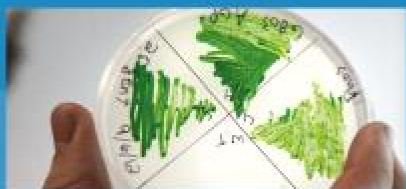



Reducing supply chain energy use in next-generation vehicle lightweighting

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Vehicle Lightweighting

- 2025 Corporate Average Fuel Economy (CAFE) Standards
  - o 54.5 miles/gallon for light-duty vehicles
  - o 163 g/mile GHG emissions
- How to decrease vehicle fuel use?
  - o More efficient engines
  - o **Lighter vehicles**

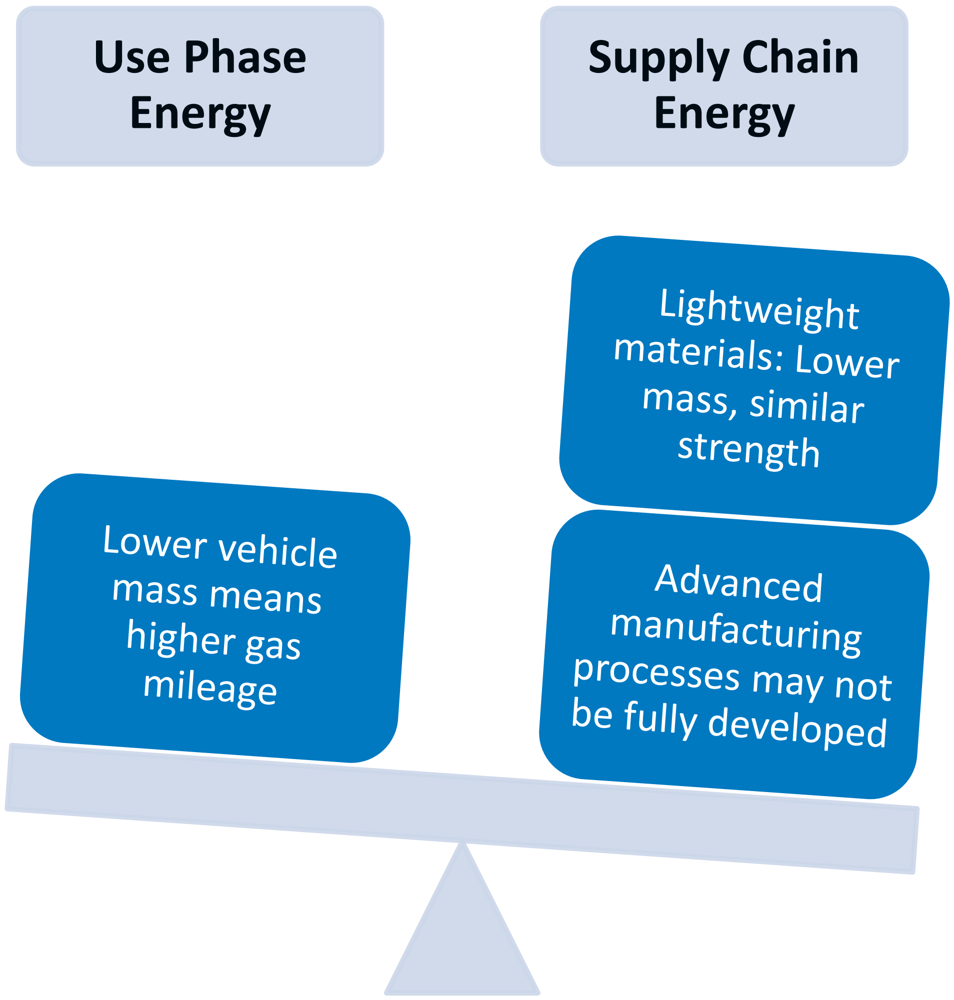
Lotus Elise

Mazda MX-5 Miata

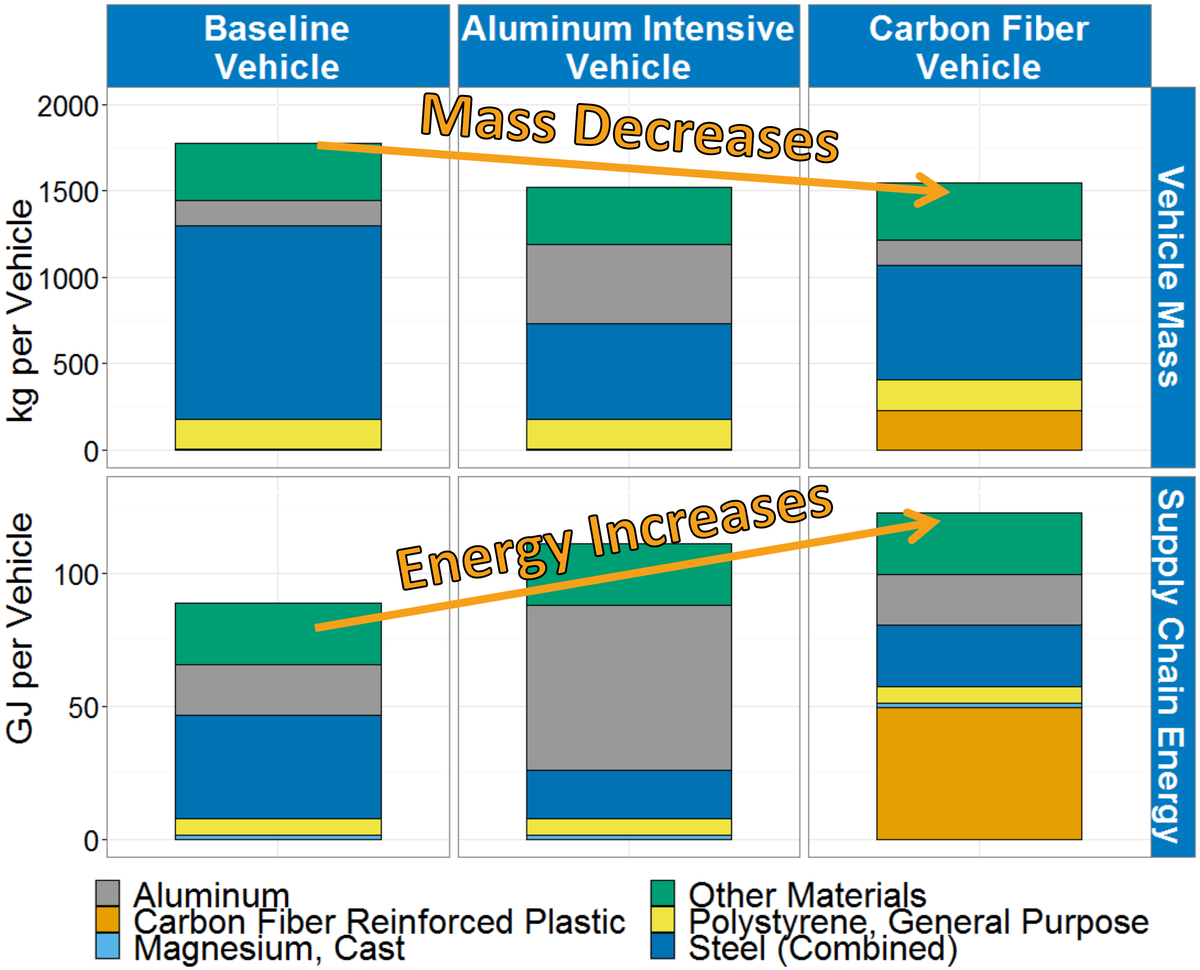
Mazda CX-5

Vehicle Lightweighting and Energy Use

- Replace conventional materials with lighter-weight alternative materials that have similar strength properties
- Lighter vehicles require less fuel to operate, resulting in large **use phase energy savings** over the vehicle lifetime
- Use phase energy savings may be reduced or completely offset by **increased energy use in the vehicle supply chain**



Aluminum and Carbon Fiber Composite Lightweight Vehicles



From the baseline…

- Vehicle mass *decreases*
  - Aluminum: 18%
  - Carbon fiber: 16%
- Vehicle supply chain energy *increases*
  - Aluminum: 37%
  - Carbon fiber: 49%

Reducing the vehicle supply chain energy results in greater energy savings over the vehicle life cycle.

