Automated Electric Transportation

Transforming America's Transportation Future

Oak Ridge National Laboratory

Utah State University

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California Energy Commission

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Automated Electric Transportation:

Transforming America's Transportation Future

This paper describes a bold, new approach to transform transportation in America that integrates energy, vehicle, highway, and communication infrastructures into a flexible, convenient, and Automated Electric Transportation (AET) system. AET has the unique potential to simultaneously and dramatically reduce petroleum use, carbon emissions, air pollution, traffic congestion, and highway crashes in America while creating millions of new jobs. It could save the U.S. economy trillions of dollars over the next few decades and enable GDP growth rivaling the economic value derived from constructing the Interstate Highway System. The first step in realizing this potential is a coordinated, national effort leading to a comprehensive technology and deployment roadmap.

1. Introduction

America's economy and quality of life depend heavily on energy and transportation systems that are functioning well. The two tightly-coupled systems work together to connect people to jobs, family, medical care, education, entertainment, and the goods needed for everyday life. Some estimates are that construction of the Interstate Highway System led to an estimated quarter of the productivity gains realized in America over the last four decades.[1]

Unfortunately, our continued prosperity is endangered by highway use and energy demand that are now exceeding capacity and draining the American economy by over $1 trillion annually.[2]

Vehicles traveling on our nation's roadways are fueled almost exclusively by liquid petroleum. This makes the U.S overly dependent on foreign sources of energy and transfers billions of American dollars to other nations each day. Our 230 million autos, trucks and buses account for more than half of the daily petroleum consumption in the U.S. and are responsible for 45% of the world's vehicular CO_2 production (one-third of U.S. total CO_2 emissions).[3]

However, energy and greenhouse gas emissions aren't the only problems we face in road travel. Traffic congestion continues to worsen, robbing American citizens and businesses of tens of billions of dollars in productive time each year. The average commuter spends the equivalent of a 40 hour work week each year sitting in traffic.[4] The present system also contributes to a variety of environmental problems, especially in those areas that fail to meet federal clean air standards, home to over half of the U.S. population. On American highways over 40,000 people are killed each year and our roadway infrastructure is deteriorating faster than we can maintain it.[5]

These statistics show the need to fundamentally rethink the basic premises and paradigms of the mobility choices we make. To pose deeper questions: must vehicles be self-propelled-powered solely by energy stored on board? Is it possible to remove humans from the tasks of vehicle navigation and control?

By challenging conventional wisdoms, it may be possible to "leapfrog" existing innovation pathways that provide only incremental improvements in favor of a bold, new mobility pathway that employs disruptive technologies.

These pathways would integrate vehicle, energy and highway infrastructures at a time when our nation's transportation infrastructure is in need of an extensive overhaul.

Though electricity is finding increasing use in vehicle travel, it's unlikely that a transition to electricity will occur until the electric grid's unique ability to move energy quickly and inexpensively to where it's needed is realized. This suggests that electrification will someday extend beyond delivering energy to the on-board batteries of stationary vehicles and include technologies that deliver energy on demand and in real time to moving vehicles. Unlike today's transportation system—fueled almost exclusively by oil—one based on electricity would enable robust competition between several primary fuel sources such as solar, wind, clean coal, nuclear, and natural gas.

Recent research results on wireless energy transfer using a phenomenon known as "wireless resonance coupling" at the U.S. Department of Energy's Oak Ridge National Laboratory suggest that infrastructure upgrades to electrify highway networks may be possible without the need for the overhead wires or "third rails" of old. Coupling advances like this with recent developments in grid technologies, power electronics, wireless communication, on-board computing, and new sensor and control technologies. America is poised for a paradigm shift and radical redesign of vehicle travel: a new era of Automated Electric Transportation. If history repeats itself, AET represents the catalyst for productivity gains rivaling those seen with the construction of the Interstate Highway System.

