Life Cycle Analysis of Road Transport Vehicles in India

Life cycle assessment methods to support India's efforts to decarbonise transport

Workshop under the DTEE and NDC-TIA projects
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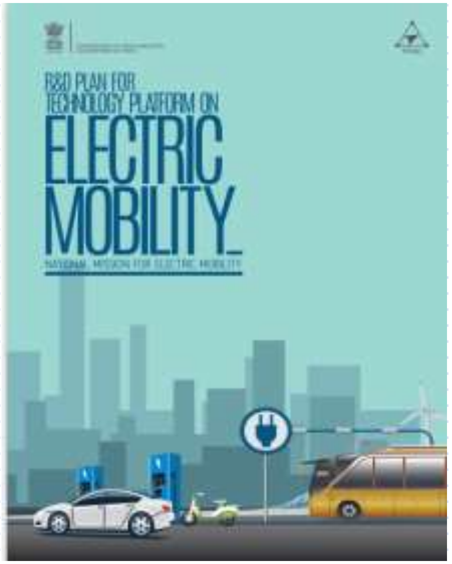
TIFAC
Arghya Sardar
Technology Information, Forecasting and Assessment Council (TIFAC)

About TIFAC

- An autonomous body under the Department of Science & Technology, GoI.
- Technology Foresight/ Vision, Technology Roadmapping. Technology Assessment and promotion of key technologies
- Collaborative Automotive R&D (2003-2010): Pre-competitive consortia projects
- R&D Plan on Electric Mobility: Prepared by TIFAC with support from the Department of Heavy Industry. Released in October 2018
- Impacts of Electric Mobility: Modelling of EV penetration in India, Materials/ resource requirement, grid impacts, charging infrastructure
- Assessment of biofuel potential in India
- Study on production and utilization of methanol



Transport LCA Case Studies at TIFAC

Previous Works

- Plug in Hybrid Electric Bus
- Passenger Car – Steel Body vs Aluminum Body
- Passenger Car – Gasoline vs Electric
- Electric Bus – Steel Body vs Aluminum Body

Motivation

Evaluation of emerging technology options for road transportation and their potential impacts

Current Focus

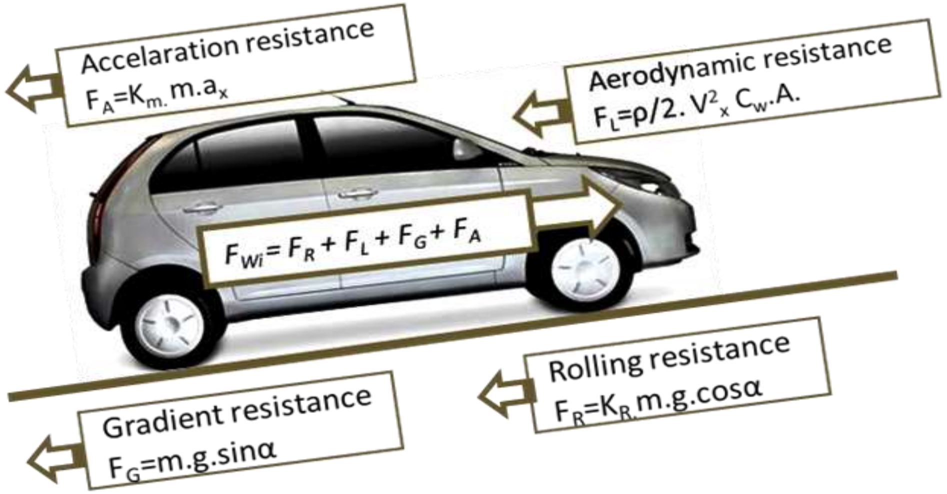
Comparing various charging strategies of electric vehicles