Objectives & Methodology

- Analyze two lightweight vehicles under current and next-generation production technology scenarios
  - Aluminum intensive vehicle (AIV)
  - Carbon fiber composite vehicle (CFV)
- Evaluate **supply chain energy use** and **life cycle energy use** for a baseline non-lightweight vehicle and the two lightweight vehicles

Vehicle Life Cycle	
Supply Chain	Use Phase
Calculate energy consumption with NREL's **Material Flows through Industry (MFI)** supply chain modeling tool	Combine supply chain energy with use phase energy consumption from **Das et al. (2016)**

Supply Chain Modeling

Material Flows through Industry (MFI) is a linear network model of the U.S. manufacturing sectors.

- Models industrial commodity supply chains
- Captures processes from natural resource extraction through commodity production
- Extendable to include consumer products, the use phase and end-of-life processing
- Can represent current U.S. industrial practices or a variety of alternative manufacturing scenarios

Supply Chain Modeling

- Vehicle material inventories from Das et al. (2016) were used to model vehicle supply chains
- Lightweight vehicle supply chains were modeled under several next-generation technology scenarios

Material	Baseline Vehicle (kg)	Aluminum Intensive Vehicle (kg)	Carbon Fiber Vehicle (kg)
Steel (all)	1,119	552	665
Aluminum (all)	147	458	147
Carbon Fiber Composite	0	0	227
Magnesium	5	5	5
Plastics	174	174	174
Other Materials	330	330	330
Total Mass	1,775	1,519	1,548

Technology Scenarios

Current Technologies

- All processes in vehicle supply chain reflect standard U.S. industrial practice
- Carbon fiber is produced 98% from polyacrylonitrile (PAN), 2% from pitch
- Aluminum smelting is via the Modern Hall-Heroult process

Next-Generation Carbon Fiber Technologies

- **Lignin** is a renewable precursor not currently used at an industrial scale
- **State-of-the-art (SOA)** technologies reduce process energy consumption

Next-Generation Aluminum Smelting Technologies

- **Carbothermic** electric furnace, **Clay Carbochlorination**, **Hall-Heroult Inert Anode** and **Hall-Heroult Wetted Cathode** are advanced smelting technologies that reduce process energy consumption