If this paradigm shift is to occur, however, the United States must channel its research and industrial prowess towards game-changing solutions that simultaneously address energy security, environmental, and mobility challenges. As new AET technologies are developed and deployed, U.S. automakers, energy and infrastructure providers, engineering firms, and others will create new jobs, stimulate the economy, and sell American innovations to emerging economic giants like China to help reduce their energy use and CO_2 emissions.

AET Vision *We envision a systematic transition to a national automated electric transportation system that dramatically improves America's mobility and energy security. The system will: a) provide energy directly to vehicles from electric highways—dramatically reducing their use of petroleum and the emission of CO_2, and b) automate control of the vehicles while on the highways, reducing congestion, improving safety, freeing the driver's time, and providing new in-vehicle services. The system will extend, not replace, our current highway system—vehicles capable of traveling on electric highways will also be able to drive as conventional vehicles on conventional roadways.*

2. The New Path Forward

At the present time, there is no uniform vision for the future of our roadway transportation system. The different federal agencies that set policy and manage research have not considered the problem from a holistic perspective. The U.S. Department of Energy and U.S. Department of Transportation have initiatives which address the improvement of passenger and heavy vehicles, development of alternative fuels and new on-board energy storage techniques, vehicle-infrastructure integration, congestion pricing, and improvement of overall infrastructure. Fundamentally, these initiatives do not alter the century-old paradigm that this initiative seeks to change.

However, many of the building blocks of AET are natural outgrowths of existing federal programs, which could be unified by such an initiative.

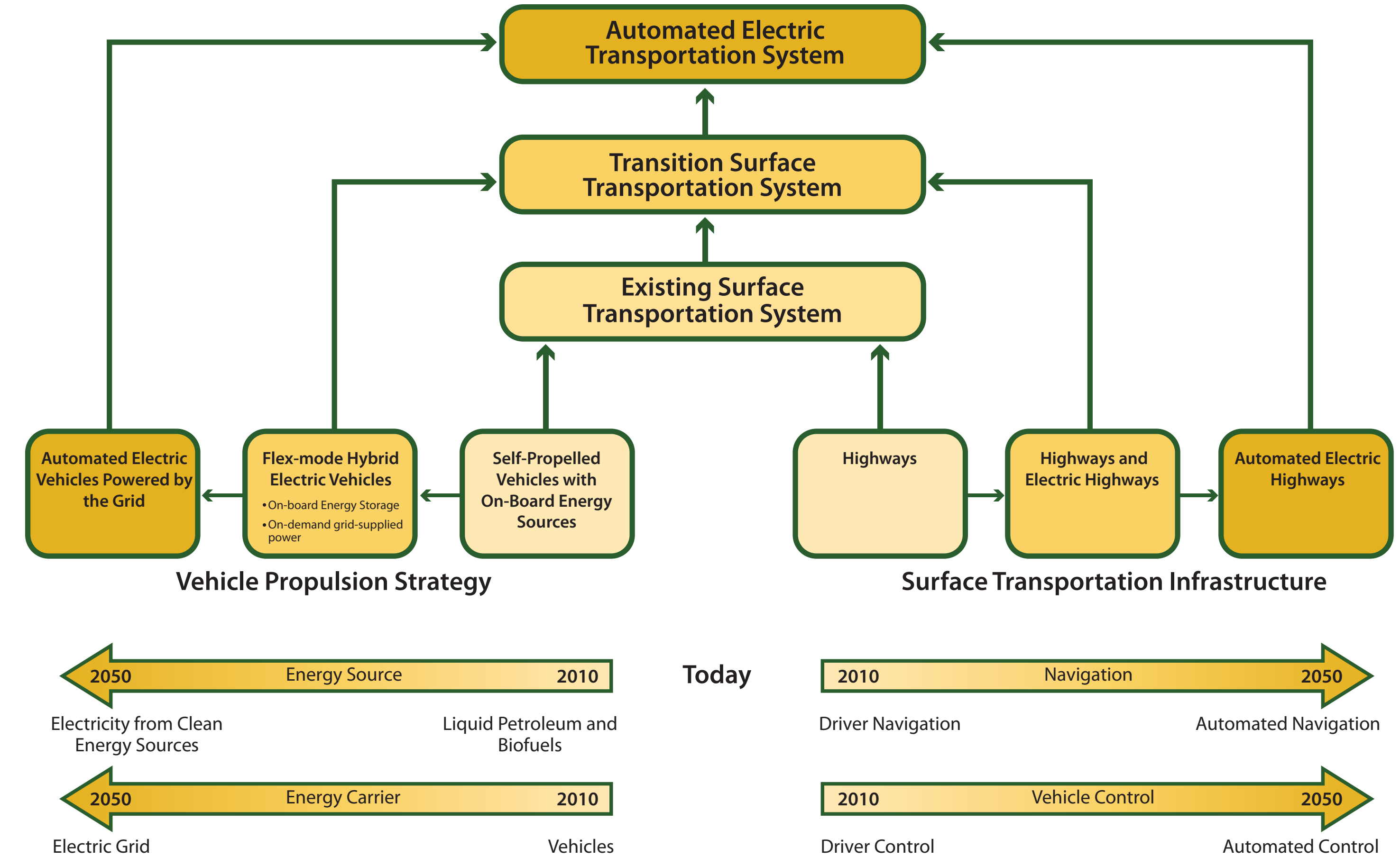
As the use of our roadways has increased in intensity, the basic mechanics of the system have remained unchanged. AET challenges what we consider the basic fundamental "certainties" of our roadway systems today and provides a vision to develop alternative options offering step-function improvements in mobility and energy security. But at the same time, AET is a natural outgrowth and next step beyond the Vehicle Infrastructure Integration (VII), plug-in HEV, and hydrogen-powered vehicle initiatives of today. The envisioned new infrastructure will leverage these investments—first supplementing, then dramatically expanding, the intelligent transportation system and vehicle electrification capabilities being developed today.

