APPENDIX C

Life-Cycle Assessment Studies

Table C-1. Studies Analyzed in Chapter 6, Life-cycle Assessment of Vehicle Energy, Materials, and Technologies

Study Analyzed	Technologies/Materials Covered[a]	Life-cycle Boundaries[b]	Environmental Impacts Estimated[c]
Alonso, E., T.M. Lee, C. Bjelkengren, R. Roth, and R.E. Kirchain. 2012. Evaluating the Potential for Secondary Mass Savings in Vehicle Lightweighting. *Environmental Science & Technology*.	Mass decompounding; lightweighting	Material production	Mass savings (energy use in abstract terms)
ATDynamics. 2014a. *Aerodynamics 101*.	Aerodynamic devices	Vehicle use	Energy requirements
Bachman, L.J., A. Erb, and C.L. Bynum. 2005. *Effect of Single Wide Tires and Trailer Aerodynamics on Fuel Economy and* NO_X *Emissions of Class 8 Line-Haul Tractor-Trailers.* SAE International.	Tires	Vehicle use	Energy requirements (hydrocarbons); air emissions including carbon dioxide, carbon monoxide, and NO_X
Bandivadekar, A., K. Bodek, L. Cheah, C. Evans, T. Groode, J. Heywood, E. Kasseris, M. Kromer, and M. Weiss. 2008. *On the Road in 2035: Reducing Transportation's Petroleum Consumption and GHG Emissions.* Massachusetts Institute of Technology.	Lightweighting; vehicle design; engine downsizing; BEVs, fuel-cell vehicles; HSS; aluminum	Cradle to grave	Energy requirements; GHG emissions
Baratto, F. and U. M. Diwekar. 2005. Life Cycle Assessment of Fuel Cell-based APUs. *Journal of Power Sources*.	Fuel-cell APUs; SOFCs	Cradle to grave	Fuel use; GHG emissions; criteria pollutants
Barbir, F. 2006. PEM Fuel Cells. *Fuel Cell Technology: Reaching Towards Commercialization.* Springer London.	SOFCs; PEM fuel-cells	Not applicable	Not applicable

Table C-1. Studies Analyzed in Chapter 6, Life-cycle Assessment of Vehicle Energy, Materials, and Technologies

Study Analyzed	Technologies/Materials Covered[a]	Life-cycle Boundaries[b]	Environmental Impacts Estimated[c]
Baumers, M., C. Tuck, R. Wildman, L. Ashcroft, and R. Hague. 2011. *Energy Inputs to Additive Manufacturing: Does Capacity Utilization Matter?* Additive Manufacturing Research Group, Wolfson School of Mechanical and Manufacturing Engineering, Loughborough University.	Additive manufacturing; selective laser melting; direct metal laser sintering; electron beam melting; laser sintering; fused deposition modeling of polymers	Materials production	Energy requirements
Bertram, M., K. Buxmann, and P. Furrer. 2009. Analysis of Greenhouse Gas Emissions Related to Aluminum Transport Applications. *International Journal of Life Cycle Assessment*.	Aluminum; steel; cast iron	Cradle to grave	GHG emissions
Birat, J.P., L. Rocchia, V. Guerin, and M. Tuchman. 2003. *Ecodesign of the Automobile, Based on Steel Sustainability.* SAE International.	Aluminum; steel; recycling	Cradle to grave	CO_2 emissions
Boland, C., R. DeKleine, A. Moorthy, G. Keoleian, et al. 2014. *A Life Cycle Assessment of Natural Fiber Reinforced Composites in Automotive Applications*. SAE International.	Glass-fiber-reinforced polymer; cellulose-fiber-reinforced polymer; polymer composites; lightweighting	Cradle to grave	Fuel use; GHG emissions
Brodrick, C., Lipman, T. E., Farshchi, M., Lutsey, N. P., Dwyer, H. A., Sperling, D., Gouse III, S. W., Harris, D. B., and F. G. King. 2002. *Evaluation of Fuel Cell Auxiliary Power Units for Heavy-Duty Diesel Trucks.* Transportation Research Part D.	SOFCs; PEM fuel cells; APU	Vehicle use	GHG emissions, criteria pollutants

Table C-1. Studies Analyzed in Chapter 6, Life-cycle Assessment of Vehicle Energy, Materials, and Technologies

