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Transformational Technologies Reshaping Transportation – An Industry Perspective

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2020 L. RAY BUCKENDALE LECTURE

This lecture, presented annually at the SAE Commercial Vehicle Engineering Congress, focuses on automotive ground vehicles for either on- or off-road operation in either commercial or military service. The intent is to provide procedures and data useful in formulating solutions in commercial vehicle design, manufacture, operation and maintenance.

Established in 1953, this lecture commemorates the contributions of L. Ray Buckendale, 1946 SAE President. L. Ray Buckendale, by his character and work, endeared himself to all who were associated with him. Foremost among his many interests was the desire to develop the potential abilities in young people. As he was an authority in the theory and practice of gearing, particularly as applied to automotive vehicles, it was in this field that he was best able to accomplish his purpose. To perpetuate his memory, SAE established this lecture to provide practical and useful technical information to young people involved in vehicle engineering.

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Transformational Technologies Reshaping Transportation - An Industry Perspective

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Abstract

Freight trucking has always embraced continuous improvement although the general public may be largely unaware of the tremendous changes that have occurred to date in vehicle safety, efficiencies, emissions mitigation and asset utilization. Today's freight industry is in the early stages of dramatic technological advances in areas such as connectivity, automation and electrification. Fleet and manufacturer perspective on these transformational technologies are universally supportive, driven both by economic and regulatory factors. The early stages of these technological revolutions are characterized by a multitude of competing concepts confusing choices, complicated by a significant number of competing vested interests obscuring objectivity, and clouded by billions of dollars of venture capital. The objective of this report is to provide unbiased insight into the freight industry's thoughts on these transformational technologies.

Contents

1. Introduction

This SAE L. Ray Buckendale report is the third in a series on transformational change in the commercial vehicle industry. The first in 2018 presented a government perspective [1]. The second in 2019 presented an academia perspective [2]. This current report provides an industry perspective. The primary purpose of the Buckendale is to provide new engineers with critical insights on key relevant topics, but experience has shown that Buckendale lectures and reports are useful to industry, regulators, policy makers, researchers and the public [3].

There are many transformational technologies becoming available to the trucking industry including automation, connectivity, electrification and even shared services. The opportunities abound, but they can also appear very challenging as they have the potential to improve or obstruct our ability to sustainably move goods in North America. Each offers their unique benefits and challenges and, in some cases, can build upon one another in an integrative solution to help with many of our transportation problems. It is a very exciting time to be in commercial vehicle engineering.

One technology that has incredible opportunity is the electrification of the trucks hauling goods from small Class 3 or 4 package delivery to long haul trucks carrying over 50,000 pounds of goods across our lands at up to 1,000 miles per day. The cost and emissions savings are enormous, but the challenge of hauling goods with batteries and electricity versus engines and diesel are large including the infrastructure to charge them. Solutions though exist today for some of the applications of this market that averages over the cycle to produce about 600,000 new medium and heavy duty trucks each year.

A key point to the success of a new technology is the correct application of it with the end user. End users have much to consider when deciding to pursue and ultimately adopt a given product offering. First, it must be technically feasible to do the job and then, economically feasible to purchase and operate. Oftentimes there are many benefits and consequences, which offer economic savings and additional costs. Finally, the end user must be confident they can implement the change in their fleet with their drivers, service technicians, suppliers and others.

Part of the successful diffusion or scaling of a technology is for the earliest adopters to be the best "place" for the technology, one where the benefits are exploited, and the consequences are mitigated. Later the technology can be advanced to satisfy a larger group of users for additional scale.

The paper will include the sharing of experiences from early adopting fleets that are currently in the middle of making the technologies work best for them. They include active case study sharing by PepsiCo, United Parcel Service (UPS) and NFI.

2. Scope

There are no average trucks. No average routes. No average fleets. No average drivers. No average loads. Averages are simplifications of the very complex freight industry.

Duty cycles vary by route, by fleet, by region, by load, and by many other factors. A comprehensive evaluation of technology adoption for every truck type in use in North America would fill volumes. The focus of this report is on moving freight, dry and refrigerated goods, using medium- and heavy-duty trucks and tractor-trailers. These vehicles today are largely fueled by diesel or gasoline internal combustion engines (ICE).

Trucks are classified by their gross vehicle weight rating (GVWR), the maximum permissible weight including freight for that vehicle, by the U.S. Federal Highway Administration (FHWA) as tabulated in Figure 1. The FHWA, as the name implies, has regulatory responsibility for the interstate freeway system which includes pavement design. FHWA required a system to differentiate between vehicles using then available sensors, primarily simple road tubes, to count and classify vehicles using the roads [34].

These weight classifications can include people movers like buses, a variety of construction and work trucks, refuse trucks, emergency vehicles, bulk tankers, flatbeds, etc. that are vocations outside the scope of this freight and fleet focused report.

Light duty, which includes pick-up trucks, a variety of vans, cars and sport utility vehicles (SUV) may haul freight in small volumes but are outside the scope of this report primarily because of their limited weight capacity. This is somewhat of an artificial division, since fleets may operate these for last mile delivery of products in smaller quantities, for example the growing fleet of blue Amazon delivery vehicles as shown in Figure 2. While last mile delivery is clearly part of the freight

FIGURE 1 Vehicle classification (FHWA/AFDC).

Gross Vehicle Weight Rating (lbs)	Federal Highway Administration	
	Vehicle Class	GVWR Catagory
<6,000	Class 1: <6,000 lbs	Light Duty <10,000 lbs
10,000	Class 2: 6,001–10,000lbs	
14,000	Class 3: 10,001–14,000 lbs	Medium Duty 10,001–26,000 lbs
16,000	Class 4: 14,001–16,000 lbs	
19,500	Class 5: 16,001–19,500 lbs	
26,000	Class 6: 19,501–26,000 lbs	
33,000	Class 7: 26,001–33,000 lbs	Heavy Duty >26,001 lbs
>33,000	Class 8: >33,001 lbs	

Reprinted from Ref. [31]. U.S. Department of Energy

FIGURE 2 Amazon Sprinter Delivery Van.

Reprinted with permission from Ref. [32]. © R. Mihelic supply chain, these vehicles have traditionally been outgrowths of automotive programs, generally gasoline-based powertrains, with multiple end uses aside from freight. +

The Union of Concerned Scientists (USC) reasoned that Class 2b vehicles should be considered as "heavy-duty" vehicles in considering emissions reductions [33]. UCS is referring to emissions classifications from the U.S. Environmental Protection Agency (EPA) as shown in Figure 3. EPA has regulatory authority over emissions of vehicles. While the FHWA and EPA lists are similar, the EPA list is more granular on weight ratings and also includes engines.

Medium duty Class 3 through Class 6 includes a variety of vans used primarily in urban delivery of freight. The ubiquitous delivery vans from UPS, DHL, FedEx and other carriers, examples of which are shown in Figure 4.

Heavy-duty (HD) trucks are Class 7 between 26,000 lbs. to 33,000 lbs. and Class 8 over 33,001 lbs. per the FHWA definitions. The term truck is commonly used to describe all freight vehicles, but they actually fall into two distinct groups. The first are straight trucks with the examples shown in Figure 5, where there is no use of a trailer. The second are tractor-trailer units alternatively referred to variously as semis, semi-trailer trucks, and semitrucks, 18-wheelers, etc., with the common theme of requiring a single trailer to carry

FIGURE 4 Example delivery vans.

Reprinted with permission from Ref. [32]. © R. Mihelic

FIGURE 3 Emissions Classifications by vehicle weight (EPA/AFDC).

Gross Vehicle Weight Rating (lbs)	EPA Emissions Classification			
	Heavy Duty Vehicle and Engines			Light Duty Vehicles
	H.D. Trucks	H.D. Engines	General Trucks	Passenger Vehicles
<6,000 6,000	Light Duty Truck 1 & 2 <6,000 lbs	Light Light Duty Trucks <6,000 lbs	Light Duty Trucks < 8500 lbs	Light Duty Vehicle < 8500 lbs
8,500	Light Duty Truck 3 & 4 6,001–8,500 lbs	Heavy Light Duty Trucks 6,001-8,500 lbs		
10,000	Heavy Duty Vehicle 2b 8,501–10,000 lbs	Light Heavy Duty Engines 8,501 lbs–19,500 lbs	Heavy Duty Vehicle Heavy Duty Engine >8,500 lbs	Medium Duty Passenger Vehicle 8,501–10,000 lbs
14,000	Heavy Duty Vehicle 3 10,001–14,000 lbs			
16,000	Heavy Duty Vehicle 4 14,001–16,000 lbs			
19,500	Heavy Duty Vehicle 5 16,001–19,500 lbs			
26,000	Heavy Duty Vehicle 6 19,501–26,000 lbs	Medium Heavy Duty Engines 19,501–33,000 lbs		
33,000	Heavy Duty Vehicle 7 26,001–33,000 lbs			
60,000	Heavy Duty Vehicle 8a 33,001–60,000 lbs	Heavy Heavy Duty Engines Urban Bus >33,001		
>60,000	Heavy Duty Vehicle 8b >60,001			

Reprinted from Ref. [31]. U.S. Department of Energy freight. Tractors can be day cabs or a variety of sleeper configurations. Trailers are enclosed dry van or refrigerated and can have a variety of lengths between 28 feet and 53 feet, with the highest current volume being 53-foot trailers. An example tractor-trailer is shown in Figure 5.

There are additional designations referred to as Long Combination Vehicles (LCV) such as A-trains, B-Trains, Rocky Mountain Doubles, Triples, etc. which can have multiple trailers or atypically long single trailers beyond 53 feet in length. An additional permutation of configurations is called a dromedary and combines a tractor that carries a box payload directly behind the cab while also pulling a trailer [36]. These LCVs are legal in various regions of the U.S. and Canada, and can carry, generally through permits, higher weight.

Complicating the topic further, there are intermodal container carriers that appear similar to tractors pulling van trailers, but the box is separable from the trailer chassis, and can be also used on trains, as illustrated in the examples in Figure 6. The 53-foot ones are not used on ships, where the primary standard lengths are 20 ft. and 40 ft. (see ISO 668 and ISO 1496 standards) [46, 47]. The 20 ft. length is referred to as a TEU (20-foot equivalent unit). A 40 ft. is then 2 TEU, a 48 ft. is 2.4 TEU. The majority of ship containers are 40 ft.

FIGURE 5 Example straight trucks (top) and tractor-trailer (bottom).

Reprinted with permission from Ref. [32]. © R. Mihelic

FIGURE 6 Container on separable chassis examples.

Reprinted with permission from Ref. [32]. © R. Mihelic

Various government, public and private analysis of commercial fleet vehicles may group and sort vehicles substantially differently. These definitions are further clouded in making comparisons between vehicles in different countries, which have different designations, configurations and requirements. Care must be taken to clarify which vehicles are included or excluded from data.

The focus of this report is on fleet perspectives on adoption of technologies for FHWA defined Class 3 through 8 North American straight trucks and tractor-trailers hauling dry or refrigerated freight in box trucks and box trailers.

3. Current Dynamics

The primary purpose of the freight industry is to be profitable and safe. Whatever the role, whether the vehicle manufacturers, their tier 1, tier 2 or tier 3 suppliers, the shippers, the fleets, the drivers, the inspectors, the regulators, the end customers, they all are inextricably tied to the business of moving freight for the purposes of safely making money. Without profitability, businesses fail, and the entire model spirals into the ground. Continuously improving profitability is a fundamental driving force for businesses. Focusing on improving business efficiency is one key method for accomplishing this, and a constant factor in today's freight industry dynamics.

Social responsibility, acting in a manner that benefits society beyond just being profitable, is a choice. Or rather, a series of choices. Social responsibility could be recognizing that truck driver's quality of life is important, that a driver being able to be home every night after driving 400 miles is important to family and community values. It could mean that factories and warehouses are well lit, with minimal noise and clean conditions for workers. It could mean sufficient pay structures such that employees can sustain their families and be contributing members to the community.

Social responsibility could be recognizing that truck drivers, auto drivers, pedestrians, and just people living near roads and facilities should not be harmed during the transport of freight. Vehicles should not collide and should not emit pollutants. The sourcing, distribution and use of the energy in the freight system should not be wasteful or harmful to society.

The freight industry has been increasingly challenged to monetize social responsibility, to put dollar value to socially responsible choices. How do you relate - in terms of dollars - the benefit to profitability of a driver's quality of life? How do you value in dollars that a parent can see their child each day? Or the dollar benefit to the freight industry of reduced pollutant levels in a community? How do you value reduction in regional community medical issues to a business operating there?

Regulations are merely codification of social responsibility by elected officials through policy making. Standards are merely consistent measuring sticks. Putting social responsibility into the dollar math of freight business is a major part of today's freight industry dynamics.

Transformational technologies in the freight industry are critical to improving business efficiency. They are critical to monetizing social responsibility. Three specific areas where these technologies are readily apparent in today's freight industry dynamic are electrification, autonomy and logistics.

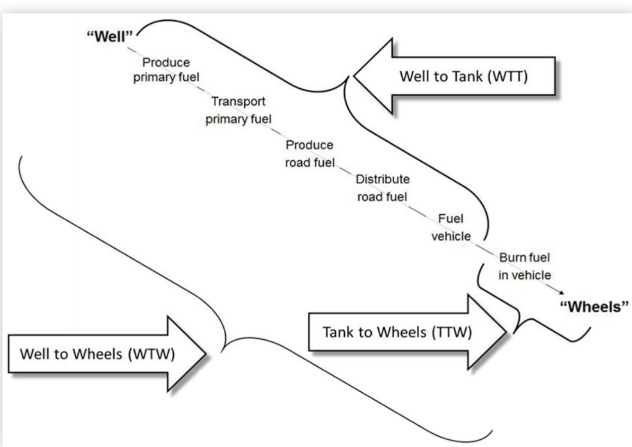
3.1. Electrification

We've grown to describing transport in terms of miles per gallon. It's easy to visualize: you fill a tank with an amount of fluid fuel, the vehicle goes so many miles, you refill. That pump-to-wheel view ignores all that is involved in getting the fuel to the pump, the drilling, the refining, the tankers, the trains, the pipelines, and all the associated factors tied to those. It also largely ignores the effect the combustion has after the fuel is used in the vehicle, the emissions. A broader perspective is often termed well-to-wheel. Figure 7 illustrates differences in scoping energy.

Placing energy use in terms like "fuel" and "well" has proven problematic as the industry is developing battery (BEV), fuel cell (FCEV) and catenary (CEV) electric vehicles - these three all fall under the term "electric vehicles". Electricity is poorly described as "fuel," does not have to originate from a "well," and does not have to be combusted, although there are electric energy supply chains that do include wells and do burn fuels. To differentiate these, the term "green" is often applied. For example, green electricity originating from non-polluting methods such as hydropower (dams), wind turbines, solar panels, and occasionally nuclear power is thrown into that definition.

A true system perspective might question that these "green" energy methods also have environmental cost impacts - dams inhibit salmon flows, wind turbines can damage birds or have noise-related environmental issues, solar panels require significant space that may reduce arable farmland, and end of life disposal or recycling is always a factor. All these "green" methods also have infrastructure and

FIGURE 7 Tank to wheel vs well to wheel (NACFE/EU) [36].



manufacturing impacts - building and manufacturing these "green" installations have environmental footprints.

The convention of using the terms WTW and TTW, however, have become commonplace to reflect system versus vehicle level comparison and will be used in this report.

Fleets and vehicle manufacturers alike have seen the tremendous growth in production and sales of electric cars and buses. The response has been massive investment towards electrifying trucking.

"Prior to this decade, changes in the heavy truck OEM club were extremely rare. Brand marks like Diamond REO, White, Sterling (formerly Ford Louisville), Marmon and LaFrance were absorbed or changed ownership before disappearing from the North American marketplace. Others were absorbed by parent corporations as with Daimler's purchase of Freightliner or rebranded such as when the International Corporation became Navistar. Entirely new OEMs were largely non-existent between 1950 and 2000 [7]."

The past decade has seen a significant increase in the number of North American OEMs with recent start-ups such as Tesla, Nikola, Arrival, Workhorse, Chanje, Motiv, Rivian, Xos (formerly Thor Trucks) and others. International companies formerly without significant medium- or heavy-duty North American truck product lines have been contemplating electric market entries. Older smaller volume nameplates are getting greater media attention and investment such as Lion and BYD. Tier 1 suppliers such as Ballard Power, Meritor/TransPower and Cummins have helped build prototypes. These are all now competing with the well-established big brands such as Freightliner and Western Star (Daimler Trucks North America), Volvo and Mack (Volvo Group), Kenworth and Peterbilt (PACCAR), International (Navistar) and smaller nameplates like Autocar and Oshkosh.

There are many factors contributing to electrification:

- Competitive Forces
- Accountants & Stockholders
- Regulations
- Proactive Engagement in Technology
- Grants and Incentives
- Marketing Brand Image
- Need for Drivers
- Corporate Sustainability Goals
- Venture Capital
- Grid Improvement/Revitalization

These multiple factors are fueling a significant sea change in truck propulsion systems with the fundamental common thread that today's internal combustion engine vehicles can be replaced by emission-free powertrains and the business case, in dollar terms, will be positive.

As with all fledgling technologies, getting started with electric trucks has been challenging. Startups with optimistic initial announcements of product launch dates in 2019 or 2020 have all missed their introduction dates. Established brand OEMs consistently targeted post-2020 dates, some suggesting

2023-2025 for limited production, and have relied on aftermarket chassis modifiers like Fontaine Modification, Roush, and others to help get prototypes into field use with fleets. Early medium-duty electric truck entrants like Modec and Smith-Newton in the 2006-2009 time frame went bankrupt waiting for the market to take off.

While catenary electric vehicles are in evaluation in parts of Europe, the expanse and complexity of North American roads is focused on pure battery electric and hydrogen fuel cell trucks. While some categorize this as completely distinct vehicle types, both are more accurately described as battery electric vehicles with differing range extension energy storage systems. "Green" versions of both start from the generation of electricity - creating environmentally responsible hydrogen starts from renewable forms of electricity generation.

The debate over whether BEVs or FCEVs will "win" the mass market are flawed. Electrification of freight is not a "winner take all" fight between competing technologies. The diversity of duty cycles in freight requires a range of vehicles and the future solution space will see both developed into a wide range of purpose-built implementations. Even in context of today's diesel-based vehicles, fleets operate a range of technologies specified ("spec'd") for each fleet's interpretation of their own duty cycle requirements. Today's truck manufacturers have millions of permutations of option content to offer solutions to fleets because duty cycles and needs vary.

Current fleets may have a range of gasoline and diesel medium-duty vehicles next to a range of heavy-duty day cab and sleeper cab diesel tractors of differing technology vintages and manufacturers. There are no "average" trucks in fleet operations.

The hope with EVs is that they are economically viable, that they actually have a net environmental improvement, that they actually have lower operating costs, and that their uptime and reliability are equivalent or better than the gasoline and diesel trucks they are intended to replace. Trucks are tools, they wear out and need replacement. While waiting for that future, fleets must continuously invest in today's vehicles. OEMs must not just innovate future alternatives, they must refine existing ones, so investment in improved diesels, compressed natural gas (CNG), and hybrids based on both will continue for some years to come.

The North American Council for Freight Efficiency (NACFE) describes this near future as the "messy middle," with fleets investing in a variety of technologies, those evolved from the known reliabilities of current powertrains and those unproven revolutionary ones, as a bridge to a future state with net-zero emissions and finally zero-emission solutions prevailing, as illustrated in Figure 8. Truck powertrain technologies bridging to the zero-emission future.

The freight marketplace will sort out the technologies. Good fits for specific duty cycles will be replaced by better ones as technology matures and fleets get field experience with them, feeding that back to the manufacturers to iterate on designs. Poor technology fits, placing the wrong technologies in the wrong applications, will quickly suffer. Market forces ultimately drive the success or failure of technologies. Regulations may level the technology playing field for manufacturers and fleets, but products that do not deliver ultimately fail in the market and are replaced by those that can get the job done. The history of the freight industry is littered with failures and success stories on transformative technologies. Time will tell where electrification falls on that spectrum.

3.2. Automation and Autonomy

Interest in automation of all things has been around remarkably for centuries. Analog solutions to automate repetitive tasks or to improve consistency of results include ancient water wheels automating grain grinding, the Jacquard loom in the 1700s that enabled weaving complex, repetitive fabric patterns, the not-so-simple reliable clock, or rather "chronometer," needed to enable repeatable navigation, mechanical computers for targeting weapons like World War I and II battleships. The dot.com boom and bust in the late 1990's stemmed in part from a desire to digitize many forms of business and in so doing, eliminate manual labor, improve analysis of data and ultimately reduce operating costs. That business goal persists in today's cloud based, sensor rich, cell phone and digitized world.

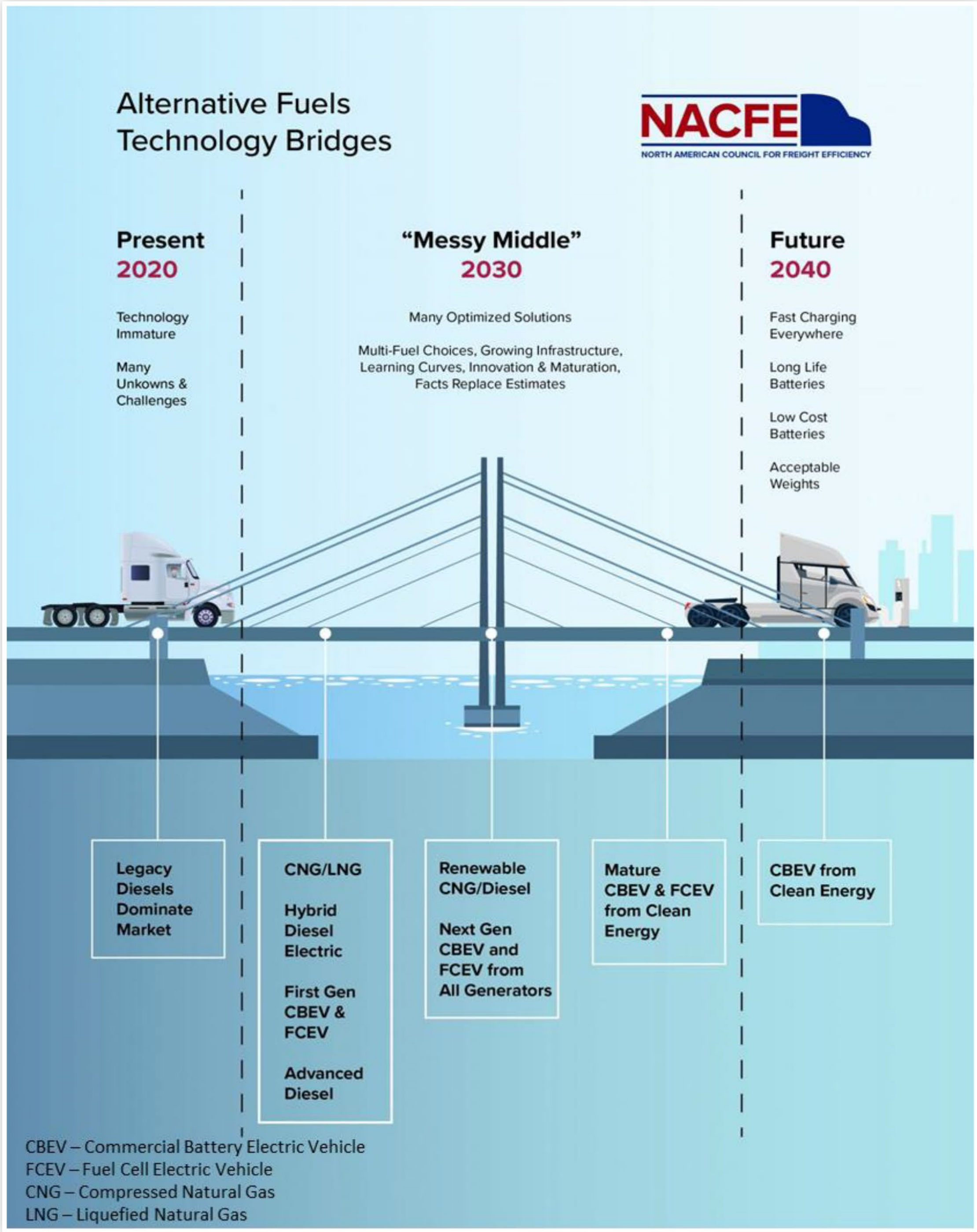
Applying automation to freight vehicles has been on-going since at least the first introduction of automatic transmissions by Allison in the 1940s, automatic braking systems (ABS) introduced by Bosch and Daimler in the 1970s, and programmable engine controllers by Cummins and others in the 1980s [38, 39, 40]. The 50th anniversary of Earth Day in 2020 prompted NACFE to generate a summary of advances in freight shown in Figure 9.

