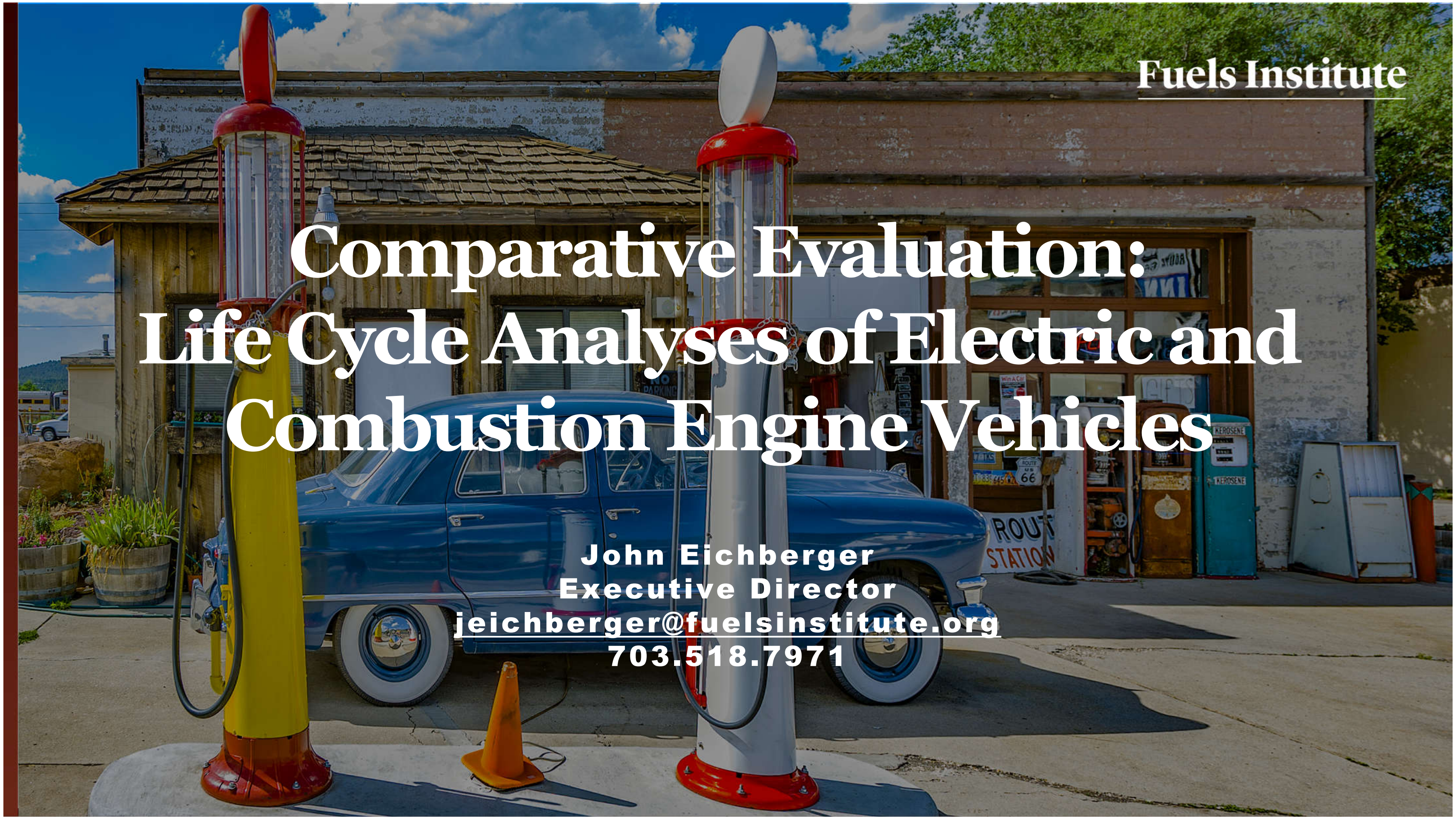
Fuels Institute
Comparative Evaluation:
Life Cycle Analyses of Electric and Combustion Engine Vehicles
John Eichberger
Executive Director
jeichberger@fuelsinstitute.org
703.518.7971

Agenda

- High Level Summary of Findings
- Methodology
- Summary of Literature Review Findings
- Life Cycle Analyses of Component Parts
- Sensitivity Analysis
- Total Cost of Ownership
- Takeaways according to John

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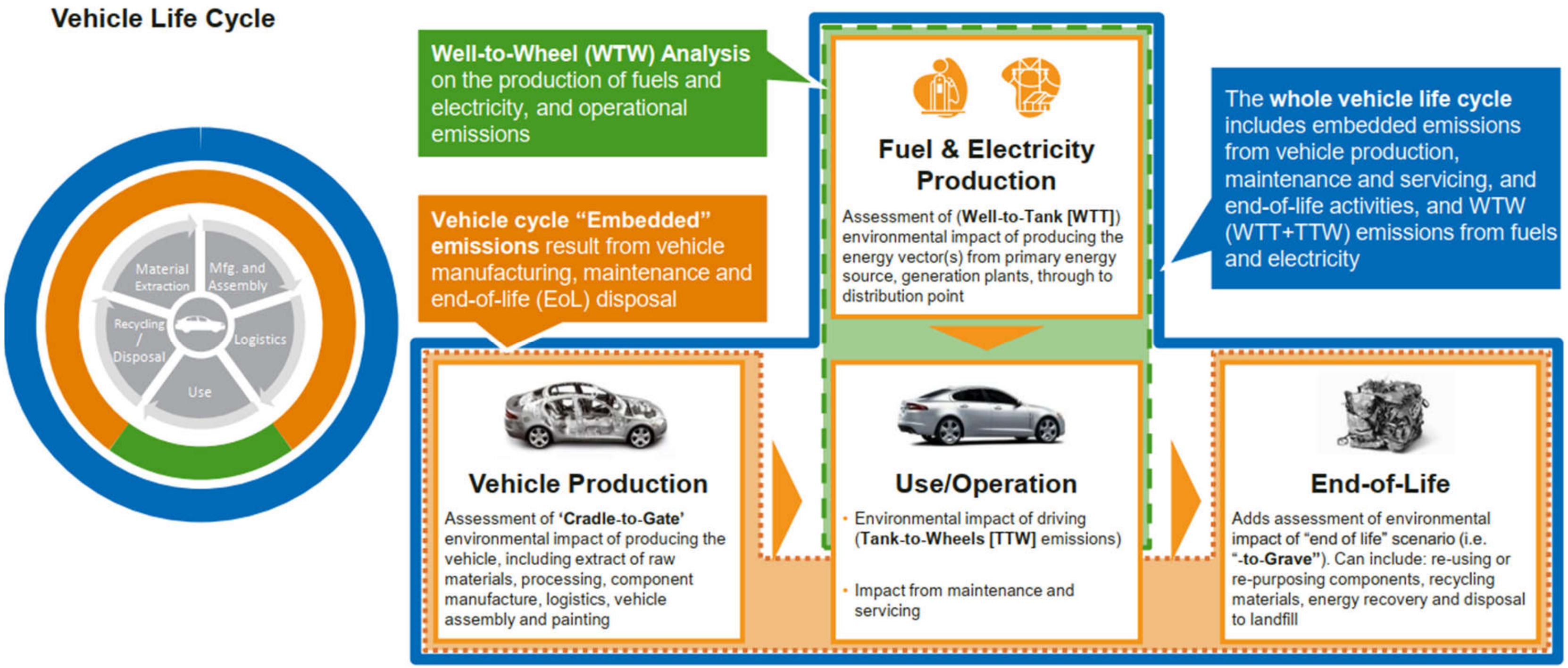
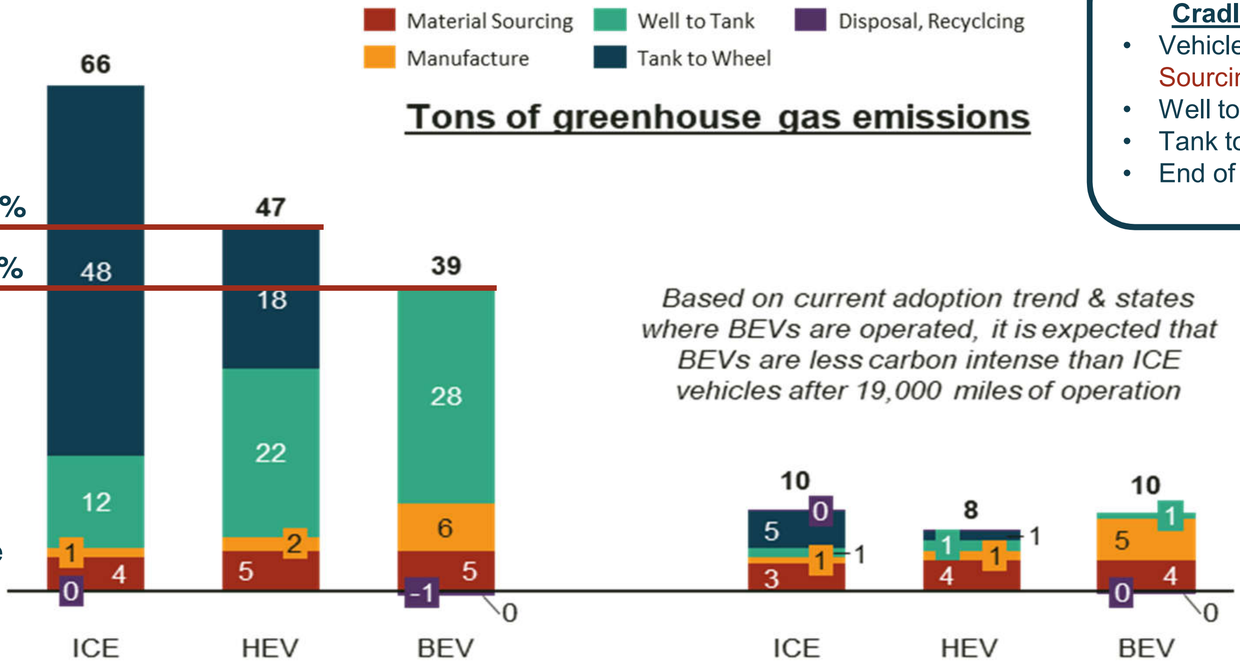
The Components of the Life Cycle Analysis

Study evaluates every component of the life cycle of a vehicle and its respective fuel/energy



High Level Summary – LCA Comparison

Mileage and carbon intensity of grid influence LCA, but in most cases BEVs emit less carbon



200,000 miles
(average USA electricity mix)

19,000 miles
(states with low carbon electricity)

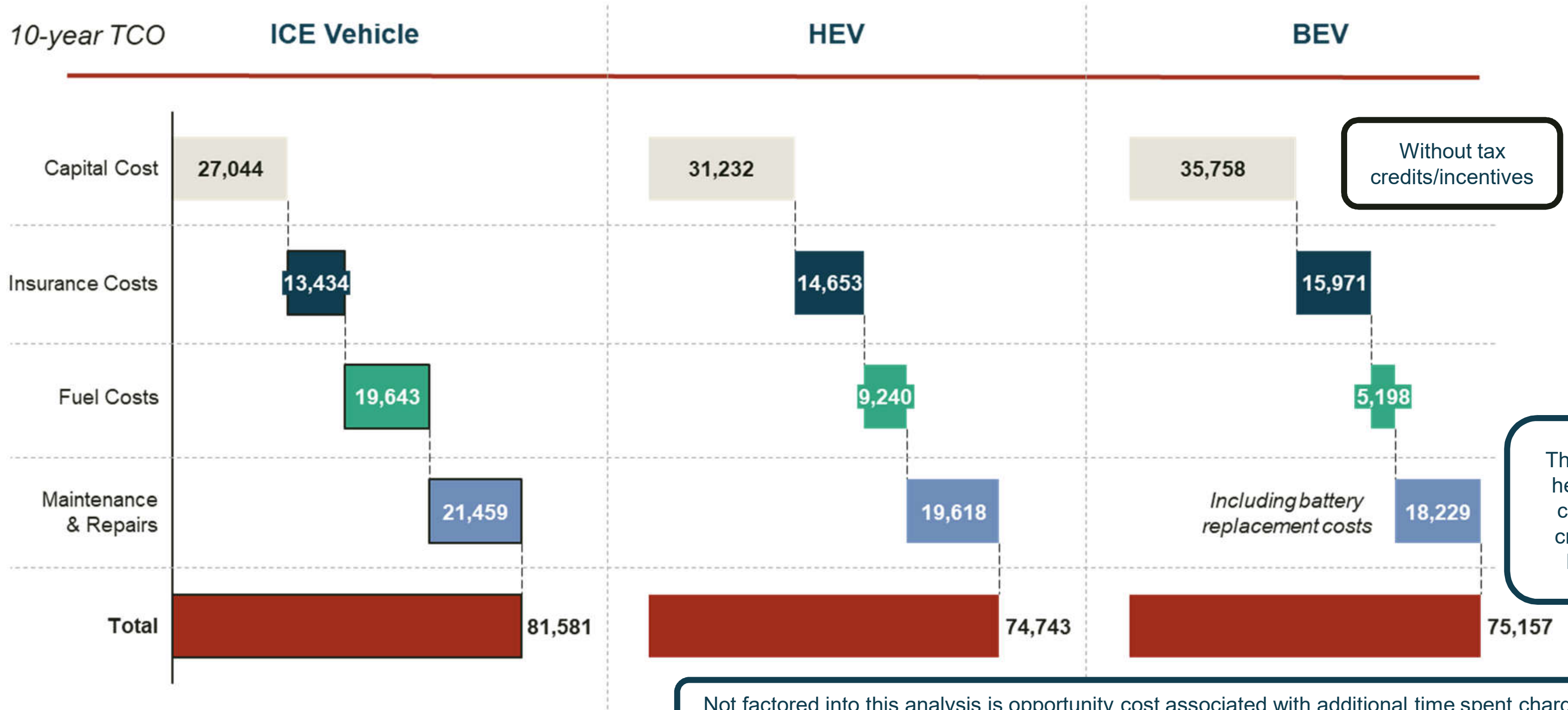
Cradle to Grave Definitions
- Vehicle Production: Material Sourcing + Manufacture
- Well to Tank: Energy Production
- Tank to Wheel: Use of Energy
- End of Life: Disposal/Recycling

Sensitivities Studied
- Lifetime miles
- Grid carbon intensity
- Ambient temperature
- Driver behavior
- Vehicle weight
- Battery chemistry
- Battery density
- Biofuels blends

Study assumes average of travel of 15,000 miles/year. Therefore, 19,000 miles would be about 15 months of ownership

High Level Summary – TCO Comparison

Even without tax credits, BEVs estimated to deliver lower total cost of ownership.



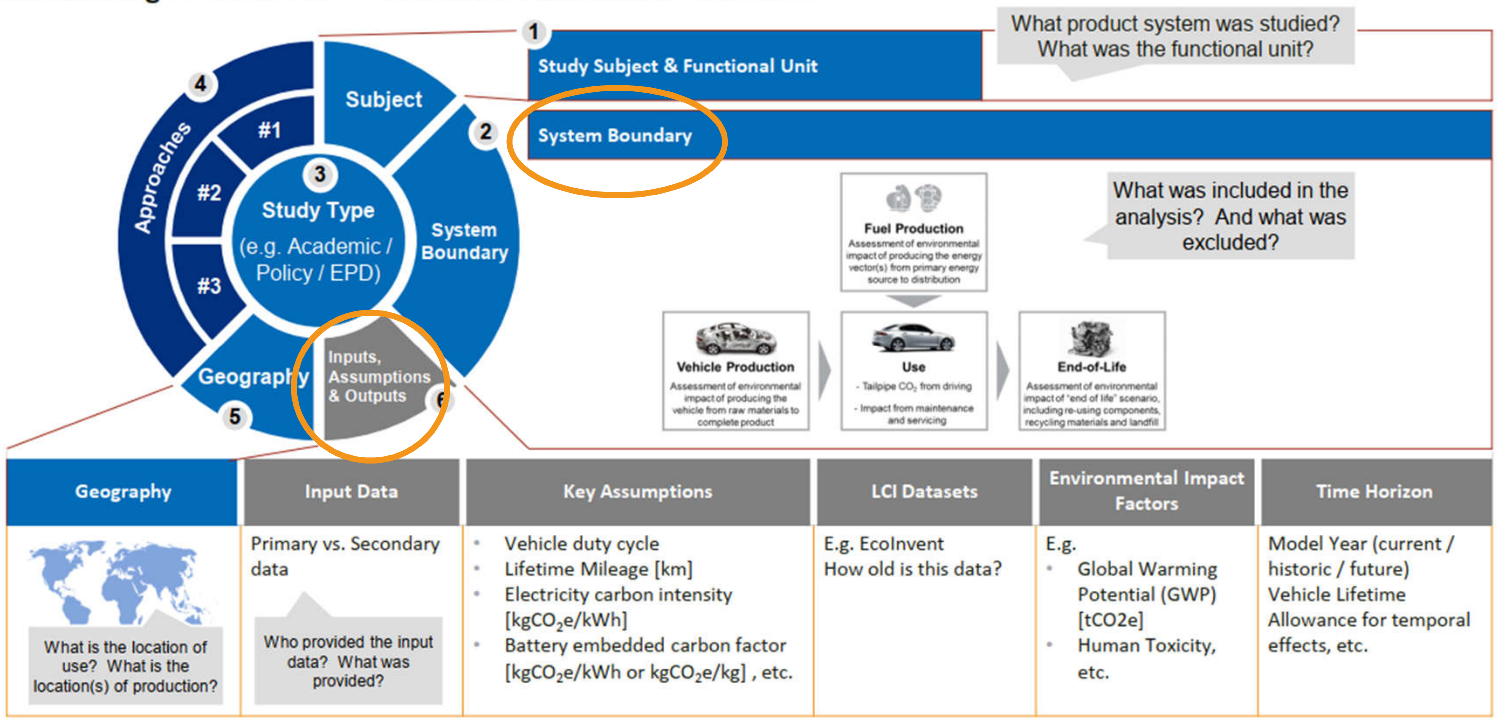
The BEV TCO presented here represents a worst case scenario – no tax credits plus expense of battery replacement.

Not factored into this analysis is opportunity cost associated with additional time spent charging a BEV at a public charging facility – how much is the inconvenience worth to a consumer?

