# Life in the Fast Lane:
## Evolving Paradigms for Mobility and Transportation Systems of the Future

26-27 October 2016

**IEA Experts' Group on R&D Priority Setting and Evaluation**
**Washington, DC**

# International Energy Agency

The International Energy Agency (IEA), an autonomous agency, was established in November 1974. Its mandate is two-fold: to promote energy security among its member countries through collective response to physical disruptions in oil supply and to advise member countries on sound energy policy. The IEA carries out a comprehensive program of energy cooperation among 28 advanced economies,[1] each of which is obliged to hold oil stocks equivalent to 90 days of its net imports.

The Agency aims to:

- Secure member countries' access to reliable and ample supplies of all forms of energy—in particular, through maintaining effective emergency response capabilities in case of oil supply disruptions.
- Promote sustainable energy policies that spur economic growth and environmental protection in a global context, particularly in terms of reducing greenhouse gas emissions that contribute to climate change mitigation.
- Improve transparency of international markets through collection and analysis of energy data.
- Support global collaboration on energy technology to secure future energy supplies and mitigate their environmental impact, including through improved energy efficiency and development and deployment of low-carbon technologies.
- Find solutions to global energy challenges through engagement and dialogue with non-member countries, industry, international organizations, and other stakeholders.

## IEA Experts' Group on R&D Priority Setting and Evaluation Research (EGRD)

Research, development and deployment of innovative technologies is crucial to meeting future energy challenges. The capacity of countries to apply sound tools in developing effective national research and development (R&D) strategies and programs is becoming increasingly important. The EGRD was established by the IEA Committee on Energy Research and Technology (CERT) to promote development and refinement of analytical approaches to energy technology analysis, R&D priority setting, and assessment of benefits from R&D activities.

Senior industry and policy experts engaged in national and international R&D efforts collaborate on topical issues through international workshops, information exchange, networking, and outreach. Nineteen countries and the European Commission participate in the current program of work. The results and recommendations provide a global perspective on national R&D efforts that aim to support the CERT and feed into analysis of the IEA Secretariat. For further information, see http://www.iea.org/aboutus/standinggroupsandcommittees/cert/egrd. For information specific to this workshop, including agenda, scope, and presentations, see http://www.iea.org/workshops/egrd-evolving-paradigms-for-mobility-and-transportation-systems-of-the-future.html.

This document reflects key points that emerged from the discussions held at the October 2016 EGRD workshop. The views expressed in this report do not represent those of the IEA or IEA policy, nor do they represent consensus among the discussants.

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[1] Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, Republic of Korea, Luxembourg, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, Turkey, United Kingdom, and United States; the European Commission also participates in the work of the IEA.

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# Executive Summary

The International Energy Agency's (IEA's) Experts Group on R&D Priority Setting (EGRD) held a workshop titled *Life in the Fast Lane: Evolving Paradigms for Mobility and Transportation Systems of the Future* to help decision makers determine research, development, and deployment (RD&D) priorities and policy needs in support of low carbon, transformative transportation systems.  The U.S. Department of Energy (DOE) hosted the workshop 26–27 October 2016 in Washington, DC. The workshop sought to identify novel approaches and RD&D needs, gaps, and opportunities that could accelerate innovation and facilitate market uptake and transformation. Participating technology experts from research entities, academia, and leading agencies across the world offered a wide range of perspectives and insights.

## The Transportation Landscape

Advanced technologies and changing business models are transforming the transportation industry. Societal megatrends such as increased automation, greater connectivity, growing electrification, and evolving societal preferences are critical drivers of this change. Collectively, these factors have significant implications for policymakers and impact the energy consumption, safety, security, and equity of a society. Several scenarios emerge which present challenges and opportunities. Governments have the opportunity to shape these scenarios by framing decisions and policies to help deliver significant, cost-effective reductions in greenhouse gas (GHG) emissions.  Policymakers need to consider both logistical (reliable, accessible, and time-efficient) and energy efficient mobility.

Transportation use and urbanization are projected to continue to increase over the next few decades. To limit worldwide global warming to well below 2°C (as agreed by more than 190 countries at the Paris Agreement), transport emissions need to peak and decline within the next ten years, according to the IEA's *Energy Technology Perspectives (2016)*. This will entail decoupling transportation activity from GHG emissions. Successfully transitioning to a low-carbon pathway will require a clearer understanding of these megatrends and the critical linkages between advanced technologies, human behaviour, and energy usage.

Existing efforts and programs are working to adapt their approaches to this rapidly changing landscape. Governments are adopting a more holistic view of the vehicular industry that looks beyond independent and discrete efficient vehicle technologies to explore untapped transportation system-level efficiencies (Figure E-1). New approaches are being adopted: governments, research institutes, and others are shifting away from a prescriptive approach and undertaking a prototyping approach instead, testing and analysing the results, and considering new deployment scenarios that focus on passenger miles travelled instead of vehicles.

**Figure E-1. U.S. DOE's five key pillars of transportation-as-a-system.**

## Trends Shaping Future Transportation Systems Worldwide

Advanced technologies in development can transform the future of transportation services and significantly reduce GHG and criteria emissions of future transportation systems, and can have implications for transportation demand. However, developing an advanced technology, like autonomous vehicles, does not necessarily translate into its adoption; consumer behaviour remains a critical factor. Delivering GHG reductions and increasing efficiency requires strong economic incentives for consumers and industry. Consideration of the unique economy, demography, and societal preferences of a particular region is critical for successful implementation of incentives or other policies. Economic models focused on understanding consumer behaviour can help policymakers develop more effective policies.

Different countries and regions have effectively deployed a variety of solutions to reduce GHG and criteria emissions of future transportation systems. Norway, which currently has the largest battery electric vehicle (EV) market share in the world, uses a strong tax structure to incentivize GHG emissions reductions. Norway assesses potential and existing policies in part based on a behavioural discrete choice model for automobile purchase coupled with a dynamic stock-flow model predicting how fiscal and regulatory changes might affect GHG emissions. Germany's National Innovation Program on Hydrogen and Fuel Cell Technologies, a program jointly undertaken by several ministries, focuses on RD&D of hydrogen and fuel cell technology and has had a number of accomplishments to date. The European Union has adopted several strategies to promote the use of alternative fuels for transport, including the adoption of union-wide standards for EV charging and the development of several financing mechanisms for funding research and development (R&D) in this space. In the U.S., California's Zero Emission Vehicle (ZEV) Mandate has been a successful driver for EV adoption by creating a market-based trading system for ZEV credits, which incentivises the private sector to develop and sell greater volumes of ZEVs. The private sector also serves a crucial role in advancing innovative vehicle technologies. Programs such as DOE's SuperTruck—which aimed to make drastic improvements in truck efficiency—are testament to the value of private sector participation. The SuperTruck program invited collaboration among government and industry and has provided a

springboard for more advanced fuel-saving technology commercialization. Large original equipment manufacturers (OEMs), like General Motors and Toyota, are also independently developing solutions, such as General Motors' Super Cruise feature that will debut in a Cadillac CT6.

## Barriers and Solutions

A number of social and technological trends have widened the scope of sustainable transportation R&D. The interconnected nature of an ACES (Automated, Connected, Electrified, Shared) transportation system that receives inputs from several complex linear and non-linear interactions makes it critical for OEMs and policy makers to have a better understanding of these interactions. Vehicles and their respective travellers are no longer the only factor in the equation; researchers and policymakers must now include the entire transportation system along with a built environment to support it. For example, in the U.S., the National Renewable Energy Laboratory (NREL) has adopted a holistic approach to sustainable transportation, viewing it at four discrete levels: traveller, vehicle, transport system, and built environment—rather than just as vehicles and roads (Figure E-2).
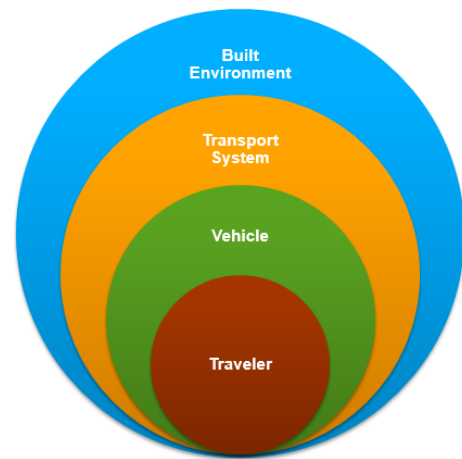


Figure E-2. Visualization of NREL's holistic approach to sustainable transportation research.

One factor inhibiting change is a lack of accurate data and models, specifically regarding consumer decision making and behaviour. Because of rapidly changing social and mobility trends, past predictions of automotive industry change have generally been inaccurate, and complexities inherent to the connected and autonomous vehicle (CAV) adoption timeline indicate that, in the absence of improved data and models, accurate predictions will remain the exception rather than the rule. Analysis of consumer decision making is becoming more complex as consumers face new decisions that do not mirror historical trends. This increased complexity is partially due to advanced technologies and shifting modal trends (e.g., increased use of ride-sharing like Uber, teleworking) that present more efficient and convenient options to consumers. Harnessing future mobility trends requires a better understanding of consumer choice and, therefore, improved methods for customer choice modelling. Furthermore, current modelling of the energy impacts of an ACES transportation system exhibit high levels of uncertainty due to the lack of accurate consumer predictability. Developing models that more accurately predict the energy impacts of these technologies could facilitate development of policies and products that support the shift to a low carbon transportation system.

Many barriers are technical in nature, especially regarding the future of CAVs. Fully autonomous systems must be able to handle a wide variety of inputs, and operation must be unhindered in all environmental conditions and traffic conditions. Current positioning localization, and sensing and perception systems are not yet capable of handling all driving domains; however, the pace of development of advanced technologies continues to accelerate. Numerous fully commercialized technologies exist that can be utilized and ultimately lead to achieving full-scale CAV deployment.

To respond to the rapid pace of technology advancements, many research efforts have adopted new approaches to respond in real time. For example, Finland's capital city Helsinki serves as a "living lab" that enables a large number of pilots, tests, and demonstrations of smart systems and services. In the U.S., a Smart City Challenge award was won by Columbus, Ohio, which aims to be a model city that plans to fully integrate innovative technologies – connected and automated vehicles, smart sensors – into their transportation network, foster open data standards for analysis, and draw on best practices for future technology deployments. Empirical testing data is not readily available for CAV technology, so industry and governments are utilizing different techniques to advance both the technology itself, as well as the policies to regulate its use.

## Supporting Future Transportation Systems

As technology and social trends continue to evolve, policymakers will need to identify the best policy levers—price-based, regulatory, and RD&D—to drive deep decarbonisation. This will require new metrics, increased collaboration, new business models, and consideration of future trends and drivers.

Understanding consumer adoption and behaviour towards new technology and mobility services is important to developing policy and markets that will encourage low-carbon transportation systems. Researchers are working on consumer studies that will help legislators make evidence-based CAV policy decisions. Because the technology is new, unfamiliar, and not available to consumers, there is a need to develop new metrics (e.g., intent to use or consumer acceptance) and interview methodologies to provide valuable data to regulators on consumer perception and behaviour. Surveys by the Texas A&M Transportation Institute revealed that people who would not use a self-driving car if available cited a lack of trust in the technology as the primary reason, followed by safety and cost. These results demonstrate the types of barriers that future policies and incentives will need to account for, although more data is needed to provide quantitative policy guidance.

Collaboration between governments and industry will be essential to ensure effective RD&D and policy decisions. Governments can learn from each other's experience by looking to EV market leaders such as Norway, the Netherlands, and California for regulatory guidance. For example, China's 2014 EV mandate, which was based on California's zero-emission EV mandate structure, has caused the largest increase in EV sales to date. In addition, Netherlands has invested in the deployment of connected and cooperative driving, platooning, and automated passenger vehicles, and like Finland, aims to be a "living lab" test bed for these new technologies. The results from these research efforts will provide critical knowledge that can benefit countries around the world.

As technology and social trends continue to evolve, standard automotive business models will need to change. There is currently little to no financial incentive for vehicle OEMs to improve fuel efficiency outside of regulation. A step change in energy efficiency is needed, but to do so, energy efficiency must become a profitable part of a working business model.

Policies also need to consider the changes that will accompany increased automation; the mobility field will look drastically different going forward. If CAVs become a dominant transportation form, there could be an increase in overall vehicle miles travelled, resulting in more congestion. Next generation urban transport systems may be massively networked, dynamically priced, user-centred,

integrated, and fully reliant on new models of private–public collaboration. Understanding this potential future is critical for developing efficient and effective solutions.

## Conclusion

The policy decisions made today will shape the future of the transportation industry. Creating a low-carbon future will require policymakers to understand the potential energy implications of new technologies and the key interactions between consumer behaviour and decision making. As business models and consumer preferences shift, mobility will need to be examined from different perspectives and measured against different metrics. Policymakers need to assess the industry at a system-level vantage point, rather than as individual and separate vehicular entities.

RD&D in several areas will serve a critical role in unravelling the complexities of this emerging landscape. Research is needed to develop technical solutions, including batteries with larger storage capacities and enhanced sensing and perception systems, and ensuring that the system is secure. However, many barriers are psychological and legal rather than technological, necessitating research that examines customer decision making and behaviour towards new technology.

Policies and regulatory frameworks must allow room for creativity and innovation, and these policies need to be designed such that they avoid lock-in of technologies. Innovative policies grounded in an understanding of consumer behaviour are needed to accelerate the deployment of new, low-carbon technologies. Governments will be critical in providing the right incentives and policies to nudge the behaviour of both consumers and industry to deliver the safe, secure, and low-carbon outcomes.

# Background

To reach the Paris Agreement goal of limiting global warming to well below 2°C (the 2-degree scenario, or 2DS), significant emission reductions from the transportation sector—which accounts for about 28% of global energy consumption—are required. While yielding such reductions could be challenging, the convergence of a number of societal megatrends—together with improving vehicle and fuel technology and the pervasive expansion of information infrastructure—represents an opportunity to transform the transportation sector and reduce greenhouse gas (GHG) emissions.

Many technology advancements will contribute to this transformation, such as improved and higher efficiency automotive powertrains, sustainable and low-carbon alternative fuels, and lightweight materials. However, these advancements alone are unlikely to achieve the GHG reductions required by 2050.

Societal megatrends are important drivers of transport energy use and emissions. These trends include shifting societal preferences, geospatial changes in work activity, widespread adoption of smart devices and social media, and greater connectivity and convergence across sectors. Other drivers include rapid advancements in information technology and infrastructure and affordable low-carbon energy technologies. Collectively, these factors offer potential for a radical transformation to a future with a variety of new mobility systems.[2]

It may be possible to harness these megatrends to deliver cost-effective and major reductions in GHG emissions. Some illustrative examples follow.

**Shifts in societal preferences**, such as increased car- and ride-sharing, can lead to higher rates of asset utilization, which may boost the adoption of fuel-saving technologies and compact, efficient vehicles as owners place greater focus on lowering operating costs. Car-sharing can also benefit the built infrastructure; the reduced need for parking lots could provide space for alternative modes and enable greater building density. Policies and shifts in cultural preferences and priorities are promoting more efficient transport modes. These shifts also have potential downsides. Car- and ride-sharing services may be parasitic on public transport and may lead to more driving in aggregate, thereby increasing fuel use and congestion. These sharing services (as well as vehicle automation) may also make it more convenient to live further away from the city centre—and thus promote further sprawl.

**Information and communication technologies (ICT) integration** uses electronic control modules and sensors that enable vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications. These technologies enable adaptive vehicle control and improve driving performance to optimize energy efficiency. ICT can also guide electric vehicles (EVs) to charging stations and may provide a robust means to coordinate energy flows among energy storage devices, power electronics, and the power grid. ICT connecting equipment (e.g., sensors, global positioning devices, mobile phones) has the potential to improve system efficiency via monitoring real-time conditions to optimize route planning and freight logistics. A V2V network could dramatically reduce the severity and frequency of

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[2] Source: U.S. Department of Energy workshop *Overview: Future of Mobility Workshop Series: Forward-Looking, Flexible Transportation Policy*, held July 12–13, 2016.

traffic jams. There are, however, some potential risks to ICT. V2V and V2I systems must be secure to protect data and prevent system hacking. In addition, codes and standards are needed to ensure interoperability between devices and manufacturers and across national boundaries.

**Electrification of road transportation** is gaining momentum. In recent years, annual sales of a wide range of EVs have begun to grow dramatically. Electrification can bring about emissions reductions by displacing oil with renewable energy. Still, there are several unknowns regarding EVs, such as how quickly electrification can occur and how EVs will affect power grids.

**Automated and autonomous road transport** (e.g., connected and autonomous vehicles [CAVs]) has the potential to enable computer-optimized driving that could improve energy efficiency. Such networks might use V2V and V2I communications to improve the capacity of roadways and system efficiency. On an automated highway system, for example, the distance between vehicles can be safely shortened to decrease aerodynamic drag and reduce traffic congestion by increasing lane throughput. However, the convenience and reduced congestion created by vehicle autonomy might increase overall demand for travel.

Trends toward low-carbon mobility can also give rise to other local benefits, such as improved air quality, increased safety, and reduced transport-related noise. These benefits may translate into increased economic productivity and broader social benefits.

Such sweeping changes in technology and society's approach to mobility have implications for transport policy and national investments in associated research, development, and demonstration (RD&D). Developing a clearer understanding of these changes will help policy makers, businesses, and individuals make smarter long-term investments in programs, technologies, and infrastructure.

## The Workshop

The International Energy Agency's (IEA's) Experts Group on R&D Priority Setting (EGRD) held a workshop 26–27 October 2016 in Washington, DC, hosted by the U.S. Department of Energy. The workshop focused on the evolving paradigms for future mobility and transportation systems and gathered input from a wide range of actors, sectors, and regions. Key speakers were from leading agencies, research entities, and academia. The workshop's goal was to identify novel approaches and RD&D needs, gaps, and opportunities that could accelerate innovation and facilitate market uptake and transformation. Participants discussed potential barriers and strategies to address them.

## Key Questions

Questions that were considered by the participating technology experts include the following:

On technology:
- What key trends in the transportation sector are driving technology breakthroughs?
- What technologies must be further developed to address freight movement and aviation?
- What are the potential impacts of electrification of transportation for passenger vehicles and, potentially, the road freight and the maritime sector?
- How can ICT in vehicle technology help enable efficiency improvements?

On modal shift:
- What positive lessons can we take from developments such as Uber and increased ICT technology, and what risks do we see?
- How will new ride-sharing business models or the adoption of CAVs affect the overall size and utilization rate of the car fleet, and what will be the impacts on the supply chain?
- What transportation network issues do urban planners and policy makers need to address to ensure competitiveness of low-carbon technologies and practices?
- Which policies or frameworks have proven to be effective in reducing transport demand?
- Are there country- or region-specific advantages to adopting particular transport systems or technologies?

On modelling/planning:
- What are key challenges to decarbonizing the transport sector to well below the 2DS?
- What can be learned from behavior programs aimed at mobility?
- What is the role of congestion charging, ultra-low emission zones, and other fiscal and regulatory travel demand management policies in planning and modelling?
- How can shared mobility contribute to significant GHG reductions?

On policy measures:
- Which potential future transport paradigm has the greatest potential and the least number of barriers to implementation (e.g., financial, policy, or RD&D)?
- What actions are needed to achieve further efficiency gains? Who is primarily responsible (e.g., manufacturers, entrepreneurs, or policy makers)?
- Which financing mechanisms have proven to be successful for new transport programs?

In addition to EGRD national experts, the workshop attracted RD&D decision makers, strategic planners, and program managers from industry, academia, think tanks, national laboratories, and government.

## Report Structure

This report summarizes the results of the workshop, as follows:
- The first section provides background and context of a highly connected, automated, and electrified transportation industry.
- The second section explores the emerging trends, shifting mobility paradigms, and new technologies that can transform the future of transportation demand and services, and significantly reduce GHG emissions of future transportation systems in different regions/countries and worldwide.
- The third section discusses the factors inhibiting new technology and significant changes in mobility, as well as possible solutions for overcoming the barriers.
- The fourth section discusses the necessary policies and markets to support future transportation systems.
- A final discussion and takeaways section follows the session summaries.

Appendices to the report provide a list of acronyms, workshop participants, additional source information, and the workshop agenda.

Presentations are available at http://www.iea.org/workshops/egrd-evolving-paradigms-for-mobility-and-transportation-systems-of-the-future.html.

# Session Summaries

## Session 1. Introduction

Chair: Robert Marlay, EGRD Vice-Chair, U.S. Department of Energy, United States

### 1.1    Overview

The transportation industry is undergoing transformational changes driven by increased automation, greater connectivity, growing electrification, and evolving societal preferences. Advanced vehicle technologies coupled with convenient and accessible mobility services are reshaping conventional business models, delivering change at a rapid pace.

Furthermore, projected growth in urbanization and increased transportation use, especially in developing countries, can have significant implications for energy use and GHG emissions. Transport emissions need to peak and decline within the next ten years in order to limit worldwide global warming well below 2°C. Decisive and effective policies are needed to spearhead the scale of global clean energy deployment required to meet the 2°C target. Switching to a low-carbon pathway will involve a coherent portfolio of policies and instruments, ranging from supra-national and national policies to local policies, including those in the transportation sector.

Our shared climate and energy goals, as agreed to by countries at the 2015 UN Climate Conference in Paris, raise tough policy and technology questions for the transportation sector, while simultaneously presenting opportunities. Understanding and utilizing critical linkages between advanced technologies, human behaviour, and energy consumption will be necessary to make the transportation industry more efficient, safe, and equitable. Rather than examining technologies individually, a more holistic view of the transportation industry should be taken. Increased connectivity and automation is leading to a complex decision making environment with interactions between manufacturers, consumers, energy and charging infrastructure, and cities/regions. Research and development (R&D) focused on understanding the impacts of this dynamic transportation landscape can help in better decision making. Concrete research results will deliver clarity to help facilitate policymaking. To ensure that the international community meets its energy and economic goals, energy use and economic value creation should be a centrepiece of these research efforts.

Very few existing regulatory frameworks address the rapid challenges faced by the transportation industry. Rather than predicting the future, research will need to shape the future and support development of sound policy options for decision making. To avoid playing catch-up and ensure that adequate policies and frameworks guide these changes, new approaches such as prototyping will need to be adopted. Consumer decision making will need to be better understood to help nudge policies and measures that promote the desired outcome.

