report/lidar-market>

**Industry Personas**

- Tech Enthusiast: These individuals are early adopters of LiDAR technology and often work in research and development roles, pushing the boundaries of its applications.
- Market Innovator: Innovators in the LiDAR market who create new applications and solutions for the technology, driving its evolution.
- Data Analyst: Professionals who specialize in processing and interpreting LiDAR data for various industries, including forestry, agriculture, and archaeology.
- Regulatory Expert: Experts in the field of LiDAR regulations and standards, ensuring the technology's safe and compliant use in various sectors.

**Industry Headwinds****Technical Challenges and Limitations**

One of the primary technical headwinds facing LiDAR technology is the limitation in its range and resolution capabilities. For autonomous vehicles and other high-precision applications, the effective range and accuracy of LiDAR systems are crucial. Most current LiDAR systems have a limited range, which restricts their use in high-speed or complex environments where long-distance detection is essential. Additionally, the resolution, which determines how detailed the captured data is, may not be sufficient for intricate tasks like distinguishing small or distant objects, crucial for autonomous navigation in urban settings.

LiDAR sensors are highly susceptible to environmental factors. Adverse weather conditions such as rain, fog, snow, or even heavy dust can significantly impair the performance of LiDAR systems. This sensitivity results in decreased reliability, as the laser pulses used in LiDAR can be scattered or absorbed by atmospheric particles, leading to incomplete or inaccurate data. This issue poses a substantial challenge for autonomous vehicles, where safety and reliability are paramount.

Integrating LiDAR systems with other technologies like GPS, cameras, and radar is a complex task. This integration is essential for creating a comprehensive environmental perception system in autonomous vehicles. However, ensuring compatibility and effective data fusion between these diverse systems, while maintaining processing efficiency and cost-effectiveness, is a significant challenge. This complexity increases the developmental time and cost, impacting the commercial viability of LiDAR-based solutions.

### ***Regulatory and Safety Concerns***

The widespread deployment of LiDAR, especially in consumer markets like autonomous vehicles, faces significant regulatory challenges. Government and safety regulations are still evolving to keep pace with these new technologies. Meeting safety standards, passing certification processes, and addressing liability issues in the event of system failure can be lengthy and costly processes. These regulatory hurdles can delay product launches, impact public trust, and increase development costs.

Public acceptance of LiDAR technology, particularly in autonomous vehicles, is a critical factor. The technology's reliability and safety record directly influence public perception. Any incidents, even if isolated, can lead to negative publicity and heightened skepticism about the technology's readiness and safety. Building public trust requires not only technological reliability but also transparency and education about the technology's capabilities and limitations.

### ***Economic and Market Factors***

The high cost of LiDAR technology is a significant barrier to its widespread adoption. Current LiDAR systems, especially those with advanced features like higher resolution or longer range, are expensive. This cost is prohibitive for mass-market applications like consumer vehicles. Furthermore, scaling production while maintaining quality and performance standards is challenging, adding to the economic headwinds facing the technology.

LiDAR faces stiff competition from alternative sensing technologies such as radar, sonar, and computer vision systems. These technologies, often cheaper and more mature, offer different advantages and are being continuously improved. The competition intensifies as these alternatives become more sophisticated, potentially capturing market share from LiDAR, especially in cost-sensitive applications.

**Industry Tailwinds**

***Regulatory Tailwinds***

The LiDAR industry is facing tailwinds within the realm of regulations. Public officials are actively advocating for the inclusion of advanced driver-assistance system (ADAS) capabilities in existing regulations, with an emphasis on basic SAE L1 and L2 ADAS features. As highlighted by Austin Russel, CEO of Luminar Technologies, there is a substantial push for safer vehicles, leading to notable regulatory support for LiDAR technology. Companies trying to replace drivers may see regulation as a barrier; however, this is not the vision of some companies such as Russel’s. Luminar and its competitors want to enhance drivers, not replace them. The auto industry, public officials, and regulators agree that autonomous driving and its respective features have the potential to save lives. Automakers can leverage this LiDAR technology to enhance drivers and increase safety on the road. With a primary emphasis on saving lives, this strategic approach not only prioritizes safety but also has the potential for substantial financial gains.