The Study

Methodology – Literature Review

Understanding LCA Studies – "Guidance Framework" Overview



Identified >150 documents to start the review

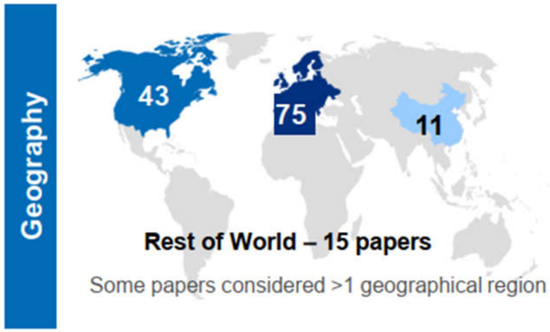
Literature Review Dashboard

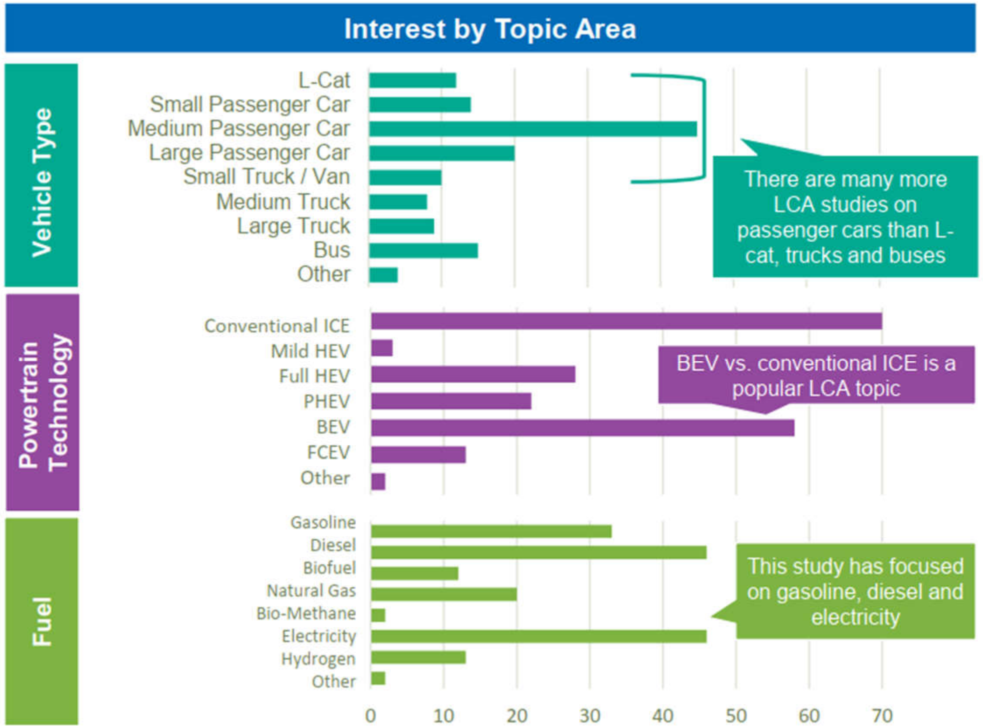
130+
papers & reports identified

15+
Literature Searches completed

papers scan read/ review in progress

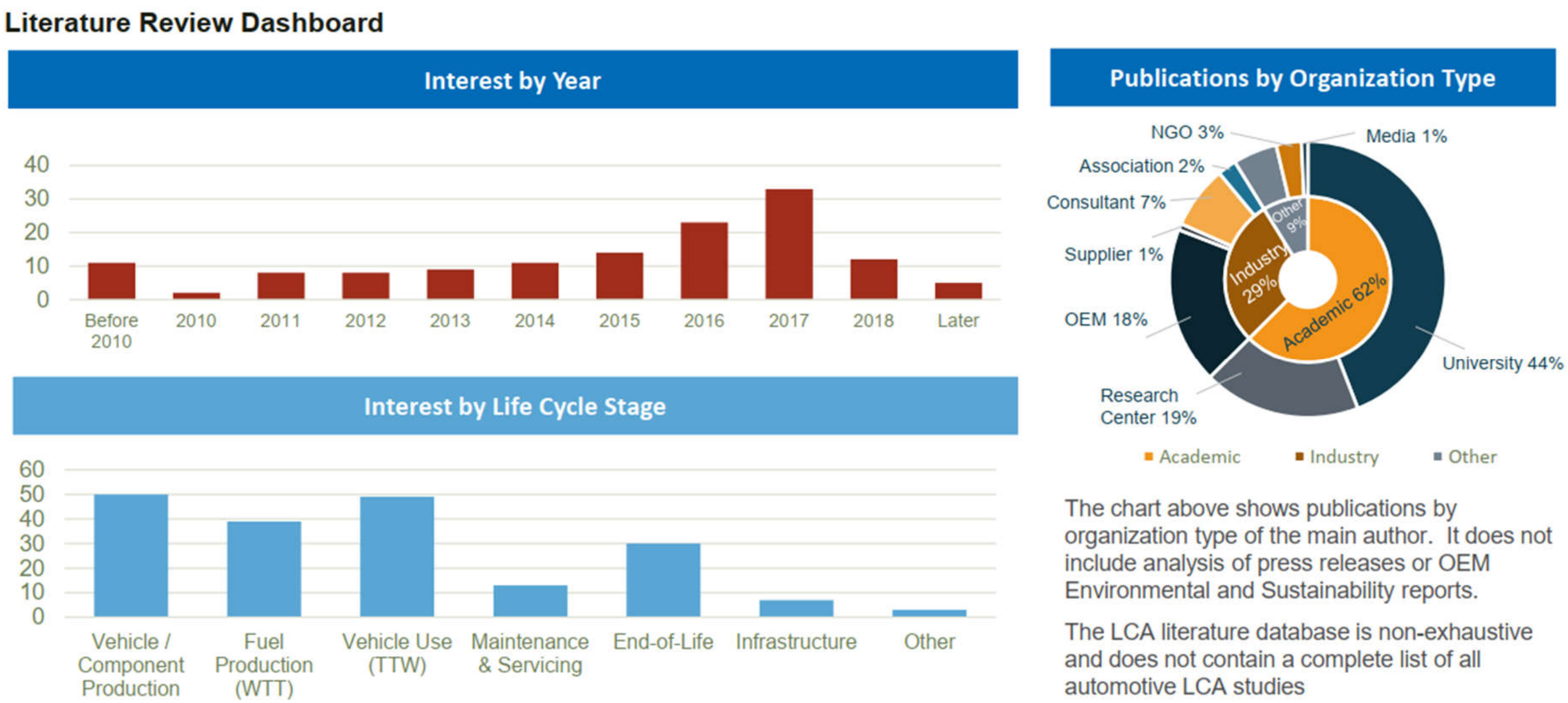
In addition **30** News Articles and **~20** OEM and Supplier Sustainability & Environmental reports also identified





Review focused on more recent publications

62% were from academic sources.

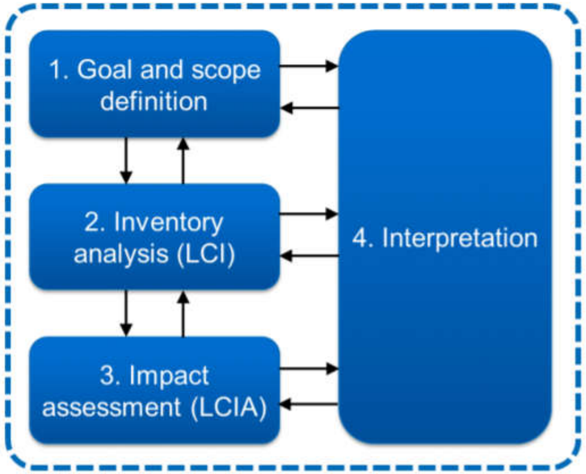


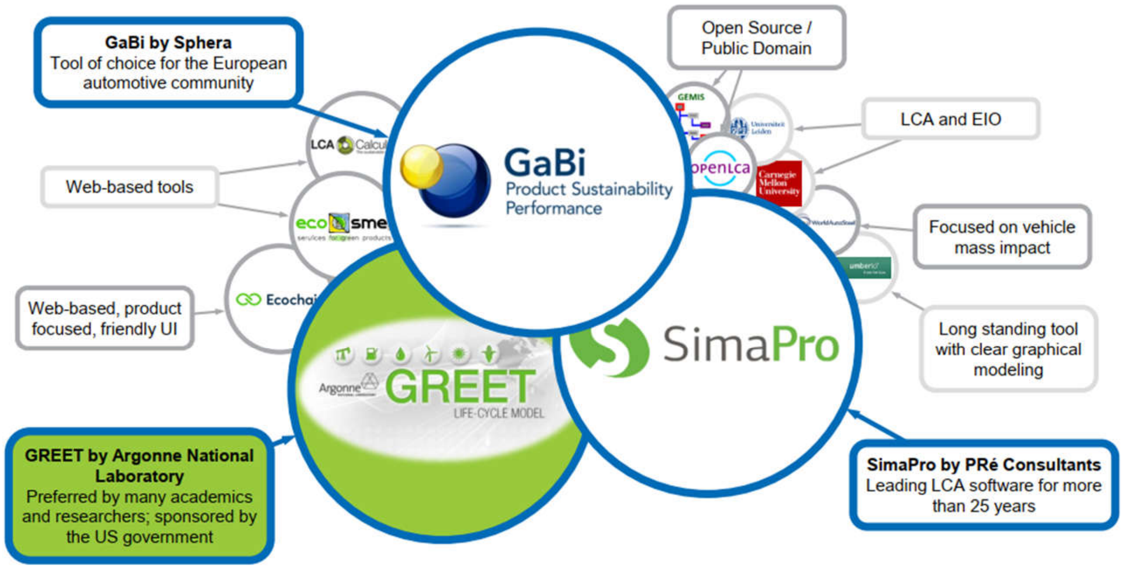
The chart above shows publications by organization type of the main author. It does not include analysis of press releases or OEM Environmental and Sustainability reports.

The LCA literature database is non-exhaustive and does not contain a complete list of all automotive LCA studies

Methodology LCA – Informed by Lit Review

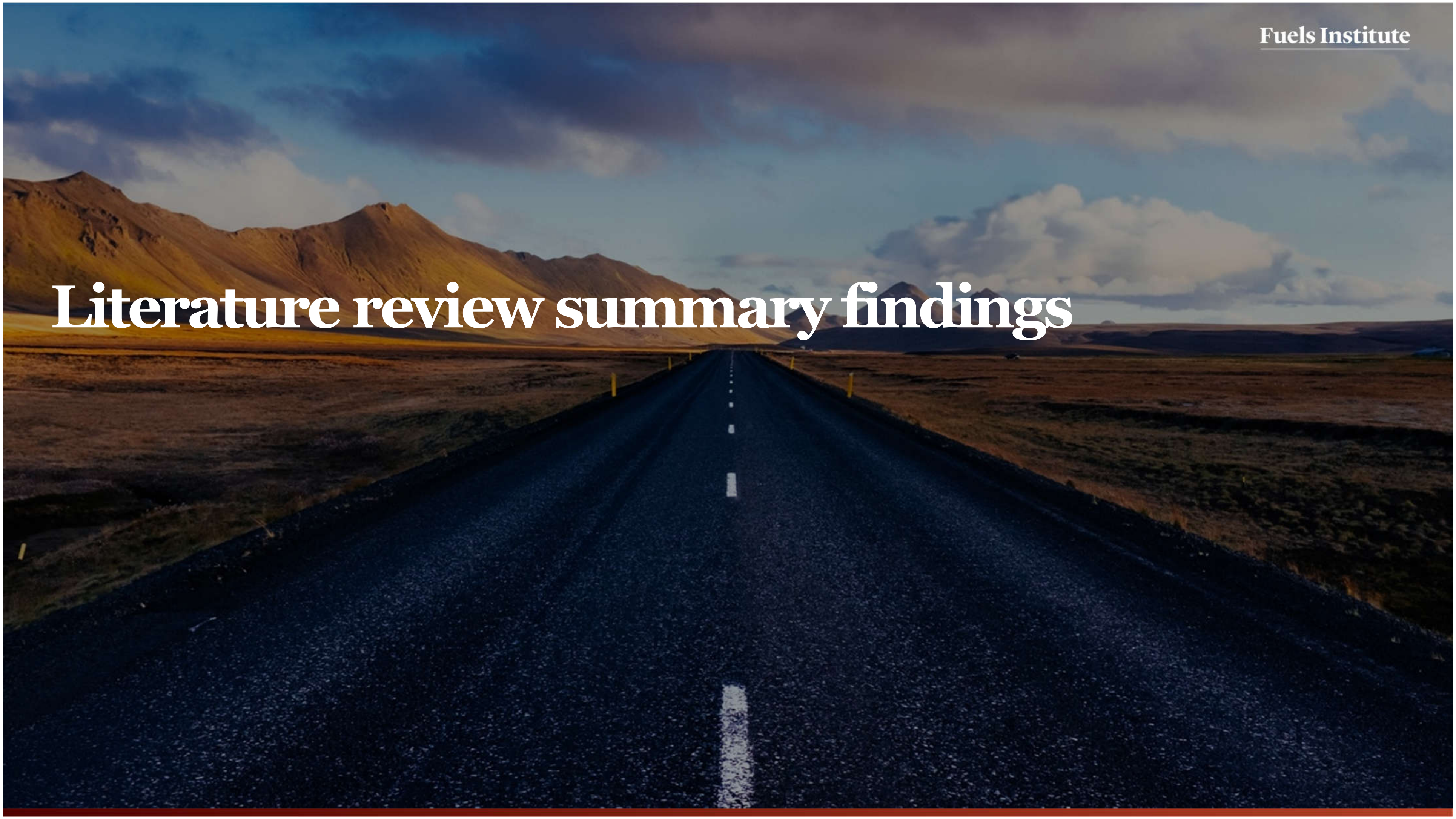
Breakdown life cycle stages into component parts and run each through GREET to determine CO2 emissions. Then, modify GREET results based upon various sensitivities that could affect overall vehicle emissions.





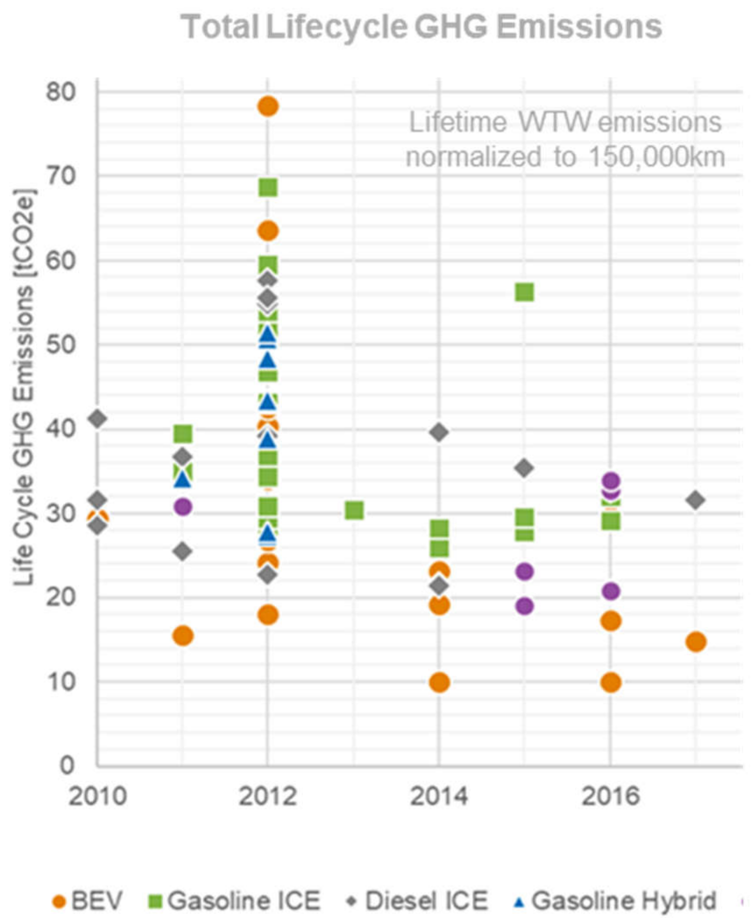
GREET series 2 would be used for any LCA modeling completed in this project.
GREET exists with two distinct model sets, GREET series 1 focuses on “use” LCAs (for example, Well-to-Wheel) and GREET series 2 focuses on product Cradle-to-Grave modeling

Literature review summary findings



Ricardo Energy and Environment Consulting - 2018

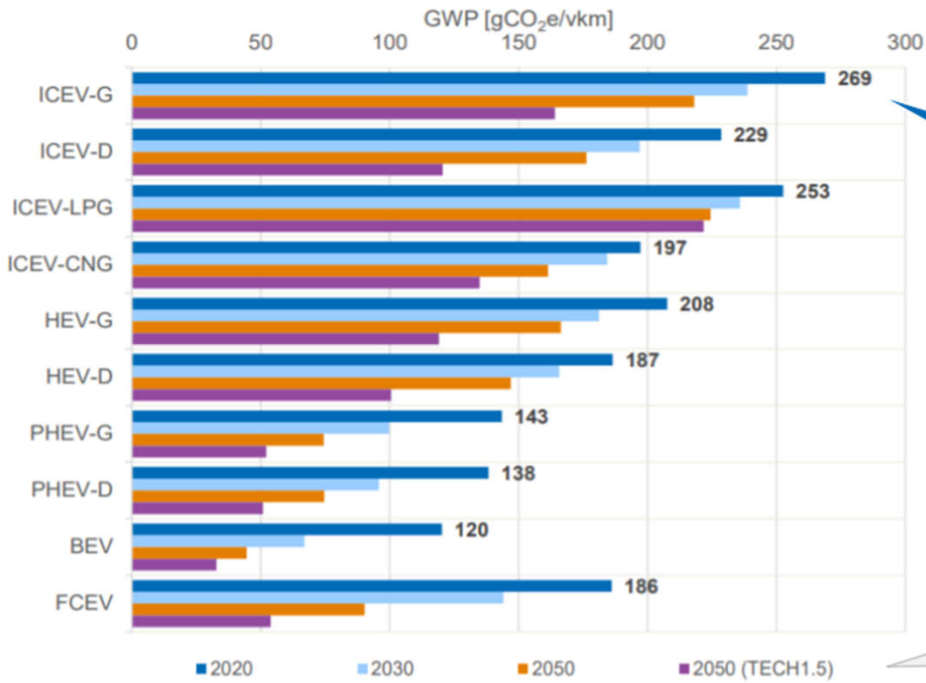
- Findings of most studies are aligned.
- Variations due to differences in vehicle and powertrain specifications, vehicle energy consumption, electricity and fuel carbon intensity, and study methodology.
- GHG emissions from BEVs and HEVs are lower than gasoline and diesel ICE equivalent vehicles in most LCA studies and sensitivity scenarios.
- Exception: Because BEVs have higher embedded GHG emissions, if the grid carbon intensity is as high as gasoline and diesel WTW emissions, then the BEV will have higher life cycle GHG emissions.



