# Autonomous Truck Corridors: Concept and Implementation Plan

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**16. Abstract**

Freight trucks are central to the design and operation of the US National Highway System (NHS). However, passenger vehicles are uncomfortable traveling alongside these trucks because of their large size and high propensity for injury-related accidents. The trucking industry also faces significant challenges: fuel is costly and emits greenhouse gases, there is a 30% shortage of qualified truck drivers, and traffic delays lead to an estimated loss of $63 billion per year. Autonomous and electric trucks are being developed to address these challenges, but their limited haul distances have not allowed them to enter the market.

This white paper describes the vision for an autonomous truck corridor (ATC), a long-life corridor for autonomous, powered, heavy freight trucks that have both electric and diesel engines. This corridor would be separated from passenger cars, be specially designed for autonomous heavy freight trucks, and feature overhead electric power lines to provide constant power to the trucks.

Freight trucks that use the ATC can travel continuously without stopping for fuel or driver rest periods, can travel at closer spacing, and can travel autonomously because they would be separated from passenger vehicles. The ATC would charge the batteries on the trucks so that they can remain powered once they leave the ATC to make local deliveries. This corridor can largely be built using existing right-of-way or as major highways are expanded. This would reduce land acquisition costs, allow freight to follow existing delivery lines, and leverage existing infrastructure. It is estimated that the ATC can reduce carbon emission by as much as 60% and reduce costs by as much as 57%.

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# AUTONOMOUS TRUCK CORRIDORS: CONCEPT AND IMPLEMENTATION PLAN

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**Authors**
M. Tyler Ley, Paul Tikalsky, Tara Cavalline, Norb Delatte, and Sara Tayebi



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A report from
**National Concrete Pavement Technology Center**
**Iowa State University**
2711 South Loop Drive, Suite 4700
Ames, IA 50010-8664
Phone: 515-294-8103 / Fax: 515-294-0467
https://cptechcenter.org

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## ACKNOWLEDGMENTS

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# EXECUTIVE SUMMARY

The US National Highway System (NHS) is critical for the efficient transport of goods and the safety and freedom of the traveling public. An important vehicle that uses the NHS is heavy freight trucks, which carry more than 50% of the US gross domestic product and whose traffic loadings are the primary input in the design calculations for roads and bridges.

While freight trucks are central to the design and operation of the NHS, it is uncomfortable for passenger vehicles to travel alongside these trucks because of their large size and high propensity for injury-related accidents. The trucking industry also faces significant challenges. The fuel for these vehicles is costly and is responsible for 7% of greenhouse gas emissions, there is also a 30% shortage of qualified truck drivers, and traffic delays lead to an estimated loss of $63 billion per year. Vehicle manufacturers are developing autonomous and electric trucks to address these challenges, but their limited haul distances have not allowed them to enter the market. Addressing this limitation would enable significant economic improvements while improving the lives of the traveling public and reducing the impact of the trucking industry on the environment.

This white paper describes the vision for an autonomous truck corridor (ATC), a long-life corridor for autonomous, powered, heavy freight trucks that have both electric and diesel engines. This corridor would be separated from passenger cars, be specially designed for autonomous heavy freight trucks, and feature overhead electric power lines to provide constant power to the trucks.

Freight trucks that use the ATC can travel continuously without stopping for fuel or driver rest periods, can travel at closer spacing, and can travel autonomously because they would be separated from passenger vehicles. The ATC would charge the batteries on the trucks so that they can remain powered once they leave the ATC to make local deliveries. This corridor can largely be built using existing right-of-way or as major highways are expanded. This would reduce land acquisition costs, allow freight to follow existing delivery lines, and leverage existing infrastructure. It is estimated that the ATC can reduce carbon emission by as much as 60% and reduce costs by as much as 57%.

## OVERVIEW

The US National Highway System (NHS) is critical for the efficient transport of goods and the safety and freedom of the traveling public. An important vehicle that uses the NHS is heavy freight trucks. These freight trucks carry more than 50% of the US gross domestic product, and the traffic loadings from freight trucks are the primary input in the design calculations for all roads and bridges.