Study Analyzed	Technologies/Materials Covered[a]	Life-cycle Boundaries[b]	Environmental Impacts Estimated[c]
Cáceres, C.H. 2009. Transient Environmental Effects of Light Alloy Substitutions in Transport Vehicles. *Materials & Design*.	Magnesium; aluminum	Alloy production	Recycled materials
CEM (Council of Energy Ministers). 2009. *On the Road to a Fuel-Efficient Truck, 2009.*	Aerodynamic devices	Vehicle use	Energy requirements; GHG emissions
Cheah, L. 2010. *Cars on a Diet: The Material and Energy Impacts of Passenger Vehicle Weight Reduction in the U.S.* Massachusetts Institute of Technology.	Magnesium, aluminum; HSS; polymer composites	Cradle to grave	Energy requirements; GHG emissions
Cheah, L., and J. Heywood. 2011. Meeting U.S. passenger vehicle fuel economy standards in 2016 and Beyond. *Energy Policy*.	Lightweighting; HEVs; PHEVs; advanced diesel	Not applicable	None
Cheah, L., Heywood, J., and R. Kirchain. 2009. Aluminum Stock and Flows in U.S. Passenger Vehicles and Implications for Energy Use. *Journal of Industrial Ecology.*	Aluminum	Not applicable	Energy requirements
Chen, W.Q., and T.E. Graedel. 2012a. Anthropogenic Cycles of the Elements: A Critical Review. *Environmental Science & Technology*.	Aluminum; steel	Not applicable	None
Chen, W.Q., and T.E. Graedel. 2012b. Dynamic Analysis of Aluminum Stocks and Flows in the United States: 1900–2009. *Ecological Economics*.	Aluminum	Not applicable	None

Table C-1. Studies Analyzed in Chapter 6, Life-cycle Assessment of Vehicle Energy, Materials, and Technologies

Study Analyzed	Technologies/Materials Covered[a]	Life-cycle Boundaries[b]	Environmental Impacts Estimated[c]
Colett, J. 2013. *Impacts of Geographic Variation on Aluminum Lightweighted Plug-in Hybrid Electric Vehicle Greenhouse Gas Emissions.* University of Michigan: Ann Arbor, MI.	Lightweighting; aluminum; PHEV	Cradle to gate	Energy requirements; GHG emissions
Das, S. 2011. Life Cycle Assessment of Carbon Fiber-Reinforced Polymer Composites. *International Journal of Life Cycle Assessment*.	Steel; carbon-fiber-reinforced polymer	Cradle to grave	Energy requirements; GHG emissions
Das, S. 2014. Life Cycle Energy and Environmental Assessment of Aluminum-Intensive Vehicle Design. *SAE International Journal of Material Manufacturing*.	Lightweighting; aluminum; HSS; steel	Cradle to grave (including recycling)	Energy requirements; GHG emissions
Dubreuil, A., L. Bushi, S. Das, A. Tharumarajah, and G. Xianzheng. 2010. *A Comparative Life Cycle Assessment of Magnesium Front End Autoparts*. SAE International.	Magnesium; aluminum; steel	Cradle to grave	Energy requirements; GHG emissions; criteria pollutants
Ehrenberger, S. 2013. *Life Cycle Assessment of Magnesium Components in Vehicle Construction*. German Aerospace Centre e.V. Institute of Vehicle Concepts.	Magnesium	Cradle to grave	Energy requirements; GHG emissions; acidification; eutrophication; depletion of abiotic resources
EPA. 2015. *Natural Gas Vehicles, Section 13.1, Detailed Life-Cycle Analysis, GHG Emission and Fuel Efficiency Standards for 2018 MY + Heavy-Duty Engines and Vehicles.* Draft NPRM.	Natural gas fuel	Well to wheels	GHG emissions

Table C-1. Studies Analyzed in Chapter 6, Life-cycle Assessment of Vehicle Energy, Materials, and Technologies