Passenger Car life cycle GHG emissions results from ~20 published studies, normalised to the same lifetime mileage (150,000 km)

Ricardo 2018 study continued

GWP = Global Warming Potential – read as “Carbon Emissions Equivalent/Vehicle Kilometer Traveled”



Light Passenger Vehicles

GHG emission results in alignment with ICCT research (results within 5%)

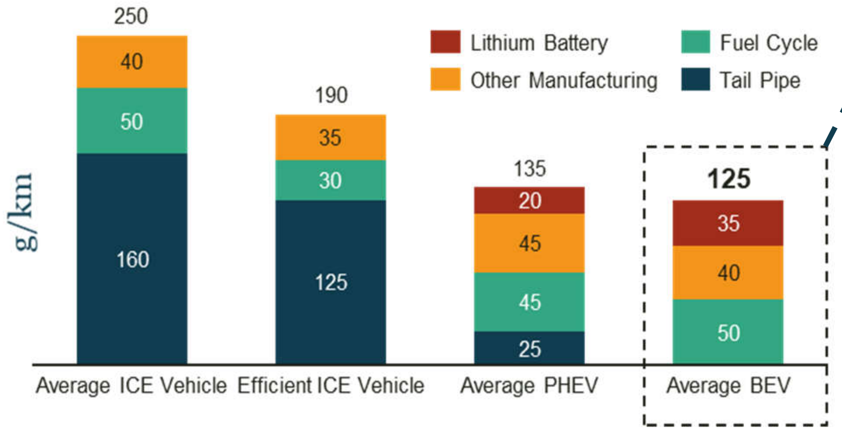
Cradle to Grave GHG Emissions

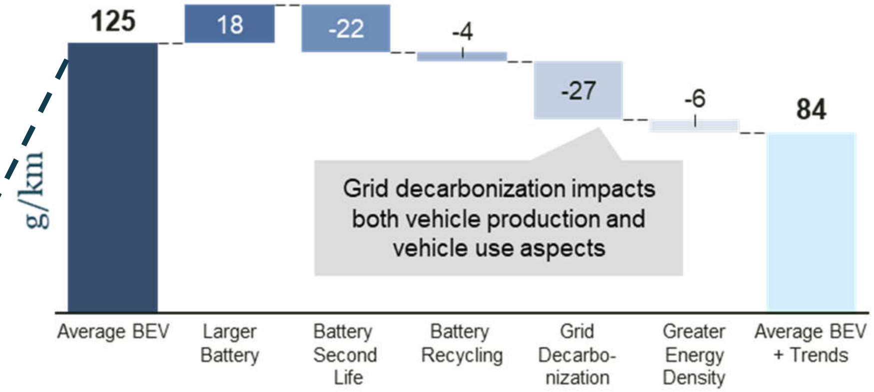
The results show that electrified powertrains have a lower GWP impact than conventional equivalents, that this benefit increases with an increasing degree of electrification and also that benefits increase over time

Tech 1.5 scenario represents case where the degree and tempo of technological advancement, adoption and penetration is much higher

ICCT LCA - 2018

In future scenario, grid decarbonization seems to have greatest influence on LCA for BEVs





Technology Trend	% change in battery manufacturing emissions	Change in lifecycle CO2 – g e/ km
Larger EV Battery	+33% to +66%	+18
Battery Second Life	N/A	-22
Battery Recycling	-7 to -17%	-4
Projected Grid Decarbonization	-17%	-27
Higher Battery Energy Density	-10 to -15%	-6

International Council on Clean Transportation

Reconciliation of multiple studies into electricity carbon intensity performed to understand the spread of results

1 GHG in g $CO_{2,e}$/MJ of electricity generation

Source	Coal	Oil	Natural gas	Hydro	Nuclear	Solar	Wind	Biomass	Geothermal
CAE (Chinese Academy of Engineering)	274.41	254.05	150.2	2.81	3.31	15.69	5.0	5.0	10.0
NEI	271.9	236.9	128.3	7.2	3.6	14.7	3.3	12.78	11.7
Buekers et al.	215.56	236.9	103.6	3.4	3.4	14.8	2.5	5.0	7.9
ANRE	270.8	206.1	156.5	3.1	6.5	14.7	8.1	5.0	4.2
E. Mallia, G. Lewis	277.2	183.6	131.2	6.1	1.4	14.7	3.1	4.1	7.9

- Based on the corresponding inputs and underlying assumptions in LCA calculations, the results of the analysis are distributed
- Study performed to evaluate the level of variability in electricity generation GHG emissions from the variations in the source of electricity

- Considering the current mix of electricity sources in the USA, the variability factor has been included in the estimating the range of GHG emissions
- **84 – 121 g CO2,e/MJ** is projected to be the GHG associated with electricity production in the USA as an average

Carbon intensity for electricity and gasoline production identifies the range of BEV and PHEV GHG emissions estimated in concurrent studies

2 GHG for gasoline production & utilization (g CO2,e/MJ)

Source	Gasoline
T. Peng, S. Zhou et al.	91.2
Argonne National Laboratory	89.3
E. Robert, L. Jeanfrancois et al.	87.2
J.C. González Palencia, et al.	92.0
K. Lattanzio Richard	99.8

- Considering the current mix of gasoline production, transport and utilization, the degree of variability of the GHG emissions potential is studied
- **87 – 100 g CO2,e/MJ** is projected to be the GHG associated with gasoline production and utilization
- CO2 emission factors of the vehicle-use phase (gasoline combustion in the ICE) is calculated based on fuel oxidation rate of gasoline for vehicles at 0.99

1

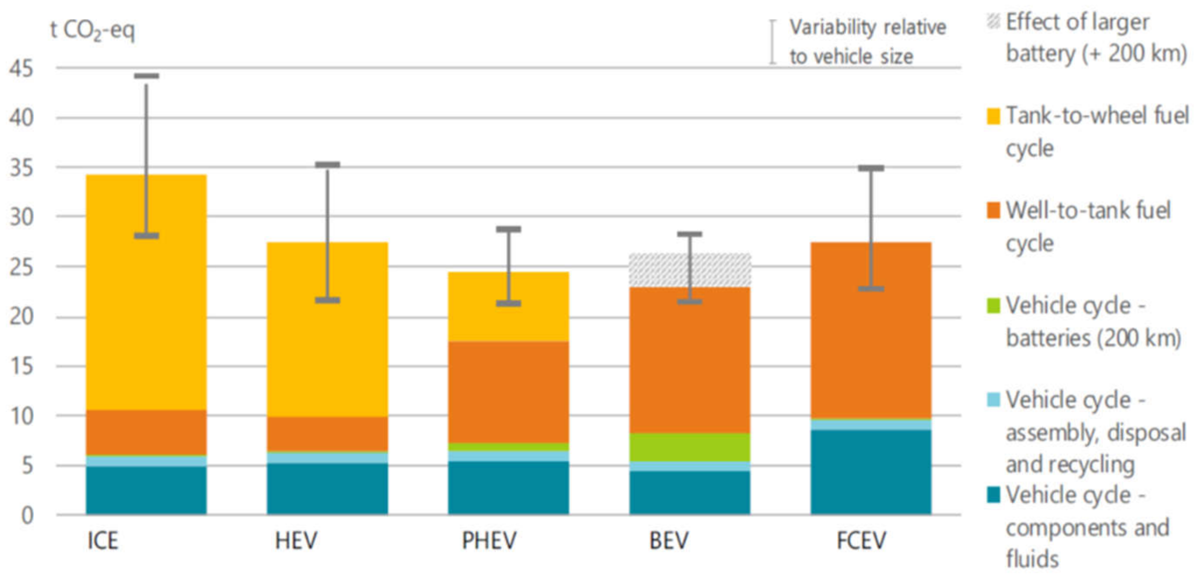
2

GHG emissions of operation of EVs in the USA

Data source	Item	Region	GHG Intensity (g CO2,e/km)
ICCT	BEV	U.S.A	125.0
Tianduo Peng, Xunmin Ou et al.	BEV	U.S.A	130.8
ANL	BEV	U.S.A	131.9
Orsi et al.	BEV	U.S.A	138.0
ICCT	PHEV	U.S.A	135.0
Tianduo Peng, Xunmin Ou et al.	PHEV	U.S.A	162.7
ANL	PHEV	U.S.A	168.6
Orsi et al.	PHEV	U.S.A	160.0

Comparison between ANL results and current model results highlights the significance of model input parameters in the results

Cradle to Grave GHG for vehicles – ANL research result

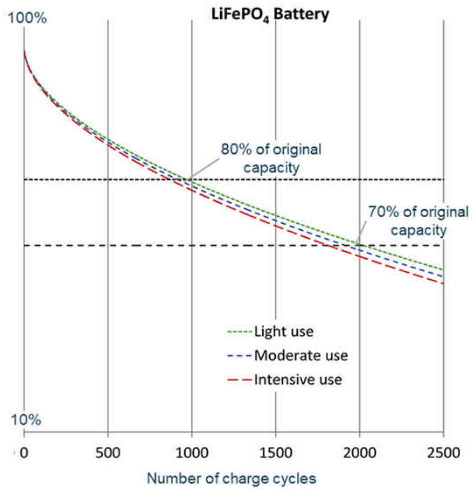


Key Factors

- ANL research is performed for VMT of ~120,000 miles
- Current estimations are being performed for 200,000 vehicle life
- In comparison with the results from the current analysis, there is a high degree of alignment for the vehicle manufacture portion of the LCA
- Vehicle operations portion is dependent on the mileage assumption
- Normalizing the mileage, the results from current analysis are within the bounds of variability as mentioned in the ANL research report

Battery Degradation Research

- Degradation is most often not included in LCA models
- OEMs typically warrant replacement of battery below 70% capacity
    - Estimated at 1,700 – 2,100 cycles of charging/discharging
- Intensive driving behavior lowers range on a battery charge
- Ricardo estimates 1 – 2.4 sets of battery packs over vehicle lifetime



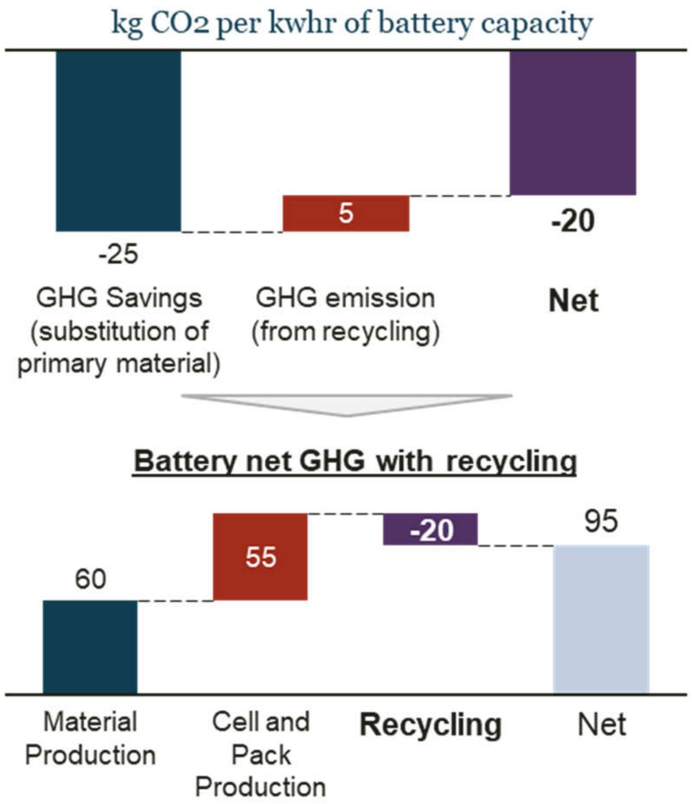
	Lithium Manganese Oxide 24kWhr			Lithium Iron Phosphate 24kWhr		
Use Case	Light	Moderate	Intensive	Light	Moderate	Intensive
Energy Consumption Wh/km	105	178	214	114	187	223
Driving Range (new battery)	229	135	112	211	128	108
Driving Range (EOL battery – 70% capacity)	160	94	79	147	90	75

	Lithium Manganese Oxide			Lithium Iron Phosphate		
Use Case	Light	Moderate	Intensive	Light	Moderate	Intensive
Total Energy Transferred (kWhr)	18,905	17,896	16,947	24,572	23,260	22,019
Total Distance Travelled (km)	180,047	100,541	79,192	214,703	124,086	98,544
Use Cycles	1555	1472	1394	2022	1914	1812
Number of batteries required (for 200k km life)	1.1	2	2.4	1	1.6	2

Equivalent number of batteries to follow a similar lifecycle as ICE vehicles

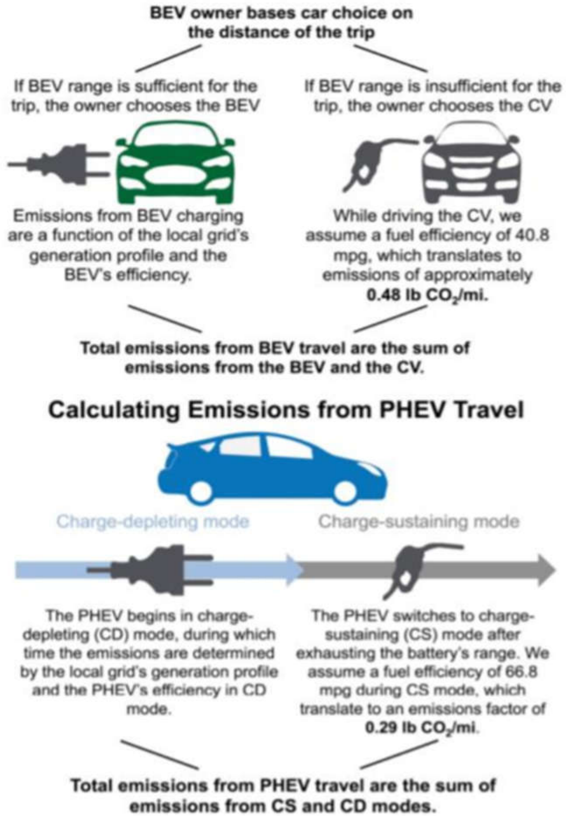
Battery Repurpose/Recycling LCA

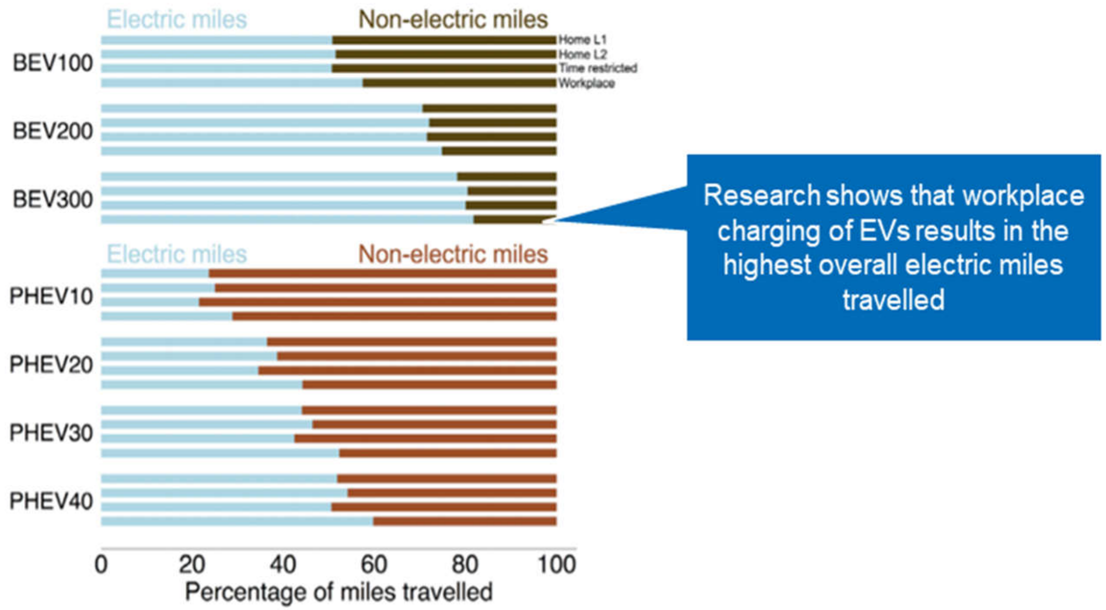
- Discarded vehicle batteries retain 70% of their initial capacity
- Many are re-deployed to stationary applications, like storage for renewable energy sources
- Recycling performed to extract nickel, cobalt and aluminum
- Purity standards stringent wrt re-using materials in new cells, constraining benefits of recycling and challenging the economics
- Despite limitations, there is a projected net reduction in GHG emissions from recycling



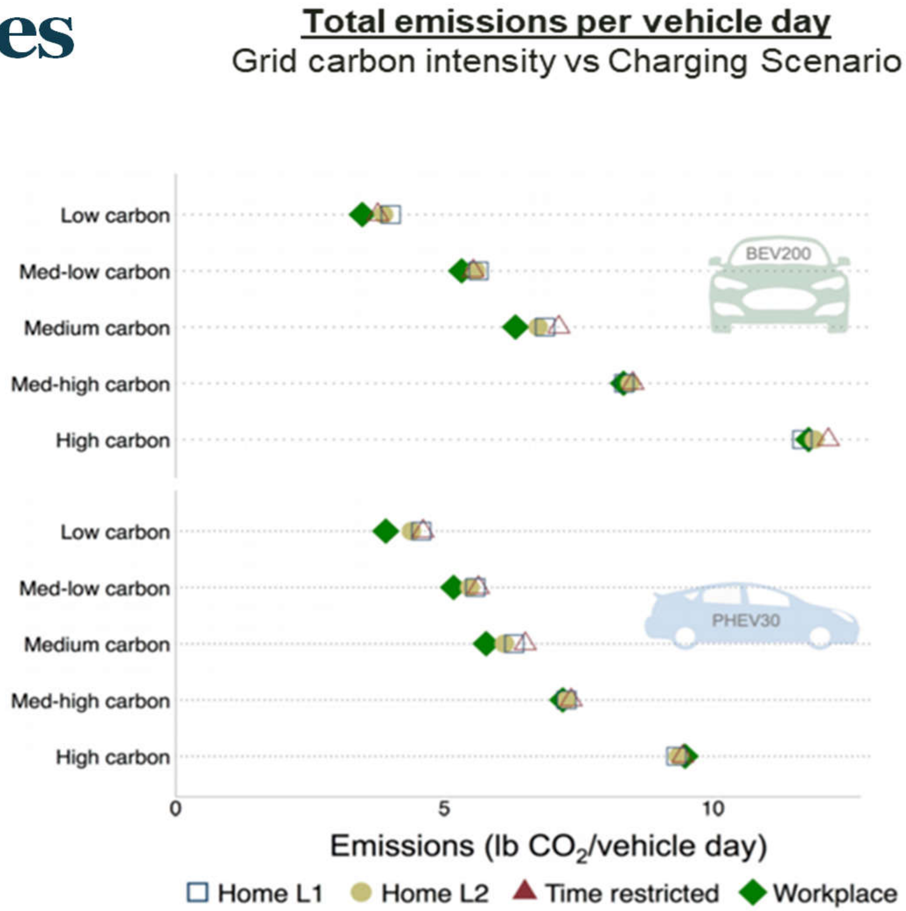
Charging Scenario Study - NREL

Studied the fraction of electric and non-electric miles traveled by EV owners as well as GHG emissions associated with grid carbon intensity