While freight trucks are central to the design and operation of the NHS, it is uncomfortable for passenger vehicles to travel alongside these trucks because of their large size and high propensity for injury-related accidents. The trucking industry also faces significant challenges. The fuel for these vehicles is costly and is responsible for 7% of greenhouse gas emissions (Greene 2023). There is also a 30% shortage of qualified truck drivers, and traffic delays lead to an estimated loss of $63 billion per year. Vehicle manufacturers are developing autonomous and electric trucks to address these challenges, but their limited haul distances have not allowed them to enter the market. Addressing this limitation would enable significant economic improvements while improving the lives of the traveling public and reducing the impact of the trucking industry on the environment.

This document describes the vision for an autonomous truck corridor (ATC), a long-life corridor for autonomous, powered, heavy freight trucks that have both electric and diesel engines. This corridor would be separated from passenger cars, be specially designed for autonomous heavy freight trucks, and feature overhead electric power lines to provide constant power to the trucks. A preliminary concept for the ATC is shown in Figure 1.

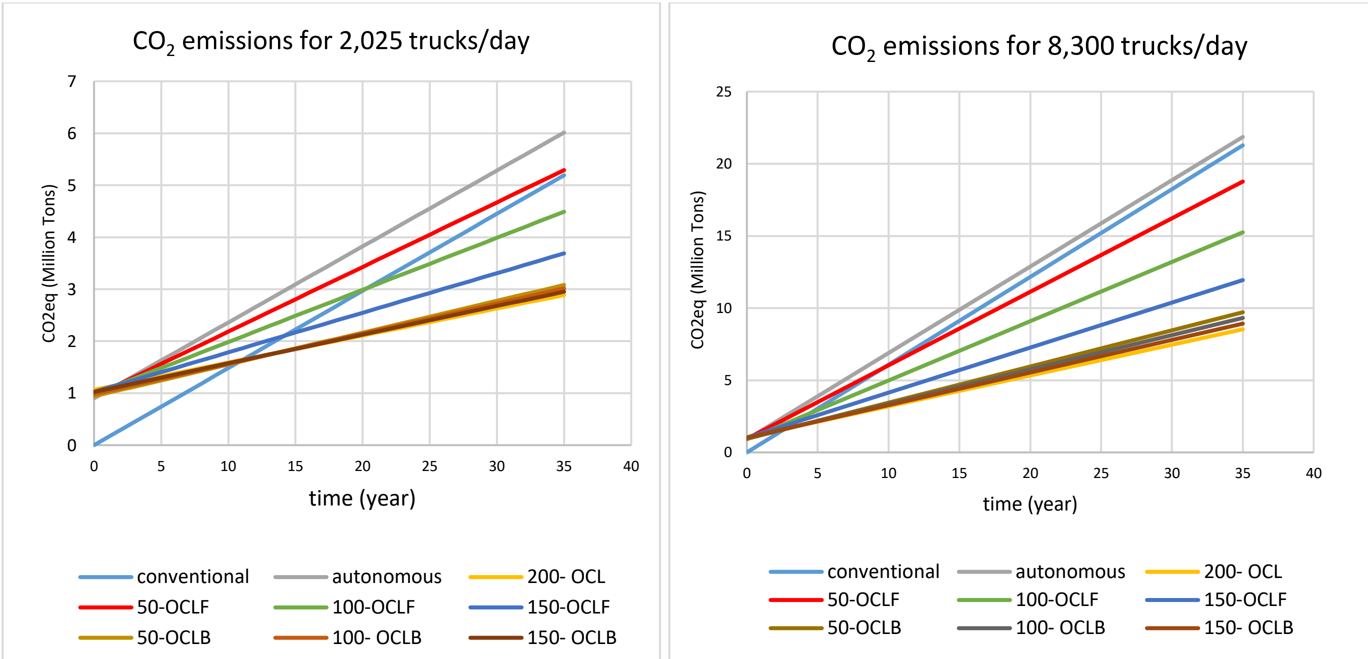

**Figure 1. Illustration of the ATC concept developed by Oklahoma State University**

The ATC has the potential to be a game changer because the freight trucks that use the corridor can travel continuously without stopping for fuel or driver rest periods, can travel at closer spacing, and can travel autonomously because they would be separated from passenger vehicles. The ATC would charge the batteries on the trucks so that they can remain powered once they leave the ATC to make local deliveries. This corridor can largely be built using existing right-of-way or as major highways are expanded. This would reduce land acquisition costs, allow freight to follow existing delivery lines, and leverage existing infrastructure. As summarized in the following section, a case study has shown that the ATC can reduce carbon emission by as much as 60% and reduce costs by as much as 57%.