Alternative concepts of electrifications: Electric Road Systems

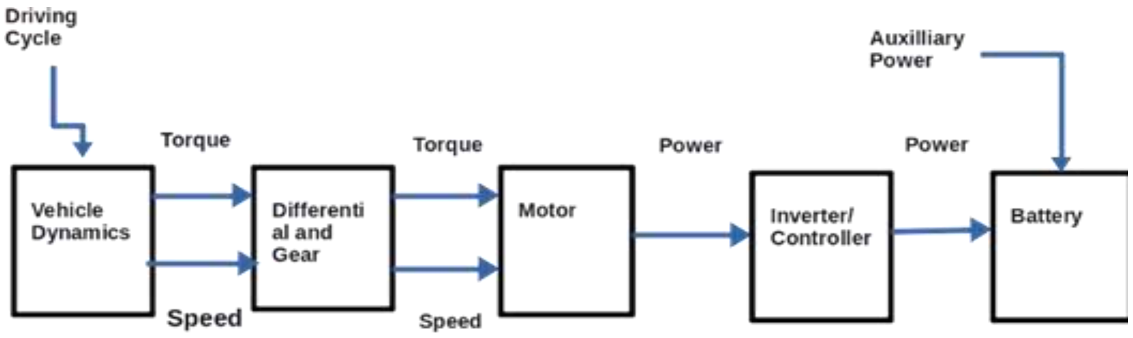
Other alternative propulsion: Fuel Cell Vehicles

Tools Used for Estimating Use Phase Energy

- Parametric Evaluation of Vehicle Energy Consumption (PAMVEC) (Simpson, 2006)
- Offline, backward facing model for vehicle powertrain developed using Scilab/ XCOS

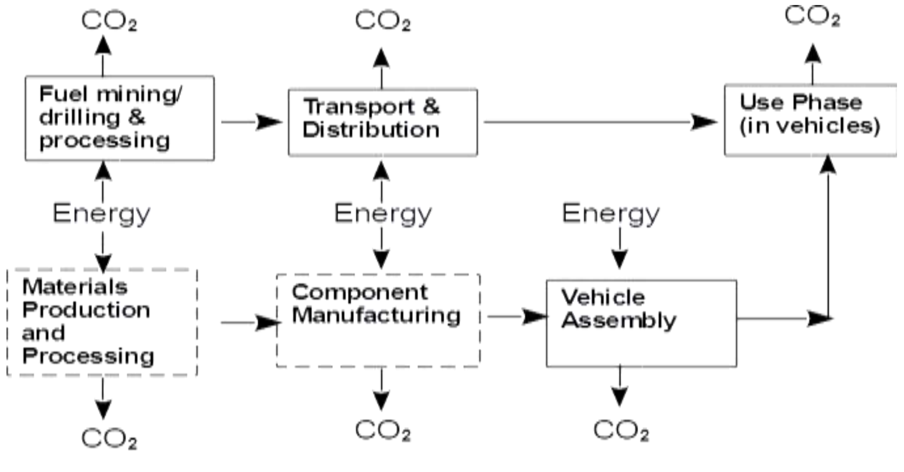


Fwi	Total Resistance
ρ	Density of atmosphere
Cw	Aerodynamic Resistance Coefficient
A	Frontal Area
V_x	Speed
K_R	Rolling resistance coefficient
m	Mass
g	Gravitational constant
α	Gradient Angle
K_M	Acceleration Resistance Coefficient
a_x	Acceleration