Carbon Fiber Technologies

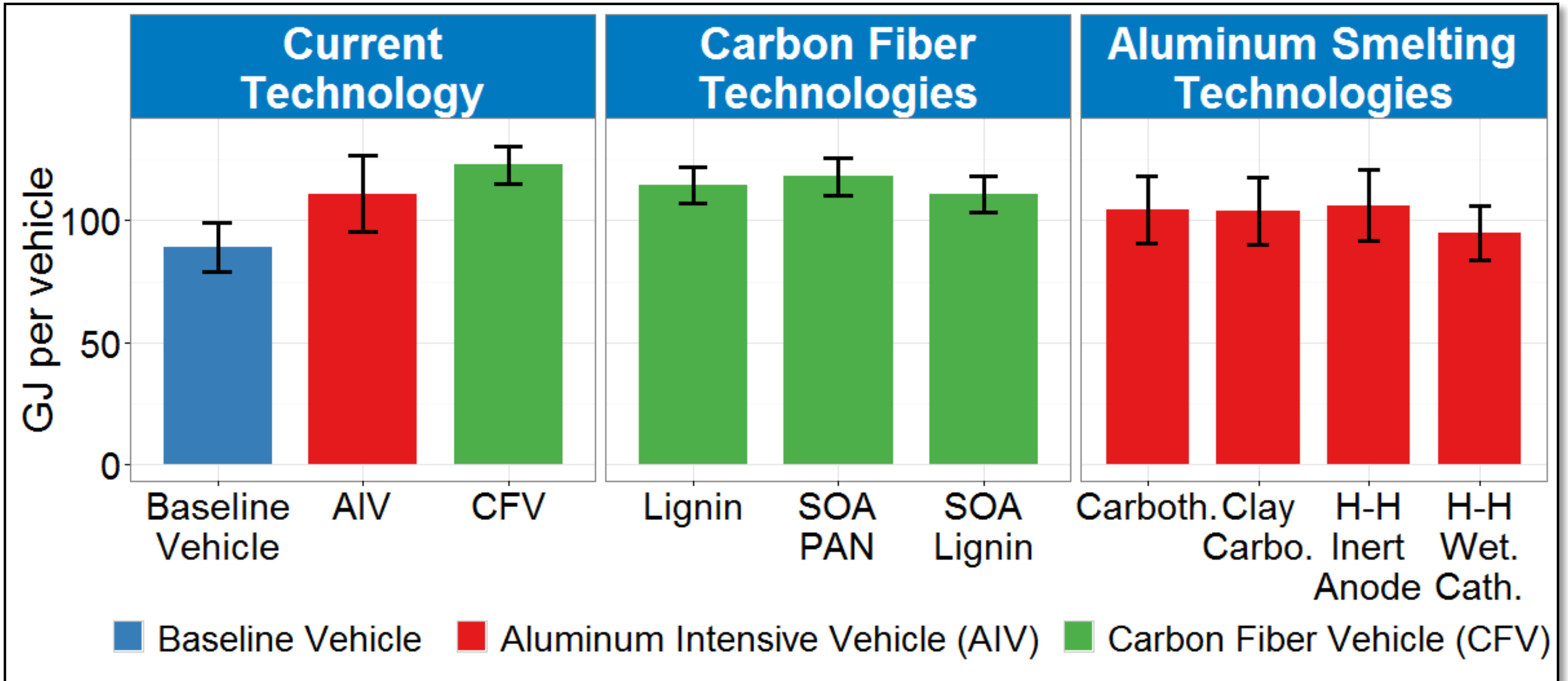
- Renewable, biomass-derived **lignin** precursor reduces energy consumption upstream of carbon fiber production relative to fossil-derived PAN precursor (Das, 2011)

- **State-of-the-art (SOA)** technologies reduce process energy consumption with more efficient process equipment and other process improvements (DOE, 2016)
    - Examples: Upgrade oxidation furnace, implement advanced process control for continuous optimization
- SOA improvements apply to both PAN and lignin precursors

Aluminum Smelting Technologies

- Aluminum smelting is one of the most energy-intensive steps in aluminum production
- Four next-generation alternatives to the current modern Hall-Heroult process are: (Das, 2012)
  - Carbothermic smelting
  - Clay Carbochlorination
  - Hall-Heroult Inert Anode
  - Hall-Heroult Wetted Cathode
- All reduce smelting energy relative to the modern Hall-Heroult process
- Barriers to industrial implementation may exist
  - Process safety, economics