## A CASE STUDY

A case study was undertaken to compare the environmental and economic costs of different types of trucks operating on a 200 mi roadway along the I-35 corridor between Oklahoma City, Oklahoma, and Dallas, Texas. Different scenarios were evaluated that considered both human drivers and autonomous vehicles using conventional engines, overhead cable lines (OCLs), and batteries. One of the systems evaluated—the ATC—involves the implementation of a dedicated lane and specialized infrastructure, including passive protection devices, masts, catenary wires, etc., with OCLs to power the trucks. These trucks operate using electricity supplied by overhead feedlines running along the road, offering a sustainable and efficient alternative to conventional trucks. The findings suggest that by using autonomous trucks with internal batteries and a 50 mi long overhead cable for battery charging, the ATC can result in potential cost savings of over 50% and a carbon footprint reduction of over 40% relative to conventional trucks.

Figure 2a presents the calculated $CO_2$ emissions for the various truck types evaluated under truck traffic volumes of 2,025 and 8,300 trucks per day over a span of 35 years, and Figure 2b depicts the costs of each truck type over 10 years for both the higher (8,300 trucks/day) and lower (2,025 trucks/day) volumes of truck traffic.




(a)


(b)

**Figure 2. $CO_2$ emissions (a) and costs (b) of each type of truck for higher and lower volumes of truck traffic**

The scenario that shows the best performance in terms of carbon footprint and financial cost features a set of dedicated overhead lines that are 50 mi long where battery-powered autonomous trucks can be charged as they drive. These lines can be thought of as charging stations that the trucks can use while they are in motion. These dedicated charging lanes should ideally be positioned approximately 75 mi from the corridor's primary starting point. Since only 50 mi of dedicated infrastructure needs to be created, the logistical challenges of finding the space and constructing the infrastructure are significantly reduced. For truck traffic volumes of 2,025 and 8,300 trucks per day, this scenario reduces carbon emissions by almost 41% and 54% and reduces costs by 42% and 55%, respectively, relative to conventional diesel trucks with a human driver.

## WHY DO WE NEED AN ATC?

The US economy is highly dependent on the NHS to deliver goods and people to their destinations. For example, the NHS has over 218 million users that travel over 3.2 billion mi annually. More than 90% of Americans live within 5 mi of the NHS, and this system carries more than 75% of the heavy truck traffic in the country. These trucks carry an estimated $9.1 trillion in goods each year, or roughly 50% of the US gross domestic product (BTS 2017). The mobility provided by the NHS is critical for workers, tourism, and the movement of goods and, as such, is an essential part of the nation's infrastructure and economy.

Heavy freight trucks are an essential part of the economy that is currently being underutilized. While the NHS is designed based on the number and size of freight trucks, the NHS is not optimized for them. For example, if a corridor were to be built that only serves autonomous heavy freight trucks, then it could be designed with new lanes and ways to power the trucks directly. This corridor could also be designed to be separate from other traffic so that passenger cars could not enter. If the trucks were to travel in separate lanes, it would be much easier to make them autonomous and to provide them power. This, in turn, would allow the trucks to drive continuously without stopping.

According to the case study summarized in the previous section, an ATC can reduce $CO_2$ emissions by 64% and reduce costs by 57% relative to conventional trucks on existing highways. Additional benefits include reducing many of the 4,000 highway fatalities per year resulting from truck-car accidents, relieving congestion, improving power and internet infrastructure, and providing security and response corridors during times of national disasters and emergencies. All of this can be achieved while also reducing heavy truck traffic by more than 75% on the existing NHS lanes. By relieving traffic on the existing NHS lanes, any repairs and new construction efforts on the NHS would last longer, since the roads would primarily be carrying passenger vehicles and local traffic. The ATC concept promises to extend the life of the existing NHS, allow transportation spending to close the gap in infrastructure repairs, and create a new level of economic growth.

In order for the ATC to supply power to the trucks that use it, it must be equipped with both electrical and fiber optic lines. The high-power electrical lines must be designed to provide continuous power to the autonomous vehicles as well as to charge high-capacity batteries for off-

ATC delivery and loading. Because the corridor would be separated from other traffic and designed for this application, trucks would be able to travel without interruption or downtime. An example of a truck equipped to connect to overhead power lines is shown in Figure 3.