Study Analyzed	Technologies/Materials Covered[a]	Life-cycle Boundaries[b]	Environmental Impacts Estimated[c]
Facanha, C., and A. Horvath. 2007. Evaluation of Life-Cycle Air Emission Factors of Freight Transportation. *Environmental Science & Technology*.	Road freight transportation vehicles, infrastructure, and fuels	Cradle to grave	Energy requirements; GHG emissions; criteria air pollutants
Frey, H. C., and P. Kuo. 2009. Real-World Energy Use and Emission Rates for Idling Long-Haul Trucks and Selected Idle Reduction Technologies. *Journal of the Air and Waste Management Association*.	Diesel generator APU	Vehicle use	Fuel use; GHG emissions; criteria pollutants
Gaines, L., and C. Brodrick Hartman. 2009. *Energy Use and Emissions Comparison of Idling Reduction Options for Heavy-Duty Diesel Trucks. Argonne National Laboratory.* Ninetieth Annual Meeting of the Transportation Research Board.	Diesel APU; direct-fired heater; electrified parking space	Vehicle use	GHG emissions, criteria pollutants
Gaines, L., J. Sullivan, A. Burnham, and I. Belharouak. 2011. *Life-Cycle Analysis for Lithium-Ion Battery Production and Recycling*. Argonne National Laboratory.	Batteries (Li-ion)	Cradle to gate	Energy requirements; GHG emissions
Galipeau-Belair, P., M. El-Gindy, S. Ghantae, D. Critchley, and S.A. Ramachandra. 2013. A Review of Side Underride Statistics and Protection Device Literature and Designs. *International Journal of Heavy Vehicle Systems*.	Aerodynamic devices	Vehicle use	Energy requirements; GHG emissions

Table C-1. Studies Analyzed in Chapter 6, Life-cycle Assessment of Vehicle Energy, Materials, and Technologies

Study Analyzed	Technologies/Materials Covered[a]	Life-cycle Boundaries[b]	Environmental Impacts Estimated[c]
Galitsky, C. 2008. *Energy Efficiency Improvement and Cost Saving Opportunities for the Vehicle Assembly Industry: An ENERGY STAR Guide for Energy and Plant Managers.* Lawrence Berkeley National Laboratory.	Energy efficiency during vehicle assembly; hydroforming	Material production	Energy requirements
Geyer, R. 2008. Parametric Assessment of Climate Change Impacts of Automotive Material Substitution. *Environmental Science Technology*.	Lightweighting; aluminum; HSS; steel	Material production and vehicle use stages only	GHG emissions
Gibson, T. 2000. Life Cycle Assessment of Advanced Materials for Automotive Applications. *Society of Automotive Engineers, Inc.* 109(6):1932–1941.	Nine advanced and conventional materials including graphite, titanium, steel, aluminum, and carbon composites	Cradle to grave	Energy use; GHG emissions; air emissions including SOx and NOx; water emissions; solid waste; hydrogen fluoride.
Hakamada, M., T. Furuta, Y. Chino, Y. Chen, H. Kusuda, and M. Mabuchi. 2007. Life Cycle Inventory Study on Magnesium Alloy Substitution in Vehicles. *Energy.*	Magnesium; steel; aluminum	Cradle to grave	Energy requirements; CO_2 emissions
Heath, G.A., P. O'Donoughue, D.J. Arent, and M. Bazilian. 2014. *Harmonization of Initial Estimates of Shale Gas Life Cycle Greenhouse Gas Emissions for Electric Power Generation.* Proceedings of the National Academy of Sciences of the United States.	Shale gas; conventionally-produced natural gas; coal; electricity.	Cradle to grave	GHG emissions
Holt, D.E. 2001. Auxiliary Power Units. *Service Technology Magazine*.	APUs	Not applicable	Not applicable

Table C-1. Studies Analyzed in Chapter 6, Life-cycle Assessment of Vehicle Energy, Materials, and Technologies