The rapid pace of computer evolution has seen the simple wall mounted rotary Bell telephone of the 1950's replaced by disposable handheld multi-purpose devices that were the things of science fiction in the 1960s. Developments in truck automation, while a somewhat slower pace, have seen deployment of automated, adaptive and predictive cruise control systems [41]. ABS systems have seen significant improvement for tractor-trailer driving to improve stopping distances and reduce risks of jack-knifes and rollover events with stability control advances. Collision avoidance and mitigation systems have evolved with forward and side looking blind spot sensor systems. Mirrors are beginning to be replaced with digital camera systems bringing with them potential for a variety of digitized driving functions beyond just vision. Lane keeping assistance systems are resulting from combinations of these technologies. Collectively, these transformational technologies can be described as driver assistance systems (DAS). In general, they operate as required to assist the human driver and can also be referred to as active safety systems.

Fleets and OEMs generally support the addition of DAS systems on vehicles to improve operating efficiencies, mitigate accidents and improve the ability of drivers to see and respond to emergencies. These may be monetized in relation to reduced operating costs, reduced legal and insurance costs, improved new driver attraction and existing driver retention costs, and better on-time delivery metrics that can garner industry freight rate premiums.

Automated driver systems (ADS), sometimes referred to as Advanced Driver Assistance Systems (ADAS), are more substantial, characterizing automation systems that perform

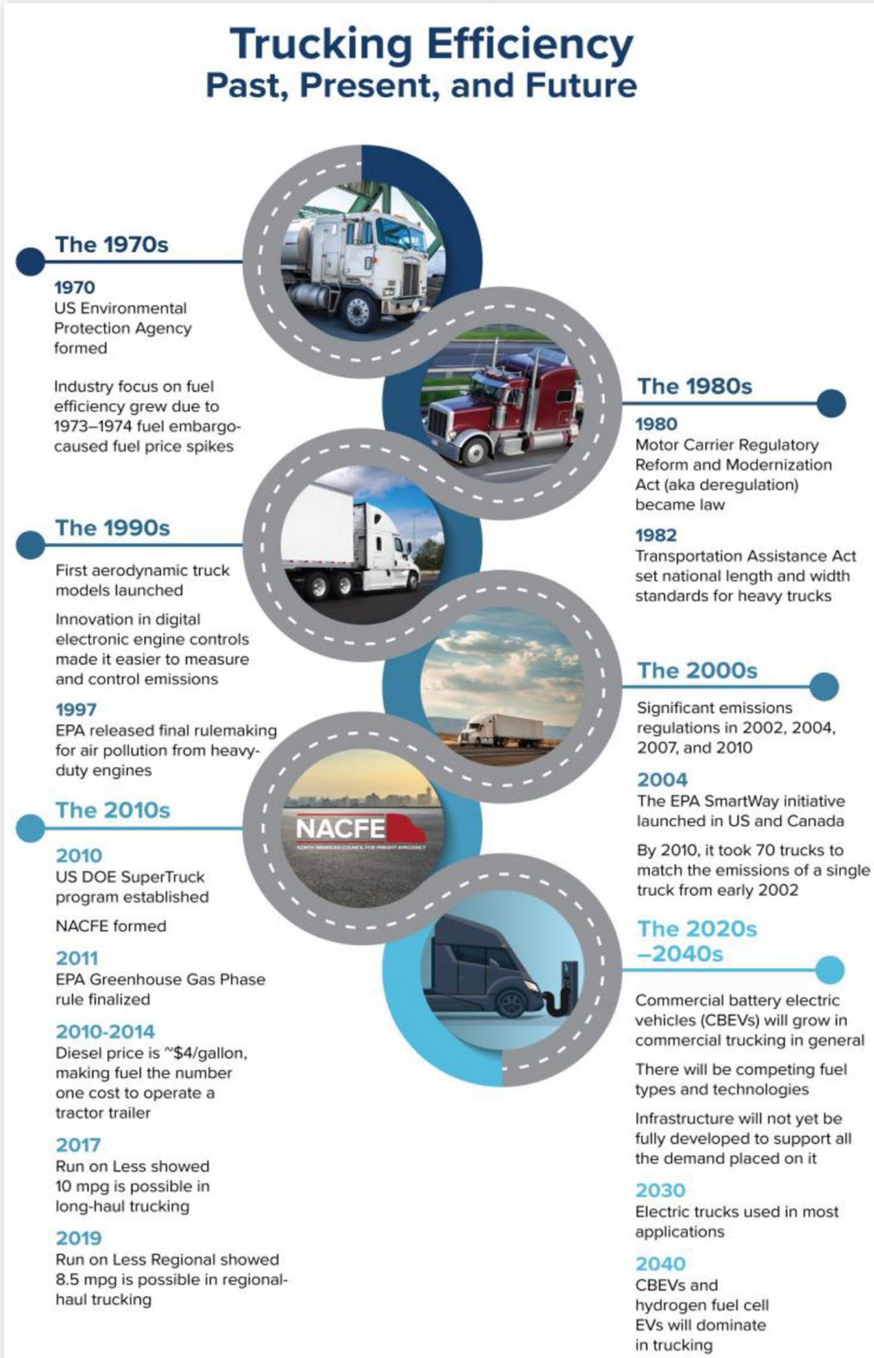
FIGURE 8 Truck powertrain technologies bridging to the zero-emission future.



part or all of the dynamic driving task (DDT) on a sustained basis. The common source document for definition is SAE J3016 Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles [42].

Monetizing ADS transformational technologies in freight involves estimating the value of the human in freight operations, valuing the flexibility and experience of the human to intercede in operations for the positive, versus estimating the potential risks that human may also unintentionally or intentionally through negligence introduce to the operation of the vehicle. For example, how do you value the worth of the experience of a million-mile safe truck driver's avoided accidents - measurement of avoided problems is usually difficult to obtain, where occurring problems are actively tracked. How do you predict the number of accidents a fully automated truck may have given that extremely automated systems like planes, spacecraft and nuclear power plants still encounter failure modes? Does it make sense to take the driver

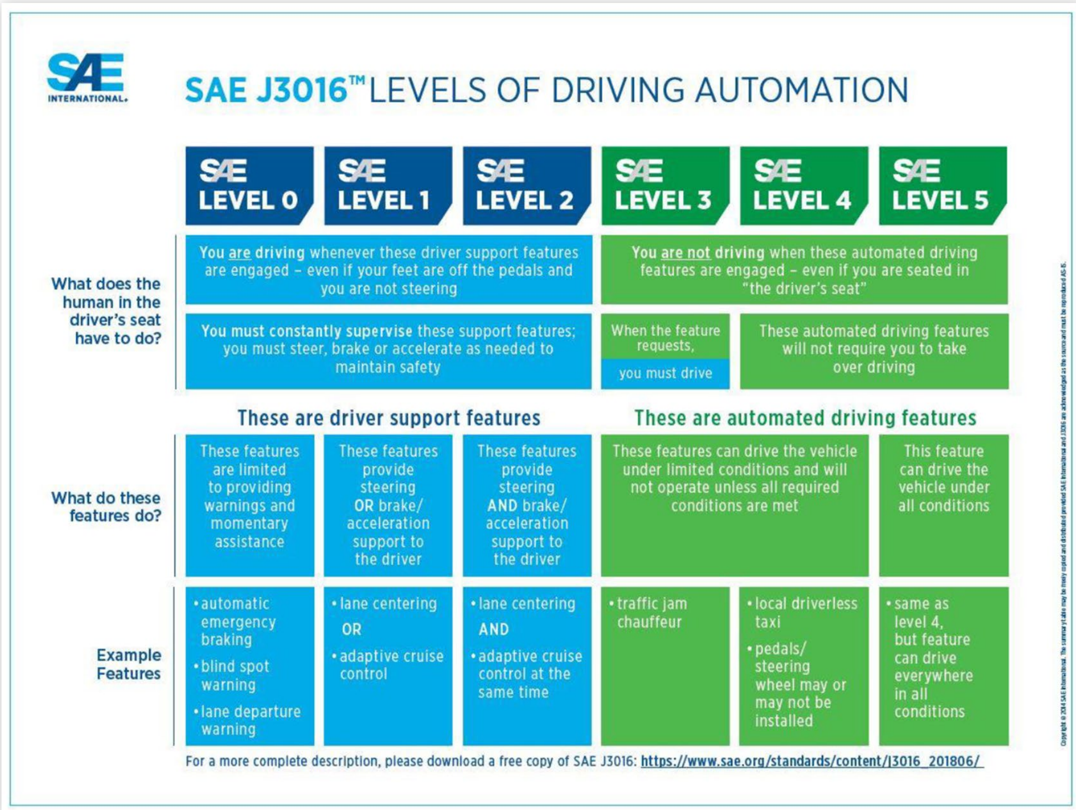
FIGURE 9 Trucking efficiency 50 year progress.



(or occupant) out of the truck entirely? Removing the driver from freight economics has the potential of reducing vehicle operational costs by one-third to one-fifth, but what are the capital cost increases to add sensors, computers and software to the vehicles and what operational maintenance costs do those systems generate? Much of this in the absence of operational examples is crystal ball speculation.

The SAE document outlines six levels of automation from none (level 0) to full driving automation (level 5), as illustrated in Figure 10. Level 4 is applicable to limited on-road driving situations and Level 5 is unlimited driving situations. Level 4 automation entirely without a human vehicle attendant might be considered in geo-fenced implementations such as a warehouse loading dock operation with trailers being dropped (parked) or hooked (driven off) in human free yard operations. A limited on-road Level 4 application might be a vehicle traveling on a freeway between two near-freeway stopping locations where a human driver is in control before and after the trip when getting into more complex urban driving conditions. Level 5 might be a vehicle operating on public roads with or without human occupants with no expectation of human intervention in safe operation of the vehicle.

FIGURE 10 SAE J3016 levels of driving automation.



Vehicle automation and autonomy are not destinations, but journeys. As with all technologies, individual major innovation spurs many less obvious minor innovations in a seemingly endless process of maturation, seemingly that is until the technology is ultimately deemed obsolete by the market and existing examples are relegated to the scrap yards or museums. Vehicles in freight service tend to have long lives, and retirement of technologies can take decades. The speed of obsolescence of rapidly changing new technologies is a challenge and a concern in the complex freight industry dynamic on transformational technologies.

3.3. Logistics

The management of, or more exactly, the coordination of, moving freight is termed logistics. Customer A orders a box of widgets from supplier B through intermediary C. How does the package get from its point of creation to its final destination? What does it cost? How long does it take to get there? How is it protected in transit? All of that collectively is logistics.

Prior to the digital revolution with computers, the majority of logistics management was done by people, with varying levels of expertise, usually involving paper-based systems. Old habits die hard in freight movement. Some operations may still be human and paper-based, even today, residing in the colloquially termed back office operations.

Smart logistics are rapidly evolving. Significant market penetration of web-based tools and software systems have brought about digital load boards where fleets can nearly instantaneously match available loads to available transportation assets to expedite the supply chain delivery of materials. GPS based tracking systems can constantly monitor and report on asset utilization for fleets including not just location, but loads, speeds, dwell times, stops, vehicle condition and more. Where paper-based systems were cumbersome and labor intensive to manage assets, fleets now are faced with perhaps too much logistics information at their fingertips. Filtering and prioritizing the mass of available data and bringing it all from disparate information silos into common platforms for rapid analysis are becoming the challenge for logistics managers.

Some fleets have had to staff information technology positions to deal with the growth in data management requirements, having to trade off driver positions to pay for IT ones. Vehicle maintainers have also seen challenges with obtaining skilled personnel capable of dealing with the new wealth of data coming from the vehicles. This is spawning growth in third party service providers to help fleets.

A traditional model for companies was to own their own delivery fleets. This was a natural extension of trying to reduce operating costs by not paying profits to intermediaries. However, the growth in e-commerce has brought with it a new generation of shippers that can be described as not wanting to be fleet operators, they just want their products handled and delivered. This has spawned a group of intermediary service providers termed third party and fourth party logistics suppliers, abbreviated 3PLs and 4PLs. These service providers facilitate movement of products from manufacturers to consumers. 3PLs are generally asset based with trucks, trailers, drivers and often warehouses. 4PLs are generally not asset based, single point of contact facilitators for the parties wishing to ship product. The definition of 3PL was codified in 2008 by U.S. Congress "as a person who solely receives, holds, or otherwise transports a consumer product in the ordinary course of business but who does not take title to the product. Prohibits deeming a logistics provider to be a manufacturer, distributor, or retailer solely by reason of receiving or transporting a consumer product in the ordinary course of its business [44]." While the definition of 4PL is not codified, Cerasis, a logistics provider, explains that their role is to manage the entire supply chain. Cerasis, referring to a glossary by the Council of Supply Chain Management Professions, explains that first party logistics providers (1PL) can be a manufacturer that owns its own delivery services, and a second party logistics provider (2PL) can be a segment based shipping provider such as a rail operator, shipping line or trucking company hired to move product from point A to point B [45, 46].

Transformational technology opportunities in logistics management abound. Asset tracking is expanding from tracking not just the tractors, but the trailers and the individual packages in loads. Drivers are also being tracked. This abundance of near instantaneous geospatial information is being combined with performance metrics from vehicles, combined with crowd sourced traffic condition information, combined with location specific weather condition data, and even parking spot planning systems are being implemented [23]. The ability to keep trucks moving, keep drivers driving, and shorten freight delivery paths and times is the opportunity for logistics innovation.

4. Other Influencing Factors

Transformational technologies come in many flavors. Some apply only to the physical truck, such as an aerodynamic fairing or replacing a standard mirror with a camera system. Others apply to how the vehicle is operated on the road, or at the depot or warehouse, such as idle management and idle reduction systems like auxiliary power units, or automated manual transmissions that simplify and standardize shifting. Still others apply to back office operations such as improving routing and asset allocation through digital order boards, reducing empty miles, and maximizing driver utilization. The common thread is a continuous focus on improving efficiency at every opportunity.

4.1. Platooning

Platooning has been in use for decades where truck drivers noticed they got better fuel efficiency by closely following another truck than alone on the road, often violating safe following distance rules. The racing term is called drafting. The transformational technology today is in applying fast computing and sensors to safely automate platooning,

FIGURE 11 Platooning example.

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removing the human reaction times in applying braking, allowing shorter, safe following distances, improving net fuel economy and potentially allowing the second vehicle to be fully automated [48, 49, 50].

Automated platooning is a transformational technology affecting the operation of two or more vehicles on road. It can impact back office load and asset management. It can impact driver hours of service and potentially let one driver control two vehicles. In its basic implementation, it is a driver assistance system, not unlike adaptive cruise control that automatically attempts to maintain a specific gap between your vehicle and the one in front for the purposes of reducing aerodynamic drag on both and thus improving fuel economy. However, it is more complex in that both vehicles are driving in a digital partnership, where both the drivers and the vehicles are connected, and the vehicles operate as a cooperative unit. The goal is to safely attain better fuel economy over shared portions of a journey while giving the vehicles the flexibility to separate and operate independently to go to different final mile destinations, and to reduce physical demands on the drivers.

A more extreme implementation of platooning is fully automating the follower vehicle(s) such that the lead driver is the only human in control of the platoon. The added goal here is to safely increase the payload per driver, a critical metric in a perennial shortage of qualified drivers and projections of ever-increasing freight demands over time [23].

Opinions differ at OEMs over the potential benefits, costs and challenges with platooning technology. However, the fundamental elements of platooning are universally included by OEMs in the discussion of automating trucking. NACFE's opinion is that platooning may be viewed as simply a subset of the topic of automating freight.

4.2. Automation

Automating freight is considered by some as a way to improve highway safety, reduce physical demands on drivers, help to deal with current and projected driver shortages in the industry, and ultimately reduce fleet operating costs. Others view these claims as largely unproven, unsubstantiated, and Pollyannaish. Drivers and their organizations are particularly sensitive to the potential of eliminating driving jobs. Safety organizations are both intrigued and concerned by the prospect of unmanned trucks on highways with a mix of passenger vehicles of various vintages and driver skill sets. People familiar with the development of automated piloting systems for aircraft point out that pilots are still in today's passenger jets and that accidents still occur with both the automation and the humans, after decades of technology development.

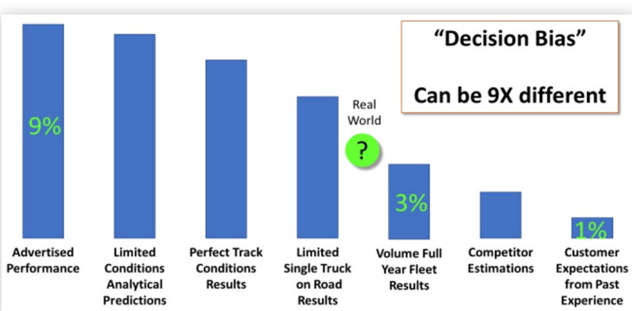
A challenge with rapidly evolving technologies and marketplaces is providing sufficient regulatory oversight while not inhibiting innovation. A variety of industry groups and government agencies at the state and federal levels are wrestling with this tradeoff between responsible and legally bound oversight of new technologies and the potential of becoming overly intrusive or misdirecting innovation.

The tradeoffs tend to include significant vested interests which can obscure or confuse the analysis. NACFE has reported on decision bias in technology discussions where vested manufacturers may overstate real world performance by a factor of three while end users, underrate advertising claims by as much as another factor of three based on past experiences. This can lead to as much as a 9x difference between manufacturer claims and customer expectations, as illustrated in Figure 12 [36]. Real world performance is often somewhere between these two perspectives.

Decision bias points to why new technologies don't just need to be equivalent in cost and performance to the ones they are replacing, they need to be substantially better to win industry attention and market share. Claims of "10%" improvement are common as this value seems to be aimed at obtaining interest from venture capital. Controlled track tests and analysis can often be conducted to support these claims, however in the complex real world, these projections often come up short. The variety of industry duty cycles and operating conditions is significant and rarely are there average trucks or average conditions. Industry fleets tend to take advertised claims with a grain of salt, and the larger fleets will each prove them out in their own operations before significant investment. Smaller fleets will look to the larger fleets' experiences for guidance.

Automation and human drivers are not mutually exclusive positions. Full automation of a vehicle will add equipment to the vehicle. Additional computers, sensors, software, wiring, connectors, testing, training etc. will add costs. If the driver is still in a fully automated vehicle, there may be limited

FIGURE 12 Technology decision bias.



offset opportunities to save costs, other than to lower pay. However, partial automation can improve the driver's safety, on-time performance, up time, perhaps even allow hours of service changes in the future allowing greater ranges - there are offsetting cost reductions possible with partial automation while keeping the driver still on board in value added roles. Insights combining automation with keeping drivers employed are provided by Steve Viscelli in Driverless? Autonomous Trucks and the Future of American Trucker [51].

The three images from Viscelli's research in Figure 13 illustrate the typical freight model today that is largely human driver centric, then the second is a likely full automation future freight model with significantly less roles for human drivers, and finally the third image reflects a cooperative future vision where automation technology and human drivers work in a cooperative world.

Automation of freight is much more than just automating one vehicle, a much deeper topic than figuring the return on investment for adding a trailer skirt or roof fairing. There are ramifications to the back office, to customers, to the public, the economy and to drivers. It's a complex topic.

4.3. Connected Vehicles

The trucking industry has been migrating to using the phrase "automated and connected" in describing future vehicles, recognizing at various levels that improvements require vehicles to not operate in complete isolation, but feed off of a number of data sources and interactions with other vehicles, with infrastructure, with crowd sourced databases, satellites and cell towers, and more.

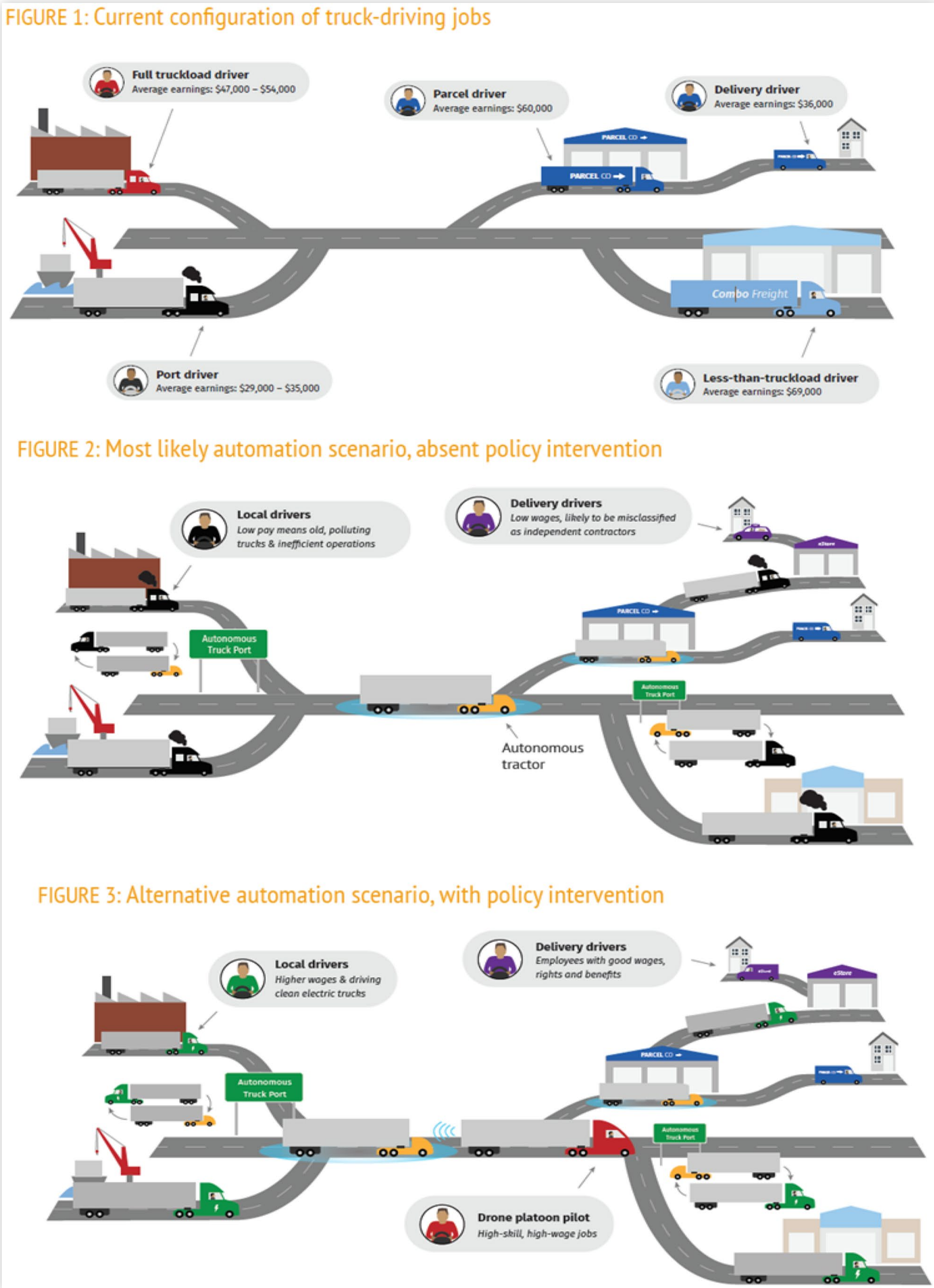
There are terms like V2V (vehicle to vehicle), V2I (vehicle to infrastructure), V2G (vehicle to grid), V2X (vehicle to everything) and various applications of the term "smart" to reflect intelligence of the systems such as "smart charging." New terms and acronyms appear frequently.

