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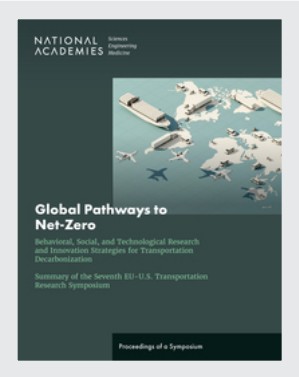

Global Pathways to Net-Zero: Behavioral, Social, and Technological Research and Innovation Strategies for Transportation Decarbonization; Summary of the Seventh EU-U.S. Transportation Research Symposium: Proceedings of a Symposium (2024)

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98 pages | 8.5 x 11 | PAPERBACK

ISBN 978-0-309-72931-4 | DOI 10.17226/28192

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Washington, DC

Global Pathways to Net-Zero

Behavioral, Social, and Technological Research and Innovation Strategies for Transportation Decarbonization

Summary of the Seventh EU–U.S. Transportation Research Symposium

Katherine F. Turnbull, *Rapporteur*

Organized by the

Coordination and Support Action
SYMPEUS

European Commission

Transportation Research Board

U.S. Department of Transportation

Proceedings of a Symposium

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This activity was supported by a contract between the National Academy of Sciences and the Office of the Assistant Secretary for Research and Technology of the U.S. Department of Transportation. Any opinions, findings, conclusions, or recommendations expressed in this publication do not necessarily reflect the views of any organization or agency that provided support for the project.

International Standard Book Number-13: 978-0-309-72931-4
International Standard Book Number-10: 0-309-72931-9
Digital Object Identifier: https://doi.org/10.17226/28192

This publication is available from the National Academies Press, 500 Fifth Street, NW, Keck 360, Washington, DC 20001; (800) 624-6242 or (202) 334-3313; http://www.nap.edu.

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Printed in the United States of America.

Suggested citation: National Academies of Sciences, Engineering, and Medicine. 2024. *Global Pathways to Net-Zero: Behavioral, Social, and Technological Research and Innovation Strategies for Transportation Decarbonization: Summary of the Seventh EU-U.S. Transportation Research Symposium: Proceedings of a Symposium*. Washington, DC: The National Academies Press. https://doi.org/10.17226/28192.

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Transportation Research Board Staff

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THOMAS MENZIES, Director, Consensus and Advisory Studies
VICTORIA SHEEHAN, Executive Director

[1] The SYMPEUS project is a Coordination and Support Action funded by the European Commission coordinated by VTI, and involving ECTRI and VDI/VDE-IT, which aims to support the overall organization of the EU-U.S. symposium series from the European side.

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Reviewers

This Proceedings of a Symposium was reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise. The purpose of this independent review is to provide candid and critical comments that will assist the National Academies of Sciences, Engineering, and Medicine in making the published proceedings as sound as possible and to ensure that it meets the institutional standards for quality, objectivity, evidence, and responsiveness to the charge. The review comments and draft manuscript remain confidential to protect the integrity of the process.

We thank the following individuals for their review of this proceedings:

GEREON MEYER, VDI/VDE Innovation + Technik GmbH
BENJAMIN SOVACOOL, Boston University

TRB also thanks National Academies' staff reader Rebecca DeBoer.

Although the reviewers listed above provided many constructive comments and suggestions, they were not asked to endorse the contents of the proceedings nor did they did see the final draft before its release. The review of this proceedings was overseen by **NURIA FERNANDEZ (NAE),** Federal Transit Administration (retired). She was responsible for making certain that an independent examination of this proceedings was carried out in accordance with standards of the National Academies and that all review comments were carefully considered. Responsibility for the final content rests entirely with the rapporteur and the institution.

The planning committee thanks Katherine F. Turnbull for her work in preparing this proceedings.

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Global Pathways to Net-Zero: Behavioral, Social, and Technological Research and Innovation Strategies for Transportation Decarbonization; Summary of ...

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Preface

This proceedings summarizes Global Pathways to Net-Zero: Behavioral, Social, and Technological Research and Innovation (R&I) Strategies for Transportation Decarbonization, a symposium held June 11–12, 2024, at the National Academy of Sciences Building in Washington, DC. Hosted by the U.S. Department of Transportation (U.S. DOT), the European Commission (EC), and the Transportation Research Board (TRB) of the National Academies of Sciences, Engineering, and Medicine, it was the seventh annual symposium sponsored by the European Commission and the United States. The goals of these symposia are to promote common understanding, efficiencies, and transatlantic cooperation within the international transportation research community while accelerating transport-sector innovation in the European Union (EU) and the United States.

The 2-day, invitation-only symposium brought together high-level experts to share their views on decarbonizing the transport sector. With the goal of fostering transatlantic collaboration in research and deployment, symposium participants discussed policies, programs, and innovative approaches for decarbonizing the transport sector.

A bilateral planning committee organized and developed the symposium program. Chris Hendrickson from Carnegie Mellon University and Gereon Meyer from VDI/VDE Innovation + Technik GmbH served as the co-chairs of the planning committee. The planning committee members provided expertise in public road and transit systems, freight, advanced technologies, clean fuels, electrification, land use and transport planning, and social science.

The planning committee noted that decarbonization is a global challenge and that international cooperation is essential for nations and regions across the world to be successful in meeting shared decarbonization goals. As world leaders move toward net-zero emission economies, the European Union and the United States will need to work closely together to meet decarbonization goals, in addition to setting an example for the rest of the world to follow. With the transportation sector being a leading source of emissions, it is essential that immediate steps are taken to decarbonize transportation and to continue to invest in the research needed for our decarbonization commitments to be met.

The climate crisis poses a threat to life on the planet, with human health, ecosystem, and economic impacts globally. These impacts are projected to worsen in the future, as greenhouse gas (GHG) emissions continue to rise and warming to date continues to produce adverse effects.[1] For example, in 2022 alone the United States

[1] Intergovernmental Panel on Climate Change, *Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Geneva, Switzerland, 2023, https://www.ipcc.ch/report/sixth-assessment-report-cycle.

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experienced 18 separate billion-dollar weather and climate disasters, totaling $165.1 billion (€150.5 billion).[2] In the European Union, the economic losses and human suffering stemming from the more frequent climate-related extreme events, such as floods, droughts, and forest fires, already average more than €12 billion per year.[3]

Reducing GHG emissions is needed to avoid the worst impacts of climate change. Transportation is a significant proportion of GHG emissions globally. The transportation sector accounts for one-third of all GHG emissions in the United States, and nearly one-quarter in the European Union.[4] Thus, prioritizing decarbonization of the transportation sector to reduce GHG emissions overall is important.[5]

The planning committee was responsible for organizing the symposium, identifying speakers, commissioning a white paper, and developing the exploratory topic papers to facilitate discussion at the symposium. The white paper is provided in Appendix A, and the exploratory topic papers are presented in Appendixes B through F.

The exploratory topic papers addressed accelerating the transition to electrification and alternative fuels; ensuring a just transition to net-zero transport; leveraging digitalization, artificial intelligence, and other integrated system-of-systems technologies to decarbonize transport; and implementing sustainable and resilient land use and transportation system design. The final exploratory topic paper focused on relevant policies, programming, and collaboration between the United States and the European Union. The papers were developed and presented by planning committee members to help frame discussions in the breakout groups, which focused on identifying research topics appropriate for EU and U.S. collaboration.

The symposium's interactive format enabled ongoing input from the assembled experts. A copy of the symposium program is provided in Appendix G and the list of participants is provided in Appendix H. The symposium began with welcomes from sponsoring organizations and keynote presentations by Robert Hampshire and Ann Shikany from U.S. DOT. The white paper prepared for the symposium was also presented in the opening session by co-authors Kelly Fleming from the Federation of American Scientists and Gereon Meyer.

Members of the planning committee summarized the key elements of the first four exploratory papers on the opening day of the symposium. Participants discussed challenges and opportunities and potential research needs on the topics in breakout groups. Planning committee members summarized the key discussion points in a general session with participants providing additional feedback. On the second day, Gretchen Goldman from U.S. DOT and Torsten Klimke and Jane Amilhat from the European Commission provided a keynote presentation on Setting the Scene: Relevant U.S. and EU Policy, Programming, and Collaboration Considerations. Two general sessions followed with facilitated discussions on the fifth exploratory topic addressing potential transatlantic research and innovative programming-level and policy-level pathways.

The planning committee thanks the many individuals who contributed to the organization and preparation of the symposium, including topic experts and moderators, TRB staff, and liaisons from U.S. DOT, the European Commission, and the European Conference of Transport Research Institutes.

This proceedings, prepared by Katherine F. Turnbull of the Texas A&M Transportation Institute, the symposium rapporteur, is a compilation of the presentations and a factual summary of the ensuing discussions at the event. The planning committee was responsible solely for organizing the symposium, identifying speakers, and developing breakout session topics. The views contained in the proceedings are those of individual symposium participants and do not necessarily represent the views of all participants, the planning committee, TRB, U.S. DOT, the European Commission, or the National Academies.

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[2] National Centers for Environmental Information, U.S. Billion-Dollar Weather and Climate Disasters, National Oceanic and Atmospheric Administration, 2023, https://www.ncei.noaa.gov/access/billions.

[3] Joint Research Centre, *Climate Change Impacts and Adaptation in Europe: JRC PESETA IV Final Report*, edited by L. Feyen, J. Ciscar, S. Gosling, D. Ibarreta, and A. Soria, European Commission Publications Office, 2020, https://data.europa.eu/doi/10.2760/171121.

[4] U.S. Environmental Protection Agency, Inventory of U.S. Greenhouse Gas Emissions and Sinks, 2019, https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks; European Commission, Climate Action: Transport, https://climate.ec.europa.eu/eu-action/transport_en.

[5] *Long-Term Strategy of the United States: Pathways to Net-Zero Greenhouse Gas Emissions by 2050*, U.S. Department of State and Executive Office of the President, 2021, https://www.whitehouse.gov/wp-content/uploads/2021/10/US-Long-Term-Strategy.pdf.

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Acronyms and Abbreviations

2ZERO	Towards Zero Emission Road Transport
AI	artificial intelligence
AV	automated vehicle
BEV	battery electric vehicle
BIL	Bipartisan Infrastructure Law
CCAM	Connected, Cooperative, and Automated Mobility
CHIPS	Creating Helpful Incentives to Produce Semiconductors
EC	European Commission
EPA	U.S. Environmental Protection Agency
ERTRAC	European Road Transport Research Advisory Council
EU	European Union
EV	electric vehicle
FCEV	fuel cell electric vehicle
FHWA	Federal Highway Administration
GHG	greenhouse gas
HEV TCP	Hybrid and Electric Vehicle Technology Collaboration Program
ICE	internal combustion engine
IEA	International Energy Agency
IIJA	Infrastructure Investment and Jobs Act
IRA	Inflation Reduction Act

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LCFS	Low Carbon Fuel Standard
LDV	light-duty vehicle
MOU	Memorandum of Understanding
NAS	National Academy of Sciences
NEVI	National Electric Vehicle Infrastructure
NO_x	nitrogen oxide
PHEV	plug-in hybrid electric vehicle
$PM_{2.5}$	particulate matter
RDT	Research, Development, and Technology
SAF	sustainable aviation fuel
SMART	Strengthening Mobility and Revolutionizing Transportation
STRIA	Strategic Transport Research and Innovation Agenda
SUV	sport utility vehicle
TEN-T	Trans-European Transport Network
TRA	Transport Research Arena
TRB	Transportation Research Board
U.S.	United States
U.S. DOE	U.S. Department of Energy
U.S. DOT	U.S. Department of Transportation
USDA	U.S. Department of Agriculture
UTC	University Transportation Center
ZEWT	Zero-Emission Waterborne Transport

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Opening Day

Victoria Sheehan, *Transportation Research Board, National Academies of Sciences, Engineering, and Medicine*
Firas Ibrahim, *U.S. Department of Transportation*
Gretchen Goldman, *U.S. Department of Transportation*
Torsten Klimke, *European Commission's Directorate-General for Mobility and Transport*
Jane Amilhat, *European Commission's Directorate-General for Research and Innovation*
Robert Hampshire, *U.S. Department of Transportation*
Ann Shikany, *U.S. Department of Transportation*
Chris Hendrickson, *Carnegie Mellon University*
Gereon Meyer, *VDI/VDE Innovation + Technik GmbH*
Kelly Fleming, *Federation of American Scientists*
Patricia "Paty" Romero-Lankao, *University of Toronto*
Karen Vancluysen, *POLIS Network*
Margriet van Schijndel-de Nooij, *Eindhoven University of Technology*
Heng Wei, *University of Cincinnati*
Tasman Crowe, *University College Dublin*
Timothy Sexton, *City of Minneapolis*

WELCOME FROM THE TRANSPORTATION RESEARCH BOARD

Victoria Sheehan

Victoria Sheehan provided a welcome from the Transportation Research Board (TRB) of the National Academies of Sciences, Engineering, and Medicine. She noted that TRB was pleased to host the seventh European Union–United States (EU-U.S.) Symposium, sponsored by the U.S. Department of Transportation (U.S. DOT) and the European Commission (EC).

Sheehan noted that TRB assisted with the first six symposia, which have enhanced transatlantic information sharing, coordination, and cooperation in transportation research. The symposia provide the opportunity for individuals from public agencies, academia, and industry to discuss key issues, research needs, and joint activities.

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Sheehan expressed her gratitude to the TRB staff assisting with the symposium, including Tom Menzies and Brittany Bishop. She also recognized the symposium planning committee, including the co-chairs, for the development of an outstanding agenda.

WELCOME FROM THE U.S. DEPARTMENT OF TRANSPORTATION

Firas Ibrahim and Gretchen Goldman

Firas Ibrahim extended a welcome from U.S. DOT. He emphasized the value of the transatlantic partnership, since transportation is important in all areas of the world. Transportation connects families, friends, jobs, education, health care, and recreation. It is vital to the economy and drives prosperity.

Ibrahim noted that the unintended consequences of the transportation system include contributing approximately one-third of the greenhouse gas (GHG) emissions that contribute to climate change. He commented that these impacts can be noted on a daily basis with record high temperatures and more frequent storms. Furthermore, he noted that climate change recognizes no boundaries, affecting all areas of the world.

Stressing the importance of the decarbonization revolution, Ibrahim discussed action that was needed now to save our way of life and to build a better future for everyone. He encouraged participants to think of themselves over the 2-day symposium as architects of the future. Ibrahim noted that embracing global partnerships will be important to ensure that the future does not include a conflict between progress and sustainability. He noted the importance of embracing green technologies and change as a moral obligation to future generations.

Gretchen Goldman provided a welcome from the U.S. DOT Climate Change Research and Technology Program and the U.S. DOT Climate Change Center. Goldman noted that assisting with the symposium was one of the first tasks she took on when she moved to U.S. DOT from the White House a year ago. She described the challenge of addressing transportation decarbonization without sacrificing mobility, accessibility, and equity. She noted that the decisions made now will determine if, and when, the United States is able to reach zero emissions from the transportation sector.

Goldman described the two main strategies being used by U.S. DOT to meet the zero-emissions goal. The first strategy focuses on implementing the diverse programs contained in the Bipartisan Infrastructure Law (BIL), the Creating Helpful Incentives to Produce Semiconductors (CHIPS) and Science Act, and the new U.S. Environmental Protection Agency (EPA) fuel economy standards. The second strategy focuses on investments in research and technology. Goldman stated that now is the time to make clear-eyed decisions to address decarbonizing the transportation sector. She indicated that working with diverse groups will be needed to accomplish the goal of decarbonization. She also noted that that there is much to be learned and shared between the United States and the European Union to help achieve the goal.

WELCOME FROM THE EUROPEAN COMMISSION

Torsten Klimke and Jane Amilhat

Torsten Klimke provided a welcome from the European Commission's Directorate-General for Mobility and Transport. Noting the benefits of the previous symposia, Klimke stressed the importance of relaunching the EU-U.S. symposia, which were initiated in 2013. Klimke noted the importance of focusing on the topic of decarbonizing the transportation sector. He discussed the European election the previous weekend, which will influence future directions of the European Union. He noted that the transition to decarbonization will need to be inclusive, affordable, fair, and competitive. He suggested that the similarities between the European Union and the United States support the importance of working together on decarbonizing the transportation sector.

Jane Amilhat provided a welcome from the European Commission's Directorate-General for Research and Innovation. Amilhat discussed the benefits of the previous symposia, including sharing information, experiences, and research results between the European Union and the United States. She described the extensive coverage of transport research topics in the current, ninth research framework program, Horizon Europe. She noted that plan-

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ning for the 10th research framework program from 2028 to 2034 is beginning. Amilhat said that the ideas from this symposium will be beneficial in developing the next program. She also noted that the existing and future research programs focus on both technology and social science projects. Ensuring that technology enhances mobility, access, and equity is important in both the European Union and the United States. She stressed that there are many common interests between the European Union and the United States and working together on research and innovation will help accomplish similar goals.

KEYNOTE ADDRESSES

Robert Hampshire and Ann Shikany

Robert Hampshire welcomed colleagues from Europe and North America to the symposium on behalf of the U.S. DOT Office of the Assistant Secretary for Research and Technology. Hampshire noted that moving research and innovation into action was an important theme of the symposium from the U.S. DOT perspective. He noted that the National Oceanic and Atmospheric Administration prediction of a historic hurricane season speaks to the importance of the symposium topic of decarbonizing the transportation sector.

Hampshire encouraged participants to focus on transforming research and innovation into action. He noted that the BIL and the Infrastructure Reduction Act, as well as the CHIPS and Science Act, represent transformational legislation that provides funding that can be used to build projects working with diverse stakeholders in communities throughout the country. He noted that the legislation provides opportunities for major transportation improvements to ensure thriving communities that are resilient in the face of climate change. He challenged participants to discuss working with state, local, and tribal partners to move research into action and deliver transportation projects that focus on addressing climate change.

Hampshire reviewed many of the programs funded through his office, which focus on improving transportation mobility and revolutionizing transportation. The Strengthening Mobility and Revolutionizing Transportation (SMART) grant program represents a community-driven technology program. A total of 93 Stage 1 SMART grant awards have been made, representing approximately $14 billion in funding. The projects focus on resiliency, reducing congestion, expanding the use of low-carbon vehicles, and improving transit services and bicycle and pedestrian facilities to provide individuals with more mobility and active transportation options. The projects target at least one of eight technology areas—connected vehicles, delivery and logistics, sensors, systems integration, coordinated automation, innovative aviation, SMART grid, and SMART infrastructure. He noted that SMART grant projects provide a holistic approach to transportation and move research from the laboratory into practice.

The following University Transportation Centers (UTCs) represent a second program administered by his office. The UTC program provides $450 million for the 5-year period to support consortiums that include some 140 universities throughout the country. Hampshire reported that the UTCs provide a brain trust of transportation expertise, conducting research and educating the next generation of transportation professionals.

Hampshire noted that the conversations at this symposium will help move research into action. He described his participation as a faculty member in the 2016 EU-U.S. symposium in Brussels. He said that the symposium provided introductions to colleagues throughout the United States and the European Union. He said it was very beneficial to learn from others and to share different perspectives and experiences. He noted that the importance of restarting the EU-U.S. symposium was to foster transatlantic collaboration.

As the U.S. DOT Deputy Assistant Secretary for Transportation Policy, and one of the lead U.S. DOT climate change policy officials, Ann Shikany noted the importance of the symposium. She stressed the benefits and special nature of working with a small group of colleagues from the European Union and the United States to discuss the issues with and opportunities from decarbonizing the transportation sector.

Shikany discussed the importance of addressing climate change. She suggested that the symposium results will be beneficial to communities, industries, and the ecosystem. She noted that the U.S. DOT Policy Office works closely with Hampshire and the research group to provide the data and tools to inform solid climate policies that are vital to reaching goals addressing global climate change.

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Shikany supported the comments by other speakers that recent federal legislation provides numerous opportunities to address critical issues, including funding for research that will help address climate change. She noted the need for a future transportation system that is sustainable, equitable, and resilient.

Shikany described the National Blueprint for Transportation Decarbonization developed by the Policy Office and the U.S. Department of Energy (DOE), the U.S. Department of Housing and Urban Development, and EPA. The blueprint focuses on how to holistically reduce GHG emissions. The three main strategies in the blueprint address efficiency, convenience, and clean fuels. Efficiency focuses on making each mile of driving less carbon intensive and promoting mode shifts to bicycling and walking, as well as moving freight from trucks to rail and maritime where possible. Convenience focuses on making trips easier and reducing the amount of travel or the need to travel. The third strategy focuses on electric, hydrogen, and other zero-emission fuels. She noted U.S. DOE's hydrogen initiative as an example of one possible approach. She also highlighted the recent U.S. DOT Notice of Funding Opportunity that provides $1.3 billion for electric vehicle (EV) charging infrastructure. She noted that all of these strategies require research and good data.

OPENING COMMENTS FROM THE SYMPOSIUM CO-CHAIRS

Chris Hendrickson and Gereon Meyer

Chris Hendrickson and Gereon Meyer welcomed participants on behalf of the symposium planning committee. They reviewed the purpose, scope, and agenda for the symposium. Hendrickson noted that the symposium topic was selected due to the ongoing impacts of climate change. These impacts range from extreme weather to glacial melting and sea level rise. Hendrickson reported that addressing climate change by reducing GHG emissions from vehicles and the movement of people and goods represents the broad focus of the symposium. Other topics of interest are the additional negative impacts of the transportation sector, including inefficiency, cost, lack of resiliency, and inequality. He said the discussions at the symposium should seek ways to mitigate these negative impacts and to identify actions that can be taken. He supported Hampshire's comments that the symposium could improve the relationship between the European Union and the United States.

Meyer reiterated the comments of other speakers on the critical need to decarbonize the transportation sector to address climate change. He also stressed the urgency of taking action to reduce transportation contributions to GHG emissions. He noted that this symposium could help identify research and actions to enhance the European Union and United States collaboration to decarbonizing the transportation sector.

Meyer reviewed the symposium agenda, which included presentations, breakout groups, and full group discussions. The first morning included a summary of the white paper prepared for the symposium and overviews of the four exploratory topics. The topics included accelerating the transition to electrification and alternative fuels; ensuring a just transition to net-zero transport; leveraging digitalization, artificial intelligence (AI), and other integrated system-of-systems technologies to decarbonize transportation; and implementing sustainable and resilient land use and transportation system design.

Participants spent the remainder of the morning and early afternoon in breakout groups discussing one of the four exploratory topics. The breakout groups were tasked with identifying research topics of mutual interest, collaboration opportunities, and potential follow-up actions. Summaries of each breakout group were presented in a plenary session, with all participants having the opportunity to provide additional thoughts and ideas.

The second day included a summary of all the discussions on the four exploratory topics and presentations on relevant U.S. and EU policies, programming, and collaboration. General sessions were held to discuss research and innovation collaboration pathways for opportunities, challenges and themes, and policy-level strategies, instruments, and tools. The symposium closed with remarks from the lead delegates.

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PRESENTATION OF THE SYMPOSIUM WHITE PAPER

Decarbonization in the Transportation System: A Joint Perspective from the United States and the European Union

Kelly Fleming and Gereon Meyer

Kelly Fleming and Gereon Meyer summarized their white paper "Decarbonization in the Transportation System: A Joint Perspective from the United States and the European Union." The white paper was distributed to participants in advance of the symposium and is provided in its entirety in Appendix A, including references for the information summarized in their presentation.

Fleming and Meyer discussed the urgency and global approach needed to address climate change, including transatlantic research collaboration focusing on the role that the transportation sector plays in addressing these issues. The white paper content focuses on the impacts of transportation emissions, including social, economic, and environmental implications. It also highlights challenges of and barriers to decarbonization and new and emerging technologies that may help address these issues. Finally, the white paper reviews examples of U.S. and EU policies and programs and identifies key questions on research and collaboration for further discussion at the symposium.

Fleming reviewed the GHG emissions from different economic sectors. She noted that the transportation sector accounts for 23% of global GHG emissions, 28% of GHG emissions in the United States, and 23% of GHG emissions in the European Union. On-road vehicles account for the majority of these emissions. She noted that in the European Union, the aviation sector represents the largest increase in GHG since 1990, while road transportation has been relatively constant. Fleming indicated that the aviation and maritime sectors, along with heavy-duty trucks, are the most challenging to electrify. She reported that 97% of transportation GHG emissions are from petroleum fuel, which also emits particulate matter ($PM_{2.5}$), nitrogen oxides (NO_x), and sulfur dioxide. Furthermore, 98% of Class 8 heavy-duty trucks in the United States use diesel fuels. These vehicles account for 57% of $PM_{2.5}$ emissions and 45% of NO_x emissions.

Fleming noted that in the United States, on-road vehicles are the largest contributor to GHG in the transportation sector. More than half of the GHG emissions in the United States are from light-duty on-road vehicles and passenger vehicles. She noted that despite the best efforts of regulators in the United States, emissions have not decreased. One factor influencing this trend is that vehicles continue to increase in size, offsetting efficiency improvements that reduce GHG emissions.

Fleming highlighted the potential technology pathways to decarbonization for the various modes. She noted that the use of battery electric sources holds the greatest long-term potential for light-duty vehicles, while hydrogen seems to be the most promising fuel for long-haul trucks. Sustainable liquid fuels represent the greatest long-term opportunity for the maritime and aviation modes. She also noted that clean fuels may supplement the transition to electric-powered vehicles. Furthermore, connected and automated vehicle technology and smart infrastructure may play a role in reducing emissions. She described some of the research and development needs associated with different technologies.

Fleming discussed equity and environmental justice implications of decarbonization of the transportation system using historic data from the San Francisco/Oakland region in California. She highlighted the impacts of previous transportation projects on air pollution in lower income areas. She stressed the need to include all groups in public outreach and engagement. She also highlighted the potential job creation impacts from different EV systems and activities.

Meyer described the following barriers to strategies, policies, and programs aimed at decarbonizing the transportation system:

- Public perceptions, acceptance, and expectations;
- Uncertainties related to potential changes in public policies;
- Complexity of the innovation process, including technology, society, business, regulation, and human factors;
- Integration of energy, transportation, and data systems; and
- Global supply chain dependencies that may inhibit decarbonization efforts.

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Meyer described the differences in the sale and registration of EVs and plug-in hybrid electric vehicles (PHEVs) in the United States, Europe, and China. Although the market shares for EVs and PHEVs are growing throughout the world, the levels are higher in China and Europe, partially due to differences in public policies, perceptions, and acceptance levels.

Meyer discussed future directions that will influence progress toward decarbonizing the transportation sector. He noted that advances in resource efficiency, including batteries, light-weight materials, and the circular economy will be important. He suggested that the digital transformation will continue to drive efficiency with the use of AI and big data. The impact of automated and software-defined vehicles and robotics will also be important. He suggested that the shift from bottom-up to top-down system control will play a role. He suggested that the demand-pull versus push for technology and societal readiness will play an important role.

Fleming reviewed recent U.S. policies and programs that influence decarbonizing the transportation sector. She noted that the BIL and the Inflation Reduction Act provide funding for numerous programs and projects targeting decarbonization. She highlighted executive orders and agency rulemaking, including Justice40 and EPA actions. She also noted efforts in California, including carbon fuel standards, advanced clean cars, advanced clean trucks, and advanced clean fleets.

Meyer highlighted examples of EU policies and programs supporting decarbonization of the transportation sector, which were discussed in more detail in a separate session. He noted that the European Green Deal represented the main guiding policy framework that has been broadly agreed upon by the main EU institutions (i.e., the European Commission, Parliament, and Council). It is supported by the Fit for 55 legislative package, which includes specific programs to reduce GHG emissions in the European Union by at least 55% by 2030 compared to 1990 levels, and put the European Union on course to achieve climate neutrality (net-zero) by 2050.

Other EU policies and programs highlighted by Meyer included alternative fuels infrastructure regulation, the smart and sustainable mobility strategy, and the urban mobility framework. Meyer also noted the strategic transport research and innovation agenda, the European partnerships, and the climate-neutral and smart cities mission. He described the category of Important Projects of Common European Interest, which combine collaborative research across the European Union with public investments by Member States into the highest level of technology readiness (i.e., first industrial deployment) to build and sustain European value chains for electric batteries, hydrogen, microelectronics, and other commodities Meyer also noted that the European Green Deal is similar to the U.S. Inflation Reduction Act.

Meyer described examples of collaborative approaches between the European Union and the United States, including the Electric Vehicles Initiative of the Clean Energy Ministries and the Hybrid and Electric Vehicle Technology Collaboration Programme of the International Energy Agency. Other examples cited in the white paper are the Collaboration of European Battery Alliance and the U.S. Li-Bridge Alliance. Furthermore, he noted the U.S.-EU Trade and Technology Council joint 2023 report on smart grid interoperability and electric mobility, which includes a number of gaps and recommendations.

In closing, Fleming and Meyer highlighted some of the key research questions included in the white paper. Examples focused on methods to accelerate the transition to electrification and alternative fuels, approaches to ensure a just transition to net-zero transportation, and ways to leverage digitalization, AI, and other integrated system-of-systems technology to decarbonize the transportation sector. Other examples focused on developing and implementing sustainable and resilient land use and transportation system design and identifying approaches for both programming- and policy-level collaboration.