Study Analyzed	Technologies/Materials Covered[a]	Life-cycle Boundaries[b]	Environmental Impacts Estimated[c]
Jain, S., Chen, H., and J. Schwank. 2006. Techno-Economic Analysis of Fuel Cell Auxiliary Power Units as Alternatives to Idling. *Journal of Power Sources*.	SOFCs; PEM fuel cells; APUs	Vehicle use	Fuel use
Johnston, P. Undated. *New Technologies—Tires.* Michelin North America, Greenville, SC.	Tires	Vehicle use	Energy requirements; GHG emissions
Kaierle, S., M. Dahmen, and O. Gudukkurt. 2011. *Eco-Efficiency of Laser Welding Applications.* SPIE Eco-Photonics 8065.	Laser welding	Cradle to grave	Energy requirements; material use
Kassel, R. and J. Annotti. 2015. *EPA and NHTSA's Medium- and Heavy-Duty Phase 2 Rule: Recommendations to Enhance the Use of Natural Gas in Trucks and Buses.* Neandross and Associates: 1-17.	Natural gas as vehicle fuel	Vehicle use	GHG emissions; air emissions
Keoleian, G.A., and K. Kar. 1999. *Life Cycle Design of Air Intake Manifolds: Phase I: 2.0 L Ford Contour Air Intake Manifold.* EPA/600/R-99/023. University of Michigan Center for Sustainable Systems.	Aluminum; nylon composite	Cradle to grave	Energy requirements; GHG emissions; solid waste; air emissions; water effluents
Khanna, V., and B.R. Bakshi. 2009. Carbon Nanofiber Polymer Composites: Evaluation of Life Cycle Energy Use. *Environmental Science Technology.*	Polymer nanocomposite; CNF and CNF-GF hybrid polymer; Carbon nanofiber-reinforced polymer nanocomposite; carbon nanofiber glass-fiber hybrid PNCs; steel	Cradle to gate and use stage	Energy requirements

Table C-1. Studies Analyzed in Chapter 6, Life-cycle Assessment of Vehicle Energy, Materials, and Technologies

Study Analyzed	Technologies/Materials Covered[a]	Life-cycle Boundaries[b]	Environmental Impacts Estimated[c]
Kim, H.J., C. McMillan, G.A. Keoleian, and S.J Skerlos. 2010a. Greenhouse Gas Emissions Payback for Lightweighted Vehicles Using Aluminum and High-Strength Steel. *Journal of Industrial Ecology*.	Lightweighting; aluminum; HSS	Cradle to grave	GHG emissions
Kim, H.J., G.A. Keoleian, and S.J. Skerlos. 2010b. Economic Assessment of Greenhouse Gas Emissions Reduction by Vehicle Lightweighting Using Aluminum and High Strength Steel. *Journal of Industrial Ecology.*	Lightweighting; aluminum; HSS; steel; glass-fiber reinforced plastic	Cradle to grave	Energy requirements; GHG emissions
Kim, H.C., and T.J. Wallington. 2013a. Life Cycle Assessment of Vehicle Lightweighting: A Physics-Based Model of Mass-Induced Fuel Consumption. *Environmental Science & Technology*.	Lightweighting; aluminum; HSS; steel; glass-fiber reinforced plastic	Vehicle use	Energy requirements; GHG emissions
Kim, H.C., and T.J. Wallington. 2013b. Life-Cycle Energy and Greenhouse Gas Emission Benefits of Lightweighting in Automobiles: Review and Harmonization. *Environmental Science & Technology*.	Lightweighting; aluminum; HSS; steel; glass-fiber reinforced plastic	Cradle to grave	Energy requirements; GHG emissions
Kocańda, A., and H. Sadlowska. 2008. *Automotive Component Development by Means of Hydroforming.* Archives of Civil and Mechanical Engineering.	Hydroforming	Not applicable	Not applicable

Table C-1. Studies Analyzed in Chapter 6, Life-cycle Assessment of Vehicle Energy, Materials, and Technologies

Study Analyzed	Technologies/Materials Covered[a]	Life-cycle Boundaries[b]	Environmental Impacts Estimated[c]
Koffler, C., and J. Provo. 2012. *Comparative Life Cycle Assessment of Aluminum and Steel Truck Wheels.* Prepared by PE International, Inc. and Five Winds Strategic Consulting for Alcoa, Inc.	Truck wheels; aluminum; steel	Cradle to grave	Primary energy demand; acidification potential; eutrophication potential; GHG emissions; ozone depletion potential; smog formation potential; human toxicity; eco-toxicity
La Clair, T.J., and R. Truemner. 2005. *Modeling of Fuel Consumption for Heavy-Duty Trucks and the Impact of Tire Rolling Resistance*. SAE International.	Tires	Vehicle use	Energy requirements
Lattanzio, R.K. 2014. *Canadian Oil Sands: Life-Cycle Assessments of Greenhouse Gas Emissions.* Congressional Research Service.	Oil sands crudes; global reference crudes; gasoline	Cradle to grave plus well to wheels	GHG emissions
Lechtenböhmer, S., Altmann, M., Capito, S., Matra, Z., Weindrorf, W., Zittel, W. 2011. *Impacts of Shale Gas and Shale Oil Extraction on the Environment and on Human Health.* European Parliament Directorate General for Internal Policies.	Hydraulic fracturing; shale gas	Cradle to grave	Land use; air pollutants; soil contamination; surface and ground water pollution; earthquakes; human health impacts; GHG emissions
Lee, D-Y, V.M. Thomas, and M.A. Brown. 2013. Electric Urban Delivery Trucks: Energy Use, Greenhouse Gas Emissions, and Cost-Effectiveness. *Environmental Science & Technology*.	Diesel fuel; electric powered HD vehicles; HEVs; PHEVs; vehicle manufacturing; batteries; EV recycling	Cradle to grave plus well to wheels	Energy requirements; GHG emissions