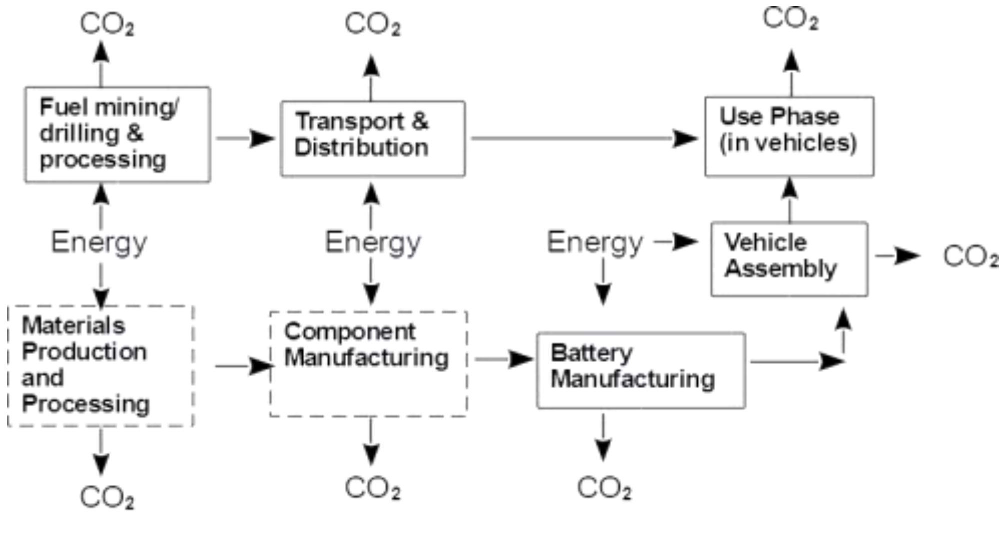


Plug-in Hybrid Electric Bus vs IC Engine Bus

- Public transport buses in Delhi, CNG as fuel for IC engine
- Use phase energy and emissions calculated using parametric model
- Functional unit: 600,000 km
- Materials production, processing and component manufacturing (except battery) were assumed to be same for both conventional vehicle and PHEV.
- From comparative analysis of components, battery was identified as the major difference between PHEV and conventional bus



IC Engine Vehicle: LCA Boundary



PHEV Vehicle: LCA Boundary

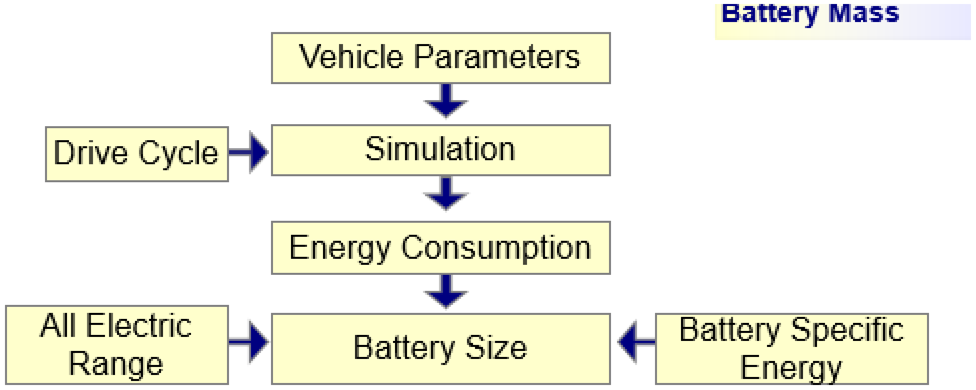
CNG Bus and Plug-in Hybrid Electric Bus

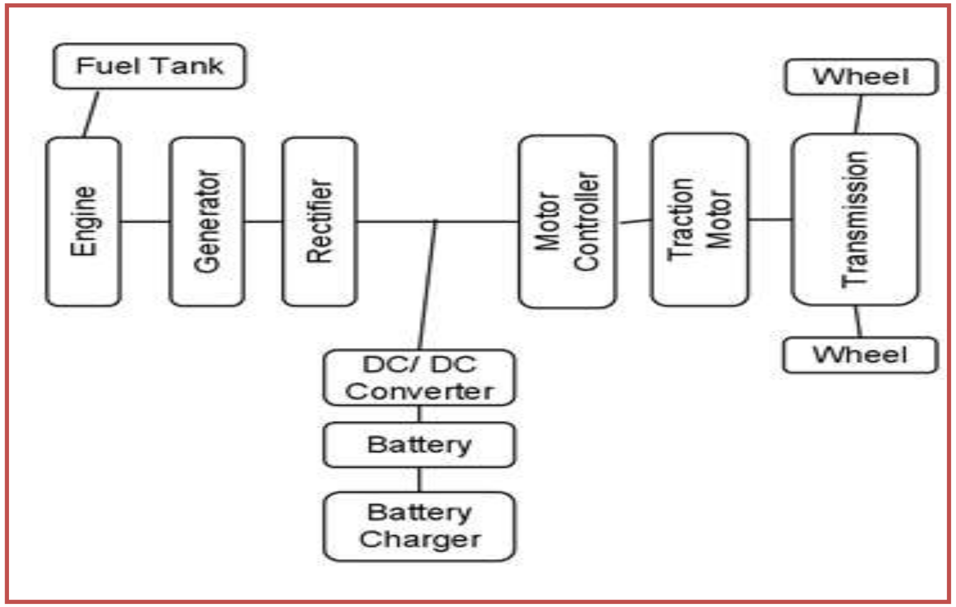
- PHEV bus with 100 km all electric range, daily run of 200 km
- Energy for battery manufacturing assumed to be 1700 MJ/kg
- Use phase energy estimated using PAMVEC
- GHG Intensity of Grid: 0.8 T/MWh