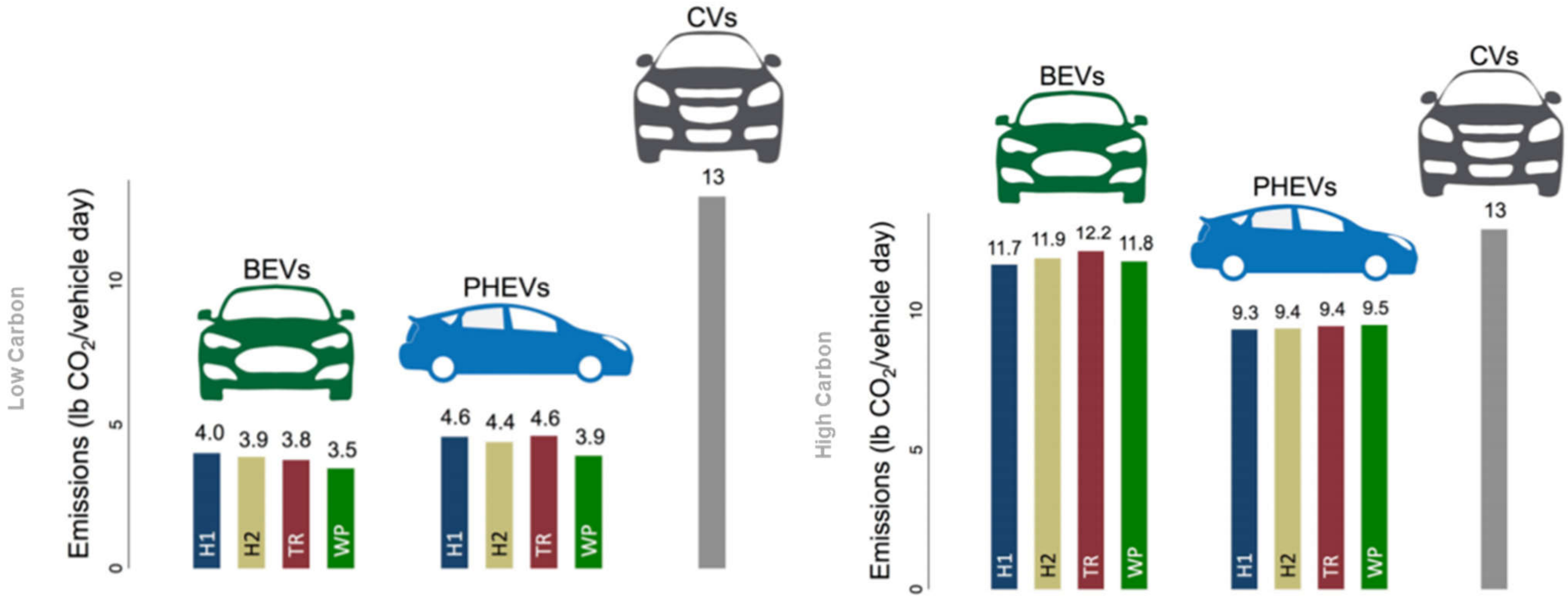


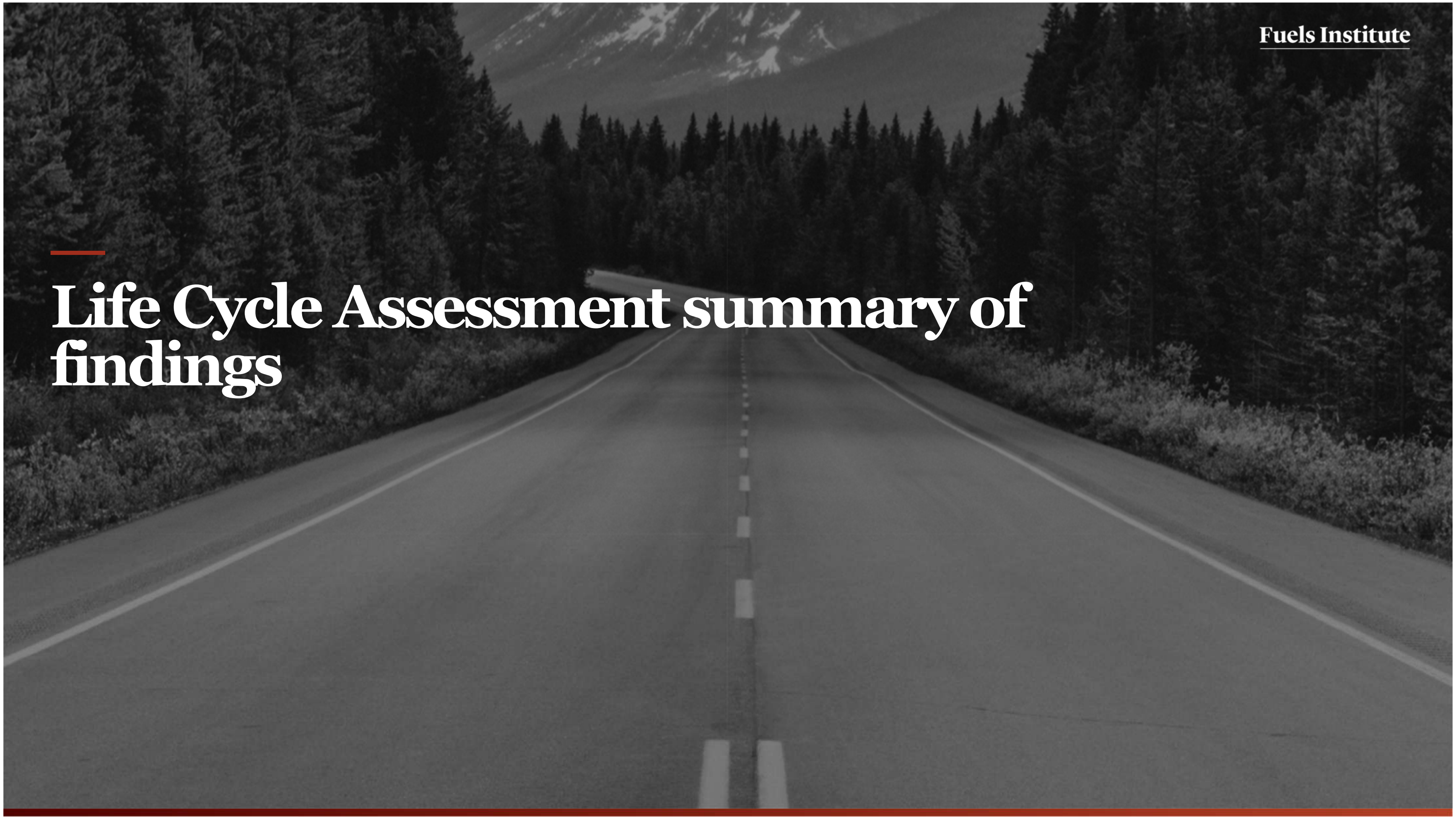
Grid influences emissions



Charging Scenario Study – NREL (cont'd)

Comparing total emissions from vehicles wrt to carbon intensity of the grid (assumes BEV are electric, does not consider non-electric miles driven)





Life Cycle Assessment summary of findings

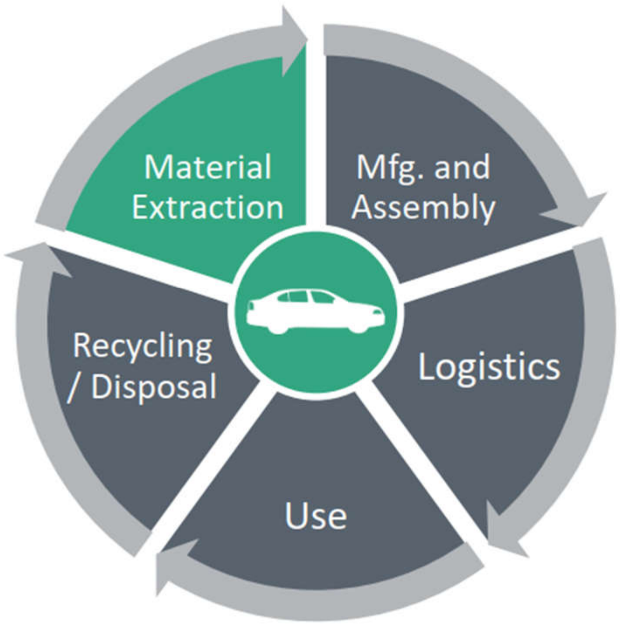
LCA Methodology

Leveraged the open source, highly credible GREET Model to run the life cycle analyses

- Material Extraction
- Manufacturing and Assembly
- Operation Cycle
- Vehicle After Life Management
- Sensitivity Analysis
    - Mileage
    - Electric Grid
    - Ambient Temperature
    - Driving Style
    - Vehicle Weight
    - Battery Chemistry
    - Battery Energy Density
    - Alt Fuels

Material Extraction

Base Case Analysis



	ICE Vehicle	BEV	HEV
Glider	Chassis components similar for the vehicle configurations except BEVs do not carry the intake and exhaust systems		
Powertrain	Includes engine, transmission, driveline	Includes battery packs, traction motors, transmission	ICE + BEV systems (different capacities)
Fluids	Engine Oils, Transmission Fluid, Lubricants	Transmission Fluid	Engine Oils, Transmission Fluid, Lubricants

Material Extraction – Weight Assessment

Determine the typical mass of system, evaluating corresponding elements and their respective weight using A2Mac1 Automotive Benchmarking. Weight of each subsystem then subjected to GREET to determine CI.

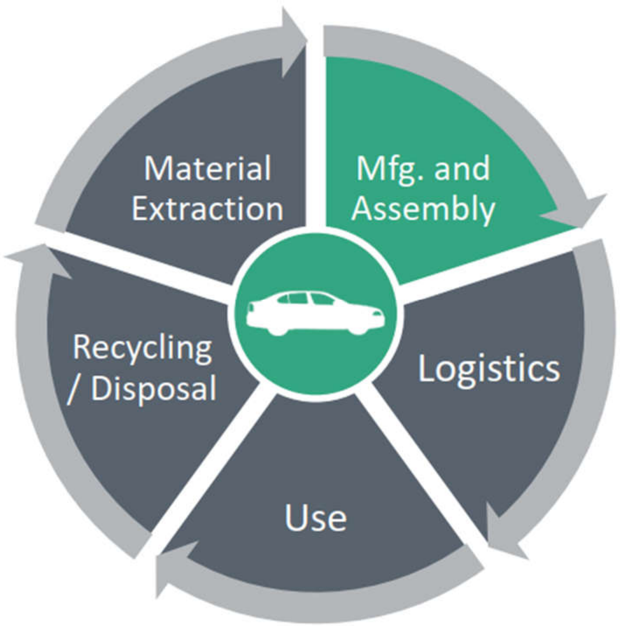
Normalized Subsystem Weight (lbs)	ICEV	HEV	BEV
Powertrain System	488	772	153
Transmission System	201	171	182
Chassis Systems	809	739	789
Traction Motor		73	228
Generator		73	
Control Unit & Electronics		61	188
Body	1,685	1,540	1,644
Battery Pack	36	142	1,211

Material Extraction – Findings

GHG Emissions *kg of GHG/ vehicle*	ICEV	HEV	EV
Powertrain System	573	1,351	1,790
Transmission System	294	309	267
Chassis	1,001	1,128	977
Body	2,016	2,270	1,967
Fluids	104	98	62
Intake	10	9	
Precious Metals	21	20	
Total	**4,021**	**5,185**	**5,062**

Manufacturing and Assembly

Base Case Analysis



ICEV | **HEV** | **BEV**

Vehicle Manufacturing & Assembly

Similar for various vehicle types

Standard inventories in-built in GREET will be used

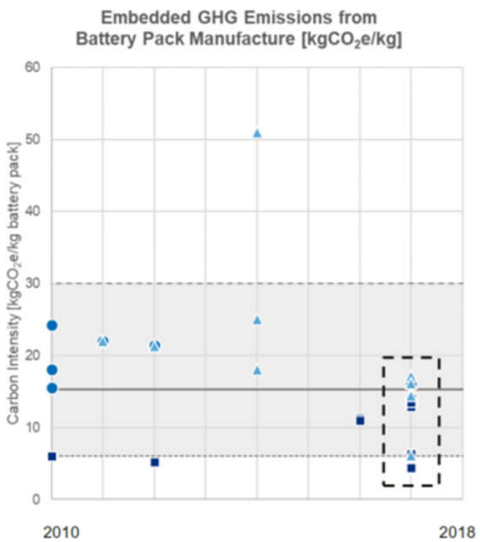
Powertrain Manufacturing & Assembly

- Battery systems build and assembly
- Engine, transmission, drivelines build and assembly

Standard inventories in-built in GREET will be used

Many studies evaluate LCA of battery mfg.

Summary of Literature on GHG Emissions associated with manufacture of Li-Ion batteries



Research Paper	Adjusted kg CO2/kg of battery
ANL Research	12.2
Saeed Rahimpour Golroudbary, Daniel Calisaya Azpilcueta et al.	15.8
Guillaume Majeau-Bettez*, Troy R. Hawkins, and Anders Hammer Strømman	16
M. Zackrisson, L. Avellán, J. Orlenius	14
C. Bauer	14
D.A. Notter, M. Gauch, R. Widmer, P. Wäger, A. Stamp, R. Zah, et al.	13.8
Yuhan Liang, Jing Su, Beidou Xi et al.,	12.7

Range of adjusted GHG emissions from manufacturing of Lithium-ion batteries from literature review

12-16 kg of GHG per kg of battery

- Adjustment from kg/ kWhr carried out assuming a standard US vehicle battery weighing 6 kg per kWhr
- Research materials all do not reference the same battery chemistry – in such cases the adjustment is performed using normalization from a bottom-up approach
  - Broken down in to corresponding components and unique approach of normalization is followed for each individual component
  - Additional details in the appendix

Manufacturing and Assembly - Findings

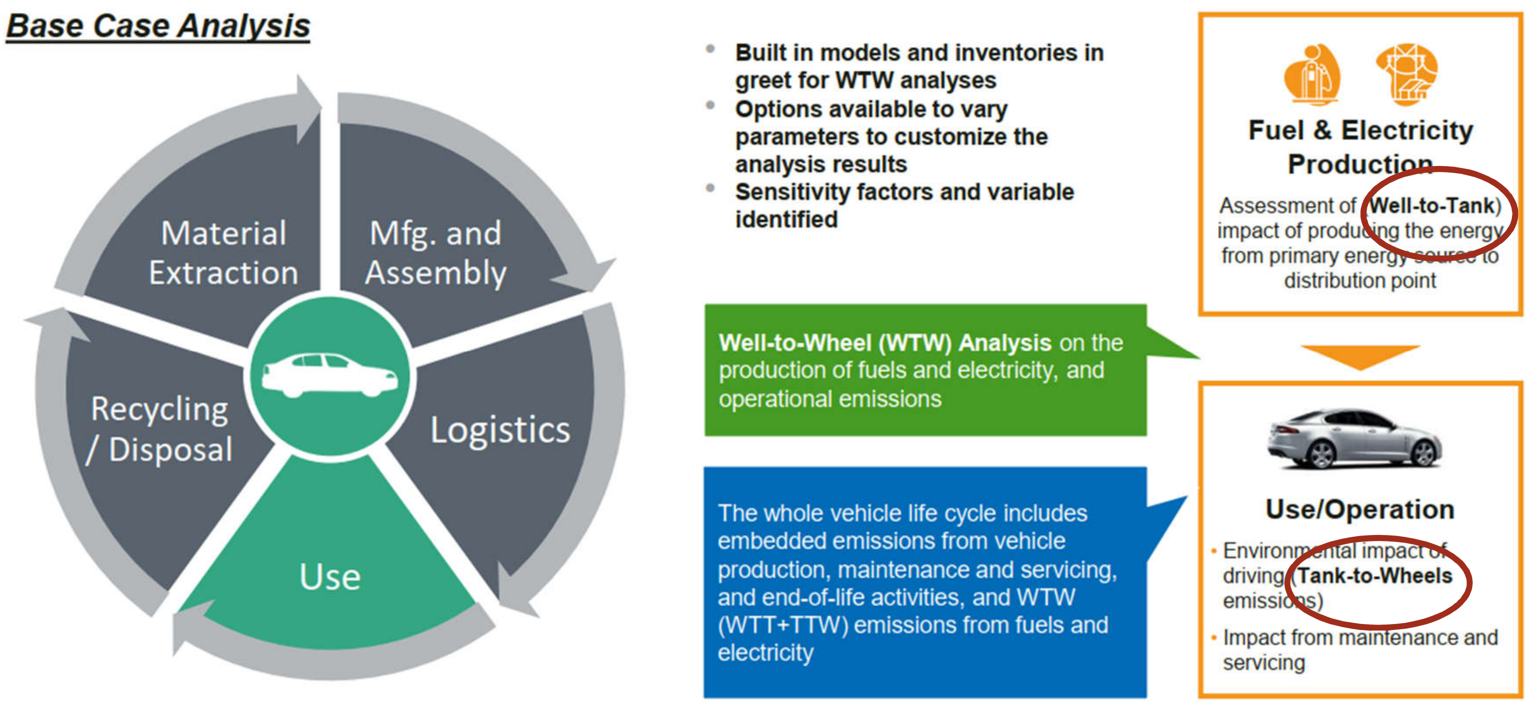
GREET LIFE-CYCLE MODEL

Model Output

GHG emissions (kg GHG/ unit weight)	ICEV	HEV	EV
Battery Processing + Assembly	-	38.54	38.54
Vehicle Processing + Assembly	0.74	0.74	0.74
Lead-Acid Battery	0.8	0.8	0.8
Castings	0.66	0.66	0.66