Connected vehicles encompass a wide range of potential transformational technologies. The development of smart cell phones and tablet computers has revolutionized access to each other and to data. Much of the freight industry still runs on paper, though, so opportunities abound for improving the freight model through connectivity.

Connectivity can provide near instantaneous situational awareness for truck drivers and their vehicles. Real time traffic conditions, weather, route alternatives, load availability, parking availability, fueling or charging availability, maintenance, and more. With this increased access to information comes the need for filtering to avoid being overwhelmed. NACFE ran a 17 day Run on Less Regional event in the fall of 2019 in which 10 tractors and their drivers were constantly monitored with data loggers on the primary communication bus for the engines and that included GPS tracking data tracking a 1 Hz frequency. The event accumulated over 7 million lines of data and hundreds of channels from each vehicle.

Technology to obtain data is outstripping the ability to digest it in meaningful ways in both the back office and at the driver level. A critical need for absorbing connectivity is developing robust and efficient means of processing the massive

FIGURE 13 Automated vehicle alternative futures



Reprinted with permission from Ref. [51]. © Steve Viscelli amounts of available information into useful and timely actionable information.

4.4. SuperTrucks I & II

Technology demonstration is critical to fleet acceptance. Evolutionary technologies tend to be evaluated by larger fleets to validate them before making significant long-term commitments. Smaller fleets look to examples from larger fleets, or end up accepting their decisions during buying secondary market trade-ins. Revolutionary change as are shown by OEMs in futuristic prototypes may be intriguing "what if" experiments, but may not capture actual market interest as the technologies may be one-off with significant unknowns. Enter the Department of Energy's SuperTruck programs.

In concert with recommendations from the 21st Century Truck Program, and somewhat facilitated by the dynamics of the 2008-2009 great recession, the Department of Energy created the SuperTruck program. SuperTruck was in part a jobs creation/maintenance program in parallel with an opportunity for OEMs to demonstrate system level design methodology applied to greatly improve the efficiency of an on-highway tractor-trailer vehicle system. Emphasis was placed on technologies that were near production or could be put into production in two years or less. The DOE set a challenging goal of achieving a 50% improvement in freight ton efficiency [54]. Four vehicles shown in Figure 14 came into public view between 2014 and 2016 by the OEM teams, all four readily exceeding the challenge goal.

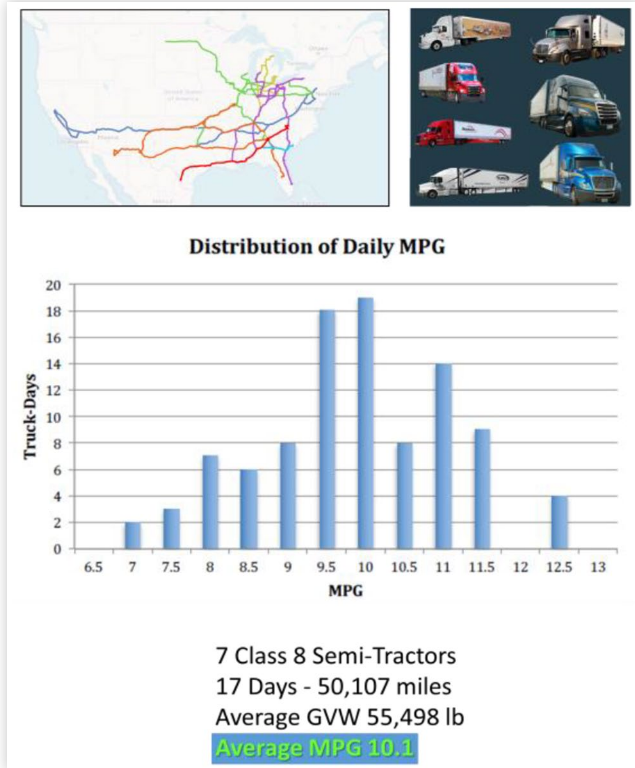
Many of the technologies successfully demonstrated in SuperTruck were in production when NACFE ran their 2017 Run on Less demonstration. This event took available production trucks with top notch drivers and demonstrated the feasibility of high efficiency operation attaining a 17 day on-highway average of 10.1 mpg carrying real loads in real weather conditions that included the ramifications of two major hurricanes. The demonstration is summarized in Figure 15 [53].

The SuperTruck II program was launched in 2016 building off the success of SuperTruck I [56]. The Funding Opportunity Announcement (FOE DE-FOA-0001447) from the Department of Energy required demonstration of "more aggressive" goals of "greater than 100% freight efficiency goal

FIGURE 14 DOE SuperTrucks 2014-2016

Reprinted from Ref. [52]. Composite from U.S. Department of Energy sources

FIGURE 15 Production vehicle efficiency demonstration.



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and greater than or equal to 55% engine brake thermal efficiency goal" versus the 2009 baseline [55]. As of the June 2020 DOE Annual Merit Review (AMR), all five SuperTruck II teams were on track to meet or exceed these "more aggressive" goals [92] with demonstrator vehicles on road in the 2021-2022 timeframe.

A key requirement for both SuperTruck I and II programs was the need for project teams to demonstrate commercially viable technologies, captured by the SuperTruck II FOA text:

"In addition, SuperTruck II places greater emphasis on creating and enhancing technology suites that can be more cost-effective for end users to purchase and operate and places less emphasis on technology solutions with no credible pathway to cost-competitive commercial adoption in real-world applications. DOE's specific focus is on technologies (or systems of technologies) with realistic current or future potential for cost-effectiveness as expressed in terms of a simple payback (years to recoup initial investment through fuel cost savings), with shorter payback periods being deemed more cost-effective than longer periods. Those selected for award under this FOA must annually report current and potential future cost-effectiveness for the planned technology innovations in terms of simple payback or provide additional information to describe cost-effectiveness beyond simple payback if so desired. A generally-accepted industry measure for "commercially cost-effective" is a less than three-year simple payback. However, this may vary based on technology, customer, market needs, and regulatory environment [55]."

The DOE funds each year a number of technology paths. Some are clearly early in maturity while others, as with the SuperTruck programs, are expected to be near to being in production. Fleets as the end technology adopters have interests in supporting innovation and welcome research into new ideas, and they realize some ideas take years to evolve. They also need these ideas, once they have matured to the point they can be commercially purchased, to be cost effective for their operations.

The SuperTruck II teams have pursued some similar technologies such as advances in waste heat recovery, reduction in friction through improved coatings and lubricants, improvements in tire rolling resistance, etc. They have also pursued differing paths such as downsizing engines, creating purpose built axle configurations, potentially reintroducing the cab-over shape to the North American marketplace, use of smaller diameter tires and wheels, ride lowering technologies that reduce ride height when at highway speeds, and more [92].

There is an element of timing to technology transition, as exemplified by aerodynamic device history in light of SuperTruck I success. While fuel economy has always been a fundamental cost factor for fleets, improved aerodynamics has had a somewhat cyclical focus since the 1950s.Ideas like roof fairings, tractor and trailer skirts, gap fairings and trailer boat tails have been marketed in past decades with limited success until the perhaps the 2005-2020 time frame. Many of the SuperTruck I aerodynamic improvements have migrated as of 2020 into volume production tractors and trailers. Evaluating the success and relevance of the multiple technologies included by the SuperTruck II teams will become more apparent in the mid-to late 2020 production tractors.

4.5. Emission Regulations

Emissions reduction have been industry priorities since 1995 when EPA issued an Advanced Notice on Proposed Rulemaking and then in 1997 issued the New Emission Standards For Heavy-Duty Diesel Engines Used In Trucks And Buses [56]. Emissions rules initially were focused on NOx (oxides of nitrogen) and hydrocarbons, and later rules incorporated greenhouse gases. Progressively more stringency was applied over time leading to near continuous improvement in diesel emissions.

A challenge for industry is that continuous change in technology means that new technologies have trouble maturing from field experience before being obsoleted and replaced with newer technologies focused on meeting even more demanding requirements. It can take years for a completely new vehicle to go from concept, through development and then into production. Major systems like new engine technologies are similar [7]. Continuously moving the target can mean vehicle technologies are constantly immature.

Comparisons between new models and older model vehicles also become more challenging since their functional requirements are no longer the same. Yes, a model year (MY) 2020 tractor and a MY 2010 tractor both are designed to pull a 53 ft. van trailer, but the MY2010 does not meet the same stringent requirements on emissions as the MY2020. The more current model has more technology. Key metrics like tare weight, available freight capacity, range, etc. likely have changed. The investment decision in a new vehicle may also be fait accompli where the new regulation prevent purchasing an older technology for a new vehicle. The choice then is to buy the new technology vehicle to continue to be in business in that region, or not buy it, and cease doing business.

4.6. Alternative Fuels

Continuous improvement in combustion processes is leading to several nearer term parallel improvements. Renewable versions of diesel and natural gas are made from sources such as waste products from garbage dumps and dairies and non-food plants. These solutions are focused on arriving at a net zero contribution to emissions, while still using internal combustion powertrains. The net zero fundamentally assumes that the emission sources such as waste sites, dairies and non-food grasses will continue to produce emissions. Capturing and repurposing those emissions into fuel for combustion-based engines then provides a net zero solution for the environment while enabling freight transport to occur.

Electrification of powertrains in concert with a variety of internal combustion engines and fuels are collectively called ICE based hybrids. These can be optimized for a variety of duty cycles where the electric drivetrain operates for some portion of the time, and then the ICE powertrain provides additional range or power where needed. These solutions tend to reduce net emissions versus traditional diesel-based engines. As such, they are steps towards a zero-emission world, but cannot get there.

4.7. Zero Emission Zones

Fleet decisions to procure new technology or stop doing business have been occurring since the advent of emission regulations in the 1990s. These decisions are becoming even more apparent in regions adopting zero emission regulations. Zero emission vehicles are just that, zero. Any configuration that combusts fuel to attain vehicle motion has emissions. At present, true zero emission vehicles are battery electric, hydrogen fuel cell electric, and variations of catenary electric vehicles where the electricity originates from renewable energy sources such as wind, solar, geothermal, hydropower, etc.

Policy makers must find mechanisms to retire older technologies and facilitate adoption of new technologies without destroying businesses. In some cases, this is being accomplished with grants where the rules to obtain the grant for the new technology mandate scrapping the old, in a one-for-one trade, the grant helping to value the prior investment in the older technology rather than zeroing it.

5. Understanding Truck Development

Freight truck vehicle development is a complex interlacing of multiple technologies through an involved process of integration referred to as systems engineering, with the objective of producing a competitive product that can win market share and be manufactured, operated and supported at a viable cost

FIGURE 16 Technological successes, market failures.

Based on Ref. [4]. Betamax: © Leo / Shutterstock.com; Hindenburg: © Everett Collection / Shutterstock.com; Concorde: © Senohrabek / Shutterstock.com; Apple Lisa: © Vladeep / Shutterstock.com; Tucker Torpedo: © Mike Brake / Shutterstock.com; Segways: © Kzenon / Shutterstock.com; Titanic: © antoniradso / Shutterstock.com.

point such that both the manufacturers and end buyers sustain profitability [7].

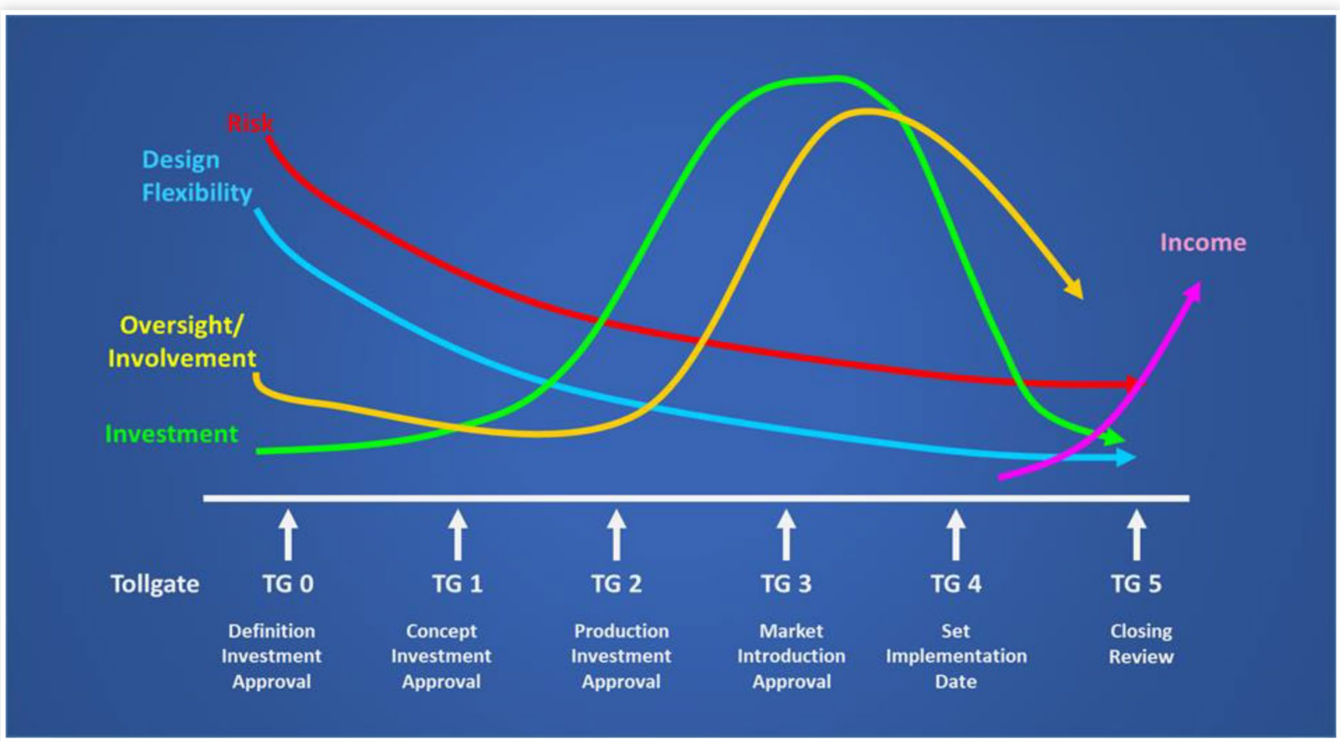
The path to that goal is somewhat unique for each product line, manufacturer and fleet. The key differentiator is often an assumption of acceptable risk. Risk represents unknowns and factors out of direct influence or control. All product development decisions have risk, there is no 100% certitude of right and wrong in product development.

History is replete with examples of technologically impressive engineering accomplishments. Figure 16 illustrates a numbers of significant engineering advances that failed in the marketplace for a variety of reasons [4]. The Apple Lisa, the market never took off on this because of its price point, restrictive software agreements and complexity, but many of the technology developments bred new industry-wide products. The Concorde Super Sonic Transport never a financial success, due in large part to an inability to fly over the U.S. and limited range and seat quantity. The Tucker Automobile, squashed by a number of legal, political and production issues but still considered innovative today. The Hindenburg rigid airship hampered by high cost, high risk, low volume and political constraints on gases. The Titanic steamship - the biggest and best of its time, yet its safety and navigation systems failed. Sony Betamax the competitor to VHS now almost unknown, both replaced by cloud services today. The Segway - advertised as changing the world, to revolutionize transportation and even reinvent urban planning as we know it, but production volumes have never approached planned plant capacities. Others not shown in the figure are the Iridium Motorola Satellite Phone came out in parallel with the Nokia cell phone market and could never compete at volume. The Apple Newton Message Pad, the personal digital assistant that Apple manufactured in the 1990s - innovative but rapidly outpaced by technology. HD-DVD which lost out to Blu-Ray in a commercial standard showdown.

All these technological advances provided insights for later product developers, paving new ground in materials, processes and markets.

Commercial truck development is summarized against a series of check points, or tollgates (TG), beginning prior to TG 0 as illustrated in Figure 17 [3]. Conception of ideas for products

FIGURE 17 Project trends.



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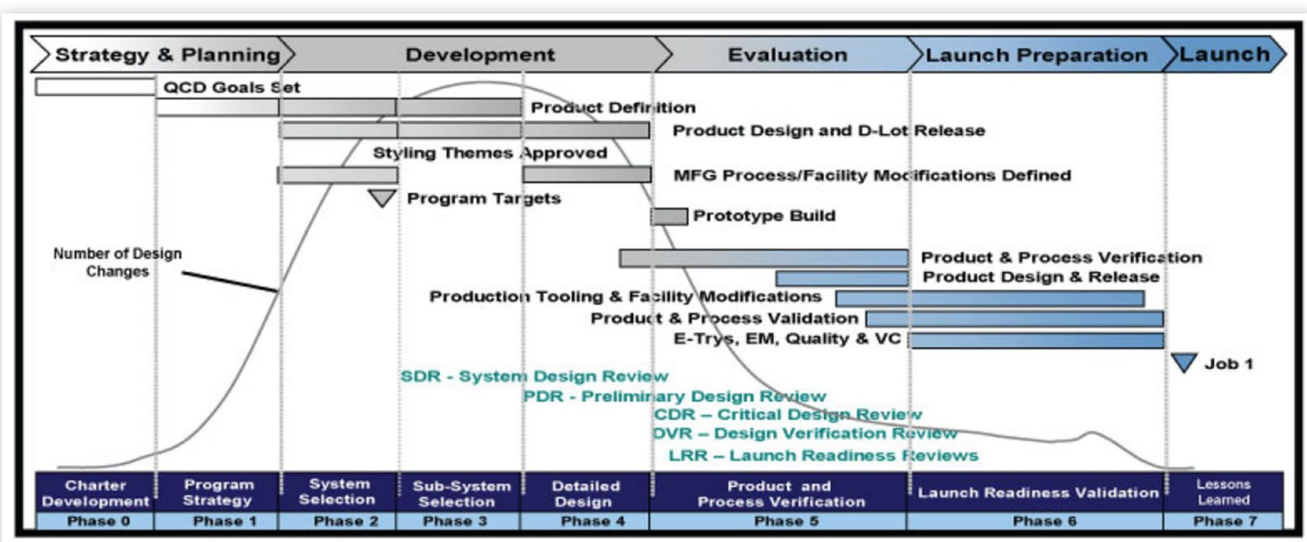
comes before an official approval to proceed with development. Innovation stems from a variety of sources in combination to arrive at a viable concept for consideration. Research and development (R&D) often includes data mining past successes and failures for viewing in present and future perspectives. An example are truck and trailer aerodynamics that were patented and marketed in the depths of the 1970's oil embargo, but failed to survive in the markets of the 1980s, but have been reinvented and thriving in the 2010s market [5, 6].

Each curve represents a level of intensity over the course of a development program [6].

a. Investment — Initial investment for a vehicle is in labor hours as engineers and others initiate the ideas for a new vehicle. As those ideas become plans out of TG1, further funds are required to begin prototyping and evaluating concepts, and more labor joins the project. Long lead tools and production plant space needing a significant level of investment as the start of building a production capability begin with TG2. As the product gets into the marketplace in TG3, significant funds are needed to develop the infrastructure to support the production product in the field and to market it and complete additional option content offerings. As the product enters stable production after TG4, costs drop to levels needed to support production, and engineering labor and other costs decrease.
b. Design Flexibility — At the idea stage, all things are possible, and everything exists in a virtual solution space. As time proceeds, decisions are made that have a waterfall effect on subsequent choices, reducing the solution space for the parts of the project that are not yet defined. As money is committed to expensive tooling and production line development, changes become increasingly more expensive and time consuming so are limited to must-have changes. The overall trend in a project is that design flexibility decreases the closer to production the project gets.
c. Income — Projects in development have no positive cash flow until production products can be sold or leased to customers. That does not occur until the vehicles are in some level of production towards the end of a project.
d. Oversight/Involvement — Early oversight of development projects manage less detail and resources than later stages. As projects develop, and decisions to commit major funds become necessary, greater management oversight and involvement occurs. Some decisions inadequately thought out or reviewed early in a program become major problems at this point. As the vehicles enter production, a business as usual attitude tends to reduce management and oversight to a normal level consistent with other production products. A goal of many of the project management systems is to help push oversight and involvement earlier in the process reducing the risks of having to change designs and get better value from development program investments.
e. Risk —The goal of projects is to be successful. Success has many interpretations, but generally includes that the product is desired by the market, meets or exceeds the needs of the customer, obtains continued growing sales, performs well in the field such that warranty is minimized and drivers offer positive reviews, and the manufacturer and fleet buyer are profitable. Every decision made during a program can either add risk or reduce it. A mark of successful programs is that risk is reduced over the course of the project. Decisions made are evaluated and considered to reduce risk towards obtaining a successful product.

Vehicle manufacturers that have outlined their commercial vehicle development process in public sources include Navistar, Volvo, PACCAR, and Daimler [7]. Newer manufacturers may be pursuing their first production launches. One example is shown in Figure 18 from Navistar [8].

FIGURE 18 Navistar Product Creation Process circa 2006.



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The demands for cash flow from products, market competition for media coverage and integration of production with other company product lines can all influence the decisions to officially start production.

The decision point where a vehicle is officially designated in production inherently assumes some level of product maturity by the manufacturer. The extent to which those products have been tested and evaluated in all operational conditions and the variety of options available will vary by manufacturers such that the term "in production" will differ. This means to the customer that, essentially, the risk level assumed by the customer may vary significantly by product and manufacturer.

6. Understanding Fleet Adoption

Technology adoption by fleets tends to follow a traditional S-curve as illustrated in Figure 19, where the Y-axis represents potential expressed in terms of performance, reliability, life span, economy or other factor, and the X-axis represents time [9].

6.1. S-Curve Dynamics

New technologies start by having to overcome several challenges. They must compete against established products so winning market share initially is difficult until the product has gained acceptance. New technology is often immature with limited field testing, and the marketplace expects several iterations before committing to a major investment to purchase the new products. Often the new technologies are competing internally at companies with other product lines so start with smaller production numbers. In the graphic, these are described as fledgling market entrants.