## 1.2  Introduction and Meeting Objectives

Rob Kool, EGRD Chair, RVO.nl, Netherlands

➢ Link to presentation slides:
https://www.iea.org/media/workshops/2016/egrdtransportsystemsofthefuture/0IntroEGRDKoolokt16.pdf

IEA's EGRD is a part of the IEA Technology Network. The group organizes two workshops every year on relevant R&D topic areas. EGRD focuses its program of work on analytical approaches to energy technologies, policies, and R&D. EGRD recommendations support the Committee on Energy Research and Technology (CERT) and the Technology Collaboration Programme (TCP) network by informing IEA analysis, enabling a broad perspective of energy technology issues. The recommendations contribute to supporting the methodology of priority-setting and evaluation, assist in creating collaborative opportunities between IEA and practitioners, and explore topic areas in a cross-cutting manner that helps identify solutions faster and determine blind spots.

IEA's World Energy Outlook (2014) highlights energy efficiency's critical contribution to energy savings, with global efficiency savings in 2040 amounting to almost three-quarters of the European Union's (EU's) current energy demand.  IEA labelled energy efficiency as "the first fuel", and a focused IEA workshop on one of the major energy end-use sectors (i.e., transportation) is both timely and necessary.

The potential energy savings achieved by addressing this "first fuel" will be facilitated by several megatrends in the coming decades, such as changing societal preferences, ICT integration, electrification of road transportation, and automated and autonomous road transportation. The aim of this workshop is to examine, in a holistic manner, the R&D issues related to technology, modal shift, modelling/planning, and policy measures.

## 1.3  Key Note: Energy Efficient Mobility Systems (EEMS)

Reuben Sarkar, Deputy Assistant Secretary for Transportation, U.S. Department of Energy, United States

➢ Link to presentation slides:
https://www.iea.org/media/workshops/2016/egrdtransportsystemsofthefuture/1ReubenSarker.pdf

As advanced technologies and changing business models transform the transportation industry, several potential future scenarios can be envisioned. External trends driving these changes include increased congestion with demand explosion at large scale, automated driving, connectivity, E-mobility on demand, urbanization, and data collection and computation. Several policy and technology questions need to be addressed. For example, there should be an exploration of the intersections between transportation, small entrepreneurial juggernauts, and large original equipment manufacturers (OEMs), and the opportunities that these create; how to leverage future technologies to enable further GHG reductions; the intersections of safety, energy, and mobility, and the opportunities they create; and ways to make the system better for advanced vehicles using better consumer decisions, fuels, etc. Transportation experts at the U.S. Department of Energy (DOE) have been focused on unravelling these tough questions and shaping the dialogue such that energy and economic value creation remain the focus of this rapidly changing industry.

**Figure 1. U.S. DOE's five key pillars of transportation-as-a-system.**

Historically, DOE's Office of Energy Efficiency and Renewable Energy (EERE) has focused its work on independent and discrete efficient vehicle technologies. In acknowledgment of this changing landscape, and the increasing degree of automation, EERE is adopting a more holistic view of the vehicular industry, and its work is currently focused on the following five key pillars (Figure 1):

- **Connectivity and Automation –** An increased understanding of the impact of connected and automated vehicles and their implications on transportation and vehicle technologies, such as electrification and overall mobility.
- **Urban Mobility Science –** Integrated city-scale models that explicitly consider energy impacts of urbanization by collecting real-world data and collaborating with local governments.
- **Mobility Decision Science –** New knowledge and applications of socio-behavioural science to collect and analyse real-world data on transportation decision making, alternative fuel vehicle (AFV) and EV market drivers and barriers, and new mobility options.
- **Vehicles and Infrastructure –** Integrated vehicle-fuel models to explore value propositions (consumer and provider), business models, and opportunities for increased sustainable transportation deployment.
- **Multi-Modal –** Dynamic passenger/freight modal and energy-intensity modelling with explicit consideration of consumer/market preferences and energy implications.

This holistic approach is being adopted across the U.S. federal government (Department of Transportation [DOT], Basic Energy Sciences [BES], EERE, ARPA-E) to explore the untapped system-level efficiencies at planning and operations timescales.

Initial studies of implications of mobility-as-a-service (MaaS) and CAV technologies found mixed results in terms of the energy consumption implications; results range from +200% to -90% in 2050 (Figure 2). The negative implications (+200%) could be driven by changing trends such as more travel, faster travel, modal shifting, or increased shipping; while the positive implications can be driven from reduced congestion, smoother traffic flow, efficient operations, and adoption of zero-emission vehicles (ZEVs). Study results highlight the need for more pointed research to establish a deeper understanding of the potential energy implications in various scenarios.
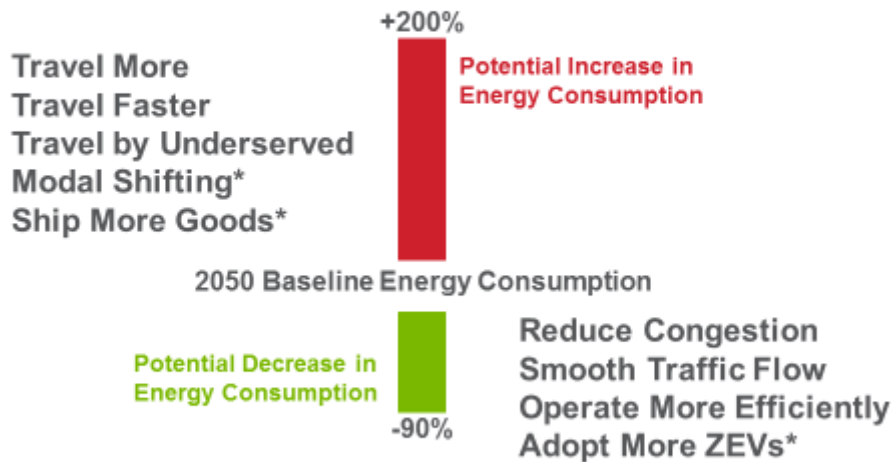
**Figure 2. Results of early MaaS and CAV studies indicate high degree of uncertainty: energy consumption could increase or decrease dramatically by 2050.**

As the vehicular industry evolves into increased automation and connectivity, the result is a highly complex decision making environment with interactions occurring between connected travellers, CAVs, energy and charging infrastructure, and cities/regions. This complexity must be transformed into clarity for decision makers. To facilitate this transformation, DOE is developing an ambitious analysis framework for interconnections between cities and regions, inter-city, and rural areas focusing on many different infrastructure systems (data management, connected travellers, CAVs, charging and fuelling infrastructure, etc.).

In its first pillar, "Connectivity and Automation," DOE's focus is to quantify the energy impact of multiple CAV technologies across a wide range of scenarios; inform policy and research on connected vehicle technology to maximize sustainability impacts; and identify CAV-enabled opportunities to promote greater vehicle electrification, vehicle light weighting, powertrain optimization, vehicle utilization, and reduced vehicle miles travelled (VMT). The foundational work includes modelling the energy impact of technologies and quantifying energy savings due to platooning. The impact of CAVs on energy consumption is unclear; energy consumption could potentially double as a result of several factors such as increased convenience. On the flip side, it is also possible that energy consumption could reduce by up to 50% due to increased efficiency and other factors. More research is required, especially as the economic impacts could potentially be significant, with CAVs potentially contributing $1.3 trillion in annual savings to the U.S. economy alone due to reduced accident rates, fuel consumption per mile, and travel time.

The "Urban Mobility Science" pillar is a relatively new class of data science with several unknowns. Researchers attempt to determine how the built environment will drive mobility and how cities will manage mobility, accessibility, land use planning, etc. DOE's focus is on building new city-scale computational models calibrated and validated by large transportation data sets that can inform

local decision making processes, and developing frameworks and analytical tools to build and run composite models of urban components related to sustainable transportation. Initial work is being conducted by academia and by state and local governments.

The "Mobility Decision Science" pillar focuses on exploring why people do what they do, how to predict behaviour, and how to "nudge" policies and measures to get the desired outcome. New transportation technologies require market acceptance. The Sunshot's Solar Energy Evolution and Diffusion Studies (SEEDS) initiative offers a guiding template to predicted changes to travel and ownership patterns based on anecdotal evidence. Enhanced vehicle adoption and choice models inform holistic policy decisions, vehicle R&D, and infrastructure investments to accelerate plug-in electric vehicle (PEV) adoption. It is important to understand individual and market behaviour in response to future technologies, policies, and transportation systems. The foundational work being conducted includes expanding modelling techniques to consider cognitive behaviour science, and combining real-world data and empirical analysis with social–anthropological analysis in multi-scale transportation system modelling.

The "Vehicles and Infrastructure" pillar examines systems optimization. DOE is studying the integrated modelling of vehicle and fuel technologies with consumer preferences to best leverage public–private resources for EV/AFV fuelling infrastructure. Charging at the workplace or home tends to have the highest value, and while the current focus is on structure and location of charging infrastructure, the questions that need to be addressed for the future are different. These will look into the value of a central depot concept, battery swapping, and concepts of car ownership in terms of businesses vs. consumers. A variety of work is being conducted including the memorandum of understanding (MOU) between DOE and the Edison Electric Institute on increased EV adoption and vast data collection efforts on EV and electric vehicle supply equipment (EVSE) use, bioenergy and hydrogen feedstock logistics studies and consumer research, and development of demand-based infrastructure models.

Under the "Multi-Modal" pillar, the focus is on energy-efficient, seamless multi-modal transport of people and goods. Research is being conducted to determine ways to counteract projected growth of freight energy consumption (through 2040) by leveraging disparate modal energy intensities (e.g., streamline transfers or shifting to new modes) and other topics. Within the U.S. federal government, the topics under this pillar are of primary interest to DOT, and DOE works with DOT to assess intermodal freight logistics and impacts from the MaaS trend.

All these pillars coalesce in the SMART (Systems and Modeling for Accelerated Research in Transportation) Mobility collaboration. A multi-laboratory consortium seeks to answer pressing questions such as whether and how advanced mobility concepts can reduce energy intensity of transportation, enable greater use of low-carbon energy sources, and lower VMT. Next-generation mobility concepts are considered part of the "Internet of Things," and SMART Mobility engages these concepts holistically and explores the nexus of energy and future mobility paradigms. The ultimate goal is to decouple carbon from transportation.

DOE's first steps are to undertake modelling and simulation exercises, including multi-scale mobility models. The goal is to provide a sound foundation for the research that DOE conducts and inform DOE's future research portfolio.

## 1.4 Energy Technology Perspectives 2016: National and Local Policies to Promote Sustainable Transport in an Era of Urbanization

Jacob Teter, Transport Energy Analyst, International Energy Agency

> ➢ Link to presentation slides:
> https://www.iea.org/media/workshops/2016/egrdtransportsystemsofthefuture/2EGRD_Teter_25_10_2016.pdf

IEA's signature report, outlines the technologies and policies needed to reduce greenhouse gas (GHG) emissions to a level that will limit the global temperature increase to below 2°C (the 2°C Scenario, or 2DS). In its latest edition (2016), IEA focused on the role of urbanisation in the development of potential energy futures, focusing on three main scenarios corresponding to increasing limits on global temperature increase.[3]
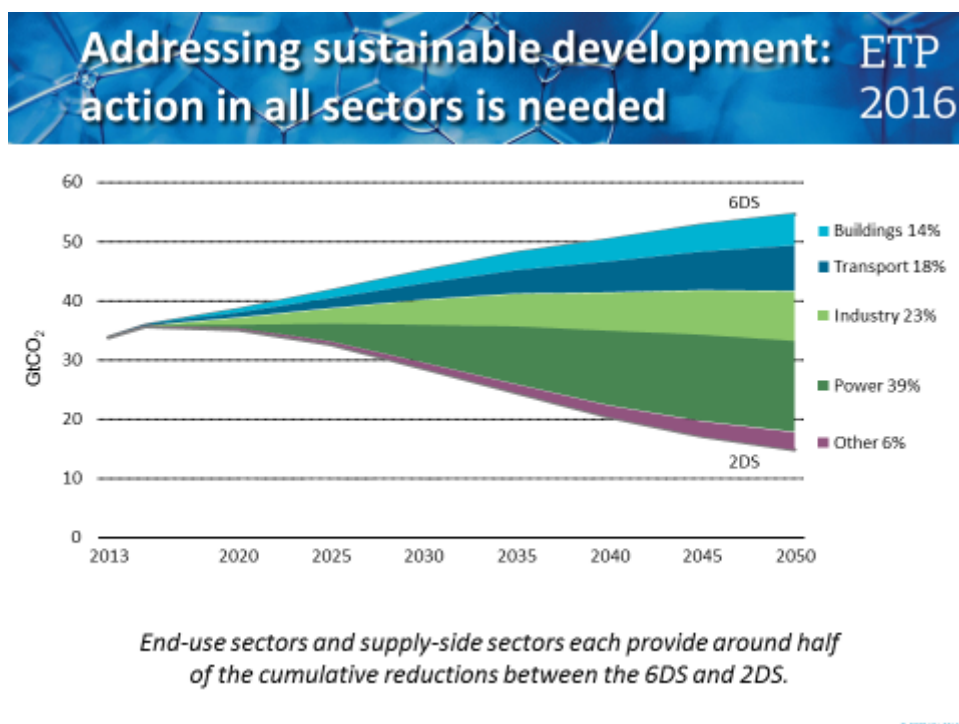


**Figure 3. GHG reductions needed by sector to achieve a 2 degree scenario by 2050.**

To better grasp trends and more effectively formulate policies to meet the 2DS, clean energy deployment needs to differentiate between urban and non-urban developments. The 2016 edition of the ETP includes a focused discussion on sustainable urban energy systems with objectives of setting GHG mitigation targets, environmental sustainability, energy security, and economic development. The ETP explores how local and national energy policies can be effectively aligned.

The ETP analysis indicates that concerted efforts in all sectors will be needed to achieve a 2DS scenario (Figure 3) and that the end-use sectors and supply-side sectors will each provide about half

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[3] The three main ETP scenarios are a 6-degree scenario (6DS), in which there are limited policy developments beyond current targets and technology deployment is limited to incremental improvements; a 4-degree scenario (4DS), in which current strategies and recent pledges for energy efficiency are extended to 2050; and a 2-degree scenario (2DS), a carbon dioxide ($CO_2$) emission mitigation scenario that also incorporates improvements in the sustainability of energy systems.

the cumulative reductions to move from the 6DS to the 2DS. Achieving the latter scenario will also require that transport emissions peak and begin to decline within the next ten years, and this entails considerably faster improvements than historical rates. Strong policies and other measures that promote vehicle efficiency, low-carbon fuels, and sustainable transport modes will be needed.

Globally, urban areas dominate primary energy use and $CO_2$ emissions, and transport systems is a major source of final energy demand in urban areas. Transport contributed 21% of global energy-related $CO_2$ emissions in 2015. The growth rate of transport emissions closely follows that of energy demand, and these depend on changes in transport activity, shares of activity in various transportation modes, energy efficiency of the mode, and carbon content of the fuels. Another key determinant of transport emissions is the differing characteristics between urban and non-urban areas.

ETP projections demonstrate that urban transport-related GHG emissions have peaked in Organisation for Economic Co-operation and Development (OECD) countries in all three scenarios while urban GHG emissions in non-OECD countries continues to grow. As a result, urban areas in developing economies are the key to the global sustainable energy transition. For the transportation sector, this urban low-carbon potential lies in compact urban development, public transport, travel demand management, innovative vehicles, and smart energy networks.

The ETP compares transportation and energy use in different countries, which provides some insights into various modes and their effects on consumption. Motorised passenger transport activity in China in 2015 was almost 50% higher than in the United States. However, the aggregate energy demand and emissions due to transport in China is only a bit more than half that of the United States. This can be explained by the greater use of aviation in the United States as a mode of transportation; greater reliance on higher efficiency modes such as buses and passenger rail in China; and greater use of two- and three-wheelers and small and medium cars in China for personal mobility as compared to the United States.

Freight currently accounts for about 40% of total transport energy use. Even though it is responsible for only 1% of total tonne-kilometres (tkm) travelled, urban freight modes account for 21% of freight energy use and emissions.  Currently, shipping constitutes 81% of tkm travelled, but it accounts for only 24% of energy use. Trucks, on the other hand, are the dominant energy users, due to the higher energy intensity per tkm of truck transportation.

Passenger services is responsible for about 60% of energy consumption in the transportation sector, with about 80% from urban areas. As expected, cars are the main energy consumers (76% of global energy demand) in passenger transport, followed by aviation. Regional differences between OECD and non-OECD countries are marked. In non-OECD countries, two-wheeler (motorized bicycles and motorcycles) energy demand is higher than that of urban light and medium commercial vehicles. As incomes rise, personal vehicles will account for the most growth in urban mobility with non-OECD countries experiencing the fastest growth in cars' share of transport.

ETP shows that while transport energy demand in 2015 amounted to about 107 exajoules (EJ), in the ETP scenarios energy demand can vary from 100 EJ (2DS) to 184 EJ (6DS) in 2050. By 2050 all three scenarios undergo increased energy supply diversification, with the 2DS experiencing the most. In

the 2DS, electricity generated through renewables and low-carbon biofuels are both needed as substitutes for oil-based fuels. Natural gas is a viable alternative in medium and heavy trucks and shipping (LNG), but methane emissions must be avoided. Both technology and policy measures will play critical roles in achieving the required reductions.

A 2DS scenario calls for a more long-term strategy that facilitates vehicle electrification and spurs greater use of public transportation. Electrification of passenger vehicle fleets needs to occur rapidly, with two-wheelers being completely electrified by 2050 in the 2DS. Cars' current share of transport is maintained well below the range for the other scenarios. Motorised two- and three-wheelers account for an increasing share of passenger activity in urban areas, especially in developing Asian countries.

Transitioning to a 2DS pathway requires economic development without a proportional increase in transport activity and associated emissions, i.e. decoupling economic activity and GHG emissions. The primary actions to enable this are reducing trips and trip distances, shifting activity to public transport, and getting efficient, low-carbon vehicles on the road. The Avoid/Shift/Improve framework[4] can be used to conceptualize the most effective measures to reduce transport emissions and energy use. Avoid/Shift measures are crucial to avoid lock-in of car dependency and urban sprawl, and Improve actions will reduce emissions through increased vehicle efficiency. Technologies like information and communication technologies (ICT) allow travel management to occur, while advanced hardware technologies can increase vehicle efficiency.

A coherent portfolio of policies and instruments can be used to switch to a low-carbon pathway. At the national and supra-national levels, these include removal of fuel subsidies; taxes, including vehicle feebates/bonus–malus schemes[5]—of both purchase and circulation—and well-to-wheels $CO_2$ taxation on fuels; fuel economy standards; and RD&D support. At the local level, pricing policies and regulatory measures can serve as levers to support development of compact cities and increasing investments in public transportation.

## 1.5    The Defining Transportation Challenges of the 21st Century

J. Christian Gerdes, Chief Innovation Officer, U.S. Department of Transportation, United States

➢ Link to presentation slides:
https://www.iea.org/media/workshops/2016/egrdtransportsystemsofthefuture/3IEAMobilityGerdes.pdf

"Beyond Traffic" is an initiative launched by the U.S. Department of Transportation (DOT) Secretary Anthony Foxx. The purpose of the initiative was to launch a national conversation on the implications for the different modes of transportation, develop a framework highlighting the big decisions, and frame the key opportunities for research. Released in February 2015, the draft document was not

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[4] Avoid policies are those that address transport energy use and emissions by slowing travel growth via city planning and travel demand management; "Shift" policies enable and encourage movements from motorised travel to more energy efficient modes, such as public transit; and "improve" policies can reduce energy consumption and emissions of all travel modes through the introduction of efficient fuels and vehicles. IEA, 2013. "A Tale of Renewed Cities". Available at: http://www.iea.org/publications/freepublications/publication/Renewed_Cities_WEB.pdf

[5] A scheme that consists of a financial reward (bonus) for purchasers of environmentally friendly cars, and a financial penalty (malus) for those buying cars emitting high levels of $CO_2$.

meant as a prescriptive plan but rather an exploration of potential options. The document describes trends shaping the U.S. transportation system, the future scenario if challenges are not addressed, and policy options for addressing challenges.

Several demographic changes are underway in the United States. The U.S. population is growing and aging, with a large suburban population in spite of growing urbanization. Currently, the U.S. population travels nearly 3 trillion vehicle miles annually. Additionally, as the U.S. economy grows, the freight volume increases rapidly, with projections showing a 45% increase by 2040. Transportation emissions account for about 28% of all anthropogenic GHG emissions in the United States; with transportation on the rise, improving fuel efficiency across all modes has become critical.

Transportation spending by the U.S. government has been declining over the last decade (Figure 4). The gas tax has remained unchanged in the last 20 years, is declining, and there is a fragmented institutional environment that relies on decentralized decision making. Additional infrastructure spending is needed, especially on highways and transit. This provides an economic opportunity that can amount to about $3 trillion a year, and involving the private sector is an option. Private sector investment is already increasing, as it has begun providing services for providing the last mile travelled, and several organizations are positioning themselves as mobility companies. However, the private sector must emphasize profitability, and as a result, from the 3-million pie, focuses on the low-hanging fruit to maximize gains. The growing role of businesses can have significant policy implications, as questions related to poverty, safety, and accessibility remain unaddressed. Safety and access depend upon the neighbourhood, and poverty is making its way into less accessible suburban areas, presenting increasing challenges.
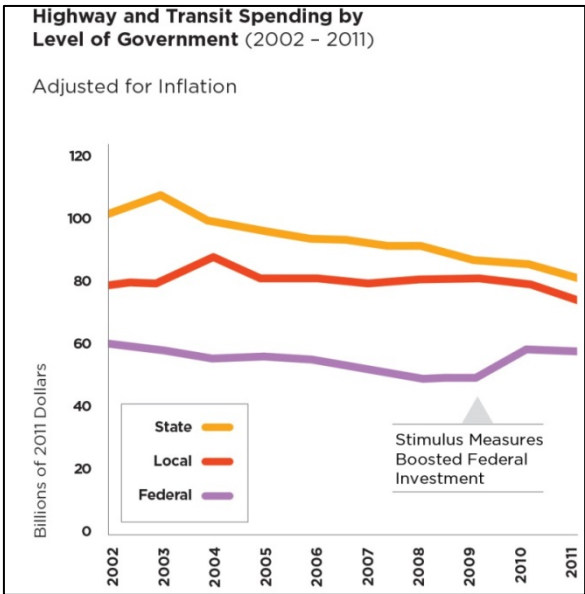


Figure 4. Highway and Transit Spending by the U.S. government (2002-2011) showing a declining trend.

To address this rapidly changing landscape, several less traditional approaches are being adopted. Rather than being prescriptive, DOT is undertaking prototyping approaches, testing and analysing the results. These help identify the critical R&D needs in this space. Several advances that can be expected in the next few years include automation of cars, trucks, buses, ships, etc.; increased use of unmanned aircraft; modernization of the U.S. air traffic control system; and new designs for infrastructure.