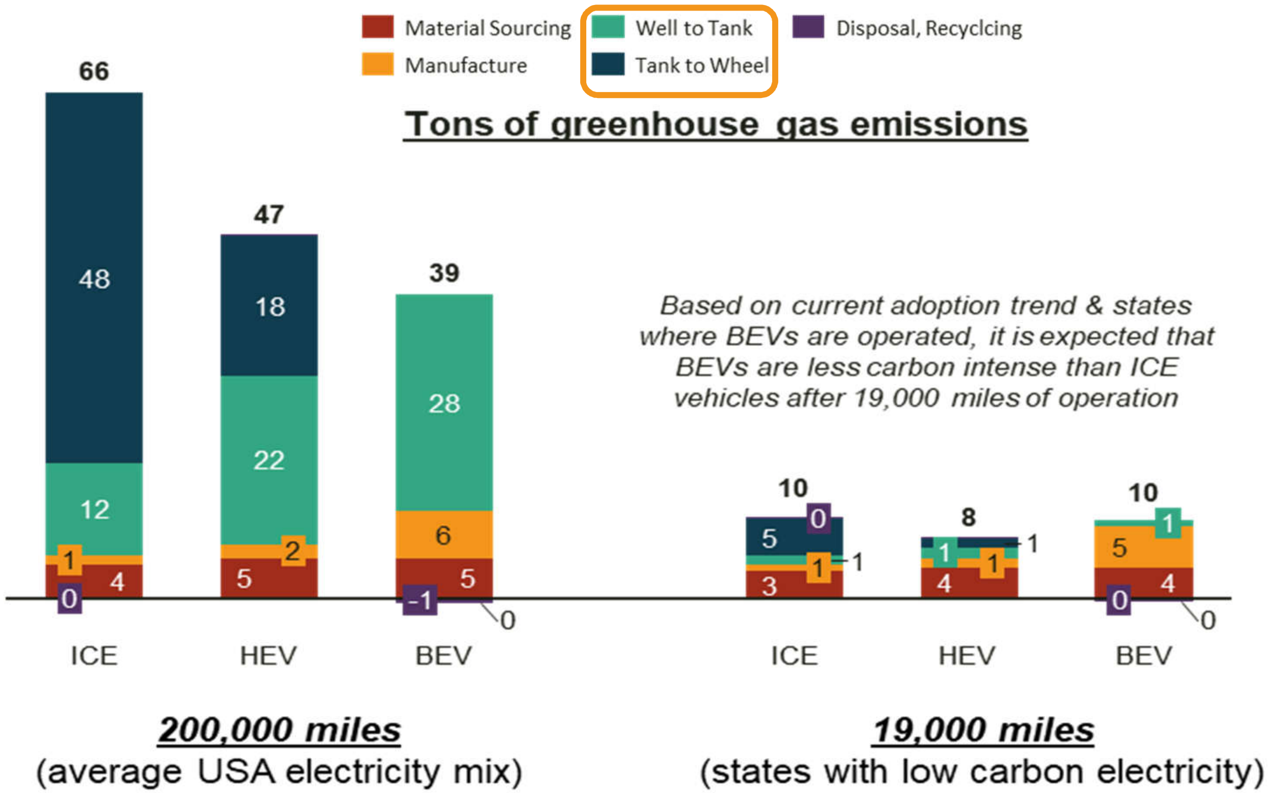
GHG Emissions *kg of GHG/ vehicle*	ICEV	HEV	EV
Battery Material Processing	-	41	319
Battery Assembly	-	467	5,094
Vehicle Processing + Assembly	1,066	1,133	988
Lead-Acid Battery	13	8	8
Castings	53	38	12
Total	**1,132**	**1,687**	**6,420**

Operation Cycle



High Level Summary – LCA Comparison

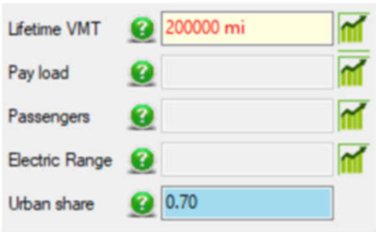
Mileage and carbon intensity of grid influence LCA, but in most cases BEVs emit less carbon

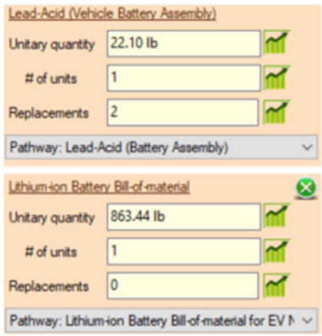


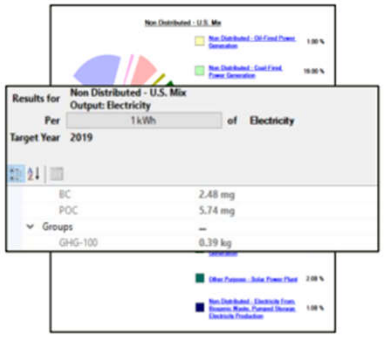
Operation Cycle

Input Parameters

SI HEV
300 BEV – NMC Battery
SI ICEV E10







Vehicles Considered

ICE vehicle with E10 capability, BEV with an estimated 300-mile range and hybrid electric vehicle with a 30-mile range battery are considered for the analysis

Vehicle Driving Parameters

For this simulation, 200,000 miles is considered the life of the vehicles and urban share of 0.7 as default is considered

Vehicle Components

Base case scenario assumes no HV battery replacement, and this will be considered as a part of the sensitivity factors

Electricity Mix

US average electricity mix and the corresponding carbon intensity is considered as the base

Operation Cycle

BEVs emit 53% less kg of CO2 per mile than comparable ICE, while HEVs emit 33% less

FIGURE 37: WELL TO WHEEL GREET MODEL OUTPUT PER UNIT MASS OF SUBSYSTEMS

Vehicle operational results analyzed using customized GREET models

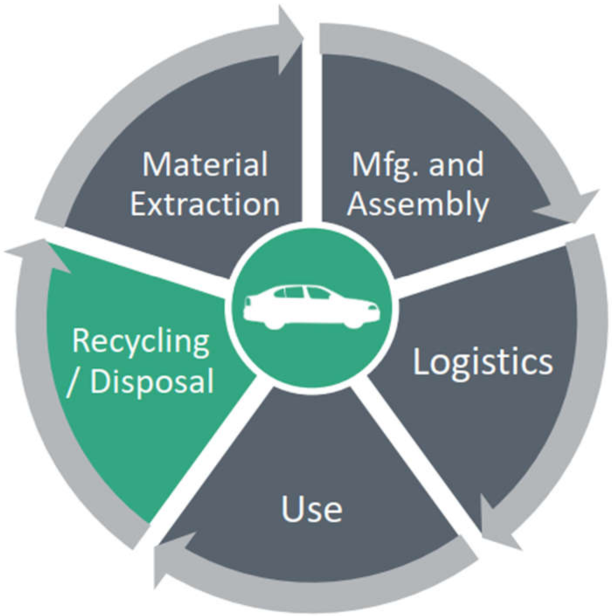
Name	WTP	TTW	WTW
BEV	0.14	-	0.14
ICE	0.06	0.24	0.30
HEV	0.11	0.09	0.20

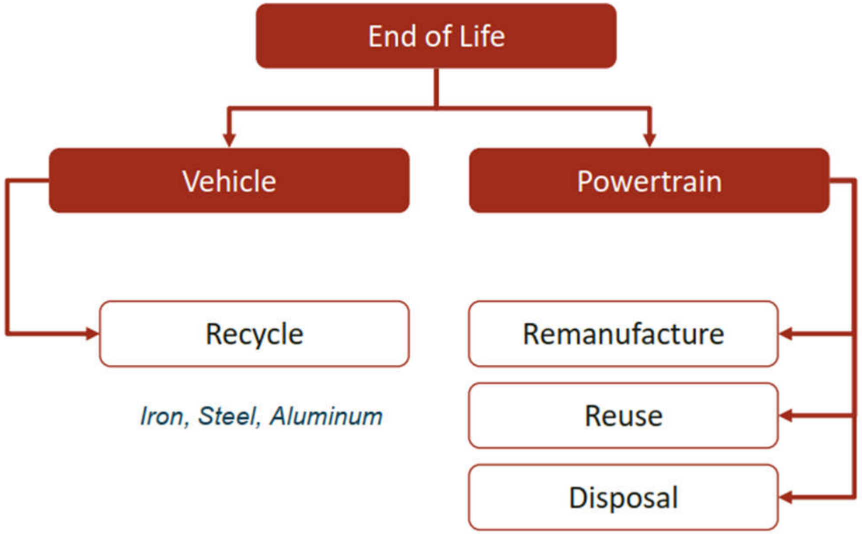
CO2 in (kg/mi)

WTP – Well to Pump, TTW – Tank to Wheel, WTW – Well to Wheel

Vehicle After Life

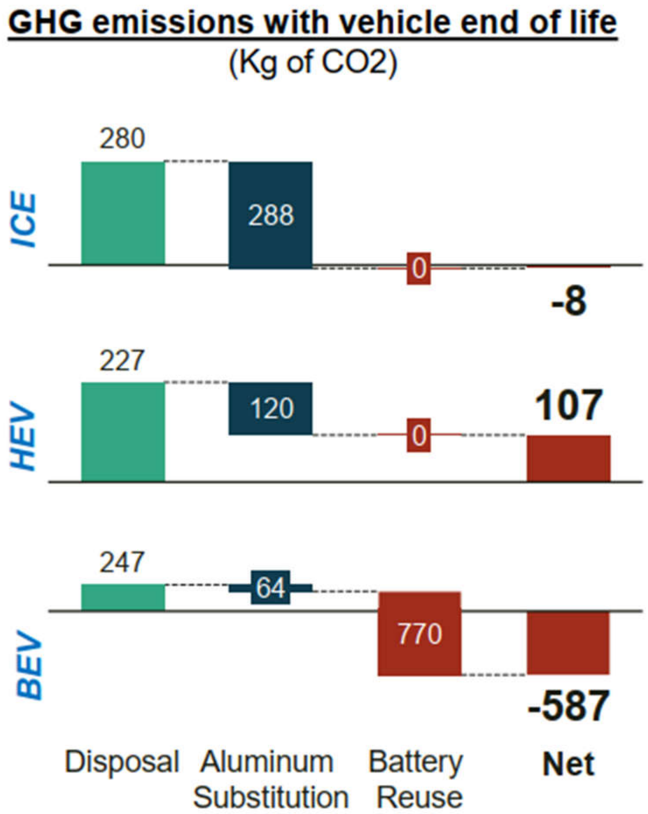
Base Case Analysis





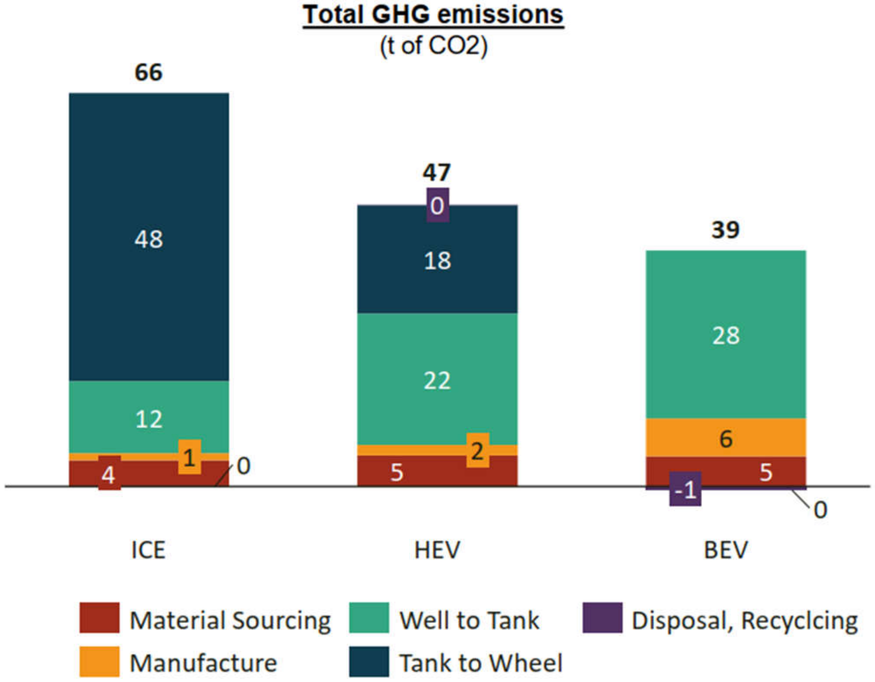
Vehicle After Life

Reusing BEV batteries provides a significant reduction in cradle-to-grave CO2 emissions.



Cradle to Grave GHG Emissions - Baseline

Ricardo used the GREET model to evaluate independent LCA for each component, which can be used to validate the results of the literature review. The output seems to indicate relative consistency across the literature, with some modest variability.



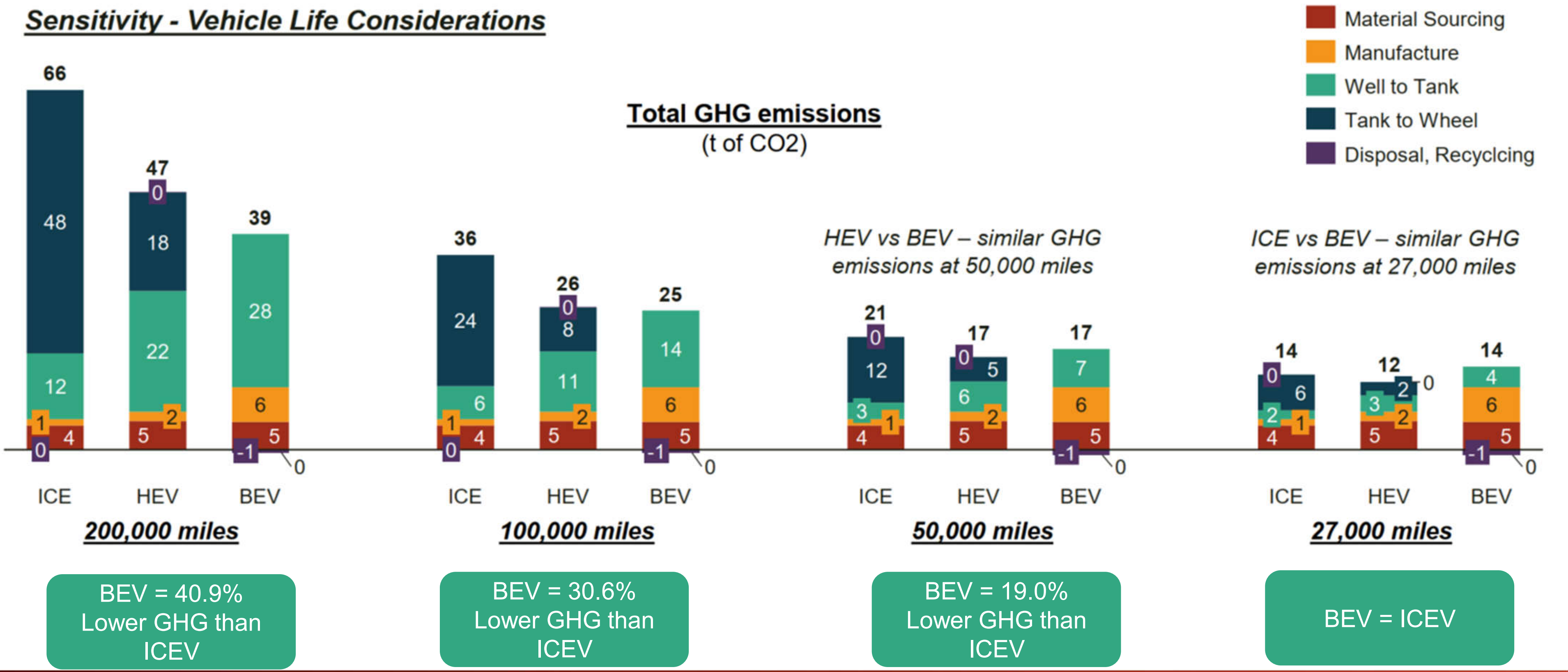
	ICE	HEV	BEV
Material Sourcing	4	5	5
Manufacture	1	2	7
WTT	12	22	28
TTW	48	18	0
Disposal, Recycling	0	0	-1
Total	**66**	**47**	**39**

- 200,000 miles considered as the lifetime vehicle life
- Operational GHG emissions are hence a higher proportion of the emissions

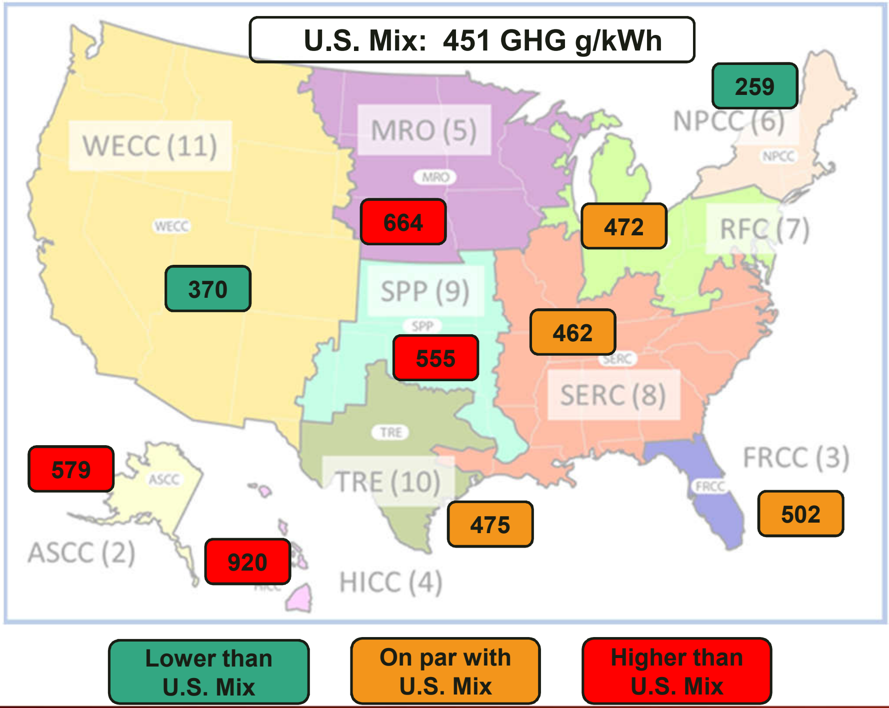
Sensitivity Analysis

Vehicle Mileage Sensitivities

Assuming U.S. average grid carbon intensity



Electric Grid Sensitivities



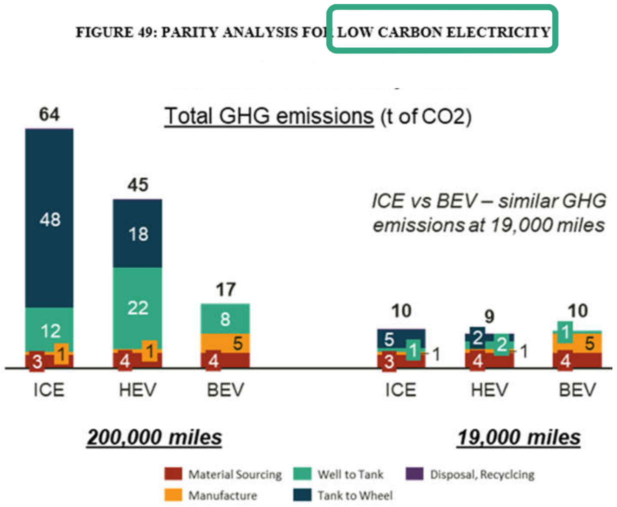
Current Electricity Mix in the USA (%)