Tobias Ohls, 2016, Scania/DHM Bergendahl Professional

**Figure 3. Heavy freight truck using overhead power lines on a highway in Europe**

**WHY ARE HEAVY TRUCKS SO DETRIMENTAL TO THE HIGHWAY SYSTEM?**

Interstate highways currently carry a mixed traffic stream of passenger vehicles and, in many areas, a relatively high percentage of trucks. On many of these highways, the percentage of trucks is well beyond what was considered in their design, and this can greatly shorten their service life. According to the American Association of State Highway and Transportation Officials (AASHTO) *Highway Capacity Manual*, the addition of freight trucks reduces the capacity available for passenger vehicles by more than 40%. In addition, conflicts between passenger vehicles and trucks cause more than 4,000 fatalities and an equal amount of incapacitating injuries every year. A surprising statistic is that 1 in 10 highway deaths involves a heavy truck and that more than 80% of these deaths are not truck occupants (IIHS HLDI 2017). This fact shows the improvement in public safety that is possible if trucks are separated from the main traffic stream. Further, reducing the number of trucks on the roadway will increase roadway capacity without additional construction.

Most roadways are assumed to fail from accumulated distress caused by repeated loading. Past studies have shown that the load-related damage to a roadway is increased to the fourth power for every unit increase in load (Huang 2003). This means that if the loading of a vehicle is increased, for example, by only 10%, then the load-related damage inflicted on the roadway will increase by nearly 50% ($1.1^4 = 1.46$). By the same token, if a truck axle is loaded to 20,000 lb and a typical sedan is 2,000 lb, then the truck will cause 10,000 times more damage than the sedan. By removing these trucks from the roadways, the service life of existing pavements will be greatly extended.

## HOW CAN THE ATC BE FUNDED?

The ATC has the potential to create significant cost and time savings for the trucking industry while also allowing the autonomous trucks that use the corridor to be powered with electricity instead of diesel fuel. Modest tolls that are commensurate with user cost savings could be charged to pay for the ATC as well as other public works projects. This additional supply of revenue can be used to renew the country's transportation infrastructure at the same time that the wear on the existing infrastructure is reduced.

The ATC is estimated to generate significant savings for every stakeholder while decreasing pollution, improving driver safety, reducing traffic congestion, and decreasing the rate of deterioration on existing highways. Based on the case study summarized above, implementing the ATC can result in financial cost savings of about 50% relative to the use of conventional driver-operated diesel trucks on the existing highway system. If trucks using the ATC were to be charged a portion of these savings as a toll, then this would cover the maintenance costs of the ATC and provide funds for expansion of the concept.

The ATC represents a transformational opportunity to spur economic growth in the United States while also reducing many burdensome issues facing future generations. It is anticipated that the ATC will generate the revenue necessary to support construction and maintenance activities on the NHS. Moreover, the savings and value provided by this corridor could create a federal "Corridor Trust Fund" for utilities and freight. This trust fund would provide revenues that are much greater than the existing Highway Trust Fund and would recover any general state or federal funds used to build this corridor while paying substantial future dividends.

## WILL TRUCK DRIVERS STILL HAVE JOBS?

The use of totally autonomous trucks will greatly help the trucking industry as well as truck drivers. The trucking industry currently faces a 30% shortage of truck drivers, and long-distance trucking companies have a 93% annual turnover in drivers (LTX Transportation Services n.d.). These drivers work long hours and face a growing number of health risks. The ATC can relieve these stresses on the industry while also allowing drivers to improve their lives and remain employed. While the ATC will be capable of transporting goods rapidly over long distances, local distribution will still be needed within a city or region. Human drivers would be used for these jobs. This arrangement will allow drivers to work more regular hours and spend less time away from their homes and families. The ATC will also create new jobs related to the construction and maintenance of the ATC and the autonomous trucks that use the corridor.

## HOW WILL THE ATC BRING GOODS TO A CITY?

The ATC is anticipated to be a branching network of corridors placed in high-demand areas to serve current and future freight traffic needs without disrupting traffic in major cities. This would necessitate that the ATC be built adjacent to existing highways, within the existing highway right-of-way. Moreover, the ATC would be routed through remote areas miles away from major cities. A single corridor spoke into a city could be created for the autonomous vehicles to deliver goods locally, or the goods could be delivered to a local freight facility and then transferred to local delivery trucks. This range of options allows great flexibility in the planning of the ATC.

