TRANSPORTATION ENERGY INSTITUTE

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Using Life Cycle Analysis in the Transportation Energy Sector

As the transportation system continues to progress towards a lower or zero-emissions future, it is essential to understand and accurately measure emissions. Regulations in the United States have taken multiple approaches to evaluating emissions from the sector, applying different methodologies to different emissions sources. For example, light duty vehicles are primarily regulated by tailpipe emissions, while liquid fuels are sometimes regulated based on the entire production process, known as the "life cycle." This difference complicates effective evaluation of the emissions reduction achievements and raises questions about the overall effectiveness of these programs. Globally, there is little uniformity in how different countries address transportation-related emissions. A more holistic and uniform approach could achieve efficiencies in reducing emissions.

This paper considers how a life cycle assessment (LCA) methodology could be applied to evaluate emissions from the transportation sector, considering energy and vehicles as a holistic system. By doing so, an LCA can provide a comprehensive understanding of the full environmental footprint of the sector across all stages of its life cycle—from raw material extraction, through production, use, and disposal of both energy and vehicles.

If the overall objective of emissions reduction efforts is to reduce emissions, including greenhouse gas emissions, then it is important to account for emissions wherever they are generated, apply reduction efforts where they can yield the greatest benefit and credit the transportation sector for all reductions. With regards to atmospheric concentration of GHG, emissions reductions achieved anywhere in the supply chain, such as a petroleum or bio-refinery or electricity generating facility, are just as important and valuable as reducing emissions from the tailpipe of a vehicle.

Further, by evaluating the life cycle emissions of the sector, businesses and policymakers can make informed decisions about product design, material sourcing, production methods and policy provisions to maximize the efficiency of emissions reductions. An LCA also can reveal the stages where resource use or environmental impacts are the highest, allowing organizations to focus on reducing these impacts to deliver the greatest value to the environment. By identifying resource inefficiencies or areas of waste in the production and use phases, an LCA can suggest ways to optimize costs.

Other research seeks to compare and contrast varying approaches used throughout the world to track and calculate emissions in an attempt to determine what a cohesive approach may look like. Before this insight can be effectively applied, however, there must be a general understanding regarding the scope of emissions from the transportation sector, recognition from where these emissions emanate and a credible approach to evaluating their impact. The discussion presented in this paper should spur discussions on how current approaches might be improved.

What is a Life Cycle Analysis (LCA)?

An LCA is a systematic process used to evaluate the environmental impacts of a product, service, or system throughout its entire life cycle. It includes all stages, from raw material extraction, production, distribution, utilization, to eventual disposal or recycling. The goal of an LCA is to understand the full environmental footprint of a product or service to make more sustainable choices.

The following four-step methodology is defined for analyzing life cycle impacts from cradle to grave, provided by the International Organization for Standardization (ISO). ISO 14040:2006 and ISO 14044:2006[1] provide the norms for common, standardized LCA studies and are presented as found in 14044-2006. The methodological choices applied within an LCA need to be appropriate for the goal and scope of the analysis and should be defined at the beginning of the project.

1. **Goal and Scope Definition** - The scope, including system boundary and level of detail, of an LCA depends on the subject and the intended use of the study. The depth and

[1] International Organization for Standardization, "ISO 14040:2006 Environmental management — Life cycle assessment — Principles and framework," (English version), https://www.iso.org/obp/ui/#iso:std:iso:14040:ed-2:v1:en; International Organization for Standardization, "ISO 14044:2006 Environmental management — Life cycle assessment — Requirements and guidelines," (English version), https://www.iso.org/obp/ui/#iso:std:iso:14044:ed-1:v1:en

the breadth of LCA can differ considerably depending on the goal of a particular LCA.

2. **Inventory Analysis (LCI)** - The LCI is an inventory of input/output data with regard to the system being studied. It involves the collection of the data necessary to meet the goals of the defined study.
3. **Impact Assessment (LCIA)** - The LCIA provides additional information to help assess a product system's LCI results so as to better understand their environmental significance.
4. **Interpretation** - The results of an LCI or an LCIA, or both, are summarized and discussed as a basis for conclusions, recommendations and decision-making in accordance with the goal and scope definition.