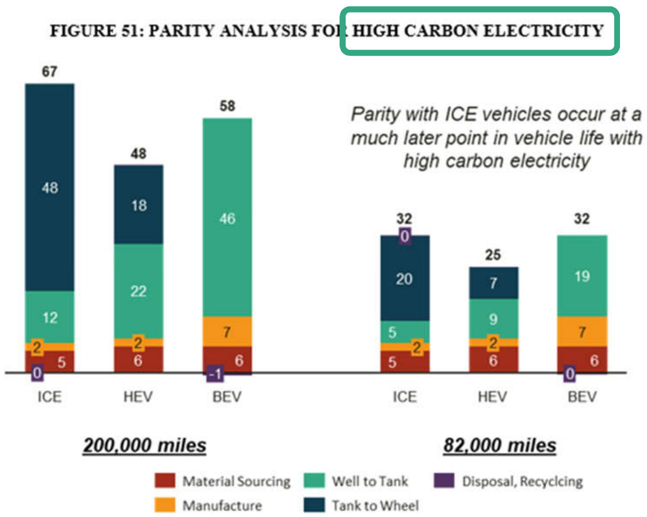
	US National Average	Michigan	Maine	West Virginia
Natural Gas	40	33	17	5
Nuclear	20	29	-	-
Coal	19	27	1	89
Wind	8	7	24	3
Hydro	7	-	34	3
Solar	2	1	1	-
Biomass	1	2	20	-
Oil	1	1	-	1
Geothermal	1	-	-	-
Other Fossil	1	1	3	-

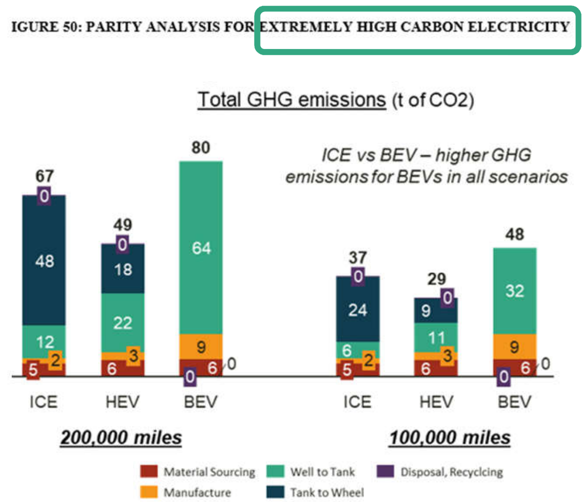
Electric Grid Sensitivities

Charts Show: The lifecycle emissions in tons of CO2 when operating under different grid carbon intensities.

BEV CO2 Emissions at 200,000 miles compared with:	Low Carbon	High Carbon	Extremely High Carbon
ICEV	73% Lower	13% Lower	19% Higher
HEV	62% Lower	21% Higher	63% Higher



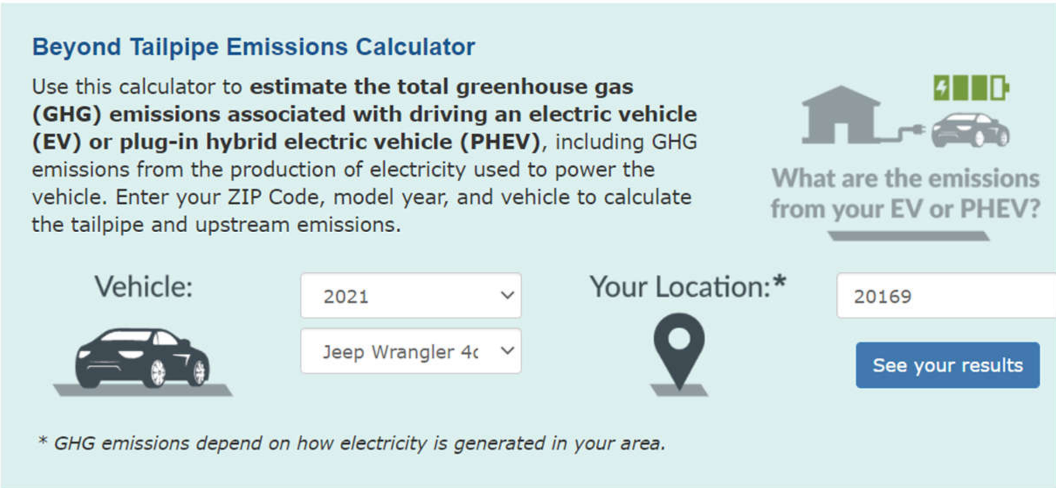


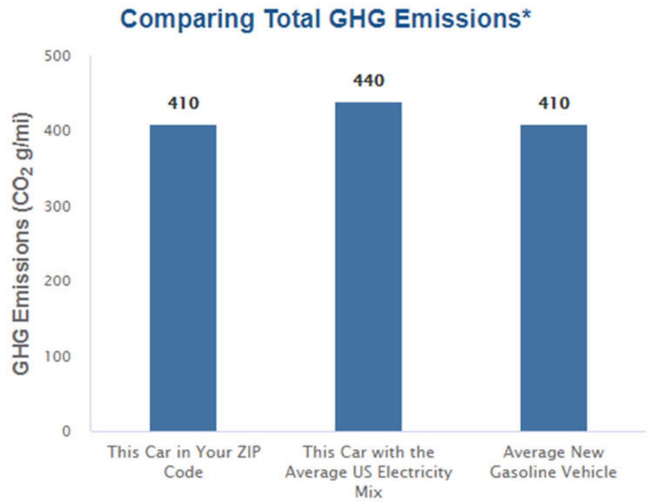


GHG emissions calculator from DoE

Go to www.fueleconomy.com and search for “emissions calculator”

Greenhouse Gas Emissions from Electric and Plug-In Hybrid Vehicles





410 g/mi This Car's Total Emissions in your ZIP Code (Tailpipe + Upstream)	**440** g/mi This Car's Total Emissions with the Average US Electricity Mix	**410** g/mi Average New Gasoline Vehicle's Total Emissions

About these calculations

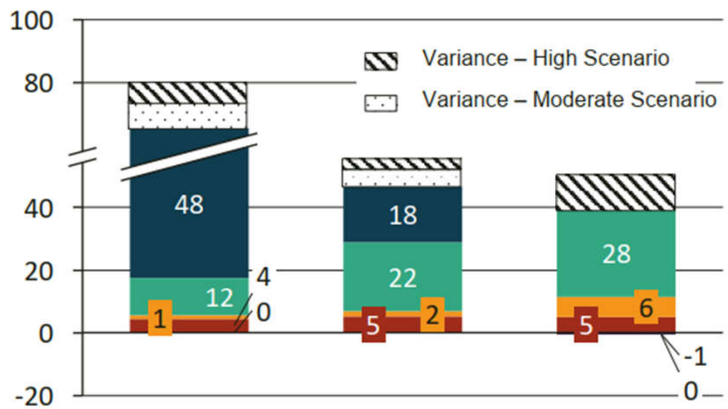
Tailpipe emissions for this vehicle are 230 g/mile.

Temperature Sensitivities

Temperature Sensitivity

- Temperature variations significantly affects the performance of all vehicles – especially BEVs
- Colder weather impacts the performance of the vehicles as the need for cabin heating is energy intensive and the performance is poor for vehicles with a lower average trip distance
- ICCT studied the performance range of the vehicle powertrains over a range of ambient temperatures
- Variation in the emissions with temperature is studied to quantify the impact

	Scenarios
ICE	15 - 24% drop in efficiency (Moderate – High)
HEV	30-34% drop in efficiency (Moderate – High)
BEV	~40% drop in efficiency



Lifetime GHG Emissions

	ICE	HEV	BEV
Base	66	47	39
Moderate	75	59	50
High	80	61	

Moderate Scenario - 10°C lower temperature than Base
High Scenario - 20°C lower temperature than Base

Driving Style Sensitivities

Low Scenario: Moderately Aggressive Driving; High Scenario: Extremely Aggressive Driving

Aggressive Driving Style → Vehicle Fuel Efficiency

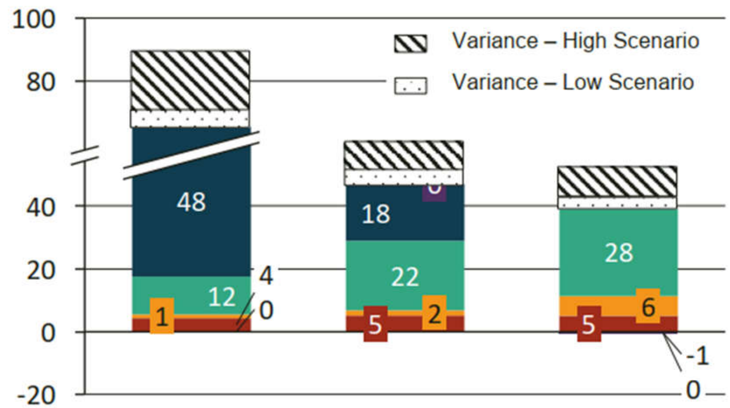
Aggressive Driving Style → Accelerate Battery Degradation

10 – 40% reduction in fuel economy is estimated with aggressive driving

Battery degradation factor

Light	Moderate	Intensive
1	1.8	2.4

Replacement using remanufactured batteries considered with ~30% attrition rate



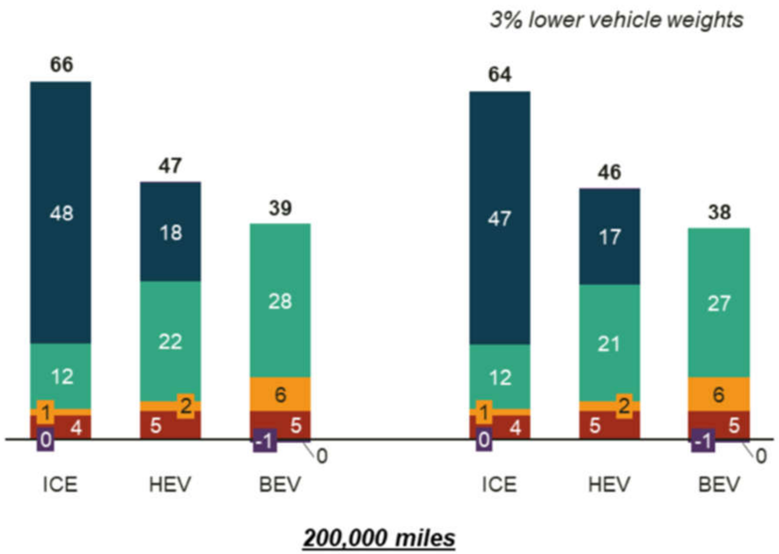
Lifetime GHG Emissions

	ICE	HEV	BEV
Base	66	47	39
Low Scenario (10% fuel economy drop, 1.8x batteries - including new & remanufactured)	72	51	44
High Scenario (40% fuel economy drop, 2.4x batteries - including new & remanufactured)	90	63	53

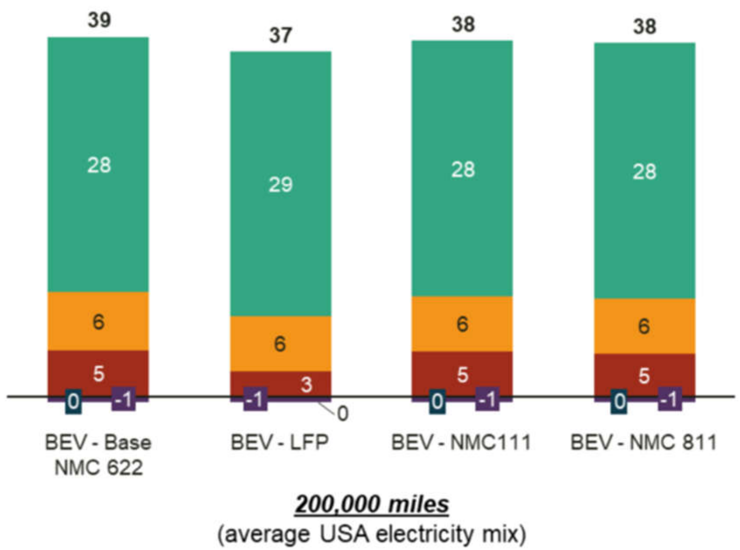
Small variations for weight and chemistry

Estimate: For every 5% drop in weight, vehicles improves efficiency by 1.3%

Vehicle Light-weighting

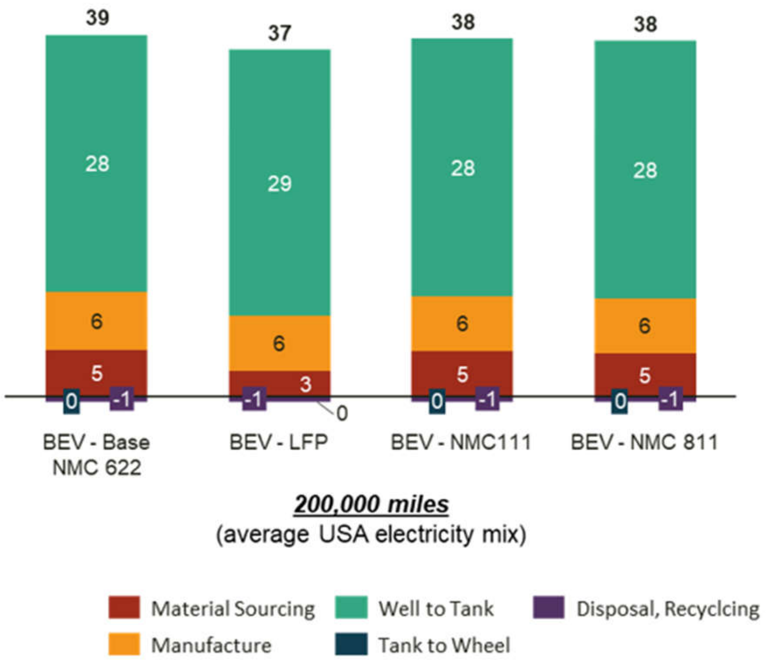


Battery Chemistry



Battery Chemistry Sensitivities

FIGURE 55: BATTERY CHEMISTRY SENSITIVITY



NMC – lithium nickel manganese cobalt oxide; LFP – lithium iron phosphate

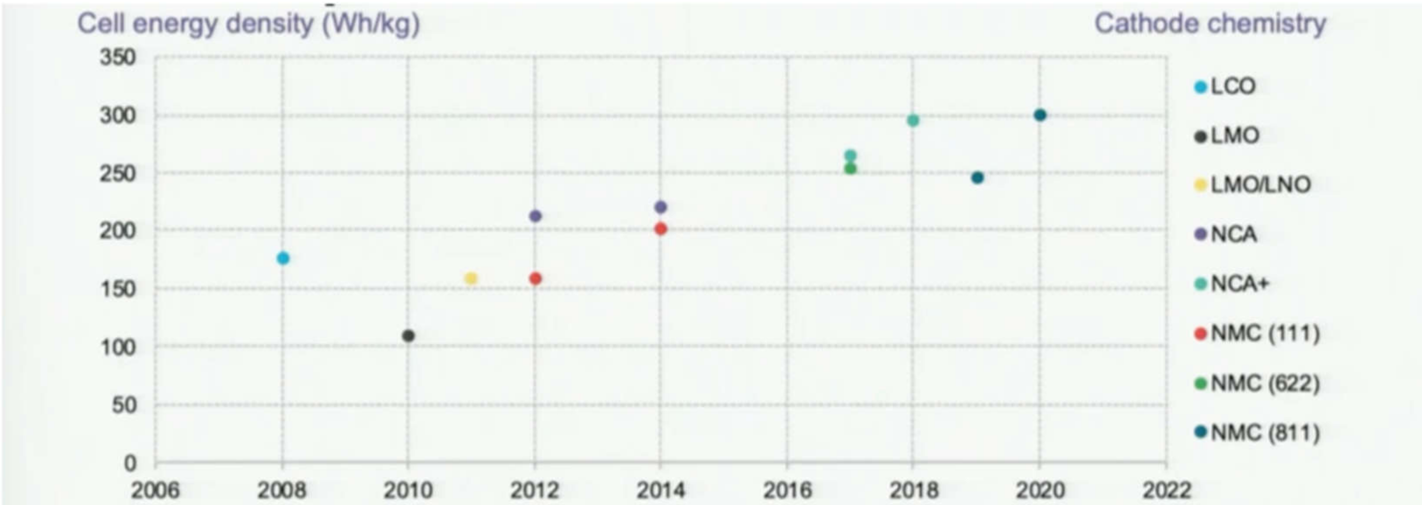
Battery	Energy density in Wh/kg	Costs in US$/kWh	Avg. lifespan in # discharge cycles	Safety
Lead-Acid	30–42	250-260	500-800	Environmental concerns
Nickel-metal hydride	60–140	-	180-2000	Environmental concerns
Lithium-ion	100 –265	273	Ca. 400–1200	Flammable materials, requires careful disposal
Solid-state	2x that of lithium -ion batteries	N/A (cheaper than li-ion)	ca. 10 years	Nonflammable
Aluminum-ion	1,060	250	>7,500	Nonflammable, non-hazardous
Lithium-sulphur	500	NA (cheaper than li-ion)	>1500	Nonflammable

Source: Statista

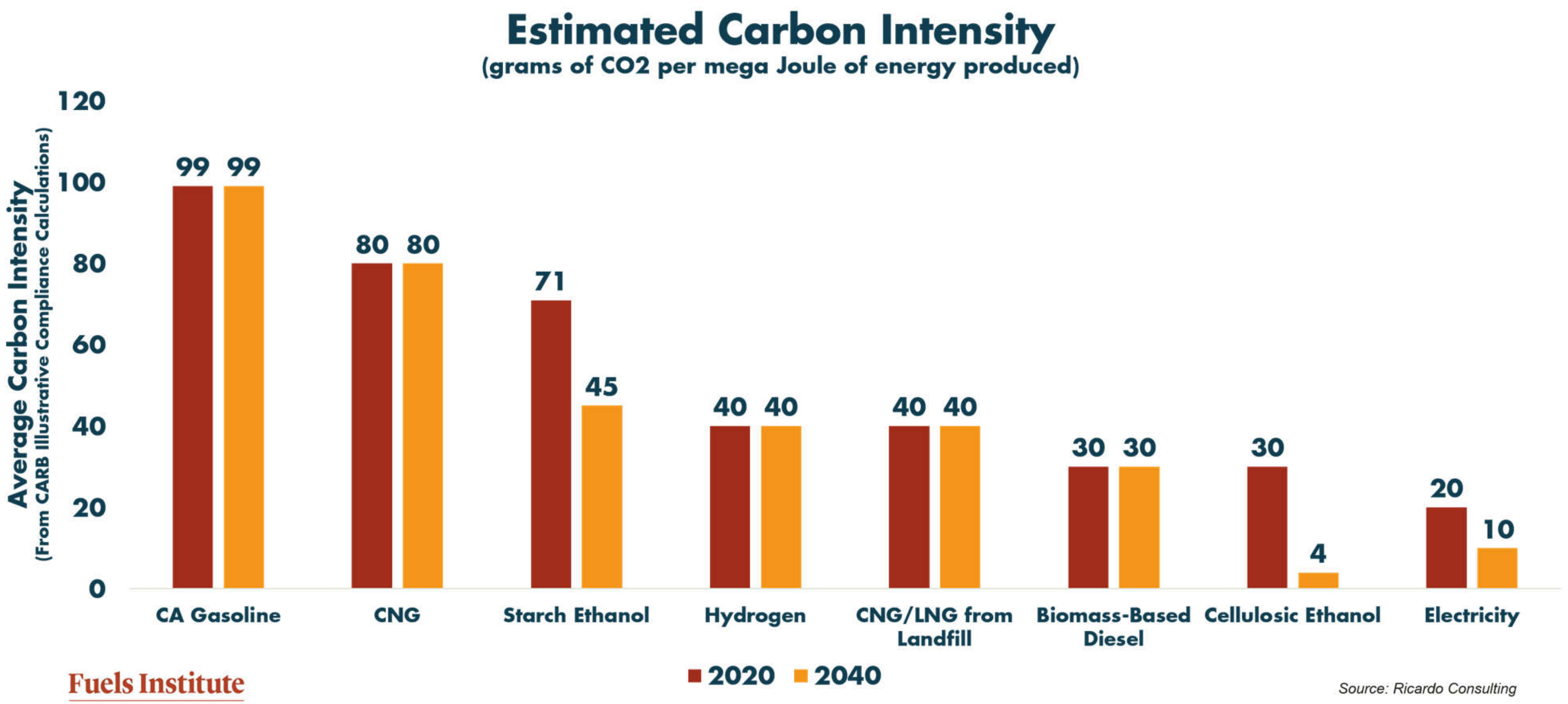
Battery Energy Density/Range Sensitivities

Increased battery densities would mean a reduction in weight of batteries in a vehicle for a given range or larger range for a given battery size influencing the emissions in manufacturing and operating the vehicles with such batteries. Considering a 10% - 20% change in battery densities in the near future, there is a 3% - 6% reduction in the overall lifecycle greenhouse gas emissions of the battery electric vehicle projected.