Vehicle automation will have an impact on every mode of transportation, as uses will be diverse (e.g., unmanned aircraft systems, truck platooning, autonomous taxis, etc.). The range of applications raises the question of what policy/guidance DOT should be developing. The Federal Automated Vehicles Policy is the primary guiding document for safety of automated vehicles and ensures safe testing and deployment of systems. DOT has also released guidance on a 15-point safety assessment that includes post-crash behaviour, vehicular cybersecurity, and data recording and sharing.

Specifying the operational design domain is critical for automated vehicles, including those that are driverless and those that offer mobility irrespective of a person's physical ability. Each case will need its own specifications. A manufacturer must state the vehicle's operational design domain, which, for each automation system, defines the domain where it operates, how it ensures it remains within the domain, what fall-back systems are in place, and how people are trained to use the vehicle.

As transportation modes change, more vehicle design options emerge, and there are always associate impacts. For example, ground drones being used for delivery can have implications for the use of sidewalks and safety for pedestrians. Regulations need to be in place to ensure safety, equity, and ethical issues are addressed.

Traditionally, technology can take 10 years or more to get to the market, but with new ownership models coming into being, this can rapidly change. The deployment of these technologies can be fairly rapid, as barriers to deployment are low, the costs of automation are already approaching the costs of having a driver, and software development costs can be amortized over many vehicles. There is already considerable use of small unmanned aircraft systems (UASs) by U.S. federal agencies, and the Federal Aviation Administration (FAA) is exploring options to conduct commercial operations along with using the aircraft for government purposes. The potential economic impact is large, with commercial drone operations likely to generate 100,000 jobs and $82 billion over the next 10 years.

Full UAS integration presents both challenges (such as remote tower operations and noise) and opportunities (such as reduced fuel use), and community engagement will play a significant role. The FAA has introduced the Part 107 Rule, a prototyping rule that provides guidance on small UAS operations, including commercial drones for agricultural use. The agency is also making progress toward the goals of its NextGen Air Traffic Control effort, which aims for full UAS integration in the airspace.

Infrastructure design must also adapt to incorporate new transportation concepts and technologies, which presents broader opportunities to bolster social equality. In the past, highways connected societies—but also disrupted neighbourhoods. Principles of inclusive design are extremely important for policy makers. Secretary Foxx has put forth Three Principles of Inclusive Design:

- Understand that transportation is essential to opportunity.
- Acknowledging that past wrongs were committed and must not be repeated.
- Make transportation decisions by, with, and for the people impacted by them.

Several challenges lie ahead as changes become necessary and come rapidly. Very few regulatory frameworks exist, and new deployment scenarios are being considered that focus on miles travelled instead of vehicles. Research needs to shape the future rather than only predicting it. New approaches such as prototyping need to be quickly adopted to keep up with the pace of the rapid changes in the industry.

# Session 2: Transportation & Mobility: Emerging Trends & Promising Technologies

Chair: Rob Kool, EGRD Chair, RVO.nl, Netherlands

## 2.1   Overview

New and advanced technologies are being developed that can transform the future of transportation demand and services and significantly reduce GHG emissions. Freight transportation presents tremendous opportunities for fuel savings, GHG emission reductions, and performance improvements. Hydrogen and fuel cells, while sparking debate, continue to be pursued by some countries and companies. The focus in these instances is on the RD&D and market integration of fuel cell and hydrogen technologies. Electric vehicles (EVs) are further along in the adoption curve. A critical element for EVs is the rate at which the manufacturing costs can outweigh those of conventional internal combustion engine (ICE) vehicles.

The private sector plays a crucial role in developing innovative vehicle technologies. Programs such as SuperTruck in the United States are testament to the value of high private sector participation. Industry participation in a competitive but collaborative environment, such as that fostered through the SuperTruck program, can deliver cutting-edge, innovative solutions to transportation challenges. SuperTruck generated ideas and technologies that significantly increased truck efficiency while delivering 500:1 return on investment, spurring the release of SuperTruck II. The importance of public sector funding must not be underestimated, and such investment can be spurred through various financing instruments, such as guarantees that allow for greater risk taking by the private sector. Transnational collaborations among research agencies can deliver gains as experts share progress on technology advancements and research, and develop options for efficient policy making.

Key consideration must be given to developing strong economic incentives to deliver GHG reductions and increased efficiency. Attention must be paid to the unique economy, demography, and societal preferences of a particular region when implementing such measures. In some instances, it has been demonstrated that $CO_2$-graduated vehicle taxation is one of the most effective GHG mitigation measures in the transportation sector, and taxing carbon emissions might not be as inefficient as many analysts believe.

Developing economic models to better understand consumer behaviour will help shape effective fiscal and regulatory government incentives. Decoupling transportation from emissions is another promising strategy. However, developing more advanced energy technology does not necessarily translate into its adoption. Technologies must be competitive. A key question will be how to encourage consumers to buy ZEVs. Research delving into predicting consumer decision making will assist in unravelling some of these questions.

## 2.2   Freight Mobility and SuperTruck

Roland Gravel, Technology Development Manager, Advanced Combustion Engine R&D, Vehicle Technologies Office, U.S. Department of Energy, United States

> ➢ Link to presentation slides:
> https://www.iea.org/media/workshops/2016/egrdtransportsystemsofthefuture/4SuperTruckBriefingOct2016IEAMtgRmG.pdf

Freight transportation continues to expand geographically across the United States with increasing demand for goods movement. As a whole, the transportation sector already accounts for 27% of U.S. energy consumption, representing a large portion of the nation's fuel usage and GHG emissions. Demand for conventional freight fuels, such as diesel and jet fuel, is expected only to increase (by 75% from 2010 to 2040). Manufacturers will need to implement new and advanced vehicle technologies to reduce the energy and environmental impacts of this growth.

In 2009, DOE determined that over-the-road Class 8 trucks would be the best "bang for the buck" with regard to investing in technologies to reduce fuel consumption and emissions. Commercial trucks comprise 4% of on-road vehicles but 18% of fuel consumption, and heavy trucks move 73% of the total U.S. freight value and tonnage. Additionally, there is a potentially high return on investment because of the massive fuel costs incurred by the trucking business, and industry is ready and willing to adopt new fuel-saving technologies. DOE acted on this opportunity with the SuperTruck I initiative, which aimed to make drastic improvements in truck efficiency through achieving a 50% improvement in freight efficiency (vs. 2009) and 50% brake thermal efficiency, with a pathway to 55%. The focus was on diesel engines only (no alternative fuels) since analysis shows diesel fuel maintaining large market share into the long term.

Four teams were awarded funding: Cummins/Peterbilt, Daimler Trucks NA, Volvo Trucks NA, and Navistar, Inc. In combination with industry cost share (>50%), the program invested $260 million into achieving the efficiency goals. DOE's benefits analysis indicates a savings of up to six billion barrels of oil in 2050 (due to SuperTruck), equal to a 500:1 return on investment. Table 1 below summarizes each team's accomplishments.

**Table 1. SuperTruck I team accomplishments**

| Team | Duration | Funding | Freight Efficiency Improvement | Brake Thermal Efficiency |
|------|----------|---------|-------------------------------|--------------------------|
| **Cummins/Peterbilt** | 4/2010–9/2014 | DOE: $38.8M Industry: $39.6M | 76% (long-haul cycle) | 51% |
| **Daimler** | 4/2010–3/2015 | DOE: $35.8M Industry: $38.3M | 115% | 50.2% |
| **Navistar** | 10/2010–9/2016 | DOE: $29.3M Industry: $40.4M | 104% | 50.3% |
| **Volvo** | 6/2011–6/2016 | DOE: $19M US Industry: $19M Sweden: $15M/$15M | 88% | 50% |

All of the teams presented a path to 55% brake thermal efficiency, and each of them is currently working on commercializing technology developed in the program. Their research intellectual property is protected for five years under the U.S. Energy Policy Act of 2005.

Each of the manufacturers involved in SuperTruck I said that the project led to more innovation and ideas, rather than depleting them. Based on this, and the strong success of the program, DOE initiated SuperTruck II. The goals of SuperTruck II are to demonstrate more than 100% improvement in freight efficiency (vs. 2009) and demonstrate 55% or greater brake thermal efficiency. Additionally, the teams must focus on maintaining or improving performance and must consider cost-effectiveness of the technologies under study. The team goals, as shown in Figure 5 below, all include some level of hybridization and/or electrification.
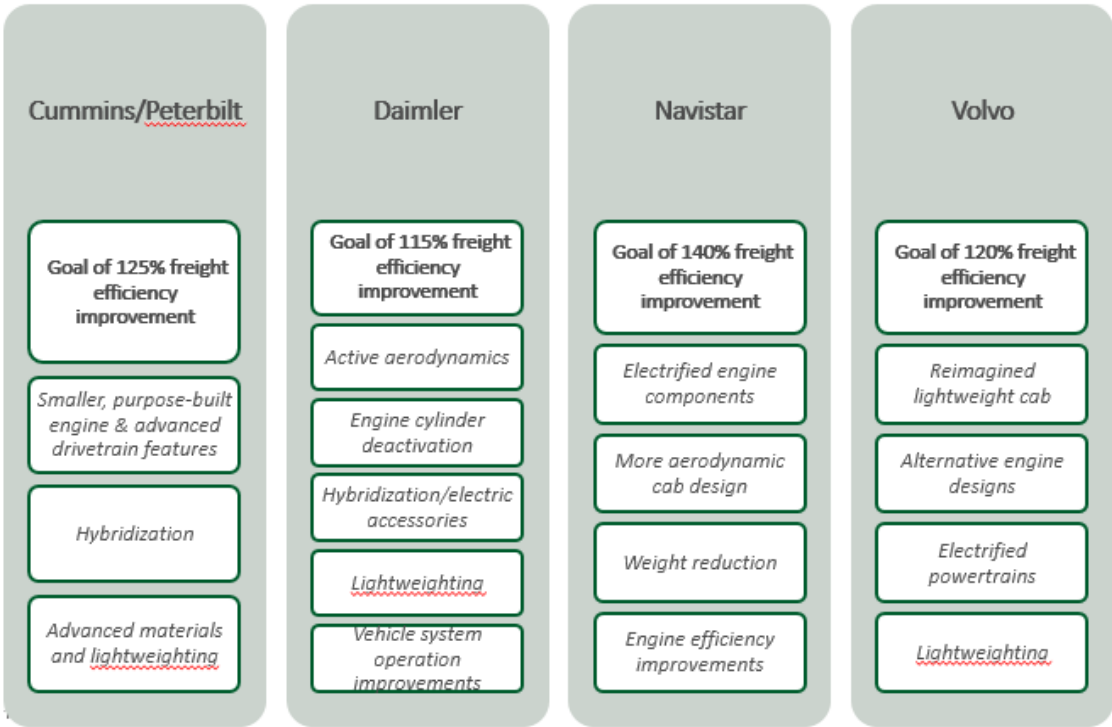


| Cummins/Peterbilt | Daimler | Navistar | Volvo |
|---|---|---|---|
| Goal of 125% freight efficiency improvement | Goal of 115% freight efficiency improvement | Goal of 140% freight efficiency improvement | Goal of 120% freight efficiency improvement |
| Smaller, purpose-built engine & advanced drivetrain features | Active aerodynamics | Electrified engine components | Reimagined lightweight cab |
| Hybridization | Engine cylinder deactivation | More aerodynamic cab design | Alternative engine designs |
| Advanced materials and lightweighting | Hybridization/electric accessories | Weight reduction | Electrified powertrains |
| | Lightweighting | Engine efficiency improvements | Lightweighting |
| | Vehicle system operation improvements | | |

**Figure 5: SuperTruck II team goals and their strategies for meeting them.**

In addition, DOE is considering connected and automated vehicle technologies for the commercial truck sector through its SMART Mobility initiative. Truck platooning systems, which provide semi-autonomous operation (throttle and braking, but not steering) are gaining exposure in the marketplace through RD&D by companies such as Peloton and Otto. Freightliner's Inspiration Truck is the first licensed autonomous commercial truck and is already being demonstrated. In general, connected and autonomous truck technology is being implemented for safety and crash avoidance; fuel savings is an additional benefit.

Class 8 commercial trucks represent an important opportunity to address GHG emissions and fuel consumption increases. The SuperTruck I program was a huge success for government and industry and has provided a springboard for more advanced fuel-saving technology commercialization. SuperTruck II is taking this initiative one step further, with the same teams from SuperTruck I (after a rigorous selection process) taking their learnings to the next level.

## 2.3 Market Uptake of Battery and Hybrid Electric Vehicles

Lasse Fridstrøm, Institute of Transport Economics, Oslo, Norway

➢ Link to presentation slides:
  https://www.iea.org/media/workshops/2016/egrdtransportsystemsofthefuture/5Fridstromdcfinal.pdf

As of 2016, Norway has the largest battery electric vehicle (BEV)/plug-in hybrid electric vehicle (PHEV) market share in the world, at 29% of the new passenger car market. Of the total vehicle fleet at year-end, 3.8 % were BEVs (see Figure 6 for visualization of the growth). This equates to 101,126 BEVs.
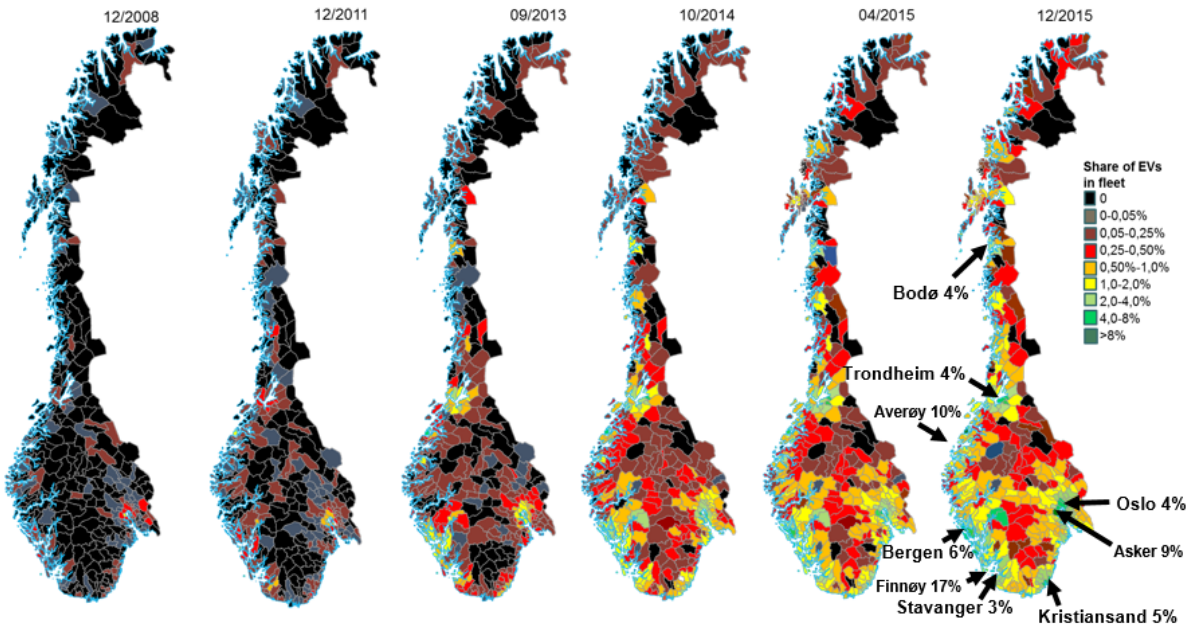


**Figure 6: Growth in Norway's BEV market share between 2008 and 2015.**

The country has a huge amount of hydropower electricity production to ensure these vehicles are truly reducing well-to-wheels emissions. Emissions reduction potential, and the incentives inherent to such reductions, have played a prominent role in the success of Norway's EV market.

Understanding Norway's approach to reducing emissions requires a quick analysis of the dominant factors in emissions production (Figure 7). The multiplicative decomposition on the right side of the equals sign is listed in descending order of political and economic cost (explanation of each factor is in blue). This discussion is focused on the two far right factors: fuel type and vehicle efficiency impacts on emissions. Changing either of these factors decouples emissions from economic welfare and growth.

$$emissions = GDP \cdot \frac{ton/\,person\,miles}{GDP} \cdot \frac{vehicle\,miles}{ton/\,person\,miles} \cdot \frac{energy\,consumption}{vehicle\,miles} \cdot \frac{emissions}{energy\,consumption}$$
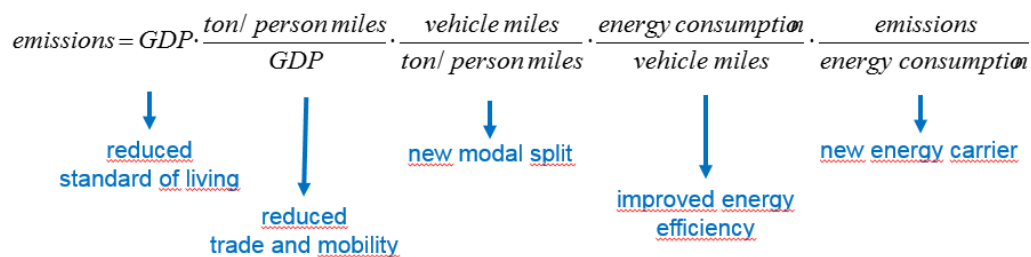
reduced standard of living

reduced trade and mobility

new modal split

improved energy efficiency

new energy carrier

**Figure 7: Multiplicative decomposition of emissions factors, in descending order of political and economic cost.**

The EU Emissions Trading System (ETS) covers all electricity installations over 20 MW in the European Economic Area (EEA), of which Norway is a part. This equates to around half of all $CO_2$ emissions in the EEA. Fossil-fuel-powered vehicles are not covered under the EU ETS (outside of intra-EEA aviation), but electricity-powered vehicles are covered. Therefore, vehicle electrification will lead to moving part of transportation energy use into the EU ETS, and, since in principle the EU ETS balances out to zero-emission electricity, all BEVs on the system have zero marginal emissions. Cap-and-trade and vehicle electrification are perfect complements.

Vehicle electrification in regions without cap-and-trade can have various GHG mitigation effects, depending on the energy mix of each region. Using the average European energy mix (510 $gCO_2$/kWh) and 0.2 kWh/km, pure EV emissions equate to 54 miles per gallon (mpg) for a gasoline driven car. This is not radically better than new conventional vehicles in Europe, but more than twice as efficient as new cars sold in the United States, which average around 25 mpg. For maximum GHG mitigation effect, vehicle electrification should be accompanied by decarbonisation of power generation.

Norway's transportation industry is currently targeting a maximum of 85 $gCO_2$/km averaged over all new passenger cars sold in 2020. The Public Roads Administration proposed new targets that would imply several more stringent clean transportation initiatives (Table 2).

**Table 2. Proposed emission targets in Norway – pending in Parliament.**

| YEAR | PROPOSED TARGETS |
| --- | --- |
| **2025** | All new passenger cars should be BEVs or FCEVs |
| **2025** | All new urban buses should be BEVs or fuel cell electric vehicles (FCEVs) |
| **2030** | All new freight vans and light trucks (<3.5 tons) should be BEVs or FCEVs |
| **2030** | 75% of new coaches should be BEVs or FCEVs |
| **2030** | 50% of new heavy trucks (>3.5 tons) should be BEVs or FCEVs |

The tax structure in Norway also provides strong incentive possibilities for GHG emissions reduction. There is an annual circulation tax ($250), a one-time re-registration tax ($185–$720 per transaction), a scrap deposit ($290 at time of purchase, refunded at vehicle end-of-life), and a value-added tax (VAT) (25%). Fuel is taxed at $2.75 per gallon plus 25% VAT, and there are tax credits available for commuters who travel more than 9000 miles per year ($0.08/mile). Figure 8 shows the additional variable taxes assessed on all new vehicle purchases. It should be noted that all of the taxes are

summed and tacked onto the final vehicle price. This is where highly efficient vehicles are able to offset a great deal of their incremental cost, specifically lower $CO_2$ enabling a credit toward paying the other taxes.
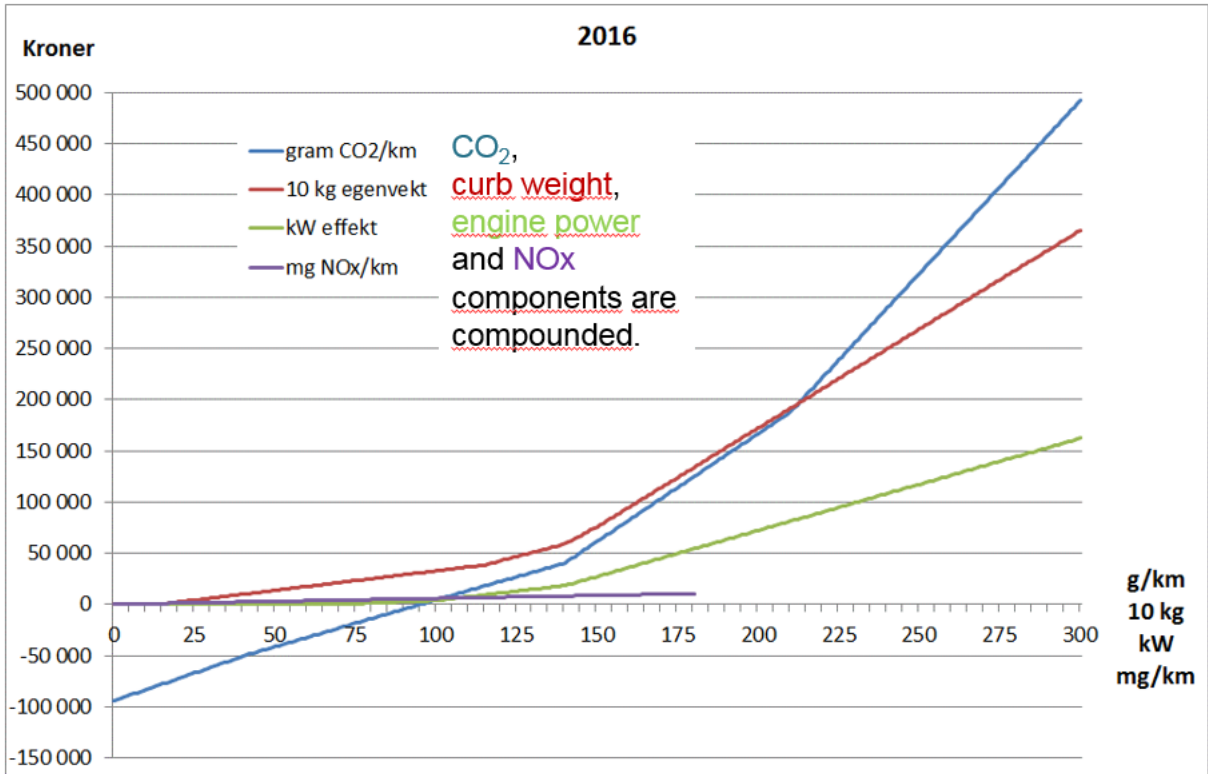


**Figure 8: Four part purchase tax on new passenger cars in Norway (2016). Note: As of September 20, 2016, $1=NOK 8.27**

ZEVs are heavily incentivized through this taxation system. They are exempt from the VAT, vehicle purchase tax, and all road tolls and public parking charges. Additionally, ZEVs have a strongly reduced annual circulation tax, reduced income tax on company cars, reduced ferry fares, and access to the bus lane. All of these incentives were intended to be temporary, through 2017 or sales of 50,000 BEVs (whichever comes first), but they are still available even though aggregate BEV sales have reached 100,000. The takeaway is that economic incentives work, as long as they are strong enough.