In time, the new technology matures and gets sufficient field use such that the market begins to demand more. The company prioritizes a greater share of production to the product. Advertising and word-of-mouth-based referrals increase sales and profits. Adoption rapidly accelerates as illustrated in the middle part of the S-curve. This portion of the curve is characterized by a series of relatively rapid improvements in performance, cost reductions, increased reliability, etc.

At a later point in time, improvements become much harder to achieve, taking longer time frames and typically greater investments. This is represented by the top of the S-curve labeled mature market dominator.

Diesel engines are one of those mature market dominators, with over a century of development, and production fuel efficiencies approaching 45%, significant improvement now takes years of engine development and significant investment. The Department of Energy has been funding such research in technologies such as waste heat recovery for 20 years and the DOE SuperTruck 2 program has a goal of demonstrating in the near future in one-off prototypes a 55% efficiency level, that might go into production in a few years.

Commercial battery electric vehicles, fuel cell electric vehicles, and a variety of alternative fuel and hybrid technologies represent the fledgling technologies, with only a few years of maturation. Figure 20 highlights the relationships between the mature diesel and fledgling new technologies.

Examples of this S-curve behavior for technologies are shown in Figure 21 from NACFE's Annual Fleet Fuel Study (AFFS), where the technology purchase and use of 21 fleets covering 85 technologies are mapped since 2003. The fleets involved operate approximately 100,000 tractors and 300,000 trailers.

Singling out powertrain technologies from these 85 technologies illustrates a few examples of technology adoption behavior by fleets in Figure 22. Some technologies have seen nearly 100% market penetration in these 21 fleets, such as the use of synthetic transmission oil and tuning engine parameters for fuel economy. Other technologies like predictive cruise control took years to establish a market and more recently have accelerated up the adoption curve. Some technologies never get up the S-curve, such as fuel additives. Others seem to plateau, as in the case of downsizing engines, where the true market potential is likely never going to be 100% of all trucks in these fleets due to duty cycle and other operational requirements.

The data presented in the AFFS reports are for 21 fleets that can be considered early adopters of technologies, so they may not represent the entire population of North American

FIGURE 19 Typical technology S-curve.

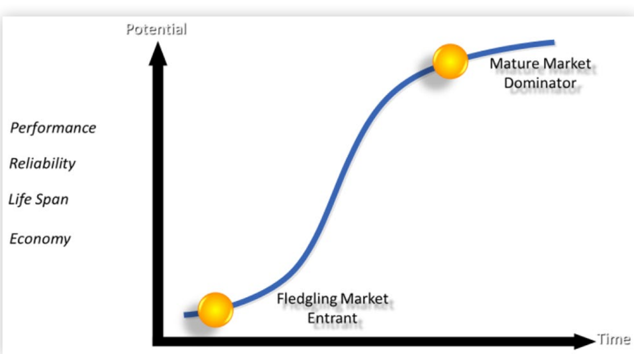

FIGURE 20 Projected powertrain market penetration

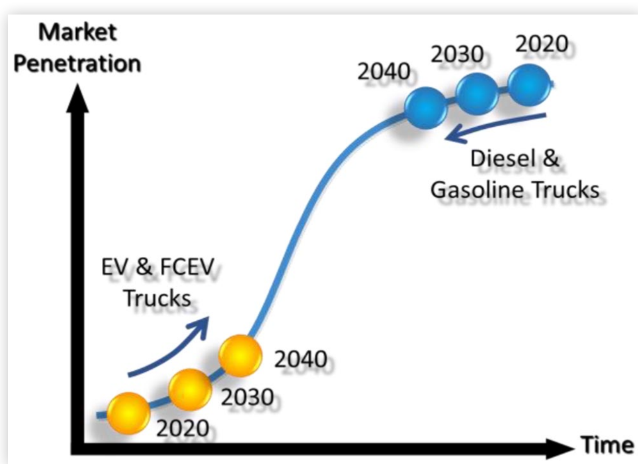

FIGURE 21 Adoption curves of 85 technologies.

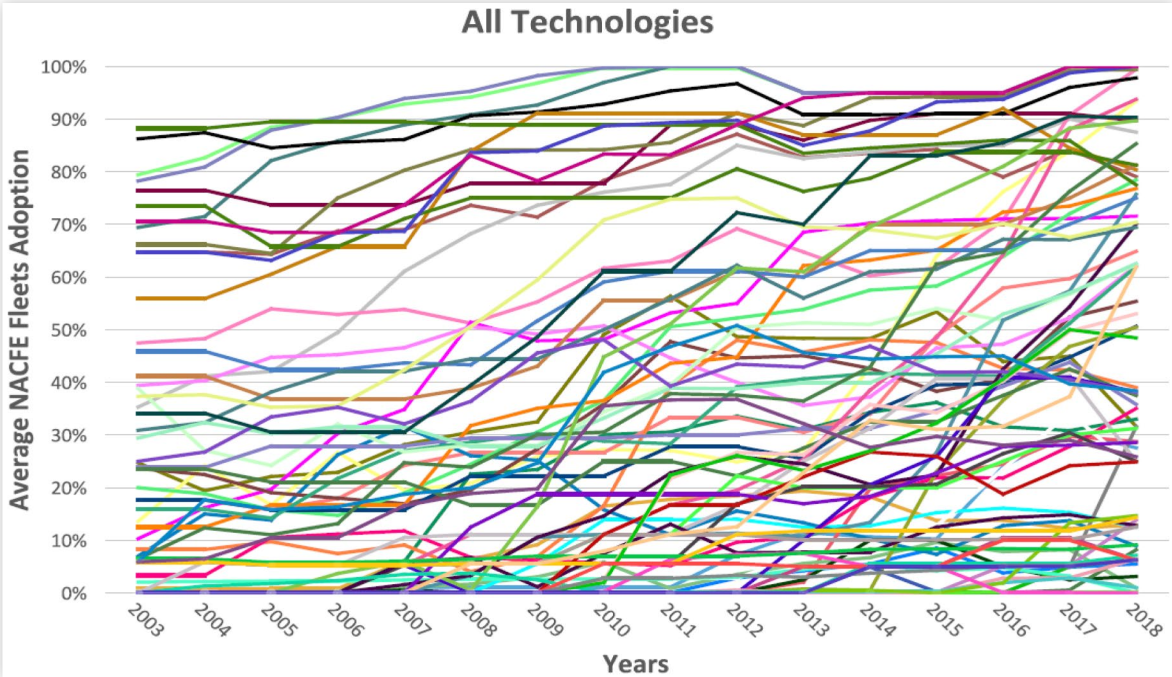

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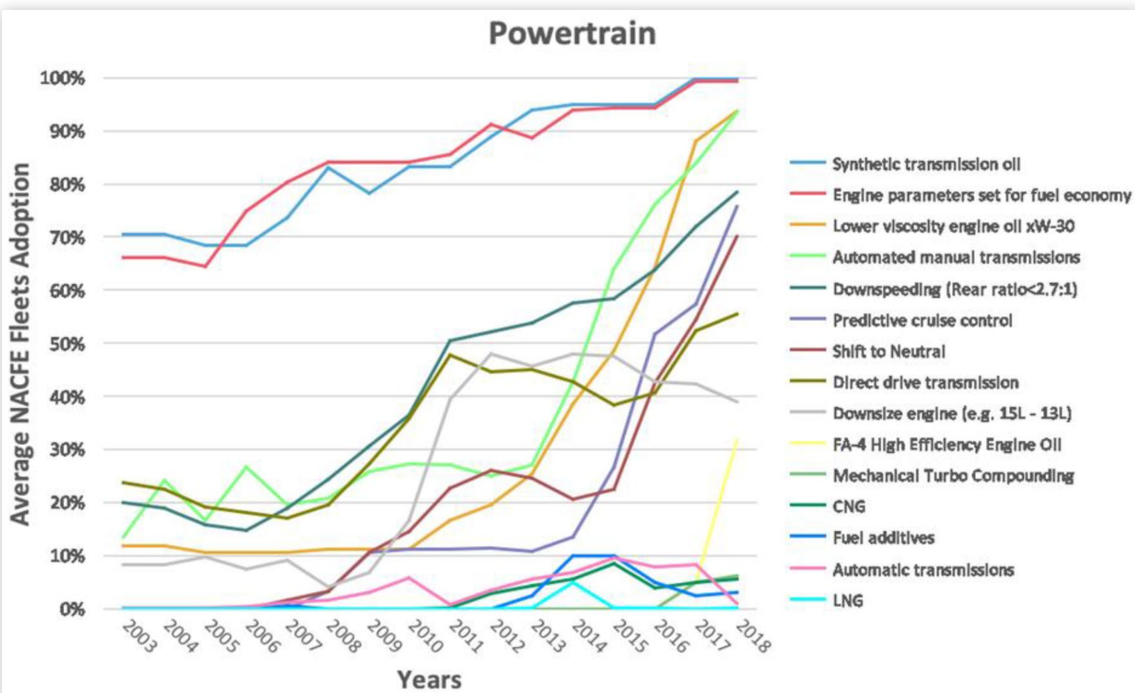
FIGURE 22 Powertrain technology adoption curves.



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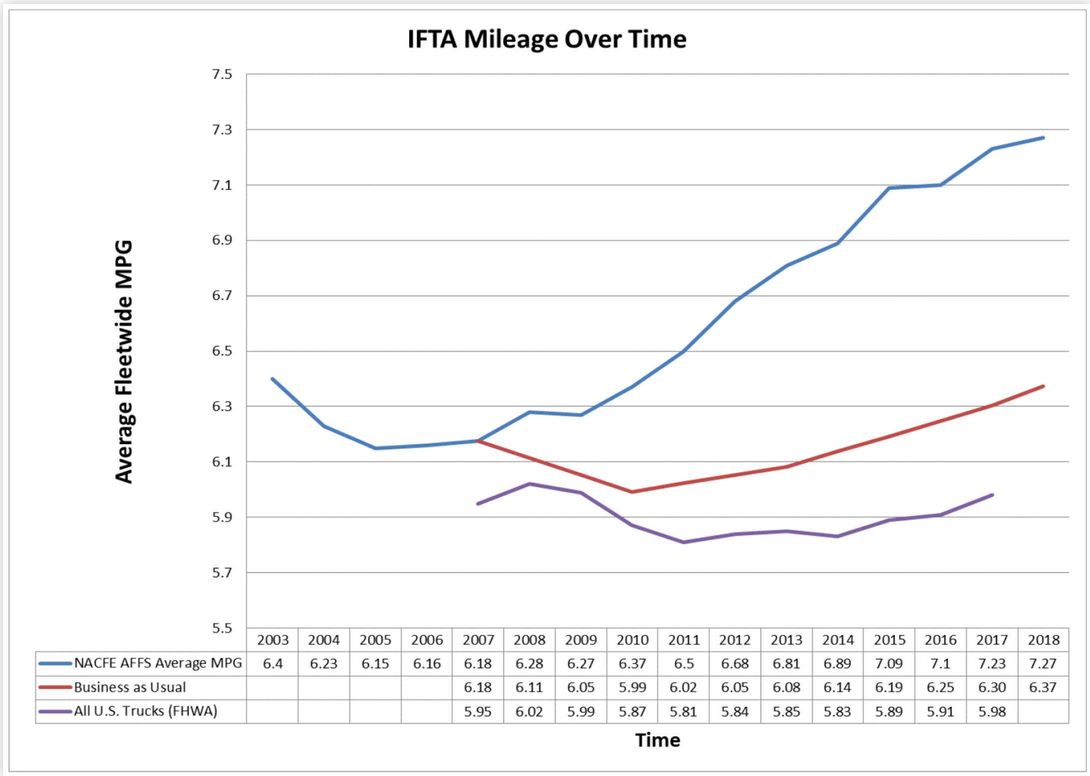
freight trucks. However, they are representative of fleets placing priorities on improving efficiency, demonstrating significant gains through technology adoption as seen in Figure 23. The upper line in this graph illustrates the improvement of fuel economy for the AFFS participating fleets while the center line represents freight truck improvement on a national level. The lower line is the U.S. average for all type heavy-duty trucks which includes non-freight vehicles.

Fleets adoption of technologies are influenced by a variety of factors:

- Competitive Forces
- Accountants & Stockholders
- Regulations
- Proactive Engagement in Technology

FIGURE 23 AFFS fuel economy versus national average.



	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
NACFE AFFS Average MPG	6.4	6.23	6.15	6.16	6.18	6.28	6.27	6.37	6.5	6.68	6.81	6.89	7.09	7.1	7.23	7.27
Business as Usual					6.18	6.11	6.05	5.99	6.02	6.05	6.08	6.14	6.19	6.25	6.30	6.37
All U.S. Trucks (FHWA)					5.95	6.02	5.99	5.87	5.81	5.84	5.85	5.83	5.89	5.91	5.98	

- Grants and Incentives
- Marketing Brand Image
- Need for Drivers
- Corporate Sustainability Goals
- Venture Capital

However, the fundamental purpose of freight hauling is for a company to be profitable. In the end, whatever factors help influence choices for or against technologies, the bottom line for companies is that the investments must make sense economically. Companies cannot run at a loss for long periods.

Traditionally conservative accounting practices for assigning costs and benefits can inhibit technology adoption. While it is relatively easy for a factory to determine how much labor it expends to install a widget, and how much the widget costs to purchase, how much warranty the widget encounters in the field, and how much the widget represents in terms of profit on the vehicle, there are a number of other soft factors that are difficult to quantify and may not be tracked to the same scrutiny as these hard costs. Examples of hard and soft costs are shown in Figure 24 [11].

FIGURE 24 Examples of hard and soft costs.

6.2. Return on Investment Factors

Return on investment (ROI) is a common factor used by fleets. The calculation assesses whether an investment in technology produces accountable financial benefits over a desired period of ownership. A payback period is a related metric, indicating the investment is recovered in a specific period. Fleets often expect payback periods for new technologies to be under 18 to 24 months. The quicker the payback period, the sooner profits can be obtained from the investment.

6.3. Residual Value Factors

Fleets also must consider the residual value of their assets. A fleet buying a new tractor may trade it in after three or four years of use. That secondary market may not value the technology features in the same way as the first buyer because the secondary market user may have different duty cycles and operating priorities.

The goal in purchasing a vehicle's technology is thus not just whether it can improve the bottom line while it is operating for the buyer, but also that it can be valued in the secondary market.

Technology that is a regulatory requirement often influences the buying practices of fleets. The EPA Model Year 2007 emission requirements introduced new technologies to the trucking market that field testing indicated might impact fuel economy and reliability, which might be less than Model Year 2006 vehicles. This led the market to a "pre-buy," where a high volume of Model Year 2006 vehicles were ordered by fleets, followed by a slump in orders for the Model Year 2007 units. This pre-buy is seen in the graph in Figure 25 [19, 12]. Pre-buys are relatively short-term solutions as commercial vehicles are capital tools that wear with use and age, eventually needing to be replaced. Fleets can delay but not avoid purchases of new trucks.

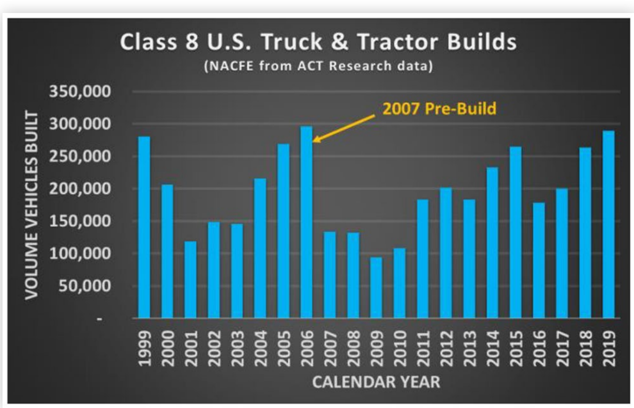
6.4. Risk Factors

Risk also surrounds the extent of new content introduced in a new product. Mihelic described that every new product is composed of a combination of existing parts termed "carry-over" and all new parts [3]. An evolutionary product design will have a smaller percentage of new to carry-over parts, and fundamentally less risk. A revolutionary product will have a high percentage of new to carry-over parts, and with those new unproven parts, a great risk of field issues. The corollary to this is that benefit potential is moderated by a low new to carry-over ratio. Greater risk can have greater benefit.

The new to existing ratio is relevant to fleets investing in new technologies. Traditionally risk averse fleets are slow to adopt new technologies, taking a "prove it" approach to any advertised claim of efficiency gain or cost reduction potential. Fleets in this category will not trust marketing claims or claims from other competing fleets and will instead conduct their own limited field testing before making significant investment in new technologies. The time involved in this approach can delay significant adoption of new technology, as such, these fleets may be described as industry technology laggards.

More aggressive technology adopters will embrace new technologies and make significant investment before production products are available. This has been occurring for alternative fuel Class 8 manufacturer start-ups with battery electric and fuel cells such as Nikola, Tesla and other medium-duty truck makers. These fleets are described as early adopters. They are also described as being on the bleeding edge of technology, a qualifier to leading edge, a reference to potential significant risk tied to unproven products.

FIGURE 25 Pre-Buy in 2006 (NACFE from ACT Research data).



6.5. Regulatory Factors

Regulators also have an impact on the time frames for technology adoption. Regulations tend to have specific implementation dates, levelling the adoption field for nearly all fleets. This is described as technology forcing and at the Federal level, typically applies primarily to new products because the regulating agencies are only authorized to impact new products sold. State and local regulators may impose retroactive rules impacting both new sales and vehicles already in the market.

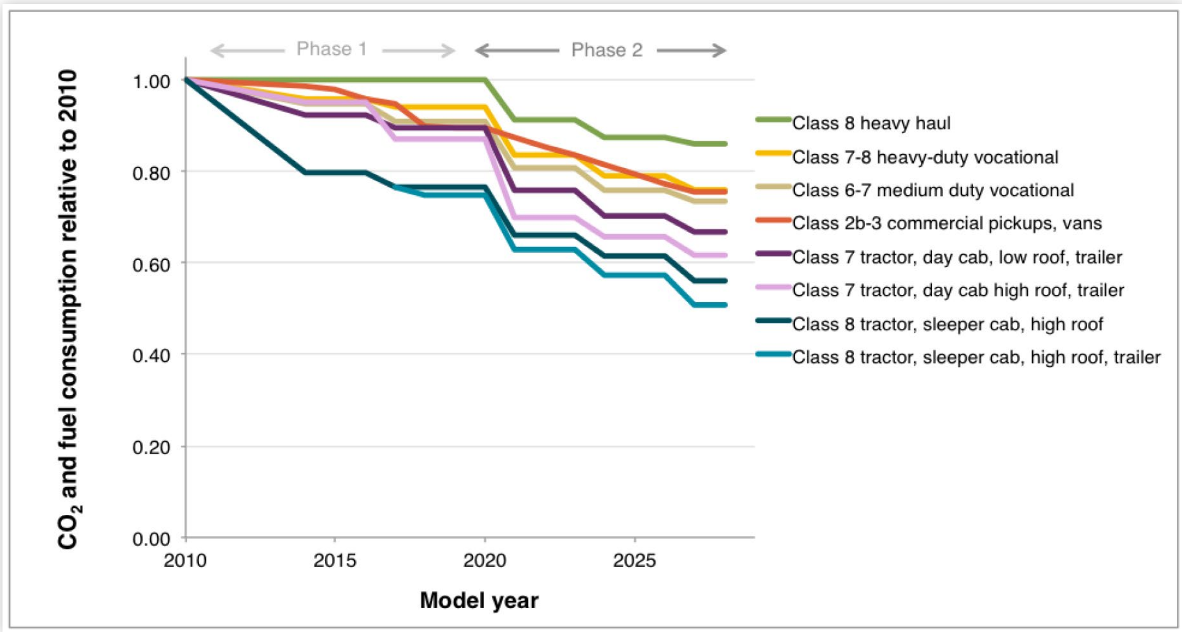
Examples of new vehicle regulations affecting nearly all OEM truck manufacturers are the EPA/NHTSA Green House Gas phase 1 and 2 regulations with specific compliance dates for new model year introductions and increasingly stringent emission standards as shown in Figure 26 [13, 14, 15].

An examples of retroactive state regulations is the California Air Resources Board (CARB) adoption of GHG rules for emissions from heavy-duty vehicles that included the provision that:

Beginning January 1, 2012, a 2010 model year and earlier model year tractor with or without a sleeper berth that pulls a 53-foot or longer box-type trailer on a California highway will be required to be equipped with SmartWay approved low-rolling resistance tires. This will be the only retrofit requirement for tractors with model years 2010 and earlier, and will allow most 2010 or earlier model year tractors to use their existing tires for the remainder of their useful life before replacing them with low-rolling resistance tires [16].

Regulations that apply across the board to all vehicles of a particular type force all fleets to adopt a technology based on a regulated time frame, usually with some exceptions or

FIGURE 26 GHG Emissions Regulatory staircase.

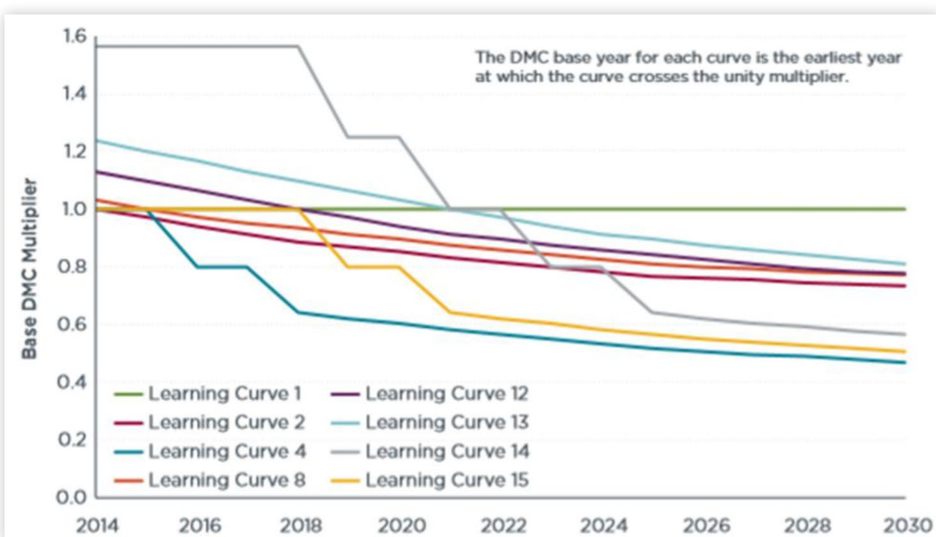


exemptions, for example farm equipment or sometimes small business exemptions. If the technology is not mature, then the entire industry may be exposed to the same level of risk. To reduce this risk, regulators are governed by rules to provide advance warning prior to mandating changes. In the case of the EPA/DOT GHG Phase 2 rules, OEMs were given a minimum of four years of official advance warning prior to the regulations taking affect. OEMs in this example also had early awareness of new rules being developed and had opportunities to be included in EPA/DOT research planning on the maturity of technologies. OEMs also participate in DOE technology development programs before the technologies are mandated for production vehicles, helping to mitigate fleet risks.

6.6. Cost Reduction Efforts

Initial product offerings may go through a series of product improvements as field use provides feedback through a combination of methods including, for example, warranty claims and market sales numbers. Internally, OEMs also refine the designs to reduce costs. The cost maturation of a variety of technology has been predicted by EPA for the GHG Phase 2 regulations and evaluated by ICCT summarized in Figure 27 [15, 17, 18]. These example predictive curves illustrate that innovation has multiple paths and prior performance may not be indicative of future trends, but past trends may be directionally used by regulators and OEMs.