PRESENTATION OF EXPLORATORY TOPICS

This section summarizes the presentations of the exploratory topic papers prepared by the symposium planning committee members. The papers were distributed to participants prior to the symposium. The four exploratory topics were presented in a general session. The symposium participants were assigned to breakout sessions addressing one of the topics. The breakout groups, which were facilitated by planning committee members, discussed challenges, opportunities, and potential research needs. The results of the breakout group discussions are presented in a separate section. There was no intent to rank or rate the research ideas discussed, nor was there any attempt

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to prioritize the potential research topics. The discussion from each breakout session group was presented in a general session, and additional ideas and suggestions were provided by symposium participants.

Exploratory Topic 1: Accelerating the Transition to Electrification and Alternative Fuels

Chris Hendrickson and Gereon Meyer

Chris Hendrickson and Gereon Meyer reviewed the first exploratory topic area which focused on accelerating the transition to electrification and alternative fuels. They noted the complexity of accelerating the transition in all transportation modes. The topic paper also highlights similarities and differences in the approaches being taken in the European Union and the United States. The text of this exploratory topic paper is presented in Appendix B.

Meyer discussed some of the issues associated with achieving the goal of zero emissions from the transportation sector. He noted that all modes must be included in this discussion—from e-bikes and scooters to passenger vehicles, to trucks and buses. Consideration must also be given to the appropriate approaches for decarbonizing the maritime and aviation sectors.

Some of the issues highlighted by Meyer included the integration of renewable energy, improvements in vehicle efficiency, and alternative fuels for the maritime and aviation sectors. Other issues discussed related to battery technology, improvements in charging capabilities, and advancements in a wide range of technologies. Meyer outlined potential strategies and prospects in technology and innovation for discussion by the breakout group.

Examples of topics included selecting the most appropriate powertrain and energy source for each mode, optimizing operational efficiency to avoid rebound effects, and developing needed infrastructure for alternative fuels. Other topics included the best business models for public EV charging stations and accelerating innovation on batteries, fuel cells, and alternative fuels. Meyer also outlined examples of social, economic, and environmental considerations related to new and emerging technologies and opportunities. Examples of topics for discussion included how to foster public acceptance of new technologies, how to encourage the use of cleaner modes, and how to ensure a just transition to zero-emission modes. The exploratory topic paper also outlined potential challenges and barriers for further discussion in the breakout group, including education and workforce development, public outreach and communication, and opportunities for further EU and U.S. collaboration on all topics.

Exploratory Topic 2: Ensuring a Just Transition to Net-Zero Transport

Patricia Romero-Lankao and Karen Vancluysen

Patricia Romero-Lankao and Karen Vancluysen discussed the second exploratory topic focusing on ensuring a just transition to net-zero transportation. They noted that the paper describes the key terms and tenets associated with transportation equity, provides examples of policies and programs, and highlights case study examples in the United States and the European Union. The text of this exploratory topic paper is presented in Appendix C.

Romero-Lankao noted that the exploratory paper addressed elements to be considered to ensure that there is a just transition to net-zero transportation, with a focus on people rather than technology. The paper highlighted that socio-institutional innovations, along with technological innovations, will be needed in the transition to net-zero transportation. The paper discussed transport equity requirements for user-tailored mobility options and entirely different transportation ecosystems. Another element of a just transition addressed in the paper is that transportation decarbonization policies would be targeted equitably at the local, national, and international levels.

Vancluysen reviewed some of the overarching questions and issues outlined in the paper for discussion in the breakout group. The questions focused on ensuring that net-zero transportation policies and innovations target equity and justice, as well as ensuring that everyone benefits from decarbonization policies. Other questions focused on identifying opportunities and barriers for an equitable transition, creating benefits for all groups, and avoiding harm and unintended consequences, especially for underserved communities. The following issues were included in the paper for discussion in the breakout group:

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- Identifying shortcomings in existing strategies, policies, and programs;
- Considering the role of public-sector oversight and funding;
- Exploring community engagement, barriers, and legacies of past practices;
- Identifying opportunities with technology innovations; and
- Examining land use planning, tailored transport options, and safety and security.

Exploratory Topic 3: Leveraging Digitalization, Artificial Intelligence, and Other Integrated System-of-Systems Technologies to Decarbonize Transport

Margriet van Schijndel-de Nooij and Heng Wei

Margriet van Schijndel-de Nooij and Heng Wei discussed the third exploratory topic focused on leveraging digitalization, AI, and other integrated system-of-systems technologies to decarbonize transport. The text of this exploratory topic paper is presented in Appendix D.

van Schijndel-de Nooij noted that the paper reviewed some of the critical challenges and issues associated with decarbonizing the transportation system and the role that system-of-systems approaches, AI, and integrated technologies can play in addressing these concerns. Examples of challenges and issues cited in the paper include the aging transportation infrastructure, outdated roadway design, bridges in disrepair, and limited intermodal connectivity. Other challenges focus on the need for resiliency and sustainability, and the need for a paradigm shift in many communities.

van Schijndel-de Nooij noted that the paper explained the use of the system-of-systems approach and leveraging AI-empowered and data-driven techniques to provide insights for effective policies and sustainable practices. It also considered using digitalization to understand, monitor, assess, and mitigate the environmental impacts of transportation. The paper highlighted examples of EU and U.S. policies, programs, and projects addressing these topics.

Heng covered some of the topics included in the paper for discussion in the breakout group. These topics included the development and implementation of evidence-based policies, differences and similarities in the United States and the European Union related to barriers toward implementation, and the rate of digital tool development and regulations. Another topic focused on emerging AI and data-driven tools for use across transportation modes.

Exploratory Topic 4: Implementing Sustainable and Resilient Land Use and Transportation System Design

Tasman Crowe and Timothy Sexton

Tasman Crowe and Timothy Sexton reviewed the fourth exploratory topic addressing sustainable and resilient land use and transportation system design. They noted that the topic area focuses on the opportunity to rethink the built environment to reduce climate-related pollution and to promote the efficient use of resources. The paper also examined minimizing environmental impacts more broadly and promoting social and equity benefits of climate smart community design. The text of this exploratory topic paper is presented in Appendix E.

Crowe highlighted that the successful transition to zero-emission technologies would have to involve a more integrated approach to land use planning and the design of the surface transportation systems, as well as sustainable urban mobility planning. Other topics covered in the paper were regional-specific challenges and opportunities through smart land use and transportation system design to encourage mode shifts, including walking and bicycling.

Crowe and Sexton explained that the paper also examines climate-smart and -resilient infrastructure and using system approaches for future planning. The paper highlighted possible barriers to sustainable and resilient land use and transportation system design, including the lack of public understanding, insufficient funding, outdated land use planning and zoning requirements, and reluctance to adopt new strategies.

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Day 2: Relevant U.S. Policies, Programming, and Collaboration

Gretchen Goldman, *U.S. Department of Transportation*
Torsten Klimke, *European Commission's Directorate-General for Mobility and Transport*
Jane Amilhat, *European Commission's Directorate-General for Research and Innovation*

RELEVANT U.S. POLICIES, PROGRAMMING, AND COLLABORATION

Gretchen Goldman

Gretchen Goldman provided an overview of federal policies and programs focusing on the decarbonization of different aspects of the transportation system. She noted that decarbonizing the transportation sector requires addressing all modes and ensuring extensive coordination, among all levels of government, as well as the private sector. She described activities related to goal setting and planning, technology deployment, regulation, research, and innovations.

Goldman highlighted the unprecedented climate, clean energy, and equity investments that have been made as a result of recent federal legislation. The Inflation Reduction Act provides the largest investment in climate-relative initiatives in history. The Bipartisan Infrastructure Law (BIL) represents a once-in-a-generation investment in the nation's infrastructure. The CHIPS and Science Act includes historic investments in U.S. manufacturing. Goldman suggested that these laws provide numerous opportunities to address critical issues related to decarbonizing the transportation sector.

As other speakers discussed, Goldman noted that transportation is the largest source of greenhouse gas (GHG) emissions in the United States She noted the U.S. commitment to net-zero GHG emissions by 2050 and a 50% to 52% reduction from 2005 levels in economy-wide net GHG by 2030. Goldman discussed the challenges of meeting these goals due to the complexity of the transportation system and the multitude of stakeholders and decision-makers with distributed and siloed responsibilities. She asserted that decisive actions are needed now to address the numerous transportation system elements that will require decades of transition.

Goldman described the U.S. National Blueprint for Transportation Decarbonization, which was developed jointly by the U.S. Department of Transportation (U.S. DOT), the U.S. Department of Energy (U.S. DOE), the U.S. Department of Housing and Urban Development, and the U.S. Environmental Protection Agency (EPA). The goal of the Blueprint is complete decarbonization of the transportation sector. The blueprint provides a comprehensive,

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system-level perspective of the transportation system across all passenger and freight modes and fuels. The document presents realistic and achievable pathways to decarbonize for every mode based on innovation and science. Goldman reported that while the blueprint focuses primarily on the use of transportation modes, it also mentions the importance of life-cycle emissions. The document includes both immediate actions to deliver meaningful results by 2030 and long-term planning activities.

Goldman highlighted that the main blueprint implementation strategies focus on transportation being convenient, efficient, and clean. The convenience strategies prioritize land use decisions and community design solutions promoting access. The efficiency strategies expand options to enable shifts to more efficient vehicles and modes. The deployments of zero-emission vehicles, fuels, and associated infrastructure represent clean strategies.

Examples of funding and technical assistance programs cited by Goldman addressing the convenience strategy included transit-oriented development programs supporting local land use planning and providing credit assistance for projects integrating local housing and transportation needs. The BIL's new Safe Streets and Roads for All discretionary program focuses on safety improvements for people walking, biking, rolling, and using other active transportation options. This new program builds on the existing Safe Routes to School program and the Transportation Alternatives Set-Aside program, as well as other formula and discretionary programs. The Reconnecting Communities Pilot Program provides funding for areas previously cut off from economic opportunities by the transportation infrastructure. She noted that the program aims to correct for historic discrimination in land use planning and connects communities to walking, bicycling, and transit opportunities. The Carbon Reduction Program provides $6.4 billion in funding for projects to reduce transportation emissions and support state carbon reduction strategies.

Goldman described the BIL programs focusing on increasing people movement and vehicle efficiency. The BIL provides up to $108 billion for public transit and $2.25 billion to improve the efficiency, safety, and reliability of goods movement around ports. Vehicle efficiency efforts include implementing the new passenger fuel economy standards, applying aviation air frame and engine technologies that reduce fuel burn and emissions, and reducing pipeline leaks to mitigate methane emissions and improve safety. Goldman reviewed the new Corporate Average Fuel Economy standards that were released on June 7, 2024. The new standards are 50.4 miles per gallon (mpg) in model year 2031 for passenger cars and light trucks, and 2.851 gallons/100 miles in model year 2035 for heavy-duty pickup trucks and vans. The new standards are projected to avoid 710 million metric tons of carbon dioxide by 2025.

Goldman described some of the federal programs available for technology deployment for zero-emission vehicles. The National Electric Vehicle Infrastructure Formula Program provides $5 billion to deploy light-, medium-, and heavy-duty EV charging infrastructure along the designated Alternative Fuel Corridors (AFCs) in the country. The Charging and Fueling Infrastructure Discretionary Grant Program includes $2.5 billion to deploy EV charging and hydrogen, propane, or natural gas fueling infrastructure along AFCs and in other publicly accessible locations. Examples of potential community charging locations include public roads, schools, parks, and publicly accessible parking facilities. The Low or No Emission Grant Program and the Grants for Buses and Bus Facilities Competitive Program provides $1.9 billion this year for the purchase or lease of no- and low-emission transit buses, as well as construction and leasing of supporting facilities.

Goldman noted that the transition to zero-emission vehicles and fuel to achieve net-zero emissions will require a suite of technology solutions across all transportation modes. In terms of fuels, she noted that battery electric provides the greatest long-term opportunity for light-duty vehicles, while hydrogen may provide the greatest long-term opportunity for long-haul trucks. Sustainable liquid fuels seem to have the greatest long-term opportunity for the maritime and aviation sectors.

Goldman reviewed President Biden's Executive Order 14008 and the Justice40 Initiative, which aims to deliver 40% or more of the benefits from climate and clean energy investments to disadvantaged communities. The Justice40 Scorecard provides public tracking by federal agencies and the Climate and Economic Justice Screening Tool identifies disadvantaged communities for Justice40 programs. In addition, Goldman noted that Executive Order 14096, Revitalizing Our Nation's Commitment to Environmental Justice for All, affirms and strengthens U.S. environmental justice commitments and bolsters the role of federal science, data, and research to inform environmental justice decision making across the government.

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Goldman also reviewed the National Transportation Decarbonization Goals contained in the report *The Long-Term Strategy of the United States: Pathways to Net-Zero Greenhouse Gas Emissions by 2050*. The report states

> Federally supported research, development, demonstration, and deployment can be the prime mover to carry new carbon-free technologies and processes from the lab to U.S. factories to the market. Research and development today will lay the technology foundation necessary to maximize economic benefits from the post-2030 transition to net-zero.

Goldman described elements of the U.S. DOT Research, Development, and Technology Strategic Plan. Climate and sustainability represent one research priority. Identified research areas include decarbonization, sustainability, and resilient infrastructure. The grand challenge for this priority is to "create a transportation system that supports an economy with net-zero greenhouse gas emissions." Goldman reported that equity represented another research priority. Research areas focus on equity and accessibility assessments, mobility innovation, and wealth creation. The grand challenge is to "create an equitable transportation system that provides safe, affordable, accessible, and convenient mobility options for all users."

Goldman noted that she heads the Climate Change Research and Technology Program within U.S. DOT. The program includes embodied carbon and concrete research, climate change and transportation research, and mobility equity research initiatives. There is also an emphasis on research and tool development, including implementation of the U.S. National Blueprint for Transportation Decarbonization. Moreover, there is a focus on investments in innovative research and technology for multimodal decarbonization strategies and deployment of decision-support tools for resilience investments. Furthermore, the program is leading the Resilience Coalition with the American Association of State Highway Transportation Officials, industry, and government leaders to quantify and address resilience challenges. Goldman also co-chairs the U.S. DOT Climate Change Center which provides support for evidence-based policy decisions across U.S. DOT.

Goldman highlighted the U.S. DOE Vehicle Technologies Office. U.S. DOE has a large research and technology program focusing on on-road, off-road, air, marine, and rail elements. On-road program elements address batteries, electrification, material technology, and mobility systems. Off-road elements include electrification, hydrogen and fuel cells, advanced powertrains, and net-zero carbon fuels. Other program elements focus on technology integration and the Clean Cities and Communities partnerships.

Goldman discussed previous and potential U.S.-EU research collaboration methods and approaches. She suggested that there is a need for innovative collaboration platforms to provide the necessary engagement opportunities for the international research community. Examples of previous approaches include information exchanges and joint events, project-to-project collaboration focused on the European Commission–U.S. DOT Transportation Research Project Twinning Initiative, and program-to-program collaborations. Examples of program-to-program collaborations include the ERA-NET Infravation Program, the Federal Highway Administration Transportation Pooled Fund Program—International Partnership, and the International Transport Forum Joint Research Centre.

In closing, Goldman suggested that there is a great opportunity to build on and expand on previous efforts, as well as undertake new innovative approaches to collaboration. She noted that the recent federal investments toward transportation decarbonization and the potential for new applications of research and technology to meet the climate goals for the transportation sector could be enhanced by U.S.-EU collaboration.

RELEVANT EU POLICIES, PROGRAMMING, AND COLLABORATION: REGULATION AND TECHNOLOGY DEPLOYMENT

Torsten Klimke

Torsten Klimke discussed Horizon Europe, the EU institutional structure, and EU transport policy in the President von der Leyen Commission. He also described the key strategies in the European Green Deal, the Fit for 55 package, and REPowerEU.

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Elements in Horizon Europe address the environment and climate, energy policy and taxation, consumer health, and the safety of citizens. Other elements are the internal market and competition policy, social policy, and cohesion and regional policy. Still other elements focus on industrial, space, and digital policies as well as trade, borders and security, innovation, and research. Klimke described the EU organizational structure, including the European Commission, the European Parliament, and the Council of the European Union. The European Commission is the European Union's executive arm, while the Council is made up of the leaders of each EU country. The Parliament is elected by EU citizens. Klimke noted that he is in the Directorate-General for Mobility and Transport. There are also directorate-generals for research and innovation, energy, climate action, growth, competition, and other areas. The European Commission is the institution that proposes legislation.

Klimke reviewed the EU transport policy in the President von der Leyden Commission as outlined in the Political Guidelines for the European Commission 2019–2024. He described elements of the European Green Deal and the European Climate Law, which enshrined the 2050 climate neutrality into law. It set the EU target for a 55% reduction in GHG emissions by 2030. It also extended the Emissions Trading System to the maritime and aviation sectors, reduced free allowances to airlines over time, and extended the system further to cover road transport and construction.

Klimke reviewed some of the binding requirements established by the European Climate Law, which is EU-wide, with all Member States having to contribute to a spirit of fairness and solidarity. It is also economy-wide with all sectors of the economy playing a part. Reductions in emissions will be based on changes made in the European Union and not on international offsetting. Calculations of the reductions are based on the emissions of GHGs into the atmosphere minus those removed.

Klimke reviewed the European Green Deal key strategies. The strategies include the 2030 climate target plan and law, increasing to at least a 55% net GHG emission reduction by 2030. The new transport strategy focuses on sustainable and smart mobility that leaves no one behind. It targets 90% emission reduction by 2050 through a comprehensive approach across all transport modes. Energy system integration strategies, sustainable value chains for batteries and other elements, and a circular economy are part of the new industrial strategy. Another strategy focuses on sustainable Europe investment, a just transition, and recovery finance.

Klimke noted that the 90% emission reduction by 2050 requires an irreversible shift in the power base of the transport sector while improving the functioning of the entire transport system. Elements to accomplish this goal include accelerating zero-emission powertrains and renewable and low-carbon fuels in all modes. Seamless, multimodal transport based on digital solutions will also be needed, along with connected, cooperative, and automated mobility services. Increased investments will be needed to establish future-proof infrastructure and support sectoral transition in a fair and just manner.

Klimke reviewed the Sustainable and Smart Mobility Strategy of December 2020. He noted that some elements have aspirational targets. Some of the key milestones with a 2030 target are a minimum of 30 million zero-emission cars and 80,000 zero-emission lorries in operation. A minimum of 100 climate-neutral cities is also a target. Other targets are doubling high-speed passenger rail traffic and increasing rail freight traffic by 50%. An increase of 25% in inland waterways and short sea shipping represents another target. Still other targets focus on paperless freight transport and automated mobility deployed at large scale, as well as integrated electronic ticketing. An additional target is that the core multimodal trans-European transportation network equipped for sustainable and smart transport with high-speed connectivity will be operational. A final target is that zero-emission oceangoing vessels will be ready for market.

The target for 2035 is having large zero-emission aircraft ready for market. Targets by 2050 include nearly all cars, vans, and buses as well as new heavy-duty vehicles being zero emission. Other targets focus on doubling rail freight traffic and tripling high-speed passenger rail traffic. The target for transport by inland waterways and short sea shipping increases 50% by 2050. The fatality rate for all modes of transport in the European Union will be close to zero. The comprehensive multimodal trans-European transport network equipped for sustainable and smart transport with high-speed connectivity will be operational.

Klimke noted that there are nine major transportation corridors in the European Union that took 2 years to analyze and designate. The corridors cross Europe both north to south and east to west and encompass 432 urban areas. He noted that by 2027 the areas must identify safety, sustainability, and accessibility activities.

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Klimke discussed the July 2021 Fit for 55 package transport-related items, which include revision of the EU emissions trading system. The Fit for 55 package also includes revisions to the energy tax directive and an amendment to the renewable energy directive to implement the vision of the new 2030 climate target. Furthermore, the package includes revision to the directive on deployment of alternative fuels infrastructure and revision of the regulation setting to CO_2 emission performance standards for new passenger cars and for new light commercial vehicles.

Klimke noted that the May 2022 REPowerEU focuses on ending the dependence on fossil fuel imports from Russia well before 2030 through energy savings, diversification of energy supplies, and accelerating rollouts of renewable energy. The Fit for 55 package also includes scaling up and speeding up renewable energy including increasing the headline target for renewables from 40% to 45% by 2030. It also includes producing 10 million tons of domestic renewable hard hydrogen and 10 million tons of imports by 2030 and increasing the production of biomethane by 2030.

Klimke described the funding for the European Green Deal. A total of 30% of all EU funding can be used for climate measures, along with 37% of the recovery and resiliency facility, which was established to help with the recovery from COVID-19, to projects that fight climate change, including a large share for sustainable mobility. The just transition strategy is funded at €7.5 billion, and the social climate strategy is funded at €72.2 billion.

RELEVANT EU POLICIES, PROGRAMMING, AND COLLABORATION: RESEARCH AND PLANNING

Jane Amilhat

Jane Amilhat discussed Horizon Europe, the European Union's Framework Programme for Research and Innovation. Horizon Europe is made up of three pillars: excellent science, global challenges and European industrial competitiveness, and innovative Europe. Her comments focused on Pillar II, which addresses climate, energy, and mobility. She also highlighted the EU partnerships and mission activities with the private sector and other groups, and the research and innovation cooperative frameworks between the European Union and the United States.

According to Amilhat, with €95.5 billion for 2021–2027, Horizon Europe is the largest research and innovation program in the world. She noted that it addresses climate change and helps achieve the United Nations Sustainable Development Goals. It also promotes the European Union's competitiveness and growth. Furthermore, Horizon Europe facilitates collaboration and strengthens the impact of research and innovation in developing, supporting, and implementing new policies, while considering global challenges. Horizon Europe supports creating and dispersing knowledge and technologies.

Amilhat noted that Horizon Europe is open to researchers and innovators from throughout the world, including the United States. The rational for international cooperation is to share experiences, knowledge, and data collected in research projects and large-scale demonstrations and pilots. She commented that international participation helps identify common research areas and fields of cooperation to exploit synergies. In the longer term, international cooperation can lead to harmonized approaches in testing, methodologies, and standards.

Pillar II of Horizon Europe is made up of 6 Clusters: Health; Culture, Creativity and Inclusive Society; Civil Security for Society; Digital, Industry and Space; Climate, Energy and Mobility; and Food, Bioeconomy, Natural Resources, Agriculture and Environment. Cluster 5, Climate, Energy and Mobility, addresses climate change by better understanding its causes, evolution, risks, impacts, and opportunities. It also focuses on making the energy and transportation sectors more climate and environmentally friendly, efficient, and competitive, as well as smarter, safer, and more resilient. Areas of research include climate science and solutions, energy supply, energy systems and grids, buildings and industrial facilities in the energy transition, and energy storage. Additional areas within this cluster focus on communities and cities, industrial competitiveness and transportation, and clean, safe, accessible, and smart transportation and mobility. Amilhat reported that the total 2021–2027 budget for Cluster 5 was €15.1 billion.

According to Amilhat, the European partnerships and missions represent a new generation of objective-driven and more ambitious partnerships in support of EU policy objectives and strategic research agendas. Examples related to clean transport include zero-emission waterborne transport, toward zero-emission road transport, Clean

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Aviation, and Eurail, which is transforming Europe's rail system. Other related examples included Clean Hydrogen; toward a competitive European industrial battery value chain; Connected, Cooperative, and Automated Mobility; and Integrated Air Traffic Management. Finally, there is a Cities Mission, focusing on 100 climate-neutral and smart cities by 2030.

Amilhat noted that the EU-U.S. symposium focuses on enhancing cooperation that can be conducted at both the program-to-program level and the project-to-project level. She highlighted several existing multilateral and bilateral cooperation programs related to decarbonization that could be used to further the activities from the symposium. The International Energy Agency cooperation in the research, development, and deployment of Hybrid and Electric Vehicle Technology Collaboration Program provides one example. The Zero-Emission Shipping Mission, a part of the global initiative Mission Innovation, which was launched at the 2015 United Nations Climate Change Conference, represented a second example. The cooperation between the European Commission and the Federal Aviation Administration on research and innovation for sustainable aviation fuels provided a third example.

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Exploratory Topics: Research Needs and Future Innovation for EU-U.S. Collaboration

Chris Hendrickson, *Carnegie Mellon University*
Gereon Meyer, *VDI/VDE Innovation + Technik GmbH*
Cristina Corchero, *Institut de Recerca en Energia de Catalunya*
Craig E. Philip, *Vanderbilt University*
Patricia "Paty" Romero-Lankao, *University of Toronto*
Karen Vancluysen, *POLIS Network*
Shima Hamidi, *Johns Hopkins University*
Oliver Lah, *Wuppertal Institut für Klima, Umwelt, Energie*
Margriet van Schijndel-de Nooij, *Eindhoven University of Technology*
Heng Wei, *University of Cincinnati*
Roberto Palacin, *Newcastle University*
Guang Tian, *University of New Orleans*
Tasman Crowe, *University College Dublin*
Timothy Sexton, *City of Minneapolis*
Maria Attard, *L-Università ta'Malta*
Joe Zietsman, *Texas A&M Transportation Institute*
Jane Amilhat, *European Commission's Directorate-General for Research and Innovation*
Gretchen Goldman, *U.S. Department of Transportation*
Tyler Clevenger, *U.S. Department of Transportation*
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Torsten Klimke, *European Commission's Directorate-General for Mobility and Transport*
Ann Shikany, *U.S. Department of Transportation*
Caroline Almeras, *European Conference of Transport Research Institutes*
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EXPLORATORY TOPICS ON RESEARCH NEEDS AND POTENTIAL EU-U.S. COLLABORATION OPPORTUNITIES

This section summarizes the discussions on the research needs appropriate for EU-U.S. collaboration associated with the four exploratory topics, which were presented by planning committee members in the opening session. The text of the exploratory topic briefing papers is included in the appendixes. Symposium participants were assigned to breakout sessions addressing any one of the exploratory topics. The breakout groups, which were facilitated by members of the symposium planning committee, discussed challenges, opportunities, and research needs associated with the specific topic suitable for transatlantic cooperation. A summary of the research needs identified in each breakout group was presented to all participants in a general session. Symposium participants provided feedback on the research needs and offered additional issues for investigation. The feedback was incorporated into a final summary in a general session with additional opportunity for input from all participants. An online poll was also conducted, which helped identify key issues and research needs. No attempt was made at any point to rank or rate the research ideas discussed, nor was there any intent to prioritize potential research topics.

The final summaries of the research needs appropriate for EU and U.S. collaboration for each exploratory topic are presented in this section. The summaries were developed by the rapporteur based on the information provided by the breakout group notetakers and the recordings of the breakout group and general sessions. The summaries use a similar format to provide consistency across the exploratory topic areas.

Exploratory Topic 1: Accelerating the Transition to Electrification and Alternative Fuels

Moderators: *Chris Hendrickson and Gereon Meyer*
Notetakers/Rapporteurs: *Cristina Corchero and Craig E. Philip*

The initial discussion in this breakout group focused on the three general themes of decarbonizing the aviation and maritime sectors (which are harder to electrify), integrating vehicles and charging infrastructure, and using a full life-cycle approach to at-scale decarbonization. The research needs identified in these themes are presented next, followed by additional research needs suggested by participants during the open discussion session. All of the research topics are appropriate for EU-U.S. collaboration and cooperation.

- Breakout group participants discussed the challenges associated with decarbonizing the aviation and maritime transportation sectors, as well as long-haul trucking. Suggested research needs focused on identifying and assessing global solutions that consider appropriate energy sources, the infrastructure and supply chains to implement those sources, and adaptation to local conditions, organizational structures, and policies. Research focusing on developing sustainable business models decarbonizing these sectors was also identified as a need by participants. Another research need associated with this theme was developing and implementing measures, metrics, and tracking systems to evaluate progress toward decarbonization and to inform future policies and programs.
- The second theme area discussed by participants addressed vehicle integration and charging and fueling infrastructure. Numerous research needs associated with this theme focusing on electrification were identified, including developing common approaches for estimating grid demand, designing grid systems, and building resiliency in the grid network. Other research needs addressed optimizing resource deployment, developing smart charging systems, linking to vehicle-to-everything communication improvements, and coordinating data sharing. Developing sustainable and scalable business models for adoption in different areas and settings, including identifying funding and financing options, ownership models, affordability of automated vehicles, and life-cycle costs, represented an additional research need.
- The third theme focused on applying a full life-cycle perspective to electrification and alternative fuel development, deployment, and evaluation. Research examining the expected efficiencies at scale and at full deployment was identified as a need that could include developing and implementing mechanisms

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and measures to track deployment, focusing on the circularity of development, supply chains, and battery passports, especially the critical minerals used to develop electric batteries. Considering the impacts associated with all life-cycle elements could be part of the research. It could also examine modal efficiencies and shifts in demands and the use of artificial intelligence and advanced technologies.