Table C-1. Studies Analyzed in Chapter 6, Life-cycle Assessment of Vehicle Energy, Materials, and Technologies

Study Analyzed	Technologies/Materials Covered[a]	Life-cycle Boundaries[b]	Environmental Impacts Estimated[c]
Lewis, A.M., G. Keoleian, and J. Kelly. 2014. *The Potential of Lightweight Materials and Advanced Combustion Engines to Reduce Life Cycle Energy and Greenhouse Gas Emissions.* SAE International.	Lightweighting; aluminum; HSS; HEVs; PHEVs; ethanol engines	Cradle to gate plus vehicle use	Energy requirements; GHG emissions
Lim, H. 2002. *Study of Exhaust Emissions from Idling Heavy-Duty Diesel Trucks and Commercially Available Idle-Reducing Devices.* U.S. Environmental Protection Agency. EPA420-R-02-025.	Diesel APUs; diesel direct fired heater	Vehicle use	Fuel use; criteria pollutants
Lin, J., Smith, D.F., Babbit, C.W., and T.A. Trabold. 2011. *Assessment of Bio-Fuel Options for Solid Oxide Fuel Cell-Based Auxiliary Power Units.* 2011 IEEE International Symposium on Sustainable Systems and Technology. Chicago IL.	SOFC APUs; bio-based fuels	Gate to gate including vehicle use	Criteria pollutants
Lloyd, S.M., and L.B. Lave. 2003. Life Cycle Economic and Environmental Implications of Using Nanocomposites in Automobiles. *Environmental Science Technology.*	Steel; aluminum; clay-polypropylene nanocomposite	Cradle to gate	Energy requirements; GHG emissions; criteria air pollutants; fuel/ electricity use; resource depletion; water use; hazardous waste generation; toxic releases
Majeau-Bettez, G., T. R. Hawkins, and A.H. Strømman. 2011. Life Cycle Environmental Assessment of Lithium-Ion and Nickel Metal Hydride Batteries for Plug-In Hybrid and Battery Electric Vehicles. *Environmental Science and Technology.*	Batteries (NiMH and Li-ion)	Cradle to gate	Global warming potential; fuel use; resource depletion; freshwater and marine ecotoxicity; freshwater and marine eutrophication; ozone depletion; metal depletion; particulate matter emissions; terrestrial acidification; human toxicity

Table C-1. Studies Analyzed in Chapter 6, Life-cycle Assessment of Vehicle Energy, Materials, and Technologies

Study Analyzed	Technologies/Materials Covered[a]	Life-cycle Boundaries[b]	Environmental Impacts Estimated[c]
Mammetti, M., D. Gallegos, A. Freixas, and J. Munoz. 2013. *The Influence of Rolling Resistance on Fuel Consumption in Heavy-Duty Vehicles.* SAE International.	Tires	Vehicle use	Energy requirements; GHG emissions
Mayyas, A.T., A. Qattawi, A.R. Mayyas, and M.A. Omar. 2012. Life Cycle Assessment-Based Selection for Sustainable Lightweight Body-in-White Design. *Energy*.	Lightweighting; HSS; aluminum; magnesium; carbon fiber/epoxy composite; glass fiber composite	Cradle to grave	Energy requirements; GHG emissions
Mohapatra, S., and S. Das. 2014. Introduction of High Strength Steel for Commercial Vehicles—Light Weighting of Vehicles. *SAE International*.	Lightweighting; HSS	Not applicable	Energy requirements; GHG emissions
NACFE (North American Council for Freight Efficiency). 2010. *Executive Report—Wide Base Tires*. North American Council for Freight Efficiency.	Tires	Vehicle use	Energy requirements
NAS (National Academy of Sciences). 2010. *National Research Council, Transportation Research Board – Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles.*	Aerodynamic devices	Vehicle use	Energy requirements
NAS (National Academy of Sciences). 2006. *National Research Council, Transportation Research Board, Special Report 286 – Tires and Passenger Vehicle Fuel Economy – Informing Consumers, Improving Performance.*	Tires	Vehicle use	Energy requirements