The government needs to understand how each potential incentive could actually influence consumer decision making. To meet this need, Norway's Institute of Transport Economics developed a model called BIG to estimate and predict the market shares of new passenger car model variants under varying tax regimes. It is based on complete disaggregate sales data from January 1996 through July 2011. This allows the country to predict the impact that fiscal and regulatory changes might have on GHG emissions, and is especially important for understanding how long it will take for the new cleaner vehicles to penetrate into the vehicle fleet as older cars are retired (stock-flow modelling). Researchers performed counterfactual back-casting to look at how the market would have turned out without the previously enacted ZEV incentives and found that average emissions from new cars would have been 20% higher in 2014. This suggests that electrifying the automobile fleet (e.g., through $CO_2$-graduated vehicle taxation) has been the single most effective GHG mitigation measure in transportation.

Norway has learned several additional lessons through experience and predictive modelling. Crucial to the cost and feasibility of electrification is how fast the manufacturing costs of BEVs, PHEVs, and FCEVs will converge to those of conventional ICE vehicles. Benefits will take the form of reduced (and possibly cheaper) energy use since BEVs are 3–4 times as energy efficient as ICE vehicles. In the best of cases, future energy savings may outweigh extra acquisition costs. A long-term economic perspective is needed.

While the lessons learned from this research are beneficial, the most difficult obstacle to cleaner transportation is still consumer choice. The final transportation system choices are made by individual consumers and businesses, not by governments. Improved energy technologies must be competitive to be attractive to society. According to Norway's experience and research, the best way for the government to encourage such competitiveness is to provide fiscal and regulatory incentives. Further modelling is needed to understand exactly how these incentives will affect consumer behaviour, and further policy research will help explore what options are available to legislators. These combined initiatives will lead to a deeper understanding of how to nudge buyers toward choosing ZEVs exclusively by 2025–2030 to be able to meet Norway's targets.

## 2.4 National Innovation Program on Hydrogen and Fuel Cell Technology in Germany

Johannes Tambornino, Project Management Julich, Germany

> ➢ Link to presentation slides:
> https://www.iea.org/media/workshops/2016/egrdtransportsystemsofthefuture/620161025_EGRD_Washinton_Tambornino.pdf

Germany's Project Management Jülich coordinates research and innovation funding programmes in several areas such as biotechnology, materials technologies, environment and sustainability, and others. One of the areas is energy with a broad focus on energy efficiency and renewable energies, including hydrogen/fuel cell technologies. On behalf of the Federal Ministry of Economic Affairs and Energy (BMWi) and the Federal Ministry of Transportation and Digital Infrastructure (BMVI), Project Management Jülich has coordinated national R&D activities in the field of fuel cell technologies over the past ten years. The National Innovation Program on Hydrogen and Fuel Cell Technologies is a joint initiative between BMVI and BMWi, in coordination with the Ministry for Education and Research and the Ministry for the Environment. With funding of about €1.4 billion, the goal of this program is to conduct RD&D and market launch support of fuel cell and hydrogen technology.

Program researchers are investigating hydrogen production, hydrogen infrastructure, and special markets, as well as how fuel cell and hydrogen technologies can be used in mobility, home energy systems, and industrial applications. Several ongoing activities are described below.

- **Optigaa2, or Optimizing the Gas Diffusion Layer (GDL) for Applications in Fuel Cell Vehicles.**
  With a focus on using applied R&D to support market entry, the Optigaa 2 goal is to increase GDL power density to 1.8 W/cm² to reduce the overall cost of fuel cell stacks. The project partners—which include Freudenberg Vliesstoffe, Daimler, ZSW, Fraunhofer ITWM, Technical University Munich, and Math2Market—are conducting basic R&D on new materials, diffusion processes (using simulation), and optimized production processes.

- **Cost reduction in fuel cell vehicles.** Car manufacturers are conducting day-to-day testing of FCEVs that are currently in production. The goal is substantial performance improvement and cost reduction.
- **50 Station Program.** This effort involves R&D for hydrogen refuelling stations and building an initial network in Germany (Figure 9).
- **Power-to-Gas.** Hydrogen production from renewable power sources can help achieve targets for a sustainable mobility system. Several ongoing projects aim to provide a renewable energy source for the transportation sector, manage the fluctuations in renewable energy sources in the power sector, contribute to energy system decarbonization, and link the energy sectors. The Power-to-Gas effort currently comprises over 30 projects that include 16 operating plants with a total capacity of 16 MW.
- **Clean Energy Partnership.** Researchers are conducting technology validation with more than 100 FCEVs (passenger cars and buses). Topics include increasing vehicle performance, fast refuelling, safety, sustainability, and customer acceptance. The project began in Berlin and extended to Hamburg. It initially used 350 bar technology and is now using 700 bar technology.

The National Innovation Program on Hydrogen and Fuel Cell Technologies has seen strong commitment from industry, a key factor in the program's success. Thus far, R&D of components and whole fuel cell stacks has seen great improvement, and program efforts have resulted in a proof of concept for the feasibility of a hydrogen infrastructure.

A detailed evaluation of the program's success over the last ten years is currently in progress. The BMVI is planning to provide €250 million for a three-year project (2016–2019) to make hydrogen technology in the mobility sector competitive within 10 years, focusing on technology readiness levels 5 to 8. BMWi is planning to continue to fund fuel cell R&D at about €25 million per year, and a new call for funding applications on (non-fuel-cell) mobility and energy projects will be issued soon. The call will focus on power to gas, new engine concepts for synthetic fuels, and alternative concepts (gas and synthetic fuels) for ships and industrial motors.
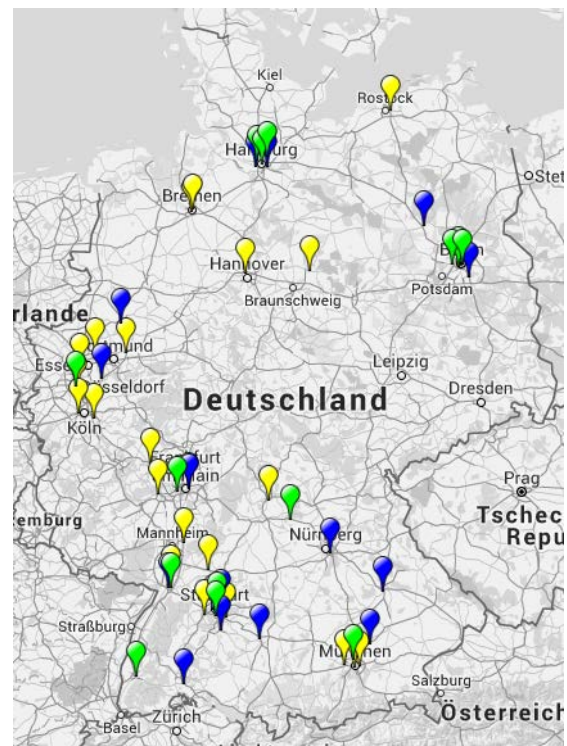


**Figure 9. Site Locations of hydrogen refuelling stations and the initial network of Germany's 50 Station Program.**

## 2.5   Energy Union EU Transport Strategy

Estathios Peteves, Head of Unit, Knowledge for the Energy Union, European Commission

➢ Link to presentation slides:
   https://www.iea.org/media/workshops/2016/egrdtransportsystemsofthefuture/7ECJRC_IEAEGRDDOEWorkshop_2526Oct.pdf

In 2013, the European Union announced the Clean Power for Transport Package (CPT Package), which is an overarching strategy for the long-term substitution of alternative fuels for oil in all transport modes. The fuels include electricity, hydrogen, liquid biofuels, synthetic and paraffinic fuels, liquefied petroleum gas, and natural gas.

The EU Directive 2014/94 for Alternative Fuels infrastructure outlines the minimum infrastructure requirements that must be implemented through the European Union's national policy frameworks: publicly accessible recharging points to be built by 2020 to allow the circulation of EVs Union-wide; publicly accessible natural gas/bio-methane refuelling points for road vehicles and ships/vessels, with common standards, on the Trans-European Transport Core Network; publicly accessible refuelling points to allow the circulation of compressed natural gas (CNG) vehicles Union-wide; and a sufficient number of publicly accessible refuelling points, with common standards, in the Member States that opt for hydrogen infrastructure. The European Commission has prepared guidelines to help Member States to prepare their national policy frameworks.

Article 4 of the Directive specifies the details for the electricity supply for transport. Per this Article, Member States must ensure that an appropriate number of publicly accessible recharging points (1 per 10 cars) are put in place by the end of 2020, in particular at public transport stations, such as port passenger terminals, airports, or railway stations. Member States must also take measures to encourage the deployment of recharging points not accessible to the public. Furthermore, the Directive states that the public must be provided with geographic locations of the recharging points, and those stations must display per-unit price comparisons between types of electricity supply to ensure transparency. The European Commission is currently doing work on fuel price comparison.

The European Union has adopted Union-wide standards for EV charging. These include a common Type 2 EV plug for slow- and fast-charging stations and normal and high-power EV recharging points. As the principle is to remain technology neutral, the standards state only that the recharging points must comply with the technical specifications set out in Annex III. The European Committee for Standardization (CEN) and the European Committee for Electrotechnical Standardization (CENELEC) adopted a standardization mandate in 2015, and work is underway to implement its. Next steps include pursuing a European standard for wireless recharging, battery swapping for motor vehicles, recharging points for L-category motor vehicles and electric buses, and addressing interoperability and data accessibility.

The European Commission has several ongoing efforts in place through activities dedicated to next-generation transportation efforts. These include the Sustainable Transport Forum, which tackles specific issues such as interoperability and alternative fuels in cities, and the Alternative Fuels Observatory.

The European Union has implemented the 2015 Energy Union Package, an overarching strategy for adopting a common energy policy for Member States. The Package identifies electrification/decarbonisation of transport as playing a significant role in breaking oil dependency, and the European Commission will work to develop market conditions for increased deployment of alternative fuel vehicles and promotion of clean vehicles. The strategy calls for continued (post-2020) focus on $CO_2$ emission standards and fuel efficiency for a range of vehicles.

The Energy Union Package was followed by the 2016 EU Strategy on low-emission mobility. The main elements of this strategy are to increase transport system efficiency, speed deployment of low-emission alternative energy, and remove obstacles to electrification of transport and wide-scale ZEV adoption.

These strategies and several ongoing projects seek to address ongoing hurdles. Guidance documents have been developed to help with the challenges of city logistics. ZeEUS (the Zero Emission Urban Bus System) and ELIPTIC (electrification of public transport in cities, a Hydrogen 2020 initiative) are tackling electric public transport adoption issues by developing a platform on eBuses for market uptake. To address challenges related to passenger cars and L-category vehicles, the European Commission has launched GEAR 2030 to help the European automotive industry adapt in the face of globalisation, changing mobility patterns, digitalisation, and consumer expectations; other projects in this area include Green eMotion (electrification of passenger cars) and CIVITAS-DYN@MO ("Mobility 2.0" systems and services). Other challenges being tackled include shore-side electricity facilities, continued and improved electrification of rail and other modes (e.g., aviation), and smart energy management.

Several financing mechanisms have been developed for funding R&D in this space. Horizon 2020 has provided significant funding for R&D in urban mobility, smart cities and communities, and transport for small and medium-sized enterprises. Horizon 2020 is now preparing funding options for its Green Cars Initiative and for the European Investment Bank's (EIB's) European Local Energy Assistance (ELENA) facility, among other efforts.

The European Commission and EIB jointly launched another important funding mechanism, the European Fund for Strategic Investments (EFSI). EFSI has issued a €21 billion guarantee with the aim to leverage an additional €255 billion. This results in total extra financing that amounts to €315 billion. Investment platforms are being created under the EFSI regulations for certain countries and sectors, including transport. The framework allows for riskier projects to employ innovative financial instruments rather than relying on more traditional, and risk-averse instruments like grants alone. The EFSI guarantee will enable the EIB to take on riskier efforts, e.g., smart urban mobility and alternative fuels projects. Priorities include research and innovation, and urban mobility. Cities and private promoters active in cities need to engage with the EIB and the national promotional banks to access this funding.

EFSI has also developed an advisory hub that provides key project players with investment advice and support, including serving as a vehicle to work with a network of national promotional banks. Regional hubs are likely to be created as well.

In addition, the European Commission and EIB have announced the creation of a new Clean Transport Financing Facility, which is expected to be functional by 2017. Clean (alternatively fuelled) buses will be an investment priority. In parallel, the Directorate-General for Mobility and Transport is advancing discussions with cities, operators, and manufacturers to better match supply and demand.

The EU transport strategy also calls for an integrated research and innovation plan. The Strategic Transport Research and Innovation Agenda (STRIA) is engaging experts and the wider stakeholder community to examine seven areas: electromobility, alternative fuels, vehicle design and manufacturing, connected and automated transport, infrastructure, network and traffic management, and smart transport and mobility services. Roadmaps have been developed for all seven topics. STRIA aims to achieve the following while considering all sectors and approaches:

- Identify options for low-carbon transport and mobility and an integrated transport system.
- Identify options to improve the system's performance.
- Make optimal use of digitisation and new mobility/logistics solutions.
- Identify needs for enablers and framework conditions.

Also serving on the integrated research front is the Joint Research Centre (JRC), the European Commission's science and knowledge service, which employs scientists to carry out research to provide independent scientific advice and support to EU policy. JRC scientists developed the JRC Integrated Electromobility Platform, a suite of models that look at the transportation sector in an integrated way to assess policy. The platform evaluates infrastructure needs, grid impacts, and energy and environmental impacts. The JRC's many initiatives on transportation and mobility involve a large number of partners (Figure 10).
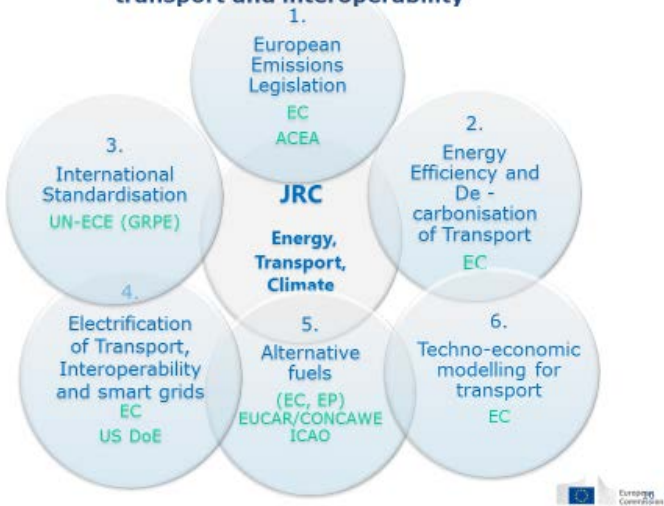


**Figure 10. Overview of JRC activities and key partners.**

For example, the JRC works in close collaboration with DOE and the U.S. national laboratories, as evidenced by the recent launch of the collaborative European Interoperability Centre for Electric Vehicles and Smart Grids.

# Session 3. Technology R&D: Barriers and Solutions

Chair: Birte Holst Jørgensen, Technical University of Denmark, Denmark

## 3.1 Overview

Social and technological trends have widened the scope of sustainable transportation R&D. The interconnected nature of the integrated transportation industry is creating layers of complexity not seen before. Vehicles and their respective travellers are no longer the only factors in the equation; researchers and policy makers must now include the entire transportation system along with a built environment to support it. The convergence of these factors will likely require connecting, automating, and electrifying vehicles to be shared through a MaaS business model. Customers will need to assess the benefits, which could include safety, convenience, comfort, accessibility, and affordability, and decide for themselves whether a given technology is a good fit for them. At the same time, policy makers and OEMs will need to develop frameworks to ensure technologies deliver lower GHG emissions and increased efficiency.

A lack of understanding of consumer behaviour, i.e., why certain decisions are made, is proving to be a critical challenge in the evolving transportation landscape. Accurately modelling consumer preferences and decision making and factoring in the impact of social media will be crucial. Some key topics that will help shape this industry include discovering how to incentivize efficient travel decision making using an app that offers options in real time, understanding how social media is linked to customer choice, and what benefits consumers can capture from ACES (Automated, Connected, Electrified, Shared) technologies. Current modelling of the energy impacts of an ACES transportation system exhibit high levels of uncertainty. Developing models that more accurately predict the energy impacts of these technologies will be critical to shift to a low carbon pathway.

Several technological challenges remain. Safety is of utmost priority, and technologies and policies must be implemented to ensure that this it is maintained or improved. Vehicle manufacturers, research centres, and others are conducting development, testing, and/or validation of accurate and reliable sensors, cameras, global positioning systems (GPSs), actuators, and software. To respond to the quick pace of technology advancements, most have adopted an approach to respond in real time. Research is being conducted in a "living lab" model, where an in-use vehicle is instrumented and analysed in real time. Empirical testing data are not readily available for CAV technology, so industry and government are utilizing different techniques to advance both the technology itself and the policies to regulate its use.

## 3.2    R&D Trends and Opportunities in Sustainable Intelligent Transportation Systems

Alex Schroeder, National Renewable Energy Laboratory, United States

➢ Link to presentation slides:
https://www.iea.org/media/workshops/2016/egrdtransportsystemsofthefuture/8102616IEASchroeder.pdf

The National Renewable Energy Laboratory (NREL) has a broad and deep research portfolio on low-carbon fuels (biofuel, hydrogen, electric) and vehicle efficiency, including analysis of the impacts CAVs might have on energy usage in the U.S. transportation sector. A recent NREL "bookend study" estimated that the fuel consumption change due to CAV deployment could range between a 90% reduction and a 200% increase based on the 2050 baseline[6].

NREL takes a holistic approach to sustainable transportation, viewing it as a network of travellers, services, and decision points connected by communication technology and decision-making tools—rather than just by vehicles and roads—to significantly reduce related energy consumption. The following discussion will describe NREL's sustainable research, working out from the centre of Figure 11.

Starting at the Traveler level, NREL and several partners initiated the Connected Traveler project to incentivize more energy efficient traveller decisions; common customer decisions include departure time, mode, ridesharing, alternate routing, alternate destinations, and trip chaining, for example. Project partner Metropia will provide a smart phone interface to help users learn efficient choices in real time, while allowing researchers to validate incentive effectiveness. A personal profile will be created for each user to help direct the incentives most effectively based on individual user data.



**Figure 11: Visualization of NREL's holistic approach to sustainable transportation research.**

NREL is also working on eco-driving; researchers have found that changing user behaviour will reduce fuel consumption by 5%–10% for the majority of drivers (20% for aggressive drivers). Analysis of existing methods to encourage eco-driving shows that they are not likely to change many people's habits, as other behaviour influences remain dominant. More research is needed in this area.

Moving out to the Vehicle level, NREL is evaluating truck platooning efficiency benefits. The fuel savings potential from truck platooning can fluctuate based on many different factors: vehicle spacing, cruising speed, speed variation, baseline aerodynamics, vehicle loading, and engine loading. Researchers are working to quantify the fuel savings sensitivity to each of these. NREL also validated
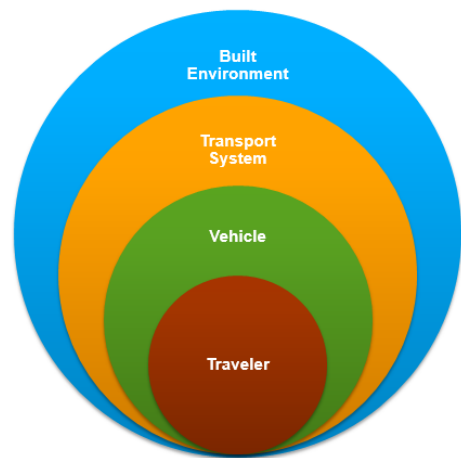
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[6] A. Brown, J. Gonder, and B. Repac. "An Analysis of Possible Energy Impacts of Automated Vehicles." Springer Book Chapter (2014).

the technology developed by truck platooning company Peloton, providing analysis of benefits for each truck in the platoon.

NREL's partnership with the Colorado Department of Transportation and a private company called Road X has been researching autonomous Class 8 trucks. Road X recently ran a Class 8 truck—one from Otto, an autonomous truck startup—on a 120-mile fully autonomous delivery[7].

Coupling transport system technologies such as eco-routing to the vehicle can provide further efficiency benefits. NREL has modelled the effects of eco-routing on two different powertrains in a real-world distribution of origin/destination pairs, optimizing the use of each to maximize different parameters (time, cost, distance). There is an aggregate energy savings potential of 4.6%.

DOT's AERIS (Applications for the Environment: Real-Time Information Synthesis) Glide Path Project bridges across traveller, vehicle, and transport system. The project uses V2I communications to optimize vehicle speed when approaching a traffic signal, based on the signal's timing. Speed recommendations can be provided to the driver using a human–machine interface, or directly to the vehicle's longitudinal control system to support partial automation. The former offered a 7% fuel economy benefit, while the latter led to a 22% benefit.

Another form of V2I, dynamic EV charging while a vehicle is in motion, could greatly improve efficiency in certain operational domains. For light-duty vehicles, covering only 1% of roadways—targeting urban areas and the most highly utilized roads—could cut fuel consumption by 25%. NREL is working with DOE's Vehicle Technologies Office to determine which roads would provide the most benefit. Converting current hybrid electric transit buses to full electric, enabled by dynamic charging, cuts fuel consumption by 50% (based on Minneapolis route data). Heavy-duty trucks work hardest on moderate-to-high-grade roadway segments; supplementing the combustion engine with electrification and 100 kW wireless charging on 1.5% or greater grades would allow engine downsizing and enable 9% fuel savings.

Integration of these technologies will require that the built environment be restructured. Asset management will likely replace asset ownership for both electric and transportation markets, and land-use planning and energy consumption considerations will converge. Vehicle electrification will create additional opportunities to exploit these integrated energy systems, but will complicate transportation infrastructure funding. Car companies are becoming major players in energy storage, while some gas and electric utilities are providing increased "transportation services."