The following additional research topics were identified by symposium participants during the open discussion:

- Research is needed on sustainable business models and the differences in the decision-making process in the public and private sectors, including the time it takes to reach agreements.
- Additional research is needed on sustainable liquid fuels in the aviation and maritime sectors. Topics that could be addressed include crop-based and other sustainable sources of fuels, the impacts on other uses of those sources, infrastructure needs, and funding options. It was suggested that this topic could be particularly relevant to the EU and U.S. partnership.
- Current gaps in the electrification system and ways to address these gaps need to be identified.

Exploratory Topic 2: Ensuring a Just Transition to Net-Zero Transport

Moderators: *Patricia Romero-Lankao and Karen Vancluysen*
Notetakers/Rapporteurs: *Shima Hamidi and Oliver Lah*

The discussion in this breakout session focused on the five general areas of governance and inclusive transportation policies, framing the narrative around decarbonization and the use of alternative transportation modes, jobs and workforce development, the life-cycle impacts of transportation across the supply chain, and cross-cutting data needs and data sharing. The research needs appropriate for transatlantic collaboration associated with these topics are highlighted below:

- Research associated with examining policy mixes and approaches applying an equity lens was discussed by breakout group participants. This research could focus on identifying the most appropriate policy mixes for different types of communities, including consideration of transit services, active transportation, congestion pricing, parking pricing, and other approaches. Sharing best practices across the European Union and the United States could be part of the research. The research could also consider approaches using systems thinking, holistic integrated approaches, public–private partnerships, and new mobility solutions to meet equity goals. Considering the balance between regulations and innovation to address decarbonization in communities could also be examined, as well as affordability and accessibility for different population segments. Additionally, examining potential unintended consequences of decarbonization, such as climate gentrification, could be examined. The use of Sustainable Urban Mobility Plans in Europe was suggested as a good example of a successful approach.
- Participants discussed the need for additional research examining the narrative and messaging associated with all aspects of decarbonizing the transportation sector. The research could use social science approaches to examine cultural values, aspirations, current behaviors, and preferences for future options. The results of these assessments could be used to develop appropriate messaging and messaging media, highlighting the benefits of different modes, and the true cost of driving. The research could also identify messages targeting different groups and could develop methods and metrics to evaluate the results of different approaches.
- Participants discussed the need for research focusing on jobs and workforce development associated with green mobility and decarbonizing the transportation sector. This research could focus on the opportunities for new jobs and upskilling existing jobs associated with all aspects of green mobility, as well as fit-for-purpose and low-tech approaches. Considering workforce development needs in both developed and developing countries could be included. New job opportunities could be identified, along with possible pathways for education and training to meet future green mobility workforce needs.

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- Participants discussed the need for research examining the circularity and life-cycle issues associated with decarbonizing the transport sector. The life-cycle issues could consider the full supply chain, including mineral and material extraction, vehicle production, fueling infrastructure, waste management, and ongoing supply and operation.
- Participants also discussed the need for research focusing on the issues in and opportunities with data management and data sharing associated with decarbonizing the transportation sector. It was noted that research on this cross-cutting topic could focus on the use of existing data to better inform operational and policy decisions, as well as identifying and using new data sources to make better decisions in the future.

The following additional research topic was identified by symposium participants during the open discussion:

- The need for research examining the international implications of electrification and other sustainable fuels was identified by some participants. This research could examine the implications of industrial policies, protectionism, tariffs, equity elements, and other aspects. It was suggested that examining these overarching policies of decarbonization could be beneficial. Exploring the impacts on different modes, including aviation and maritime, could also be considered in this assessment.

Exploratory Topic 3: Leveraging Digitalization, Artificial Intelligence, and Other Integrated System-of-Systems Technologies to Decarbonize Transport

Moderators: *Margriet van Schijndel-de Nooij and Heng Wei*
Notetakers/Rapporteurs: *Roberto Palacin and Guang Tian*

Participants in this breakout group discussed the different emerging digital technologies and the potential impact on decarbonizing the transportation sector. Topics focused on the lack of a common language for data, examining the digital technologies that reduce the amount of travel or influence a mode shift, and considering existing, as well as emerging, digital technologies. Assessing the benefits and potential negative impacts of shared automated mobility was also discussed. An additional topic considered by the breakout group was examining the interdependencies between transportation, energy, telecommunications, and digital solutions to unlock the system-of-systems benefits. Using digitalization and modeling tools, creating dynamic timetables, adaptive traffic management, software-defined vehicles, and automation were also discussed. Participants identified their top three technologies, with five selected for more discussion. The five selected were planning tools including adaptive traffic management, digitalization and modeling tools, tools and digitalization for on-demand shared mobility, automation, and software-defined vehicles. The following research needs for EU-U.S. collaborations were identified after a more extensive discussion of each of these digital technologies:

- Research examining the use of planning tools, including adaptive traffic management to identify the effects of different interventions on decarbonizing the transportation system could be beneficial. The research could help to understand the link between data, evidence, and policy development.
- Research examining the use of digital twins and other digital modeling tools to estimate the impacts of different policies and programs to decarbonize the transportation sector. The results could examine the impacts of different programs and pathways in different communities. The research could consider the system-of-systems interdependencies among critical systems in the transportation, energy, and telecommunications sectors, and help identify sustainable pathways for future development.
- Research focusing on using digital technologies to identify the minimum data requirements from shared-mobility stakeholders to develop services and maximize use. Research considering synergies with automation and the management of potential rebound effects, such as increases in vehicle miles traveled, was also discussed.
- Research focused on the decarbonization impact of automation in general, including the analysis of energy efficiency by optimized control versus energy consumption by onboard and off-board computing.

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- Research examining the policies that could encourage changes in behavior and business models to maximize the impact of automation, including policies that encourage automation to support decarbonization and encourage green mobility.
- Research examining the functionalities required for software-defined vehicles to adapt to their surroundings and provide the same level of performance and comfort through upgradability and extended lifetime of centralized and generic electronic hardware to maximize decarbonization benefits.

The following research topics were discussed by the symposium participants during the open discussion:

- Research examining the approaches to and policies on data privacy and data sharing in the European Union and the United States. The research could include exploring similarities and differences as well as sharing best practices. The research could also examine approaches to encourage more open data sharing among all groups to address decarbonization and to explore the infrastructure needed to accommodate more open data sharing.
- Research exploring how digital tools can be used to plan, operate, and evaluate mobility as a service option.

Exploratory Topic 4: Implementing Sustainable and Resilient Land Use and Transportation System Design

Moderators: *Tasman Crowe and Timothy Sexton*
Notetakers/Rapporteurs: *Maria Attard and Joe Zietsman*

The discussion in this breakout group focused on the four general areas of sustainable community design, land use and transportation policies and programs, stakeholder engagement, and new mobility. Participants outlined questions and research needs related to each of these topic areas. The following research needs for EU-U.S. collaboration were identified by breakout group participants:

- Participants discussed sustainable design and the need to match the decarbonized transportation system to the unique characteristics and needs of cities, regions, and countries. Participants identified research examining the tools that data practitioners and policymakers need and can use to assess integrating transportation and land use planning and land use development as a need. The research could explore community design to address resilience to climate change and ensure equity of access for all user groups. Other elements to be addressed in the research were developing data- and information-sharing methods to enable collaborative approaches.
- Participants discussed the disconnect between different levels of decision making at the EU/federal, state, and local levels related to land use and transportation planning, and the speed at which government regulates and the speed at which technology companies and operators move. Participants suggested that research examine different approaches for coordinating land use and green transportation strategies, and the successful outcomes of those approaches, would be beneficial. The research could focus on the design and deployment of approaches that respect local contexts and provide flexibility while moving toward a shared vision. The research could explore approaches used in other related fields, examine non-transportation data to help quantify impacts, and outline examples of successful policies and programs.
- Participants discussed the need for widespread stakeholder engagement to ensure a just transition to decarbonization and sustainable and equitable communities. Research on identifying the best models for effective stakeholder engagement was discussed by participants. The research could identify the essential characteristics of effective approaches for different contexts, the type of information needed, the different communication and engagement methods, and techniques to evaluate the results.
- Participants discussed research needs related to public agencies developing a culture of innovation that is understood and accepted internally and externally. The research could also explore partnerships among the public agencies, community groups, and the private sector to foster innovation in decarbonizing transportation and fostering resilient and equitable communities.

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The following topics were suggested by symposium participants in the general sessions:

- Some participants suggested that additional research on what makes for successful transit-oriented development could be beneficial, including the elements that support businesses and livability for residents.
- Research exploring the impact of advanced air mobility on the design of communities was suggested by some participants.
- Other participants identified exploration of the impact of parking on the design of communities, including ways to reduce the parking footprint, as part of the move to green mobility.

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Research and Innovation Collaboration Pathways: Programming and Policy

RESEARCH AND INNOVATION COLLABORATION PATHWAYS: PROGRAMMING-LEVEL OPPORTUNITIES, CHALLENGES, AND THEMES

Moderators: *Jane Amilhat and Gretchen Goldman*
Notetaker/Rapporteurs: *Tyler Clevenger and Ingrid Skogsmo*

General sessions were held with all symposium participants to discuss research and innovation pathways. The first session focused on opportunities, challenges, and themes for programming pathways. The second session addressed strategies, instruments, and tools for policy-level pathways. In both cases, the first part of the session was an open discussion with all participants sharing ideas and experiences. The facilitators and notetakers consolidated the comments during a break and presented a summary to the full group. Additional input was obtained from participants after the summary presentations.

Participants in this session discussed the programming of research and innovation topics addressing decarbonizing the transportation sector. Facilitators Amilhat and Goldman noted that the programming level focused on what could be undertaken, including research collaboration between the European Union and the United States. The next session explored policies on how the collaboration should be accomplished between the European Union and the United States. As summarized in this section, a number of common topics were identified by participants for possible EU and U.S. research and innovation collaboration.

- A major topic area identified by numerous participants was on research and information sharing between the European Union and the United States on the various types of clean fuels, including electric, hydrogen, and sustainable liquid fuels. Issues identified for further research focused on electric bidirectional charging, electric charging infrastructure development and operations, electric charging protocol standards, and integrating electric vehicles (EVs) into the electric grid. Strategies for managing charging, the roles of the public and private sectors, and business models were highlighted as important topics by participants. Addressing these topics associated with passenger vehicles, buses, trucks, and other vehicles was also noted as important by numerous participants. Cooperation among the European Union and the United States on hardware and software technologies and standards for software-defined vehicles was also suggested by numerous participants, especially related to the safety and security of automated and connected driving. Focusing on all types of applications, including shared mobility and freight logistics was noted as important

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by many participants. Considering the circularity of clean vehicle design, manufacturing, operations, and reuse was also suggested by some participants. This topic could address global perspectives as material sourcing, global markets, production facilities, and the potential impact on emerging economies. It was further suggested that examining vehicle materials and design holistically to optimize efficiency could be beneficial. This analysis could include consideration of vehicle size, weight, and other factors.

- Electric batteries represented a related topic that drew interest from numerous participants. Issues suggested for additional research included new technologies and advanced materials beyond lithium-ion, links to critical materials, ethical sourcing of materials, and the circular economy. Other topics focused on battery safety, thermal performance, and testing methods. Developing testing standards and protocols was mentioned by many participants as a needed research focus. Research to develop a digital product passport was suggested to identify the extent batteries are meeting sustainability standards. Relevant sustainability attributes could be identified to evaluate battery products and their closeness to circularity. The same approach could also be used for clean vehicles and other fuels, as well as vehicle size, weight, and other attributes.
- Research focusing on approaches to decarbonize the aviation, maritime, and off-road sectors was noted as important by participants. Working together, the European Union and the United States could examine sustainable fuels for these modes, conduct life-cycle assessments, and collaboration on standards for sustainable liquid fuels. The use of clean fuels with shared, pooled, automated vehicles as public transportation was also discussed.
- The need to expand collaboration with researchers outside the transport sector was suggested by some participants. Engaging experts in the electric grid, automation, and industrial development was noted as important. Outreach to individuals with social science and behavioral science backgrounds was also suggested by participants.
- Participants discussed a wide range of cross-cutting social science and behavioral science research topics. It was noted by some participants that social science research provides a better understanding of the social practices that encourage or inhibit the adoption of clean vehicles, technologies, and changes in modes. Examples of research topics identified by participants included behavioral, cultural, and economic factors that influence mode shifts to buses and public transportation, as well as walking and bicycling. Research exploring the growth in online shopping and home goods delivery was also noted as a need by some participants. Other suggested topics were ensuring that all communities and individuals are treated equitably and that unintended consequences do not occur. Research on best practices in public engagement opportunities was also noted as important. Examining potential impacts of electrification, pricing, and other pathways on low-income communities was highlighted by some participants. Conducting joint social science research projects on these and other topics were discussed, along with sharing experiences and lessons learned.
- Participants noted the important links between transportation, land use, and housing. Research topics related to land use planning and transportation were identified, along with possible pilot projects focusing on the design and development of green communities. Sharing best practices on land use and transportation planning, and examining the application of complete streets, transit-oriented developments, and other approaches were highlighted.
- Participants discussed prioritizing the research topics by the impact that the results might have on emission reductions and decarbonizing the transportation sector. Participants discussed the potential for collaboration between the European Union and the United States and its dependence on numerous factors, including the scope, timing, and funding levels of possible programs and projects.

RESEARCH AND INNOVATION COLLABORATION PATHWAYS: POLICY-LEVEL STRATEGIES, INSTRUMENTS, AND TOOLS

Moderators: *Ann Shikany and Torsten Klimke*
Notetakers/Rapporteurs: *Caroline Almeras and Liya Rechtman*

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Participants in this session discussed different possible cooperative models, or the "how" for collaboration between the European Union and the United States on research and innovation related to decarbonizing the transport sectors. Participants described experience with current methods of coordination and cooperation. They also highlighted new ideas and opportunities for expanding transatlantic research, innovations, and information sharing. Participants noted that there are numerous opportunities to collaborate on sharing information, but that collaborating on actual research projects is more difficult. The discussion was summarized into the following three general categories by the facilitators and notetakers after the initial summary and feedback from all participants. The moderators noted that Briefing Paper 5, "The United States and the European Union: Relevant Policies, Programming, and Collaboration" provides additional information on current collaboration programs. The text of this briefing paper is provided in Appendix F.

Build on Existing Platforms and Methods

Participants discussed several existing organizations, conferences, journals, and other mechanisms that have been used to share information between the United States and the European Union on research and innovation projects. Building on these platforms to expand collaboration was discussed. Examples of potential follow-up activities are highlighted below:

- Continue to coordinate with Transportation Research Board (TRB) activities, including organizing and holding sessions at the TRB Annual Meetings in Washington, DC, on diverse topics related to decarbonizing the transport sector. Convene the symposium participants at the 2025 TRB Annual Meeting for an information-sharing session. Promote sessions at future TRB Annual Meetings and specialized conferences.
- Organize sessions at the biennial Transport Research Arena (TRA) Conferences organized by the European Commission. The next TRA conference is scheduled for May 18–24, 2026, in Budapest, Hungary.
- Pursue possible conferences, workshops, and meetings sponsored by the symposium hosts and other organizations and groups. For example, the University Transportation Centers focusing on climate change and emissions could sponsor conferences and information-sharing events. Other organizations in the United States include the American Association of State Highway and Transportation Officials, the American Public Transportation Association, the Institute of Transportation Engineers, and the American Planning Association. International organizations include the International Civil Aviation Organization, the International Maritime Organization, the International Association of Public Transport, and the Permanent International Association of Road Congresses.
- Publish in academic journals to continue to present research results relating to decarbonizing the transport sector. Participants discussed approaches to encourage researchers from the United States and the European Union to collaborate on articles as appropriate.
- Publish articles on the symposium and decarbonizing the transportation sector in TRB's quarterly magazine, *TR News*, and other organization and agency magazines.
- Develop a PowerPoint presentation on the symposium and provide it to participants and agency staff for use at conferences, workshops, and meetings.
- Distribute the symposium proceedings to diverse stakeholders at the global, national, state, and local levels.
- Use the results of the symposium to develop research need statements and possible projects through traditional EU and U.S. funding sources.
- Use existing programs sponsored by the U.S. Department of Transportation (U.S. DOT), the Federal Highway Administration, the Federal Aviation Administration, and other modal agencies to encourage transatlantic partnerships.

Recognizing and Working Within Funding Silos

The second general area of discussion focused on the need to recognize the limitations of funding and the inability of most programs to share funds between the European Union and the United States. In most cases,

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researchers from the European Union and the United States will need to identify and secure their own funding. Possible approaches to address this are highlighted below:

- Build on existing partnerships between universities, national laboratories, research institutes, and companies in the United States and Europe to expand research addressing decarbonizing the transportation sector. Participants discussed examples of universities, national laboratories, and research institutes in the United States that have Memorandums of Understanding (MOUs) with European counterparts. Participants suggested opportunities to build these MOUs for additional research and information-sharing activities.
- Reconsider the twinning program as either a formal or informal method of collaboration.
- Explore other available programs that could assist in funding researchers from the European Union and the United States, including foundations and other non-traditional sources.
- Identify and pursue additional forms of research and innovation partnerships.
- Provide assistance to researchers on visas, export control requirements, and other guidelines.

Participants discussed a variety of new and innovative approaches to fostering EU and U.S. research and innovation collaboration. The following ideas were suggested by symposium participants.

- Build on the "Sister City" concept and develop "Sister Regions" where both sides could provide funding for related research, pilots, demonstrations, and other activities focusing on decarbonizing the transportation sector. The regions could share expertise and experiences to build ongoing partnerships of innovation.
- Take advantage of the mid- to long-term strategic planning process of the EU partnerships in the transportation sector to align objectives, budgets, and scope of funding programs between the EU and U.S. counterparts. The groups from the United States would need to identify funding sources using the existing general framework.
- Identify novel public–private partnership opportunities that could be funded by a mix of sources. These partnerships could include public agencies, academic institutions, and private businesses.

Professional Development and Educational Opportunities

Symposium participants discussed several opportunities for encouraging professional development and education. Participants noted that there are numerous funding sources in both the European Union and the United States that could be used to promote student exchanges, professional development, and training. One example cited was the potential for training on unique tools, equipment, and testing methods. The following ideas were suggested by participants:

- Utilize university programs to provide student and faculty exchange opportunities.
- Utilize the national laboratories to share information and possible exchanges of personnel.
- Share information on available experts for use in both the United States and the European Union.
- Share information on available laboratories, test tracks, equipment, and other special facilities.

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Closing Comments

Jane Amilhat, *European Commission's Directorate-General for Research and Innovation*
Torsten Klimke, *European Commission's Directorate-General for Mobility and Transport*
Victoria Sheehan, *Transportation Research Board, National Academies of Sciences, Engineering, and Medicine*
Firas Ibrahim, *U.S. Department of Transportation*

CLOSING COMMENTS FROM THE EUROPEAN COMMISSION

Jane Amilhat and Torsten Klimke

Jane Amilhat provided closing comments from the European Commission's Directorate-General for Research and Innovation. She thanked participants for their excellent ideas and robust discussions. She noted the alignment between the European Union and the United States in many of the priorities for decarbonizing the transportation sector. Similarities in priorities related to technology, electrification, the need for social science research, and the importance of equity and resiliency were described by participant from both the European Union and the United States.

According to Amilhat, the list of research and innovation topics discussed will be very beneficial for both the European Union and the United States. She noted that the symposium results will enhance cooperation between the European Union and the United States and can be used to help develop sessions at future conferences and meetings, as well as hosting joint workshops focusing on specific topics.

She further noted that the topics will be of benefit in the development of the next EU research and innovation agenda. She acknowledged that there is still work to be done developing methods for the European Union and the United States to foster collaboration on research projects, including possible joint sponsorship.

Torsten Klimke provided closing comments for the European Commission's Directorate-General for Mobility and Transport. Noting the robust discussion on wide-ranging topics, Klimke stressed the benefit of the symposium to the European Union. He noted that the results will help strengthen collaborative activities between the European Union and the United States. In addition, he said that the European Union is looking forward to hosting the next symposium in 2025 and building on the success of this meeting.

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CLOSING COMMENTS FROM THE TRANSPORTATION RESEARCH BOARD

Victoria Sheehan

Victoria Sheehan provided closing comments from the Transportation Research Board. Sheehan agreed that turning research into action was a key focus to bring about transformative change. She noted that the National Academy of Sciences (NAS) is working collectively on research and information sharing on climate change and decarbonization. The NAS Climate Crossroads initiative is taking advantage of the expertise across the National Academies of Sciences, Engineering, and Medicine. In addition to the Transportation Research Board (TRB), she highlighted the opportunities for collaboration with experts throughout NAS. She encouraged participants to reach out to TRB staff to assist with any connections.

Sheehan invited participants to attend the TRB Annual Meeting in Washington, DC, on January 5–9, 2025. A special session could be organized to highlight the symposium results. Other meetings could also be organized to share information and help turn research into practice. In closing, Sheehan thanked participants for their active engagement.

CLOSING COMMENTS FROM THE U.S. DEPARTMENT OF TRANSPORTATION

Firas Ibrahim

Firas Ibrahim provided closing comments from the U.S. Department of Transportation (U.S. DOT). He reminded participants that climate change cannot be solved in a day. It will take time to achieve the goal of zero emissions. It will require everyone to participate. Public outreach is needed to present the importance and the science of the issues and to communicate why actions are needed. He stressed the need to solve these issues together. He challenged participants to think of the one thing they will do differently to help reach the zero-emissions goal, based on what they learned at the symposium. He also urged participants to think big on ways to decarbonize the transportation sector and to continue the relationships developed at the symposium and explore opportunities for collaboration. He further challenged participants to be inspired with the energy and commitment fostered at the symposium to address climate change. He noted that U.S. DOT is committed to being a strong partner in addressing decarbonization within all aspects of the transportation sector.

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Appendix A

White Paper on Decarbonization in the Transportation System: A Joint Perspective from the United States and the European Union

Kelly Fleming, *Federation of American Scientists, United States*
Gereon Meyer, *VDI/VDE Innovation + Technik GmbH, Germany*

As the world faces the escalating challenge of climate change, the urgency to decarbonize transportation systems has never been more critical. As a significant contributor to greenhouse gas (GHG) emissions and to air pollution, the transportation sector requires concerted global efforts to reduce its carbon and pollutant emissions. In view of this major and urgent necessity, this white paper presents a collaborative approach between the United States (U.S.) and the European Union (EU), aimed at synergizing efforts toward a sustainable future. The goal is to foster a transatlantic dialogue that facilitates sharing of knowledge, enhances collaboration in research and innovation, and accelerates the adoption of effective strategies for the development and deployment of climate- and environment-friendlier vehicles and services across all modes in the transportation and mobility domain.

At the same time, the paper aims to set the scene for the Seventh EU-U.S. Transportation Research Symposium, organized by the European Commission, the U.S. Department of Transportation (U.S. DOT), and the Transportation Research Board (TRB) in June 2024 in Washington, DC, where this dialogue will be realized. The title of this event is Global Pathways to Net-Zero: Behavioral, Social, and Technological Research and Innovation (R&I) Strategies for Transportation Decarbonization. It builds on key governance frameworks, including the Agreement on Scientific and Technological Cooperation (2023),[1] the Bilateral Implementing Agreement for Cooperative Activities in the Field of Research, Development, Technology and Innovation for all Modes of Transport between U.S. DOT and the European Union (2013), as well as insights from previous symposia focused on decarbonization and climate change mitigation, such as Adaptation to Climate Change (2016) and Decarbonizing Transportation for a Sustainable Future: Mitigating Impacts of the Changing Climate (2017). At the political level, the Joint Communiqué by the U.S. DOT Secretary Pete Buttigieg and the European Commissioner for Transport, Adina Vălean on Transatlantic Cooperation from May 2023 supports the ongoing cooperation in aviation and maritime

[1] Council of the European Union, "Council Decision (EU) 2023/2073 of 25 September 2023 Concerning the Extension of the Agreement for Scientific and Technological Cooperation Between the European Community and the Government of the United States of America," September 2023, https://op.europa.eu/en/publication-detail/-/publication/b74dfd83-5dcb-11ee-9220-01aa75ed71a1/language-en.

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transport, as well as issues of common interest in transportation, such as international collaboration to fight climate change and decarbonize transport.[2]

While the exchange primarily aims to explore common priorities and instruments of coordinated research and innovation activities, it extends to examining public policies, industrial strategies, and regulatory frameworks that underpin the use of new knowledge and practices. Such a comprehensive approach is critical to understanding and implementing the transformative changes needed to achieve decarbonization goals in a sector as complex and multifaceted as transportation. According to this paradigm, the dialogue focuses on the overarching policies and measures implemented by the United States and the European Union at the federal and union levels. Nonetheless, mobility choices and transportation policy occasionally reflect the variety of regional conditions. Therefore, activities at the U.S. state or EU Member State level and particularly in urban areas are also discussed when there is particular relevance or particularly innovative approaches to the decarbonization challenge.

Structured to provide both a comprehensive overview and detailed insights into the challenges of decarbonizing the transportation sector, this white paper is organized into several focused sections. It begins by highlighting the critical issues associated with transportation emissions, including the climate crisis, impacts on human health, ecosystems, and the economy. Following this, the paper reviews current U.S. and EU policies and programs, showcasing successful collaborations and detailing the strategies, technologies, and infrastructures being implemented. It delves into the social, economic, and environmental implications, emphasizing the effects on underserved communities, affordability issues, as well as competitiveness and workforce impacts. The paper also addresses challenges of and barriers to decarbonization, such as technological limitations and slow adoption rates. Furthermore, it explores new and emerging technologies in research and innovation, offering insights into future enablers of transportation decarbonization, including the potential role of artificial intelligence (AI). The white paper concludes with key research questions and opportunities for collaboration, setting the stage for further discussion and exploration of effective strategies for a sustainable and resilient transportation future. Complementing the white paper, a series of briefing papers will detail exploratory topics and include lead questions to guide discussions at the symposium, ensuring a thorough examination of the subject matter.

TRANSPORTATION EMISSIONS

Globally, GHG emissions from the transportation sector make up the largest share of any economic sector at 23%, and continue to grow (see Figure A-1).[3] According to the U.S. Environmental Protection Agency (EPA), in 2021 transportation emissions made up 28% of all emissions in the United States, shown in Figure A-2.[4] Of those emissions, 58% are from on-road light-duty vehicles (LDVs), 23% are from on-road medium- and heavy-duty vehicles, 8% are from aircraft, 3% from marine, 2% from rail, and 6% from other modes such as transit, motorcycles, and pipelines.[5] In the European Union, like in the United States, road transportation constitutes the highest proportion of overall transportation emissions—emitting 76% of all transportation GHG emissions in 2021,[6] while rail causes less than 1%, and marine and aviation contribute the rest about equally. The large share of emissions

[2] European Commission's Directorate-General for Mobility and Transport, "Joint Communiqué by the U.S. Department of Transportation Secretary Pete Buttigieg and the European Commissioner for Transport, Adina Vălean on Transatlantic Cooperation," May 2023, https://transport.ec.europa.eu/news-events/news/joint-communique-us-department-transportation-secretary-pete-buttigieg-and-european-commissioner-2023-05-30_en.

[3] International Energy Agency, "Global Energy-Related CO_2 Emissions by Sector," July 2020, https://www.iea.org/data-and-statistics/charts/global-energy-related-co2-emissions-by-sector.

[4] U.S. Environmental Protection Agency, "Sources of Greenhouse Gas Emissions," https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions (accessed April 2024).

[5] U.S. Environmental Protection Agency, "Fast Facts on Transportation Greenhouse Gas Emissions," https://www.epa.gov/greenvehicles/fast-facts-transportation-greenhouse-gas-emissions (accessed April 2024).

[6] European Environment Agency, "Greenhouse Gas Emissions from Transport in Europe," October 2023, https://www.eea.europa.eu/en/analysis/indicators/greenhouse-gas-emissions-from-transport.

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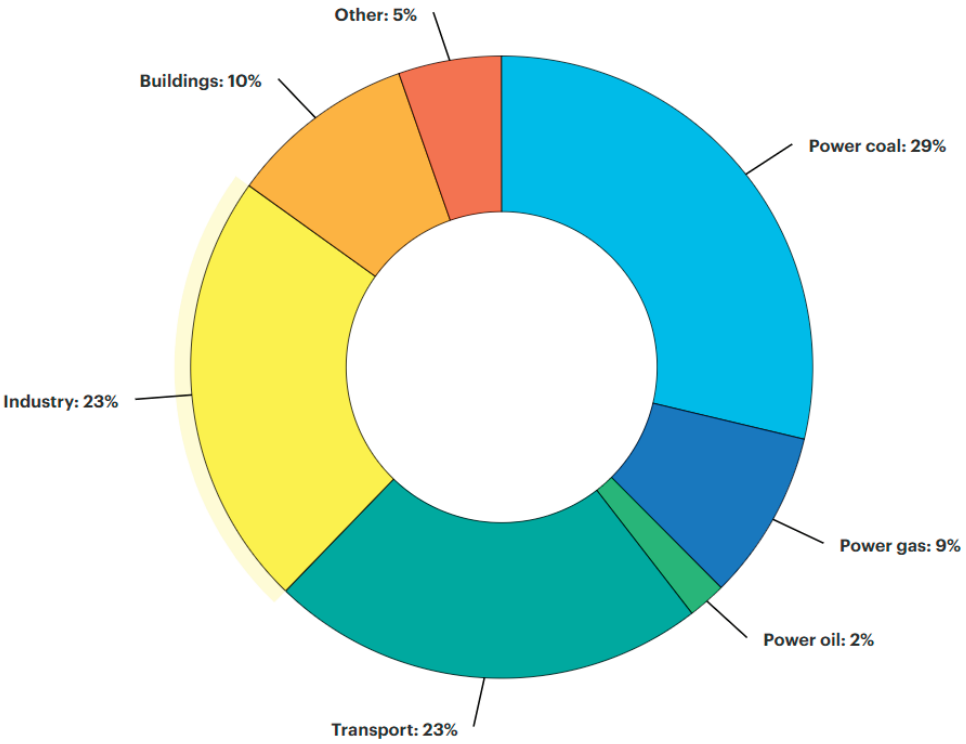

FIGURE A-1 Global greenhouse gas emissions by economic sector in 2020.
SOURCE: International Energy Agency. 2020. "Global Energy-Related CO_2 Emissions by Sector." https://www.iea.org/data-and-statistics/charts/global-energy-related-co2-emissions-by-sector. CC BY 4.0.