FIGURE 27 Direct manufacturing cost learning curves for technology cost reductions over time.



Compounding the difficulty of predicting cost reductions is that product scope rarely is static. OEMs are rarely permitted to freeze the scope of a product over multiple generations and focus only on cost reduction and improved manufacturability. An example are laptops, tablets and cell phones, all of which regularly increase in functional scope in parallel with subsequent generations. Where earlier devices had no camera at all, subsequent cell phones introduced increasingly higher resolutions and cameras front and back, and now have multiple rear cameras in the newest models with a variety of new capabilities. This scope growth occurs in nearly all products as a market requirement to continuously improve functionality and utility to maintain and grow market share.

Heavy-duty trucks see improvements introduced with each new model year, and often mid-year introductions of new feature option content. Once introduced, each new technology takes on its own trajectory for improvement, cost reduction and scope growth.

These product development trajectories introduce further risk factors for fleets. Technology that continuously sees significant change rarely stabilizes long enough for the technology to mature. These rapidly changing technologies are continuously positioned at the start of new innovation S-Curves, never seeing growth in user miles or operational hours before being replaced by significant new revisions.

Truck development is continuous and complex. New technologies are constantly being researched and developed inside the OEMs and suppliers. The existing products also go through maturation based on feedback from the field and market demands. OEMs must juggle a wide range of competing demands for investment and time. Fleets influence this development through purchasing or not purchasing technologies as exemplified through adoption S-Curves over time. A key aspect to both OEMs and fleets is determining what level of risk is acceptable in decision making on new technology adoption. Immature products may suffer in future sales, while overly long product development may be too late to market and again suffer in sales and adoption. Finding a balance between risk, cost and benefit is a challenge for every technology developer and purchaser.

6.7. Vehicle Life Expectancy

Vehicle life expectancy is a decision factor with technologies. Heavy-duty trucks and to a similar extent, medium-duty trucks, can have extremely long lives before ultimately being scrapped.

Trucks are capital investments in the same way as factory machines. They may have multiple owners over their lives and multiple uses. For example, Figure 28 illustrates a typical model for the life of an on-highway tractor.

The ICCT summarized data from Meszier on modeling both U.S. and European heavy-duty truck age and mileage over time as shown in Figure 29.

A trend expected in vehicle maintenance is that costs increase with time and mileage. Fleets have different thresholds for how much maintenance a truck can have before they decide to replace it. First owners get to specify the configuration and option content of the truck, while subsequent secondary market buyers have to choose from those available previously configured vehicles.

As maintenance increases with age and mileage, subsequent owners may level the maintenance cost growth curve by changing the duty cycle of the used vehicles to have

FIGURE 28 Example life of a heavy duty tractor.

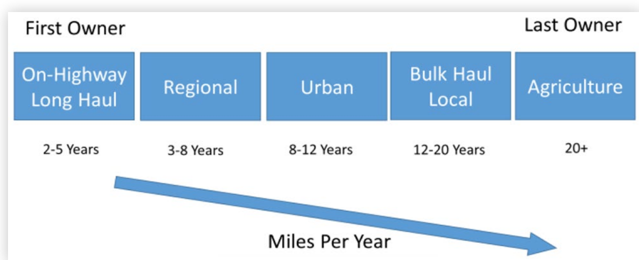


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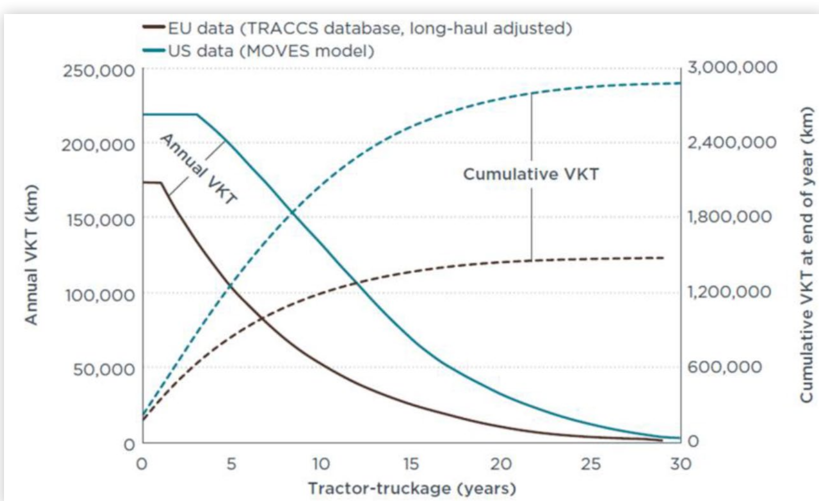
FIGURE 29 Survival weighted vehicle kilometers travelled (VKT) for long haul trucks in the European Union and U.S.



Reprinted with permission from Ref. [18]. © International Council on Clean Transportation lower miles per year. As Figure 29 illustrates, older vehicles see less annual mileage.

The long life of tractors is a factor in the penetration rate of new technologies in the marketplace. The output capacity of U.S. heavy-duty truck manufacturers saw a peak in 2018-2019 years exceeding 300,000 Class 8 tractors and trucks per year. Truck production is cyclical and average production as documented by ACT Research is approximately 253,254 Class 8 tractors and trucks per year over the period 1999 to 2019 from Figure 30.

The average age of active population Class 8 trucks in the U.S. per ACT Research from 1990 to 2020 is 5.92 year as shown in Figure 31.

As an example, if the entire production rate of new products in 2018 used a new technology, it would take the market over 20 years to reach 100% use considering industry annual build capacity, natural retirement of older trucks, and accounting for some level of freight industry growth as illustrated in Figure 32.

Since product designs continuously mature, the products introduced in 2018 would evolve into newer products in future

FIGURE 30 North American truck production by year and type (NACFE from ACT Research data)

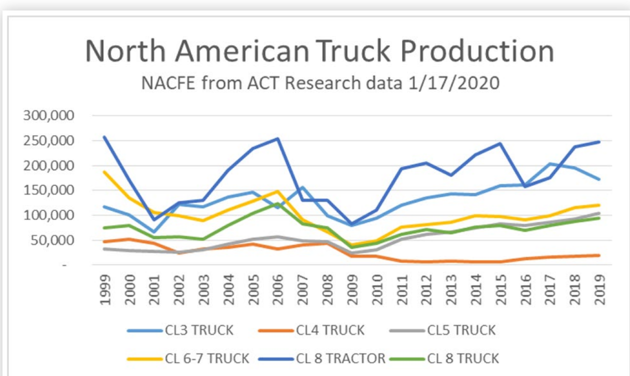


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FIGURE 31 Average age of U.S. Class 8 active tractors (NACFE from ACT Research data)

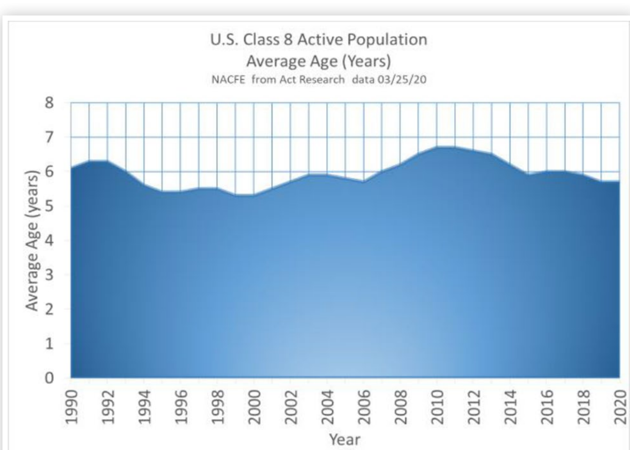

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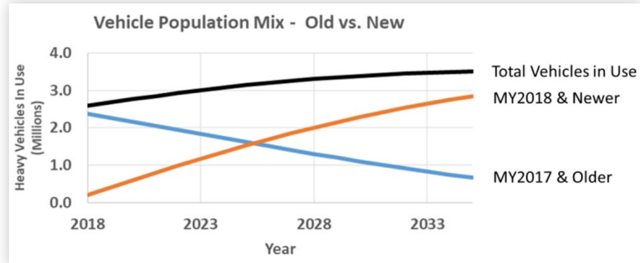
FIGURE 32 Technology penetration at 100% of annual build rate



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years, so adoption rates can get complicated. Imagine rationalizing building the same cell phone for 20 years, while your competitors continuously update every year or every six months with new features and functions. Market penetration curves for technology showing growth, like those tracked in Figure 21 and Figure 22 in the NACFE AFFS reports, are bundling individual products as technology groups. For example, aerodynamic tractors constitute a bundle of model years and products where the tractors are fundamentally differentiated by aerodynamics versus less aerodynamic traditional vehicles [10, 21].

6.8. Operating Costs

Controlling operating costs are a major factor in technology adoption by fleets. The American Transportation Research Institute (ATRI) tracks operating costs through a confidential survey process with weightings based on a variety of factors including “fleet sector type, fleet size and region of operation [23].” NACFE cautions that there are no average trucks or fleets, with significant variability in each company’s operations due to their unique duty cycles, operational preferences, and many other factors. However, for the purposes of discussing trends, the ATRI averages are relevant.

ATRI divides operational costs into these major categories:

Vehicle-based

- Fuel
- Truck/Trailer Lease or Purchase Payments
- Repair and Maintenance
- Truck Insurance Premiums
- Permits and Special Licenses
- Tolls

Driver-based

- Wages
- Benefits

Traditionally costs have been relatively consistent with one-third for the cost of fuel one-third for the cost of the driver, and one-third for the cost of the vehicle. However recent trends are skewing that distribution as graphed over time in Figure 33, with a significant shift towards driver costs as 42%, truck 34% and fuel 24% [10].

These shifts in costs are due to significant supply and demand factors tied to availability of trucks, trailers, loads and drivers, particularly in the 2018 marketplace where freight volumes exceeded capacity [23]. A number of trends were cited as contributing to demand growth as shown in Figure 34. These include continued growth in e-commerce and the consumer expectation of instantaneous delivery from on-line shopping. Other factors are tied to attracting and retaining drivers, and perennial issue in freight where 90%-100% turnover rates have been documented over several years. The cost to hire a driver is estimated by Omnitracs at $7,000 based on their survey of a population of large fleets with over $30M in revenue [26]. Fleets in 2018 focused on increasing pay for drivers and improving quality of life factors such as moving to regional haul routing where the drivers could return home on a predictable basis, often daily [23]. Other factors relate to technology advances and requirements with respect to tracking the tractors, the trailers, the drivers and the loads. One of the significant driver tracking technologies is the requirement for electronic logging devices (ELDs) which came into force in 2017 under FMCSA regulations [24, 25]. This technology replaced paper-based driver logs and their inherent potential inaccuracies. The digital-based technology is focused on ensuring hours of service compliance, but also creates a fairly uniform database of operational factors by driver and trip. Trends exist in the back offices with increased reliance on cloud-based load matching to assign tractors, drivers and trailers to loads to reduce the frequency of dead-heading, the term applied to driving empty trailers between locations where the trucks carry no paying freight loads. Bob tailing, another unpaid freight operation fleets try to minimize, is moving just the tractor sans trailer to other sites.

Projecting operating costs for the evolving new alternatives to traditional diesel engine vehicles are difficult to accurately project as few of the technologies have production vehicles in real world operations as of the writing of this document. NACFE assessed the current state of alternatives in its 2019 Guidance Report Viable Class 7/8 Electric, Hybrid and Alternative Fuel Tractors [9]. The list below estimates the number of Class 8 tractors by alternative as of the end of 2019.

- Fuel Cell Electric < 50
- Commercial Battery Electric < 100
- CNG < 50,000
- LNG < 10,000
- Propane < 1
- Diesel Hybrid Electric < 1

Categorizing costs for analysis are also subject to a variety of interpretations on what can be included and what is not included. True systems level cost analysis includes both hard and soft costs, those hard costs that are easily tracked like the cost of a part, or the cost of the time spent installing it, versus softer costs like the cost of environmental compliance, lost or gained opportunity from sales and brand image related to marketing zero and near zero emission vehicles, etc. Service costs may appear to be different if limited to discussing part replacement like not having a filter to replace, but if software troubleshooting time is included, the net may be identical. Traditional warranty cost systems also rarely quantify the cost of downtime to the fleet, only the repair costs.

FIGURE 33 Operational costs of HD trucking (NACFE/from ATRI data).

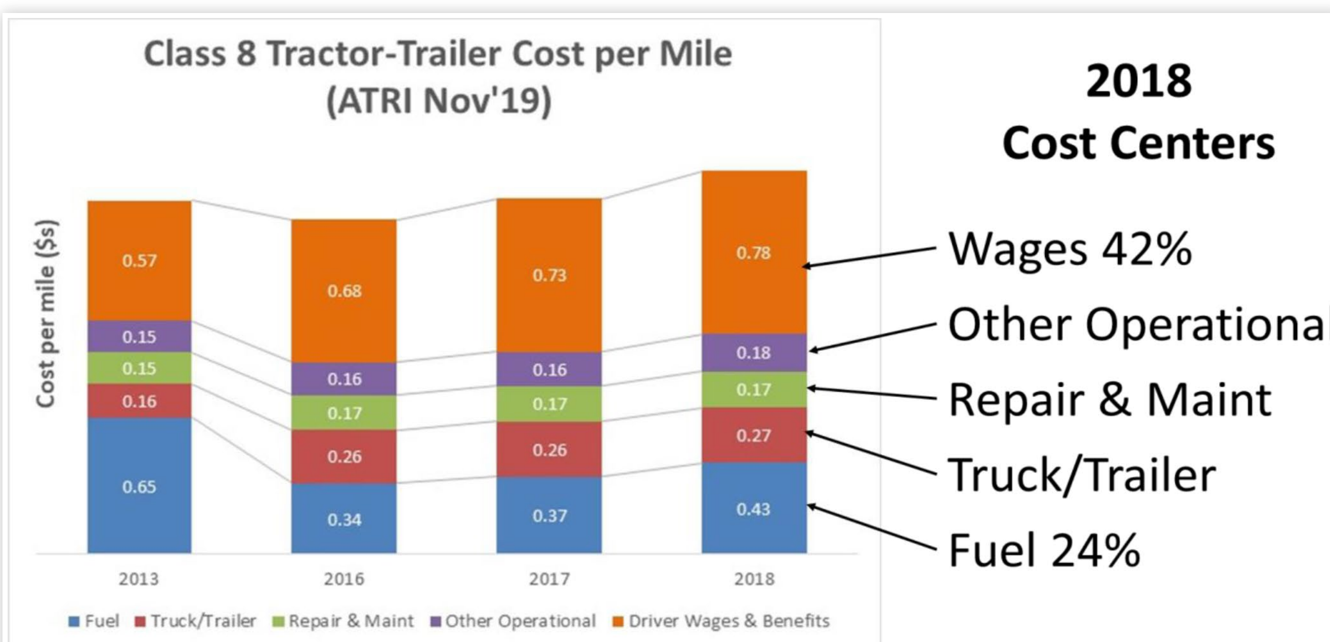


FIGURE 34 Factors impacting freight trends.

6.9. Alternative Fuels/Energy

Fuel price unpredictability shown in Figure 35, or what is commonly termed ironically as volatility, is a major uncontrollable aspect of fleet operations and impacts long-term investment in technologies.

Trucks are capital investments with long lives. Fleets must attempt to predict their return on investment where fuel prices, labor prices, and other factors such as economic catastrophes such as the great recession, wars, tariffs, trade agreements, natural catastrophes such as hurricanes and fires, and most recently pandemics impact the fundamentals of the marketplace. As the graph in Figure 35 illustrates, there has been a 47% difference between the peak national average diesel price of $4.76/gal in July of 2008 reported by EIA and the price in mid-April 2020 of $2.51/gal [27].

The growing interest in alternative fuel vehicles highlights differences in volatility of energy sources for trucking. So called green alternatives include a range of possibilities from environmentally emissions neutral forms of renewable natural gas, propane, diesel and hydrogen, to true zero emission sources such as hydroelectric, solar and wind power. The volatility of these energy sources differ significantly, or from the fleet perspective, the stability of energy pricing varies with electricity being very stable over time as shown in Figure 36 from AFDC [28, 9].

Stability or predictability of pricing looking historically may not be representative of future demands. Today's use of energy in the U.S. shown in Figure 37 per the Lawrence Livermore Laboratory assessment from EIA data shows that less than 0.08% of U.S. electric energy is used for transportation purposes (0.03 Quads out of 37 Quads estimated for electricity generation). Trucking's cyclical freight demand may introduce volatility to previously less volatile alternative energy sources. Similar conclusions can be made for natural gas which is only 3% used for transportation. Petroleum's supply and demand volatility is in part due to transportation demand representing 70.3% of petroleum's use. Since electricity has a broader base of types of producers and users, that helps stabilize supply and demand pricing.

Energy supply companies make money off of profit margins on the price of the energy and also on the capital recovery for infrastructure investment. The EIA estimates for petroleum products where costs reside as shown in Figure 38.

EIA's estimation of the breakdown of component pricing for electricity is shown in Figure 39.

The type of energy can have significantly different approaches to these two contributing factors. Petroleum based products have largely market based pricing, utility-based energy suppliers have regulated pricing models with slower reacting oversight. Utility markets do have volatility based on

FIGURE 35 Volatility in U.S. fuel prices.

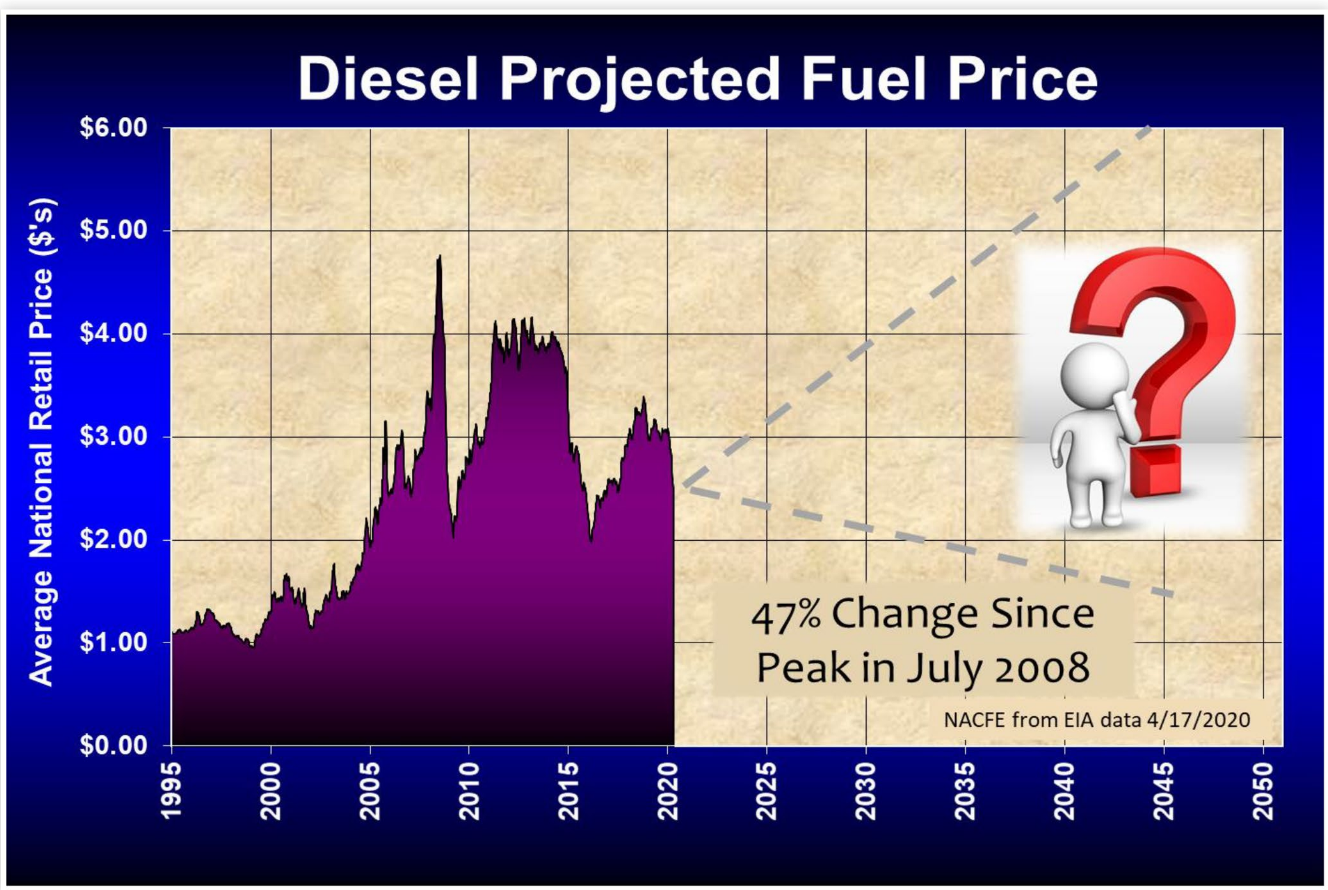
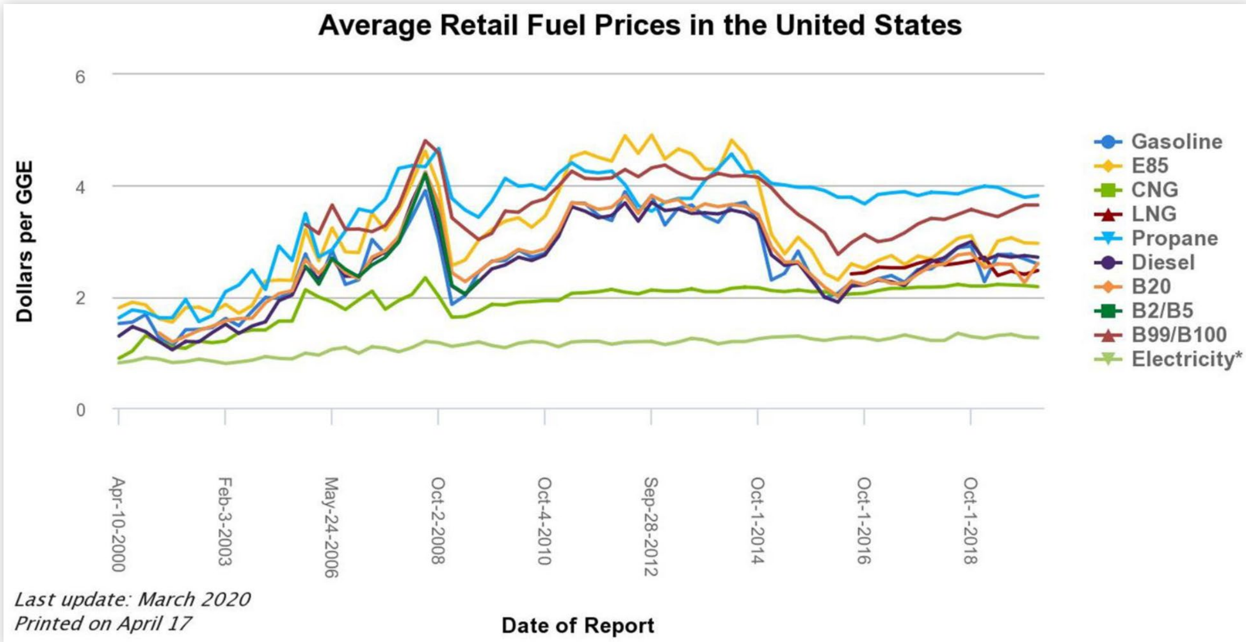
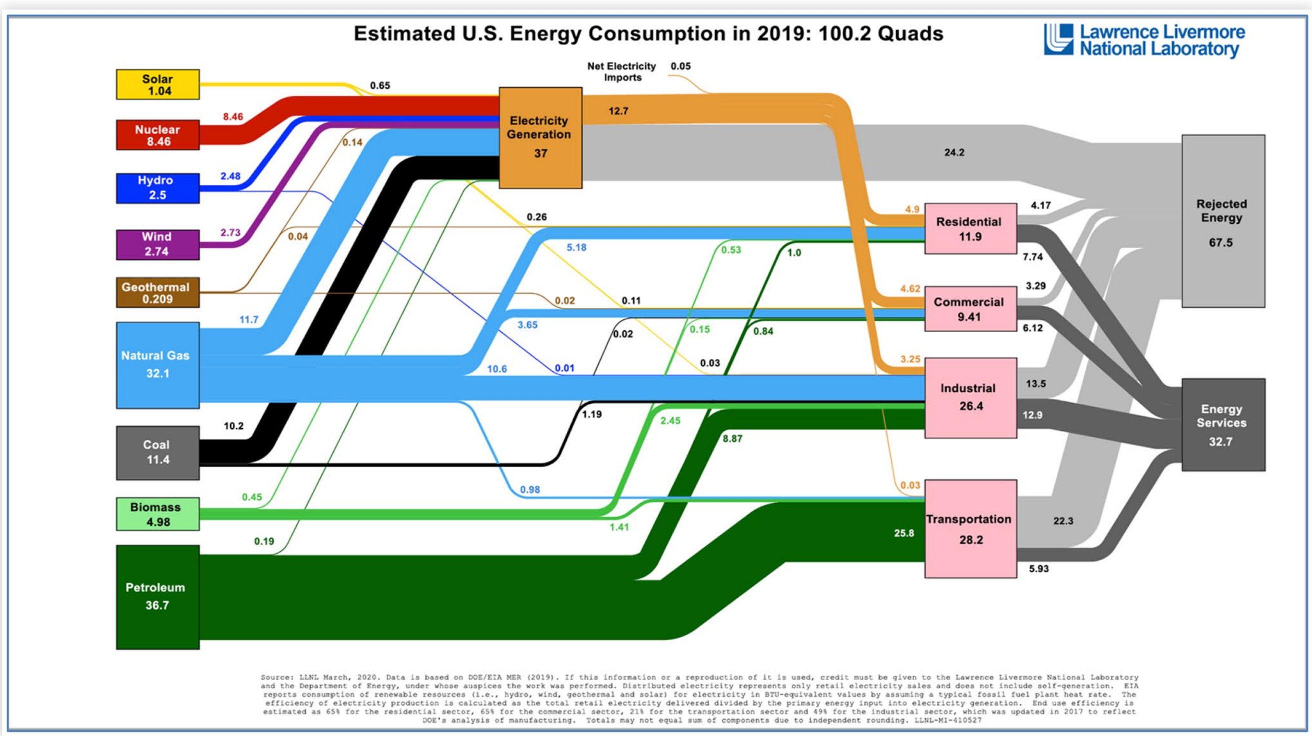


FIGURE 36 Energy price volatility in U.S. (AFDC).