All of the sustainable mobility themes will combine into an integrated mobility future: electric, connected, and automated vehicles, the internet of things, machine learning, big data, and mobility on demand.  Safety could be improved by an order of magnitude, while congestion, emissions, and fossil fuel use could be reduced considerably. Access to jobs and services could improve because of increased accessibility and mobility as well as decreased overall transportation costs. All of these factors assimilate into a single Smart City vision.

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[7] Alex Davies. "Uber's Self-Driving Truck Makes Its First Delivery: 50,000 Beers." *Wired.* 25 October 2016. https://www.wired.com/2016/10/ubers-self-driving-truck-makes-first-delivery-50000-beers/.

The DOT Smart City Challenge pledged $50 million (from DOT and Vulcan, Inc.) to one city to help it define what it means to be a "Smart City" and become the first U.S. city to fully integrate innovative technologies—connected and automated vehicles, smart sensors—into its transportation network. The initiative encouraged the concept of a "living lab", with open data to provide analysis and best practices to future technology deployments. A total of 78 cities applied (Figure 12), far above the initial expectations, and the city of Columbus, Ohio, won. Most of the cities who applied voluntarily included their additional funding on top of the $50 million prize and some will likely implement a good portion of their proposed initiatives regardless of the results of the Challenge.
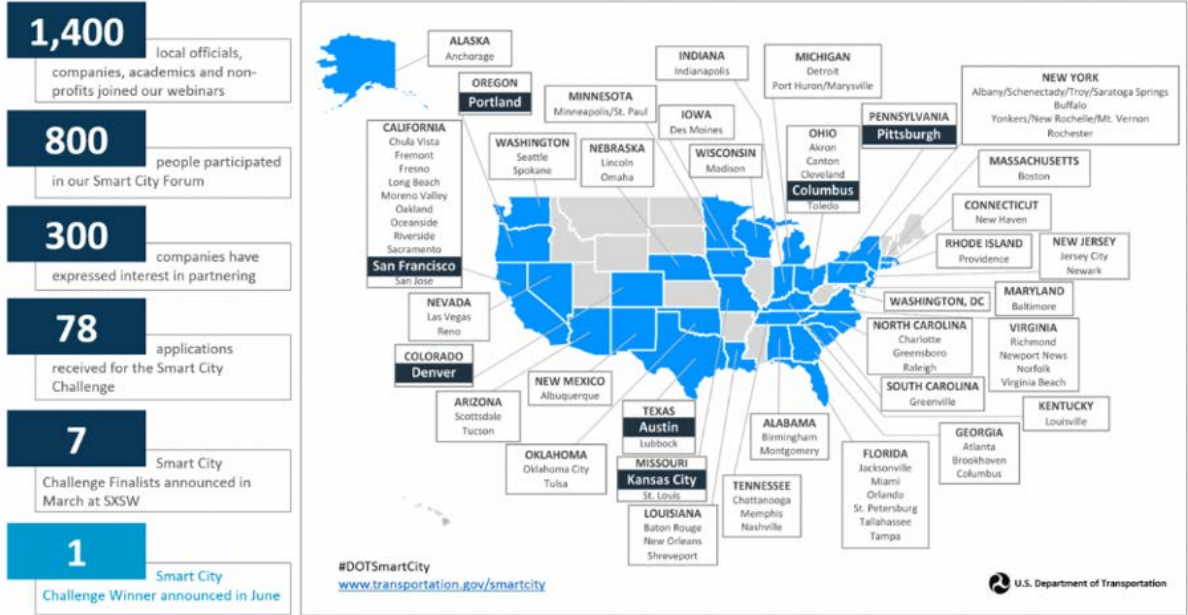


**Figure 12: Applicants for the DOT Smart City Challenge: indicating higher than expected interest from local city governments, companies, and non-profits.**

Collaboration between generally independent government agencies is increasing owing to the wide spectrum of integrated technology applications. DOE and DOT signed an MOU on transportation systems, aiming to:

- Collaborate on SMART Mobility and the Smart City Challenge.
- Provide leadership and best practices in terms of data gathering and usage.
- Leverage DOE expertise on transportation electrification.
- Leverage DOT expertise on automated and connected vehicles.
- Utilize existing stakeholder networks, such as DOE's Clean Cities Coalitions, for institutional knowledge on pre-existing local resources and effective outreach pathways in the near term and as a template for how city stakeholders can engage and support Smart City Challenge and SMART Mobility efforts that continue, or grow, in the longer term.
- Explore opportunities to support having technologists in cities.

There are several challenges due to the unparalleled level of technical and institutional complexity introduced by an integrated and efficient transportation system. Traditional sectors are being asked to collaborate in ways that aren't immediately familiar or apparent. Government institutions will need to determine how to balance potential policy trade-offs. The uncertainty posed by the speed of transformation will require new approaches to policy and regulation. Testing of next-generation

technologies and systems in the real world has already begun, even in the absence of fully known and understood outcomes.

These complex challenges can be approached by targeting R&D on key opportunities. There is a distinct lack of understanding of traveller behaviour; transportation models must be updated to include dynamic traveller choices, filling the gap between system design and behavioural psychology. Machine learning will be critical to fully utilize the overabundance of available data, enabling accurate predictive modelling. Lastly, with increased data usage comes increased concerns for personally identifiable information, privacy and cybersecurity issues; and increased connectivity has the potential to exacerbate the issue. Overall, a more aggressive and adaptive approach is needed for R&D.

## 3.3 Transforming Transportation Technologies: The Toyota Experience

William Chernicoff, Toyota Motor North America

 ➢ Link to presentation slides not available

Automotive OEMs are actively adapting their business models to address the current age of rapidly changing social and mobility trends, spurred on by evolving government regulations and rising customer demands. Past predictions of industry change have generally been inaccurate, and the complexities inherent to the CAV adoption timeline indicate that this scenario is unlikely to be the exception. For example, many in both government and industry conclude that the population is becoming less and less interested in cars and driving. The aggregated data disagrees; people are actually driving more. VMT continues to rise, and recent petroleum consumption is at an all-time high as millennials move to the suburbs and buy more cars. This trend is paralleled by a drastic increase in regulatory complexity due to overlapping and competing regulations (e.g., the Renewable Fuel Standard, the California Zero Emission Vehicle mandate, the Corporate Average Fuel Economy regulations)[8].

The timeframe (up to and past 2050) chosen in a research project can have significant impacts on the results, and if decisions are made based on inaccurate research, potential risks exist that could create a conflicting policy environment. This is evidenced by the potential for "lock-ins" and dead ends; one example is CNG, which could meet near-term emissions goals but will top out very quickly and be dropped to achieve mid-to-late-term goals. The current mix of short-term regulations will dictate where the industry goes in the long term, and both government and industry must continue working together to compromise. Higher efficiency and lower emissions can be driven by technology or by regulation; industry prefers the former, while government prefers the latter. Navigating this interaction is and will continue to be difficult, but the consumer holds final say in whether a technology will actually succeed in the market.

Analysis of consumer decision making is becoming more complex as consumers are being faced with several new and different decisions that do not mirror historical trends. Industry is researching new

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[8] Note: Toyota is still researching the GHG impacts from biofuels and has not determined whether biofuels will provide a net GHG benefit.

methods to improve the accuracy of their understanding of these decisions. Social media is playing a larger role; Toyota is currently working on a project to understand the effects of social media on decision making. One example of recent failed consumer choice analysis is in the electric vehicle market, specifically, offering free charging as an incentive to drive sales. By initially offering free charging, the manufacturer must eventually either get rid of it (reduce value to the customer) or increase investment (customers stay too long at each charger, leading to increased cost and a poor business case for charging providers). Additionally, even with further up-front incentives, people still think that the vehicles are too expensive to own; price continues to be the biggest driver.

Harnessing future mobility trends requires a much better understanding of consumer choice. The overall process of customer choice modelling must be improved, perhaps through extrapolation of analogous technology adoption timelines like the previously mentioned analysis on how consumers respond to free charging incentives, or by other means. One route is to research how social media can influence such mobility-related decision-making. In parallel, stakeholders must conduct further research on the energy impacts of vehicle autonomy; there are not enough empirical data to establish consensus on this. Toyota's long-term sustainability vision aims to pull carbon out of everything in the company's global supply and value chain - in part through a hydrogen-based society - but the level of integrated autonomy will depend on how these challenges play out.

## 3.4 Autonomous Vehicles: Past, Present, Future

Cem U. Saraydar, Director, Electrical and Controls Systems Research Lab, GM Global Research and Development

➢ Link to presentation slides:
https://www.iea.org/media/workshops/2016/egrdtransportsystemsofthefuture/10CUS_DOE_Workshop_201610 26_FINALdistrib.pdf

General Motors (GM) has a long history of interest in vehicle autonomy. At the 1939 New York World's Fair, GM's Futurama exhibit showed an imagined world in 1960, complete with automated highways. The company continued unveiling conceptual autonomous transportation designs until the National Automated Highway Safety Consortium in the 1990s. This project culminated in a 1997 demonstration along I-15 near San Diego; the focus was on platooning for safety and increased traffic density. A wide slew of technologies were demonstrated, but they were still too advanced for commercialization. The next major demonstration was part of the Defense Advanced Research Projects Agency's (DARPA's) Urban Challenge in 2007, in which GM and Carnegie Mellon University's "Boss" automated SUV finished first in a 60-mile course with urban traffic. The computation equipment and sensors filled the entire vehicle compartment and roof, preventing commercialization, but the technology was validated.

GM introduced its Electric Networked-Vehicle (EN-V) 2.0 concept at the 2014 ITS (Intelligent Transportation Systems) World Congress in Detroit, Michigan. The low-speed city car concept is equipped with active safety and automated driving technology; it would be ideal for "last-mile" personal transportation in busy inner cities or private campuses/communities. On-board technologies included cameras, GPS, light detection and ranging (LIDAR), maps, vehicle-to-everything (V2X) communications, smartphone, and radio-frequency identification (RFiD). These amounted to

autonomous chauffeur capabilities, autonomous valet parking and retrieval, urban platooning and traffic jam assistance, intersection collision avoidance, and pedestrian crash avoidance.

The first full application of GM's automated driving technology is being planned through its Super Cruise system, on the Cadillac CT6. Super Cruise is capable of lane centering, combined with adaptive cruise control, which uses GPS and cameras to keep the car in its lane through lateral and longitudinal adjustments. The system also implements collision avoidance, a long-distance radar system that detects vehicles more than 300 feet ahead and automatically accelerates or applies the brakes to maintain a preset following distance. This will be the first truly hands-off highway driving feature in a vehicle. Additionally, GM is currently testing self-driving Chevy Bolts in San Francisco, Arizona and Michigan.

Customers noted several factors when surveyed on the need for using (or not using) autonomous vehicles: staying safe and secure, avoiding danger, reaching destinations on time, door-to-door transportation, productivity, communication with others, and child safety. It should be noted that fuel efficiency and emissions reduction were not mentioned as factors; these are seen only as by-products of efforts toward the other factors.

The automated driving puzzle faces a number of challenges. Autonomous systems must be able to handle a wide variety of inputs, as shown in the context diagram below (Figure 13). Design of automated vehicles is a complex task with several complicated linear and non-linear interactions.
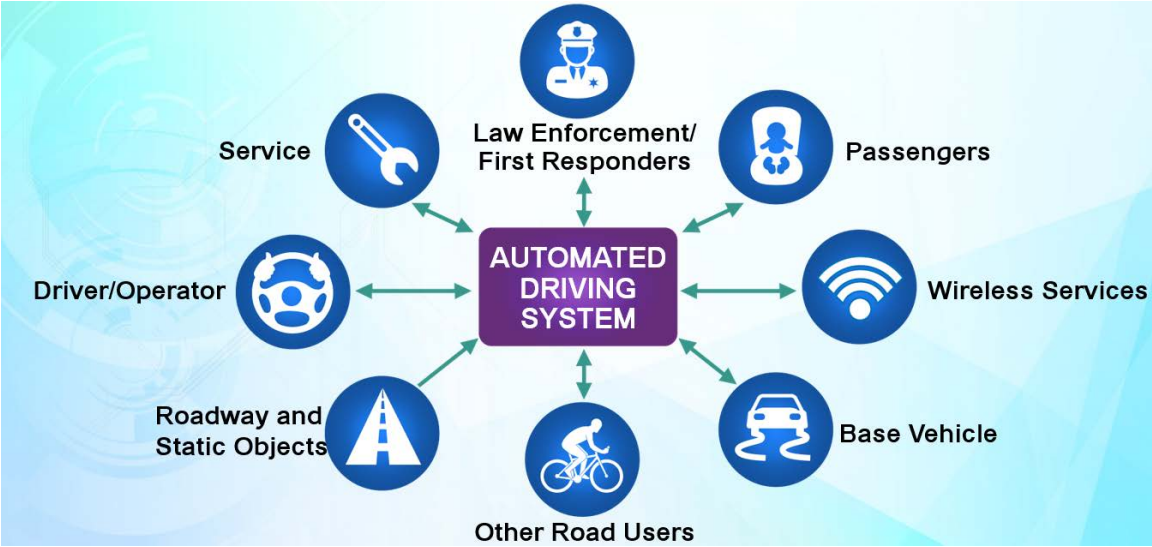


**Figure 13: Context diagram portraying the wide range of inputs that must be managed and analyzed by an automated driving system**

Sensors and signal sources provide inputs to the system, which uses them for environment perception and mapping/localization. This information is then used for planning and state management, which allows for accurate, safe, and efficient vehicle control. The elements under consideration for design of such a system are shown in Table 3.

**Table 3. Automated Driving Technology Elements**

| HARDWARE | Sensors (Camera, Radar, LIDAR) |
| | Processors (CPU, GPU, FPGA) |
| | Actuators (Brakes, Steering, Gear Select) |
| | Transceivers (Connectivity) |
| LOGIC, SOFTWARE AND DATA | Image Processing, Sensory Fusion, Perception, Planning, Behaviour |
| | High-Definition Maps and Real-Time Road Conditions |
| SYSTEMS INTEGRATION | Validation and Testing |
| MANUFACTURING | Assembly and Programming |

A key difficulty lies in determining operational domains, something which is easy for humans who have experience driving on a wide variety of road conditions, locations and geometries. An autonomous system must be able to distinguish between, and operate on, freeways, city centre local roads, arterial roads, residential roads, industrial roads, parking lots, garages, tunnels, bridges, construction zones, and more. Operation must also be unhindered in all environmental conditions, including differing road surface conditions (clear/wet/icy), illumination (day/night), and atmospheric conditions (clear/fog/blowing leaves). Traffic conditions add an additional level of complexity, with varying speed and density possible in combination with any of the above road types and environmental conditions. Outside of operating on the road, the cars must also be able to park in all situations (street side, parking lot, garage, carport), and manufacturers and policy makers will need to determine whether the vehicle must be supervised (valet).

Current technology is available to support autonomous driving capability in some operating driving domains, however sensing and perception systems are not yet robust enough for fully autonomous driving capability under all conditions a vehicle may come across regardless of its operating environment. Object sensors need to be smaller and easier to fit on the vehicle, and they need higher resolution, higher accuracy, and higher update rates with lower latency to sustain an accurate portrayal of the drive environment. The vehicles must be capable of developing situational awareness in complex environments, taking into account road type, traffic condition, environmental condition, etc. This includes the ability to react safely to new and unusual events, such as emergency situations, and compensating for diverse behaviour of non-autonomous vehicles. Advanced visualization capabilities will be required, including physics-based active sensor models and a verifiable non-robot driver model.

Automated systems must be fault-tolerant and fail-safe, either with driver-in-the-loop or not. Sensing driver attentiveness and awareness is also a major safety concern for vehicles that depend on driver-in-the-loop fail-safes. Fail-operational functionality is essential and must include procedures for sensing, actuation, processing, alert communications, and power failures.

Positioning technology is critical to fully autonomous driving capability. Digital maps and GPS must be available (e.g., in urban canyons) and accurate down to the lane level. The system needs to be able to resort to localization if there is limited accuracy or no GPS available. Additionally, there is a need for faster update rates to improve response time and accuracy.

Vehicle communication with infrastructure, other vehicles, or other entities, or what is referred to as V2X (vehicles to everything) needs to be explored further. Requirements include security/privacy, interoperability, and congestion management.

There are numerous fully commercialized technologies that can be utilized to enable autonomous and connected vehicle deployment. These include radar with various ranges, visible and infrared video used on the front and rear of vehicles, LIDAR, GPS, and existent map databases for navigation systems. Additionally, automotive manufacturers have experience in computer-controlled actuators for electric power steering, brake systems, and powertrain control. Existing communication networks such as controller area networks (CANs) and Flexray (safety critical) and Ethernet (infotainment) can be used for on-vehicle communication.

GM sees that a plethora of technology availability and social trends will enable CAVs to successfully penetrate the market. GM Chief Executive Officer and Chairman Mary Barra predicts that the auto industry will change more in the next five to ten years than it has in the last fifty.

## 3.5    Testing and Deploying New Solutions Through Collaboration

Juho Kostiainen, VTT Technical Research Centre of Finland Ltd., Finland

> ➢ Link to presentation slides:
> https://www.iea.org/media/workshops/2016/egrdtransportsystemsofthefuture/11Kostiainen20161026_v2.pdf

VTT Technical Research Centre of Finland Ltd. (VTT) provides expert services for domestic and international customers and partners, for both the private and public sectors. VTT develops new smart technologies, profitable solutions, and innovative services, and it cooperates with customers to produce technology for business and build success and well-being for the benefit of society. VTT is part of Finland's innovation system and operates under the mandate of the Ministry of Employment and the Economy, being 30% funded by the government. VTT is focused on applied research, which is bookended by universities conducting basic research and industry focusing on development.

VTT's spearhead program TransSmart (2013-2016) was established as a collaboration platform for the development of smooth-running, cost-efficient, and environmentally friendly transport systems. Its aim was to serve as a network for government, industry, and academia to jointly identify knowledge gaps, develop focused research activities, help realize bigger projects, and both pilot and demonstrate new solutions. Its four focus areas were low-carbon energy, advanced vehicles, smart transport services, and transport systems.

Autonomous, connected, electrified, and shared vehicles can potentially benefit from one another. The mobility market is worth trillions of dollars, giving OEMs a reason to work toward shared autonomous vehicles. Several mobility initiatives in Finland aim to get rid of the personal car

ownership model and, based on the results, the country introduced a MaaS concept—one for which the country is recognized.

Shared vehicles reduce overall VMT by increasing passengers per car[9]. One example, UberPOOL, claims to have saved 55,000 tons of $CO_2$ in the first seven months of 2016 by connecting rides efficiently. Sharing and new services provide traveller options and reduce the need to own a second car.

Connected vehicles are likely realizable in the not-too-distant future. Most people are already connected through their smart phones; this existing telecom connection can be used to provide services to users or collect data from them. Connection will be more difficult in rural areas, where roadside infrastructure will be costly and challenging to install and actuate. One way to approach expansion into the vehicle space is to develop popular and effective apps such as Uber, Grab, and Waze; with Waze, public authorities can actually send messages to users regarding traffic and road information. Additionally, eTag use can be expanded beyond electronic toll services. User acceptance (GPS tracking of citizens) and feasible business cases could be key limiting—as well as enabling—factors for many connected solutions.

Finland provides a few examples of trying to nudge consumer behaviour. From July 2015 to December 2015, for example, the government ran an experiment offering a temporary €1500 discount (with industry contributing €500) on a new, more fuel-efficient car when citizens scrapped an old one. Approximately 8000 people took advantage of the system, leading to an €8 million cost to the government. However, the tax income from the vehicle purchases generated €25.5 million, in addition to the reduced emissions and safety improvements. Finland has also made public transportation a realistic alternative to personal vehicle usage by making it more effective, more available, and more valuable (e.g., by providing open data and source code for smart journey planner applications and introducing USB charging on-board) to most users.

Finland aims to become a hotspot for developing and integrating new transport solutions, especially through public-private research collaboration. For example, The Finnish Transport Safety Agency (Trafi) coordinates collaboration and information exchange between transport test sites at a national level.  This "living lab" or "Traffic Lab", consists of various pilots, tests, and demonstrations of smart systems and services, such as Aurora, which is a testing site for ITS and CAVs in Northern Finland.

The transit system in the Helsinki region, managed by Helsinki Regional Transport (HRT), is taking significant steps toward emission reductions and an electric bus system. HRT is aiming to reduce its emissions by 90% between 2010 and 2025 using the vehicle mix shown in Figure 14. Together with research organisations, HRT has explored the usability of electric buses, batteries and charging systems through field studies and laboratory tests. Different manufacturers' eBuses have been tested under normal operating conditions over the past years, and now the eBuses are transitioning from the pilot phase to commercial operations.  Usually HRT does not purchase and own its buses, but in 2015 the organization decided to buy 12 eBuses as a pre-commercial procurement to start market

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[9] E. Martin and S. Shaheen. *Impacts of Car2Go on vehicle ownership, modal shift, vehicle miles traveled, and greenhouse gas emissions.* Working paper. July 2016.

discussion. HRT is collaborating with other cities to implement charging infrastructure and to exchange knowledge and best practices on electrification.
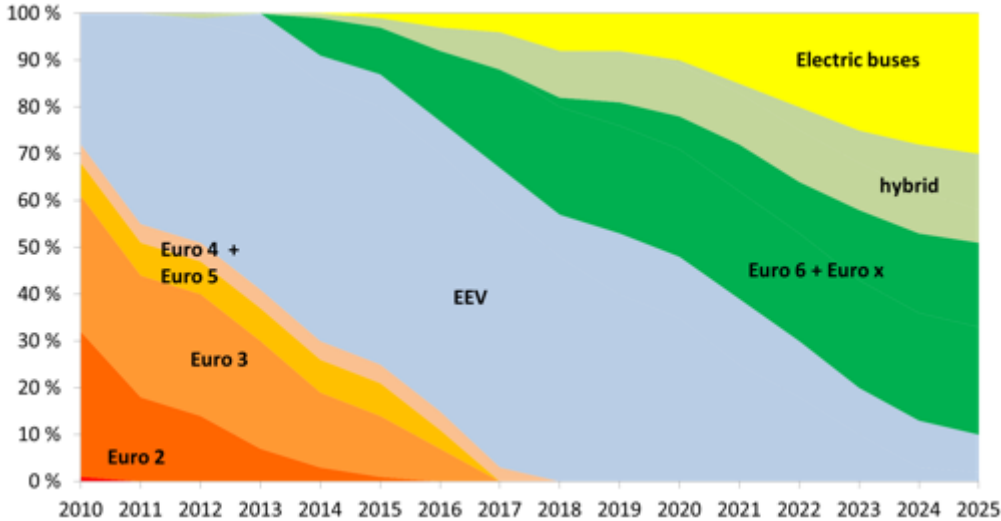


**Figure 14: Helsinki Regional Transport's Fleet Strategy through 2025**

In addition to emission reductions, the acquired eBus fleet is being used as an innovation platform for developing, piloting and demonstrating new services and technologies in real operational environment. For this, VTT is partnering with HRT, three universities and other public and private parties such the eBus manufacturer Linkker to set up the development platform and support the R&D activities. Third parties can instrument, conduct tests, and collect data on in-use eBuses that use few minute quick charging at the end(s) of the lines. Examples include using Bluetooth for passenger services and input, providing data to the driver for traffic light acceleration/deceleration, observation technologies, and collecting technical data from the bus while it is running. The goal is to enable and support collaboration and faster development of mobility services through a concrete, open test environment in a real public transport context.