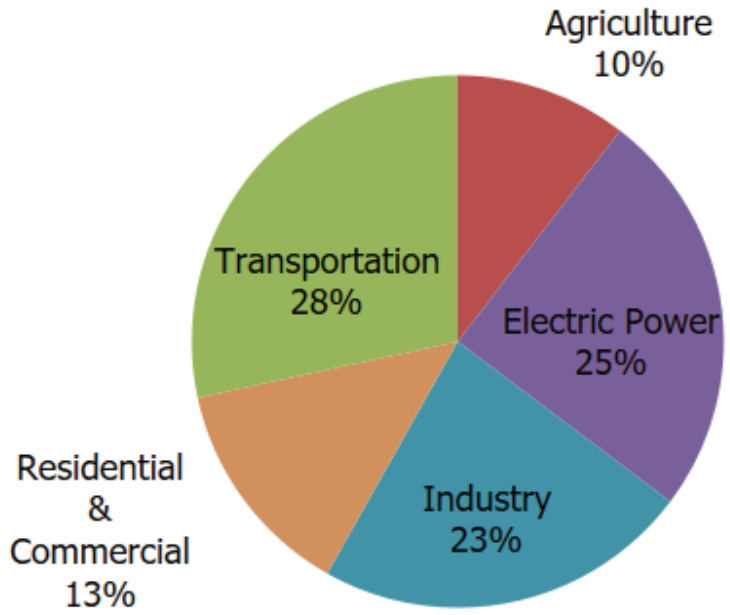

FIGURE A-2 U.S. greenhouse gas emissions by economic sector in 2022.
SOURCE: U.S. Environmental Protection Agency. https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions.

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is a result of the vehicle's reliance on combustion engines, where more than 90% of the fuel used for transportation is petroleum-based, producing carbon dioxide when it is combusted in an internal combustion engine (ICE).[7]

However, carbon dioxide is not the only harmful emission associated with combustion engines. Petroleum-based fuels contain impurities that contribute to nitrogen oxide (NO_x) emissions, particulate matter, carbon monoxide, and other emissions that contribute to significant public health and environmental problems. Emissions can lead to serious health issues such as asthma, birth defects, premature death, and heart disease. These impacts are disproportionately impacting underserved and disadvantaged communities and have immense and lasting economic impacts.[8]

In the United States, pipelines are a primary mode of freight transportation for fuels including natural gas (methane), oil, hydrogen, and carbon dioxide. While pipelines account for 4% of known transportation emissions, pipeline leaks and failures are a major issue and are responsible for the majority of emissions from pipelines. Regulatory actions to monitor and mitigate pipeline leaks have been a major priority in the United States and other countries, in addition to reducing our use of fossil fuels that are transported through them.

In the United States and the European Union, emissions from transportation continue to grow as demand for travel grows, especially with the rise of e-commerce and delivery. Added demand from shipping has raised the emissions and demand for movement from aviation, marine, and heavy-duty vehicles.[9,10] The rise of larger, heavier sport utility vehicles (SUVs), which is present in nearly all automotive markets around the world, significantly impacts the energy and fuel consumption and CO_2 emissions of road vehicles, while being just partially offset by the lower energy consumption of electric vehicles.[11] The relative size of LDVs has also increased in the United States, and a majority of emissions from LDVs come from "light trucks" including SUVs, pickup trucks, and minivans, partly as a result of the deviation of emission rules between light-duty cars and light-duty trucks as defined by the footprint of the vehicle.[12]

EPA is working to remedy this through its latest GHG Rule, stating: "In assessing new footprint curves, EPA wanted to (a) reduce the likelihood of change to average vehicle footprint as a compliance strategy and (b) to minimize the incentive to shift vehicle attributes and the resulting car/truck classification as a compliance strategy."[13]

In the European Union, where transportation also makes up about a quarter of emissions, the largest growth comes from the aviation sector rather than on-road vehicles.[14] Differences in urban layout, geography, and population sprawl result in obvious different areas of focus for emission reductions. However, policies can address the adoption of technologies in both the United States and the European Union that will result in the largest reduction in emissions.

[7] Reitz, R. D., H. Ogawa, R. Payri, T. Fansler, S. Kokjohn, Y. Moriyoshi, A. K. Agarwal, D. Arcoumanis, D. Assanis, et al., "IJER Editorial: The Future of the Internal Combustion Engine," *International Journal of Engine Research*, 21(1), 3–10, 2020, https://www.osti.gov/servlets/purl/1607021.

[8] U.S. Environmental Protection Agency, "Research on Health Effects, Exposure, & Risk from Mobile Source Pollution," https://www.epa.gov/mobile-source-pollution/research-health-effects-exposure-risk-mobile-source-pollution (accessed April 2024).

[9] Biniaz, S., "A Key Moment to Advance Green Shipping," U.S. Department of State, July 2023, https://www.state.gov/advance_green_shipping.

[10] Muñoz-Villamizar, A., J. C. Velázquez-Martínez, P. Haro, A. Ferrer, and R. Mariño, "The Environmental Impact of Fast Shipping Ecommerce in Inbound Logistics Operations: A Case Study in Mexico," *Journal of Cleaner Production*, 283, 125400, 2021, https://www.sciencedirect.com/science/article/abs/pii/S0959652620354469.

[11] Global Fuel Economy Initiative, *Trends in the Global Vehicle Fleet 2023*, November 2023, https://www.globalfueleconomy.org/data-and-research/publications/trends-in-the-global-vehicle-fleet-2023.

[12] U.S. Environmental Protection Agency, *2023 EPA Automotive Trends Report*, December 2023, https://www.epa.gov/automotive-trends/download-automotive-trends-report.

[13] U.S. Environmental Protection Agency, *Multi-Pollutant Emissions Standards for Model Years 2027 and Later Light-Duty and Medium-Duty Vehicles: Regulatory Impact Analysis*, March 2024, EPA-420-R-24-004, https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P1019VPM.pdf.

[14] European Environment Agency, "Transport and Mobility," https://www.eea.europa.eu/en/topics/in-depth/transport-and-mobility (accessed April 2024).

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CURRENT U.S. AND EU POLICIES AND PROGRAMS

Opportunities for Alignment

Both the United States and the European Union have taken steps recently to address GHG emissions from transportation through technology deployment. Europe differs greatly from the United States in terms of policy implementation, political landscape, geography, and domestic resources, which make them both very different cases, but complementary in some ways.

European countries tend to be more densely populated with better access to public transportation and historically grown trans-national railway networks and shorter distances between cities.[15] Because of these features, more emphasis can be placed on improving current infrastructure, shifting modes to less polluting ones such as bicycling and trains, and reducing on-road vehicle travel.

The United States, on the other hand, has historically been dominated by on-road vehicle travel partly due to its size, but also because the auto industry has remained a major economic generator for the country. Because of this, U.S. policies have focused on the auto industry both through regulation and incentives; however, these efforts have been met with resistance from the fossil fuel industry and the legacy automotive industry.[16]

Another main difference between transportation policy in the European Union and the United States lies in their respective degrees of centralization and institutional management. The U.S. transportation system, which historically implemented comprehensive planning of railroads and highways, today operates through a decentralized approach, involving collaboration between local stakeholders, national agencies, and legislative branches. In contrast, the European Union's current approach is characterized by detailed transnational planning set by the European Commission, including the Trans-European Transport Network (TEN-T) with less direct control over national governments' actions.[17]

Current Policies and Programs

United States

The U.S. policy landscape is limited by political realities of the two-party system, and the relationship between Congress, the Executive Branch, and the Judicial system. Despite those challenges, the 2022 Inflation Reduction Act[18] (IRA) was passed as the most significant climate legislation in the history of the United States. The IRA followed other significant legislation for climate including the CHIPS and Science Act[19] and the Infrastructure Investment and Jobs Act (IIJA),[20] both of which were passed with bipartisan support from Republicans and Democrats in Congress. Because of the U.S. filibuster rule in Congress, only legislation that is directly tied to the budget reconciliation process can be passed without 60 votes in the Senate. For this reason, the IRA only has policies in place in the form of appropriated funds for grants and tax credits—resulting in a major focus on incentives for clean energy and climate technology from the federal government.

Those legislative acts passed between 2021 and 2022 were critical in expanding new grant programs at the U.S. Department of Energy (U.S. DOE) for clean fuels, battery technologies, community engagement, and infrastructure investment including deployment programs for those technologies. Tax incentives for electric vehicles and chargers have garnered attention for the strict domestic content requirements and price caps they are now

[15] Bertaud, A., and H. W. Richardson, "Transit and Density: Atlanta, the United States and Western Europe," in *Urban Sprawl in Western Europe and the USA*, edited by H. W. Richardson and C.-H. C. Bae, Routledge, 2004, Chapter 17, https://courses.washington.edu/gmforum/Readings/Bertaud_Transit_US_Europe.pdf.

[16] Tabuchi, H., "The Oil Industry's Covert Campaign to Rewrite American Car Emissions Rules," *The New York Times*, December 2018, https://www.nytimes.com/2018/12/13/climate/cafe-emissions-rollback-oil-industry.html.

[17] Gordon, C., "Transportation Policy in the European and American Unions Compared: Lessons in Transportation Federalism," *Public Works Management & Policy*, 9(4), 292–304, 2005.

[18] H.R.5376—Inflation Reduction Act of 2022, August 2022, https://www.congress.gov/bill/117th-congress/house-bill/5376/text.

[19] H.R.4346—Chips and Science Act, August 2022, https://www.congress.gov/bill/117th-congress/house-bill/4346.

[20] H.R.3684—Infrastructure Investment and Jobs Act, November 2021, https://www.congress.gov/bill/117th-congress/house-bill/3684.

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subject to.[21] However, other significant credits important to EVs include manufacturing credits for battery production and storage facilities,[22] which has resulted in a significant increase in U.S. automakers and battery suppliers opening new facilities in states such as Georgia and North Carolina.[23] The IRA also implemented tax credits for clean fuels, with an additional incentive to produce sustainable aviation fuel (SAF). In particular, clean fuels can benefit from numerous tax incentives from the IRA that can be stacked together. The clean fuel production credit, 45Z, can be claimed along with any state credits from programs such as the Low Carbon Fuel Standard (LCFS), and the Renewable Fuel Standard (RFS). For fuels made synthetically, credits can also be claimed for the clean production of hydrogen (45V) and carbon capture (45Q). Claiming each of these can make some business models extremely profitable.[24]

Incentives in the forms of grants and loans were also a large part of recent climate legislation, which provide amounts up to $300 million in grants for new manufacturing or recycling facilities for batteries to help address battery supply chain issues and incentivize domestic producers to scale manufacturing facilities in the United States.[25] Federal loans are also a potential avenue for new clean energy technologies to secure government-backed, low interest loans that will specifically address innovative new clean technologies or help scale up the deployment of technologies with large emission reduction impacts.

The bipartisan IIJA legislation implemented some major programs and funding pots for transportation decarbonization. Of major note was the inclusion of $7.5 billion for Alternative Fueling Corridors, which have mainly been focused on building out a network of EV charging technologies. Of note, the National Electric Vehicle Infrastructure (NEVI) program made money available through partnerships with the states if the charging infrastructure complied with minimum standards. NEVI minimum standards made several things mandatory in order to receive funding for projects, including minimum operating time and reliability, public accessibility, a standard for interoperability and non-proprietary technology, and minimum percentages of "Build America, Buy America" products.[26] These rules have subsequently shaped the private-sector approach to manufacturing, installing, and approaching charging networks. IIJA also created the Joint Office of Energy and Transportation, which is the program where work on electric transportation infrastructure is conducted, along with other areas where U.S. DOE and U.S. DOT overlap in their priorities and goals.[27]

State DOTs are crucial for U.S. DOT as it implements its decarbonization programs. The majority of grant money from U.S. DOT is given to the state DOTs contingent on their plans, or through a competitive application process. DOTs at the state level vary widely in their priority areas, especially as economics, geography, and population patterns are unique in every state and city. Collaboration between states and the federal government is an essential step to ensure that funding is being allocated and implemented in the most effective and efficient way possible.

Research and development are an important federal investment for transportation technology and system advancement. Many of the grants in the IRA will come in the form of support for research and development at U.S. DOT and U.S. DOE to continue making progress in new technologies such as new battery chemistries, charging technologies, materials for vehicles and roads, automated technology, and efficiency improvements for the transportation system. The support of research and development is critical to ensure that technology continues to progress to a point that it

[21] Internal Revenue Service, "Credits for New Clean Vehicles Purchased in 2023 or After," https://www.irs.gov/credits-deductions/credits-for-new-clean-vehicles-purchased-in-2023-or-after (accessed April 2024).

[22] Internal Revenue Service, "Treasury, IRS Issue Guidance for the Advanced Manufacturing Production Credit," December 2023, https://www.irs.gov/newsroom/treasury-irs-issue-guidance-for-the-advanced-manufacturing-production-credit.

[23] U.S. Department of Energy, "American-Made Batteries: New U.S. Battery Manufacturing and Supply Chain Investments Announced Under President Biden," February 2023, https://www.energy.gov/sites/default/files/2023-02/Battery%20Supply%20Chains%20Investments%20Map.pdf.

[24] Sadler, J., "Stacking Rules, Bonus Credits, and the Future Industrial Markets the IRA Aims to Create," Rocky Mountain Institute, September 2023, https://rmi.org/stacking-rules-bonus-credits-and-the-future-industrial-markets-the-ira-aims-to-create.

[25] U.S. Office of Energy Efficiency & Renewable Energy, Vehicle Technologies Office, "Electric Vehicle Battery Manufacturing Capacity in North America in 2030 Is Projected to Be Nearly 20 Times Greater Than in 2021," January 2023, U.S. Department of Energy, https://www.energy.gov/eere/vehicles/articles/fotw-1271-january-2-2023-electric-vehicle-battery-manufacturing-capacity.

[26] U.S. Department of Transportation, "National Electric Vehicle Infrastructure Standards and Requirements: Final Rule," February 2023, https://www.transportation.gov/bipartisan-infrastructure-law/regulations/2023-03500.

[27] Joint Office of Energy and Transportation, "About the Joint Office," https://driveelectric.gov/about (accessed April 2024).

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can be deployed, such as we have seen with U.S. DOE's continued investment into battery research and development in the Vehicle Technology Office, the Hydrogen and Fuel Cell Technology Office, and the Bioenergy Technology office as well as the Advanced Research Projects Agency offices, ARPA-E and ARPA-I. This research has resulted in foundational data used for policy actions and continued progress in technology.[28]

The U.S. DOT Office of Research, Development, and Technology Programs for University Transportation Centers (UTCs), research hubs, and program management are funded. Research funded by U.S. DOT totals about $1 billion per year to continue advancing research priorities. While research at U.S. DOT spans safety, economics, equity, and technology transformation, it has recently made climate and sustainability an agency-wide and research priority. Priorities for decarbonization include electrification, alternative fuels, and embodied carbon in structures such as roads and bridges used for transportation.[29] U.S. DOT also has outlined a Research, Development, and Technology Strategic Plan (RDT) for fiscal year 2022–2026 that outlines an approach to monitoring and guiding the use of emerging technologies such as artificial intelligence to improve the efficiency and accessibility of transportation.

The Biden administration has signaled through agency goals and executive actions what areas are priorities for decarbonization. Of significance to reduce transportation emissions from aviation, U.S. DOE, U.S. DOT, and the U.S. Department of Agriculture (USDA) have signed a memorandum of understanding for the SAF Grand Challenge which creates a goal of reducing GHG emissions for SAF compared to jet fuel and producing enough SAF to meet aviation fuel demand by 2050.[30] While this is not a statutorily mandated program, it has resulted in several areas of research and funding through U.S. DOE and U.S. DOT that emphasize the research into new SAF chemistries and that support the scale-up of proven SAF technologies and infrastructure.

California

California is the leading state in the United States for transportation policy. In California, 50% of GHG emissions are from transportation,[31] so it has been identified as a main priority to cut for meaningful progress on climate goals. Programs and policies are targeted at increasing the adoption of zero-emission vehicles and charging infrastructure, using lower-carbon fuels, and reducing passenger miles.[32] In 1976, EPA granted California the power to regulate its own pollution standards to address increasingly difficult smog issues under the Clean Air Act.[33] This provision also allows other states to adopt California's standards (section 177). Under these rules, California and other states have implemented stricter fuel economy standards, zero-emission vehicle mandates, and regulations for criteria emissions.[34]

California implemented the first LCFS, which creates a crediting program for fuel producers, including renewable electricity, that fuel transportation. The value of the credit is based on carbon intensity of the fuel source. This program has resulted in decreasing emissions from the biofuel industry and has helped create the market for zero-emission vehicles.[35] California has also issued a number of aggressive policies for electric vehicles including

[28] U.S. Office of Energy Efficiency & Renewable Energy, Vehicle Technologies Office, *Analysis Program: 2022 Annual Progress Report*, 2022, U.S. Department of Energy, https://www.energy.gov/sites/default/files/2023-10/2022%20VTO%20Analysis%20Annual%20Progress%20Report%20-%20FINAL%20091223_compliant_.pdf.

[29] U.S. Department of Transportation, *Research, Development, and Technology Strategic Plan 2022–2026—Building a Better Transportation Future for All*, December 2022, https://www.transportation.gov/sites/dot.gov/files/2023-01/USDOT%20RDT%20Strategic%20Plan%20FY22-26_010523_508.pdf.

[30] U.S. Office of Energy Efficiency & Renewable Energy, Bioenergy Technologies Office, "Sustainable Aviation Fuel Grand Challenge," U.S. Department of Energy, https://www.energy.gov/eere/bioenergy/sustainable-aviation-fuel-grand-challenge (accessed April 2024).

[31] California Energy Commission, "Transforming Transportation," https://www.energy.ca.gov/about/core-responsibility-fact-sheets/transforming-transportation (accessed April 2024).

[32] Brown, A. L., D. Sperling, B. Austin, J. R. DeShazo, L. Fulton, T. Lipman, C. Murphy, J. D. Saphores, G. Tal1, et al., *Driving California's Transportation Emissions to Zero*, University of California Institute of Transportation Studies, April 2021, https://doi.org/10.7922/G2MC8X9X.

[33] U.S. Environmental Protection Agency, "Vehicle Emissions California Waivers and Authorizations," https://www.epa.gov/state-and-local-transportation/vehicle-emissions-california-waivers-and-authorizations (accessed April 2024).

[34] Ibid.

[35] California Air Resources Board, "FAQ: The Standardized Regulatory Impact Assessment for the Low Carbon Fuel Standard," https://ww2.arb.ca.gov/resources/documents/faq-standardized-regulatory-impact-assessment-low-carbon-fuel-standard (accessed April 2024).

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the Advanced Clean Cars Act, Advanced Clean Trucks, and Advanced Clean Fleets, which require an increasing percentage of zero-emission vehicles in the light-duty, medium-duty, and heavy-duty sectors, respectively.[36]

European Union

The European Union has embarked on an ambitious journey to decarbonize transportation, anchored in a comprehensive suite of policies and programs designed to achieve climate neutrality and zero air pollution by 2050. At the heart of these efforts is the European Climate Law, a central element of the European Green Deal,[37] which sets forth a vision for a net-zero GHG emissions economy, aiming to decouple economic growth from resource use while ensuring that no person and no place are left behind in the transition to a green economy. For transport-related GHG emissions, the European Green Deal sets the sector-specific goal of achieving a 90% reduction by 2050.

Central to the European Union's strategy is the Fit for 55 package,[38] a comprehensive set of legislative proposals that are key for the European Green Deal, which is designed to reduce the European Union's GHG emissions by 55% by 2030, compared to 1990 levels. It includes the target to phase out internal combustion engine (ICE) vehicles by 2035. Its interim reduction targets are –55% for cars and –50% for vans by 2030, with the ultimate goal of achieving a complete transition to zero-emission vehicles. While there have been setbacks and delays in fully passing the ban on ICE cars by 2035 in the European Union, primarily due to debate on exceptions for cars that operate solely on carbon-neutral fuels such as e-fuels, negotiations are ongoing to address these issues.

The European Union has set specific CO_2 emission standards[39] for passenger cars, vans, and trucks to reduce GHG emissions and promote cleaner vehicles. For passenger cars and light-duty vehicles (vans), these imply a stepwise reduction of fleet-wide average CO_2 emissions per kilometer for new cars, leading to the zero-CO_2 emission target from 2035 onward. As of 2025, manufacturers must meet fleet-wide average CO_2 emission targets for new heavy-duty vehicles (i.e., lorries) registered in the European Union, at first a 15% reduction compared to the EU average in the reference period, and 30% by 2030. There are financial penalties for non-compliance with these targets.

Complementing these vehicle-related measures, the Alternative Fuels Infrastructure Regulation (AFIR)[40] seeks to enhance the infrastructure necessary for alternative fuels, paving the way for a broader adoption of zero-emission vehicles. The AFIR is a binding legal instrument that mandates EU countries, charge point operators (CPOs), and electric mobility service providers adhere to specific rules when deploying public electric vehicle charging infrastructure. It sets targets (e.g., for power capacity and distance-based coverage along major roads and motorways) to ensure a robust charging network that meets demand. The AFIR goes beyond electric road mobility, though, as it also aims to ensure that there is a sufficient infrastructure network for recharging or refueling ships with alternative fuels. This includes providing solutions so that vessels at berth and stationary aircraft do not need to keep their engines running, contributing to reducing emissions and promoting cleaner transportation.

The Smart and Sustainable Mobility Strategy[41] further elaborates on the European Union's vision for decarbonizing transportation, with flagships on technology-neutral but not fossil fuel–based vehicles—for example, by aiming for all city buses to be zero-emission by 2030. It emphasizes carbon pricing, green freight, and better incentives through the "polluter pays" principle and supports informed consumer choices.

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[36] California Air Resources Board, "Advanced Clean Cars II," https://ww2.arb.ca.gov/our-work/programs/advanced-clean-cars-program/advanced-clean-cars-ii (accessed April 2024).

[37] European Commission, "The European Green Deal: Striving to Be the First Climate-Neutral Continent," https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en (accessed April 2024).

[38] Council of the European Union, "Fit for 55," https://www.consilium.europa.eu/en/policies/green-deal/fit-for-55-the-eu-plan-for-a-green-transition (accessed April 2024).

[39] European Commission, "CO_2 Emission Performance Standards for Cars and Vans," https://climate.ec.europa.eu/eu-action/transport/road-transport-reducing-co2-emissions-vehicles/co2-emission-performance-standards-cars-and-vans_en (accessed April 2024).

[40] Council of the European Union, "Alternative Fuels Infrastructure: Council Adopts New Law for More Recharging and Refueling Stations Across Europe," July 2023, https://www.consilium.europa.eu/en/press/press-releases/2023/07/25/alternative-fuels-infrastructure-council-adopts-new-law-for-more-recharging-and-refuelling-stations-across-europe.

[41] European Commission's Directorate-General for Mobility and Transport, "Mobility Strategy," https://transport.ec.europa.eu/transport-themes/mobility-strategy_en (accessed April 2024).

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The Urban Mobility Framework, another cornerstone of the European Union's strategy, focuses on creating more sustainable urban transportation systems, while the TEN-T urban nodes initiative seeks to integrate urban mobility with broader trans-European networks, enhancing connectivity and sustainability.

In the realm of research and innovation, the long-term strategy for decarbonizing transportation has been presented in the framework of the Strategic Transport Research and Innovation Agenda (STRIA) of the European Commission, particularly in the roadmaps on the "Electrification of the Transport System" (2017)[42] and on "Low-Emission Alternative Energy for Transport" (2020).[43] In terms of planning and implementing research, a number of European partnerships stand out, including the co-programmed partnerships "Towards Zero Emission Road Transport" (2Zero) and "Zero-Emission Waterborne Transport" (ZEWT), and the institutionalized partnerships "Transforming Europe's Rail System" and "Clean Aviation." These partnerships are fostering collaboration between public and private stakeholders to accelerate the development of zero-emission transportation solutions. Moreover, the European Mission "Climate-Neutral and Smart Cities" is implementing research and innovation for decarbonizing transportation and mobility, and additionally, the New European Bauhaus is playing an important role in driving the development and deployment of sustainable, inclusive, and innovative mobility solutions as part of transforming public spaces, buildings, and cities toward a greener and more livable future.

Not least, European Technology Platforms such as the European Road Transport Research Advisory Council (ERTRAC)[44] are outlining the research priorities and technological pathways to achieving the European Union's decarbonization goals in their Strategic Research Agenda and Vision, notably in the ERTRAC Roadmap on "Sustainable Energies and Powertrains for Road Transport."

Besides the implementation of the European Green Deal in transportation and research policies, it is also relevant for industry policy. Established as a response to industrial policies in the United States (such as the IRA) and in China, the Green Deal Industrial Plan[45] aims to scale up manufacturing of clean technologies, such as batteries for electric vehicles, in the European Union. The plan is covering four pillars: a predictable and simplified regulatory environment, faster access to funding, enhancing the necessary skills, and open trade for resilient supply chains. Thereby, it further continues the path of promoting innovative and strategically important key technologies which started with the Important Projects of Common European Interest (IPCEI), that allow European Members States to fund large-scale European consortia in key strategic value chains on, for example, microelectronics, batteries, and hydrogen.[46]

EU-U.S. Collaboration

For many years, the United States and the European Union, or their respective states and Member States, have exchanged knowledge and coordinated their policies in the domain of decarbonizing transportation. Examples include the Electric Vehicles Initiative (EVI) of the Clean Energy Ministerial and the Technology Collaboration Programme Hybrid and Electric Vehicles (HEV-TCP) of the International Energy Agency (IEA). A recent outcome of this collaboration is the Global Memorandum of Understanding for Zero Emission Trucks in which signatories commit to working together to enable 100% zero-emission new truck and bus sales by 2040 to facilitate achievement of net-zero carbon emissions by 2050, with an interim goal of 30% zero-emission vehicle sales by 2030. It has been signed by the United States and eight EU Member States.

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[42] European Commission's Directorate-General for Research and Innovation, *Electrification of the Transport System*, Expert Group Report, Publications Office, 2017, https://op.europa.eu/en/publication-detail/-/publication/253937e1-fff0-11e7-b8f5-01aa75ed71a1.

[43] Bauen, A., I. Gomez, E. Nanaki, D. OudeNijeweme, M. Paraschiv, and R. Schoentgen, *STRIA Roadmap on Low-Emission Alternative Energy for Transport (ALT)*, May 2020, European Commission's Directorate-General for Mobility and Transport, https://trimis.ec.europa.eu/system/files/2021-03/alternative_fuels_stria_april2020_final_version_newcover_0.pdf.

[44] European Road Transport Research Advisory Council (ERTRAC), https://www.ertrac.org.

[45] European Commission, "The Green Deal Industrial Plan—Putting Europe's Net-Zero Industry in the Lead," https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/green-deal-industrial-plan_en (accessed April 2024).

[46] European Commission, "Important Projects of Common European Interest (IPCEI)," https://competition-policy.ec.europa.eu/state-aid/ipcei_en (accessed April 2024).

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In 2022, U.S. DOE and the European Commission announced support for a collaboration between the European Battery Alliance and the U.S. Li-Bridge Alliance to accelerate development of robust supply chains for lithium-ion and next-generation batteries, including the critical raw materials segments.[47] The joint activities aim to develop sustainable industrial capabilities for the growing battery demand in transportation and energy, advance research in eco-friendly technologies, ensure ethical sourcing of raw materials, accelerate recycling and reuse, invest in workforce development, and prioritize environmental justice in the clean energy transition.

Standardization represents a successful area of collaboration between the European Union and the United States in enhancing the transportation system, especially aimed at decarbonization. This partnership specifically focuses on establishing joint standards for electric vehicle charging infrastructure, a commitment reaffirmed during the 2023 meeting of the EU-U.S. Trade and Technology Council.[48]

The U.S.-EU Trade and Technology Council also released a joint report on smart grid interoperability and electromobility in May 2023. The goal was to identify common gaps with standards for e-mobility infrastructure, support the development of smart charging infrastructure, and invest in research and development of new technologies. The report outlines several recommendations between the European Union and the United States,[49] including the following:

- Develop a joint standards support strategy (e.g., charging interoperability standards and plug standards);
- Support the development and implementation of cost-effective smart charging infrastructure to avoid stranded assets; and
- Direct research and development to support the consumer, grid, and industry.