Attribute	Conventional CNG Bus	CNG Plug-in Hybrid Bus
GVW (kg)	14500	16200
Frontal Area (m2)	8.5	8.5
Aero Drag Coeff	0.4	0.4
Rolling Resist. Coeff	0.001	0.001
Air Density (kg/m2)	1.2	1.2
Transmission Eff	87.5%	87.5%
Motor Eff		90%
Engine Eff	22.5%	22.5%
Battery Eff (All Elect)		90%
Battery Eff (CS)		85%
Charger Eff		80%

Plug-in Hybrid Electric Bus

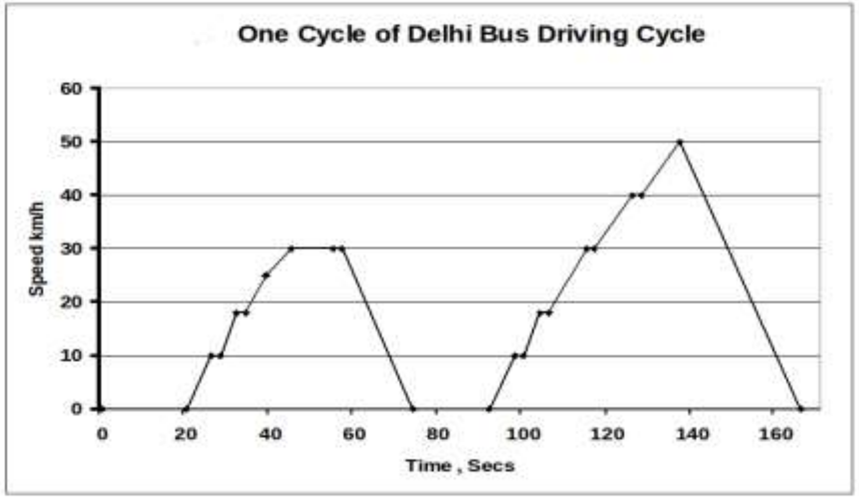
- Assumptions control strategy in CS mode
- Engine always operates at optimum efficiency
- Battery power used when required
- Upstream emissions of CNG assumed to be about 29% of the end use emission (Delucchi, 2004)