Regarding policies and regulation, flexibility is needed to supporting thinking outside the box and testing, while still ensuring fairness in the market. There needs to be a balance between pre-empting and adjusting to new solutions; one needs to think far enough ahead to allow for innovation, while maintaining safety, security, service level, and effective competition.

One example of such thinking is the proposed Traffic Code that, if approved, would bring about significant change to Finnish transport service laws. Currently, taxi service is limited; there are a fixed number of taxis that must work within a fixed area. In July 2018, new legislation will allow anyone to get a license to operate as a passenger transport service in a specified area. At the same time, the maximum cost per trip limit will also be removed. Another example of policy change is bus regulations in Finland. At the moment, HRT is the sole organizer of bus operations within the Helsinki region; no one else is allowed to set up local bus lines. In a few years, the market will be opened up, pending discussion of EU legislation giving HRT a right to monopoly for public transport services. Additionally, all transport service providers would be required to provide interfaces for users to view routes, schedules, and prices; the interface would also need to offer ticket purchasing services.

Smart systems and cities need to collaborate across sectors, including transportation, energy, information and communications, land use planning, and others.

# Session 4. Policy and Markets Supporting Future Transportation Technologies

Chair: Herbert Greisberger, eNu, Austria

## 4.1 Overview

To drive deep decarbonization, policy makers will need to identify the best policy levers—price-based, regulatory, and RD&D—to realize new technologies and mobility systems. These potentially sustainable innovations will transform the transportation industry, forcing urban planners and decision makers to address new transportation network issues inherent to pervasive connectivity between vehicles and infrastructure.

The transition to autonomous vehicles is occurring in parallel with a revolution in traditional automotive business models. Researchers are realizing that industry incumbents (i.e., most large automotive OEMs) are discerning which components of their existing business models need to be scrapped in order to make way for more service-based value production. New automotive start-ups are more nimble owing to the lack of existing customer expectations; incumbents will need to look to these niches as the transportation system and its users evolve.

Understanding consumer adoption and behaviour toward new technology is key to developing policy and markets that will effectively encourage more sustainable mobility systems. Researchers are working on consumer studies that will help legislators make evidence-based autonomous vehicle policy decisions. Since the technology is new, unfamiliar, and not available to consumers, there is a need to develop new metrics (e.g., "intent to use" or acceptance) and interview methodology to provide valuable data to regulators on how consumers perceive transportation technology trends.

One of these trends, the "ACES" paradigm, continues to gain traction as automakers transition to "mobility service providers" or partner with transportation network companies (TNCs) such as Uber and Lyft. Understanding the interdependency of these trends is important for guiding effective policy implementation and predicting how the new mobility market is most likely to emerge. While policy mandates have been the most effective at increasing electrification, consumer choice (based on cost and convenience) might be the strongest factor in implementation of shared vehicles.

A number of individual stakeholders in academia, government, and industry are working toward ACES solutions, but collaboration will be essential to ensure the most effective RD&D. Governments can learn from each other's experience with policy, for example, by looking to EV market leaders such as Norway, the Netherlands, and California State for regulatory guidance on electrification.

## 4.2 Business Models for Ultra-Low Emission Vehicles and Sustainability

Gavin D. J. Harper, Birmingham Energy Institute, United Kingdom

> ➢ Link to presentation slides:
> https://www.iea.org/media/workshops/2016/egrdtransportsystemsofthefuture/12GHarperIEAPresentationOctober.pdf

As technology and social trends continue to evolve, standard automotive business models will need to be modified. There is currently no incentive for vehicle OEMs to improve fuel efficiency outside of regulation, which is a relatively blunt instrument. A step change in energy efficiency is needed, but to do so, energy efficiency must be a profitable part of a working business model. Business models mediate between the technical inputs (e.g., feasibility, performance) and economic outputs (e.g., value, price, profit); this mediation includes the value proposition, value chain, cost/profit, value network, and competitive strategy. Generally, business models are all about value, specifically creating and capturing value. One group of researchers proposed that a company must manage its business model through three "boxes": manage the present, selectively forget the past, and create the future.

Ultra-low-emission vehicle (ULEV) OEMs are at opposite ends of the market scale spectrum: either "incumbents" or "insurgents". The incumbents (e.g., GM, Nissan) must maintain their brand and reputation, which tends to stifle innovation. The smaller niche insurgents (e.g., Tesla, Smith Electric) are building their brands and can assert new business models into the industry. There is co-evolution of sustainability start-ups and market incumbents toward the sustainability transformation of the transportation industry. This paradigm is shown in Figure 15; incumbents provide market share and work toward environmental and social performance, while insurgents' role is the transpose.
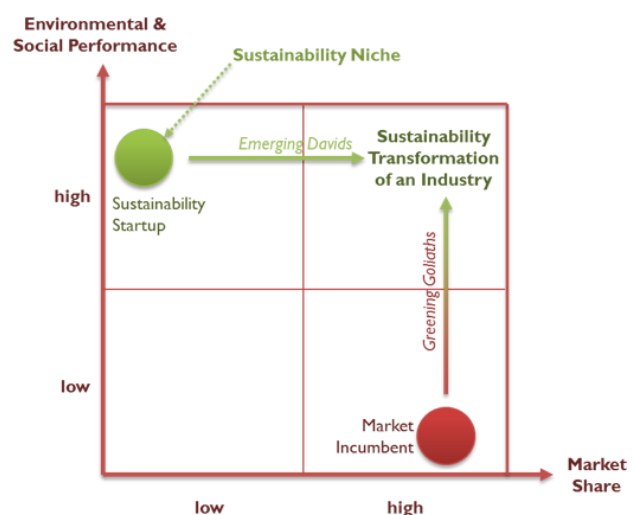


Figure 15: Co-evolution of startups and incumbents toward sustainability transformation. Startups lack market share, while incumbents lack environmental and social performance.

Incumbents must discern what bits of the present automotive industry need to be forgotten to move to more sustainable vehicles. These larger OEMs do not have the smaller volumes and lacking economies of scale that allow for a more individualized value proposition. The OEM business model has not changed much over time; in fact, most OEMs are relatively public and well known, and are derived from past innovations, including:
- Assembly lines (Ford)
- Press steel bodywork (Budd)
- Paint, model cycles, market segmentation (GM)
- Quality control, just-in-time, Kaizen (Toyota)

Unfortunately, even with all of the built-in efficiencies leading to ever-increasing vehicle quality and reliability, cars are not emotionally durable and end up being scrapped before their actual end-of-life (EOL) due to consumers' desire for something new or exciting. Incumbents will need to look toward the niche insurgents to sustainably reshape the industry moving forward.

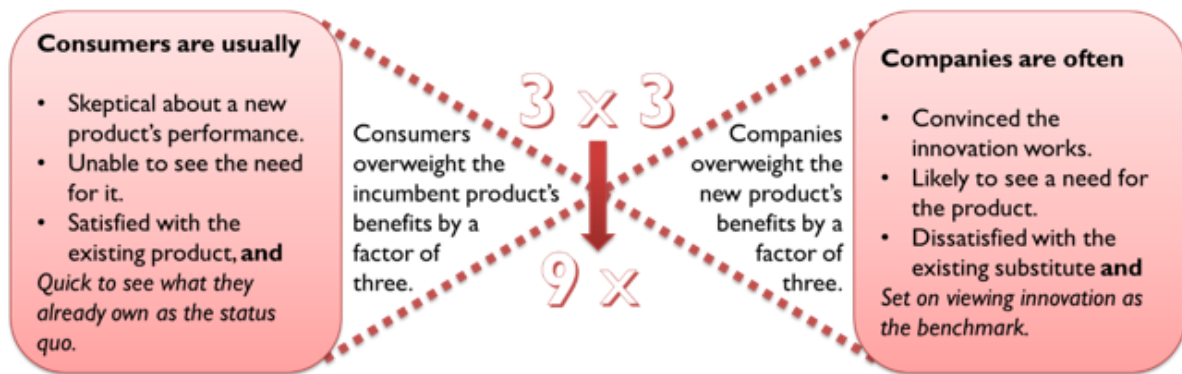Traditionally, the business model and vehicle design shape each other based on a set process (i.e., "fit powertrain in standard vehicle chassis"). Niche manufacturers such as McLaren have rearranged this, first to create the process, then to allow the process to shape the product and business model. In the example of lightweight hydrogen-based transportation company Riversimple, the business model was designed first, shaping the product based on actual user requirements. The process was then designed around the most efficient way of meeting these requirements.

This new business model structure could lead to a fourth industrial revolution, as exemplified by The Manufacturing Technology Centre's Factory in a Box. This overrides traditional processes that depend on centralized production and long supply chains with a heavily automated, digitized, and "on-the-fly" system that can be contained in a box and shipped around the world to be near its point of product consumption. The Factory in a Box would revolutionize the process of breaking into developing markets.

One example of this new business model structure is University of Birmingham's *Doing Cold Smarter* strategy for diesel transport refrigeration units (TRUs). Diesel TRUs produce 6 times more nitrogen oxide and 29 times more particulate matter than the actual vehicle powertrain because of lack of regulation. Using liquid nitrogen as the energy vector in a Dearman engine would heavily reduce emissions. Extrapolating this idea out further, one could create a *Cold Economy* in which different business models could be developed to deliver "cold" as a service to all energy sectors and decouple it from hydrocarbon fuel in the process.

University of Birmingham's Centre for Fuel Cell and Hydrogen Research partnered in an EU-funded project called SWARM to deploy 100 small lightweight fuel cell vehicles. A major challenge for these and other ULEVs is a mismatch of customers' expectations and innovators' perceptions of those desires. Gourville proposed a "9x Effect", which generally states that both consumers and companies overweigh new product benefits by a factor of three, leading to an overall dissatisfaction with the product results (summarized in Figure 16 below)[10].

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[10] John T. Gourville. "Eager Sellers and Stony Buyers: Understanding the Psychology of New-Product Adoption." *Harvard Business Review* (June 2006).

**Consumers are usually**

- Skeptical about a new product's performance.
- Unable to see the need for it.
- Satisfied with the existing product, **and**

*Quick to see what they already own as the status quo.*

Consumers overweight the incumbent product's benefits by a factor of three.

3 x 3

9 x

Companies overweight the new product's benefits by a factor of three.

**Companies are often**

- Convinced the innovation works.
- Likely to see a need for the product.
- Dissatisfied with the existing substitute **and**

*Set on viewing innovation as the benchmark.*

*There's a fundamental problem for companies that want consumers to embrace innovations: While developers are already sold on their products and see them as essential, consumers are reluctant to part with what they have. This conflict results in a mismatch of nine to one between what innovators believe consumers want and what consumers truly desire.*

**Figure 16: The 9x Effect (Gourville 2006), which characterizes a fundamental problem for consumer acceptance of innovation.**

Analysis shows that purchase price is a key barrier for hydrogen fuel cell vehicles. The SWARM team included a company and concept called Riversimple. Riversimple is service-contract-based; the consumer buys a vehicle as a contract, and the company provides infrastructure and fuel for an additional flat monthly fee. This completely transforms the consumer transportation business model. First, the manufacturer now has incentive for reducing fuel consumption; Riversimple is responsible for providing varying levels of hydrogen for a flat monthly rate. Second, selling a car delivers only 40% of the available revenue. Riversimple captures 100% of the lifetime revenue by incorporating fuelling into the business model. Third, instead of trying to fit large fuel cells in standard pressed steel body panels, the business model enables a smaller fuel cell with an ultra-capacitor in a smaller chassis. The entire MaaS concept fulfils user requirements (low capital cost and reliable transportation) and provides a stronger business model (capturing the car's value over its entire lifecycle).

Moving to a cleaner mobility solution will require the use of many strategic elements and critical materials. University of Birmingham Centre for Strategic Elements and Critical Materials is studying the vulnerability of sustainable transport to these supply chain disruptions. A number of incidents illustrate this issue; for example, the sole PA-12 (fuel system pipe liner chemical) factory caught fire in Germany in 2012, leading to a worldwide panic to start up a new supply source. The City of Birmingham is specifically researching two critical supply chain vulnerabilities: magnets and platinum. It partnered with the European Union on the Remanence Project, which focuses on the recycling of rare earth magnets and manufacture of new magnets for electric vehicle drive motors. The overall approach to manufacturing will need to consider cradle-to-cradle effects, as opposed to a linear model in which products are disposed of and the supply chain vulnerabilities are disregarded.

The goal should be to incorporate all of these considerations into a single system, with different energy vectors all working together through primarily service-based business models, designed to carefully consider the technologies' inherent supply chain vulnerabilities. Birmingham has ambitious plans to make this carbon and waste reduction transformation, having laid out its priorities in the Carbon Roadmap produced by the City's Green Commission.

## 4.3 Measuring Influences on Automated Vehicle Market Development: Consumer Acceptance and Adoption

Johanna Zmud, Transportation Policy Research Center, Transportation Institute, Texas A&M University, United States

➢ Link to presentation slides:
https://www.iea.org/media/workshops/2016/egrdtransportsystemsofthefuture/13ConsumerAcceptanceJohannaZmud.pdf

Texas A&M is one of the leaders in autonomous vehicle research in U.S. academia. The Texas A&M Transportation Institute (TTI) Policy Research Center is an independent resource to legislators that aims to facilitate evidence-based policy making. It has assessed mobility impacts of autonomous vehicles, specifically researching consumer acceptance and intent-to-use so that relevant policies, being based on evidence rather than speculation, can effectively nudge consumer behaviour toward desirable social impacts.

Developing methodology to study consumer behaviour and acceptance regarding autonomous technology is very difficult. The technology is brand new, so the majority of consumers have little or no experience with it and do not have the mental models available to reference. People cannot base their responses to questions on past or current experience as they can for surveys on other technologies, and researchers cannot measure user adoption until autonomous technology is actually available on the market; the only feasible variable to study is intent-to-use, or acceptance. This can be done by starting the consumer interview with text and video descriptions of self-driving vehicles, then asking the interviewee to consider the likelihood of their self-driving vehicle usage given that the vehicles are currently available on the market.

TTI conducted survey studies in four Texas cities: Austin, Dallas, Houston, and Waco. Around half of the people surveyed said they would use self-driving cars if they were available. For those who do not intend to use them, the primary reasoning is a lack of trust in the technology, followed by safety and cost (Figure 17). Concerns surrounding added technology complexities, privacy, and the potential for systems to be hacked, hijacked, or crashed are prominent across all respondents. For many consumers, trust in the technology is a much stronger indicator of interest than product quality.
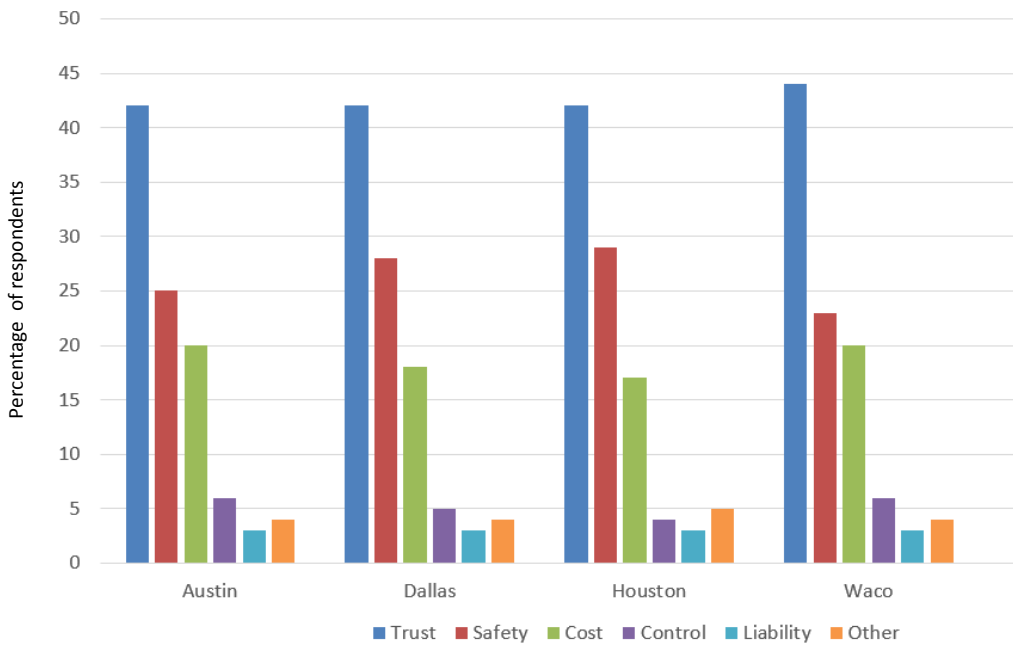
**Figure 17: Reasons for not intending to use self-driving vehicles.**

The survey data did not split down typical demographic lines; age, income, and education did not affect intent-to-use very strongly. The strongest predictors of intent-to-use were psychological and personality variables, namely people who:

- Have any physical conditions that prohibit them from driving
- Think self-driving vehicles would decrease crash risk
- Use smartphones, text messaging, Facebook, and transportation apps
- Are not concerned with data privacy about using online technology
- Think using a self-driving vehicle would be fun
- Think it would be easy to become skilful at using self-driving vehicles
- Believe people whose opinions they value would like using self-driving vehicles

There has also been a great deal of discussion on how autonomous technology will affect ownership models. Will people own or share self-driving vehicles? The majority (59%) of the survey respondents in Austin preferred personal ownership, simply because of the convenience and freedom of use associated with having the vehicle available at all times. Those who preferred sharing did so because they thought it would be both cheaper and more practical for everyone. Most also said that they would not change the number of vehicles in their household, nor would they drive any less, indicating that the energy consumption impacts of self-driving cars are still an unknown.

TTI also uses a traditional trip-based model (Capital Area Metropolitan Planning Organization, or CAMPO) to understand how road congestion might be affected, specifically in Austin, Texas. The model assumes that vehicle travel time will be less onerous with the emergence of self-driving technology, causing drivers to avoid travel less. As sensitivity to time spent inside the vehicle is reduced, the model shows:

- a slight increase in total daily VMT,
- more individual driving (increase in total automotive trips), and
- less transit use (especially local buses).

The overall energy and environmental impacts of self-driving vehicles are not a given, until there are more and better data on their actual usage. Unfortunately, measures of acceptance are more reliable than measures of adoption at this point in time, so these data are not available. There is opportunity to continue learning about people's misconceptions and uncertainties regarding the technology through qualitative interviews; and accurately measuring intent-to-use, including education of respondents prior to actual data collection, helps provide some form of quantitative policy guidance. Understanding usage will require public acceptance data, analysis of incentives and disincentives to use, and an understanding of the value of time to consumers. Situational travel behaviour ties vehicle usage to quantitation of ownership trends, specifically consumer willingness to pay for automation, ownership persistence, and size and impact of "new" owners. For whom and for what will vehicle ownership remain?

Researchers are working to solve this dilemma through behaviour analogues, which would allow them to simulate the experience of vehicle autonomy, and carefully leveraging pilot tests to study user behaviour. Acceptance, use, and impact are all moving targets; determinants may change as access to the vehicles becomes widely available.

## 4.4   E-Mobility: Yesterday, Today, Tomorrow

Levi Tilleman-Dick, Fellow, New America/Managing Director, Valence Strategic LLC, United States

> ➢ Link to presentation slides:
> https://www.iea.org/media/workshops/2016/egrdtransportsystemsofthefuture/14Levi20161025eMobilityyester
> daytodaytomorrow.pdf

The current international EV market is on a steady upward trajectory and fully autonomous vehicle technology is fast approaching. Synergies between transportation network companies (which operate vehicles as a fleet), autonomy and electrification could potentially generate substantial market pull for electric vehicle over the coming decades.

In 2016, global progress in EV technology is embodied in transition from Tesla Roadster, which was relatively impractical owing to high cost and small size, to Chevy's Bolt EV, which is affordable and practical. Vehicles like the Chevy Bolt could be game-changers for vehicle electrification.