Reprinted from Ref. [28]. U.S. Department of Energy

FIGURE 37 Energy flow chart.



Reprinted from Ref. [29]. Lawrence Livermore National Security, LLC, for the Department of Energy's National Nuclear Security Administration.

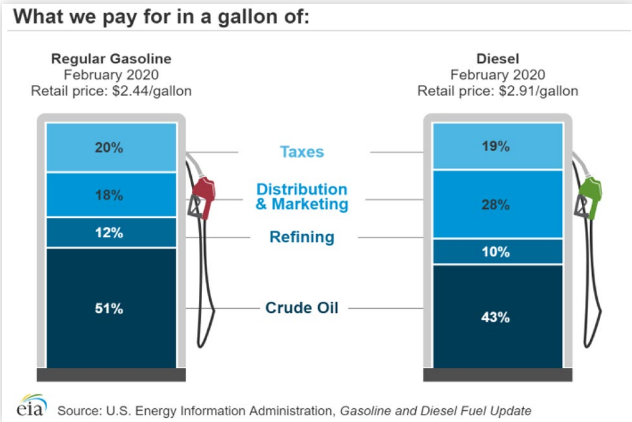
regional and seasonal factors, and volume of use factors in context of time of day and day-to-day price fluctuation. However, the graph in Figure 36 illustrates significantly less volatility over time in electricity versus petroleum based energy pricing.

Fleet Factors

This section has discussed several of the complex factors that fleets consider in deciding to invest in transformational technologies. They include:

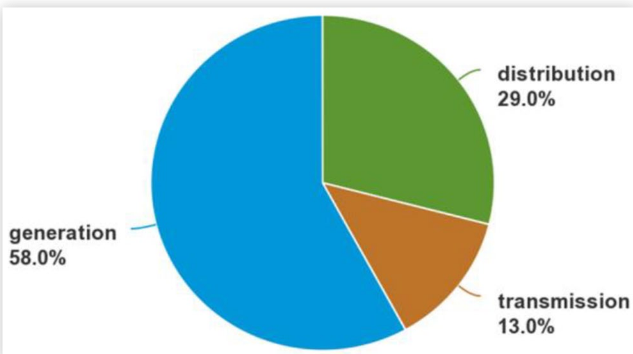
- S-Curve Dynamics
- Residual Value

FIGURE 38 Component costs of fuels (EIA).



Reprinted from Ref. [27]. U.S. Department of Energy

FIGURE 39 Component pricing of electricity (EIA).



Reprinted from Ref. [30]. U.S. Department of Energy

- Regulatory Requirements
- Risk Factors
- Cost Reduction Processes
- Vehicle Life Expectancy
- Operating Costs
- Alternative Fuels/Energy

All these factors and others impact the decision making processes.

7. Understanding Fuel and Freight Efficiency

Fleets wrestle with choosing metrics to help them make effective decisions on investment in transformational technologies. The 2016 SAE Buckendale report, Fuel and Freight Efficiency - Past, Present and Future Perspectives by Rick Mihelic, summarizes the complexity of commercial vehicle fuel and freight efficiency, so will not be repeated here [3]. Rather this section focuses on why finding ideal performance metrics is challenging.

Every measurement must have context. Fuel economy could be simply using the gallons paid for at the pump and the miles driven to estimate an average miles per gallon, or mpg, or kilometers per liter. These types of measurement have their purpose, but they tend to aggregate the composite system performance into a single, indivisible number. Weather effects, load differences, driver expertise differences, tire wear differences, seasonal differences, fuel differences, speed limit differences, traffic differences, etc. are all composited together. These factors also have a challenging habit of working in combination such that one plus one plus one may equal four or one, depending on the situation.

Combine all that with the reality that baselines are rarely static. Every model year, and often times more frequently, OEMs improve their vehicles, making a variety of changes. Those changes mean that the supposed baseline vehicle in a future A-vs.-B purchase ROI comparison is not the vehicle a fleet is currently driving. Throw in on top of that that the trailer is not a “given” either. Most operations are drop-and-hook and a given tractor may see hundreds of different trailers during a year, all different vintages, different configurations, different maintenance levels, etc. Some are configured with a lot of aerodynamic devices, some less, some none at all. Some have automatic tire inflation systems, others do not. Some have low rolling resistance tires, others do not.

Precise controlled tests can be done, but then the fact that they are controlled means they are not real world. Precise means repeatable. Accurate means they reflect the real world. Controlled vehicle level tests are inherently challenged to accurately represent real-world use. Predictive analytical tools are similarly challenged as they are all mathematical approximations of known and unknown real-world factors and typically have some level of assumption built in.

MPG then, as a fleet predictor of one technology versus another, is not particularly precise or accurate for fleets in choosing to invest, but often it is what is familiar and available. Larger fleets tend to conduct their own A-vs.-B tests at varying levels of sophistication to avoid being misled by overly optimistic or pessimistic data from manufacturers and other resources.

MPG also does nothing to clarify focus on the primary mission of fleets, which is to haul freight for compensation. A simple example puts that in perspective. A fleet operating empty trailers will significantly outperform in mpg one that operates fully loaded.

Adding freight weight to the mpg value creates the freight-ton-efficiency metric, expressed typically as freight-ton-miles-per-gallon, or more simply, freight ton efficiency (FTE). At a simplistic level, a fleet might aggregate this over a year by using the net freight weight carried, net fuel used, and net miles driven averaged over the quantity of fleet tractors. That aggregate has limited usefulness. Today’s data rich systems permit knowing the actual freight load and fuel efficiency at every moment of a trip. Furthermore, the GPS tracking systems and digital maps know exactly where the vehicle is at every moment. The data is sufficient to help quantify many of the factors contributing to the net FTE. This data rich world also permits comparison of truck to truck differences to help explain performance variation in fleet operations from technologies.

Weight is a complex factor in discussing transformational technologies. Tare weight is the vehicle absent any paid freight. Adjustments may be needed to factor in the weight of fuel and other consumable fluids, the driver and driver possessions and miscellaneous equipment like chains and load locks which might vary from route to route. The weight of freight added to the truck then gives the gross vehicle weight for that specific loaded truck at that time. The gross vehicle weight rating, or GVWR, is the max legal allowable weight of the vehicle.

Actual gross vehicle weight changes nearly with every run and varies considerably between types of freight carried The national average is between 65,000 lb. and 70,000 lb. [3, 9, 23]. A single truck might see the entire spectrum of weights during its life. For example, a load of snacks or furniture may be a relatively light load on one leg of a trip. After dropping that trailer, the next leg may be pulling a load of 50 gallon drums of chemicals at max weight. The next leg may see the truck pulling an empty trailer to a new location.

This ability of diesel tractors to be used in multiple duty cycles has been a significant market factor. New transitional technologies entering the market place may instead be purpose built and optimized for specific duty cycles. For example, a battery electric truck where battery weight may limit a beverage hauler from carrying a preferred max payload a long distance in a 53 ft. trailer, may be optimized instead for lighter, shorter range loads like drayage where shipping containers are 40 ft. in length, rarely max out weight and routes are between 50 and perhaps 150 miles.

Missing from this though is cube, the physical volume of freight carried, effectively the density of each shipment. Technologies are available today to track the freight cube inside trailers. As these evolve and gain market share, that cube data could be used along with near instantaneous freight weight, fuel efficiency, location, traffic density, etc. to arrive at a single metric that fleets could have confidence in to evaluate the benefits of individual technologies. Two examples of FTE and potential of improved cube from trailer technology choices are shown in Figure 40 with use of double 28 ft. long trailers and use of high cube trailers versus standard 53 ft. trailers.

Freight ton efficiency for alternative fuel tractors involves energy conversion to diesel gallon equivalence. This factor often mistakenly looks only at the energy content of the fuel, like hydrogen, natural gas or the kilowatt hours of the battery. The comparison is much more complex as its not just the energy content, but the efficiency of the conversion of the energy into motion of the vehicle. For a deeper dive into this complex topic, NACFE has published a detailed evaluation in their 2019 Guidance Report Viable Class 7/8 Electric, Hybrid and Alternative Fuel Tractors [9].

A fundamental maxim in continuous improvement is if you can measure something, you can improve it. Advances in measuring real-world factors are helping fleets mature in their ability to understand and evaluate the potential of new technologies.

FIGURE 40 Examples with freight cube improvement.

SouthEastern Freight Lines
Double 28’ Trailers
6% more cube than a 53’ trailer
Max FTE ~105 ton-miles/gal

Frito Lay / PepsiCo
High Cube trailer
11% more cube than standard 53’
FTE maxes out at ~70 ton-miles/gal

8. In-Production Current Technologies

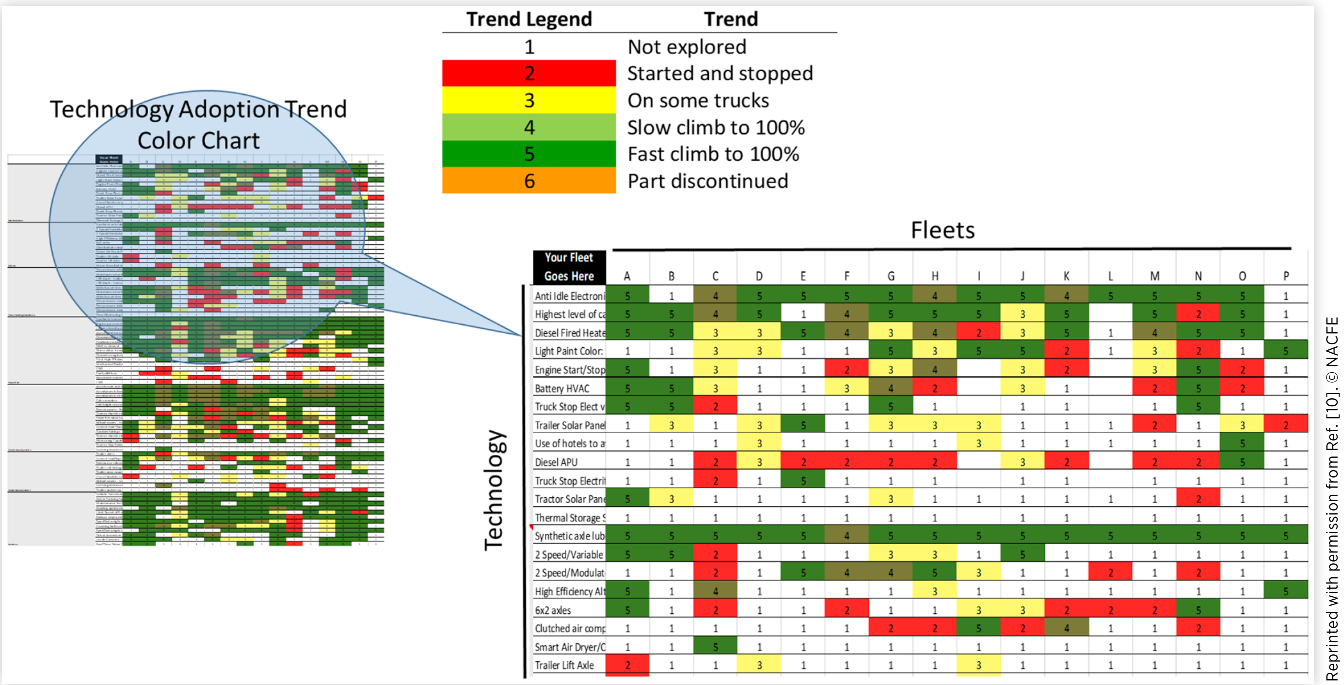
The freight industry embraces continuous improvement; the market requires it. Even conservative fleets that might be considered technology laggards are constantly impacted by changes from vehicle manufacturers constantly improving products to back-office computers and systems constantly improving. The competitive nature of the market rarely allows technology to stand still for more than brief moments. A vehicle pre-buy may temporarily avoid a technology, but trucks and back-office computers wear out and their replacements are new models incorporating the latest technologies. Smaller operators buying used models may be on a slightly different technology adoption curve timing, but they too have to embrace the new technologies as the feed stock of used trucks comes from new vehicle owners replacing trucks every two or three years.

Fleets face a massive number of new technology choices in the North American market. NACFE identified 85 technology areas to track in its 2019 Annual Fleet Fuel Study. The data shows for the 21 fleets participating in that study, there are some common adoptions of technologies. The data also shows there are multiple ways to improved efficiency, as shown in the excerpt from NACFE’s Technology Adoption Trend Color Chart in Figure 41 [10]. Each column represents the technology adoption of one of the fleets. Each row represents a technology type. Rows that show a consistent color reflect uniform agreement by these fleets on the benefit of a technology type for their own use. Where a row shows a variety of colors, each fleet has chosen to adopt or not adopt a technology. Where rows are uniformly uncolored, fleets have yet to explore the technology.

Each technology row in this example can reflect a range of products from a range of manufacturers, where each may have unique, proprietary approaches. This means each row could be subdivided much further in granularity, illustrating the significant number of choices regularly facing fleets.

The challenge for fleets is filtering through all these potential choices to prioritize investment decisions. A starting point for fleets are Confidence Reports on technologies from NACFE [90]. Other sources include industry groups like the American Trucking Associations’ Technology & Maintenance Council, and comparative studies from research agencies such as Canada’s National Research Council, the U.S. Department of Energy laboratories, the EPA SmartWay program, various

FIGURE 41 Example technology adoptions.



Your Fleet Goes Here	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Anti Idle Electroni	5	1	4	5	5	5	5	4	5	5	4	5	5	5	5	1
Highest level of ca	5	5	4	5	1	4	5	5	5	3	5		5	2	5	1
Diesel Fired Heate	5	5	3	3	5	4	3	4	2	3	5	1	4	5	5	1
Light Paint Color:	1	1	3	3	1	1	5	3	5	5	2	1	3	2	1	5
Engine Start/Stop	5	1	3	1	1	2	3	4		3	2		3	5	2	1
Battery HVAC	5	5	3	1	1	3	4	2		3	1		2	5	2	1
Truck Stop Elect v	5	5	2	1	1	1	5	1		1	1		1	5	1	1
Trailer Solar Panel	1	3	1	3	5	1	3	3	3	1	1	1	2	1	3	2
Use of hotels to a	1	1	1	3	1	1	1	1	3	1	1	1	1	1	5	1
Diesel APU	1	1	2	3	2	2	2	2		3	2		2	2	5	1
Truck Stop Electri	1	1	2	1	5	1	1	1		1	1		1	1	1	1
Tractor Solar Pane	5	3	1	1	1	1	3	1	1	1	1	1	1	2	1	1
Thermal Storage S	1	1	1	1	1	1	1	1		1	1		1	1	1	1
Synthetic axle lub	5	5	5	5	5	4	5	5	5	5	5	5	5	5	5	5
2 Speed/Variable	5	5	2	1	1	1	3	3	1	5	1	1	1	1	1	1
2 Speed/Modulat	1	1	2	1	5	4	4	5	3	1	1	2	1	2	1	1
High Efficiency Alt	5	1	4	1	1	1	1	3	1	1	1	1	1	1	1	5
6x2 axles	5	1	2	1	1	2	1	1	3	3	2	2	2	5	1	1
Clutched air comp	1	1	1	1	1	1	2	2	5	2	4	1	1	2	1	1
Smart Air Dryer/C	1	1	5	1	1	1	1	1	1	1	1	1	1	1	1	1
Trailer Lift Axle	2	1	1	3	1	1	1	1	3	1	1	1	1	1	1	1

state level groups like California's Air Resources Board, third party research centers such as Southwest Research Institute (SWRI) or FP Innovations PIT Group, and a multitude of university-based research groups and technology centers. Fleets also look to their competitors to see what technologies are being purchased.

The tsunami of information available may be directly relevant or may not. Experienced fleets know this and many will only initially invest in a small number of vehicles with a new technology, allowing it to prove out in their own unique operations with their own drivers.

9. Electrification

Freight electrification is an opportunity to observe the process of transformative technology adoption and maturation. Electrification of freight, whether BEV, FCEV or catenary, is viewed as a clearly defined revolutionary step as opposed to automation and connectivity which are more on an evolutionary path to greater adoption. While mild-hybridization may be viewed as an evolution of diesel-based vehicles by electrifying accessories, changing from a diesel to a fully electrified zero emission vehicle is a clearly a revolutionary step. This section focuses on electrification as a major commitment facing fleets in adopting transformative technologies.

While electric vehicles go back well before internal combustion engines went into production, the recent focus can be argued to have started in 2008-2010 time frame with introduction of the Smith Newton electric medium-duty truck [36, 57]. The next major milestone is shared in 2017 with parallel announcements of battery electric vehicle development programs and display of prototypes by first Cummins, Tesla, Nikola, Daimler, Peterbilt, Kenworth and a string of both established and new OEM medium- and heavy-duty brands [36, 11, 9]. Growth in automotive and bus production volumes has accelerated interest in both battery electric and fuel cell electric, both based on electric drivetrains. In parallel over this decade, CNG use for heavy-duty trucking went through the lower parts of the innovation S-curve carving out market volume through technology iterations in production products. Throwing the term "renewable" in front of fuels like natural gas and diesel has made it possible to make these alternative fuel powertrains viable in a net-zero emission context going forward. In some interpretations, these are called net-negative. Taking those ICE powertrains and combining them with electrification has created a number of hybrid possibilities as well [9, 11].

9.1. Where It Makes Sense

A fleet representative told NACFE that "trucks have an amazing ability to be the wrong truck in the wrong application." Fleets plan operations daily, and just as frequently, the market gets redefined, modified, changed and they have to respond. Donald Rumsfeld, Secretary of Defense under President Bush, famously stated in 2007 "we go to war with the army we have, not the army you might want or wish to have at a later time." Fleets face this reality every operational day. In some cases, fleets may buy jack-of-all-trades-master-of-none truck specifications to be flexible. They may buy sleeper cabs and use them in urban or regional haul applications where the sleeper never gets used, all on the chance that a market shift will require them to start doing long haul operations, or residual value realities force their hand to ensure a secondary market buyer will value the vehicle. A common

FIGURE 42 SmartWay purpose built for on-highway.

Reprinted from Ref. [58]. U.S. Environmental Protection Agency

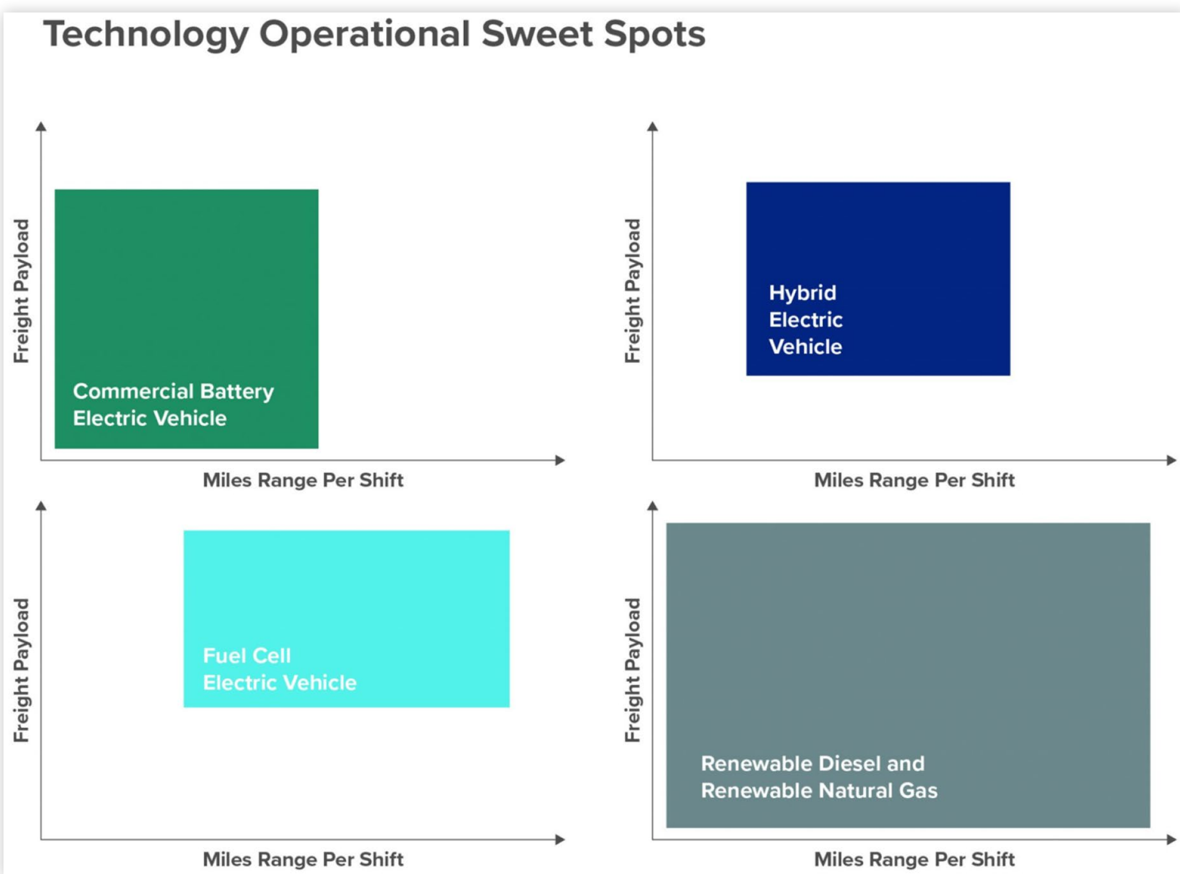
fear is that the trucks on hand are the wrong ones for the job today and need to be "parked on the fence."