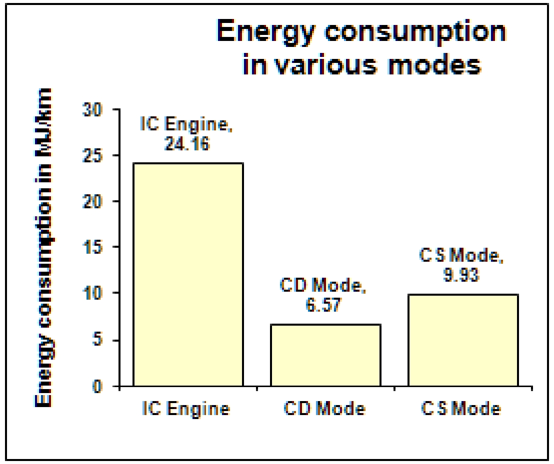




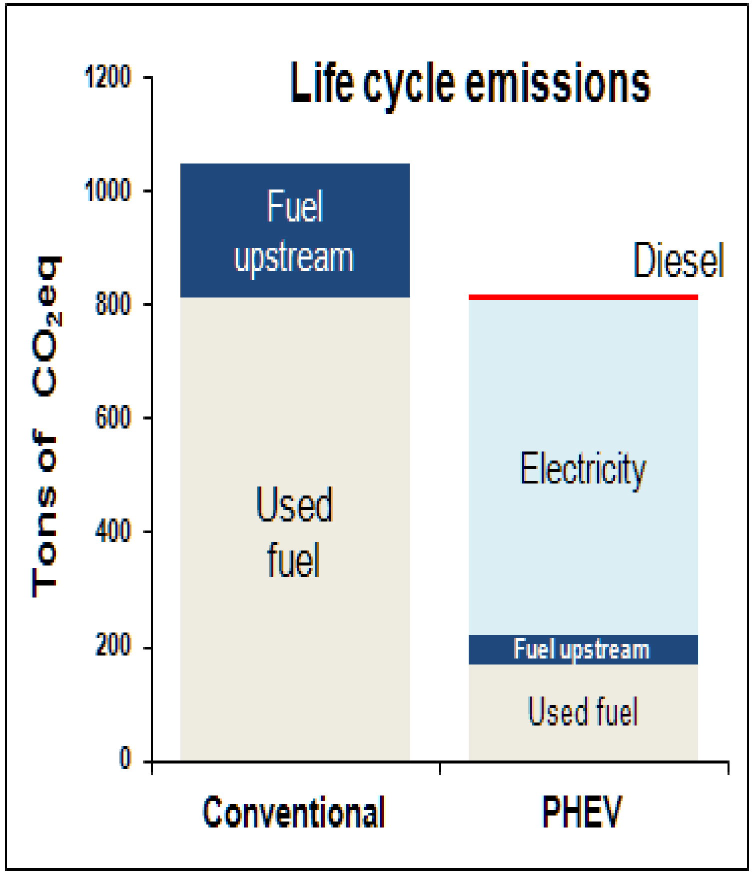
PHEV Bus – Use Phase

- Parametric Model of Energy Consumption in Road Vehicles
- Energy consumption based on
- Average Speed
- Velocity Ratio
- Root-Mean-Cubed Speed
- Characteristic Acceleration
- Model implemented in spread sheet





LCA of PHEV Bus: Results



22% saving in GHG emissions in life cycle

EV Passenger Car – Steel Body vs Aluminum Body

- Replacement of conventional steel body with aluminum
- Two different approaches
  - Scenario I:Without battery resizing
  - Scenario II: With battery resizing
- Also compared with Steel body vehicle – no lightweighitng

Reference Vehicle (Mid Size Sedan)

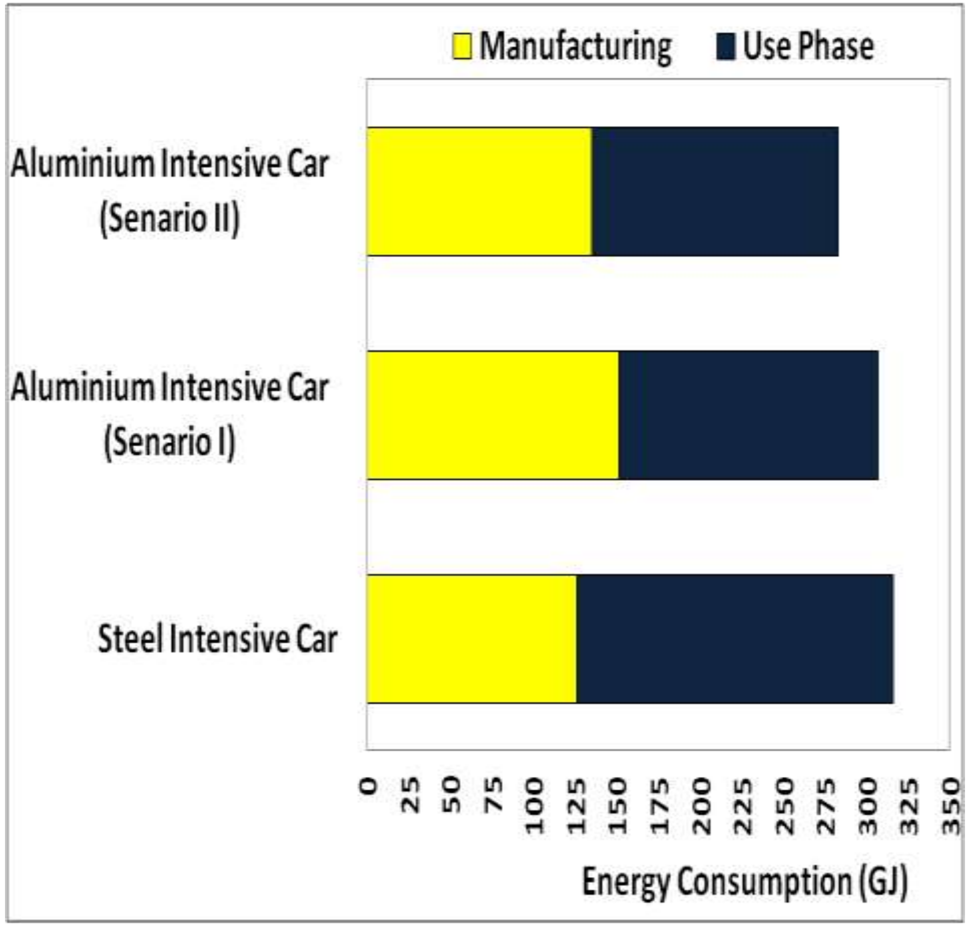
Parameter	Value
Kerb weight	1291 kg
Gross Vehicle Weight	1736 kg
Seating Capacity	4
Frontal Area	1695 mm X 1550 mm
Range	160 km
Battery Capacity	26.5 kWh
Maximum Motor Output	55 kW
Maximum Torque	157 Nm
Top Speed	114 kM/ h
Battery Type	Lithium Ion Super Polymer
Acceleration	0-30 kmph in 4.5 s