FIGURE 56: BATTERY ENERGY DENSITY CHANGE



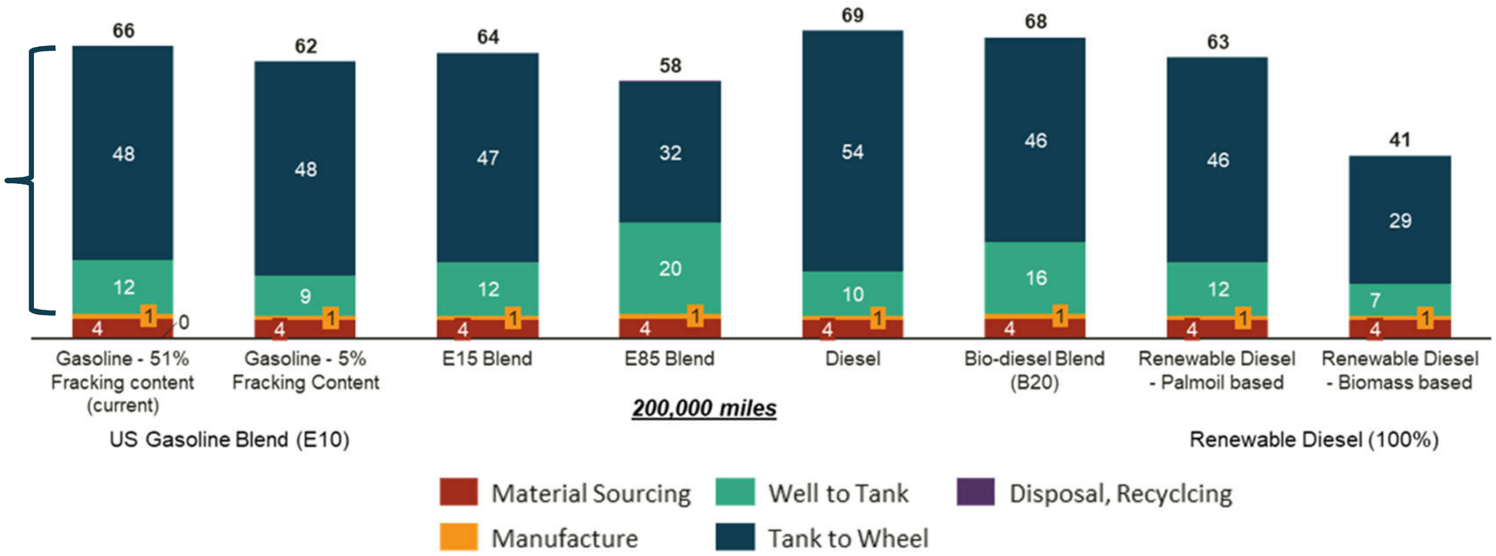
Fuel Blend Sensitivities



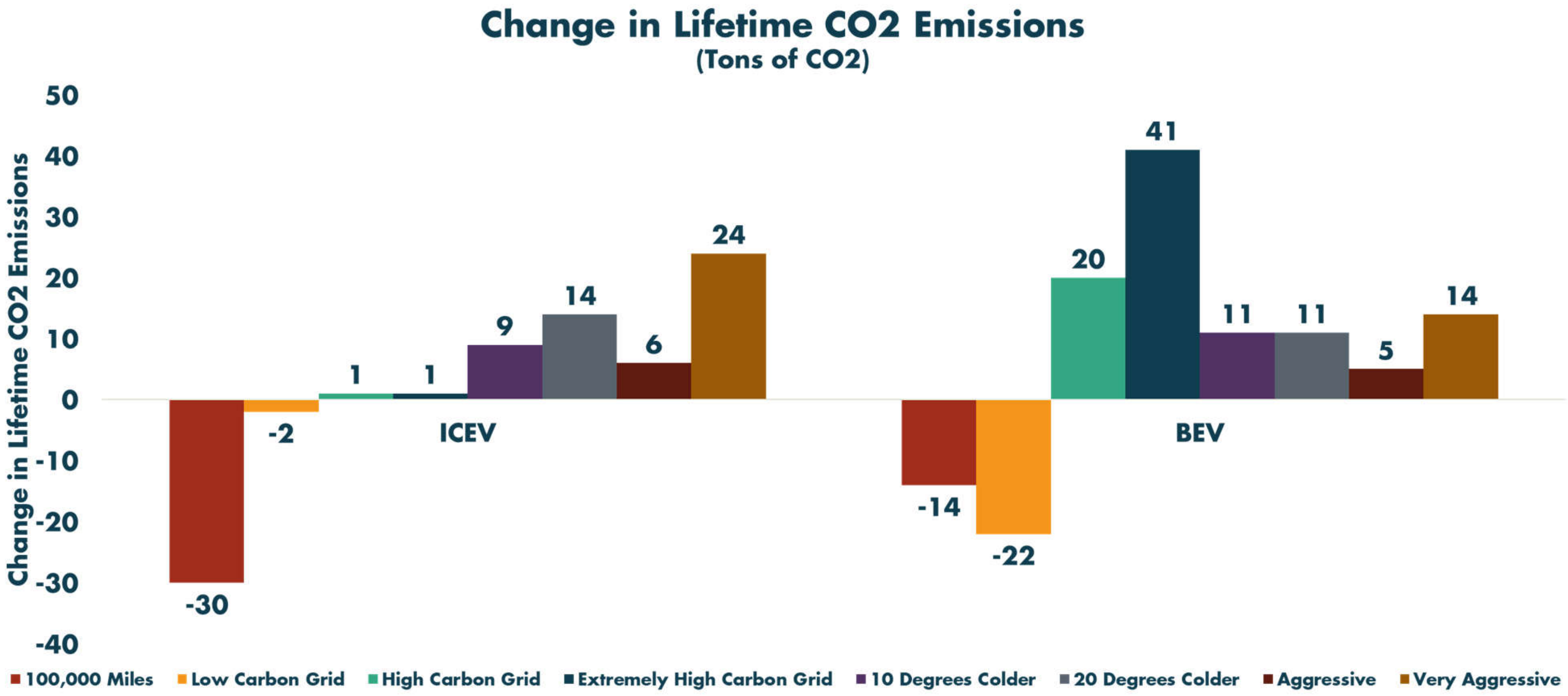
Fuels Blends Sensitivities

Life cycle impact of low-CI fuels is modest due to blend ratio and that fuel consumption represents only part of the cradle to grave emissions of a vehicle.