DEPLOYED STRATEGIES, TECHNOLOGIES, AND INFRASTRUCTURES

Current Approaches

Vehicle Electrification

Experts agree that on-road transportation will shift to EVs. EVs are less GHG-emitting than internal combustion engine vehicles, even in areas where electricity is produced primarily from coal.[50] EVs use stored energy from either a battery or a fuel cell to power the motor. Battery electric vehicles (BEVs) are the most common type of EV, but fuel cell electric vehicles (FCEVs) have also existed for decades. Plug-in hybrid vehicles (PHEVs) contain both an electric motor and an ICE that can be used if the battery is depleted. Challenges and costs associated with producing, transporting, and storing clean hydrogen on the vehicle have made the technology slower to be adopted than BEVs. A systemic and life-cycle perspective is crucial for accurately assessing the decarbonization benefits of EVs. For example, the higher GHG emissions during the manufacturing phase are offset by the lower-use-phase emissions, resulting in an overall significant reduction in GHG emissions from BEVs compared to conventional vehicles.

Globally, much of the electric vehicle market has been driven by sales of micromobility vehicles such as mopeds, scooters, and e-bikes. EV sales in the United States are accelerating as new models of light cars and trucks are introduced and prices drop, thanks in part to the incentives and regulations discussed in the prior chapter.

[47] U.S. Department of Energy, "DOE and European Commission Support Collaboration Between the U.S. Li-Bridge Alliance and European Battery Alliance to Strengthen Supply Chain for Battery Technologies," March 2022, https://www.energy.gov/articles/doe-and-european-commission-support-collaboration-between-us-li-bridge-alliance-and.

[48] "U.S.-EU Joint Statement of the Trade and Technology Council," May 2023, https://www.whitehouse.gov/briefing-room/statements-releases/2023/05/31/u-s-eu-joint-statement-of-the-trade-and-technology-council-2.

[49] EU-U.S. Trade and Technology Council: Working Group 2—Climate and Clean Tech, *Transatlantic Technical Recommendations for Government Funded Implementation of Electric Vehicle Charging Infrastructure*, May 2023, https://www.energy.gov/sites/default/files/2023-05/TTC4_WG2_Joint-Recommendations-EV-Charging-Infrastructure_vFINAL-2.pdf.

[50] Bieker, G., "A Global Comparison of the Life-Cycle Greenhouse Gas Emissions of Combustion Engine and Electric Passenger Cars," International Council on Clean Transportation, White Paper, July 2021, https://theicct.org/publication/a-global-comparison-of-the-life-cycle-greenhouse-gas-emissions-of-combustion-engine-and-electric-passenger-cars.

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Countries around the world are investing in and deploying EVs at accelerating rates. Currently in the United States, new vehicle sales are nearing 10% BEVs;[51] in the European Union, it is 12%.[52]

Medium- and heavy-duty vehicles are slower to deploy as electric vehicles due to their size and uses, but can fully shift to electric vehicles by 2040 according to manufacturers and researchers. As batteries continue to become more efficient and cheaper, and charging networks become more robust, EVs in the medium- and heavy-duty space will become more ubiquitous.

One of the main barriers to new EV adoption is lack of charging options and range anxiety. As more charging networks are built out and standardized, particularly in the United States where cars must drive farther distances between city centers, experts expect consumers to adopt these vehicles at much higher rates. One potential challenge to meeting this goal is the U.S. grid's outdated hardware and transmission system, as well as the need to add more generation from clean energy sources to support additional load from vehicle charging.

Clean Fuels

Clean fuels can be used as "drop in" fuels to directly replace petroleum equivalents in existing engines, or be used as another cleaner fuel for new combustion engines. Clean drop-in fuels can be used in existing vehicles on the road now, to reduce emissions as vehicle turnover to electric drivetrains lags. More research is needed on the air quality impacts of drop-in fuels—particularly those such as ethanol blending that may emit more of one pollutant but reduce emissions of deadly pollutants such as particulate matter.

Transportation modes such as aviation, marine, and others, require energy-dense liquid fuels, and will for the foreseeable future. Low-carbon fuels vary in emission savings depending on their feedstock, processing practices, and end use. They can be derived from biomass sources such as corn, or from cellulosic waste feedstocks such as landfill gas, switchgrass, or from combining hydrogen and carbon from carbon capture into a hydrocarbon that is chemically equivalent. While in the European Union regulations allow the production of biofuels from certain crop-based and waste feedstocks, they are phasing out feedstocks such as palm oil for fuel production because of the related deforestation risk. The primary source of biomass in the United States is corn-based crops. The amount of GHG emission reductions from crop-based ethanol has been widely debated because of the nuance in the way indirect land use change emissions are calculated when evaluating its life cycle. However, smart agriculture and new systems such as bioenergy carbon capture and sequestration has been shown to reduce the overall emissions of corn ethanol significantly in the last 20 years.[53]

One main area where clean fuels will be necessary to get to our zero-emission goals in time to reduce the worst impacts of climate change is in aviation. SAF is produced mainly with biofuels, but increasingly, synthetic fuel start-up companies are entering the space. Production and scale-up of SAF will require investment in operating SAF producers, increased yield of feedstocks, and research into new chemistries and engine technologies to optimize different new SAF fuels. In the near term in the United States, biofuels will be the readiest to deploy for SAF to meet the goals of the SAF Grand Challenge. However, biomass will also be required as a means of natural carbon removal to meet our overall climate goals. Existing biofuel producers can continue to reduce life-cycle emissions through innovative agricultural technologies and new production methods to increase fuel yield.

Mode Shifting and Digitalization

Experts agree that we must reduce vehicle miles traveled in order to meet our climate goals. Changes in behavior are essential to achieving the emissions reduction necessary to meet key climate targets. An aspect of this

[51] EV Hub, "One Million EVs Sold Through September 2023," November 2023, https://www.atlasevhub.com/weekly-digest/one-million-evs-sold-through-september-2023.

[52] ACEA, "New Car Registrations: +10.1% in February 2024; Battery Electric 12% Market Share," March 2024, https://www.acea.auto/pc-registrations/new-car-registrations-10-1-in-february-2024-battery-electric-12-market-share.

[53] Energy Systems Division, Argonne National Laboratory, *Energy and Water Sustainability in the U.S. Biofuel Industry*, ANL/ESD-19/5, June 2019, https://water.es.anl.gov/documents/EW%20survey%20report%20final%20ANL.pdf.

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involves diminishing the demand for on-road vehicles by embracing alternative modes such as transit, walking, biking, and shared mobility, particularly in urban environments where reducing travel demand is crucial.

Technologies including ridehail, micromobility, and automated vehicles (AVs) are expected to continue to disrupt the transportation industry for decades to come. Uber and Lyft have faced criticism for worsening emissions and causing congestion, especially in dense urban areas. These issues are attributed in part to "deadheading," in which rideshare vehicles add unnecessary miles without passengers. Increased emissions are also tied to greater demand for cars, with riders opting for ridehailing instead of staying home or choosing alternative transportation such as public transit or even green and healthy options such as walking, or biking. Without regulation, the introduction of AVs into rideshare networks could exacerbate these negative impacts.[54]

An important urban planning concept in this context is the 15-minute city where most daily necessities and services, such as work, shopping, education, healthcare, and leisure, can be easily reached within a 15-minute walk, bike ride, or public transit ride from any point in the city.[55]

Digitalization of travel can reduce demand for on-road vehicles and improve the efficiency of the systems we have and avoid the problems outlined above. Digitalization of data can help us better invest in multimodal transportation in an optimized way to reduce emissions. Quickly emerging technologies such as AI can help us optimize transportation systems to optimize emission reductions.

Land Use and Mode Shifting

The optimization of land use can have tremendous effects on reducing emissions from transportation and for the energy sources used for transportation. As discussed, modal shifts are necessary to meet our climate goals, and we must provide people with options outside of individually owned on-road vehicles.

Sustainable urban mobility plans play a crucial role in the decarbonization of urban mobility by strategizing the development of more efficient, greener, and integrated transportation systems and mobility options that reduce reliance on fossil fuels and lower GHG emissions. The Federal Highway Administration (FHWA) has a program called "Complete Streets" which prioritizes all street users, including pedestrians, cyclists, and transit users so that they are safe, comfortable, and connected to areas where people want to travel. FHWA has rolled this out as a funding program for cities and states who design projects and programs that meet these criteria.[56]

SOCIAL, ECONOMIC, AND ENVIRONMENTAL CONSIDERATIONS

Social, economic, and environmental considerations include areas where infrastructure decisions that have harmed underserved and disadvantaged communities (air and noise pollution, traffic violence, disruptions to communities), affordability and accessibility, workforce and public health; circular economy; safety/security; and nature protection and conservation. These areas are discussed below.

Infrastructure

Transportation Infrastructure

Transportation infrastructure in the United States has historically been used to segregate and consequently cause harm to underserved communities that are disproportionately communities of color. This is a direct result of policies

[54] Stephens, T. S., J. Gonder, Y. Chen, Z. Lin, C. Liu, and D. Gohlke, *Estimated Bounds and Important Factors for Fuel Use and Consumer Costs of Connected and Automated Vehicles*, National Renewable Energy Laboratory, Technical Report NREL/TP-5400-67216, November 2016, https://doi.org/10.2172/1334242.

[55] Gongadze, S., and A. Maassen, "Paris' Vision for a '15-Minute City' Sparks a Global Movement," World Resources Institute, January 2023, https://www.wri.org/insights/paris-15-minute-city.

[56] Federal Highway Administration, "Funding Safety for All," September 2023, https://highways.dot.gov/sites/fhwa.dot.gov/files/2023-10/complete_streets_poster_funding_safety_for_all_09132023.pdf.

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such as redlining in the 1940s.[57] Because of policies that purposely separated White communities from Black communities, interstates and highly polluted areas were concentrated around Black communities. Those neighborhoods are still located in areas with higher-than-average pollution, resulting in significant public health issues.

In addition to pollution exposure, these communities are physically separated from economic areas with access to jobs, groceries, and medical care. Furthermore, they lack safe pedestrian and cycling infrastructure at higher rates, which is compounded by their proximity to interstates and high-traffic areas.[58] Programs targeted at reconnecting communities and increasing access to transit, pedestrian, and cycling infrastructure are currently being piloted at U.S. DOT and the U.S. Department of Housing and Urban Development.

Also in Europe, uneven development and funding of transportation infrastructure has played a role in creating and exacerbating social divides, by limiting accessibility and mobility options for disadvantaged communities. A prominent example is Europe's rail system with a rising number of high-speed rail sections between major cities in many countries, but also a significant and systematic underfunding of regional train lines, causing the closure of small train stations and leading to mobility poverty over the last three decades.[59]

In general, protecting transportation networks is a key component of the European Union's overall critical infrastructure protection efforts. The European Union's Critical Infrastructure Protection Strategy recognizes the vital importance of transportation infrastructure as part of Europe's critical infrastructure, and has implemented legislative, inspection, and coordination mechanisms to strengthen the security and resilience of transportation systems across Member States.

Electric Vehicle Infrastructure

Drivers who live in low-income communities and multifamily housing face barriers to accessing EV charging. Challenges include a lack of home charging options due to factors such as the absence of designated parking spots, affordability issues, and difficulty obtaining permission or funds for charger installation in multifamily housing. Public charging infrastructure is more concentrated in wealthier neighborhoods, leading to disparities in access. Even if public charging is available in low-income areas, it can be two to four times more expensive than home charging, disproportionately affecting these households. Some policies provide rebates for installing Level 2 chargers in disadvantaged communities, but these often cover equipment costs and not installation, which can be costly.[60]

Policies outlined earlier in the white paper discuss targeted investment in charging stations along interstate corridors, as well as in communities that are experiencing worse environmental and public health outcomes because of historical policies such as redlining. U.S. investments in infrastructure upgrades supported by federal funding are targeted at low-income disadvantaged communities, defined by census tract designations. This designation is directed through the Biden administration's Justice40 Initiative.[61]

Upgrading the infrastructure required to support electric vehicles must take equity into consideration and use tools such as managed charging and vehicle-grid infrastructure to reduce the power demand needed to support EV deployment. This is especially important in areas with less power generation or transmission, such as rural areas and urban residential areas. Areas at high-risk for climate disasters also must consider resiliency of the infrastructure to prevent catastrophic damage from events such as wildfires, hurricanes, snowstorms, and high-force winds that will become more frequent because of irreversible climate change.

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[57] Lane, H. M., R. Morello-Frosch, J. D. Marshall, and J. S. Apte, "Historical Redlining Is Associated with Present-Day Air Pollution Disparities in U.S. Cities," *Environmental Science & Technology Letters*, 9(4), 345–350, 2022, https://doi.org/10.1021%2Facs.estlett.1c01012.

[58] U.S. Department of Housing and Urban Development Exchange, "Reconnecting Neighborhoods Divided by Urban Renewal Infrastructure," October 2023, https://www.hudexchange.info/programs/fair-housing/fheo-table-talks/reconnecting-neighborhoods-divided-by-urban-renewal-infrastructure.

[59] Rudolph, F., N. Riach, and J. Kees, *Development of Transport Infrastructure in Europe: Exploring the Shrinking and Expansion of Railways, Motorways and Airports*, T3 Transportation Think Tank gGmbH and Wuppertal Institut für Klima, Umwelt, Energie gGmbH, June 2023, https://t3-forschung.de/wp-content/uploads/2023/09/Research-study.pdf.

[60] Hardman, S., K. L. Fleming, E. Khare, and M. M. Ramadan, "A Perspective on Equity in the Transition to Electric Vehicles," MIT Science Policy Review, August 2021, https://sciencepolicyreview.org/2021/08/equity-transition-electric-vehicles.

[61] U.S. White House, "Justice40: A Whole-of-Government Initiative," https://www.whitehouse.gov/environmentaljustice/justice40 (accessed April 2024).

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In Europe, the AFIR mentioned previously focuses on ensuring fair and inclusive access to EV charging infrastructure across the European Union, going beyond just supporting the growth of electric mobility in already-developed markets. The regulation aims to make electric driving accessible to all.

Equity and Affordability

Underserved and disadvantaged populations, who are often heavily reliant on public transportation, currently face less access to transportation than affluent communities. Targeted planning often neglects transportation and housing costs when determining location and eligibility based on affordability. Alternative transportation modes such as bicycling and walking are not prioritized and can be unsafe due to inadequate infrastructure in underserved neighborhoods. These populations also are disproportionately burdened by environmental hazards including emissions from transportation that cause public health issues such as asthma because they tend to be located along high-traffic highway corridors or industrial areas with high rates of pollution exposure.

New mobility technologies, such as electric, shared, and automated vehicles, offer potential equity improvements, as they are not constrained by traditional transit infrastructure. Programs to deploy these innovative technologies and utilize their innovation for public transportation would not only provide solutions to those who need it most, but could save the government money through increased efficiency. It is imperative that communities and local residents are consulted when planning new mobility and infrastructure projects to ensure that their needs and challenges are being addressed.

The Briefing Paper titled "Ensuring a Just Transition to Net-Zero Transport" (see Appendix C) contains a table of key terms used throughout this section when referring to equity and justice.

Although the Biden administration has focused an effort at investing in disadvantaged and underserved communities in the United States, the metrics that are used to measure those benefits, or where those benefits are realized, is difficult to measure. For example, installing EV charging networks in low-income census tracts will help drivers who live in those areas afford EV charging; however, low-income individuals will charge their vehicles in tracts outside the ones in which they live. Furthermore, the improved air quality from using electrified vehicles benefits the communities that those vehicles travel through, not the areas they are charging. Agencies and researchers should be working collaboratively to quantify and pinpoint geographical areas for these benefits.

Public and Private Partnerships

Public transportation is one of the most impactful ways to reduce emissions from transportation. Countries with robust transit lines have less emissions per capita than those with car-centric transportation systems such as the United States. Transit and walkable cities are more efficient than personally owned vehicles. However, there is a role for private industry to help improve mode efficiency. Digitalization and technology can help us be more efficient in transportation modes. For example, data and connectivity can be used to shift transit routes to areas where there will be fewer empty seats during times when people need transit. It could also help fill in gaps during late-night shifts or off-peak hours to provide transportation to people who are the most underserved by current transit routes and schedules. Vehicle and ridesharing could be better optimized with data streamlining, and deadheading (driving between trips with passengers) could be minimized to reduce emissions from rideshare.

Public–private partnerships, sometimes known as P3s (or PPPs in the European Union), will be critical in this transition. Innovative companies providing solutions to transportation problems could partner with transit agencies and federal transportation researchers to help implement clean transportation and provide valuable insight into the ways consumers want to travel. Their partnership could help improve public transportation and fill in gaps that cannot be filled with transit.

In the European Union, PPPs involving local businesses are therefore a cornerstone for the implementation of the "Climate-Neutral and Smart Cities" Mission.

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CHALLENGES AND BARRIERS

The decarbonization of transportation systems is a global challenge not just because climate change is a worldwide phenomenon, but also because mobility is connecting places over distances short or large, its technologies rely on worldwide supply of materials and resources, and its industries are global. Hence, misalignment of goals and policy objectives of innovation, industrialization, and implementation of zero-emission transportation means and services can severely hinder the shift to greener and cleaner modes such as electric vehicles, transit, cycling, and walking.

Existing efforts are challenged by a complex mix of technological, regulatory, business, social, and behavioral factors. The rapid developments and the interplay among these elements create a significant barrier to realizing a sustainable transportation future, often resembling a Gordian knot of intertwined issues. This situation is exacerbated by ongoing global crises, such as geopolitical conflicts, trade disruptions, and resource scarcity. These issues have affected both the U.S. and EU markets, leading to shortages of critical components such as semiconductor chips and electric vehicle batteries. Simultaneously, there's an influx of undervalued products in these markets, as some entities aim for dominance. Additionally, broader challenges such as needs for renewable energy electricity sources or fuels, power grid stability, workforce readiness, safety considerations, life-cycle effects, and obstacles related to funding and planning contribute to the complexity of decarbonizing efforts. Public perception, influenced at times by misinformation in the media, causes resistance to, ignorance of, and reluctance to embrace decarbonization, despite the clear and severe impacts of climate change. As this landscape underscores the multifaceted nature of the challenge at hand, a comprehensive and nuanced approach to achieving decarbonization goals is needed, and the transatlantic dialogue is deemed an opportunity for this.

Comprehensive strategies, policies, and programs have emerged as powerful tools to navigate the barriers to a climate- and environment-friendly transportation system, driven by dedicated research that sparks innovation and facilitates a swift transition. For instance, the European Partnership 2Zero, under the Research Framework Programme Horizon Europe—and its predecessors, the European Green Cars Initiative and European Green Vehicles Initiative—showcase the collaborative efforts between private stakeholders and public authorities. These initiatives are organized through a strategic research and innovation process, embodied in a roadmap that outlines future objectives, milestones, and the actions needed to achieve these goals, derived from a back-casting method from the set objectives. This strategic planning has successfully aligned stakeholders around a common framework, advancing the development of electric vehicle technologies in Europe.

Similarly, in the United States, efforts to address these issues have just begun through the policies described above. However, the politically fraught governance system and upcoming elections create additional challenges to ensure the efforts are not disrupted. Unfortunately, because of the politicization of decarbonization efforts, election outcomes could cause the United States to undo some of the federal policies it has made progress on in recent years. However, these policies have spurred the market into one that will be hard to derail because it has attracted so much private capital that it would be politically unpopular to put those investments at risk. Such efforts highlight the effectiveness of a holistic approach that addresses not just the immediate barriers but also the broader economic, social, and political factors that influence the success and speed of decarbonization efforts.

NEW AND EMERGING TECHNOLOGIES

Digital technologies such as big data analysis, AI, machine learning, and integrated electronic systems are fundamentally transforming the transportation and mobility sector toward greater efficiency, lower carbon emissions, and smoother traffic flows. These innovations reduce unnecessary travel and support the shift to less energy-intensive modes of transport. Automation, as a cornerstone of these advancements, is scrutinized for its dual potential to either diminish or amplify environmental impacts. The move toward software-defined vehicles, with their increasingly centralized control architectures, heralds a future of vehicles that are more efficient in terms of resource use, component lifespan, and energy consumption, further enabled by the potential for upgrades extending product life cycles.

Looking ahead, the imperative to cut energy consumption while preserving safety is driving a transition from decentralized, vehicle-based control logics to a systemic, top-down control paradigm, particularly in road transport.

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This evolution demands the flexible coordination of data and energy flows, software updates, and hardware allocation across the vehicle, infrastructure, and cloud levels. Such a shift requires further advancements in sensors, networks, computing systems, embedded software, communication infrastructures, and cloud services. The push for efficiency and reliability necessitates technologies that can be widely applied and seamlessly integrated into a unified, co-designed data and energy architecture, paving the way for improved testing, validation, and vehicle function monitoring.

Digitalization is set to render transportation services and networks more efficient, resilient, and sustainable. The European Common Mobility Data Space exemplifies digitalization's role in fostering interconnected, accessible, and energy-efficient mobility across the European Union. It highlights the critical role of AI, digitalization, and Internet of Things technologies in enabling connected, electric, and autonomous mobility operations. Crucial to this transformation is the development of digital interfaces between different transportation modes, the provision of standardized solutions for intelligent and bidirectional grid integration, and the creation of digital tools for user-friendly, inclusive, and accessible mobility, marking a significant leap toward a more sustainable and interconnected transportation future.

Future prospects in battery technology, lightweight and alternative (non-rare) materials, alongside smart design and circular economy solutions, are ready to further advance decarbonization in the transportation sector. The interplay between software and hardware, augmented by robotics, outlines an evolving technological ecosystem that supports sustainable transportation from the production along the lifespan of vehicles and infrastructures toward their disassembly.

Addressing equity issues through these new and emerging technologies presents both opportunities and challenges, underscoring the importance of equitable access to the benefits of technological advancements in ensuring a sustainable, efficient, and inclusive transportation future.

KEY RESEARCH QUESTIONS AND OPPORTUNITIES

The expert discussions at the Seventh EU-U.S. Transportation Research Symposium will cover the following four exploratory topics:

- Accelerating the transition to electrification and alternative fuels;
- Ensuring a just transition to net-zero transport;
- Leveraging digitalization, artificial intelligence, and other integrated system-of-systems technologies to decarbonize transport; and
- Implementing sustainable and resilient land use and transportation system design.

The lead questions for these discussions have been provided in dedicated briefing papers that complement this white paper (see Appendixes B, C, D, and E). Furthermore, another briefing paper (see Appendix F) gives guidance for the integrated review of EU-U.S. collaboration pathways in transportation research at both the policy and program levels, such as giving advice on instruments and tools and making recommendations for common themes in research and innovation.

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Appendix B

Briefing Paper on Exploratory Topic 1: Accelerating the Transition to Electrification and Alternative Fuels

Chris Hendrickson, *Carnegie Mellon University, United States*
Gereon Meyer, *VDI/VDE Innovation + Technik GmbH, Germany*

The drive toward decarbonizing transport presents the United States (U.S.) and the European Union (EU) with complex research challenges as they aim to shift toward carbon-neutral energy production, reliable energy storage and transfer systems, and the widespread adoption of zero-emission modes of transportation—particularly for road vehicles, from e-bikes and scooters through passenger cars to heavy trucks. The integration of renewable electricity sources into the grid to support a growing fleet of electric vehicles is a primary concern, necessitating advancements in smart-charging technologies to optimize energy use and enable vehicle-to-grid capabilities. Concurrently, the energy efficiency of electric vehicles is being improved through innovations such as lightweight design and better batteries, while circular economy approaches are considered another promising path to decarbonization by optimizing the energy and resource usage. Moreover, interoperable roadside infrastructures for both private and commercial electric vehicles are to be further developed. In addition, the European Union continues to expand its already robust rail network electrification.

The exploration of alternative fuels is pivotal to the transition toward low- or zero-emission vehicles, with hydrogen emerging as a key player in aviation, maritime transport, and long-haul trucking across both regions. While the United States also delves into the potential of biofuels, the European Union is more focused on synthetic fuels, committing to extensive life-cycle analyses to assess their environmental viability and climate footprint. The potential of fuel cells, particularly for heavy-duty transport, is being tapped into, with both regions seeking cost-effective solutions through novel catalyst materials.

In a bid to create greener ports and airports, significant research efforts are being directed toward the electrification of ground support equipment and the use of alternative fuels for aircraft and ships. The pursuit of interoperable technological solutions and the formulation of international standards are also critical, with the European Union favoring regulatory measures while the United States leans on market-driven approaches. This extends to the adoption of automation and intelligent transportation systems that promise enhanced efficiency and safety in the transport sector.

At the forefront of energy solutions are next-generation battery technologies, a field where both regions compete to achieve higher energy densities, faster charging capabilities, and sustainable life cycles. Additionally,

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inductive charging technology is making headway, with the U.S. testing it for personal vehicles and the European Union for public transportation and trucks.

Both the United States and the European Union recognize the profound impact of these technological advances. They are working toward integrating them into a coherent, efficient, and sustainable transport system that appeals to users and is easily accessible. At the same time, they support the shift to greener and cleaner modes while acknowledging citizens' desire for a fair distribution of urban space. In this endeavor, methods that involve collaborative design and stakeholder participation are becoming increasingly crucial. Despite the variance in their methods, a mutual commitment to fostering a more sustainable and environmentally friendly transport sector is propelling forward-thinking and cooperative efforts on both sides of the Atlantic.

The following sections present key questions to consider for discussion during the symposium.

GENERAL CONSIDERATIONS

- Which powertrain and fuel or energy source option should be chosen for which mode in order to maximize decarbonization effects?
- How can energy efficiency of vehicle operations be optimized and rebound effects be avoided?
- How should fuel or energy priorities reflect the specific challenges of transport decarbonization within the varied geographic and socioeconomic landscapes of the United States and the European Union?
- How can we overcome behavioral barriers to vehicle electrification in the different modes?
- What are the key considerations for ensuring that new transport decarbonization technologies are user-friendly and meet the needs of diverse populations?
- How can citizens be motivated to shift to cleaner and greener modes?
- How can infrastructure development for charging/hydrogen/alternative fuels be promoted, and which side effects of it should be considered?
- What can be done to make life-cycle greenhouse gas (GHG) emissions of electric and alternative-fuel vehicles traceable in a (globally) harmonized way?

CURRENT STRATEGIES AND FUTURE PROSPECTS IN TECHNOLOGY AND INNOVATION

- How can we accelerate research and innovation in batteries, fuel cells, and alternative fuel production?
- Which drop in battery costs and increase in energy density can be expected over time?
- Which incentives and regulations (for alternative fuels, vehicle electrification, charging stations, etc.) have been successful for the various transport modes in the European Union and the United States?
- How can we encourage the creation of less costly, yet still sustainable, supply chains for batteries?
- How can alternative fuels be improved in terms of cost and supply?
- What is the best business model for public charging stations? Can charging station reservation systems help the deployment of electric mobility?
- What is the effect of vehicle electrification on the power grid? Is smart charging desirable? And, bidirectional?
- How do case studies from the United States and the European Union inform the scalability and transferability of transport decarbonization technologies across different modes, operational modes, and regions?
- How can the long-term sustainability and performance of emerging transport decarbonization technologies be estimated and evaluated?

SOCIAL, ECONOMIC, AND ENVIRONMENTAL CONSIDERATIONS

- How can social factors—such as equity in access, fair distribution of space, and affordability—be considered in the development, prioritization, and implementation of technology paths for transport decarbonization?
- In the pursuit of transport decarbonization, how do we balance or trade off technological advancement with the need to protect and sustain the environment in the different modes?
- How can more efficient operations and the shift to cleaner options be fostered in the different modes?

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- How can the competition between carbon sequestration and biofuels be solved?
- How can we lower the user cost or raise the customer value of electric vehicles?
- What strategies can be employed to foster public acceptance and promote behavior change toward decarbonized transport options?
- How does global access to resources, raw materials, and the supply of critical components (such as precious metals or semiconductor chips) influence the viability of technology options for decarbonized transportation and fuels?

NEW AND EMERGING TECHNOLOGIES OR OPPORTUNITIES

- What specific technologies, processes, and materials are critical for reducing the carbon footprint of transportation means and infrastructures in the different modes?
- What battery chemistries will be competitive in 5 years or 10 years?
- What new pathways can be deployed in 5 years or 10 years to produce inexpensive low-carbon alternative fuels?
- What alternative pathways of vehicle development (e.g., in terms of size, weight, or battery size) could significantly reduce energy consumption and thus GHG emissions?
- What role could digital technologies such as artificial intelligence, big data, or mobility data spaces play to fully exploit the potentials for decarbonization in transport?
- Does automation of road transportation increase or decrease the energy intensity of cars?
- How can shifts to cleaner and greener modes be promoted and facilitated with digital tools?