*The SAE Six Levels of Vehicle Autonomy: Adopted by the U.S. DOT*

0	1	2	3	4	5
<b>No Automation</b>	<b>Driver Assistance</b>	<b>Partial Automation</b>	<b>Conditional Automation</b>	<b>High Automation</b>	<b>Full Automation</b>
<i>Complete manual control</i>	<i>The vehicle features a single automated</i>	<i>ADAS   The vehicle can perform steering</i>	<i>Environmental detection capabilities   The</i>	<i>The vehicle performs all tasks under</i>	<i>The vehicle performs all tasks under all</i>

	<i>system, such as monitoring speed through cruise control</i>	<i>and acceleration with human monitoring</i>	<i>vehicle can perform most tasks but requires human monitoring and override</i>	<i>specific circumstances. Human override is optional</i>	<i>conditions. Human monitoring or interaction is not required</i>
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**Autonomous Vehicles**

The global autonomous cars market is growing at a CAGR of 36.3% from 2022 to 2032, with the market projected to grow from \$2.5B in 2022 to \$55.6B by 2032, according to a study by Spherical Insights & Consulting. Autonomous vehicle (AV) development can rely on LiDAR technology, although not required. The Honda Legend implements LiDAR technology and BMW is developing a LiDAR based Minimal Risk Maneuver system; however, Tesla does not implement this technology. Companies can use a combination of LiDAR, cameras, and sensors, for autonomous vehicles and partial AVs. Tesla relies on a pure vision-based approach to autonomous driving; however, cameras and the AI deep-learning required with this approach can make mistakes in detecting objects in images, incentivizing self-driving car companies to use LiDAR. This technology adds information to fill in the gaps of the deep learning neural networks. Bolstering LiDAR’s role in AVs, several disruptor Original Equipment Manufacturers (OEMs), which produce parts and components for new cars, are launching vehicles that offer L2+ systems with pre-equipped LiDAR sensors. Finally, a McKinsey survey reported that respondents believed that LiDAR is the most critical hardware component for autonomous vehicles. LiDAR technology offers reliable depth and shape recognition, something cameras alone cannot do, further increasing the reliability and safety of AVs.

**Urban City Planning and Development**

The U.S. 3D Elevation Program (3DEP)

The U.S. Geological Survey 3D Elevation Program (3DEP) exemplifies the adoption of LiDAR. The program is collecting and harnessing LiDAR data nationwide to promote safety and U.S. infrastructure.

- (1) The program is using LiDAR data to improve maps of broadband accessibility to support millions of AMericans in rural parts of the country that lack access to high-speed, always-on internet. LiDAR allows engineers to determine where signals can and cannot reach across the landscape and determine optimal locations for new towers.
- (2) LiDAR is being used to increase safety in regards to energy infrastructure. LiDAR helps identify optimal terrain locations for energy infrastructure—a key decision in ensuring the safety of millions of Americans.

- (3) As aforementioned, the program is utilizing LiDAR for flood risk management purposes. Data is being used to construct dams and levee systems, in addition to providing data critical to flood forecasting.
- (4) LiDAR is used to conduct landslide hazard assessments and landside forecasts
- (5) American farmers and the agriculture industry are increasingly using LiDAR for crop management. The greater yields and reduced losses are estimated to increase revenue by \$2B for America's farmers.
- (6) The American Society of Engineers have warned that the country's infrastructure is in fair-to-poor condition. As previously mentioned, LiDAR is being used for productivity, safety, and cost-efficiency for infrastructure projects.

Sources:

- [United States Geological Survey](#)
- [McKinsey \(1\)](#)
- [McKinsey \(2\)](#)
- [Yahoo Finance](#)
- [Synopsis](#)
- [VentureBeat](#)