Table C-1. Studies Analyzed in Chapter 6, Life-cycle Assessment of Vehicle Energy, Materials, and Technologies

Study Analyzed	Technologies/Materials Covered[a]	Life-cycle Boundaries[b]	Environmental Impacts Estimated[c]
NHTSA (National Highway Traffic Safety Administration). 2009. *NHTSA Tire Fuel Efficiency Consumer Information Program Development: Phase 2—Effects of Tire Rolling Resistance Levels on Traction, Treadwear, and Vehicle Fuel Economy.* DOT HS 811 154.	Tires	Vehicle use	Energy requirements
Notter, D.A., M. Gauch, R. Widmer, P. Wager, A. Stamp, R. Zah, and H.J. Althaus. 2010. Contribution of Li-Ion Batteries to the Environmental Impact of Electric Vehicles. *Environmental Science Technology.*	Batteries (Li-ion)	Cradle to grave	Energy requirements; GHG emissions/global warming potential; criteria air pollutants; resource depletion; Ecoindicator 99
Overly, J.G., R. Dhingra, G.A. Davis, and S. Das. 2002. *Environmental Evaluation of Lightweight Exterior Body Panels in New Generation Vehicles.* SAE International.	Aluminum; carbon-fiber-reinforced polymer; glass-fiber-reinforced polymer	Cradle to grave	CO_2 emissions; particulate matter emissions; eutrophication; photochemical smog; solid and hazardous waste generation; water quality
Patterson, J., Alexander, M., and A. Gurr. 2011. *Preparing for a Life Cycle CO_2 Measure.* Ricardo Low Carbon Vehicle Partnership.	Gasoline vehicles, diesel vehicles; PHEVs; EREVs; electric vehicles; fuel-cell vehicles	Not applicable	GHG emissions
Richardson, M., and B. Haylock. 2012. Design/Maker: The Rise of Additive Manufacturing, Domestic-Scale Production and the Possible Implications for the Automotive Industry. *Computer-Aided Design & Application PACE*.	Additive manufacturing; 3D Printing	Not applicable	Not applicable
Rooks, B. 2001. Tailor-Welded Blanks Bring Multiple Benefits to Car Design. *Assembly Automation*.	Tailor-welded blanks	Not applicable	Not applicable

Table C-1. Studies Analyzed in Chapter 6, Life-cycle Assessment of Vehicle Energy, Materials, and Technologies

Study Analyzed	Technologies/Materials Covered[a]	Life-cycle Boundaries[b]	Environmental Impacts Estimated[c]
Routhier, B. 2007. *New Generation Wide Base Single Tires.* American Trucking Associations. Presented at the International Workshop on the Use of Wide-Base Tires, October 25 and 26, 2007. Federal Highway Administration.	Tires	Vehicle use	Energy requirements
Samaras, C., and K. Meisterling. 2008. Life Cycle Assessment of Greenhouse Gas Emissions from Plug-in Hybrid Vehicles: Implications for Policy. *Environmental Science Technology.*	Batteries (NiMH and Li-ion)	Cradle to gate	Energy requirements; GHG emissions
Searchinger, T., R. Heimlich, R.A. Houghton, F. Dong, A. Elobied, J. Fabiosa, S. Tokgoz, D. Hayes, and T.-H. Yu. 2008. Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land-Use Change. *Science*.	Biofuels	Cradle to grave	GHG emissions
Shan, Z., S. Qin, Q. Liu, and F. Liu. 2012. Key Manufacturing Technology & Equipment for Energy Saving and Emissions Reduction in Mechanical Equipment Industry. *International Journal of Precision Engineering and Manufacturing*.	Digital technology; new material, near-net shape forming technology; clean production; short production process technology; waste-free manufacturing technology; automatic control technology; remanufacturing and reusing technology	Cradle to grave	Energy requirements; GHG emissions