CHALLENGES AND BARRIERS

- How do technological, societal, economic, legal, and human factors interact in hindering or accelerating the adoption of zero-emission transportation solutions in the various modes?
- How does the decarbonization of transportation depend on decisions in the energy sector?
- Is there a resistance to developing electric vehicles, and if yes, why and by whom?
- Are there any particular safety issues of heavy or light electric vehicles?
- How does the decarbonization of transportation systems affect their resilience?
- How can costs and benefits of decarbonization in transportation be monetized?
- How can the United States and the European Union jointly contribute to setting global standards for decarbonization and circularity of transportation means and their technologies and how can that drive global change and facilitate international trade and cooperation?
- Can we introduce international standards for charging hardware?
- What roles do education and workforce development play in preparing for the decarbonization of the transport sector?
- How can communication and outreach be optimized to engage all stakeholders, from industry to end users, in the support and adoption of transport decarbonization technologies and mode shifts?

CONCLUSIONS AND OUTLOOK

- What role can electrification and alternative fuels play to achieve net-zero emissions from transportation by 2050?
- Which are the accelerators, and which are the hurdles?
- What trends will become relevant, and which uncertainties remain?
- Which are the most pressing research needs?
- Which are the opportunities of transatlantic collaborations, and where are the bottlenecks?

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Appendix C

Briefing Paper on Exploratory Topic 2: Ensuring a Just Transition to Net-Zero Transport

Patricia "Paty" Romero-Lankao, *University of Toronto, Canada*
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The transition of the transportation sector to a zero-carbon future offers diverse socioeconomic benefits, such as reductions in greenhouse gases (GHGs) and tailpipe pollutants and improved public health and jobs.[1,2,3,4] Cities and regions, with their concentration of people, economic activities, infrastructure, and research and development organizations, offer considerable opportunities to transition transportation, including road, rail, freight, maritime, or air mobility, to a more sustainable future.[5,6,7] However, transportation decarbonization can produce new and, in many cases, perpetuate pre-existing inequities if promoted without intentionally focusing on concerted strategies away from past and current inequitable structures. Therefore, it is critical to comprehensively examine and address the challenges and opportunities linked to equity and justice in the transition to net-zero transportation systems (see Key Terms) to ensure that this significant transport transformation will not leave anyone behind.

A solid body of scholarship finds that focusing on decarbonizing vehicles and technological innovations alone—without a combination of user-tailored mobility modes and fundamentally rethinking entire transport ecosystems—will not be enough to meet climate and sustainable development goals and ensure equity. While these

[1] UN Technical Working Group on Transport, Analysis of the transport relevance of each of the 17 SDGs (September 14, 2015). https://sustainabledevelopment.un.org/content/documents/8656Analysis%20of%20transport%20relevance%20of%20SDGs.pdf.

[2] Brussel, M., Zuidgeest, M., Pfeffer, K., & van Maarseveen, M. Access or accessibility? A critique of the urban transport SDG indicator. *ISPRS International Journal of Geo-Information* 8, 67 (2019).

[3] Sperling, D., Pike, S., & Chase, R. Will the transportation revolutions improve our lives—or make them worse? In *Three Revolutions: Steering Automated, Shared, and Electric Vehicles to a Better Future* (ed. Sperling, D.), pp. 1–20 (Island Press/Center for Resource Economics, Washington, DC, 2018). https://doi.org/10.5822/978-1-61091-906-7_1.

[4] International Energy Agency. *Global EV Outlook 2019: Scaling-up the Transition to Electric Mobility* (2019). https://www.iea.org/reports/global-ev-outlook-2019.

[5] Kennedy, C. Keeping global climate change within 1.5°C through net negative electric cities. *Current Opinion in Environmental Sustainability* 30, 18–25 (2018).

[6] Kennedy, C., Stewart, I. D., Facchini, A., & Mele, R. The role of utilities in developing low carbon, electric megacities. *Energy Policy* 106, 122–128 (2017).

[7] Romero-Lankao, P., Wilson, A., Sperling, J., Miller, C., Zimny-Schmitt, D., Sovacool, B., Gearhart, C., Muratori, M., Bazilian, M., Zund, D., Young, S., Brown M., & Arent, D. Of actors, cities and energy systems: Advancing the transformative potential of urban electrification. *Progress in Energy* 3, 032002 (2021).

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Key Terms

Equity implies facilitating access to different (not equal) transportation benefits or actions that rectify past and/or existing injustices. While **equality** refers to distributing the same to all, equity recognizes previous and current differences in experiences and outcomes between people, groups, and communities to rectify those imbalances.[a]

Justice entails the removal of barriers that prevent equity by recognizing and warranting underserved and vulnerable groups' ability to participate in critical decision-making actions.[b]

Transport justice refers to providing tailored, safe, affordable, and sustainable transportation options to all individuals by incorporating an equity framework with the core tenets of justice—distributional, procedural, and recognition.[c]

Transport transition is an attempt by jurisdictions to transform or develop their transportation system away from fossil fuels with a large-scale technological and societal change in the provision and use of mobility.[d]

Just transport transition entails transforming the transportation system by ensuring all communities, workers, and social groups are included in the processes toward and outcomes of the net-zero future by incorporating the principles of justice.[e]

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[a] Reckien, D., & Lwasa, S. Equity, environmental justice, and urban climate change. In *Climate Change and Cities: Second Assessment Report of the Urban Climate Change Research Network* (Cambridge University Press, 2017).

[b] National Academies of Sciences, Engineering, and Medicine. *Accelerating Decarbonization in the United States: Technology, Policy, and Societal Dimensions* (The National Academies Press, Washington, DC, 2023).

[c] McCauley, D., Ramasar, V., Heffron, R. J., Sovacool, B. K., Mebratu, D., & Mundaca, L. Energy justice in the transition to low carbon energy systems: Exploring key themes in interdisciplinary research. *Applied Energy* 233, 916–921 (2019).

[d] Romero-Lankao, P., Rosner, N., Brandtner, C., Rea, C., Mejia-Montero, A., Pilo, F., Dokshin, F., Castan-Broto, V., Burch S., & Schnur, S. A framework to center justice in energy transition innovations. *Nature Energy* 8, 1192–1198 (2023).

[e] McCauley, D., Ramasar, V., Heffron, R. J., Sovacool, B. K., Mebratu, D., & Mundaca, L. Energy justice in the transition to low carbon energy systems: Exploring key themes in interdisciplinary research. *Applied Energy* 233, 916–921 (2019).

approaches may "clean up" a transportation system, they can also unleash other unequal risks from issues such as congestion, lack of accessible and affordable mobility options for underserved populations, and displacement of health impacts to areas providing energy and raw materials for electric vehicles. These risks would add other unintended adverse consequences on already disproportionally impacted groups. In other words, by only relying on decarbonization, we will not be able to ensure equity in the transition to net-zero transport.

This briefing paper discusses crucial questions on the opportunities for and barriers to achieving equity in the transition to net-zero transport. It draws lessons from existing approaches in the European Union (EU) and the United States (U.S.) for policymakers and academia to navigate and steer responses, ensuring equity and justice in the transition to net-zero transport. Below, we list the overarching questions organizing this paper:

- How are current net-zero transport policies and innovations targeting equity and justice?
- How do we ensure everyone benefits from decarbonization strategies? What opportunities do we have, and what barriers do we face?
- How can we create benefits for all from decarbonization strategies and avoid harm, particularly for underserved or disadvantaged communities?

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EQUITY TENETS AND THE SOCIOECONOMIC DIMENSIONS OF THE TRANSPORT TRANSITION

The commitment of the United States and the European Union to energy justice provides essential opportunities to further tenets and principles of transport equity and justice (see Key Terms). Yet, this increased emphasis also provides challenges as policymakers and technology developers incorporate potentially unfamiliar concepts from the social sciences into their policy and technology projects. With this in mind, this section highlights questions guided by an equity lens.

Distributional equity emphasizes questions, such as who benefits, who bears the burdens, and how the benefits and burdens of electric vehicles, shared mobility services, clean fuels, and other technological innovations are distributed among different populations within and across cities and regions and over time.

Procedural equity highlights questions of who is at the decision-making table, whose voices are heard or excluded, and how women, the elderly, the working class, rural, and other underrepresented racial or ethnic groups can participate in framing the mobility and net-zero transport needs as well as the policies and innovations to address those needs.

Recognition justice guides analysis and action targeting the legacies of historical and current transportation and land use policies and practices. Examples include questions on who benefits and is burdened by transportation corridors, transit-induced gentrification[8,9] and redlining or "the systematic denial of various [transportation] services or goods by federal government agencies, local governments, or the private sector either directly or through the selective raising of prices" (Denver Metro Chamber Leadership Foundation 2020).[10] Recognition equity also guides questions such as how the legacies of investment, regulations, and other policies and practices affect transportation inequities. How do these legacies interact with intersecting determinants of transportation inequities such as gender, income, and race?

Most recently, experts and decision makers have expanded their equity lens by integrating a life-cycle approach into a social-cycle analysis. This guides questions on who benefits, who bears the harms, and how harms and benefits play out in the following life-cycle stages of transportation: (1) raw material extraction; (2) production of vehicles, energy sources, and technologies; (3) operation and supply of electricity and transportation; (4) consumption and use of transportation services and technologies; and (5) waste management of, for example, old vehicles and their parts.[11,12,13]

An equity lens to the net-zero transportation transition helps highlight other questions and considerations. For instance:

- What are the workforce impacts and opportunities for transportation decarbonization policies and technological innovations?
- How can we avoid producing new and perpetuating preexisting inequities in access to affordable, safe, reliable net-zero services, technologies, and vehicles? And how can we do all this while ensuring no groups are left behind?
- How can we develop inclusive governance approaches throughout planning, implementation, and evaluation to engage with everyone—particularly underserved communities—and how can the ladder of engagement guide effective engagement methods that:[14]

[8] Jones, C. E., & Ley, D. Transit-oriented development and gentrification along Metro Vancouver's low-income SkyTrain corridor. *The Canadian Geographer/Le Géographe Canadien* 60, 9–22 (2016).

[9] Bardaka, E., Delgado, M. S., & Florax, R. J. G. M. Causal identification of transit-induced gentrification and spatial spillover effects: The case of the Denver light rail. *Journal of Transport Geography* 71, 15–31 (2018).

[10] Denver Metro Chamber Leadership Foundation, https://denverleadership.org.

[11] Romero-Lankao, P., & Nobler, E. *Energy Justice: Key Concepts and Metrics Relevant to EERE Transportation Projects*. NREL/MP-5400-80206 (U.S. Department of Energy Office of Energy Efficiency and Renewable Energy, 2021). https://www.osti.gov/biblio/1797919.

[12] Heffron, R. J., & McCauley, D. What is the "just transition"? *Geoforum* 88, 74–77 (2018).

[13] Maier, M., Mueller, M., & Yan, X. Introduction of a spatiotemporal life cycle inventory method using a wind energy example. *Energy Procedia* 142, 3035–3040 (2017).

[14] Arnstein, S. R. A ladder of citizen participation. *Journal of the American Institute of Planners* 35, 216–224 (1969).

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- enable minorities, disadvantaged or marginalized groups to have a front seat in the transition to net-zero transport as users, planners, decision makers, and workers?
- generate interest in the transition within groups that have not generally been involved?
- include representative bottom-up bodies (grassroots, unions) to meaningfully contribute to broader decarbonization visions or strategies locally, nationally, and internationally?
- avoid box-ticking or social washing?

CURRENT POLICIES AND PROGRAMS

This section examines how equity can be addressed in EU and U.S. legislation, programs, and practices. It points out that scholarship and practice increasingly emphasize the urgency of embedding the equity tenets and principles of fair distribution, process, and recognition in net-zero transport approaches.[15,16,17,18]

Equity is already and increasingly considered an essential respect by local, national, and international stakeholders working in or shaping the decarbonization of the transport sector. Below, we describe some examples of how the United States and the European Union have enabled the integration of equity provisions into high-level funding opportunities or policy programs.

In the United States, Executive Order 14008 (January 27, 2021) generated a comprehensive approach to addressing environmental justice concerns, including (a) a White House Environmental Justice Advisory Council to collaborate with the U.S. Environmental Protection Agency's National Environmental Justice Advisory Council, and (b) a new Interagency Working Group on Coal and Power Plant Communities and Economic Revitalization. Both were mandated to identify immediate investments in disadvantaged communities, and (c) a Climate and Economic Justice Screening Tool to identify disadvantaged communities.[19]

The executive order also established the Justice40 Initiative, tasked to ensure that low-income and disadvantaged communities benefit from the energy transition by mandating that at least 40% of the benefits of climate and energy programs go to disadvantaged communities.[20]

The $1.2 trillion Infrastructure Investment and Jobs Act (November 15, 2021) explicitly seeks to advance environmental justice through different actions. The act directs agencies to fund programs that increase access to reliable, clean, affordable power and safe drinking water and improve broadband connectivity. It also targets funds for community resilience programs, such as healthy streets, flood mitigation, and resilient infrastructure.[21]

The Inflation Reduction Act (IRA, August 16, 2022), includes requirements for "improving the White House Council on Environmental Quality's community engagement processes, creating energy credits for solar and wind facilities sited in low-income communities, and $42 million in Tribal and Native Hawaiian climate resilience investments."[22] The IRA's Greenhouse Gas Reduction Fund allocates grants for state, local, regional, and Tribal governments to provide financial or technical support so that underserved communities benefit from zero-emission technologies. The IRA also indicates that $7 billion of zero-emission technologies be deployed in underserved and low-income communities; it allocates $8 billion entirely to low-income and disadvantaged communities.

The European Union proactively creates financial mechanisms and publishes recommendations and research on overarching social themes linked to transportation, including gender equality, access to transport for all, reskilling opportunities, connecting rural and remote regions, and more. A first example is the Social Climate Fund

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[15] Ibid.

[16] Fan, Y., Guthrie, A., Van Dort, L., & Baas, G. *Advancing Transportation Equity: Research and Practice*. Report No. CTS 19-08. (Minnesota Department of Transportation, 2019).

[17] Shirmohammadli, A., Louen, C., & Vallée, D. Exploring mobility equity in a society undergoing changes in travel behavior: A case study of Aachen, Germany. *Transport Policy* 46, 32–39 (2016).

[18] Argonne National Laboratory. Electric vehicle charging equity considerations (2022). https://www.anl.gov/es/electric-vehicle-charging-equity-considerations.

[19] National Academies of Sciences, Engineering, and Medicine. *Accelerating Decarbonization in the United States: Technology, Policy, and Societal Dimensions* (The National Academies Press, Washington, DC, 2023).

[20] Ibid.

[21] Ibid.

[22] Ibid.

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(SCF), which provides Member States with dedicated funding to the most affected and vulnerable groups through structural measures and investments in transport and energy to ensure no one is left behind during the green transition.[23] It is estimated that the SCF will mobilize at least €86.7 billion over the 2026–2032 period through the EU Emission Trading Scheme and ETS 2. A second example is the Just Transition Mechanism, a tool of the European Commission that includes funds, budgetary guarantee and advisory support, and a public-sector loan facility to help mobilize around €55 billion over the period 2021–2027 to alleviate the socioeconomic impact of the transition in the most affected regions of the European Union.[24] One of the core themes includes the investment in public and sustainable transport. Finally, the European Union provides ad hoc advice on topics linked to the transport transition, such as the *Commission Recommendation of 29.11.2023 on Means to Address the Impact of Automation and Digitalization on the Transport Workforce*.[25] It raises awareness of potential adverse impacts, the need for upskilling and reskilling, improving working conditions, managing change, and offering funding opportunities—notably, to leave no one behind in the green transition.

European cities, regions, and countries are also proactively enabling the integration of equity provisions into high-level funding opportunities, regulations, and policy programs. For example, European cities have taken bold action targeting women's safety while using transport services or simply moving. From Vienna and Umeå's redesign of public space to Transport for London's *Report It to Stop It*, Safe.Brussels' *Join the Fam*, and Manchester's *Is This Okay* campaigns, there has been a range of initiatives to identify and challenge the ways mobility ignores—and indeed further marginalizes—women.[26]

These and other existing programs and policies bear a series of crucial questions organized around the following topics.

Current Strategies

- How can we mainstream equity in transport decarbonization? What must we consider to accelerate regulations, programs, and practices? Are there research gaps?
- What current policies or programs in the United States and Europe support research in enabling equity in the decarbonization of transport?
- Are current strategies, research, and policy programs in Europe and the United States using the right approach, tools, and techniques to foster equity in the transition?
- How can lessons from existing programs and practices—for example, the U.S. Federal Interagency Thriving Communities Network—inform community-centered technical assistance programs such as the U.S. Climate Opportunity Zones and Justice40? How can such learning be applied also in an EU context?
- How do we establish mechanisms for public oversight of
  - the design, implementation, and evaluation of net-zero transportation investments, programs, and instruments?
  - private mobility service provision to ensure their inclusivity, fairness, sustainability, and contribution to a just transition?
  - institutionalizing or learning from existing programs (e.g., Justice40) protocols and transparency obligations (e.g., performance metrics)?

[23] European Commission. About the Social Climate Fund. https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets/social-climate-fund_en.

[24] European Commission. The just transition mechanism: Making sure no one is left behind. https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/finance-and-green-deal/just-transition-mechanism_en.

[25] Directorate-General for Mobility and Transport, European Commission. Recommendation on means to address the impact of automation and digitalisation on the transport workforce. https://transport.ec.europa.eu/transport-themes/social-issues-equality-and-attractiveness-transport-sector/social-issues/automation-transport/recommendation-means-address-impact-automation-and-digitalisation-transport-workforce_en.

[26] Duxfield, I., Babío, L., Gustaffson, L., Jacinto, R., & Palsma, R. *SMCs Just Transition Webinar: Gender Equity Comes in… Small Packages?* (POLIS, 2023). https://www.polisnetwork.eu/wp-content/uploads/2023/03/Just-Transition-Webinar-SMCs-Report.pdf.

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Future Policies and Programs

- How can transportation decision makers engage underserved communities, community-based organizations, and smaller businesses in defining where, when, and how to allocate investments and resources?
- How do we ensure processes, methods, and procedures are fair and transparent regarding access to finance and opportunities to participate in programs (procedural equity)?
- How do we assess whether just transition financial schemes support society's most vulnerable or affected members and small businesses? How do we create measures of accountability and evaluation?
- How can we ensure transportation technologies and investments are tailored to different mobility needs, from families to small business providers of goods and services?
- What funding may be needed? How can the United States and the European Union work together on future programs?

Systems Thinking

- What structural opportunities, barriers, and legacies must be considered to achieve equity in the transition to net-zero carbon?
- How do issues of transportation equity relate to land use planning and other matters addressed by the other exploratory topics?
- How can we design transport options tailored to the mobility needs of different groups and users? For instance, can we develop system approaches to target intersecting sociodemographic factors (e.g., race, gender, social class, age, (dis)ability) and built environment factors (e.g., urban to rural areas, small towns, and transport deserts)?
- What incremental and transformational policy instruments and programs can move away from car-centered and polluting freight transportation systems?
- Are there portfolio or policy bundle approaches to providing users safe, affordable, and cleaner mobility and freight transport options?
- How can we address the legacies of past policies and practices (e.g., transportation corridors, redlining and gentrification of underserved areas)?
- How can we foster workers' and communities' capacity to navigate the changing jobs and skills demanded by the decarbonization of transport and provision of new mobility services?

Research and Funding

- What research, innovations, and collaborations are needed to achieve transportation equity in studying, prototyping, and deploying new services, social initiatives, and technological innovations?
- What tools and indicators help (a) define and measure transportation disadvantages; (b) assess the equity performance of net-zero transportation investments, policies, and practices; and (c) drive use and implementation of the indicators?
- What funding or joint programs could be developed to support actionable research?

LEARNING FROM RELEVANT CASE STUDIES

To understand what social, environmental, technological, and economic factors need to be considered to achieve equity and avoid creating new or worsening existing inequities in the transition to net-zero transport, it is essential to recognize the current legacies of historical political landscapes, policies, and practices that led to present-day disparities. This requires analyzing historical and recent trends in transportation-relevant inequities in critical areas such as urban development and transport: redlining, gentrification, transport affordability, accessibility, acceptability, technology adoption, public health and community resilience, and jobs and workforce development. This section examines concrete examples with lessons learned and options for fostering equity in the net-zero transport transition.

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The LA100 Equity Strategies, a city-wide and community-informed research program to improve equity in Los Angeles' transition to clean energy by 2035 by mapping what community members themselves feel is needed to achieve more equitable outcomes.[27,28] LA100 Equity Strategies examines how widespread transportation electrification can address transportation inequities embedded in historical practices such as zoning, renting, investment, and redlining. The Los Angeles Department of Water and Power support for transportation electrification has predominantly benefited affluent White communities. Participatory research with underserved Angelenos highlighted three transportation equity priorities:[29]

- Partner with community leaders and community-based organizations on the design, implementation, and evaluation of
  - incentives, outreach, and other programs to meet community needs;
  - electrification infrastructure and housing retrofit (e.g., electric panels);
  - affordable, reliable, accessible, and safe e-mobility options, such as e-bikes, e-scooters, shared electric vehicle programs, and walking; and
  - options to reduce air pollution and improve health, such as truck electrification.[30]
- Address community concerns about access, affordability, safety, and pollution reduction when updating, retrofitting, and expanding net-zero mobility options.
- Expand access to affordable and safe electric mobility infrastructure and ensure that charging stations are in locations that meet daily household routines and support charging of e-bikes, scooters, and other mobility options.[31]

Based on community insights, LA100 Equity Strategies assessed strategies to foster equity in transportation electrification, including the electrification of heavy vehicles, adoption of electric vehicles, access to charging infrastructure and expanding transportation electrification benefits to households who do not own cars or cannot afford an electric vehicle.[32,33] To foster city-wide efforts such as LA100 Equity Strategies, it is crucial to ask how net-zero transportation policies and technologies can

- Create procedural mechanisms for underrepresented, low-income, gender, racial, or ethnic groups to participate in framing the mobility and net-zero transport needs, as well as the policies and innovations to address those needs.
- Expand the benefits and reduce the burdens of subsidies, rebates, electric vehicles, shared mobility services, clean fuels, and other policies and innovations.

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[27] Romero Lankao, P., Rosner, N., Lockshin, J., & Zimny-Schmitt, D. Chapter 1: Justice as recognition. in *LA100 Equity Strategies* (eds. Anderson, K., Day, M., Romero-Lankao, P., Berdahl, S., & Rauser, C.). NREL/TP5400-85948 (National Renewable Energy Laboratory, Golden, CO, 2023). https://www.nrel.gov/docs/fy24osti/85948.pdf.

[28] Anderson, K., Day, M., Romero-Lankao, P., Berdahl, S., Rauser, C., et al. Executive summary in *LA100 Equity Strategies* (eds. Anderson, K., Day, M., Romero-Lankao, P., Berdahl, S., & Rauser, C.). NREL/TP5400-85947 (National Renewable Energy Laboratory, Golden, CO, 2023).

[29] Lee, D.-Y., Sun, B., Wilson, A., Day, M., Romero-Lankao, P., Rosner, N., Yang, F., Brooker, A., & Lockshin, J. Chapter 10: Household transportation electrification in *LA100 Equity Strategies* (eds. Anderson, K., Day, M., Romero-Lankao, P., Berdahl, S., & Rauser, C.). NREL/TP5400-85957 (National Renewable Energy Laboratory, Golden, CO, 2023).

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[32] Ibid.

[33] Anderson, K., Day, M., Romero-Lankao, P., Berdahl, S., Rauser, C., et al. Executive summary in *LA100 Equity Strategies* (eds. Anderson, K., Day, M., Romero-Lankao, P., Berdahl, S., & Rauser, C.). NREL/TP5400-85947 (National Renewable Energy Laboratory, Golden, CO, 2023).

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- Target redlining, gentrification, and other root causes of explaining inequity in access to affordable, safe, accessible, and reliable mobility options.

Fostering Active Travel for People with disabilities requires removing financial, infrastructural, and communication barriers while adopting a pan-impairment approach, bearing in mind the large variations within this group. Limited traffic zones and other traffic calming measures can have unintended consequences on people with disabilities, such as disproportionate increases in journey times. To mitigate these impacts, it is important to formulate key questions upstream on including people with disabilities in such projects' planning, design, implementation, monitoring, and evaluation. These could include:

- How can we meaningfully engage organizations representing people with disabilities in conceptualizing such measures?
- What are the best channels and ways to communicate changes clearly and thoroughly to people with disabilities?
- Are exemptions needed to alleviate the impact of such measures on certain groups?
- What kind of research and mapping is required to understand their needs? Who can fund these? Do we have enough data?
- What funding, research programs, or policies exist or should be created to improve the accessibility of street space?

Addressing transportation inequities across the urban–rural continuum starts by developing sustainable mobility options for rural communities and economic activities that are often car-dependent and receive less investment and attention in creating affordable, practical, and accessible transport alternatives. The mobility of rural areas affects cities, with more than a million people commuting into the city of Paris, for example. A study of transportation equity across the urban-rural continuum found that rural and exurban populations are the primary users of single-occupancy vehicles, the lowest adopters of electric cars, and the least exposed to air pollutants.[34] Therefore, investments and policies tailored to the needs of rural areas can help achieve multiple goals, such as decarbonization, decongestion, and urban-to-rural equity. Questions researchers, policymakers, and others in the field can ask include:

- How can we support transport operators deploying services in suburban, exurban, and rural areas to avoid "transport deserts"?
- Which new services and technologies currently support the mobility needs of suburban and rural areas?
- How can we curb the underinvestment in sustainable and accessible alternatives in rural areas?
- How can active travel be fostered for short-distance trips? What kind of infrastructure is desirable and possible? How can we make these options safe?
- How does the higher average age of the population living in suburban and rural towns impact sustainable mobility options that should be investigated and implemented?
- What research is needed to create practical rural-specific mobility options? Do we have enough data?
- How can instruments, strategies, and programs better connect suburban and rural areas to cities?

EMERGING AND TRANSITION TECHNOLOGICAL INNOVATIONS

In recent years, technological innovations such as electric vehicles, automated vehicles, and drones, as well as applications for shared mobility solutions, have been presented as transformational solutions to decarbonize the transportation sector, with its outsized responsibility for the unequal distribution of urban air GHGs and tailpipe

[34] Romero-Lankao, P., Wilson, A. & Zimny-Schmitt, D. Inequality and the future of electric mobility in 36 US cities: An innovative methodology and comparative assessment. *Energy Research & Social Science* 91, 102760 (2022).

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emissions.[35,36,37] While the relevance of equity and justice in this transition has been getting increasing attention, key questions remain about targeting inequities in these technological innovations, from their design to their widespread use.[38,39] For instance:

- How can technologies such as those seeking to electrify and automate transportation center equity, from their design and experimentation to their wide deployment and use?
- Are these innovations designed with an understanding of historical and current determinants of inequities?
- Do they consider only market value or social, cultural, and environmental values?
- Do they address or exacerbate the root causes of health outcomes and other transportation hardships?
- Can new technologies fill gaps created by unjust legacies of policies and programs (e.g., electric automated shuttles to reduce urban–rural public transportation divide, and automated vehicles to improve mobility of the elderly, people with disabilities)?
- How can technologies be designed and deployed to target historically entrenched inequities? What options exist to do this? For instance, can we design, deploy, and operate
  - last-mile shared options for underserved communities in core, urban, suburban, and exurban areas?
  - electric automated shuttles or shared electric mobility to reduce the urban–rural public transportation divide?
  - transportation technologies and services to improve the mobility of the youngest, the elderly, and people with disabilities?
  - services involving electric buses to address the mobility needs of users such as low-income households, school children, and employees?

CLOSING REMARKS

The decarbonization of transport offers multiple opportunities. It can help reduce GHGs, improve air quality, and reduce health impacts and create new economic activities and jobs. Still, transportation decarbonization can create or accentuate existing inequities and create new unequal risks from congestion, dislocation of jobs, and lack of accessible affordable mobility options, and displacement of negative impacts to areas providing energy and raw materials for the electrification of mobility. This briefing paper examined the challenges and opportunities to achieving equity and justice in the transition to net-zero transportation systems. It illustrated how focussing on decarbonizing vehicles and technological innovations alone—without a combination of user-tailored mobility modes and fundamentally rethinking entire transport ecosystems—will not be enough to meet climate and sustainable development goals and ensure equity. It suggested crucial questions to be discussed with the participants, on the opportunities and barriers to achieving equity in the transition to net-zero transport, while drawing lessons from existing approaches in the European Union and the United States for policymakers and academia.

[35] Brussel, M., Zuidgeest, M., Pfeffer, K., & van Maarseveen, M. Access or accessibility? A critique of the urban transport SDG indicator. *ISPRS International Journal of Geo-Information* 8, 67 (2019).

[36] Sperling, D., Pike, S., & Chase, R. Will the transportation revolutions improve our lives—or make them worse? In *Three Revolutions: Steering Automated, Shared, and Electric Vehicles to a Better Future* (ed. Sperling, D.), pp. 1–20 (Island Press/Center for Resource Economics, Washington, DC, 2018). https://doi.org/10.5822/978-1-61091-906-7_1.