Progress in electrification up until now has relied heavily on government policies to promote electric vehicles.  The California ZEV mandate was initially the biggest driver for EV adoption; it created a synthetic market for ZEV credits (generated by ZEV sales) in California and complying states. This has made innovation a more profitable business model because the credits can be sold to automotive manufacturers who are not selling enough ZEVs to meet the requirement. From 2012-2013 Tesla and Toyota reaped the largest benefit, while GM, Chrysler, and Honda purchased the most credits (Figure 18). The mandate will continue to require increased numbers of electric vehicles and the value of credits will rise and fall based on supply and demand.
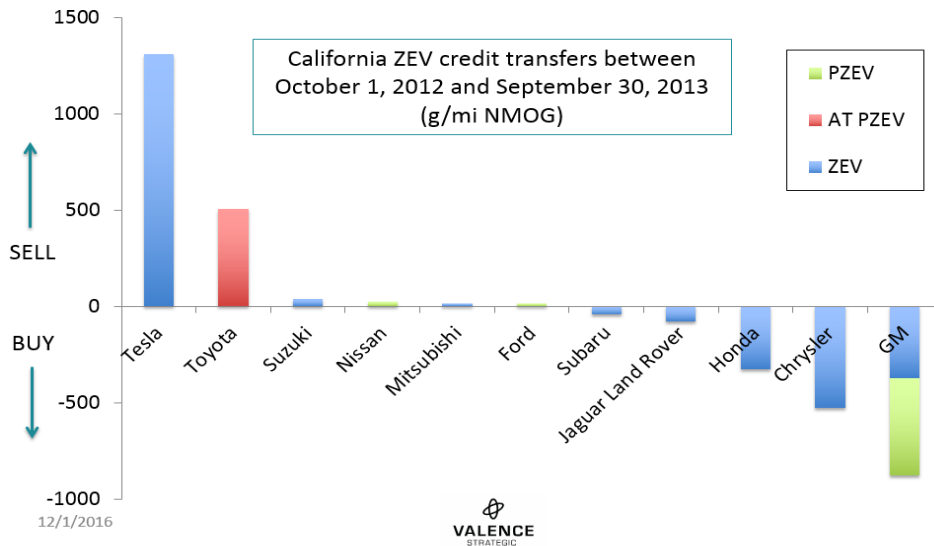
**Figure 18: Influence of California's ZEV mandate on EV adoption, showing the EV market leaders (sellers) and the manufacturers that purchase their credits to maintain compliance.**

Due to California's success, China adapted a California-style mandate in 2014 and EV sales surged in response (Figure 19). China required 10% of municipal vehicles to be electric by 2014, increasing to 30% by 2016.
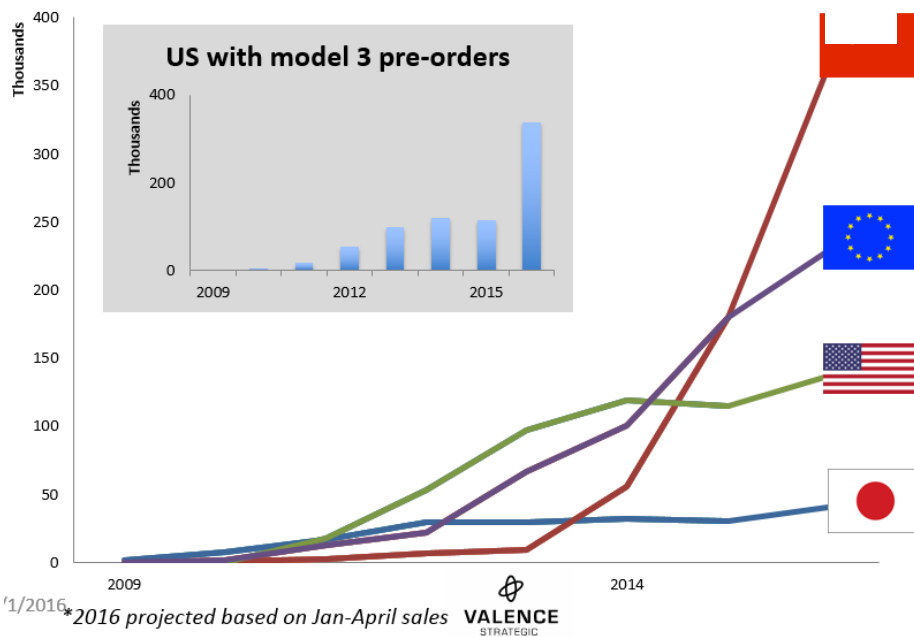


**Figure 19: PEV sales in China, the European Union, Japan, and the United States, reflecting boosts by mandates.**

Increased electrification has also been facilitated by declining lithium-ion battery costs. The first consumer-oriented lithium ion battery-powered EVs were built by Japanese manufacturers in the early 2000s. Underlying technology was strongly supported by DOE-funded R&D. Battery manufacturing has now reached scale and based on current trends, declining battery costs can be expected to make EVs competitive with ICE vehicles on a cost basis by 2019 or 2020. This aligns with DOE's goal to bring battery costs down to $125/kWh by 2018. Battery manufacturing has, until now,

been centered in China, Korea, and Japan, but the Tesla Gigafactory will accelerate a significant amount of battery manufacturing and innovation in the United States. Tesla and Panasonic, a partner in Tesla's Gigafactory, claim the Gigafactory will reduce costs by over 30%. It is one-seventh complete and is expected to enable production of 500,000 EVs annually by 2018.

Automation will lead to a system of commoditised mobility – cars will be built for safety, low operating costs, and autonomy. But this mundane mobility could prove to be revolutionary for our society. Automotive manufacturers will likely play an expanded role in the global mobility market. The automotive manufacturing sector could shrink as mobility services, including all transportation modes, continues to grow. Mobility is to the 21st century what automotive manufacturing was to the 20th century; TNCs will be the new innovation drivers.

TNCs will exploit the ACES paradigm to generate more users. They will pool multiple riders into each car to change the denominator on the efficiency and emissions equation. Automation will be in high demand from TNCs because the driver is the highest expense in a mobility service. TNCs will have more incentive to electrify their fleets as EVs approach cost parity. New York City's taxi fleet exemplifies how cost-parity vehicle electrification will impact the industry; as of 2016, 72% of New York City taxis are hybrids. ACES technologies may shrink oil demand thanks to fewer petroleum vehicles on the road, leading to lower cost per mile and attracting even more users to the service. Autonomous fleet vehicles will be extremely utilitarian and heavy utilization will lead to quick amortization, accelerating design cycles (the average New York City taxi drives 70,000 miles per year).

Several challenges remain. Regulations and liability for autonomous vehicles are still uncertain. There is, and will likely be more, labour market pushback on automation (i.e., trucking). Lastly, EV charging is currently far too slow and not profitable. Regardless, autonomous vehicles will drive electrification and will likely comprise a very large share of person miles travelled sooner than expected. As the consumer yields to fleet logic, vehicles will become more efficient, safer, cheaper, and more comfortable.

## 4.5 Future Scenarios and Technology for Urban Transport: Role of Transport Modelling in Future Transportation Systems

Otto Anker Nielsen, Professor, Head of Transport, Technical University of Denmark, Denmark

➢ Link to presentation slides:
https://www.iea.org/media/workshops/2016/egrdtransportsystemsofthefuture/15OttoAnkerNielsenTransportScenariosv3.pdf

Transport achievements across history have provided faster, more comfortable, larger, more reliable, and cheaper means to get around, moving from animals, to ships, and then finally machines. Unfortunately, the uptick in performance and user satisfaction has not been accompanied by a decrease in energy use and climate impact. Specifically looking at the nation of Denmark, one can see that transport is actually the only energy-using sector that has been increasing in energy usage in the 20th and 21st centuries; in fact, transport is now the highest energy-using sector in Denmark (Figure 20).

This and several other demand changes have quickly led to huge capacity problems in the transportation infrastructure network. The first of these changes is a rapid acceleration of urbanization over the past five years. Danes are moving into the city, while workplaces are moving into the suburbs as a result of further workforce specialization. Public transportation is increasingly unable to service the evolution of commuting patterns from this complex and widening suburban sprawl. Analysis has shown that public transport market share strongly depends on "distance from work/home" (Figure 21), so station access must be improved to regain usage. In addition to the population movement, car ownership has been on the rise. MaaS has enabled non-car owners to use cars, and changes to taxation that incentivize the price of energy efficient vehicles have led to dramatic



Figure 20: Energy use in Denmark, showing increase in transport sector.



Figure 21: Public transport market share (%), commuting. [National Transport Survey]

increases in sales to people who previously could not afford a car, both causing a decrease in public transportation usage. Additionally, Denmark's internet sales have skyrocketed to 25% of total national retail. Package delivery has tremendously increased as a result.

These combined factors have led to huge increases in congestion, which will continue to grow; delay time is projected to increase by 98% through 2025. Even with unrealistically massive infrastructure
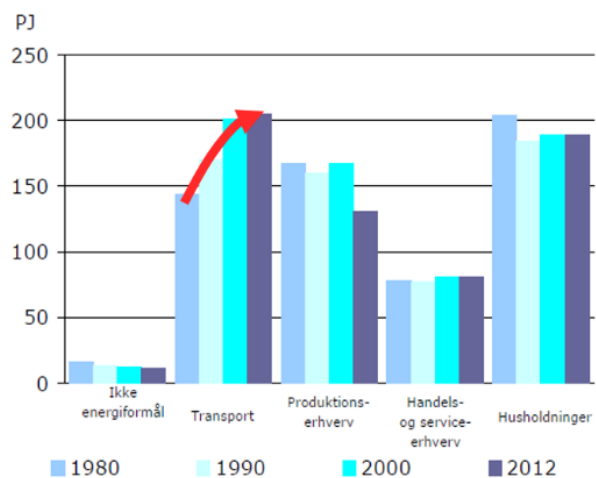
investments, this growth would only be reduced to 68%. The delay time status quo could be maintained only by introducing some form of road pricing.

Understanding the value of different transportation modes is key to unlocking higher transportation energy efficiency and emissions reductions. As shown in Figure 22, conventional public transport is still the most efficient with respect to passengers per hour per lane.
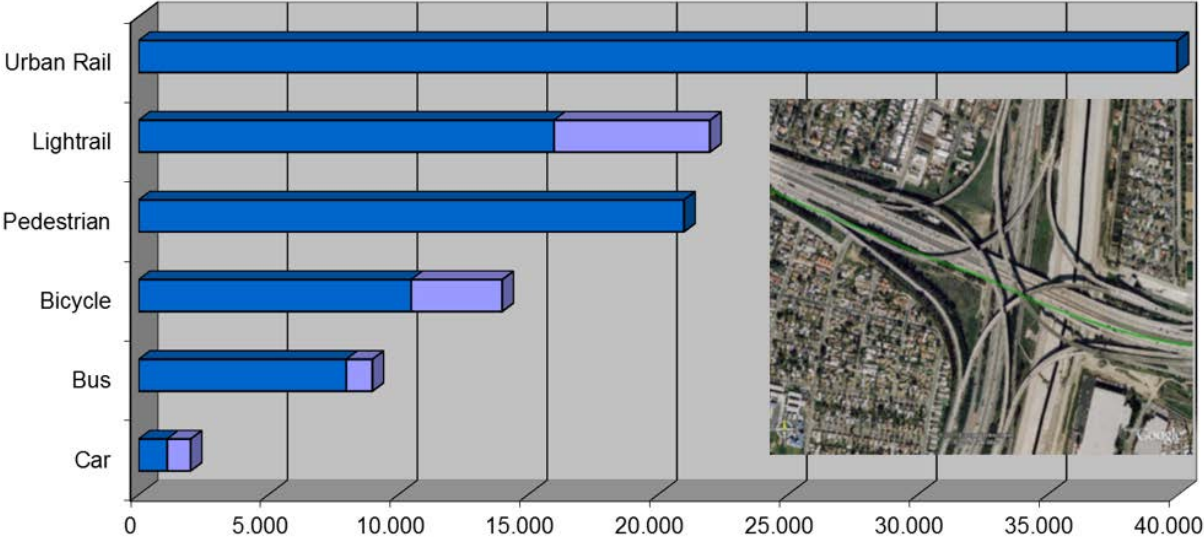


**Figure 22: Capacity for different transport modes (passengers per hour per lane).**

Denmark also has a large contingent of bicycle users, to the point where the infrastructure is not capable of safely handling increased bike usage. As discussed previously, there has been an increased interest in MaaS, which uses taxi variants (Taxa, Uber), co-driving or carpooling (Flextrafik, GoMore, DriveNow, SnappCar), and rentals (Hertz, delebilen, letsgo, Tadaa!) to provide affordable mobility. MaaS, even though it has a low passenger-per-hour-per-lane capacity (at an average of 1.3 people per car), will likely continue to grow as an attempted solution to mobility issues in Denmark. The two key questions are whether technology will replace the drivers, and whether the system will increase or decrease congestion and emissions.

When MaaS reaches a critical mass, it will be cheaper than personal car ownership and traditional taxis while offering more flexibility than traditional public transportation, especially for last mile trips to and from stations. This could occur in tandem with autonomous vehicle technology, further lowering the per-passenger cost and accessibility. Vehicle autonomy must be enabled by simultaneous progress in three interdependent technology areas: sensing, modelling and prediction, and new advanced technologies. Automation will be implemented in incremental phases:

**Level of Automation**
1. Safety features
2. Assisted driving
3. Platooned trucks
4. Platooned cars
5. Self-driving vehicles
6. Autonomous vehicles

**Location of Operation** (operational domain)
1. Special lanes
2. Motorways
3. Highways
4. Rural roads
5. Urban arterials
6. Everywhere

Assisted autonomous cars will be safer and more comfortable and will allow consumers to spend more time more productively. On the infrastructure side, motorway capacity could increase, and traffic control could improve (depending on the level of connectivity). As vehicles progress toward full autonomy, cars will be seen completely differently; people will use them as offices and hotel rooms. New user groups that were previously unable to drive will be able to use cars to get around (i.e., children, elderly, handicapped). Parking garages will be eliminated, even though there will be more cars on the road, as vehicle utilization increases to nearly 100%. This could potentially lead to more congestion, as empty cars are consistently repositioning to predict demand. Overall, autonomous MaaS will become cheaper, easier, and more reliable for the average individual while private cars will maintain higher flexibility and therefore hold market share in the upper class. It should also be noted that full vehicle autonomy will facilitate an autonomous delivery market, which will revolutionize postal and delivery businesses.

If CAVs become a dominant transportation form, there will be an increase in overall VMT due to more people travelling by car more often (low cost, high flexibility) coupled with a large amount of empty car driving. This will lead to more congestion, not less. There will need to be road user charging, or other economic policies, to balance the supply and demand. Public transport will need to play a larger role as well, as it is the most efficient use of land. As with most energy-related dilemmas, there is not a single "silver bullet solution" to the gridlock problem. Next-generation urban transport systems will connect transportation modes, services, and technologies together in innovative new ways that pragmatically address a seemingly intractable problem. It will be massively networked, dynamically priced, user-centred, integrated, and fully reliant on new models of public–private collaboration.

## 4.6 Pioneering E-Mobility through Knowledge Exchange and Innovative Networks

Peter van Deventer, Consulate General of The Netherlands, Coast to Coast Smart e-Mobility Program, Netherlands

➢ Link to presentation slides:
https://www.iea.org/media/workshops/2016/egrdtransportsystemsofthefuture/16PetervanDeventer.pdf

The Netherlands is one of the most densely populated countries in the world, evidenced by the vehicle hours lost to congestion (55.6 billion hours in 2015 and an estimated 74.3 billion hours in 2021), which can cause unnecessary increases in emissions and safety hazards to the population. The country has a strong focus on CAV RD&D to alleviate these risks. Specifically, the Netherlands has invested in deployment of connected and cooperative driving, platooning, and automated passenger vehicles and aims to be a "living lab" testing bed for these new technologies, integral to a "learning by doing" approach.

V2V and V2I technologies are vital to reaching these targets. For example, the Netherlands is reducing phenomena such as shock-wave traffic jams, caused not by over-capacity but by stop-and-go traffic, through free phone apps that utilize ITS corridors to alert drivers ahead of time. Collaborative partnerships between the public and private sectors create a sustainable and effective innovation ecosystem; individual villages within the Netherlands have been able to cooperate and work together to undertake smart mobility initiatives. Through this open framework, researchers

have expanded the shock-wave traffic reduction work into three other projects: road work warning in ITS corridors (in collaboration with Germany and Austria), developing hybrid test environments, and nationally upscaling other driver in-car services. Additional V2V efforts include platooning, which adds intelligence to the transport and logistics sectors and greatly increases both safety and efficiency of each truck involved. The V2V communications developed for platooning can also provide road information to truck drivers, including road work, route updates, and congestion warnings.

The Netherlands is using new technologies and systems to address several vulnerabilities: vulnerability to climate change, as about half of the country is below sea level; vulnerability to the fossil fuel market, as the country has a strong dependence on foreign oil; and vulnerability to inefficiencies, as road congestion leads to lost time. The issues are being addressed in different ways, the first being electrification of the vehicle fleet. Due to the success of the ZEV mandates, Norway, Netherlands, and California are leading the world in EV market penetration (Figure 23). The Netherlands currently has 100,000 EVs, supported by 40,000 EVSE. Over 10% of the nation's EVSE are located in Amsterdam. The growth in EVSE deployment has been strongly correlated with use of the OCPP+ EV charging infrastructure communications standard. These three governments are also marking urban air quality zones and mandating reduced emissions in ports (15 ships produce more sulphur than 1 billion passenger vehicles).

There are still several barriers to continued proliferation of EVs:
- **Technology**: Batteries, vehicle range, and safety implications
- **Social impact:** Job production/reduction, and bias toward the rich
- **Infrastructure:** Need for public charging, strong electricity grid, and quicker home charger installation
- **Environment:** Need to improved clean energy power production for positive well-to-wheels impacts, research battery recycling
- **Cost:** Electricity prices, tax increases
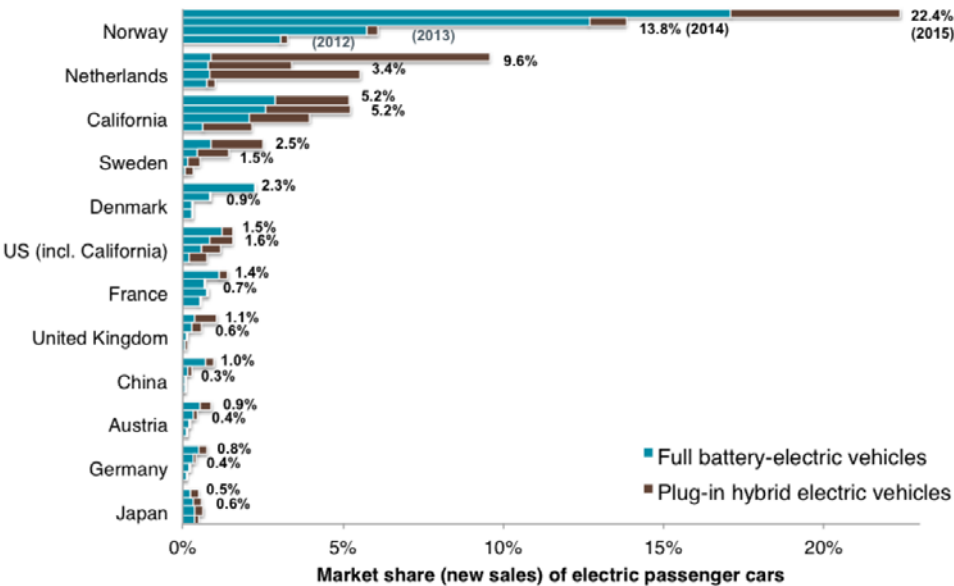- **Market**: Consumer adoption and decision making



**Figure 23: Countries with the highest EV market penetration.**

The sum of these barriers leaves stakeholders in a "policy game", trying to determine whether regulators and industry should wait and see what happens with the early movers, or capitalize on the advantages of being a first mover. EV policy is very complex because of both the technology and the multi-actor nature of the system. The Dutch government decided to implement a public–private partnership with California in its transatlantic Coast-to-Coast Smart e-Mobility (C2C) program. The C2C program, with a €2 million total budget (including in-kind costs), facilitates trade missions and study tours, development of bilateral relations between U.S. and Dutch decision makers, stimulation and realization of pilot projects and new business development, and knowledge and innovation dissemination between their respective governments and universities. C2C has led to several tangible results:

- Agreements environmental cooperation between the California Environmental Protection Agency and the Ministry of Infrastructure and the Environment of the Netherlands (2013, 2015)
- Under2MoU between California and various (sub)national jurisdictions (2015)
- Setting up of the International Zero Emission Vehicle Alliance with California and Quebec (2015)
- Working agreement with the California Energy Commission on Smart e-Mobility (2015)
- An E-mobility tour of The Netherlands for Commissioner Scott of the California Energy Commission , including the Dutch SolaRoad (2014)
- Development of a bilateral Smart and EV investment fund to provide equity to small/medium-sized Dutch and California companies in The Netherlands, and loans and guarantees in California with only two to three years of experience
- Continuous interaction to develop and introduce the first four-passenger solar car in the world: STELLA, designed by students, winning a Tech Crunch Award (2015)
- Visits between the U.S. Environmental Protection Agency and the Netherlands Ministry to expand Smart and the Green Mobility Mission (2015, 2016)
- Letter of intent between the State of Ohio and Dutch Smart e-Mobility (2016)
- A stream of projects, academic collaborations, and business ventures in California and the Netherlands: APPM, EVGrid, E-Traction, EVBox, EV4LLC, Greenlots, NSOB, NXP, SolaRoad, Tacstone, and Tesla

The ambition, growth, and diversification of global EV sales continue, and charging and navigation solutions coupled with smart city development will be needed to support higher market penetration. Heavy-duty transport is included in the drive toward electrification as well; 100% of buses sold in the Netherlands are required to be zero-emission by 2025. Smart e-Mobility will require both connected and autonomous capabilities in shared vehicles, all as a part of MaaS systems.

# Discussion and Conclusions

The world sits at the cusp of a revolutionary change that is sweeping the transportation industry. Consumers are presented with several mobility choices, shifting societal preferences toward increased car- and ride-sharing, and upending the age-old individual car ownership business model. Increased availability of advanced vehicular technologies such as automation and electrification, coupled with information and communication technologies, could transform the way consumers view these transportation and mobility services. These trends are occurring at a rapid pace and in a policy and regulatory vacuum. Policy decisions made at this juncture will play a critical role in shaping the future of the transportation industry. Decision makers must ensure that along with meeting energy and climate goals, safety, accessibility, and equity issues are adequately considered.

The interconnected nature of these trends raises several policy and technology questions that are important to unravel for sound policymaking. It is important to understand the key interactions between: consumer behaviour and decision making; ACES vehicles; widening availability of different transportation modes; the ITS network; OEMs and TNCs; and local, regional, and national government entities. Unravelling this complex decision-making environment will provide clarity and facilitate sound policy decisions for a range of potential scenarios. As business models and consumer preferences shift, the future needs to be examined from different perspectives and measured against different metrics. For example, VMT and individual ownership will likely become less helpful as other factors emerge, e.g., person miles travelled, fleet logic, systemic control (vs. individual control), and rapid innovation cycles. Several different narratives exist as to how the future can unfold.

Two important aspects that lie at the nexus of energy, safety, and mobility are logistical mobility (reliability, accessibility, and efficient use of time) and energy efficient mobility. Transportation, in general, is an inefficient system—and one which consumer buy-in exacerbates. While the vehicles themselves tend to be increasingly efficient, consumers utilize them inefficiently. Expanded use of ICT and automation can help with logistical mobility but will also affect overall transportation system energy usage. The increased use of self-driving vehicles, growing discretionary income, and increased movement of goods can have a longer-term aggregate impact on climate and energy concerns. It is critically important for policy makers to understand the potential energy implications of these changes, thus avoiding lock-in of technologies and ensuring that policies steering next-generation transport systems meet the objective of shifting to a low-carbon pathway. To have the greatest impact, a key goal from an energy perspective should be to decouple carbon from transportation, and one of the ways to achieve this would be to provide ACES vehicles to minimize per-mile emissions.

Along with the OEMs, a new suite of private sector companies are playing an increasingly large role in shaping the industry. Companies such as Google and Uber are positioning themselves as mobility companies, or TNCs, even as the OEMs are transitioning to mobility service providers instead of vehicle hardware manufacturers. To generate the greatest profit, these companies will tend to focus on the VMT that provides the most value. Thus the government role of providing the right incentives and policies to influence behaviours will be critical. The transformative nature of the ACES system forces policy makers to explore difficult questions, for example: Will society be safer as a whole? Can the population live with the currently unknown and unintended consequences of drastic mobility

change? What will the implications be for lower-income populations that are increasingly moving to the suburbs and depending on personally owned vehicles?

Key consideration must be given to assessing the entire industry from a system-level vantage point, rather than as individual and separate vehicular entities. Industry must move away from traditional approaches of examining transportation as a private asset. Instead, the private sector needs to explore transportation as a service. Embracing the "idea of creative destruction" will help industry move toward more sustainable vehicles.