FIGURE 57: ALTERNATE FUELS LCA

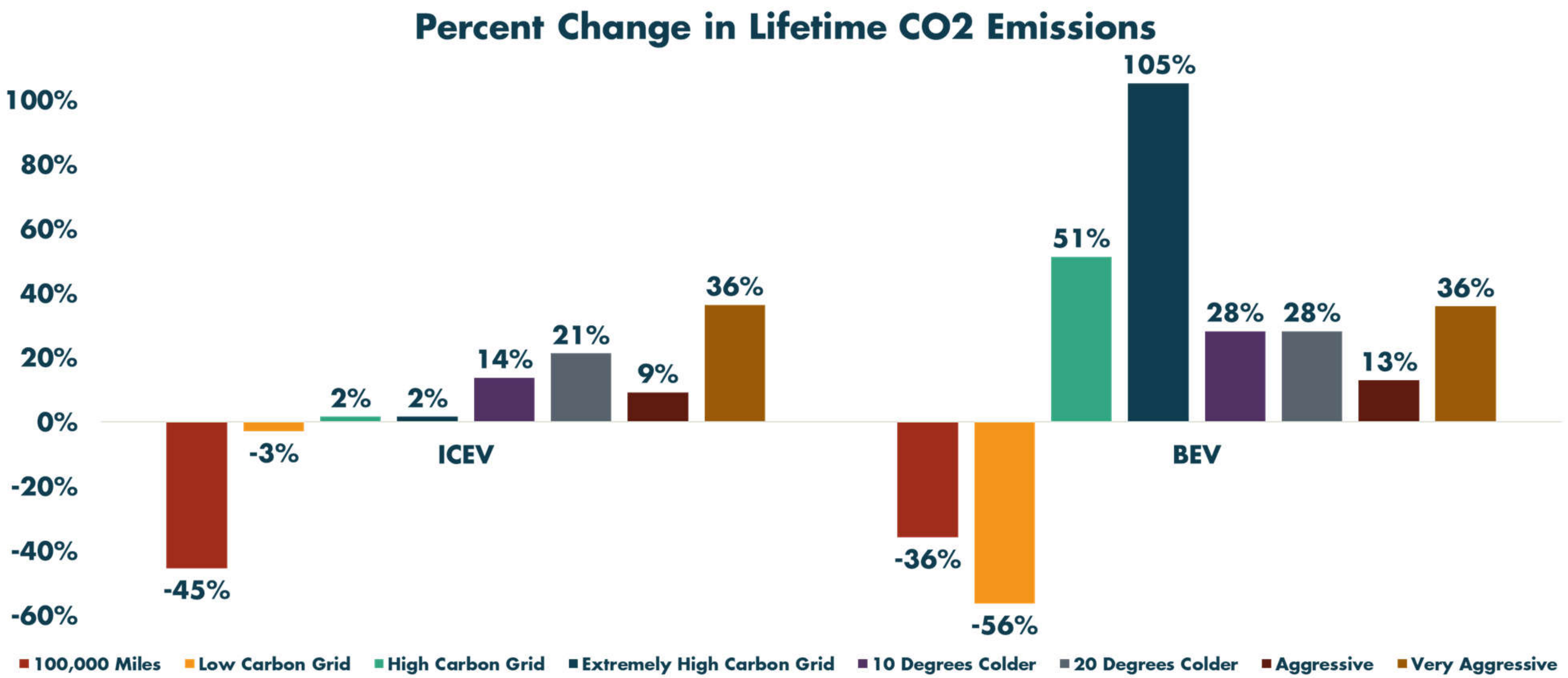


BEVs more sensitive to variables than ICE



Fuels Institute

Variability of BEVs pronounced on % change

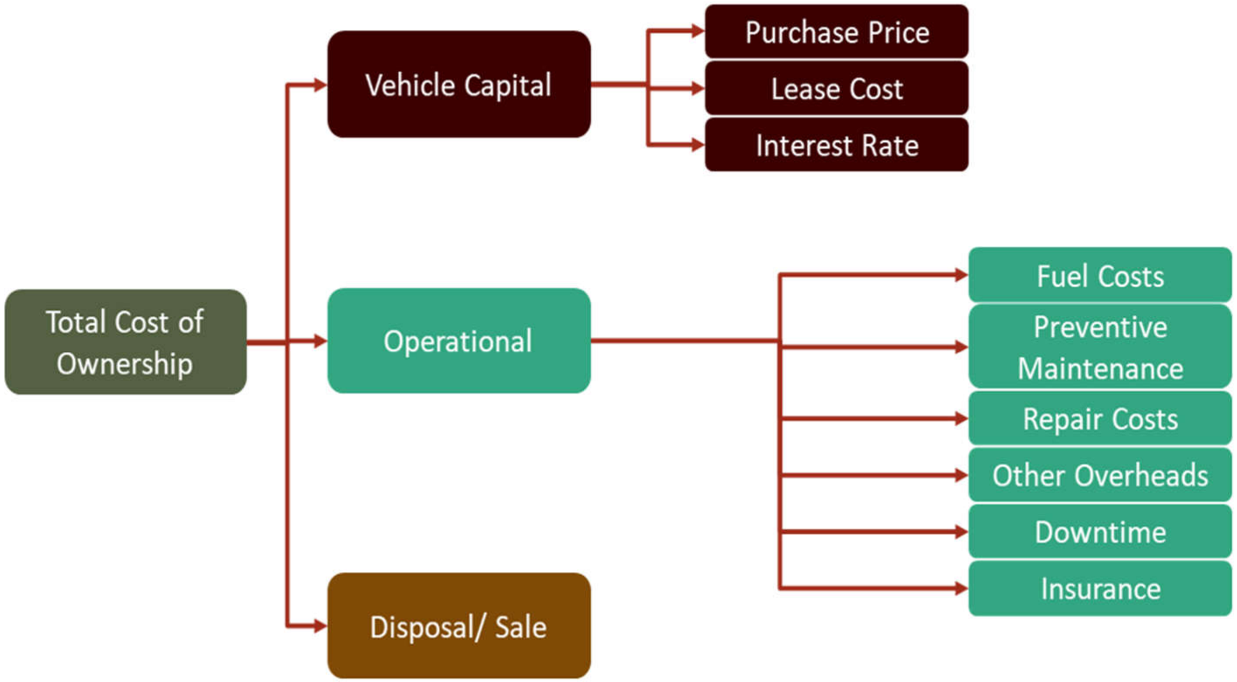


Fuels Institute

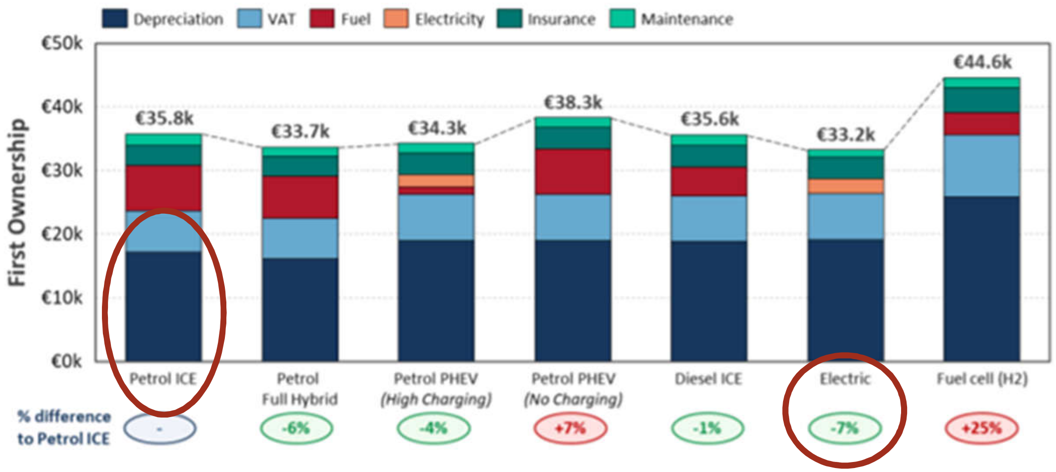
Total Cost of Ownership

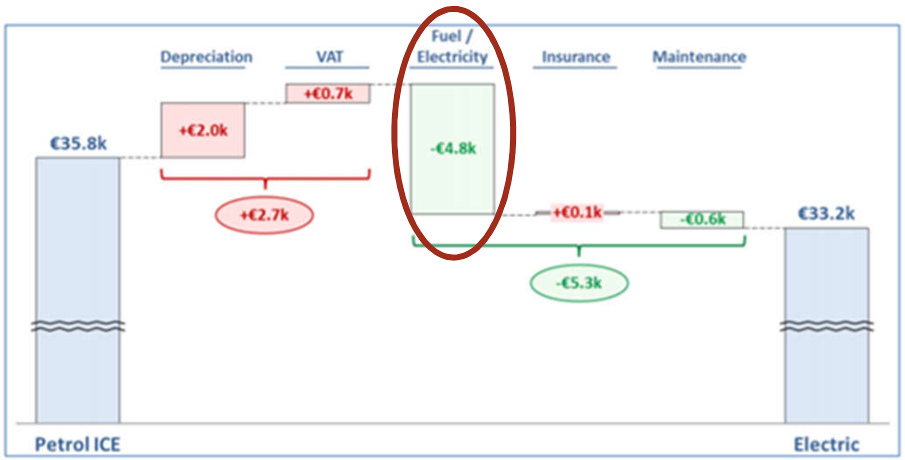
TCO Methodology

Literature Review plus Synthesis Summary

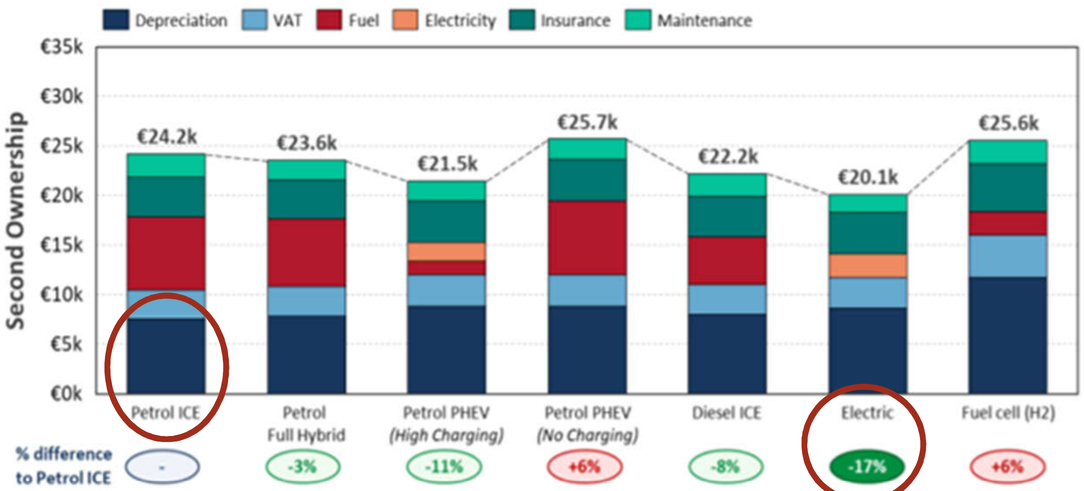


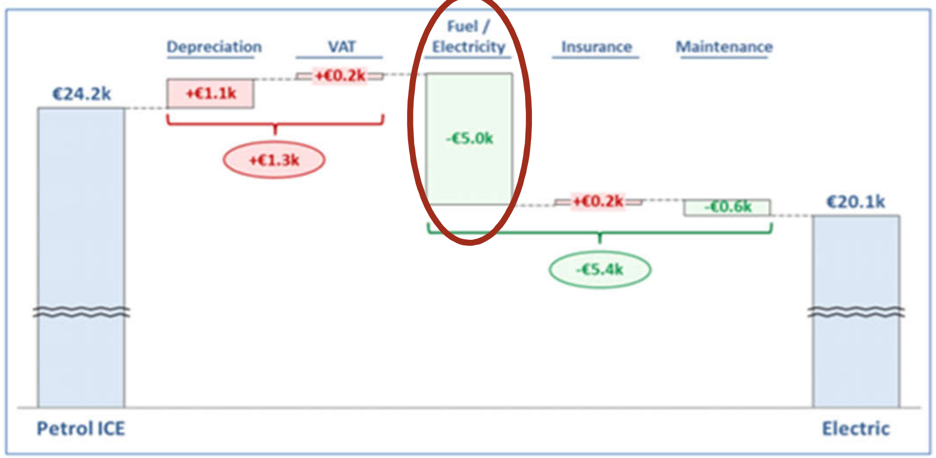
First Owner TCO - EU





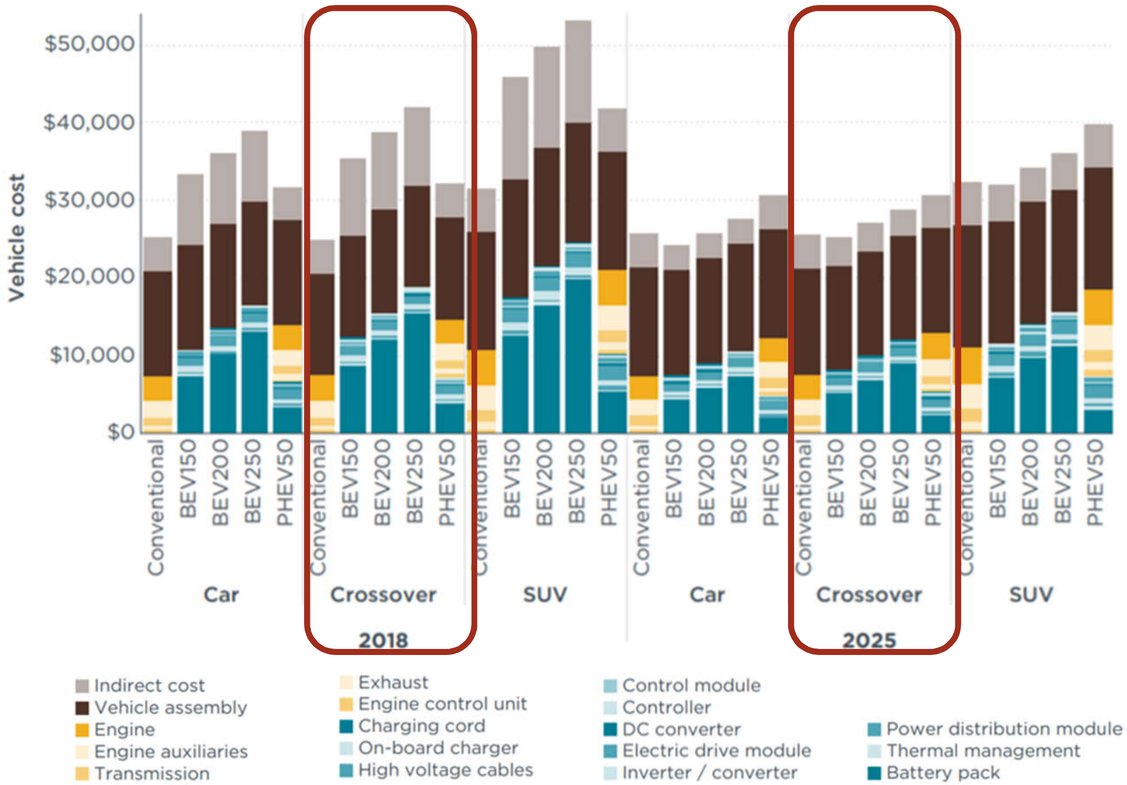
Second Owner TCO - EU





Vehicle Cost – Bottom Up Approach

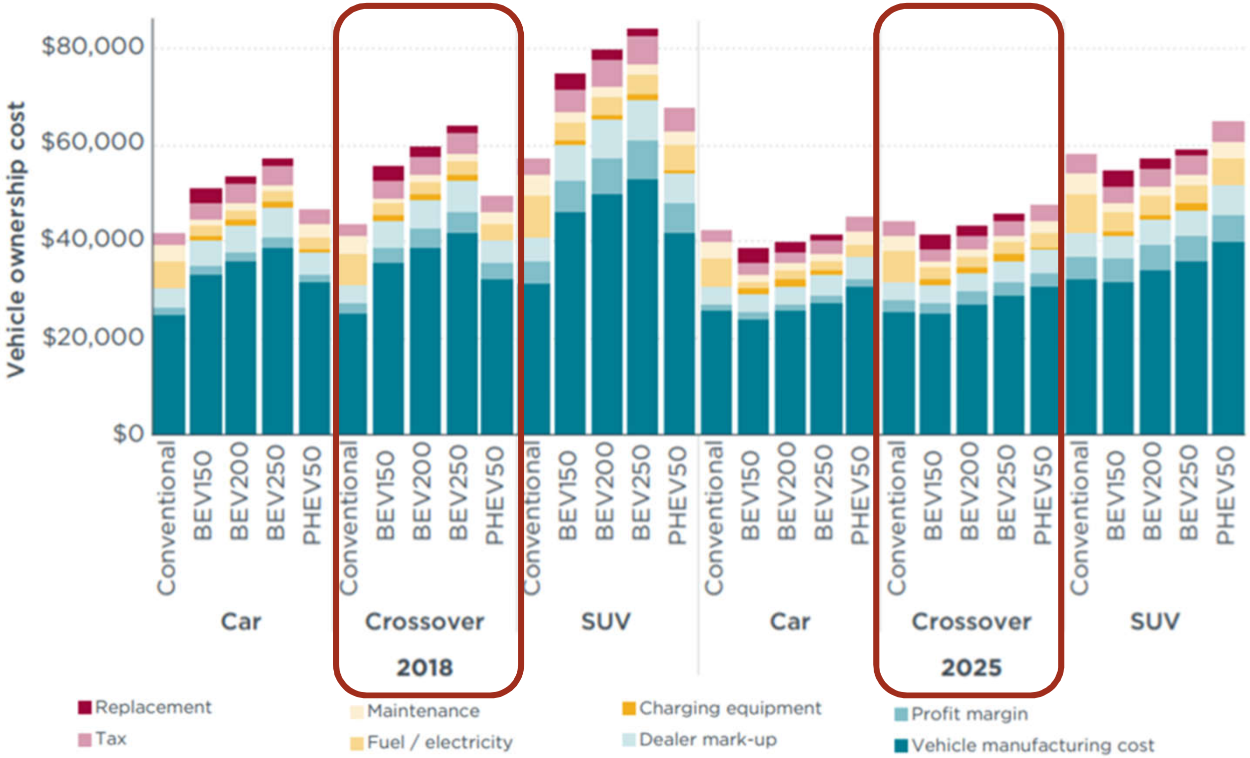
BEVs close the cost gap with ICEV around 2025



Adapted from ITTC

Total Cost of Ownership

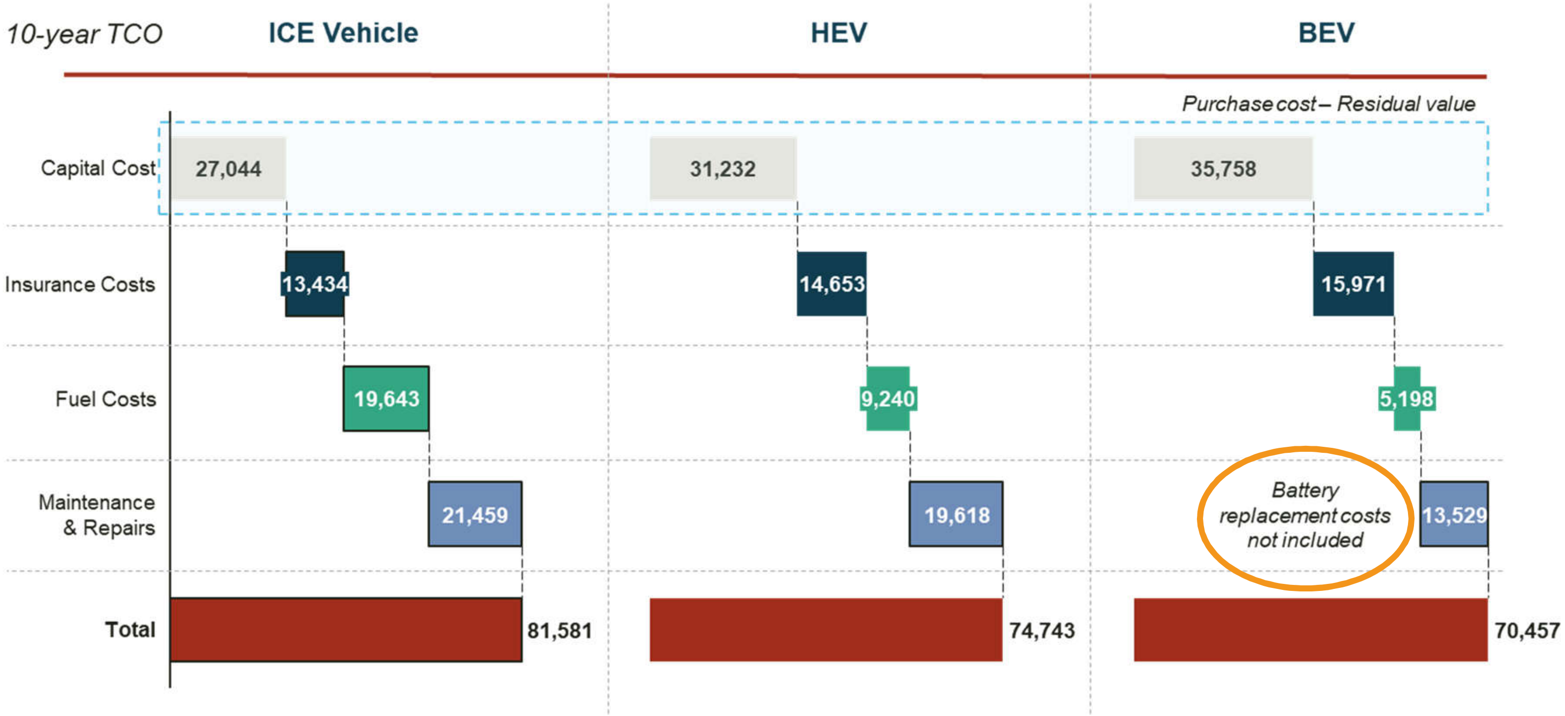
By 2025, BEVs are projected to have a lower total cost of ownership than ICEV



Adapted from ITTC

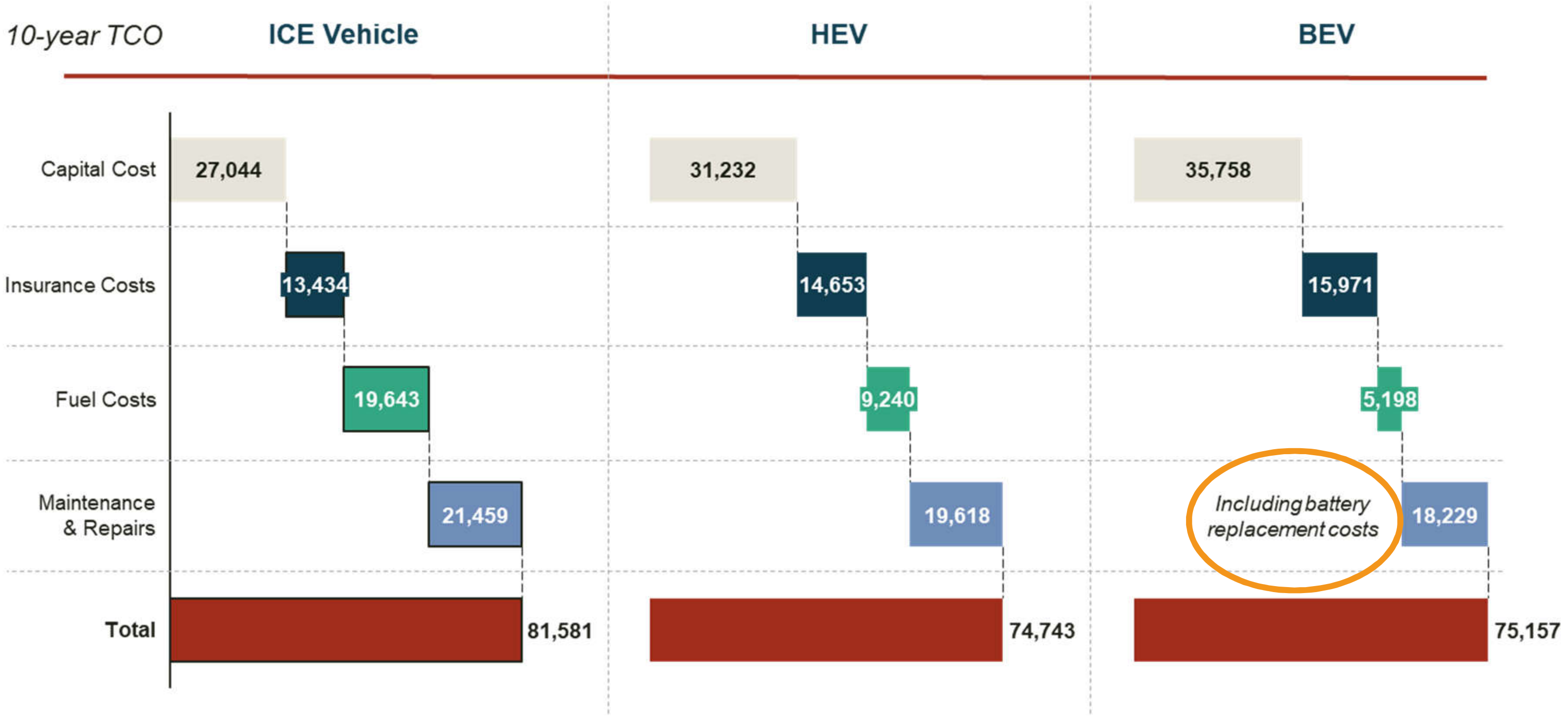
TCO Model Summary w/o Battery Replacement

If no battery replacement is necessary, BEVs deliver a 13.6% total cost of ownership savings.



TCO Model Summary w/ Battery Replacement

When battery replacement is factored in, the BEV is still lower TCO but advantage declines to 7.9%



Opportunity Cost

How much time does it take to "refuel" a vehicle over 200,000 miles?

Assumptions

ICEV

- 25 mpg
- Fuel dispenser flows at 10 gallons/minute

BEV

- 75kW battery (Model Y)
- 326 mile range (Model Y)
- 150kW DCFC is used
    - 2.5 kW/minute
- Option 1: DCFC used for 20% of charging
- Option 2: DCFC used for 80% of charging

Lifetime Energy Units Consumed

ICEV: 8,000 gallons BEV: 46,512 kW

Energy Units Purchased Away from Home

ICEV: 8,000 gallons
BEV-1: 9,302 kW
BEV-2: 37,209 kW

Time Spent Buying Energy Away from Home

ICEV: 13 hours
BEV-1: 62 hours
BEV-2: 248 hours

Opportunity Cost @ $15/hour

ICEV: $200
BEV-1: $930
BEV-2: $3,721

Key takeaways according to John…

- BEVs on average are less carbon intense, but exhibit more variability based upon different conditions
  - Recognizing optimal geographic deployment will enhance BEVs contributions to carbon mitigation
  - Ensuring consumers understand the impact of external factors on range and battery durability is essential
- The battery component of BEVs makes them much more carbon intense when they come off the line, but ICEVs lose their advantage when consuming energy
  - This means reducing the carbon intensity of liquid fuel can help bridge the gap between the technologies
- HEVs can contribute significantly to emissions reduction:
  - HEVs emit 29% less carbon than ICEV, but 20% more than BEVs
  - HEVs would benefit from lower carbon liquid fuels also
- BEVs represent a lower total cost of ownership, even when factoring in battery replacement
  - Will consumers make that calculation?
  - When cost parity at point of purchase is achieved, will consumers opt for the new tech?
  - The time value of refueling and recharging a vehicle, while not something most people would calculate, is an uncertain question in the minds of time starved consumers and can have a real impact on their purchase decision
- HEVs offer TCO advantage over ICE and BEVs when battery replacement is factored in.
- Driving behavior has a much more significant effect on battery life and range per charge than on efficiency of an ICE vehicle
  - A very aggressive driver can lose 50% range and have to replace the BEV battery 2x during a 200,000 lifetime
- Time spent securing transportation energy away from the home is much greater for BEVs and least for HEVs due to increase MPG efficiency

Final Thoughts & Questions

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