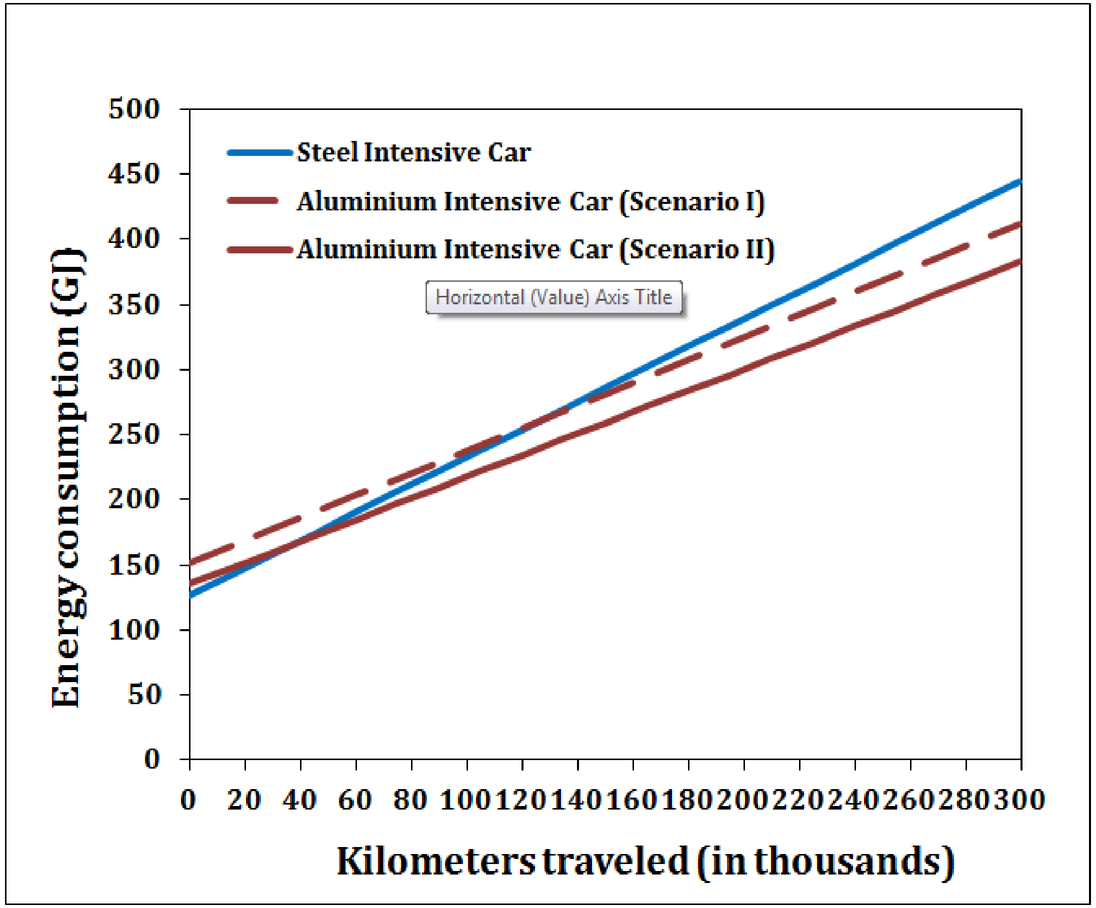
Materials Production and VMA

Material	% of Curb Weight	Weight (kg) for Steel Car	Energy Intensity Value MJ/Kg
Steel	54.2	560	60
Iron	10.1	104	37.3
Aluminium	6.4	66	231
Copper/ Brass	1.7	18	95
Lead	0.9	9	20
Rubber	6.8	70	88
Plastics	9.8	101	80
Glass	2.8	29	16
	92.7	958	