## WHAT ARE THE BENEFITS OF THE ATC OVER FREIGHT TRAINS?

Freight trains are amazing point-to-point hauling machines, ideal for taking large amounts of heavy goods from one location to another. A good example is the freight rail system used for hauling coal from a mine to a power plant. However, the biggest weakness of trains is that they are not flexible. First, when the engine stops to unload one or several cars, every car that the train is carrying also stops. This means that every car not being unloaded is sitting idle while the others are being unloaded. The ATC does not have this problem because each individual truck will have the ability to exit the ATC while the others continue. A new train track is also expensive to construct and requires a significant amount of land for safety. This requirement is especially challenging in urban areas, where land is limited. Since the ATC is designed to use the existing right-of-way on a highway, this challenge is eliminated. Various options for integrating the ATC into the existing right-of-way are shown in Figure 4.

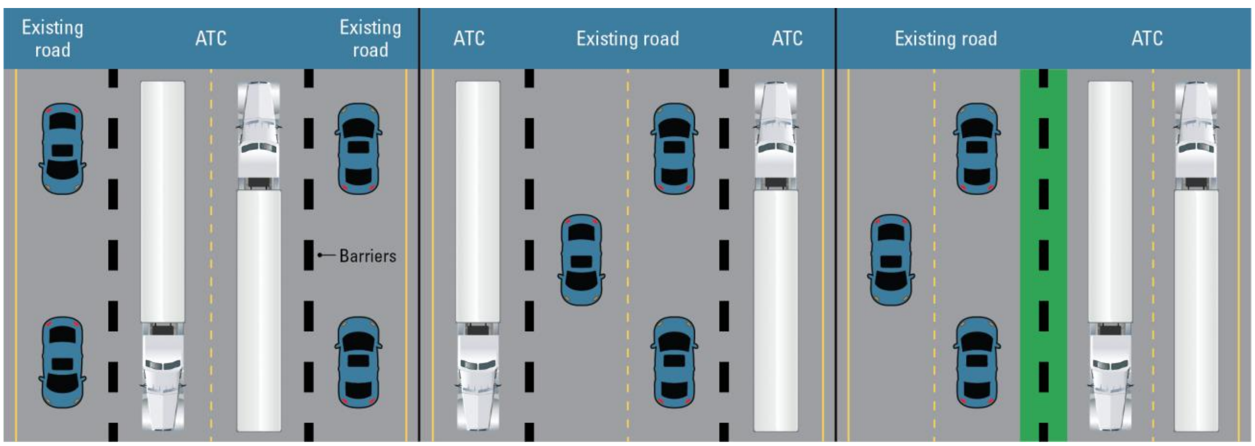



**Figure 4. Different ways of dedicating existing lanes for the ATC**

## HOW CAN THE ATC BE USED TO IMPROVE RESILIENCY?

One challenge that arises during emergencies such as earthquakes, hurricanes, and floods is that people must be evacuated quickly from the affected area. Subsequently, supplies and construction materials must be brought into the area to support recovery while debris is rapidly removed. The ATC provides many opportunities to create an infrastructure system that is better able to function during and after these disasters and that ultimately supports emergency management plans. During emergencies, much of the ATC could be devoted to disaster response.

While the autonomous trucks that use the ATC would typically carry cargo, they could be also used to carry people away from the affected areas rapidly. After evacuation, the ATC lanes could be used for the movement of emergency or other recovery vehicles. After the emergency, all lanes of the ATC could be used to take supplies directly to the affected area.

The Strategic Highway Network (STRAHNET), critical to the Department of Defense's domestic operations for the emergency mobilization and movement of military vehicles, could be enhanced by the construction of the ATC. The ATC could be a designated component of STRAHNET, used to either transport these vehicles on autonomous trucks or facilitate their travel directly on the roadways. All of these benefits provide additional examples of how the ATC network can be used to improve the lives of US citizens.

## WHERE SHOULD THE ATC BE LOCATED?

A key step in the development of the ATC is to ensure that the first segments be located in areas with high levels of current and forecasted freight movement. To achieve this goal, data-driven analysis, cost forecasting, and decision-making tools must be extended so that they are applicable to the ATC in order to provide for an objective and transparent identification and selection of corridor locations. This approach directly supports the recommendations of the Committee for Economic Development (CED) by providing a "uniform process of asset management that looks at true needs and life-cycle costs instead of elective politics" (Geddes and Madison 2017). In addition, data analytics can be used to quantify the extent of the demand, forecast the expected usage statistics, and quantify system-level impacts in order to study the economics behind the widespread implementation of this transformative shift in the design of the nation's highway system.