Using a network of intelligent electric highways and hybrid electric vehicles energized by those highways—either directly or wirelessly—the systematic transition to domestic fuels and automation afforded by electrification becomes a feasible way of addressing our primary transportation challenges.

The reality of our vision will be vehicles running more efficiently with increased throughput—reducing the need for roadway expansion and easing the funding shortfall needed to maintain roads. As the system matures and roadway infrastructure is rebuilt, a portion of the electric grid will be merged with highway infrastructure. Furthermore, the transition of operator-controlled vehicles to a system that takes the human element out of the control and navigation loop will allow for increased mobility, improvements in driver comfort and safety, reduction of operator stress, and reduced travel times for both intra- and inter-city travel.

As AET develops, we anticipate a transition period beginning with niche applications such as the movement of high-value freight and military equipment being readied for airlift operations.

Possible Transition Path to Automated Electric Transportation



The new network will enable suitably equipped vehicles to operate under automated control, relieving drivers of lower-level driving chores or eliminating the drivers altogether and making it possible to accommodate higher density traffic with improved traffic flow and efficiency. It will include the internal combustion engine and hybrid electric vehicles (HEVs) of today, new "flex-mode" HEVs, and eventually all electric vehicles, as shown above. The flex-mode HEVs will be different from hybrids of today—powered by on-board fuels over traditional roads and by the electric grid on new electric highways.

3. Challenges

Significant technical, financial, institutional, and political risks are inherent in a disruptive technological revolution like AET. But the societal benefits—reducing carbon emissions, air pollution, traffic congestion, crashes, and our dependence on foreign oil—are all monumental and worth the risk.