## Investable Opportunities

### ***Autonomous Vehicles***

Arguably the greatest potential for LiDAR technology exists in the autonomous vehicle (AV) industry. Enabling a detailed 3D map of the vehicle's environment to be constructed with far greater accuracy than traditional cameras, LiDAR is considered a critical part of the sensor suite necessary for AVs to operate safely. Essentially, LiDAR is used to add "eyes" to AVs. Most applications of LiDAR in AVs utilize time-of-flight (ToF) detection: sensors on vehicles send short electromagnetic pulses of light into the surrounding environment, which then make contact with an obstacle and reflect back to the sensor. The system then calculates the distance between itself and the object based on elapsed time. By emitting over 160,000 light pulses per second, LiDAR paints a precise 3D replica of the vehicle's surroundings, thereby enabling the vehicle to make calculated decisions in a rapid manner. Traditional vehicles utilize radar for blind-spot monitoring systems, adaptive cruise control, and automatic emergency braking, however LiDAR's continuous 360-degree capabilities offers greater accuracy and efficiency in these same features. Thus, LiDAR can accelerate the capabilities of advanced driver assistance systems (ADAS) to decrease the possibility of human error on the road. Taking this a step further, LiDAR opens the door for L5 automated vehicles without the need for human assistance whatsoever. Although the concept of autonomous driving initiates ethical considerations, continued innovation in LiDAR has the power to make AVs more capable decision-makers than humans. In turn, the roads become safer and traffic accidents are drastically reduced. Currently, many automakers can not justify the elevated cost of LiDAR

sensors to make the transition from traditional cameras; an opportunity exists to back companies racing to develop long-range LiDAR sensors within automakers' price ranges.  
Companies

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### ***Voluntary Carbon Markets***

LiDAR technology has numerous applications related to carbon content measurement. First, when utilized in tangent with high-altitude satellites and drones, LiDAR can provide accurate measurements of vegetation structures, including canopy cover, tree density, and tree heights. Given that such data is critical to estimating forest biomass and carbon stocks, LiDAR is highly effective for projects focused on reforestation, avoiding deforestation, and afforestation. While ground-level data is more accurate, it is unfeasible for vast areas; remote sensing using LiDAR to create color and 3D maps of vegetation provides great visibility into estimating carbon absorption capacity. Likewise, companies buy carbon credits in commodities markets to neutralize their own carbon emissions with projects designed to absorb carbon from the air. LiDAR vegetation mapping data can be used to price carbon projects trading on commodity markets, for companies to accurately assess their sustainability goals, and if emissions reporting becomes mandated by the SEC in the near future, it will enable many companies to report such data. Evidently, the market for carbon capturing data is growing exponentially and will continue to blossom in the future, with LiDAR serving as a critical component. Furthermore, LiDAR is effective in monitoring changes in vegetation structure over time. By conducting LiDAR surveys, project managers can ensure the progress and success of carbon reduction initiatives to guarantee compliance with carbon credit commitments. Also, given the precise mapping and assessment capabilities of LiDAR technology, it can be used to optimize carbon sequestration efforts within limited spaces, such as urban reforestation projects. As cities declare climate change goals and revitalization projects, such an application is becoming increasingly mission critical.

Sources:

- <https://www.forbes.com/sites/sabbirangwala/2023/07/18/terrestrial-airborne-and-satellite--lidar-enables-accurate-and-scalable-carbon-content-measurements/?sh=1278e80a73e9>

- <https://www.linkedin.com/pulse/lidar-technology-context-voluntary-carbon-markets-din-esh-babu-phd/>

### ***Asset Performance Management (APM)***

For companies whose business models rely on considerable PPE, LiDAR technology drastically improves asset performance management (APM). Drones/UAV LiDAR data provides valuable aerial insight into industrial assets that are difficult to inspect, including power lines, civil infrastructure, and other industrial assets. Detailed 3D models of operating assets enable visibility into ongoing performance. As such, companies can effectively catalog assets, identify vulnerabilities, and plan maintenance schedules to reduce downtime. Similarly, remote data collection through LiDAR minimizes the need for physical data collection in hazardous or hard-to-reach locations, simultaneously reducing costs and providing additional data collection. Companies can use this data to aid in proactive asset maintenance and reduce the need for unnecessary (and costly) physical inspections. Contrarily, visibility enables a company to identify vulnerabilities in advance, thereby avoiding operational disruptions and lengthy repair processes. Running simulations to test asset performance under varying levels of stress also aids with future resource allocation and task prioritization. Likewise, LiDAR data enables a time-series analysis to periodically track changes and deterioration in asset conditions, which allows for identification of emerging issues before they become performance-deteriorating. In particular, power utilities companies utilize airborne LiDAR technology to acquire geo-referenced spatial data for power line asset management. Many utilities companies suffer from vegetation encroachment on transmission lines, which can cause outages and severe downtime. Highly-accurate and real-time asset visibility enables utilities companies to limit the negative impacts of vegetation and clear power lines, thereby inducing considerable cost savings.