To do this, the following efforts must be carried out:

- Analyze historic traffic patterns, freight patterns, asset management data, funding sources, and financial potential to forecast future demands in commerce and the movement of goods
- Identify suitable existing highways for the development of the ATC
- Quantify the anticipated life-cycle benefits from implementing the ATC on existing roadways

The case study summarized in a previous section shows that substantial financial savings of 40% can be obtained on segments with truck volumes as low as 2,025 trucks per day.

The selection criteria must be gathered in a single metric that can be used to evaluate the value of the ATC to a certain region. The following equation can be used to obtain a rough estimate of this value:

$$a \times \text{Congestion reduction} + b \times \text{Freight tonnage} + c \times \text{Safety improvement} + d \times \text{Reduced maintenance} + e \times \text{Environmental Impact} = \text{Benefit Score}$$

Weighting factors are used before each term to help determine how much each factor contributes to the overall decision. These weighting factors still need to be determined, and this is an area of future work.

## IS IT POSSIBLE TO BUILD A LONG-LASTING HIGHWAY CORRIDOR?

From 2000 to 2005, the Pennsylvania Department of Transportation and the Federal Highway Administration undertook a multimillion-dollar project to build 10 mi of Interstate highway that would cost the same as a contemporary highway yet last more than 100 years. This project was constructed along I-99 in Pennsylvania and has been named "The 100-Year Highway." The 10 bridges in this section were built for the same construction costs as similar bridges in Pennsylvania. Each presented a different solution to providing long-life performance, but all were designed and constructed using different approaches. At its last evaluation, this project was in nearly pristine condition with minimal cracking or deterioration. This outcome shows that it is possible and practical to build better infrastructure than what is currently built. This concept of a long-lasting transportation corridor is not fiction but is something can actually be delivered cost-effectively.

## HOW CAN WE DESIGN FOR AN ATC THAT HAS SO MANY UNKNOWNS?

Construction of the ATC will require collaboration and the development of consensus among many stakeholders. This could be done through a joint conversation between autonomous truck manufacturers, trucking companies, utility providers, state and federal agencies, and contractors.

The ATC would offer an impetus for vehicle manufacturers to optimize the design of their vehicles for freight movement. If given the opportunity, these companies could redesign their drive trains, chassis, and guidance systems to optimize performance on the ATC. Furthermore, the design of roadways that offer a supply of continuous power and allow for high speeds and minimal stops would create unprecedented opportunities for vehicle manufacturers, along with a new set of challenges.

Because of the ATC's heavy use of electrical and fiber optics infrastructure, utilities and communications companies will be important partners in the system's development and construction. These utilities will be asked to provide and manage unique types of power lines and wired connections to this corridor, but they stand to gain significant benefits through the removal of right-of-way purchasing and environmental permitting.

Construction companies and design firms must understand the requirements of the ATC and determine how to provide successful services for this project. These companies will be important sounding boards to present preliminary designs and concepts that can serve as a baseline for the other partners to modify their needs.

State and federal transportation agencies will play an important role in the ATC. These agencies have the expertise to build and maintain the large infrastructure components and systems required for the project, and the ATC will require right-of-way that these agencies already own. The ATC also has the potential to provide a continuous revenue stream to pay for the ATC and its expansion corridors while generating excess funds to support other public works projects.

## HOW MUCH WILL THE ATC COST?

In the case study referenced earlier, different scenarios for the ATC system were compared in terms of both cost and carbon footprint. These scenarios involved various combinations of highways and vehicles, including existing highways, corridors with different lengths of OCL, autonomous or conventional vehicles powered by diesel fuel, and autonomous vehicles powered by a combination of OCL and either onboard batteries or diesel fuel. The length of the OCL was assumed to either extend continuously along the 200 mi distance between Oklahoma City, Oklahoma, and Dallas, Texas, or cover only a portion of that distance (50, 100, or 150 mi), with the remaining distance requiring trucks to be powered by internal batteries or diesel fuel. All scenarios were investigated for truck traffic volumes of 2,025 and 8,300 trucks per day.