In spite of the rapid pace of technological change, the ACES paradigm faces more psychological and legal barriers than technological ones. The development of legal regulatory frameworks and public acceptance of these technologies will drive the rate of adoption. Rather than viewing this dynamic environment as a competitive one, governments and industry should engage in promoting both innovation and safety, motivating one another and finding solutions that lead to a sustainable transportation system.

## R&D Needs and Opportunities

Policy makers are faced with a pressing need for rapid adaptation, evolution, and decision making that helps achieve the desired outcomes, yet the pace of technological and societal change presents challenges in information-gathering. More data are needed in several areas for informed decision making. R&D will play a critical role in unravelling the complexities of this emerging landscape. Several of the key areas that require further investigation are highlighted below.

- Understanding the intersections between advanced technologies, ICT, mobility options, and consumers' decision making process will be of critical value for robust policymaking going forward. Conducting modelling and analysis will help in understanding the factors influence behaviour related to mobility decisions.
- Determining the overall energy impact of a fully ACES transportation system, or any variant between such a system and the current vehicle fleet. Past research implies a huge uncertainty (between a 90% decrease and a 200% increase in fuel use). Many of the R&D needs and opportunities discussed below will assist in achieving a better understanding and reducing uncertainty, of these energy impacts.
- Additional empirical data regarding ACES technology trends are needed, as well as innovative approaches to R&D by governments, research institutes, and the private sector that incorporates the rapid pace of technological change. Prototyping and testing models in real time, and "learning by doing" will help in responding to the dynamic real-world environment. The concept of "living labs", already being implemented in several countries, will provide opportunities to test technologies in real time and analyse consumers' decision-making behaviour. Comparative analysis and modelling to predict and understand this behaviour will help inform policy making.
- Predicting consumer behaviour is a key challenge. "Mobility decision science", a new and evolving area of R&D, is becoming increasingly important as researchers delve into questions that help in understanding consumer decision making. Some of the areas that are being explored are incentives that drive consumers toward efficient traveller decision making; the

use of apps offering several mobility options in real time; social media and its links to customer choice; and the benefits perceived by consumers using ACES technology.

- Research into barriers limiting mobility systems and the deployment of new technologies will be critical. As technology advances, it is being hindered by the existing inefficiencies in the transportation industry that can be addressed by automated driving systems.

- Connectivity and the "internet of things" comes with vulnerability, and the importance of cybersecurity must not be underestimated. Research into how to make this integrated system cyber-secure is of critical value.

- Research methodologies must be improved, especially around evolving areas such as customer choice modelling. The impacts of findings on policy making can be significant. Modelling different scenarios that represent the changes that are underway, ensuring that data sources are sound, understanding the limitations behind any modelling or data analysis, and establishing open data will help decision makers use the research results appropriately.

- Researchers are working on consumer studies that will help legislators make evidence-based autonomous vehicle policy decisions. Since the technology is new, unfamiliar, and not available to consumers, there is a need to develop new metrics (i.e., intent-to-use, or acceptance) and interview methodology to provide valuable data to regulators on how consumers perceive transportation technology trends.

- There is a general lack of understanding of the linkages between vehicle usage and vehicle ownership. Research to better understand incentives or disincentives that can influence vehicle use, willingness to pay, and ownership persistence will assist the industry as well.

- Conducting research on mass mobility and niche applications (such as refrigerated transportation) in more connected and automated transportation systems will facilitate solutions that will generate both energy savings and cost savings. There are some interim solutions, such as increased use of CNG or LNG that can help meet short-term energy savings goals. The tussle between higher efficiency and lower emissions will be played out between consumers, governments, and industry, ultimately leading to more effective solutions as the technology development and deployment occurs.

- Industry and policy makers will both benefit from research into technologies that can drive greater fuel savings, such as truck platooning, automating cars to provide optimal deceleration/acceleration of cars, and wireless charging. Industry in particular would be well served by insight into how supply chains of these new technologies evolve, including identifying bottlenecks.

- The storage capacity of EV batteries may become a limiting factor, driving the need to identify technical solutions and to understand both the EV's role in the electric system and how that could affect business models. Policy lessons can be learnt from other counties. For example, in China, the uptake of electric batteries has occurred in a very short time, and understanding the drivers of this change may help understand consumer behaviour.

- Further research is needed to explore how the convergence of advanced technologies could affect vehicle operating design. Replacing human drivers with autonomous algorithms could eliminate the ever-increasing need for higher vehicle performance. If vehicle manufacturers start designing for fleets rather than for individuals, the primary emphasis could shift from performance and "fun-factor" to utility and efficiency. This change has the potential to reduce aggressive driving, allowing downsized vehicle powertrains and increased fuel economy. Additionally, the autonomous driver would theoretically be far safer, and a great

deal of safety equipment currently integrated into modern vehicles would be unnecessary. Weight reduction would increase fuel economy and could increase range or reduce battery pack size for electric vehicles. Conversely, if the new autonomous drivers are not programmed for fuel efficiency but for time efficiency, vehicles would continue to increase in performance and use more, rather than less, fuel per mile. Understanding how design could be affected, and how to use this opportunity to increase fuel efficiency, is important for policy makers as they nudge industry and consumers (including fleets) toward lower-emission choices.

- Developing technologies for automated vehicles is a complex task with several complicated linear and non-linear inputs and interactions. Robust sensing and perception systems that are fault-tolerant and fail-safe, accurate positioning technology that is able to judge lane-level data, and reliable technologies to detect driver distraction will all help in quicker adoption of this technology. Research is also needed to better understand the interaction of automated vehicles with non-automated technologies, roadway congestion, and system interoperability.

## Policy Recommendations

- Policies and regulatory frameworks need to be crafted in coordination with rapidly shifting advanced technology deployment, adoption, and consumer preferences. To facilitate this, policy makers must allow room for creativity and innovation, as well as policy experimentation that will help them lead to their policy objectives (e.g., safety and accessibility, energy efficiency, and mobility). A need for policy guidance and standardization of regulations can help drive these outcomes.

- Policy incentives should be crafted to avoid choosing favourites among advanced technologies, aiming to maintain technology neutrality and fair competition.

- While vehicle electrification technology adoption has widely been successful, battery costs remain high. Lack of adequate policies remains a barrier. California, Norway, China, and others have implemented successful electrification policies and incentives, substantiating that aggressive policy making can bring technologies to market. Other regions and countries should examine the policies adopted and learn from these successful initiatives.

- Decision makers should explore how implementing the right incentives could result in changes to usage and availability of public transportation, including urban rail, light rail, and buses. These transportation modes have generally been the most efficient in terms of passengers per hour per lane and the cheapest form of travel for consumers. Travelers could show a preference for automated single-passenger vehicles over these more efficient modes if the price is set right. Policy makers need to investigate which policies will send the right signals for higher adoption of these modes of transportation, thus achieving sustainability goals.

- The newly emerging connected and shared transportation industry will result in increased data-sharing and information-exchange. In such an environment, privacy issues become critically important, and policies will need to be framed to avert privacy breaches. Increased industry ICT use will necessitate establishing policies that address cybersecurity issues.

- The successful experience of Netherlands with electric vehicles is partially due to the establishment of open charging data protocols. Policy makers should explore how the safe

practice of open data protocols could be extrapolated from EV charging to CAV systems to further encourage and accelerate both R&D and adoption.

- By creating a competitive environment, the Smart City challenge demonstrated the effectiveness of providing innovative incentives to accelerate deployment of technologies. The winning city, Columbus, raised $90 million in funding—outside government support—and several other non-winning cities are adopting policies to enable ACES technologies as well. Emulating such creative approaches in other cities will help deliver technology and energy advancements around the world.

- Policies in emerging and developing economies must avoid lock-in of technologies that lead to city/regional planning that increases vehicle ownership. Norway's feebate approach and Finland's public bus system provide examples of effective approaches.

- Establishing ambitious goals can deliver innovative results. For example, the Supertruck initiative in the United States fostered strong engagement between the government and private sector. The initiative had established an aggressive goal that made the private sector hesitant initially. However, as OEMs conducted R&D on technologies in a competitive environment, they quickly became committed. The initiative delivered energy savings and technology advancements beyond what was expected, resulting in the announcement of the Supertruck 2 initiative. Similarly, Norway has set aggressive transportation/mobility goals. Modelling shows that policy measures and incentives should be both targeted to shared climate goals and customized to local circumstances; with the right policy portfolio in place, even aggressive objectives are achievable.

# Appendices

## Appendix A. Acronyms

| Acronym | Meaning |
| --- | --- |
| °C | Degrees Celsius |
| 2DS | 2-Degree Scenario |
| 4DS | 4-Degree Scenario |
| 6DS | 6-Degree Scenario |
| ACES | Automated, Connected, Electrified, Shared |
| AERIS | Applications for the Environment: Real-Time Information Synthesis |
| AFV | Alternative Fuel Vehicle |
| ARPA-E | Advanced Research Projects Agency–Energy |
| AT PZEV | Advanced Technology Partial Zero-Emission Vehicle |
| BES | Basic Energy Sciences (DOE) |
| BEV | Battery Electric Vehicle |
| BMVI | Federal Ministry of Transport and Digital Infrastructure (Germany) |
| BMWi | Federal Ministry of Economic Affairs and Energy (Germany) |
| C2C | Coast-2-Coast (program) |
| CAMPO | Capital Area Metropolitan Planning Organization |
| CAN | Controller Area Network |
| CAV | Connected and Autonomous Vehicle |
| CEN | European Committee for Standardization |
| CENELEC | European Committee for Electrotechnical Standardization |
| CERT | Committee on Energy Research and Technology (IEA) |
| cm | Centimetre(s) |
| CNG | Compressed Natural Gas |
| $CO_2$ | Carbon Dioxide |
| CPU | Central Processing Unit |
| CPT | Clean Power for Transport (EU) |
| DARPA | Defense Advanced Research Projects Agency |
| DOE | U.S. Department of Energy |
| DOT | U.S. Department of Transportation |
| EEA | European Economic Area |
| EERE | Office of Energy Efficiency and Renewable Energy (DOE) |
| EFSI | European Fund for Strategic Investments |

| Acronym | Meaning |
| --- | --- |
| EGRD | Experts' Group on R&D Priority Setting and Evaluation Research (IEA) |
| EJ | Electro-Joules |
| ELENA | European Local Energy Assistance (EU facility) |
| EN-V | Electric Networked-Vehicle |
| EOL | End of Life |
| ETP | Energy Technology Perspectives |
| ETS | Emissions Trading System |
| EU | European Union |
| EV | Electric Vehicle |
| EVSE | Electric Vehicle Supply Equipment |
| FAA | Federal Aviation Administration |
| FCEV | Fuel Cell Electric Vehicle |
| FPGA | Field-Programmable Gate Array |
| FPU | Floating Point Unit |
| g | Gram(s) |
| GDL | Gas Diffusion Layer |
| GHG | Greenhouse Gas |
| GM | General Motors |
| GPS | Global Positioning System |
| HRT | Helsinki Regional Transport |
| ICE | Internal Combustion Engine |
| ICT | Information and Communication Technologies |
| IEA | International Energy Agency |
| ITS | Intelligent Transportation System(s) |
| JRC | Joint Research Centre |
| km | Kilometre(s) |
| Kw | Kilowatt(s) |
| kWh | Kilowatt Hour(s) |
| LIDAR | Light Detection and Ranging |
| LNG | Liquid Natural Gas |
| MaaS | Mobility-as-a-Service |
| MOU | Memorandum of Understanding |
| mpg | Miles Per Gallon |
| MW | Megawatt(s) |
| NREL | National Renewable Energy Laboratory |
| OCPP | Open Charge Point Protocol |

| Acronym | Meaning |
| --- | --- |
| OECD | Organisation for Economic Co-operation and Development |
| OEM | Original Equipment Manufacturer |
| PEV | Plug-in Electric Vehicle |
| PEV | Plug-in Hybrid Electric Vehicle |
| PZEV | Partial Zero-Emission Vehicle |
| R&D | Research and Development |
| RD&D | Research, Development, and Demonstration |
| RFiD | Radio-Frequency Identification |
| RVO.nl | Netherlands Enterprise Agency (Rijksdienst voor Ondernemend Nederland) |
| SMART | Systems and Modeling for Accelerated Research in Transportation (Mobility) (DOE) |
| STRIA | Strategic Transport Research and Innovation Agenda |
| SUV | Sport Utility Vehicle |
| SWARM | Demonstration of Small 4-Wheel Fuel Cell Passenger Vehicle Applications in Regional and Municipal Transport (EU) |
| tkm | Tonne-Kilometre |
| TNC | Transportation Network Company |
| TRU | Transport Refrigeration Unit |
| TTI | Texas A&M Transportation Institute |
| UAM | Unmanned Aircraft System |
| ULEV | Ultra-Low-Emission Vehicle |
| U.S. | United States |
| USB | Universal Serial Bus |
| V2I | Vehicle-to-Infrastructure |
| V2V | Vehicle-to-Vehicle |
| V2X | Vehicle-to-Everything |
| VAT | Value-Added Tax |
| VMT | Vehicle Miles Travelled |
| VTT | VTT Technical Research Centre of Finland Ltd. |
| W | Watt(s) |
| ZeEUS | Zero Emission Urban Bus System |
| ZEV | Zero-Emission Vehicle |

# Appendix B. List of Participants

| Name | Organization | Country |
|------|-------------|---------|
| William Chernicoff | Toyota Motor North America | United States |
| Lasse Fridstrøm | Institute of Transport Economics | Norway |
| J. Christian Gerdes | U.S. Department of Transportation | United States |
| Roland Gravel | U.S. Department of Energy | United States |
| Herbert Greisberger | eNu | Austria |
| Gavin D. J. Harper | Birmingham Energy Institute | United Kingdom |
| Birte Holst Jørgensen | Technical University of Denmark | Denmark |
| Rob Kool | EGRD Chair, RVO.nl | Netherlands |
| Juho Kostiainen | VTT Technical Research Centre of Finland | Finland |
| Robert Marlay | EGRD Chair | United States |
| Otto Anker Nielsen | Technical University of Denmark | Denmark |
| Estathios Peteves | Knowledge for the Energy Union | European Commission |
| Cem Saraydar | General Motors | United States |
| Reuben Sarkar | U.S. Department of Energy | United States |
| Alex Schroeder | National Renewable Energy Laboratory | United States |
| Johannes Tambornino | Projektträger Jülich | Germany |
| Jacob Teter | International Energy Agency | France |
| Levi Tilleman-Dick | Valence Strategic LLC | United States |
| Peter van Deventer | Consulate General of the Netherlands, Coast to Coast Smart e-Mobility Program | Netherlands |
| Johanna Zmud | Texas A&M Transportation Institute | United States |

# Appendix C. Additional Material

Birmingham Centre for Fuel Cell and Hydrogen research
www.birmingham.ac.uk/fuelcells

Birmingham Centre for Strategic Elements & Critical Materials
www.birmingham.ac.uk/BCSECM

Business Model Generation
www.businessmodelgeneration.com

Energy Research Accelerator
www.era.ac.uk

European Alternative Fuels Observatory
www.eafo.eu

European Commission, Mobility and Transport
http://ec.europa.eu/transport/themes/urban/studies/urban_en.htm

European Investment Advisory Hub
http://www.eib.org/eiah/index.htm

Harper, G.D.J., *The role of business model innovation in transitioning ultra-low emission vehicles to market*, PhD Thesis, Cardiff University. Available at http://orca.cf.ac.uk/71735/

Living Lab Bus
www.livinglabbus.fi

Nieuwenhuis, P., & Wells. P. (2003) *Did Ford really invent mass production?*Cardiff: The Centre For Business Relationships, Accountability, Sustainability and Society. Available at http://orca.cf.ac.uk/39703/

Nieuwenhuis, P., & Wells, P. E. (2007). *The all-steel body as a cornerstone to the foundations of the mass production car industry*. Industrial and Corporate Change, 16(2), 183-211. Available at http://dx.doi.org/10.1093/icc/dtm001

Remanence
http://www.project-remanence.eu/

Texas A&M Transportation Institute
http://tti.tamu.edu/policy/technology/

# Appendix D. Agenda

**DAY 1 – Wednesday, 26 October 2016**

**Session 1: Introduction**

The Session provides background and context for the workshop. It reminds participants of the purpose, interactive nature of presentations, dialogue and social interactions, and the expected outcomes, and post-meeting activities and communications.

- *Background and Previous Work of the EGRD*
- *Rationale of the Workshop*
- *Expected Outcomes of the Workshop*
- *Evolving Trends in the Transportation Sector, with Input from IEA*
- *Current R&D Activities in Intelligent Transportation Systems*

| Introduction | | | |
|---|---|---|---|
| *Chair: Bob Marlay* | | | |
| 08:30 | Registration (Allow 30 minutes to allow time for DOE Security) | | |
| 9.00 | Welcome | | Paula Gant, Principal Deputy Assistant Secretary for International Affairs, DOE |
| 9:10 | Introduction | | Rob Kool, Chair EGRD, Bob Marlay, Vice Chair EGRD, U.S. DOE |
| 9:25 | 1 | Key note | Reuben Sarkar, Deputy Ass't Secretary for Transportation, DOE |
| 10:00 | 2 | Technology and Policy Pathways to Achieve the Two-Degree Scenario (Energy Technology Perspectives 2016) | Jacob Teter, IEA |
| 10:35 | 3 | The Future of Transportation: the Defining Challenges for the 21st century | Chris Gerdes, Chief Innovation Officer, U.S. Department of Transportation |
| 11:10 | Coffee break | | |

**Session 2: Transportation & Mobility Emerging Trends and Promising Technologies**

This session notes emerging trends, shifting mobility paradigms, and new technologies that can transform the future of transportation demand and services, and significantly reduce GHG emissions of future transportation systems in different regions/countries, and worldwide.

- *What are the key trends in the transportation sector driving breakthroughs in technology?*
- *What are the technologies shaping these changes and giving rise to a new vision of the future?*
- *What are the potential energy impacts of connected and automated vehicles, ride-sharing, and other smart mobility concepts?*
- *What are the most important modelling/planning topics to decarbonize the transport sector to well below the 2DS?*
- *What possible scenarios could tip the balance in favor of one technology?*

| Transportation and Mobility Technologies of the Future | | | |
|---|---|---|---|
| *Chair: Rob Kool* | | | |
| 11:30 | 4 | Freight Mobility and Supertruck | Roland Gravel, Vehicle Technology Office, DOE |
| 12:05 | 5 | Market uptake of battery and hybrid electric vehicles. Targets, incentives and research needs as experienced in Norway | Lasse Fridstrøm, Institute of Transport Economics, Norway |
| 12:40 | 6 | National Innovation Programme on Hydrogen and Fuel Cells in Germany | Johannes Tambornino, Projektträger Jülich |
| 13:15 | Lunch | | |
| 14:00 | 7 | The EU's Experience in Transportation Innovation | Estathios Peteves, European Commission |
| 14:35 | Discussion | | |
| 15:10 | Coffee Break | | |

**Session 3: Technology R&D: Barriers and Solutions**

This session discusses factors inhibiting new technology and significant changes in mobility, and possible solutions for overcoming the barriers.

- *Examining potential future transport paradigms, what key barriers are the greatest inhibitors to widespread implementation (e.g. financial, policy, RD&D, or other)?*
- *What are the consumer adoption challenges to deployment of new mobility systems?*
- *What are the new pathways to reaching consumers and what are the impacts on the traditional sales model (i.e. big data, social media, sharing economy, etc.)?*
- *What actions are needed to achieve further efficiency gains and who is primarily responsible (e.g. manufacturers and policy makers)?*

| | | **Technology R&D: Barriers and Solutions** | |
|---|---|---|---|
| | | *Chair: Birte Holst Jørgensen* | |
| 15:40 | 8 | Current Market Trends in Transportation and R&D opportunities for ITSs | Alex Schroeder, National Renewable Energy Lab, DOE |
| 16:15 | 9 | Transforming Transportation Technologies: The Toyota Experience. | William Chernicoff, Toyota Motor North America |
| 16:50 | 10 | Technology R&D Challenges in Enabling Autonomous and Connected Vehicles | Cem Saraydar, General Motors |
| 17:25 | 11 | Testing and deploying new solutions through collaboration | Juho Kostiainen, VTT Technical Research Centre of Finland |
| 18:00 | Discussion | | |
| 18:30 | Close Day 1 | | |
| 19:15 | No-Host Voluntary Dinner<br><br>Farmers Fishers Bakers<br>3000 K St NW<br>Washington, DC 20001<br>Phone: 202.298.8783 | | |

## DAY 2 - Thursday, 27 October 2016

**Session 4: Policy and Markets Supporting Future Transportation Technologies**

This session focuses on necessary policies and markets to support future transportation systems.

- *What are the best policy levers – price-based, regulatory, and RD&D – to realize new technologies and mobility systems and drive deep de-carbonization? (e.g. new regulatory framework to measure fuel economy)*
- *What transportation network issues must urban planners and policy makers address to facilitate developing and implementing low-carbon technologies and practices?*
- *Which policies or frameworks have proven most effective in reducing transport demand?*
- *Is the concept "Mobility as a Service (MaaS)" a possible game changer?*

| Policy and Markets Supporting Future Transportation Technologies | | | | |
|---|---|---|---|---|
| Chair: Herbert Greisberger | | | | |
| 09:00 | 12 | Business models for ultra-low emissions vehicles' and sustainable business models | | Gavin Harper, Midlands Univ., U.K. |
| 09:35 | 13 | Measuring Influences on Automated Vehicle Market Development: Consumer Acceptance and Adoption | | Johanna Zmud, Director, Texas A&M Transportation Institute |
| 10:10 | Coffee break | | | |
| 10:40 | 14 | Drivers for a Sustainable Future Transportation System: Policy, Market and Technology Insights | | Levi Tilleman-Dick, Fellow, New America/Managing Director, Valence Strategic LLC |
| 11:15 | 15 | Future Scenarios and Technology for Urban Transport/ Role of Traffic modeling in future transportation systems | | Prof. Otto Anker Nielsen, Technical University of Denmark |
| 11:50 | Lunch | | | |
| 13:20 | 16 | Pioneering E-mobility through Knowledge Exchange and Innovative Networks | | Peter van Deventer, Consulate General of the Netherlands, Coast to Coast Smart e-Mobility Program |
| 13:55 | Discussion | | | |
| 14:25 | Coffee Break | | | |

## Session 5: Synthesis and takeaways

| Synthesis and takeaways | |
|---|---|
| Chair: Robert Marlay | |
| 14:55 | Discussion, recommendations |
| 16:00 | Workshop conclusions |
| 16:30 | Close Day 2 |