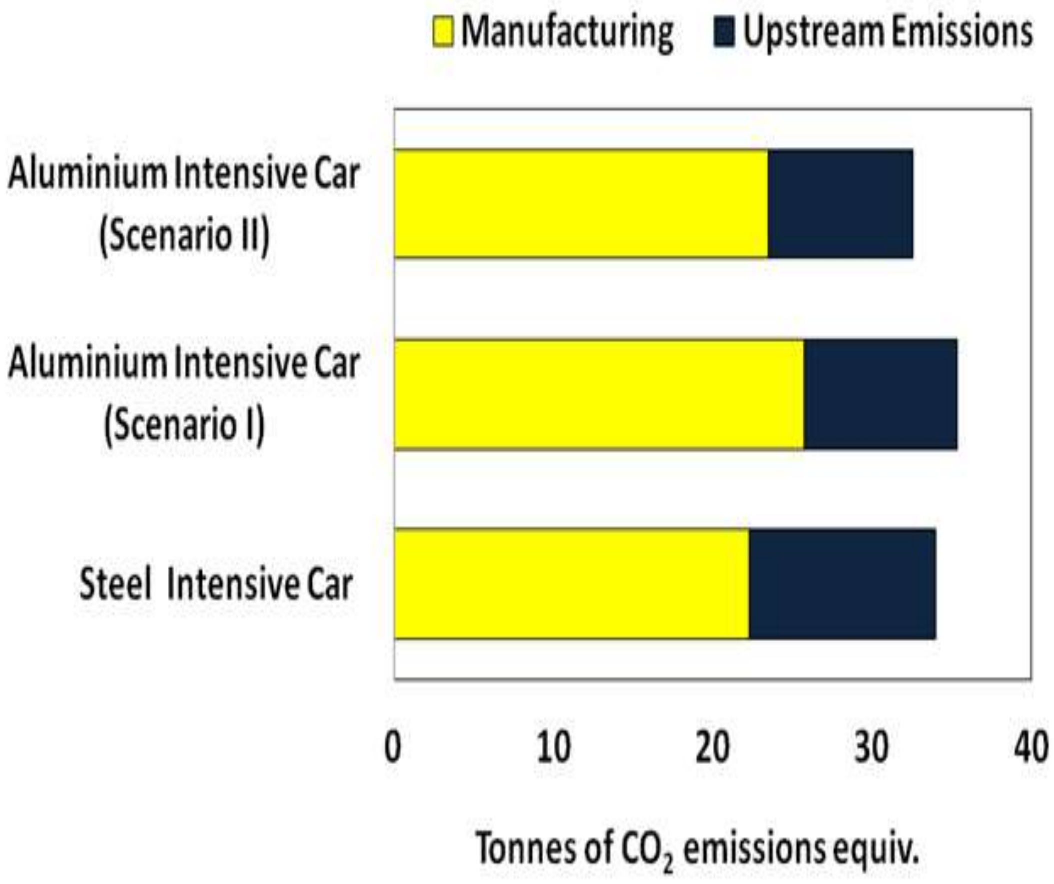
- For manufacturing and assembly, energy requirement for the various processes that the materials go through are considered (Sullivan et al, 2012)