A decrease in life-cycle cost relative to the baseline scenario was found for all scenarios except for the scenario involving a 200 mi long OCL under the lower truck traffic volume. At the higher volume of truck traffic, each scenario studied showed cost savings between 48% and 56%. Importantly, these savings were not impacted by the length of the overhead cable or the method used to power the trucks. These variables were not sensitive for the higher truck traffic volume because the infrastructure costs are divided by a larger number of vehicles, and the savings in driver salaries become more significant as the number of trucks using the system increases.

At the lower truck traffic volume, the method and infrastructure to power the trucks become more important factors in the cost calculations. For example, when the length of the overhead cable is 50 mi, the system can provide savings of approximately 40% regardless of whether the trucks use internal batteries or diesel fuel. This is an important finding because this scenario also showed the highest amount of financial savings for the higher truck traffic volume and a breakeven point (the point at which savings offset initial costs) of two years.

## HOW MUCH CAN THE ATC REDUCE $CO_2$ EMISSIONS?

The ATC can reduce $CO_2$ emissions by a significant amount because trucks are connected to and powered by overhead lines instead of using diesel fuel. The results of the case study referenced earlier show that autonomous trucks in the scenario featuring 200 mi of OCL have the lowest $CO_2$ emissions over a 35 year analysis period, specifically 62% and 64% lower relative to conventional trucks for 2,025 trucks per day and 8,300 trucks per day, respectively. Also, the trucks powered by OCL and either an internal battery or diesel fuel show a reduction in carbon footprint ranging from 15% to 63% compared to conventional trucks. The data show that as the length of the overhead cable decreases for scenarios that involve trucks powered by a combination of OCL and diesel fuel, the carbon savings also decrease.

It is important to note that although the OCL infrastructure does incur initial $CO_2$ costs for creating the infrastructure, the rate of $CO_2$ emissions decreases substantially in subsequent years, and the $CO_2$ costs for this initial construction are offset within two years in the worst case scenario. It is worth noting that these initial $CO_2$ emissions include construction of the overhead power lines, masts, and dedicated roads and bridges.

Overall, the results of the case study show the significant potential for 200 mi of OCL powering trucks with both internal batteries and diesel fuel to reduce $CO_2$ emissions.

## HOW CAN WE ENSURE THAT THE ATC STAYS IN GOOD WORKING ORDER?

It is critical that the latest technologies be used to protect the investment made in the ATC and that the corridor remain perpetually open. The key to maintaining a critical piece of infrastructure like the ATC is to catch deterioration as early as possible to ensure proactive planning for repair, rehabilitation, or replacement.

The use of structural health monitoring for such purposes has been heavily discussed but not often implemented. This technology would be implemented for the ATC, and protocols would be developed to guide data collection and make decisions based on the data. These efforts would include developing new approaches to link performance data to materials characteristics, materials proportions, and construction characteristics on a network level. Information from existing department of transportation (DOT) pavement management system (PMS) databases would be combined with advanced monitoring systems that rely on 3D scanning and sensors to provide a holistic understanding of how to maintain the system's long-term performance.

## RESEARCH NEEDS

The following is an initial compilation of research needs related to ATC implementation:

- A roadmap for ATC implementation is needed that encompasses the efforts required in finance, planning, design, technologies, utilities and services, and vehicle design. A framework is needed for each of these areas, and the interactions between the areas should also be explored. This roadmap will highlight the challenges in each area and will create priorities to be pursued.
- Pilot sections need to be created to establish contractor expertise and to allow different ATC technologies to be evaluated.
- Work is needed to formalize the quantitative decision matrix outlined in this document in order to guide decisions on the best locations for the ATC. This is an important step in deciding where to begin to implement the ATC.

- Market research is needed to understand the incentives necessary for freight companies to switch their development efforts to the technologies needed for the ATC and the best way to collect either taxes or tolls to recover costs.
- Best practices need to be gathered to provide long-lasting infrastructure for the ATC:
    - Performance-engineered mixture (PEM) practices should be implemented to help ensure that the materials used in the ATC are durable under field conditions. For example, if joint and material-related failure mechanisms can be eliminated, then fatigue would dominate the long-term behavior of the concrete pavements that constitute much of the ATC's infrastructure. A small increase in pavement thickness can increase fatigue life by a factor of five (Delatte 2014).
    - Long-term surface smoothness will also be imperative to improve energy efficiency on these roads. These roads should be constructed to be smooth at the outset and to stay this way. In addition, the top of the pavement should be designed to have at least a half-inch excess thickness of concrete to accommodate future diamond grinding to restore and retain pavement surface smoothness.

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