The diesel truck has evolved into a tool adaptable to many duty cycles, although it may be optimized for the first owner's purpose. The second and tertiary owners take the used trucks that are available and figure out how to use them for their own needs. It's common to see used on-highway SmartWay certified sleeper tractors in use in drayage operations or bulk hauling gravel in urban routes and sometimes off-road at construction sites, where the vehicles are parked in a depot every night and drivers never use the sleepers as sleepers.

The voluntary EPA SmartWay program in the U.S. and its related use by Transport Canada guide first owner decision making towards a purpose built truck specification intended to optimize on-highway performance, as illustrated in Figure 42. The EPA/NHTSA GHG 1 and 2 rules and derivatives in Canada and the states following California ARB direction, are not voluntary, but mandates from regulatory organizations to purpose build specifications favoring aerodynamics, low rolling resistance, low emissions and improved fuel economy.

These purpose-built specifications highlight examples of a growing trend for first market purchases to be optimized for specific duty cycles. That trend plays well to the variety of future powertrain alternatives like battery electric, fuel cell electric, hybrid electric, and renewable fuel users of natural gas and diesel. These alternatives, when optimized to accentuate their positives, currently represent subsets of diesels spectrum of operations. This is illustrated in the graphic in Figure 43 showing NACFE's assessment of alternative fuel performance optimization [9]. Pure battery electric vehicles have challenges with weight of batteries as range increases, so current and near future vehicles should be optimized for lower range applications like urban and regional haul. Fuel cell electric vehicles combine the complexity of fuel cells with electric drivetrains, but the energy density of the fuel at very high pressure favors longer ranges and weight sensitive duty cycles. Hybrid electric vehicles combine classic ICE based

FIGURE 43 Alternatives optimize to subsets of diesel.



Reprinted from Ref. [9]. © NACFE

engines, although smaller sizes, with electric vehicle powertrains, and are more suited to medium range and medium freight payload operations. Just as with specifying diesel trucks, putting the right vehicle in the right application is critical. Unlike diesel trucks, where a day cab tractor might be a less than optimum substitute for a long haul beverage hauler day cab where the driver might get put up in a hotel in route, a pure battery electric sleeper cab may not be physically capable to do a long haul route with acceptable payload in the required delivery time. Where a long haul diesel can be substituted for a short haul day cab, a fuel cell long haul truck may not be able to operate economically in short urban low mileage runs with significant traffic conditions. Maintenance is largely unknown at present with all of these new technologies as very few are in the field in production volumes with significant miles in actual fleet drivers' hands [9, 11].

Additional perspectives and sources on where transformational technologies may make sense can be found in the 2018 SAE Buckendale report by Steudle, and Annelin, Transformational Technologies Reshaping Transportation—A Government Perspective, and the 2019 SAE Buckendale report by Rizzoni et al, Transformational Technologies Reshaping Transportation - An Academia Perspective [1, 2].

Visions of future states are great for research and development and future fleet planning, but fleets have to buy the trucks that are available today to replace the ones that need to be replaced now.

9.2. MD Tractors

Medium-duty electric trucks have been on a more accelerated path into production than the heavy-duty ones, with a number of production vehicles available from OEMs and aftermarket modifiers. The business case for medium-duty trucks hinges on the installation of charging infrastructure at a depot versus having multiple remote charging locations. Depot charging, or another term is return-to-base (RTB), or inside-the-fence (ITF) charging, puts the energy source and the truck in the same spot where it would sit overnight anyway. Some fleets currently maintain on-site fueling for their diesel and gasoline medium-duty trucks, or they have dedicated fueling stations nearby. RTB charging is not significantly different. What is different is that rather than a fuel truck arriving every so often to restock tanks, electrification requires tapping into electricity sources. That could be connecting to the utility power grid or connecting to a local micro-grid such as solar panels on a warehouse roof or nearby wind turbine farm or tapping into an on-site industrial scale battery storage system. It could mean combinations of all three.

Medium-duty truck duty cycles are more likely to see one shift operations where the trucks have significant dwell times allowing off-peak charging at lower electricity rates. Bread delivery, beverages and snacks, laundry services, office supplies, and many ecommerce available products currently are delivered in one shift operations for a variety of reasons tied to preferred hours of operation.

Two and three shift operations do occur, and duty cycles may actually vary between shifts. In those instances, more rapid charging systems are required. Those higher wattage systems greatly increase pricing of both the truck and the charging systems, and the cost of building in the infrastructure. However, utilization greatly increases the net benefit of the electric vehicles. The use at three shifts per day increases mileage per truck and reduces emissions per truck three times faster than a one shift operation. The break-even point for ROI investment is expected to happen significantly sooner in calendar days.

Urban use also plays to a feature of electric drivetrain vehicles that of energy recapture through regenerative braking. Unlike traditional diesel trucks where braking only wastes energy, electric drivetrains can recover energy with appropriate use of braking. The electric motors are conversely electric generators depending on the moment. Operation in many major urban areas globally are also associated with current and future zero emissions regulations and to a lesser extent noise regulations to which electric trucks are well suited.

9.3. Class 8 HD Battery Electric Tractors

Class 8 heavy-duty electrification is progressing with roll out of a growing number of prototypes. BYD has a limited number of production Class 8 vehicles in use as well. New heavy-duty truck manufacturers such as Tesla, Nikola, and Xos, are experiencing what traditional makers like Daimler's Freightliner, PACCAR's Kenworth, Peterbilt and DAF, Navistar, Volvo and more know from experience, birthing a new truck product is involved. While announcements started in 2017, manufacturers have been doing R&D for years on the technologies for electrifying heavy-duty trucks. The concept of mild-hybrids and 48V systems date at least back to the 1990s.

9.3.1. Current State

The challenge has always rested on the battery: on battery energy density, battery robustness, battery pricing and battery charging infrastructure. The growth in automotive and bus use as well as seemingly endless other uses of lithium ion batteries has fueled massive investment in battery technology. The fundamentals of industrial scale vehicle use has been proven out in automotive use with marks like Tesla, Toyota, Honda, GM and others. Applying these to the more demanding world of heavy-duty trucks in an economical beneficial way is the challenge. Early applications in 2020 seeing production heavy-duty battery electric vehicles include yard transfer vehicles, commonly known as yard mules. These vehicles may get used in multiple shifts but see relatively short daily mileage and significant stop-and-go operations that are regenerative friendly. They also see multiple dwell time periods at the depot allowing for multiple short duration charging events all day.

Fuel cells have also been around a long time with use in aerospace going back to the Gemini and Apollo days in the 1960s. Only more recently successfully used in production automobiles like the Toyota Mirai and various transit buses powered by makers like Ballard, Hydrogenics, Bosch and others. Use in heavy-duty production trucks is still limited in 2020 to prototypes in North America. These have similar cost challenges in bringing technology to the market as battery electrics. Volume pricing and standardization is difficult in a marketplace that has demands in the tens or hundreds of thousand vehicles a year versus the more robust automotive market were millions of vehicles are in demand.

Whether battery electric or fuel cell electric, a foundational issue for green energy for these vehicles is the need for electric grid infrastructure. While it seems fairly obvious that battery electric trucks require significant amounts of grid electricity capacity, less obvious is that hydrogen fuel cells require massive amounts of green electricity to convert raw materials into hydrogen fuel. The efficiencies in the utilization of the electricity from well to wheel is a major topic for consideration, as outlined NACFE's 2019 Guidance Report Viable Class 7/8 Electric, Hybrid and Alternative Fuel Tractors [9].

9.3.2. Future Improvements Innovation in electric powertrains is inextricably tied to levels of investment in research and development. The media may report on some company's or university's great new advancement in a technology at the laboratory level, but it can be years before those innovations percolate into production [7]. Investment for the long haul requires commitment over years to first generate ideas and then mature them into production, and then see them through the initial lean years as the products gain market share. Electrification has been riding significant levels of investment for the last 20 years, boosted by successful automotive product ramp ups such as the Nissan Leaf, Tesla Model S, Toyota Prius and Chevy Volt and other production products. Investment in freight electrification has risen significantly in the last decade, but birthing a production battery electric or fuel cell electric heavy-duty truck has taken years, and medium-duty trucks have already seen several false starts such as Smith Newton liquidating in 2014 and most recently in 2020 perhaps Mitsubishi Fuso whose promising eCanter may be on hold with announcements in May of 2020 that Mitsubishi Fuso will no longer sell trucks in the U.S [91, 36].

There seem to be two leading investment paths forward in electrification. The first is pure battery electric with all the infrastructure, vehicles and systems needed for that to be successful. The second is hydrogen fuel cell electric and, again, all the infrastructure, vehicles and systems need for that to succeed. While both share fairly common elements such as a need for electric motors, rechargeable batteries, high power cabling, sensors and control systems, they differ significantly beyond those.

The differences are highlighting different vested interests. Pure battery electric requires engaging the utility industry to expand into providing electrical energy for transportation. Fuel cells require hydrogen at scale, which appears to be an opportunity for expansion by existing hydrogen providers and opportunities for similar gas and liquid energy providers to have a new path forward into the zero emission future with transportation use.

They are both fundamentally tied to needing electricity. Hydrogen does not exist as a fuel for vehicles without first being converted from some naturally occurring product like water or methane. Electricity is fundamental to this conversion.

The challenge for fleets in adopting either of these new technologies will be an insecurity about which will ultimately prevail as vested interests and politics may have unpredictable impacts on the trajectories of market adoption of these technologies.

10. Case Studies

Three electrification and alternative fuel case studies in 2020 where leading edge technology is being demonstrated are PepsiCo, UPS and NFI. A common alternative term for early adopters is sometimes "bleeding edge" reflecting the higher risk levels they may encounter with fledgling technologies.

10.1. PepsiCo

PepsiCo, and its Frito-Lay division, are leading adopters of technology improvements for hauling freight. The company has extensively invested in its sustainability goals to reduce its absolute greenhouse gas (GHG) emissions by 20% by 2030 [59, 60, 61, 62]. The food and beverage leader is on track to source 100% renewable electricity for PepsiCo's U.S. operations in 2020. The company's commitment to reduce GHG emissions through Frito-Lay's Transforming Modesto project at its Modesto, Calif., manufacturing site was announced in October 2019, stating:

> *"…Frito-Lay aims to replace all of its existing diesel-powered freight equipment with zero-emission (ZE) and near-zero emission (NZE) technologies at its Modesto, Calif. Manufacturing site. The project will transform the 500,000-squarefoot site - one of Frito-Lay's largest in the U.S. - into an industry-leading showcase for environmentally sustainable manufacturing, warehousing and distribution."*

The multi-year project, which is one of the most advanced in the industry, focuses on converting an entire fleet, electrifying parking stalls for employees to incentivize electric car use, installing on-site solar and battery storage to reduce impact on the grid, and employing both electricity and compressed natural gas (CNG) generated from renewable sources by 2021. The project is funded in part through California Climate Investments, a statewide program that puts billions of Cap-and-Trade dollars to work reducing greenhouse gas emissions, strengthening the economy, and improving public health and the environment — particularly in disadvantaged communities.

Converting an entire fleet is a holistic approach, a true systems engineering approach, to demonstrating technology transition. According to a large fleet operator executive in an April 2020 interview with NACFE,

> *"Really respect what PepsiCo is doing in Modesto. We have the same vision. PepsiCo is doing it right, committing fully to it rather than a patchwork approach. PepsiCo will be an example of what good looks like."*

Frito-Lay has extensive experience with both battery electric and CNG vehicles in its fleet. Overall, the Frito-Lay fleet is consistently ranked first on the 2018 and 2019 Transport Topics Top 100 Private Fleets list with 11,250 tractors, 4,300 straight trucks, and 16,700 smaller trucks [66]. Their first deployment of CNG tractors was in 2011. By 2016, the company had more than 500 CNG vehicles in operation with over 100 million miles of use and making use of 16 CNG public fueling stations [63, 64]. As of 2020, Frito-Lay has more than 700 CNG tractors and uses CNG from renewable sources (RNG). They were one of the first to own and operate Smith Newton electric medium duty trucks starting with 21 in 2010 and eventually operating 280 in a variety of U.S. locations [65].

Using RNG requires no physical change to the CNG vehicles but does require special considerations to leverage the complex national and state regulations, certifications and credit markets required to receive credit for using RNG. In California, RNG users can receive credits under the Low Carbon Fuel Standard (LCFS) for reducing emissions with low carbon fuels. Each LCFS credit equates one ton of emissions reduced, and ACT News estimates that the LCFS program can provide substantial economic value to the RNG producer, fuel supplier and end user which can help offset the increased up-front and ongoing cost of generating the fuel and operating CNG vehicles. Both CNG and electric Class 8 vehicles qualify for the 82,000 lb. GVWR weight limit, providing a 2,000 lb. additional federal weight allowance max [69].

Electric vehicles may see a similar wide range of one-time and on-going credits. Electricity that is sourced from renewable energy are purchased as renewable energy credits (REC). “RECs are issued when one megawatt-hour (MWh) of electricity is generated and delivered to the electricity grid from a renewable energy resource [68].” These credits may be used with your own utility while the actual generation is in some other region of the country in another utility. The fungible nature of electricity allows this to occur. At the vehicle level, similar to RNG use, electric vehicles qualify for LCFS credits, qualify for the 82,000 lbs. GVWR weight limit, and potentially savings related to differential pricing on tollways, parking, etc.

The Modesto, Calif., manufacturing site was selected as a template location for conversion to zero- and near-zero emission technologies because it is one of the largest Frito-Lay facilities in California and it is located in a disadvantaged community where economic, health and environmental burdens can be high. The Modesto Frito-Lay facility is planning to operate a range of zero- and near-zero emission vehicles by 2021. The facility will be equipped with on-site battery storage for multiple uses including facilitating employee use of electric cars, assisting in facility power demand leveling and reducing peak demands on the grid. The scale of the Modesto endeavor is illustrated in Figure 44.

The components of the Frito-Lay Transforming Modesto project include:

- An American Natural Gas (ANG) CNG fueling station: The publicly available fueling station is next to the Modesto plant and will support fueling of the CNG tractors with natural gas with renewable attributes.
- Three (3) BYD 8Y battery electric yard tractors: The yard tractors will support trailer movements in the yard for loading and unloading and will allow an opportunity to charge between shifts and during operator breaks.
- Twelve (12) ChargePoint electric vehicle charging stations: The Level 3 DC charging stations will charge

FIGURE 44 Modesto facility plans.

the Class 6 box trucks at 62.5 kW and the Class 8 electric yard tractors at 125 kW.

- Ten (10) employee electric vehicle charging stations: The Level 2 charging stations will be available for employees and visitors.
- Twelve (12) Crown battery electric forklifts powered by lithium- ion technologies: The forklifts will support warehouse operations and opportunity charge between shifts and during operator breaks.
- Six (6) Peterbilt 220EV battery electric box trucks: The box trucks will deliver Frito-Lay products and charge overnight.
- Fifteen (15) heavy-duty Tesla battery electric tractors ("Semi"): The tractors will transport Frito-Lay products with backhauls and fast charge between trips. Tesla claims to provide 2 kWh/mile performance and 500-mile range with the long-range option.
- Four (4) Tesla charging stations ("Mega chargers"): Specifications for the high-power DC Mega chargers have not yet been released but are expected to charge the Semis in 1 to 1.5 hours.
- One (1) MW Tesla solar carport: The solar installation will be tied into the plant and employee electric vehicle charging station electrical load.
- Two (2) Tesla battery energy storage systems (BESS): There will be a 2.5 MWh BESS to support the Mega chargers and a 696 kWh BESS associated with the solar carport.
- Thirty-eight (38) Volvo tractors with low NOx engines powered by natural gas with renewable attributes: The CNG tractors will transport Frito-Lay products with backhauls and fuel primarily at the nearby ANG station using RNG. The tractors have an estimated range of 700 miles.

Each of these new technologies will be field-tested to confirm range, efficiency and ideal duty cycles.

This holistic approach to converting an entire fleet to zero- and near- zero emission use is a significant demonstration of technology adoption at the fleet level. The term "at scale" is always a factor in judging the maturity of technology development, pushing beyond the handful of prototype vehicles used earlier in testing.

10.2. United Parcel Service (UPS)

UPS is aggressive in demonstrating and evaluating technologies for its diverse global operations. They operate a test fleet called their Rolling Laboratory, with over 1,000 light-, medium- and heavy-duty vehicles in multiple locations to prove out the viability of new ideas. The successful technologies are then rolled out in scale. UPS operates approximately 24,000 medium-duty and 12,000 heavy-duty diesel vehicles. Some 4,000 of these are CNG/RNG, one of the technologies that UPS vetted in their test fleets in prior years. UPS also operates in excess of 60,000 gasoline vehicles. The fleet also includes approximately 1,200 propane-based vehicles. UPS has also major interests in electrification and expects it to be a major part of their future operations.

The 2016 graphic from UPS in Figure 45 illustrates the variety of technologies and duty cycles UPS has and are investigating. The UPS operations, in essence, are an example model of the complexity and breadth of road freight. Their interest in pursuing a wide variety of technologies highlights NACFE's "messy middle" assertion that the near future will see a variety of powertrain solutions in trucking.

The UPS Rolling Laboratory demonstrates two key elements for fleet adoption of transformational technologies, flexibility and the need to adapt to change. There are no one-size-fits-all solutions for UPS. Many solutions are affected by local and regional factors. An optimal solution for one location may be less than desirable in another. A single large truck in rural use may not be desirable in a region with tight streets where smaller vehicles are better suited.

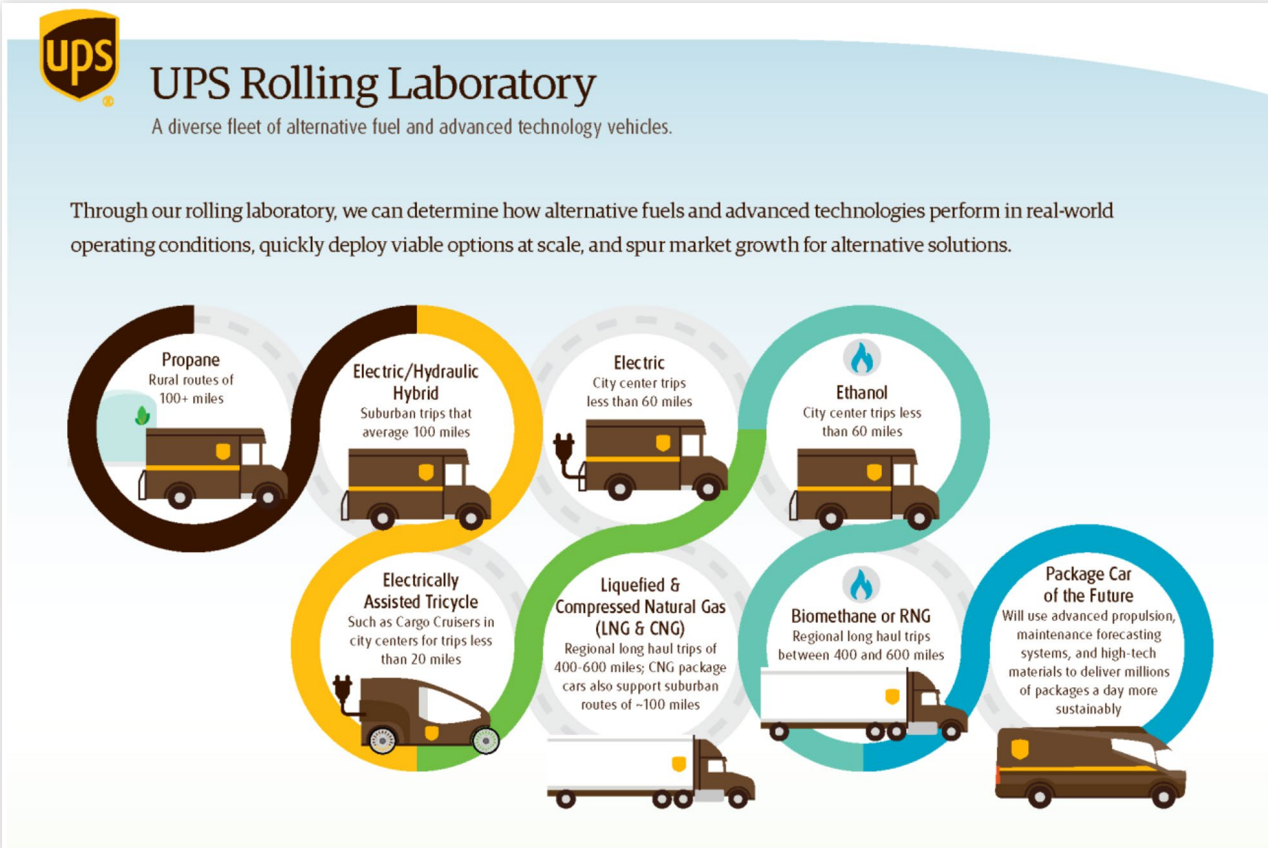
The marketplace has also often challenged detailed fleet plans by altering direction. For example, a focus on aerodynamics for heavy-duty freight tractors was helped by increasing fuel costs peaking at more than $4.50 per gallon of diesel in 2008. The Great Recession that soon followed along with vast expansion in oil production through a new technology, hydraulic fracturing, and reintroduction of other new oil sources led to a glut in oil supply by 2014. Compounding that was growth in adoption of increasingly fuel efficient vehicles reducing demand. The economics of supply and demand led to depressed fuel prices that reduced the interest in after-market aerodynamic product investment and extended payback periods after 2015.

UPS has experience in trying to predict shifts in the marketplace. Out of the Rolling Laboratory came confidence in investment in natural gas heavy-duty tractors for long haul routes. UPS evaluated LNG vs CNG at that time and determined that LNG was the optimum solution for their requirements, ultimately purchasing approximately 1,300 LNG tractors and investing in fueling and servicing infrastructure. A 2013 EPA announcement highlights UPS had four existing LNG fueling stations and had funded nine additional ones to support a planned fleet of 1,000 vehicles. In parallel, UPS had 1,000 CNG vehicles in operation [79].