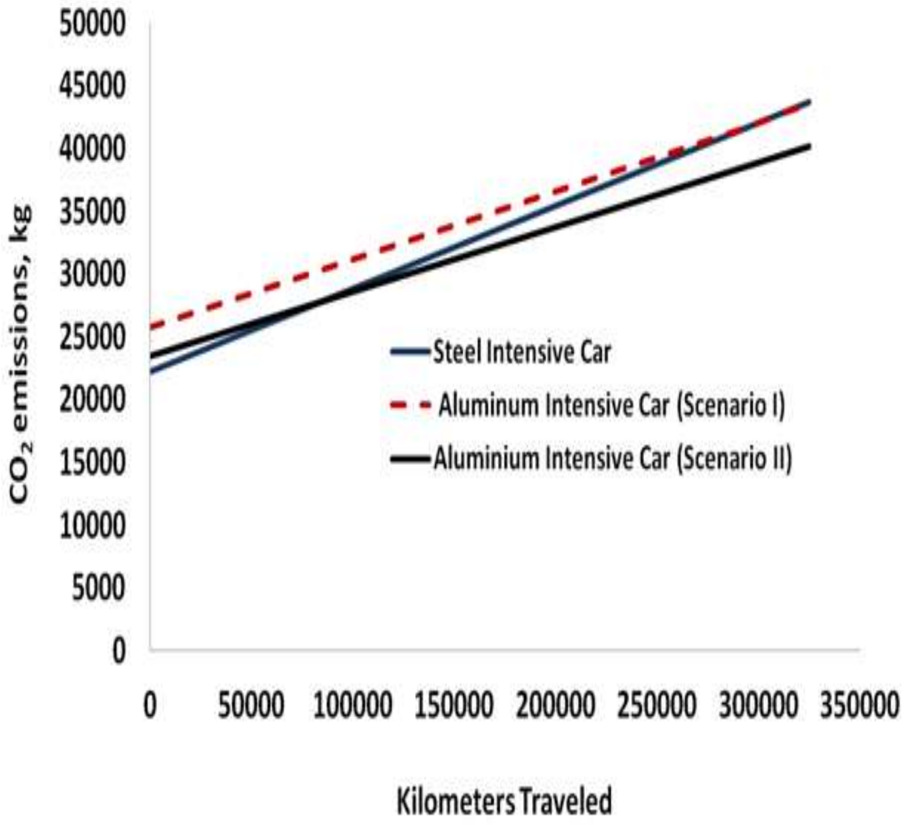
Steel Body vs Aluminum Body: Lifecycle Energy





Steel Body vs Aluminum Body: Lifecycle GHG





Passenger Car Gasoline vs Electric

- Comparative lifecycle analysis of conventional gasoline passenger car and BEV passenger car
- Functional unit: Lifetime of the vehicle
- Driving Cycle used: Modified Indian Driving Cycle (MIDC). Considered only the city part.
- A backward facing, quasi-static powertrain model was used for for estimating energy consumption in use phase

Well to pump energy consumption assumed 0.225 MJ/MJ gasoline. CO_2 emission 19 g CO_2/ MJ (Wang et al 2004)

Parameter	BEV	ICEV
Kerb Mass (kg)	1291	1065
GVW (kg)	1736	1510
Frontal Area (m2)	2.4	2,4
Range (km)	160	
Battery Capacity (kWh)	26.5	
Battery Weight (kg)	258	
Max Motor Output (kW)	52	
Max Torque (Nm)	157	
Drag Coeff	0.29	0.29
Rolling Res Coeff	0.01	0.01
Battery Type	Li-ion Super Polymer	

LCA Results : IC Engine Car (Gasoline)

Phase	**IC Engine Car ($kgCO_2$)**	**BEV Car ($kgCO_2$)**
Materials Production	3469	3370
Vehicle Manufacturing and Assembly	4070	2180
Battery Manufacturing	-	1548
Use Phase	58500	49440
Fuel Production, Delivery	13163	

Transport LCA: Current Initiatives in TIFAC

- Various emerging concepts of Electric Mobility (Electric Road System, Opportunity Charging, Battery Swapping, Renewable Energy Integration etc.)
- Impact of LCA for various technology options for critical components – energy storage, motor
- Other alternative propulsion technology – Fuel Cell Vehicles
- Incorporating more detailed analysis – fuel production/ distribution cycle etc.

Conclusions

- Significant benefits in terms of lifecycle GHG and energy were observed for electric vehicles
- Improvement in T&D Efficiency and use of renewable energy can further enhance the benefits of electric mobility
- In case of lightweighting measures such as use of aluminum in vehicle body, there is break even point beyond which overall lifecycle benefit becomes positive
- Since various charging strategies and technology choices such as energy storage are emerging in case of electric mobility, there many more use cases that need to be evaluated
- Various other alternative propulsion technology options also need to be evaluated
- Materials inventory of Indian vehicles will help in LCA

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Thank You

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