For reference, if the LCA is primarily concerned with greenhouse gas emissions (GHG), then the following will be assessed throughout the inventory analysis. These GHG emissions are commonly used in LCA to account for major emissions that have a significant GHG impact. For ease of reporting all emissions are normalized to the equivalent GHG impact of CO2, noted by CO2e, whereas "e" refers to "equivalency." For example, if all emissions were just CO2, CO2e indicates what mass of CO2 would create the same impact. In several LCA tools the term GHG-100 is used to show that the emissions scale represents the GHG impact of all emissions over a 100-year timeframe as though all emissions were just CO2. Most environmental agencies and international agreements use GWP-100 as the standard metric and the numbers might vary wildly for different time scales.

Greenhouse Gas (GHG)	Chemical Formula	Global Warming Potential (GWP) over 100 years
Carbon Dioxide (CO_2)	CO_2	1 (baseline)
Methane (CH_4)	CH_4	28
Nitrous Oxide (N_2O)	N_2O	265
Hydrofluorocarbon-23 (HFC-23)	CHF_3	12,000
Hydrofluorocarbon-134a (HFC-134a)	CH_2FCF_3	1,430
Sulfur Hexafluoride (SF_6)	SF_6	23,500
Nitrogen Trifluoride (NF_3)	NF_3	16,100

Application to the Transportation Sector

LCA is used in various industries to improve sustainability, guide design improvements, inform policies, and support decisions related to product development, marketing, and consumer behavior. For the transportation sector, the structure and bounds of an LCA are critically important because it is easy to get lost in a series of tangents that lead far away from the core objective. It is essential to clearly articulate the purpose of the LCA and define which subcategories are within scope of the analysis, such as:

- **Transportation vehicles** – Any combination of on-road passenger or freight vehicles, off-road service vehicles, airplanes, trains, marine vessels, etc.
- **Energy consumed** - Petroleum, biofuels, electricity, natural gas, hydrogen, etc.
- **Transportation system** – Public transit, personal vehicles, commercial/freight, etc.
- **Transportation infrastructure** - Roads or railway construction and maintenance, vehicle refueling and charging stations, distribution systems, etc.

Next, the LCA must have well-defined system boundaries. By defining the stages of the life cycle to be included in the assessment, the LCA can be applied appropriately and effectively. Some elements that could be included are:

- **Vehicle production** - Material extraction, manufacturing processes, logistics, etc.
- **Vehicle operation** - Fuel and energy production, consumption and emissions during use, component wear and degradation, etc.
- **Vehicle maintenance** - Repair, upgrades, etc.
- **End-of-life** - Disposal, recycling, and waste management of vehicles or infrastructure, etc.

Establishing the bounds of the LCA helps guide the study and ensures it remains manageable and meaningful. Without clearly defining the bounds of the LCA, it is very easy for the scope to become unmanageable. For example, in a transportation-focused LCA, research might consider:

- When evaluating the life cycle impact of biofuels production, should the LCA include such factors as the production of fertilizer, seed development or tractor manufacturing? How might the LCA like sustainable agriculture practices and indirect land use?
- When applying LCA to vehicles, what elements are deemed relevant and verifiable? For example, should the LCA consider all variations in the build combinations for the same vehicle or is this considered extraneous?

When an LCA is being used in a policy or regulatory framework, additional considerations are important. It is essential to ensure that regulated entities are held accountable only for the contribution to life cycle emissions for which they are responsible, but that all efforts throughout the life cycle are recognized when evaluating the emissions reduction effect of the policy. This can be complicated, but the goal should be to support and account for total emissions reductions while not imposing unrealistic requirements on affected stakeholders. In the environment of regulatory compliance, use of LCA often includes prescriptive requirements that are much less opaque than those under a voluntary framework. However, regulated LCAs typically differ from state-to-state and country-to-country and the application of a universally accepted model would greatly improve the effectiveness of emissions assessments.