Sources:

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- <https://www.linkedin.com/pulse/leveraging-lidar-enhanced-asset-management-advantages-matt-wilkie/>

### ***Smart Cities***

As an increasing number of people move to urban areas and modern cities continue to adopt new technologies to become interconnected and efficient “smart cities”, the demand for LiDAR technologies is obvious across public and private domains. Specifically, public organizations, like governments, hope to achieve several goals in their vision of a smart city, including smooth traffic flow, infrastructure management, pedestrian safety, security, emergency management, and crime prevention. LiDAR technology can help cities effectively achieve these goals by providing services like traffic monitoring, pedestrian monitoring, and security management. In

terms of traffic monitoring, LiDAR provides a beneficial alternative to cameras and video analytics, which had previously been used to analyze traffic patterns, because of its increased privacy and 360 degree coverage. This allows governments to increase pedestrian safety by reducing near misses and accidents, reduce pollution by lowering the number of idling vehicles, and reduce commute time by improving traffic flow without compromising public privacy and eliminating the need for numerous feeds of camera footage. Additionally, when LiDAR is paired with artificial intelligence, it can efficiently detect and communicate pedestrian traffic at parks, stadiums, and downtown spots, which can alert government agencies and police departments of large gatherings or demonstrations so that they can effectively and efficiently increase security and, in turn, safety. Not only this, but LiDAR technology can be useful for private organizations, like retail stores, malls, casinos, restaurants, and public venues/stadiums, who are trying to be a part of smart cities through people counting and queue management applications that provide countless benefits like optimizing floor occupancy, regulating foot traffic, reducing wait time, and much more.

Sources:

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### ***Augmented Reality Devices***

In recent years, there has been a race among big tech companies and startups alike to create devices that either fully embrace or partially integrate augmented reality, and LiDAR technology has and will continue to be an integral part of this race. For example, Apple has incorporated LiDAR technology in many of its new products since the release of the iPhone 12 and iPad Pro in 2020, and this technology allows for many use cases such as measuring objects and speeding up auto-focus in the camera app as well as providing third-party apps, such as interior design apps, 3D scanning apps, and augmented reality games to use the LiDAR scanners for their own uses. However, these current use cases of LiDAR in AR devices are just the tip of the iceberg in terms of what LiDAR can be used for in future devices and in creating augmented environments. These LiDAR scanners provide an accurate, real-time understanding of the physical environment around a device, which can be used to create complex AR environments. In fact, Apple has announced that its upcoming Vision Pro AR headset will use a LiDAR scanner to deliver 3D mapping of the surrounding environment and Meta's Artemis glasses were planned to include a LiDAR scanner before they had to eliminate the feature in an attempt to cut costs. Therefore, since LiDAR scanners are essential in allowing AR devices to detect their surroundings and import 3D objects including faces and bodies into the digital

world, the potential upside of LiDAR technology in AR devices is very promising as the race for AR devices continues and the need for LiDAR's solutions multiply.

Sources:

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### ***Robotics and Industrial Applications***

LiDAR technology aids robots in navigating their environment by delivering real-time data on object perception, identification, and collision avoidance. Through LiDAR sensors, robots gain a real-time understanding of their surroundings, including walls, doors, people, and various other obstacles, which empowers robots to execute diverse tasks and operate autonomously. These advanced robots, such as driverless forklifts, allow for safer and more efficient warehouses, and they can increase the throughput and reduce the cost of key processes in industries such as material handling, logistics, and port automation. Additionally, in industries like mining and construction, mobile LiDAR can be utilized by attaching LiDAR sensors to drones that can provide numerous capabilities including generating a precise map of a worksite, identifying key geological features of a worksite, producing stockpile estimates, and much more. Despite these numerous applications, LiDAR-enabled robots are almost useless without human supervision to guide and direct them. Therefore, there is a lot of uncaptured potential that lies within industrial applications of LiDAR technology that can be unlocked with the development of and future research into natural grounded language processing, which refers to machine learning being able to connect the meaning of language to actual perception and sensation in the real world. Once the powerful abilities of AI and LLMs are connected to physical robots that can interact with and impose upon stimuli in the real world, the upside of LiDAR-enabled robots and industrial applications of LiDAR technology is immense.

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