[37] International Energy Agency. *Global EV Outlook 2019: Scaling-up the Transition to Electric Mobility* (2019). https://www.iea.org/reports/global-ev-outlook-2019.

[38] McCauley, D., Ramasar, V., Heffron, R. J., Sovacool, B. K., Mebratu, D., & Mundaca, L. Energy justice in the transition to low carbon energy systems: Exploring key themes in interdisciplinary research. *Applied Energy* 233, 916–921 (2019).

[39] Romero-Lankao, P., Rosner, N., Brandtner, C., Rea, C., Mejia-Montero, A., Pilo, F., Dokshin, F., Castan-Broto, V., Burch S., & Schnur, S. A framework to center justice in energy transition innovations. *Nature Energy* 8, 1192–1198 (2023).

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Appendix D

Briefing Paper on Exploratory Topic 3: Leveraging Digitalization, Artificial Intelligence, and Other Integrated System-of-Systems Technologies to Decarbonize Transport

Margriet van Schijndel-de Nooij, *Eindhoven University of Technology, The Netherlands*
Heng Wei, *University of Cincinnati, United States*

The U.S. National Blueprint for Transportation Decarbonization establishes a visionary goal of eliminating nearly all greenhouse gas (GHG) emissions from the transportation sector by 2050. With the rapidly evolving development of Internet-of-Things (IoT)-based mobility information and connected and automated vehicle (CAV) technologies, we are in a transformative era for transportation.[1] As pointed out in the U.S. Department of Transportation (U.S. DOT) Research, Development, and Technology Strategic Plan for Fiscal Years 2022–2026 (U.S. DOT RDT Strategic Plan), "we have entered a transformative era for transportation. This transformation is blurring boundaries between traditional transportation domains, enabling a vast array of technological innovations and fostering public awareness of the highly interconnected, multimodal, complex nature of modern transportation."

The European Commission has set out its vision and ambition in the 2020 document Sustainable and Smart Mobility Strategy—putting European transport on track for the future. The vision is accompanied by an action plan, based on 10 flagships, to establish a fundamental transport transformation. As a result, the ambition is to have a 90% cut in emissions by 2050, delivered by a smart, competitive, safe, accessible, and affordable transport system.

Despite extensive support through a myriad of policy, planning, and technological solutions, the transition process has proven persistently unsustainable, with GHG emissions on a continual rise. The absence of a paradigm shift in communities and culture remains a critical issue.[2] Essentially, behavioral patterns have not undergone sufficient changes to provide decision makers with the necessary support for implementing more aggressive measures to address the pressing needs.

When responding to the critical challenges of aging roads, bridges needing significant repair, and limited intermodal connectivity, improving infrastructure adaptability, resilience, and sustainability has also been a local focus of many American and European cities. However, historical development patterns and geographical factors have left a legacy of dated roadway design, with low multimodal connectivity networks and facilities in those areas.

[1] U.S. Department of Energy, *The U.S. National Blueprint for Transportation Decarbonization: A Joint Strategy to Transform Transportation*, 2022.

[2] National Academies of Sciences, Engineering, and Medicine, *Decarbonizing Transport for a Sustainable Future: Mitigating Impacts of the Changing Climate*. The National Academies Press, Washington, DC, 2018, https://doi.org/10.17226/25243.

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Mode shift has been viewed as a big contribution to environmental sustainability and mitigating the impacts of climate change. Mode shift commonly denotes a transition or alteration in transportation modes, a concept frequently employed in urban and transportation planning to promote and assess individuals' choices of low-carbon and efficient transportation alternatives. The mode shift has been extended to include electric vehicles, micromobility modes (e.g., e-bikes and e-scooters), and Mobility-as-a-Service (MaaS) mode.

The U.S. DOT RDT Strategic Plan points out that leveraging digitalization, artificial intelligence (AI), and other integrated system-of-systems (iSOS) technologies has been recognized as a way to achieve the decarbonize goal. This is twinned by the European policy on the Green Deal from March 2022 titled "Towards a Green, Digital and Resilient Economy: Our European Growth Model,"[3] and more detail for several sectors, including mobility, in June 2022, titled "Towards a Green & Digital Future—Key Requirements for Successful Twin Transitions in the European Union."[4]

Leveraging data-driven insights is essential for creating effective policies, encouraging sustainable practices, and driving innovations to achieve meaningful transportation decarbonization and address climate change. Digitalization is an invaluable tool for understanding, monitoring, and mitigating the environmental impact of transportation. Siemens's research on Infrastructure Transition Monitor (2023) advocated that reshaping the next generation of infrastructure "will be enabled by the world's best technologies, data-driven strategies, and hundreds of big ideas."[5]

Released in October 2023, President Biden's Executive Order on the Safe, Secure, and Trustworthy Development and Use of Artificial Intelligence emphasizes the critical importance of responsibly overseeing AI development and implementation. This directive has catalyzed a unified, government-wide endeavor to accomplish this objective efficiently. In the transportation sector, it is imperative to adopt a comprehensive approach to harnessing the evolving capabilities of AI for the betterment of our security, economy, and society. At the same time, there is a growing recognition that maximizing the potential benefits of AI while mitigating its inherent risks is crucial. This necessitates preventing irresponsible use that could exacerbate harms within the transportation domain.

When leveraging AI and digitalization, and iSOS technologies to decarbonize transportation, a set of underlying questions are raised to facilitate further directing and promoting transportation decarbonation solutions, as described in the following sections.

RELEVANT POLICIES AND PROGRAM

This section focusses on the policies and joint programming relevant to support potential leveraging effects of digital tools and AI technologies to decarbonize transport. It includes facilitating conditions for deployment and related research needs, as well as user acceptance. Key questions include:

- How can government programs, initiatives, and policies support the potential leveraging effects? How can they stimulate actual large-scale effects?
- What do governments need to develop and implement evidence-based policies for implementation and deployment of such systems' technologies?
- Which collaboration across local, regional, national, and international governments would be beneficial for harvesting the decarbonization potential of these technologies?
- How can government programs, initiatives, and policies help to safeguard against risks or misuse of these technologies, when widely implemented in our mobility systems?

[3] European Commission, "Towards a green, digital and resilient economy: our European Growth Model," March 2, 2022, https://ec.europa.eu/commission/presscorner/detail/en/ip_22_1467.

[4] European Commission, Joint Research Centre, Muench, S., Stoermer, E., Jensen, K., et al., *Towards a Green & Digital Future—Key Requirements for Successful Twin Transitions in the European Union*, Publications Office of the European Union, 2022, https://data.europa.eu/doi/10.2760/977331.

[5] *Siemens Infrastructure Transition Monitor 2023: The Great Divide on the Path to Net Zero*: *How Divisive Issues and Different Pathways Threaten the Speed, Scalability, and Efficiency of the Infrastructure Transition*, 2023, https://static.dc.siemens.com/infrastructure-transition-monitor/2023.

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- What differences and similarities between the European Union and the United States can be found in their (central) approaches? What can be learned from this?
- What policy barriers are expected in transferring best practices from one region to another?

CURRENT STRATEGIES, TECHNOLOGY, AND RELEVANT CASE STUDIES

Several current strategies are having an impact on the research and development and implementation of new solutions. Examples include the U.S. DOT RDT Strategic Plan, the EU policy regarding the Green Deal,[6] the AI Act,[7] and the Data Act.[8] The development rate of digital tools is much higher than the development rate of new regulations and strategies. U.S. DOT maintains several data resources that can be of use to the AI research community. They include Data.gov—Transportation, ITS DataHub[9] and Data for Automated Vehicle Integration.[10] Additionally, the Fixing America's Surface Transportation Act[11] required U.S. DOT to designate national alternative fueling corridors,[12] including Freight Electric Vehicle Corridors in alignment with the U.S. National Zero-Emission Freight Corridor Strategy.[13] Key questions related to these policies and programs are:

- How do policies boost, steer, or slow the development and implementation of new solutions?
- Which strategies are being used? What are the benefits or downsides?
- How are the Chips Act, the AI Act, and U.S. counterparts facilitating actual leveraging effects for decarbonization? What is missing or could be helpful to speed the developments?
- How well known are the leveraging effects of digitalization, AI, and other iSOS technologies for decarbonization? To what extent are the potential benefits quantifiable? What could be done to improve this?
- How can stakeholders be incentivized to adopt and participate in the use of AI-enabled digital products to enhance their effectiveness and uptake in the transport sector? How can governments play an active role in this shift?
- How can stakeholders from different sectors collaborate to address regulatory and institutional barriers to the optimization of digital interfaces between modes of transport?
- How can program resilience and climate adaptations with AI technologies be programed into "system of systems" scenario design (e.g., connected cyber–physical systems) in planning and engineering measures?
- What life-cycle analysis, social technology-based climate change adaptation and environmental impacts are considered in projects?
- What skills do governmental agencies need to reinforce to play a leading role in these discussions and developments?
- What is the role of research and evidence in current policy-making processes? Are changes needed in that role, and if so, which ones?
- What strategies are in place to create coherency among transport modes? What system framework or architecture reference is needed to holistically measure the contributions of mode shifts to climate change mitigation?
- How can we enhance AI-enabled, data-driven prediction of human behavior in heavy weather and in disasters? What data sources are considered for reducing inherent bias and inequity concerns?

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[6] European Commission, "Towards a green, digital and resilient economy: Our European Growth Model," March 2, 2022, https://ec.europa.eu/commission/presscorner/detail/en/ip_22_1467.

[7] European Commission, "AI Act," https://digital-strategy.ec.europa.eu/en/policies/regulatory-framework-ai.

[8] European Commission, "Data Act," https://digital-strategy.ec.europa.eu/en/policies/data-act.

[9] U.S. Department of Transportation, ITS DataHub, https://www.its.dot.gov/data.

[10] U.S. Department of Transportation, "Data for Automated Vehicle Integration (DAVI)," https://www.transportation.gov/av/data.

[11] Public Law 114-94, December 4, 2015.

[12] Title 23, United States Code, Section 151.

[13] Federal Highway Administration, Freight Electric Vehicle Corridors, https://www.fhwa.dot.gov/environment/alternative_fuel_corridors/freight_ev_corridors.

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The utilization scenarios can be associated with the advancement of the Software Defined Vehicle, or the establishment of a platform for MaaS, alongside AI-enabled data analytics, and digital twins to comprehensively evaluate the impacts of climate change on transportation, whether directly or indirectly, by integrating land use, community and transportation planning, and system management and operations. Life-cycle and social technology-based analysis should be considered in the scenario assessment.

Conversely, tools are crucial for facilitating the utilization of AI technologies to fortify adaptive and resilient policies for transportation and land use in the face of climate change events. They also play a pivotal role in enhancing the identification and monitoring of transportation vulnerability and resilience among socially vulnerable populations, among other functions.

SOCIAL, ECONOMIC, AND ENVIRONMENTAL CONSIDERATIONS

For the EU and U.S. partners to fully leverage the potential benefits of digitalization, AI, and iSOS technologies to decarbonize transport, it will be essential to have a clear understanding of the social, economic, and environmental aspects related to this, and how to address these. An understanding of emerging trends and behavior are to be established. Key questions include:

- Which societal trends can significantly impact the pace and success of these technologies for decarbonization (e.g., aging population, territorial conflicts, pandemics, lack of skills)?
- How can we create user embracement of such technologies to harvest the decarbonization benefits in daily use or at scale?
- How can trust be established in such technologies, and who should act in creating this?
- How can we ensure inclusivity and affordability with the new tools and technologies?
- What other novel aspects, in practice or research, are to be considered?

NEW AND EMERGING TECHNOLOGIES OR OPPORTUNITIES

Primarily, the Fourth Industrial Revolution is distinguished by the fusion of technologies that dissolve the barriers between physical, digital, and biological domains, collectively referred to as cyber–physical systems (CPS). The emergence of CPS in transportation (CPS-T) promises to revolutionize how individuals interact with engineered systems, leveraging AI, digitalization, and iSOS technologies.

The potential of CPS-T lies in its ability to reshape transportation dynamics through advancements such as CAV-enabled cooperative driving automation, cooperative intelligent transportation systems (C-ITS), and decentralized intelligent sensing and information networking technologies. These innovations seamlessly integrate into physical transportation infrastructures via vehicle-to-everything communications, IoT, human–machine interface, and AI-enabled, data-driven analytics technologies.

Advancements in AI approaches, including Explainable AI, Large Language Models, Generative AI, and Edge AI are rapidly emerging and are finding their way also to the transport domain.

Consequently, there arises an urgent need for a comprehensive, evidence-based, and system-engineering-oriented approach to ensure the sustainable transition of such new and emerging technologies on a broader scale. Key questions include:

- What promising digital technologies can we see emerging, and what is needed to speed their development? How can EU-U.S. collaboration help?
- How can we make more structural use of the innovation potential and out-of-the-box thinking by young scientists and new start-ups and scale-ups?
- How can the various modes of transport collaborate in developing and deploying these new technological solutions, to enlarge the decarbonization effects?

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- How can we leverage digitalization, AI, and other integrated system-of-systems technologies in design, renovation, or revamping of transportation infrastructures to make them adaptable to implementing digital shift strategies?
- How can mode shift be incentivized and optimized through the implementation of digitalization, AI, and other integrated system-of-systems technologies in the transport sector?
- How can we use social-technological digitalization tools to get community engagement involved in the participatory design processes as part of systemic solutions for accessible and inclusive transportation infrastructure and services, particularly in marginalized communities?
- How can AI-based predictive modeling techniques (e.g., neural networks, decision trees, and support vector machines) be adapted to effectively and efficiently predict transportation-related outputs with negative climate impacts, such as traffic congestion, vehicle emissions, and energy consumption?
- How do we fortify the system against potential data security threats, preserving CPS-T integrity and ensuring the trustworthiness of the information it disseminates and safe operations?
- How can we holistically streamline policy, planning, and engineering approaches in an integral process to transform traditional auto-dependent transportation into the climate-friendly and resilient transportation systems for all the users, within underserved communities and beyond?

CHALLENGES AND BARRIERS

- How can barriers such as lack of user engagement, disharmonious business models, insufficient funding for sustainable projects, and resistance to adopting new technologies be overcome?
- How can a coherent approach toward cybersecurity be developed? How can we effectively gauge cyber–physical security concerns and accurately forecast vulnerabilities for all users amid climate change events by using AI-driven data analysis tools or methodologies?
- To what extent do we need international standards and harmonization, and for what benefits?
- What are the key challenges and opportunities associated with optimizing digital interfaces between different modes of transport (e.g., road, rail, waterways) to reduce traffic congestion?
- How can we ensure that the applications and benefits are valid across various demographic regions (including urban and rural)?

CONCLUSION

- What are the critical factors and design principles for developing user-friendly digital tools that cater to the diverse needs of different user groups, including elderly and marginalized populations, while ensuring privacy and data security?
- What are the key technological advancements and innovations driving the development of automated transportation solutions, and how can these be leveraged to promote mode shift away from personal vehicles?
- What are the factors influencing individuals' decisions to adopt automated transportation solutions, and how do these factors differ across different demographic groups and geographic regions?
- What are the challenges and opportunities associated with integrating automated transportation solutions with active transport modes such as walking and cycling, and how can these be addressed to encourage mode shift?
- Given the complexity of the system of systems technologies, what architecture reference framework is needed to guide the best practice of digitalization, AI, and C-ITS for transportation decarbonization at regional or local levels, following the principles for a comprehensive societal shift to decarbonized systems, that is, transformation, integration, and universality, as outlined in the Paris Agreement and the 17 Global Sustainable Goals established at the United Nations 21st Conference of the Parties?

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Appendix E

Briefing Paper on Exploratory Topic 4: Implementing Sustainable and Resilient Land Use and Transportation System Design

Tasman Crowe, *University College Dublin, Ireland*
Timothy Sexton, *City of Minneapolis, United States*

A shift to zero-emission vehicles is critical to prevent the worst potential outcomes of the climate crisis. However, we need to do more than simply substitute vehicles powered by low/zero-emission fuels for current fossil fuel–powered vehicles or we will fail to achieve climate goals in other economic sectors (e.g., housing, industry, agriculture) and perpetuate existing inequities in health, safety, and access to economic opportunities. This topic area is built around opportunities to rethink our built environment to reduce climate pollution AND promote efficient use of resources, minimize environmental impacts more broadly, and promote the social and equity benefits of climate-smart community design. Sustainable and resilient land use and transportation system design are built around the following topics:

1. Integrated land use and surface transportation system design to enable low-carbon mobility, including the movement of people (walking, cycling, public transport, passenger rail) and the movement of goods (trucking, rail, and maritime freight transport needs).
2. Sustainable urban mobility planning, such as carbon-neutral cities, 15-minute cities, and reallocation of space.
3. Region-specific challenges and opportunities to shift modes based on movement of people or goods, geography, weather, land use patterns, and other variables.
4. New mobility, land use, and logistics options that consider smart land use and transportation system design.
5. Climate-smart and resilient infrastructure connections to low-carbon mobility, such as urban heat islands, sustainable pavements, and stormwater management.
6. System approaches to transport decarbonization (e.g., effects of setting targets or goals, holistic policy packages, assessing impacts and user needs).

The following sections present key questions to consider for discussion during the symposium.

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RELEVANT POLICIES AND PROGRAMS

Sustainable transportation system design, including land use considerations, is directly influenced by government policies, programs, incentives, and investments that target decarbonization. However, land use and sustainable transportation systems may be even more influenced by government actions where transportation is not the primary consideration. This is especially true in the United States where the majority of transportation investment decisions are made at the state or county level but where nearly all land use decisions are made locally.

This disconnect between transportation investment and land use authority is one reason why state goals, policies, and incentives that target sustainable transportation may not be realized on the ground, especially in outer suburban or exurban communities focused on growth.

Sustainable Design

- How can sustainable design principles be integrated into land use and transportation planning?
- How can we integrate low-carbon goods transport vehicles and operations into land use planning?
  - E.g., how can government agencies partner with industry to develop Sustainable Urban Logistics Plans for refueling infrastructure, curb access for deliveries, timing and pricing considerations for urban deliveries, etc., to reduce congestion, noise, and other negative impacts?
- How should we design urban, sub/semi-urban, and urban communities for city concepts that support walking and cycling (e.g., 15-minute cities), while also taking account of housing and real-estate considerations?
- How can land use and transportation systems be designed to enhance resilience to climate change and natural disasters?
- How do we make the adoption of climate-smart infrastructure on urban streets economically feasible in transitioning to climate-neutral cities?
  - E.g., how can we maximize economic, ecologic, and safety co-benefits of green infrastructure?

Policies and Programs

- How can government policies, programs, and initiatives support compact growth in urban areas, suburbs, and rural towns?
  - E.g., how to provide public transport services for people in low-density rural and suburban areas?
- How do federal, state, and/or local transportation funding processes and requirements support or disincentivize climate-friendly land use?
- Where is the overlap between network management and public transport planning (e.g., ordinary versus emergency or disaster circumstances) and how can it be leveraged to promote climate resilience?

Public Engagement

- How are communities involved in land use and transportation planning decisions?
- How can involvement help stimulate acceptance and behavioral change?

New Mobility

- How do we increase safety for shared, micro-mobility, and other active transport modes and vehicle innovations (e.g., autonomous vehicles) in interactions with people walking, biking, and driving in order to enable shared and reduced car usage in cities and foster green mobility?
- How can public health benefits of active transportation modes be leveraged to strengthen policy and increase uptake?

Are there multidisciplinary approaches that can aid forecasting to improve the disaster management cycle (mitigation, preparedness, response and recovery, etc.) for transportation networks?

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CURRENT STRATEGIES, TECHNOLOGY, AND RELEVANT CASE STUDIES

There is a growing base of examples and case studies of strategies to promote sustainable transportation system design at the various levels of government in the United States and the European Union, some of which have lessons learned that can be applied more broadly. The following thoughts and questions are meant to support a broader discussion about those best practices to better understand which have the potential for more universal application.

- What are examples of planning strategies that focus on sustainable land use, compact development, and transportation alternatives to support economic growth while minimizing environmental impact?
- How can planning policy allow for the coexistence of residential, commercial, and industrial uses in the same area, reducing the need for extensive travel?
- What factors influence individuals' transportation choices and behaviors and how can we design interventions that encourage sustainable modes of transport?
- How can emerging technologies such as advanced data analytics, artificial intelligence, and the Internet of Things help with optimizing transportation systems and enhancing resilience?
- How do we encourage sustainable transport modes between towns in close proximity or clusters that may provide different services (schools, general public, shops, etc.) and therefore currently generate significant numbers of car journeys?
- What could be the impact of reduced "'car storage'" requirements (when autonomous vehicles are dominant) on land use in town centers? Would this free up space for more housing, commercial activity, and green spaces?
- How can we manage limited urban space more dynamically (e.g., adaptive curbside management using real-time data)?
- What levers can be used to regulate access to space appropriately and effectively (e.g., for parking)?
- What are the opportunities for and costs of these strategies and technologies?
- What do we need to consider for adopting these strategies or technologies faster?
- What additional research is needed?

SOCIAL, ECONOMIC, AND ENVIRONMENTAL CONSIDERATIONS

For the clean energy transition to be successful and sustainable, governments, nonprofits, and private-sector actors can prioritize actions with social, economic, and environmental co-benefits. For example, if we replace all internal combustion engines with electric motors, people walking, biking, and driving would still be killed in car crashes and Black, Indigenous, and People of Color would still be killed disproportionately to White people in the United States. Furthermore, people with lower incomes would still have the financial burden of car ownership that accounts for more than 30% of total income in the United States. In comparison, communities are generally denser in the European Union and have more complete transit networks that reduce the need for car ownership and driving to access critical services such as work and healthcare.

The following intends to inspire discussion about the specific consideration described above and encourage sharing of systems and decision-making frameworks that support transportation decarbonization and promote equity, social benefits, and economic vitality.

- How can design processes be structured to ensure social equity and inclusivity in urban and rural development to accommodate diverse communities?
- What methods should be used for involving communities and stakeholders in the decision-making processes related to land use and transportation planning?
- How can the true social and environmental costs of car dominance be made evident to communities to support a cultural and behavioral shift?
- How can we better understand perceived and real risks to a modal shift; what can be learnt from case studies where segregated sustainable transport infrastructure has been successful in precipitating a modal shift in rural areas?

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- What strategies could support the transition to sustainable modes and/or autonomous vehicles, and how can we bring communities along with the changes? Where has this been achieved and how? What is the role of collaborative information and community technology tools in this?
- How do we ensure seamless connectivity for optimized and decarbonized transport while accounting for the unquantifiable social qualities of streets (sense of place and belonging, social interaction, vitality, etc.)?
- How can city planners design climate-proof urban streets (e.g., through wider inclusion of green infrastructure) while considering the pressure on urban land development and, at the same time, not losing street design qualities that contribute to street walkability, such as human scale, street proportions, and degree of enclosure?
- What actors (e.g., infrastructure owners, service users) are involved in decision making and land use planning? What objectives do the actors have and do they conflict? Can any objectives be seen as constraints and what are the limitations (e.g., network capacity in terms of flow that can be carried)?
- What aspects of network interdependence need to be considered? For example, in terms of electric vehicles, is there overlap or separation between the peak/off-peak hours of the power grid and transport network/traffic flows? Depending on the correlation, what strategies could help overcome related barriers?

NEW AND EMERGING TECHNOLOGIES OR OPPORTUNITIES

- What are the benefits and challenges of integrating green spaces (parks, urban forests) and blue infrastructure (water bodies, wetlands) into urban planning for enhanced sustainability and resilience?
- Is the New European Bauhaus (values and principles) an appropriate and effective framework for supporting the implementation of sustainable and resilient land use and transportation system design?
- What are the implications of co-working spaces (CWSs) on commuting habits and transportation system design? How does the location of a CWS (e.g., in a town center or in a peripheral business park site) relate to sustainable and resilient land use and transportation system design?
- How can we promote collaborative research efforts across disciplines—such as urban planning, engineering, environmental science, and sociology—to address the multifaceted nature of sustainable urban development?

CHALLENGES AND BARRIERS

The following examples outline different barriers in land use and transportation design and potential solutions to overcome these obstacles. Despite political, land use, and other differences, there are common threads and shared lessons between the United States and the European Union.

- Barrier: Lack of public awareness and involvement.
  - Solution: Implement robust public engagement strategies to involve communities in decision-making processes. Educate the public about the benefits of sustainable and resilient practices, addressing concerns and fostering support.
- Barrier: Insufficient funding for sustainable projects.
  - Solution: Explore innovative financing models, such as public–private partnerships, green bonds, and value capture mechanisms. Advocate for dedicated funding sources and demonstrate the long-term economic benefits of sustainable and resilient infrastructure.
- Barrier: Resistance to adopting new technologies.
  - Solution: Promote the integration of smart technologies and data analytics to optimize transportation systems. Offer training and incentives to encourage the adoption of innovative solutions among planners, engineers, and policymakers.
- Barrier: Outdated or restrictive zoning regulations.
  - Solution: Update zoning codes to accommodate mixed-use developments, higher density, and diverse housing options. Encourage flexible zoning that supports sustainable practices while meeting the needs of growing populations.

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- Barrier: Lack of consideration for climate change impacts.
  - Solution: Integrate climate resilience considerations into planning processes. Conduct vulnerability assessments and develop adaptive strategies to address the potential impacts of climate change on transportation infrastructure.
- Barrier: Reluctance to adopt unproven strategies.
  - Solution: Implement small-scale demonstration projects and pilots to showcase the benefits and feasibility of sustainable and resilient practices. Use these projects as evidence to build support and confidence among stakeholders.
- Barrier: Short-term focus and lack of flexibility.
  - Solution: Adopt long-term planning perspectives that consider future trends and uncertainties. Design systems with the flexibility to adapt to changing conditions and emerging challenges.

CONCLUSION

The goal of this briefing paper was to inspire thoughts and discussion about how transportation professionals can and should think beyond technology to decarbonize our transportation systems. This includes solutions using existing technology and ways to use new transportation decarbonization technologies that will be introduced in the future. In some ways, there are vast differences between the United States and the European Union in terms of land use, governance, economics, etc. In other ways, there will be shared strategies, thought processes, creative solutions, and decision-making frameworks that can be successful in both places, sometimes with modifications to address these differences. When thinking through these strategies, big picture questions that should be considered include:

- What does the decarbonization of transport look like in urban and rural contexts?
- How will it affect land use and planning, particularly in rural towns and villages?
- How can the transition be made irresistible for communities?

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Appendix F

Briefing Paper 5: The United States and the European Union: Relevant Policies, Programming, and Collaboration

Alasdair Cain, *U.S. Department of Transportation, United States*
Maria Carbone, *European Commission, Belgium*
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CURRENT U.S. TRANSPORTATION DECARBONIZATION POLICIES AND PROGRAMS

Regulation and Technology Deployment

Recent historic United States (U.S.) regulatory actions and federal investments are driving greenhouse gas (GHG) emission reductions in the United States, where the transportation sector is roughly one-third of domestic GHG emissions. Most prominently, the 2022 Inflation Reduction Act (IRA) is the most significant climate legislation in U.S. history, with substantial federal investments in clean energy and transportation deployment, as well tax incentives and regulatory action to reduce GHG emissions, mitigate other environmental pollution, and advance environmental justice. Among other program and policy investments, the law invested $7.5 billion in Alternative Fuel Corridors and established the National Electric Vehicle Infrastructure Program to work with states on standards and charging infrastructure buildout nation-wide. The 2021 Infrastructure Investment and Jobs Act (IIJA) was a generational investment in the nation's infrastructure and the 2022 CHIPS and Science Act is building domestic manufacturing capability for clean technology production. Furthermore, the Justice40 Initiative, launched by President Joseph R. Biden, and bolstered with resources from the IRA and the IIJA, is working to ensure that at least 40% of the benefits of the nation's climate and clean energy investments are going toward disadvantaged communities. Together, these three laws are shifting the U.S. domestic GHG emissions trajectory toward meeting our national and international climate goals, through unprecedented investments and actions spanning research and deployment of clean fuels including sustainable aviation fuels and hydrogen, battery technologies, pollution mitigation and environmental justice, and climate resilience.

Several federal and state-level policies and programs are making substantial progress. In March 2024, the U.S. Environmental Protection Agency (EPA) issued a final rule for GHG emission standards[1] for light- and medium-

[1] U.S. Environmental Protection Agency, "Regulations for Greenhouse Gas Emissions from Passenger Cars and Trucks," https://www.epa.gov/regulations-emissions-vehicles-and-engines/regulations-greenhouse-gas-emissions-passenger-cars-and (accessed May 2024).

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duty vehicles, leveraging clean car technologies to lower GHG emissions for future car model years. At the U.S. Department of Transportation (U.S. DOT), the National Highway Traffic Safety Administration issues Corporate Average Fuel Economy Standards and the Joint Office for Energy and Transportation works to deploy a network of electric vehicle chargers, zero-emission fueling infrastructure, and zero-emission transit and school buses. The Federal Transit Administration's Low or No Emission Grant Program and Grants for Buses and Bus Facilities program[2] have deployed $3.3 billion including nearly 1,800 zero-emission transit buses, and the Federal Railroad Administration has invested $16.4 billion under the Federal-State Partnership for Intercity Passenger Rail Grant Program[3] to encourage mode shift to lower-carbon rail trips. Several U.S. states also play a leading role in driving regulatory standards, incentives, and other programs to accelerate decarbonization of the transportation sector.