Benefits of Applying LCA to Transportation

A transparent LCA provides a variety of benefits to both business and policymakers by incorporating a holistic view of the transportation sector, enabling assessments that inform decisions to be made based upon maximizing the emissions reduction value of different strategies and investments. Specifically, an LCA can help identify:

- Environmental Benefits – Identifying where emissions can be reduced most effectively and efficiently will accelerate and amplify the benefits to the environment.
    - Carbon emission - Identify ways to reduce the carbon footprint of various elements within the transportation systems which will combine to deliver greater benefits to the global environment than any single effort alone.
    - Air pollutants - Identify where air pollution is most acute, evaluate its sources and deploy new technologies and processes to effectively reduce NOx and PM emissions to improve air quality for local communities.
    - Resource depletion – Discover which stages of the system most inefficiently use natural resources and focus on improving operations to be more efficient and conservation-friendly.
- Economic Benefits – Identifying where investments in environmental improvements would represent the best financial value will encourage such investments.
    - Cost savings – Investments in resource efficiency can yield cost savings through reduced energy and water consumption, resulting in higher returns for business and lower costs to taxpayers through government programs
    - Risk mitigation – Environmental sustainability investments reduce exposure to risks associated with regulatory compliance, satisfy requirements imposed by business customers and enhance brand reputation among consumers, lenders, insurers, and investors.
    - Additional market opportunities – Reducing a business' environmental footprint creates an opportunity to generate ancillary revenue through emissions reduction credit and trading programs, voluntary carbon markets and other financial mechanisms supported by industry and/or government designed to encourage and reward such investments by spreading the resulting value throughout the system.
- Societal Benefits – Reducing emissions and conserving natural resources has far reaching benefits to society as a whole.
    - Public health – Air and water pollutant emissions present an immediate and tangible threat to public health and welfare, elevate medical costs for all and impose additional financial and resource burdens on communities to remedy pollution.
    - Human rights – Sourcing of some raw materials may have detrimental human impacts to workers and nearby communities, in addition to those affecting the environment. Some of the impact might be improved through alternative, more efficient, technologies and extraction methodologies.

Conclusion

To mitigate the environmental impact of the transportation sector, it is essential to apply a life cycle analysis and discover where action can yield the greatest benefits. Emission reducing technology must be supported by demand for those new technologies. Often, new technology brings efficiencies that reduce the cost or volume of energy required to perform the same level of work. Such solutions deliver immediate value to the consumer and drive demand, increasing utilization of the lower emissions technology and amplifying the benefits to the environment.

A life cycle approach enables emissions reduction investments where they make the greatest economic and environmental sense. By deploying such technologies in multiple stages of a life cycle, the combined incremental benefits will be significantly higher with potentially much lower costs. An LCA helps identify where such efforts can yield the greatest and most sustainable benefits to the market. In conclusion, adopting a life cycle assessment approach is not only crucial for accurately measuring and reducing emission but also for driving sustainable innovation and ensuring a greener future for the transportation sector.

Light Duty Vehicle LCA Case Study

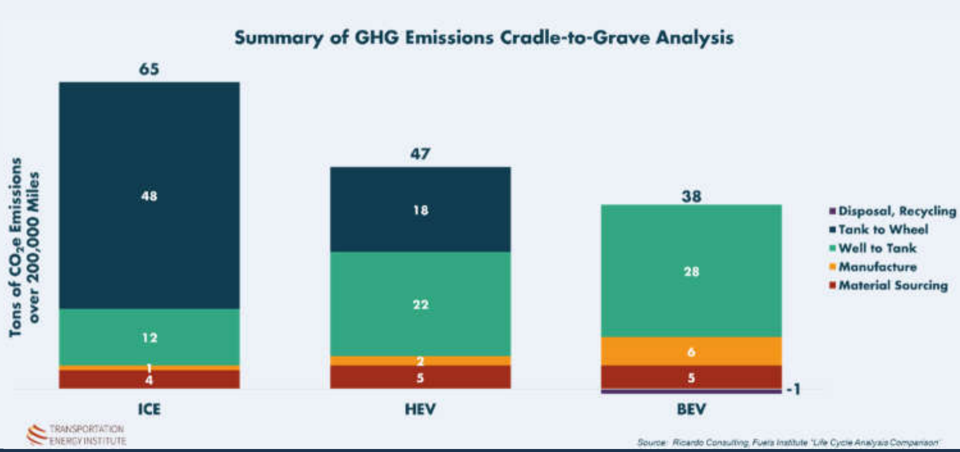
In 2022, the Transportation Energy Institute (TEI) published a report, "Life Cycle Analysis Comparison: Electric and Internal Combustion Engines." This study presented a LCA methodology for the transportation sector that took into consideration the whole vehicle life cycle (focused on a small-size sport utility vehicle), including embedded emissions, vehicle production, maintenance and servicing, and end-of-life activities and well-to-wheel emissions from fuels and electricity. This included the following boundaries:

- **Well-to-wheel** (WTW) analysis on the production of fuels and electricity and operational emissions.
    - **Fuel and electricity production**: Assessment of well-to-tank (WTT) environmental impact of producing the energy vector(s) from primary energy source, generation plants, through to distribution point.
    - **Vehicle Use/Operation** – Environmental impact of driving (tank-to-wheels, or TTW).
- **Vehicle cycle "embedded" emissions** result from vehicle manufacturing, maintenance and end-of-life disposal.
    - **Vehicle production** – Assessment of "cradle-to-grave" environmental impact of producing the vehicle, including extract of raw materials, processing, component manufacture, logistics, vehicle assembly and painting.
    - **Use/Operation** – Impact from maintenance and servicing
    - **End-of-life** – Adds assessment of environmental impact of "end of life" scenario (i.e., -to-grave), such as re-using or repurposing components, recycling materials, energy recovery and disposal to landfill.

In addition to developing this baseline LCA methodology, Ricardo also recognized that there are significant variables that can affect the outcome of a systemic LCA and conducted a series of sensitivity cases. Upon completion of the primary LCA, they adjusted key inputs to evaluate the impact each change might have on the ultimate outcome. For the TEI paper, Ricardo applied the following sensitivities to understand the impact of each:

- **Lifetime mileage** - Low or high lifetime vehicle mileage assumptions
- **Regional Sensitivity** - Examples of variation in impacts for different states (due to different road mileage shares, electricity mix)
- **Temperature** - Sensitivity exploring the relative impact for different powertrain types of operating at very low or very high ambient temperatures
- **Electric range** - Alternative assumptions for electric range for xEVs
- **Glider material innovations** - Alternative trajectories for glider material composition, including vehicle body, chassis, interior, exterior and components
- **Battery second life** - Sensitivity on high share of xEV battery second-life applications (included in vehicle driving-style factor)
- **Battery energy density** - Alternative assumptions on battery technology improvement/future chemistries, impacting particularly on energy density
- **Alternate fuels and methods** - Various blends of gasoline and diesel fuels in the US
- **Battery chemistry** - Various cell chemistries used in the vehicles

The report developed an overview of the life cycle GHG emissions from small cross-over utility vehicles over a 200,000-mile life span. The results showed the GHG emissions from each major stage of a vehicle's life and discovered that nearly two-thirds of emissions from both combustion and electric vehicles came from the energy consumed, e.g., fuel combustion and electricity generation. (Note: The study applied a national average carbon intensity for both gasoline blends and electricity.) Such an approach allows stakeholders to focus attention on the sectors of the market that could yield the greatest benefits to reducing emissions.



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About the Transportation Energy Institute

The Transportation Energy Institute, founded by NACS in 2013, is a 501(c)(4) nonprofit research-oriented think tank dedicated to evaluating the market issues related to vehicles and the fuels that power them. By bringing together diverse stakeholders of the transportation and fuels markets, the Institute helps to identify opportunities and challenges associated with new technologies and to facilitate industry coordination to help ensure that consumers derive the greatest benefit.

The Transportation Energy Institute commissions and publishes comprehensive, fact-based research projects that address the interests of the affected stakeholders. Such publications will help to inform both business owners considering long-term investment decisions and policymakers considering legislation and regulations affecting the market. Research is independent and unbiased, designed to answer questions, not advocate a specific outcome. Participants in the Transportation Energy Institute are dedicated to promoting facts and providing decision makers with the most credible information possible so that the market can deliver the best in vehicle and fueling options to the consumer.

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