Table C-1. Studies Analyzed in Chapter 6, Life-cycle Assessment of Vehicle Energy, Materials, and Technologies

Study Analyzed	Technologies/Materials Covered[a]	Life-cycle Boundaries[b]	Environmental Impacts Estimated[c]
Sharpe, B., and M. Roeth. 2014. *Costs and Adoption Rates of Fuel-Saving Technologies for Trailers in the North American On-Road Freight Sector*. The International Council on Clean Transportation.	Trailers; aerodynamic devices; tires	Vehicle use	Energy requirements
Shurepower. 2007. *Electric-Powered Trailer Refrigeration Unit Demonstration*. Prepared for the New York State Energy Research and Development Authority (NYSERDA) and the U.S. EPA SmartWay Transport Partnership by Shurepower, LLC.	Trailers; trailer refrigeration units; hybrid diesel-electric trailer refrigeration unit	Vehicle use	Energy requirements; carbon monoxide emissions; particulate matter emissions; NOx emissions
Song, Y.S., J.R. Youn, and T.G. Gutowski. 2009. Life Cycle Energy Analysis of Fiber-Reinforced Composites. *Composites: Part A*.	Fiber-reinforced composites	Cradle to grave	Energy requirements
Stodolsky, F., Vyas, A., Cuenca, R., and L. Gaines. 1995. *Life-cycle Energy Savings Potential from Aluminum-Intensive Vehicles.* Argonne National Laboratory.	Lightweighting; aluminum; recycling technology	Cradle to grave	Energy requirements; fuel use
Surcel, M.D., and J. Michaelsen. 2010. Evaluation of Tractor-Trailer Rolling Resistance Reducing Measures. SAE International.	Trailers; tires	Vehicle use	Energy requirements; GHG emissions
Tempelman, E. 2011. Multi-Parametric Study of the Effect of Materials Substitution on Life Cycle Energy Use and Waste Generation of Passenger Car Structures. *Transportation Research Part D*.	Lightweighting; HSS; fiber-reinforced plastics; aluminum	Cradle to grave	Energy requirements; waste generation

Table C-1. Studies Analyzed in Chapter 6, Life-cycle Assessment of Vehicle Energy, Materials, and Technologies

Study Analyzed	Technologies/Materials Covered[a]	Life-cycle Boundaries[b]	Environmental Impacts Estimated[c]
TIAX. 2009. *Assessment of Fuel Economy Technologies for Medium- and Heavy- Duty Vehicles.* Final Report to National Academy of Sciences.	Tires	Vehicle use	Energy requirements
Ungurean, C.A., and S. Das. 2007. *Development of a Sustainability Scoring Method for Manufactured Automotive Products: A Case Study of Auto Body Panels.* ASME International Mechanical Engineering Congress and Exposition.	Aluminum; steel alloy	Not applicable	CO_2 emissions
U.S. Department of Energy. 2013c. *Workshop Report: Trucks and Heavy-Duty Vehicles Technical Requirements and Gaps for Lightweight and Propulsion Materials*. U.S. Department of Energy, Energy Efficiency and Renewable Energy, Vehicle Technologies Office. DOE/EE-0867.	Aerodynamic devices	Vehicle use	Energy requirements
U.S. House of Representatives Committee on Energy and Commerce. 2011. *Chemicals Used in Hydraulic Fracturing.*	Hydraulic fracturing; natural gas;	Natural gas production	Human health impacts; ground water contamination; air pollution
U.S. State Department. 2014. *Final Supplemental Environmental Impact Statement for the Keystone XL Project.* U.S. Department of State Bureau of Oceans and International Environmental and Scientific Affairs.	Oil sands crudes; global reference crudes; gasoline	Well to wheels production	GHG emissions; land use; water pollution; air pollution; energy requirements; human health impacts

Table C-1. Studies Analyzed in Chapter 6, Life-cycle Assessment of Vehicle Energy, Materials, and Technologies