CNG system designers figured out how to more effectively build and package tanks on tractors in more aerodynamic modules stacked vertically behind the cabs and at high enough energy densities to out-perform LNG. As the market shifted more to CNG from LNG, so too has UPS. In June 2018 UPS announced further investment in CNG fueling stations and 400 semi-tractors and 330 terminal trucks tractors [80]. They also announced a clear path to using RNG to reduce life cycle greenhouse gas emissions with announcements in 2017 [81]. In October 2019, UPS announced further investment in CNG/RNG vehicles ordering more than 6,000 natural gas-powered trucks beginning in 2020 and running through 2022 [82].

A UPS CNG tractor participated in the 2019 NACFE Run on Less Regional (ROLR) demonstration in October 2019, where 10 fleets ran 10 trucks over three weeks and 50,000 miles with data loggers recording at 1 Hz frequency [86]. CNG is generally measured by volume at a standard

FIGURE 45 UPS variety of technology investigations.



pressure and temperature. When reporting fuel efficiency, this value is often converted to a diesel gallon equivalent based on energy content in an equal mass of natural gas and diesel. However, even with this unit conversion, CNG-fueled trucks are difficult to compare to diesel fueled trucks on an MPG-to-MPG basis. For a number of reasons, the diesel engines on the road today operate at a higher thermal efficiency than CNG-fueled engines resulting in lower MPG for CNG-powered trucks. This was the case with the UPS truck. Analysis of the data indicates that its MPG was 2.5 to 2.7 MPG lower (~30%) than the diesel-powered trucks in RoLR after other conditions such as weight, terrain and weather are accounted for [86]. In discussions with other fleets not participating in RoLR but experienced with CNG trucks in their own fleets, the UPS, CNG powered tractor's performance was very impressive. According to one fleet executive, "We would give our right arm for MPGs like that in our CNG fleet."

The LNG vs CNG example also highlights the ramifications of long-term commitment to infrastructure that goes hand-in-hand with many of the new powertrain alternatives. Capital investment in buildings and fuel storage may have decades-long implications. Every decision to invest may lock-in solutions in locations and prevent changing horses. Large capital investments may take on a life of their own, requiring downstream reinvestment in technology upgrades as more cost effective than replacing the facilities with alternatives. This is one of the major challenges facing adoption of battery electric vehicles and hydrogen fuel cell electric vehicles.

UPS fully recognizes the need and potential for true zero emission solutions as reflected by their investment and commitment to purchase 10,000 medium-duty vehicles from Arrival in January of 2020 [83]. UPS purchases vehicles for life, so their vehicle specifications have been tuned by them with OEMs to ensure adequate life spans. Often their specifications become the example for smaller fleets to emulate with some confidence. UPS did not just order vehicles from Arrival, they took a minority stake in the company to ensure their vehicles would meet their requirements, schedules and costs. Stated Denis Sverdlov, Arriva's Chief Executive, "Together, our teams have been working hard to create bespoke electric vehicles, based on our flexible skateboard platforms that meet the end-to-end needs of UPS from driving, loading/unloading and back-office operations. We are pleased that today's investment and vehicle order creates even closer ties between our two companies." A concept for the European version is shown in Figure 46.

UPS actively reveals progress on new technologies reflecting a trait true for PepsiCo and NFI of sharing experience. UPS examples include a vision whitepaper done with GreenBiz in 2018 and webinar on UPS' conversion of a complete facility to electric vehicles in London [84, 85]. A key

FIGURE 46 Arrival UPS concept.

Reprinted with permission from Ref. [89]. © 2020 Arrival Ltd.

lesson learned from the UPS experience is to be sure to place the right technology for its maturity in the right application. This may mean using technologies now that are different than later. For example, RNG now, battery electric or fuel cells later for UPS's dedicated fast turn cycles.

10.3. NFI

NFI classifies itself as a 3PL, a third-party logistics provider. As discussed previously, the definition of 3PL was codified in 2008 by U.S. Congress "as a person who solely receives, holds, or otherwise transports a consumer product in the ordinary course of business but who does not take title to the product." NFI has in excess of 50 million square feet of warehouse space, more than 4,500 tractors and in excess of 12,500 trailers [71, 72, 75].

They have operations in many regions in the U.S. They handle a complete range of logistics including air and ocean freight logistics, global transportation and distribution, and in trucking, they have dedicated fleets, refrigerated transport, brokerage, intermodal, drayage and yard management. NFI ranked 19th in Transport Topics 2019 Top 100 For-Hire carriers.

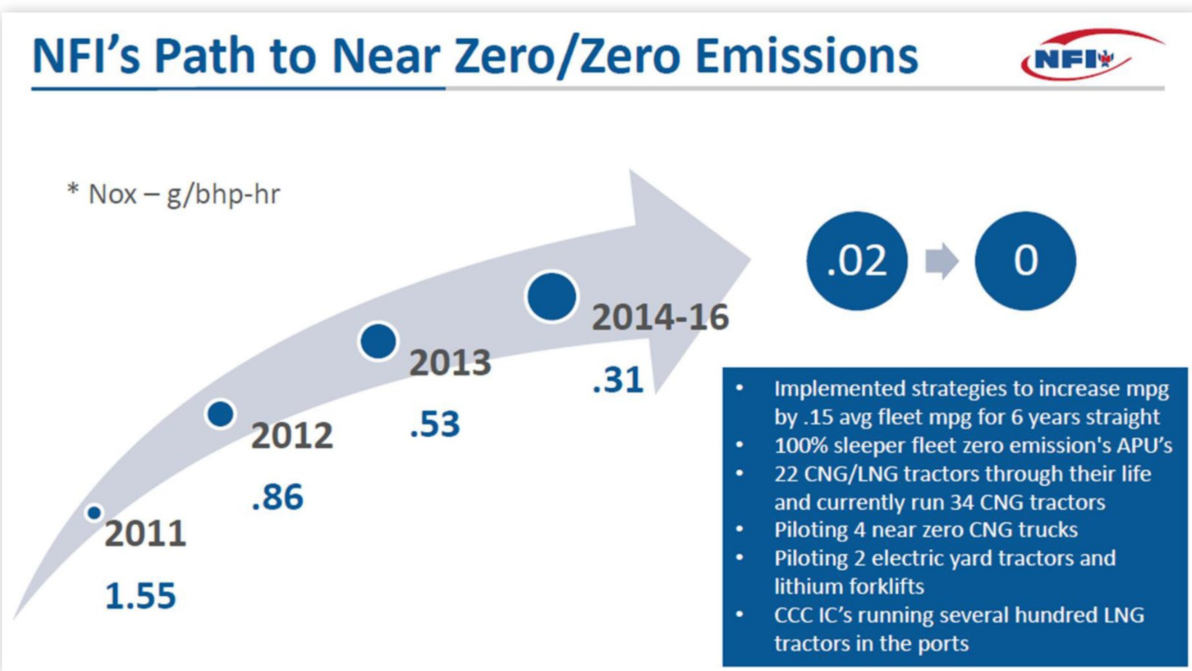
NFI is a leading-edge company in the pursuit of near zero and zero emission operations. Bill Bliem, Senior Vice President of Fleet Services for NFI provided an overview, shown in Figure 47. NFI progress improving emissions. of NFI's progress and plans towards reducing emissions at the Spring 2018 American Trucking Association (ATA) Technology & Maintenance Council (TMC) event [73].

In 2020, NFI plans to have "over 40 electric vehicles in California including 14 Class 8 tractors and 27 electric yard tractors [74]." NFI began taking delivery and using heavy-duty battery electric vehicles in drayage service between the ports of Los Angeles/Long Beach and their Inland Empire facilities in Chino, California, approximately 50 miles in each direction. They also are using battery electric yard trucks and forklifts. NFI has installed charging infrastructure to support these vehicles. NFI is also exploring the viability of Class 8 hydrogen cell vehicles.

James O'Leary, Vice President of Fleet Services for NFI, said, "Social responsibility is a core value for our company, trying to do whatever we can to reduce our environmental impact to the Chino area [75]."

The Chino to Los Angeles/Long Beach ports drayage locations were selected as the opportunity to successfully prove out the new technologies. The combination of battery friendly duty cycle of ~110 mile duty cycle range, load weights that are never maximum, plus significant monetary support from state and local groups for both the chargers and the trucks make this route a perfect real-life operation to demonstrate

FIGURE 47 NFI progress improving emissions.



Reprinted with permission from Ref. [73]. © NFI Industries successfully the benefits of electric trucks. The operation from port to Inland Empire covers work with 11 major NFI customers, all closely located with NFI operations. The weather is optimum as well. According to James O'Leary, "It's a real-life application that can grow after the pilot." The NFI goal is to fully electrify Chino. They have 65 tractors at Chino they wish to electrify.

Vehicle plans outlined to NACFE in 2019 interviews with NFI were:

- 10 Daimler Class 8 eCascadia tractors
- 4 Volvo Class 8 from the Volvo LIGHTS project (Low-Impact Green Heavy Transport Solutions)
- 2 Kalmar T2E yard tractors already in use
- 5 Nikola all electric tractors
- 10 Tesla semi-tractors
- 2 Peterbilt Class 8 battery electric tractors
- 25 Ottawa yard tractors

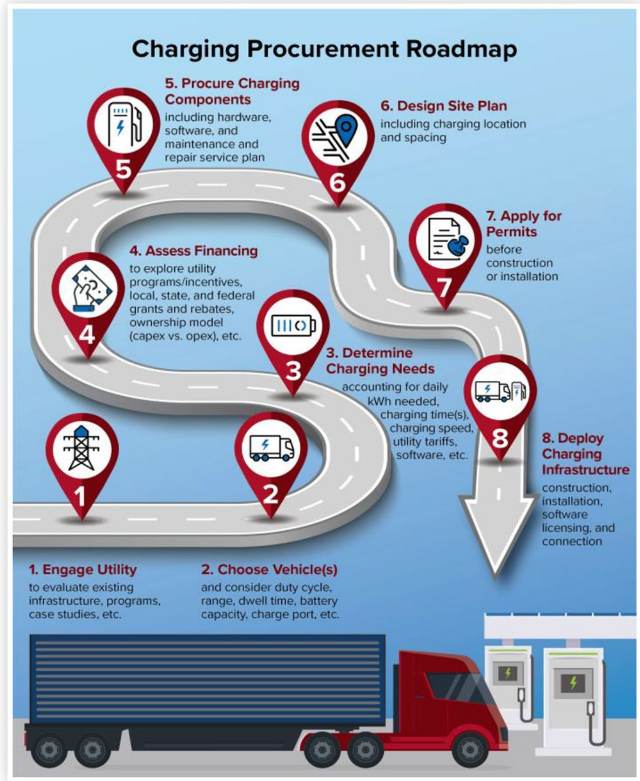
As of May 2020, all 10 eCascadias are in operation. Volvo reported at that time that five VNR electric trucks were delivered for use in Southern California operations [74, 75]. NFI as of May 2020 did not yet have theirs in use. NFI expects the first Volvo to arrive in Mid-August 2020.

Early adopters are finding funding assistance for charging systems and for the vehicles as both the utilities and the state of California are providing funding to move to zero emission transportation. According to a 2020 FreightWaves article, "California makes tryouts of zero-emission electric trucks a relatively low financial risk by using money raised from excessive carbon fines as incentives to reduce the cost of electric trucks, which can cost twice as much as their diesel counterparts. The state's Hybrid and Zero Emission Truck and Bus Voucher Incentive Program provides $80,000 per vehicle [76]." There are a number of grant, incentives and other methods to help offset the cost of vehicles and infrastructure as described in NACFE Guidance Reports [9, 11, 36, 77]. Navigating these has sprouted a number of third-party service groups to assist such as Gladstein, Neandross and Associates (GNA), CALSTART, Black & Veatch, Southern California Edison, PG&E, ChargePoint and many others.

A key element of executing NFI's plans has been lead time and communicating with the much larger group of parties that are now integral to electric truck success. The graphic in Figure 48. The charging infrastructure roadmap. The graphic outlines the basic process required for early adopters [77]. Unlike with diesel where fueling stations are ubiquitous, obtaining electric trucks also requires deploying the charging infrastructure. For small numbers of vehicles that can have slower charge times, the time required to create the infrastructure may be measured in months. To scale to large installations with fast charging, may be measured in years between starting planning and finally operating the first vehicles.

NFI estimates that net consumption on the drayage routes of 120-140 miles are between 1.6 and 2.4 kWh/mi depending on traffic conditions, loads, etc. O'Leary stated that "given the performance of the ten tractors utilized in drayage NFI has

FIGURE 48 The charging infrastructure roadmap.



no concerns with the tractors completing the 150 mile round trip required for these first deployments. There is plenty of energy left in the battery such that NFI is very confident the driver will make it back".

Key lessons learned from the NFI examples are to get involved early utilizing incentive funds, engaging all participants early and often, and plan to move fast at the site and then move on to others.

11. Conclusions

The author summarizes key conclusions discovered during research for this report as follows:

1. Transformational technologies in transportation, such as electrification, autonomy and sustainable logistics, are moving out of the laboratories and proving their potential to provide real value for users. They are not only improving the costs to move goods, but also doing so while being much more socially responsible.
2. Many technology solutions for improving efficiency and reducing emissions are emerging that can be combined or adopted separately. Combining them can offer additional opportunities but increases the complexities for introduction into their operations.
3. Quick adoption of new technologies in transporting goods occurs when value is clearly delivered by the technology providers and measurable through

calculation of total cost of ownership. True TCO may require a comprehensive view of operational costs including soft and hard costs and benefits. Early adopters expect higher costs initially but believe that the total cost of ownership will reduce over time and be a good investment.

4. Early adopters, especially given the benefits of many of these technologies for carbonless goods movement, understand that costs may be higher in the early years. They accept this challenge to pave the way for their own company and future end users to benefit from the technologies.
5. Electrifying the powertrains of trucks, both medium and heavy duty offer many benefits and are attracting much investment and even becoming mandated through regulation at country, region and urban government levels.
6. Success with early adopters who benefit the most from the technology will hasten product development and broader availability by the manufacturers. Three case study companies highlighted in this report, PepsiCo, UPS and NFI, are demonstrating the path to success and these end user fleets are sharing their successes and challenges as they begin deployment.
7. Transformational technologies are ever on-going in the trucking industry. The key to success is through transparency and communication between end users, manufacturers, communities, energy suppliers and others. The more transparent and robust the communications between all vested parties, the better the new technologies can be matured and help solve the many challenges tied to moving goods.

12. Recommendations

The primary purpose of the SAE Buckendale is to provide new engineers with critical insights on key relevant topics, but experience has shown that Buckendale lectures and reports are useful to industry, regulators, policy makers, researchers and the public. The author completes this report with recommendations gleaned from writing it, and from an extensive career experience developing, observing, analyzing and reporting on technologies for the freight industry:

1. All participants in the supply chain should stay informed on transformational technologies and incorporate their revolutionary benefits while also evolving their operations through a process of continuous improvement.
2. All should stay focused on total cost of ownership to maintain sustainable profits while recognizing that solutions for social responsibility particularly with respect to climate change, will be costly at first.
3. Monetize as many of the benefits and consequences of each individual technology adoption and be realistic with the calculations including utilizing correct baselines.
4. Early adopter end users are pioneering these new changes and need support from technology investors, incentives by parties who will enjoy long term benefits and from any others who can help them pave the way. Be transparent with your actions such that others benefit and can help provide scale.
5. All should share quantitative and qualitative insights, knowledge and data in the early development to encourage later adopters and accelerate implementation.

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Appendix A: List of Figures

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PAST LECTURES

1954	KENNETH W. GORDON SP-130 “Design Evaluation & Selection of Heavy-Duty Rear Axles”
1955	No Lecture
1956	CARL GEORGE ARTHUR ROSEN SP-131 “The Role of the Turbine in Future Vehicle Powerplants”
1956	WILLIAM PEARSE MICHELL SP-132 “New Drive Lines for New Engines”
1957	ROBERT M. RIBLET and CHARLES M. KITSON SP-133 “Bearing Application for Heavy-Duty Axles”
1958	No Lecture
1959	OLIVER K. KELLEY SP-134 “Planetary Gearing – Basic Design Information & Typical Application to Commercial & Military Ground Vehicles”
1960	GEORGE J. HUEBNER, JR. SP-172 “Computer-Based Selection of Balanced-Life Automotive Gears”
1961	V. J. JANDASEK SP-186 “The Design of Single-Stage, Three Element Torque Converter”
1962	WELLS COLEMAN SP-221 “Design and Manufacture of Spiral Bevel and Hypoid Gears for Heavy-Duty Drive Axles”
1963	G. ROBERT HARTING SP-239 “Design and Application of Heavy-Duty Clutches”
1964	G. P. MATHEWS SP-251 “Art and Science of Braking Heavy-Duty Vehicles”
1965	PHILIP J. MAZZIOTTI SP-262 “Dynamic Characteristics of Truck Drive Line Systems”
1966	WILLIAM J. SIDELKO SP-276 “An Objective Approach to Highway Truck Frame Design”
1967	PAUL K. BEATENBOUGH SP-284 “Engine Cooling Systems for Motor Trucks”
1968	V. G. RAVIOLO SP-341 “Planning Product”
1969	J. A. DAVISSON SP-344 “Design and Application of Commercial Type Tires”
1970	GARY L. SMITH SP-355 “Commercial Vehicle Performance and Fuel Economy”
1971	CHARLES M. PERKINS SP-363 “Principles and Design of Mechanical Truck Transmission”
1972	PETER R. KYROPOULOS SP-367 “Human Factors Methodology in the Design of the Driver’s Workspace in Trucks”
1973	JOHN W. DURSTINE SP-374 “The Truck Steering System – From Hand Wheel to Road Wheel”
1974	RICHARD L. STAADT SP-386 “Truck Noise Control”
1975	PHILLIP S. MYERS SP-391 “The Diesel Engine for Truck Application”
1976	ERNEST R. STERNBERG SP-402 “Heavy-Duty Truck Suspensions”
1977	RAYMOND E. HELLER SP-413 “Truck Electrical Systems”
1978	KENNETH W. CUFFE SP-425 “Air Conditioning & Heating Systems for Trucks”
1979	MARTIN J. HERMANNS SP-437 “Front Drive Systems for 4WD Light Trucks”
1980	JOHN R. KINSTLER SP-454 “Wheels for Commercial Vehicles”
1981	JOHN C. WALTER SP-479 “A Guide for Powerplant Installation in Trucks”
1982	RAY W. MURPHY SP-506 “Endurance Testing of Heavy Duty Vehicles”
1983	HANS J. BAJARIA SP-533 “Integration of Reliability, Maintainability and Quality Parameters in Design”

PAST LECTURES (CONTINUED)

1984	JAMES D. SYMONS SP-563 “Dynamic Sealing Systems for Commercial Vehicles”
1985	THOMAS D. GILLESPIE SP-607 “Heavy Truck Ride”
1986	TREVOR O. JONES SP-647 “Commercial Vehicle Electronics”
1987	RICHARD DROLLINGER SP-688 “Heavy Duty Truck Aerodynamics”
1988	FRED S. CHARLES and THOMAS L. FORD SP-729 “Heavy Duty Truck Tire Engineering”
1989	SIDNEY F. WILLIAMS, JR. and WILLIAM A. LEASURE, JR. SP-789 “Antilock Systems for Air-Braked Vehicles”
1990	DANIEL J. BOSCH and JOHN D. REAL SP-824 “Heavy Truck Cooling Systems”
1991	CHARLES R. JONES SP-868 “Heavy Duty Drivetrains - The System and Component Application”
1992	WILLIAM R. CAREY SP-913 “Tools for Today’s Engineer - Strategy for Achieving Engineering Excellence”
1993	DAVID CEBON SP-951 “Interaction between Heavy Vehicles and Roads”
1994	DAVID F. MERRION SP-1011 “Diesel Engine Design for the 1990’s”
1995	WESLEY M. DICK SP-1063 “All Wheel and Four Wheel Drive Vehicle Systems”
1996	No Lecture
1997	FARHANG ASLANI, CHING-HUNG CHUANG, SHABBIR DOHADWALA, JEFF HUANG, BIJAN KHATIB-SHAHIDI, PATRICK J. LEE, DAVID S. ROHWEDER, RANDAL H. VISINTAINER and DAVID E. WATTS SP-1310 “CAE Methods and Their Application to Truck Design”
1998	LEONARD C. BUCKMAN SP-1405 “Commercial Vehicle Braking Systems: Air Brakes, ABS and Beyond”
1999	VALERIE A. NELSON, MARY L. RANGER and PETER KANEFSKY SP-1541 “A Systems Approach to Engine Cooling Design”
2000	RONALD P. ZIEBELL SP-1567 “Commercial Use of Military Truck Technology”
2001	VERN ANDREW CARON SP-1650 “Commercial Vehicle Electronics Design”
2002	LEE R. ARMSTRONG SP-1727 “Electronic System Integration”
2003	MARK G. THOMAS SP-1816 “Electronic Systems Testing and Validation for Commercial Vehicles”
2004	WILLIAM J. CHARMLEY 2004-01-2708 “The Federal Government’s Role in Reducing Heavy-Duty Diesel Engine Emissions”
2005	STEPHEN J. CHARLTON 2005-01-3628 “Developing Diesel Engines to Meet Ultra-low Emission Standards”
2006	MATTHEW BAUS, ANTHONY COOK, and DAVID SCHALLER 2006-01-3545 “Integrating New Emissions Engines into Commercial Vehicles: Emissions, Performance & Affordability”
2007	DEBORAH FREUND 2007-01-4298 “Foundations of Commercial Vehicle Safety: Laws, Regulations and Standards”
2008	PETER L. GODDARD 2008-01-2680 “System Safety Applied to Vehicle Design”
2009	ALI F. MALEKI 2009-01-2924 “Embedded Software Engineering in Automotive and Truck Electronics”
2010	MARK P. ZACHOS 2010-01-2053 “Merge Ahead: Integrating Heavy-Duty Vehicle Networks with Wide Area Network Services”

PAST LECTURES (CONTINUED)

2011	RICHARD JOSEPH HANOWSKI 2011-01-2305 “The Naturalistic Study of Distracted Driving: Moving from Research to Practice”
2012	DANIEL EUGENE WILLIAMS SP-2337 “Multi-Axle Vehicle Dynamics”
2013	DONALD WAYNE STANTON 2013-01-2421 “Systematic Development of Highly Efficient and Clean Engines to Meet Future Commercial Vehicle GHG Regulations”
2014	MEHDI AHMADIAN 2014-01-2408 “Integrating
2015	RICHARD WOOD 2015-01-2859 “Reynolds Number Impact on Commercial Vehicle Aerodynamics and Performance”
2016	RICHARD R. MIHELIC 2016-01-8020 “Fuel and Freight Efficiency Past, Present and Future Perspectives”
2017	DR. RAIMUND VARNHAGEN 2017-01-1945 “Electronic Horizon: A Map as a Sensor and Predictive Control”
2018	KIRK T. STEUDLE, P.E. & Niles Annelin 2018-01-2011 “Transformational Technologies Reshaping Transportation, a Government Perspective”
2019	GIORGIO RIZZONI 2019-01-2620 “Transformational Technologies Reshaping Transportation, an Academia Perspective”