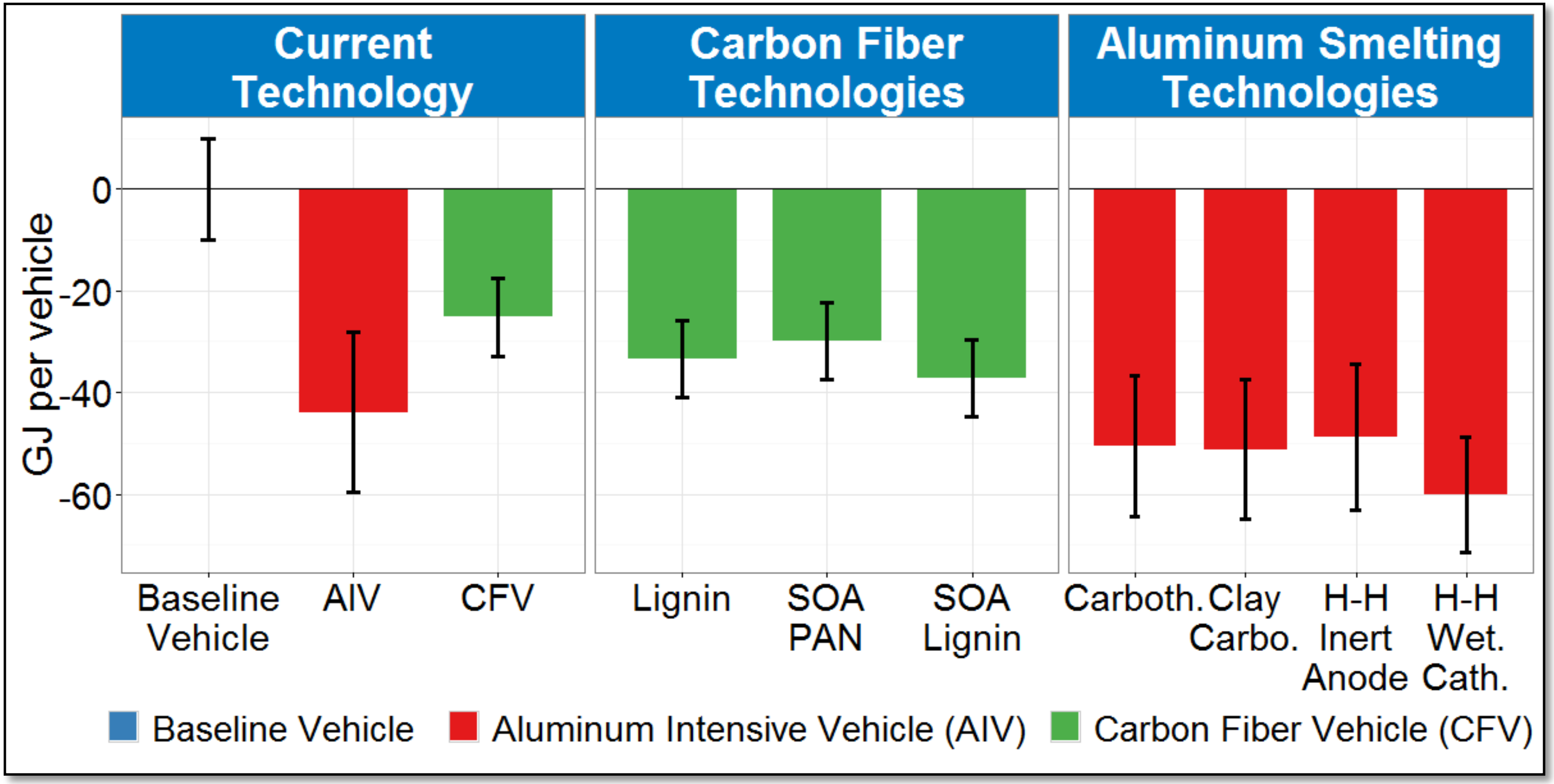
Supply Chain Energy Consumption



Uncertainty bars indicate variability in the amount of primary and recycled steel and aluminum used in each vehicle.

- Mild steel: 25 - 50% primary
- High strength steel: 85 - 89% primary
- Aluminum: 40 - 70% primary

Life Cycle Energy Use, Relative to Baseline Vehicle



A more negative value indicates greater life cycle energy savings.

Conclusions

- Across the scenarios analyzed, both vehicles offer savings over the baseline vehicle, although life cycle energy savings are currently greater for the aluminum vehicle than for the carbon fiber vehicle
- Next-generation technologies reduce supply chain energy relative to current technology for both lightweight vehicles
- Neither lightweight vehicle has lower supply chain energy than the baseline vehicle, under any technology scenario

Vehicle	Current Technology		Next-Gen Technology, Best Case	
	Supply Chain (GJ/vehicle)	Life Cycle (GJ/vehicle)	Supply Chain (GJ/vehicle)	Life Cycle (GJ/vehicle)
Baseline	78	537	--	--
Aluminum Intensive	107	500	91	484
Carbon Fiber	116	516	104	504

Extensions and Future Work

- Include more lightweighting material and next-generation technology alternatives in analysis
- Evaluate time to reach zero net energy for different lightweight vehicles
- Expand the scope of the analysis to the entire U.S. passenger vehicle fleet
- Project fleet-level supply chain and use phase energy consumption forward in time using information on the technology adoption rate of lightweight vehicles

Questions?

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