Safe and efficient transfer of energy from roadway to vehicles represents a fundamental challenge, but there are a number of strategies to achieve energy transfer through direct, inductive, and or resonance coupling architectures. Acceptable coupling efficiency must be demonstrated and failure of power transfer mechanisms must not have catastrophic consequences. New power electronics must be developed depending upon whether continuous or intermittent charging is used, and the design of transmitting and receiving devices must minimize human exposure to electromagnetic radiation. Energy production and delivery for AET will be through infrastructure that does not exist today, though the intelligent grid being developed by electric utilities can be expanded to ensure a robust and flexible energy delivery system. AET will also require the development of sophisticated software to perform safety-critical functions on road vehicles operating under a wide range of complicated operating conditions.

In addition to technical challenges, architectural level change, especially for networked systems, is much more difficult than individual product or process changes. It requires complementary elements to move together toward the new vision when they are locked in status quo equilibrium. The speed at which the new shared infrastructure is built will control end-use technology adoption and the rate at which energy, economic and mobility benefits are realized. Previous attempts of systems-level change in the transportation sector have failed in part because of an inability to provide backwards compatibility to previous systems. Thus, one of the key challenges will be to develop ways to ensure a smooth transition from the current system to an automated electrified transportation system.

A shift to a new equilibrium can occur either synchronously or in stages. A new network alternative can be established by coordinating the incentives for innovators, distributors, and users. Alternatively, the current network can be gradually co-opted through various strategies such as targeting niche, underserved, segments. The network must also introduce a "new", "faster", "improved" complement to the status quo, or one or more hub stakeholders in the network must leverage their influence to enable the shift. Recognizing that the introduction of a new transportation network is an equilibrium shift will be important.

Our Mission *is to develop, demonstrate and deploy within a generation, approaches to merge vehicle, highway, energy, and communications infrastructures into an integrated, flexible, convenient, and increasingly-automated electric transportation system fueled by clean, domestic sources of energy.*

A fundamental change to large, capital-intensive systems cannot be accomplished within the typical two or four year election cycle.

Thus, one major challenge will be to educate political and industrial decision makers on the long term value of this initiative so they will provide the necessary lasting support and advocacy.

Development of AET will come with a host of new institutional challenges. For example, liability for crashes is currently managed through automotive insurance, paid for by the drivers who are ultimately responsible for virtually all crashes. Because of AET's greater reliance on infrastructure and vehicle components, it has yet to be determined where responsibility for crashes will reside, though the total liability cost should be less. Likewise, infrastructure upgrades are currently financed via taxes derived from the purchase of gasoline. AET will accelerate efforts to overhaul transportation financing structures currently being debated in conjunction with the upcoming transportation reauthorization bill.

These interdependent challenges must first be addressed through foundational R&D and a technology and deployment roadmap developed by a wide variety of public and private stakeholders. If successful, AET has the potential to be more technically feasible, address more interdependent transportation challenges, and do so less expensively than the compilation of pathways being pursued by different federal agencies working separately within the current transportation paradigm.

4. The Next Step: An AET Roadmap

AET has the potential to become a 21st century equivalent of President Eisenhower's Interstate Highway System and provide a national initiative similar to President Kennedy's Apollo Program. Unfortunately, there is no one entity within the federal government where an interdisciplinary undertaking of such complexity and with so many infrastructure interdependencies naturally resides. Public and private stakeholders representing a wide range of interest groups vested in the existing transportation system must first be convinced to set aside institutional interests in the status quo and deeply entrenched policies and programs based on an increasingly-outdated technical, financial, and institutional business model. For these reasons, a coordinated, national effort involving representation from several federal and state agencies, non-governmental organizations, industry associations, and private industry is imperative.

An obvious place to start developing the AET framework is in the university, national laboratory, and industry research communities where new, high-risk, high-payoff ideas—even those that represent system-level change—can be vetted and evaluated.

The natural first step in the process is the development of an interdisciplinary AET technology and deployment roadmap.

The roadmap must include critical system requirements, top-level research, development, demonstration, and deployment (RDD&D) goals, major barriers and pathways to overcome them, resource needs, and a timeline to deployment.

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