Research and Planning

In recent national commitments, the United States has established a goal of net-zero GHG emissions by no later than 2050[4] with an interim, near-term milestone of a 50–52% reduction from 2005 levels in economy-wide net GHGs by 2030. U.S. national climate goals, and the need for research and technology, is laid out in several key documents. The Long Term Strategy,[5] released in 2021, lays out the vision for a net-zero nation by 2050, including near complete decarbonization of the transportation sector, noting that

> Federally-supported research, development, demonstration, and deployment can be the prime mover to carry new carbon-free technologies and processes from the lab to U.S. factories to the market.… R&D today will lay the technology foundation necessary to maximize economic benefits from the post-2030 transformation to net-zero.

The U.S. National Blueprint for Transportation Decarbonization,[6] released in 2023 by U.S. DOT, the U.S. Department of Energy (DOE), the U.S. Department of Housing and Urban Development, and EPA, provides a comprehensive, system-level perspective for decarbonization of the entire transportation system across all passenger and freight travel modes and fuels. Implementing immediate strategies that achieve meaningful emission reductions this decade is essential to reaching our nation's 2030 emissions reduction goals in line with the president's commitment and the U.S. Nationally Determined Contribution under the Paris Agreement. Through an interagency Memorandum of Understanding, the federal government agencies that produced the blueprint are now developing detailed action plans for implementation of the blueprint and the strategies, partnerships, and levels of government needed to achieve these goals.

Additionally, several programs across the government make important contributions to decarbonization planning and research activities. The U.S. Global Change Research Program,[7] comprising 14 federal departments and agencies, invests in coordination of climate-related research and climate services activities across the federal government and produces landmark reports including the National Climate Assessments and National Nature Assessment. U.S. DOE has substantial research investments in fuels, carbon management, vehicle and battery technology, as well as energy-efficient mobility systems, and the newly launched U.S. DOT Climate Change Research

[2] U.S. Federal Transit Administration, "FY23 FTA Bus and Low- and No-Emission Grant Awards," https://www.transit.dot.gov/funding/grants/fy23-fta-bus-and-low-and-no-emission-grant-awards (accessed May 2024).

[3] U.S. Department of Transportation, "President Biden Advances Vision for World Class Passenger Rail with $16 Billion Investment in America's Busiest Corridor," November 2023, https://railroads.dot.gov/sites/fra.dot.gov/files/2023-11/FRA%2011-23.pdf.

[4] U.S. Departments of Energy, Transportation, Housing and Urban Development, and the U.S. Environmental Protection Agency, "The U.S. National Blueprint for Transportation Decarbonization: A Joint Strategy to Transform Transportation," January 2023, https://www.energy.gov/sites/default/files/2023-01/the-us-national-blueprint-for-transportation-decarbonization.pdf.

[5] U.S. Department of State and Executive Office of the President, "The Long-Term Strategy of the United States: Pathways to Net-Zero Greenhouse Gas Emissions by 2025," November 2021, https://www.whitehouse.gov/wp-content/uploads/2021/10/us-long-term-strategy.pdf.

[6] U.S. Departments of Energy, Transportation, Housing and Urban Development, and the U.S. Environmental Protection Agency, "The U.S. National Blueprint for Transportation Decarbonization: A Joint Strategy to Transform Transportation," January 2023, https://www.energy.gov/sites/default/files/2023-01/the-us-national-blueprint-for-transportation-decarbonization.pdf.

[7] U.S. Global Change Research Program, "U.S. Global Change Research Program Releases Fifth National Climate Assessment," https://globalchange.gov (accessed May 2024).

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& Technology Program[8] is working to bridge research and decision making on decarbonization and resilience efforts across the U.S. government. U.S. DOT's University Transportation Centers program[9] supports research partnerships with university consortiums, including centers focused on climate and environmental preservation, and other U.S. DOT research programs support sustainable aviation fuel, maritime decarbonization strategies, and other key transportation decarbonization research areas.

CURRENT EU TRANSPORTATION DECARBONIZATION POLICIES AND PROGRAMS

Regulation and Technology Deployment

The European Green Deal, approved in 2020, is a set of policy initiatives by the European Commission with the overarching aim of making the European Union (EU) climate neutral in 2050. The plan is to review each existing law on its climate merits and introduce new legislation on the circular economy, building renovation, biodiversity, farming, and innovation.

The president of the European Commission, Ursula von der Leyen, stated that the European Green Deal would be Europe's "man on the moon moment." On December 13, 2019, the European Council decided to press ahead with the plan, with an opt-out for Poland. On January 15, 2020, the European Parliament voted to support the deal as well, with requests for higher ambition. A year later, the European Climate Law was passed, which legislated that GHG emissions should be 55% lower in 2030 compared to 1990. To deliver on these targets, the Commission proposed "Fit for 55" legislative packages in July and December 2021.

The European Commission's climate change strategy, launched in 2020, is focused on a promise to make Europe a net-zero emitter of GHGs by 2050 and to demonstrate that economies will develop without increasing resource usage. However, the Green Deal has measures to ensure that nations that are already reliant on fossil fuels are not left behind in the transition to renewable energy. The green transition is a top priority for Europe. The EU Member States want to reduce GHG emissions by 55% by 2030 from 1990 levels and become climate neutral by 2050.

Following Russia's military aggression against Ukraine, the European Commission published the REPowerEU Communication[10] in May 2022, which emphasizes the need to ramp up rapidly and efficiently the clean energy transition. In line with the REPowerEU priorities, this work program contributes to the move toward the elimination of Europe's dependency on Russian fossil fuel imports by bolstering the diversification of Europe's gas supply, the electrification of the energy system, and the transformation of (energy-intensive) industries.

To support a just and inclusive transition within the Green Deal, the European Commission has established the Just Transition Mechanism[11] that supports those regions and Member States that rely heavily on very carbon-intensive activities. It also supports the citizens most vulnerable to the transition, providing access to reskilling programs and employment opportunities in new economic sectors. Also, the Social Climate Fund[12] provides Member States with funding so that the most affected vulnerable groups, such as households in energy or transport poverty, are directly supported and not left behind during the green transition.

From a global perspective, a fair green transition also means addressing the disproportionate burden of climate change borne by countries in the Global South as well as Indigenous communities worldwide vulnerable to climate change. While historically contributing less to carbon emissions, these nations and peoples often face the

[8] U.S. Department of Transportation, "DOT Climate Change Center," https://www.transportation.gov/priorities/climate-and-sustainability/dot-climate-change-center (accessed May 2024).

[9] U.S. Department of Transportation, "University Transportation Centers," https://www.transportation.gov/content/university-transportation-centers (accessed May 2024).

[10] European Commission, "REPowerEU: Joint European Action for More Affordable, Secure and Sustainable Energy," March 2022, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2022%3A108%3AFIN.

[11] European Commission, "The Just Transition Mechanism: Making Sure No One Is Left Behind," https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/finance-and-green-deal/just-transition-mechanism_en (accessed May 2024).

[12] European Commission, "Social Climate Fund," https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets/social-climate-fund_en (accessed May 2024).

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brunt of environmental degradation and extreme weather events. A just green transition entails not only supporting developing countries and climate vulnerable communities but also addressing the systemic inequalities that perpetuate this vulnerability.

Research and Planning

International cooperation is a driver of world-class research and innovation (R&I). The European Union's strategy for international cooperation is set out in the Global Approach to Research and Innovation Communication.[13] Horizon Europe, the European Union's Framework Programme for Research and Innovation, is one of the main tools to implement this strategy.

Horizon Europe offers opportunities to researchers and innovators from all over the world, albeit with the possibility of restrictions where necessary. Horizon Europe (HE), the €95.5 billion R&I framework program is the EU tool to support these challenges. Transport research is highly visible in HE, embedding all activities in the Cluster 5 "Climate, Energy and Mobility" with a total budget of €15 billion.

At least 35% of its funding will be dedicated to climate action, with partnerships as an important mechanism contributing to key areas, and the Green Deal Missions[14] will inspire and catalyze ambitious R&I. Almost 50% of EU funding in the transport part of HE Cluster 5 is implemented via public–private partnerships, in the form of either institutionalized partnerships (i.e., Clean Aviation, SESAR3, Europe's Rail Joint Undertakings in the areas of aviation and rail) or co-programmed partnerships (i.e., Towards Zero-Emission Road Transport [2Zero], Connected, Cooperative, and Automated Mobility [CCAM], and Zero-emission waterborne transport [ZEWT]) in the areas of automotive and waterborne. Additional partnerships such as the BATT4EU (in the field of batteries, co-programmed partnership) and Clean Hydrogen Joint Undertaking (institutionalized partnership) and in particular one Mission, the Climate-Neutral and Smart Cities Mission, are also relevant for transport R&I within the HE Cluster 5.

MULTILATERAL AND BILATERAL COOPERATION PROGRAMS THAT INCLUDE THE EUROPEAN COMMISSION AND THE UNITED STATES IN THE FIELD OF RESEARCH AND INNOVATION (R&I) FOR TRANSPORTATION DECARBONIZATION

There are different ways of cooperation between the European Union and the United States in the field of R&I, at the project-to-project level and at the program-to-program level. In addition, there is ongoing policy cooperation with international institutions such as the International Civil Aviation Organization for aviation and the International Maritime Organization for the maritime sector.

At the program-to-program level, cooperation can be done either at the multilateral level or the bilateral level. It is hope that reinforced cooperation and/or development of this type of cooperation can be achieved through this symposium on transportation decarbonization. Here are some of the programs or groups where this cooperation has started and can be enhanced (which is not exhaustive):

1. Bilateral collaboration between the European Commission and the U.S. Federal Aviation Administration. Both sides acknowledged the importance of continued investments in R&I to reach climate neutrality in aviation. Coordination will continue on sustainable aviation fuels and addressing the non-CO_2 climate impacts of aviation.
2. Multilateral collaboration in the framework of the International Energy Agency (IEA) Co-operation in the Research, Development and Deployment of Hybrid and Electric Vehicle Technology Collaboration Programme (HEV TCP). In 2024, the European Commission represented by the Directorate-General for

[13] European Commission, "Global Approach to Research and Innovation: Europe's Strategy for International Cooperation in a Changing World," May 2021, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2021%3A252%3AFIN.

[14] European Commission, "The European Green Deal," https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en (accessed May 2024).

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Research and Innovation (DG RTD) joined the HEV TCP (where U.S. DOE is also a member), which enables member parties to discuss their respective needs, share key information, and learn from an ever-growing pool of experience from the development and deployment of hybrid and electric vehicles. A topic of strong common interest could easily turn into a task co-led by the European Union and the United States with funded projects from both sides contributing to it. For transport modes other than road, the TCP-AMF on advanced motor fuels may be relevant too.[15]

3. Multilateral collaboration through Mission Innovation. Mission Innovation is a global initiative to accelerate public and private clean energy innovation to address climate change, make clean energy affordable to consumers, and create green jobs and commercial opportunities. It was launched at the United Nations Climate Change Conference in November 2015 and currently comprises 24 countries (including the United States) and the European Commission. Two main areas for the transport sector are Mission Innovation in Waterborne and Mission Innovation in Road Transport. The United States and the European Union already cooperate though the Zero-Emission Shipping Mission under the framework of Mission Innovation, with the United States being a co-lead and the European Union being a supportive member.
4. Multilateral collaboration in the framework of International Transport Forum at the Organisation for Economic Co-operation and Development (ITF/OECD) within Transport Research Committee (TRC) meetings and studies, funded by annual gross domestic product–based contributions from member countries including many in the European Union as well as the United States. ITF at OECD is an intergovernmental organization with 66 member countries. It acts as a think tank for transport policy and organizes the annual summit of transport ministers. ITF is the only global body that covers all transport modes. The European Commission (EC), through the DG RTD and the Directorate-General for Mobility and Transport (DG MOVE), attends the meetings of the TRC as an observer whereas U.S. DOT attends as a full partner or as a member of ITF. The main aim for attending the meetings is to encourage the implementation of EU priority policies from the perspective of transport R&I and to follow up on the action points that are on the agenda, especially as regards the European Green Deal. An important activity was providing financial support to the "Decarbonising Transport" project led by ITF, which aimed to help governments and decision makers to identify and implement policy measures for reducing transport carbon dioxide emissions and attain the Paris Agreement targets. The ITF 2024–2025 Programme of Work[16] includes new collaborative decarbonization research projects that are commencing in 2024 and will be completed in 2026. Good examples of a fruitful EC-ITF cooperation in the recent past include the Horizon 2020 research projects Decarbonising Transport in Europe and Transport Decarbonisation: Driving Implementation (DT Implement).

PROJECT-TO-PROJECT COOPERATION IN KEY R&I ACTIVITIES

For the project-to-project cooperation, main areas are to be discussed during the symposium. Funding to projects on both sides of the Atlantic, which are equally balanced in terms of research targets and budgets, can enhance the exchanges and information sharing but also build trust and momentum and more effectively address global transport targets. This type of cooperation in the field of transportation decarbonization could be of mutual benefit, for example, in the fields of road transport, aviation, maritime/ports, batteries, logistics, and urban mobility.

There are nevertheless, at this time, limitations on project-to-project cooperation (and how to overcome them); for example, misfit between programs' focus, timing, budget, and participation rules, and reactive instead of proactive instruments. In the past (Framework Programme 6, Framework Programme 7, and Horizon 2020), "twinning" of EU and U.S. projects was used in several sectors. While some twinned projects in the CCAM space achieved successful collaboration outcomes, the EU-U.S. twinning concept had limited overall impact. The area of technology testing and evaluation is one area that has high potential for project-to-project collaboration,

[15] Technology Collaboration Programme on Advanced Motor Fuels, https://www.iea-amf.org (accessed May 2024).

[16] International Transport Forum, "ITF's Transport Research Programme of Work for 2024–2025," January 2024, https://summit.itf-oecd.org/2024/wp-content/uploads/2024/02/itf_programme_of_work_itf_annual_consultation_30_january_2024_0.pdf.

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for example, using the same impact assessment framework to develop system solutions that are nationally and internationally harmonized, exchanging research data supporting the improvement of good practices and taking advantage of roadmap-based research agendas for the alignment of programs.

PROGRAMMING (WHAT)

Current Strategies and Models

- What are the environmental, economic, and social impacts of the current strategies for decarbonization transportation, and how do these impacts differ between the United States and the European Union?
- What are examples of successful research and collaborations? What about failed research or collaboration attempts? What aspects made them successful or unsuccessful, and where/how can we apply these lessons moving forward?

Short-Term Programming Actions

- What should the United States and the European Union be prioritizing now to set us on the best path toward a net-zero transportation sector? To what extent should U.S. and EU governments be prioritizing deployment versus research and technology investments in the short term?
- What research topics and themes are the most important areas to focus on moving forward?

Long-Term Programming Actions

- How do we bridge the different aspects of transportation decarbonization research (i.e., technologies, digitalization, land and transportation planning, social and environmental considerations) to create a research action plan?
- Are there gaps in research that should be prioritized for future investments and EU-U.S. cooperation? If so, what are those gaps?
- In what technical areas are there opportunities for additional collaboration and partnership between the European Commission and U.S. DOT leaders on decarbonization?
- Are there other research areas that are ripe for international collaboration?

Discussion Goals

- "What" are the R&I actions and themes to cooperate on in the field of transport decarbonization, identifying a list of collaboration areas and priorities in the different transport sectors (based on the briefing papers and discussions at the symposium)?
- What are the potential obstacles or barriers to achieve R&I actions (e.g., regulations, competition, or other framework conditions)?

POLICY (HOW)

Current Strategies and Models

- At the level of program-to-program cooperation, what types of partnerships—such as between public agencies, private companies, academic institutions, and nongovernmental organizations—do you consider to be the most effective, and why, in advancing transportation decarbonization efforts in the European Union and the United States?
- What models exist for successful international partnerships in technology development and deployment, and how might these be applied to transatlantic collaborations, at either bilateral or multilateral level?

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- What are the possible instruments and tools that exist or are to be developed at the U.S. and at the EU level to implement this R&I cooperation?

Short-Term Policy Actions

- How can strategic planning be best used to align priorities on a proactive and multiannual basis?
- What are the mechanisms, programs, entry points, etc., for facilitating research collaboration?
- What lessons learned or best practices can be shared between the European Union and the United States in terms of effective short-term strategies?
- What tools and strategies can we use to develop programming in these areas and more effective collaborative efforts between the European Commission and U.S. DOT?

Long-Term Policy Actions

- In what R&I policy areas are there opportunities for additional collaboration and partnership between the European Commission and U.S. DOT on decarbonization?
- Where are the gaps in R&I policy investments toward transportation decarbonization that should be prioritized for future investments and EU-U.S. cooperation?
- What mechanisms can be put into place to ensure that the U.S. DOT and the European Commission not only share research findings, but also actively learn from one another's policy successes and setbacks in transportation decarbonization?

Opportunities, Challenges, and Barriers

- What barriers are in place that hinder collaborative action, and what options or opportunities are there to move past these barriers? Identify areas of opportunities, as well as bottlenecks, for collaboration between the European Commission and U.S. DOT.

Discussion Goals

- How can we organize and develop an action plan with concrete steps and strategic rationale for moving forward in transport research cooperation.
- Several program-to-program cooperation frameworks already exist between the European Union and the United States. How can we build on them (e.g., Mission Innovation, IEA HEV-TCP)?

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Appendix G

Program

Global Pathways to Net-Zero: Behavioral, Social, and Technological Research and Innovation (R&I) Strategies for Transportation Decarbonization

Seventh EU-U.S. Transportation Research Symposium

Organized by the
European Commission
U.S. Department of Transportation
Transportation Research Board
Coordination and Support Action SYMPEUS

June 11–12, 2024
National Academy of Sciences Building
Washington, DC

TUESDAY, JUNE 11, 2024

7:30 a.m. Registration and Breakfast

8:00 a.m. **Welcome and Opening Remarks**
Dr. Firas Ibrahim, Director of the Office of Research, Development, and Technology, U.S. Department of Transportation
Dr. Gretchen Goldman, Climate Change Research and Technology Director, U.S. Department of Transportation
Torsten Klimke, Head of Innovation and Research, European Commission's Directorate-General for Mobility and Transport
Jane Amilhat, Head of Clean Transport Transitions, European Commission's Directorate-General for Research and Innovation

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8:25 a.m. **Keynote Speakers—Importance of and Opportunities for Transportation Decarbonization**
Dr. Robert Hampshire, Deputy Assistant Secretary for Research & Technology, U.S. Department of Transportation
Ann Shikany, Deputy Assistant Secretary for Transportation Policy, U.S. Department of Transportation

8:35 a.m. **Introductions, Purpose, and Scope for the Seventh EU-U.S. Symposium: Global Pathways to Net-Zero**
Dr. Chris Hendrickson, Professor Emeritus, Civil and Environmental Engineering, Carnegie Mellon University, *Co-Chair*
Dr. Gereon Meyer, Head of the Department European and International Business Development, VDI/VDE Innovation + Technik GmbH, *Co-Chair*

8:55 a.m. **Presentation of White Paper: Decarbonization in the Transportation System: A Joint Perspective from the United States and the European Union**
Dr. Kelly Fleming, Associate Director of Clean Energy, Federation of American Scientists
Dr. Gereon Meyer, Head of the Department, European and International Business Development, VDI/VDE Innovation + Technik GmbH

9:20 a.m. **Review of the Four Exploratory Topics**

Exploratory Topic 1: Accelerating the Transition to Electrification and Alternative Fuels
Dr. Chris Hendrickson, Professor Emeritus, Civil and Environmental Engineering, Carnegie Mellon University
Dr. Gereon Meyer, Head of the Department, European and International Business Development, VDI/VDE Innovation + Technik GmbH

Exploratory Topic 2: Ensuring a Just Transition to Net-Zero Transport
Dr. Patricia Romero-Lankao, Professor and Canada Excellence Research Chair in Sustainability Transitions, Department of Sociology, University of Toronto
Karen Vancluysen, Secretary General, POLIS

Exploratory Topic 3: Leveraging Digitalization, Artificial Intelligence, and Other Integrated System-of-Systems Technologies to Decarbonize Transport
Margriet van Schijndel-de Nooij, Program Director of Smart Mobility, Eindhoven University of Technology, The Netherlands
Dr. Heng Wei, Professor, Civil and Architectural Engineering and Construction Management, University of Cincinnati

Exploratory Topic 4: Implementing Sustainable and Resilient Land Use and Transportation System Design
Dr. Tasman Crowe, Professor and Vice-President for Sustainability, University College Dublin, Ireland
Timothy Sexton, Director of Public Works, City of Minneapolis

9:50 a.m. Morning Refreshment Break

10:10 a.m. **Exploratory Topics: Group Discussions on Research and Innovation**

1:00 p.m. Networking Lunch

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2:00 p.m. **Exploratory Topics: Group Discussions on Outcomes and Suggestions**
Each topic group reconvenes for 1 hour to synthesize summary on outcomes, suggestions, and takeaways to be discussed with the larger group during the open discussion.

3:00 p.m. **Open Discussion on Exploratory Topics—Topics 1 and 2**
Everyone convenes in the same room and allows for open discussion of each topic. Each topic gets 30 minutes—5-minute outcomes summary by notetakers from the working group session, followed by 25 minutes of open discussion for additional comments on each topic.

4:00 p.m. Afternoon Refreshment Break

4:15 p.m. **Open Discussion on Exploratory Topics—Topics 3 and 4**
Everyone convenes in the same room and allows for open discussion of each topic. Each topic gets 30 minutes—5-minute outcomes summary by notetakers from the working group session, followed by 25 minutes of open discussion for additional comments on each topic.

5:15 p.m. **Wrap-Up for Day 1 and Adjourn**
Group photo with Einstein statue

5:30 p.m. **Networking Reception**
Light snacks and drinks available

(Notetakers and member(s) of the planning committee review takeaways, consolidate information overnight, and prepare key points for report out the next morning.)

WEDNESDAY, JUNE 12, 2024

7:30 a.m. Breakfast

8:00 a.m. **Review of Day 2 Agenda and Goals**
Dr. Chris Hendrickson, Professor Emeritus, Civil and Environmental Engineering, Carnegie Mellon University, *Co-Chair*
Dr. Gereon Meyer, Head of the Department, European and International Business Development, VDI/VDE Innovation + Technik GmbH, *Co-Chair*

8:15 a.m. **Report Out on the Exploratory Topic Discussions**
Facilitated by members of the planning committee
Four testimonies given by one volunteer/notetaker for each exploratory topic

8:45 a.m. **Setting the Scene: Relevant U.S. and EU Policies, Programming, and Collaboration**
Dr. Gretchen Goldman, Climate Change Research and Technology Director, U.S. Department of Transportation
Torsten Klimke, Head of Innovation and Research, European Commission's Directorate-General for Mobility and Transport
Jane Amilhat, Head of Clean Transport Transitions, European Commission's Directorate-General for Research and Innovation

9:45 a.m. **Expert Feedback and Priorities**
Review of participants' feedback and priorities from Slido poll

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10:00 a.m. Morning Refreshment Break

10:30 a.m. **R&I Collaboration Pathways—Programming Level: Opportunities, Challenges, and Themes**
Moderated by Jane Amilhat and Dr. Gretchen Goldman

12:00 p.m. Networking Lunch
(Notetakers consolidate information and prepare key points for report out.)

1:00 p.m. **Report Out on R&I Collaboration Pathways—Programming Level: Opportunities, Challenges, and Themes**
Facilitated by notetakers

1:10 p.m. **R&I Collaboration Pathways—Policy Level: Strategies, Instruments, and Tools**
Moderated by Torsten Klimke and Ann Shikany

2:40 p.m. Afternoon Refreshment Break
(Notetakers consolidate information and prepare key points for report out and closing debate.)

3:10 p.m. **Report Out on R&I Collaboration Pathways—Policy Level: Strategies, Instruments, and Tools**
Facilitated by notetakers

3:20 p.m. **Closing Debate: Last-Chance Assertions for Both Days**
Facilitated by Dr. Chris Hendrickson and Dr. Gereon Meyer

4:00 p.m. **Next Steps and Closing Remarks by Lead Delegates**
Jane Amilhat, Head of Clean Transport Transitions, European Commission's Directorate-General for Research and Innovation
Torsten Klimke, Head of Innovation and Research, European Commission's Directorate-General for Mobility and Transport
Victoria Sheehan, Executive Director, Transportation Research Board, National Academies of Sciences, Engineering, and Medicine
Dr. Firas Ibrahim, Director of the Office of Research, Development and Technology, U.S. Department of Transportation

4:30 p.m. Adjourn

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Appendix H

Symposium Attendees

INVITED EXPERTS

Florian Allroggen
Massachusetts Institute of Technology
United States

Maria Attard
L-Università ta'Malta
Malta

Eric Ballot
Mines ParisTech
France

Maria Boile
University of Piraeus
Greece

Matthew Botill
California Air Resources Board
United States

Jean-Baptiste Burtscher
Valeo
France

Brian Caulfield
Trinity College Dublin
Ireland

Yao Cheng
University of Maryland, College Park
United States

Cristina Corchero
Institut de Recerca en Energia de Catalunya
Spain

Tasman Crowe
University College Dublin
Ireland

Pietro D'Arpa
Procter & Gamble
Italy

Sergio Fernandez
EMT Madrid
Spain

Kelly Fleming
Federation of American Scientists
United States

Shelley Francis
EVHybridNoire
United States

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Francoise Guaspare
Rep. Paris/Ile de France Brussels
France

Shima Hamidi
Johns Hopkins University
United States

Chris Hendrickson
Carnegie Mellon University
United States

Ben Holland
Rocky Mountain Institute
United States

Jari Kauppila
International Transport Forum
Finland

Oliver Lah
Wuppertal Institut für Klima, Umwelt, Energie
Germany

Gorazd Lampic
Elaphe Propulsion Technologies Ltd.
Slovenia

Kimberly Lucas
City of Pittsburgh's Department of Mobility & Infrastructure
United States

Michael Lunter
Dutch Ministry of Infrastructure and Water Management
The Netherlands

Nicholas "Nic" Lutsey
General Motors
United States

Nayantara Mehta
CMA CGM
United States

Gereon Meyer
VDI/VDE Innovation + Technik GmbH
Germany

Darwin Moosavi
California Department of Transportation
United States

Maria Morfoulaki
Centre for Research and Technology Hellas
Greece

Hayes Morrison
Massachusetts Department of Transportation
United States

Simon Mui
Natural Resources Defense Council
California

Suzanne Murtha
AECOM
United States

Nina Nesterova
Breda University of Applied Sciences
The Netherlands

Roberto Palacin
Newcastle University
United Kingdom

Craig E. Philip
Vanderbilt University
United States

Amanda Pietz
Oregon Department of Transportation
United States

Bàrbara Pons Giner
Barcelona Regional
Spain

Cristina Pronello
Politecnico di Torino
Italy

Sophie Punte
We Mean Business Coalition
The Netherlands

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Patricia "Paty" Romero-Lankao
University of Toronto
Canada

Mats Rosenquist
Volvo
Sweden

Timothy Sexton
City of Minneapolis
United States

Benjamin Sovacool
Boston University
United States

Daniel Sperling
University of California, Davis
United States

C. Anna Spurlock
Lawrence Berkeley National Laboratory
United States

Guang Tian
University of New Orleans
United States

Margriet van Schijndel-de Nooij
Universiteit Eindhoven
The Netherlands

Karen Vancluysen
POLIS Network
Belgium

Heng Wei
University of Cincinnati
United States

Joe Zietsman
Texas A&M
United States

SPEAKERS, MODERATORS, LIAISONS, AND STAFF

Caroline Almeras
European Conference of Transport Research Institutes
Belgium

Jane Amilhat
European Commission
Belgium

William Anderson
Transportation Research Board
United States

Brittany Bishop
Transportation Research Board
United States

Alasdair Cain
U.S. Department of Transportation
United States

Maria Carbone
European Commission
Belgium

Tyler Clevenger
U.S. Department of Transportation
United States

Gretchen Goldman
U.S. Department of Transportation
United States

Robert Hampshire
U.S. Department of Transportation
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K. John Holmes
Board on Energy and Environmental Systems
United States

Firas Ibrahim
U.S. Department of Transportation
United States

Torsten Klimke
European Commission
Belgium

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Katherine Kortum
Transportation Research Board
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Timothy Marflak
Transportation Research Board
United States

Thomas Menzies
Transportation Research Board
United States

Patrick Mercier-Handisyde
European Commission
Belgium

Dylan Rebstock
Transportation Research Board
Belgium

Liya Rechtman
U.S. Department of Transportation
United States

Victoria Sheehan
Transportation Research Board
United States

Ann Shikany
U.S. Department of Transportation
United States

Ingrid Skogsmo
Swedish National Road and Transport Research Institute
European Conference of Transport Research Institutes
Sweden

Katherine Turnbull
Texas A&M
United States

Elizabeth Zeitler
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