Study Analyzed	Technologies/Materials Covered[a]	Life-cycle Boundaries[b]	Environmental Impacts Estimated[c]
Volz, C.D., K. Ferrar, D. Michanowicz, C. Christen, S. Kearney, M. Kelso, and S. Malone. 2011. *Contaminant Characterization of Effluent from Pennsylvania Brine Treatment Inc., Josephine Facility Being Released into Blacklick Creek, Indiana County, Pennsylvania.*	Shale gas; hydraulic fracturing	Shale gas extraction	Water pollution; human health impacts
Vujičić, A., N. Zrnić, and B. Jerman. 2013. Ports Sustainability: A Life Cycle Assessment of Zero Emission Cargo Handling Equipment. Strojniški vestnik—*Journal of Mechanical Engineering*.	Diesel fuel; electric power; port-based HD vehicles	Cradle to gate and cradle to grave plus end of life	Global warming potential; ocean acidification; eutrophication potential; ozone depletion; radioactive waste
Wang, M., M. Wu, and H. Huo. 2007. Life-Cycle Energy and Greenhouse Gas Emission Impacts of Different Corn Ethanol Plant Types. *Environmental Research Letters*.	Corn ethanol	Ethanol production	GHG emissions; energy requirements
Weiss, M.A., J.B. Heywood, E.M. Drake, A. Schafer, and F.F. AuYeung. 2000. *On the Road in 2020: A Life-Cycle Analysis of New Automobile Technologies.* Massachusetts Institute of Technology.	Lightweighting; HEVs; BEVs; fuel cells; HSS; aluminum; plastics; alternative fuels	Cradle to grave	Energy requirements; GHG emissions
Werrell, C., and F. Femia. 2012. *The 3D Printing Revolution, Climate Change and National Security: An Opportunity for U.S. Leadership.* The Center for Climate and Security.	3D Printing	Not applicable	Not applicable

Table C-1. Studies Analyzed in Chapter 6, Life-cycle Assessment of Vehicle Energy, Materials, and Technologies

Study Analyzed	Technologies/Materials Covered[a]	Life-cycle Boundaries[b]	Environmental Impacts Estimated[c]
Witik, R.A., J. Payet, V. Michaud, C. Ludwig, and J.E. Manson. 2011. Assessing the Life Cycle Costs and Environmental Performance of Lightweight Materials in Automotive Applications. *Composites: Part A*.	Sheet moulding compound (SMC), GlassMat Thermoplastic (GMT), Glass Fiber, Magnesium, Carbon Fiber	Cradle to Grave	GHG emissions, resource depletion, human health, ecosystem quality
Yeh, S., S.M. Jordaan, A.R. Brandt, M.R. Turetsky, S. Spatari, and D.W. Keith. 2010. Land Use Greenhouse Gas Emissions from Conventional Oil Production and Oil Sands. *Environmental Science & Technology*.	Biofuels; fossil fuels; conventional oil; oil sands surface mining; oil sands in situ production	Fuel production	Land use; energy requirements; GHG emissions
Zhao, H., Burke, A. Miller, M. 2013. *Analysis of Class 8 Truck Technologies for Their Fuel Savings and Economics.* Transportation Research Part D.	Diesel fuel; HEV; FCEV; LNG; Electricity and Hydrogen	Vehicle use	Energy requirements; operational costs

Notes:

[a] AHHS = advanced high strength steel; APU = auxiliary power units; BEV = battery electric vehicle; CNF = carbon nanofiber; CNF-GF = carbon nanofiber-glass fiber; EREV = extended range electric vehicle; FCEV = fuel cell electric vehicle; HEV = hybrid electric vehicle; HSS = high strength steel; ICE = internal combustion engine; LFP-G = phosphate-graphite; Li-ion = lithium-ion; LMO-G = lithium, manganese, and oxygen-graphite; LMO-TiO = lithium, manganese, and oxygen-titanium and oxygen; Na-S = sodium-sulfur; NCA-G = nickel, cobalt, and aluminum-graphite; NiCd = nickel-cadmium; NiMH = nickel-metal hydride; PEM = proton exchange membrane; PHEV = plug-in hybrid electric vehicle; SOFC = solid oxide fuel cells.

[b] Cradle to gate = assessment of a partial product life cycle that includes the raw material extraction and manufacturing stages, and transportation between these stages; cradle to grave = life-cycle assessment that includes all five stages of a product's life cycle (i.e., raw material extraction, manufacturing, vehicle use, end-of-life management, and transportation between the various stages); gate to gate = assessment of a partial product life-cycle that includes only the manufacturing stage.

[c] CO_2 = carbon dioxide; GHG = greenhouse gas.