Zero-Emission Long-Haul Trucking Technologies

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Purpose of this Study

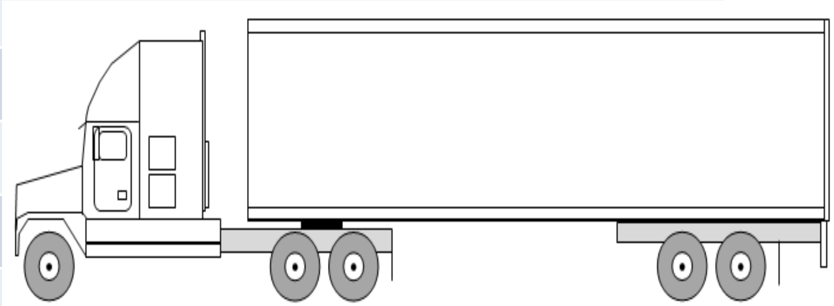
To review zero emission trucking technologies and compare them in terms of the capital and O&M costs for long-haul freight applications.

The zero-emission technologies considered are:

- In-road dynamic inductive charging
- Catenary electric
- Hydrogen fuel cells

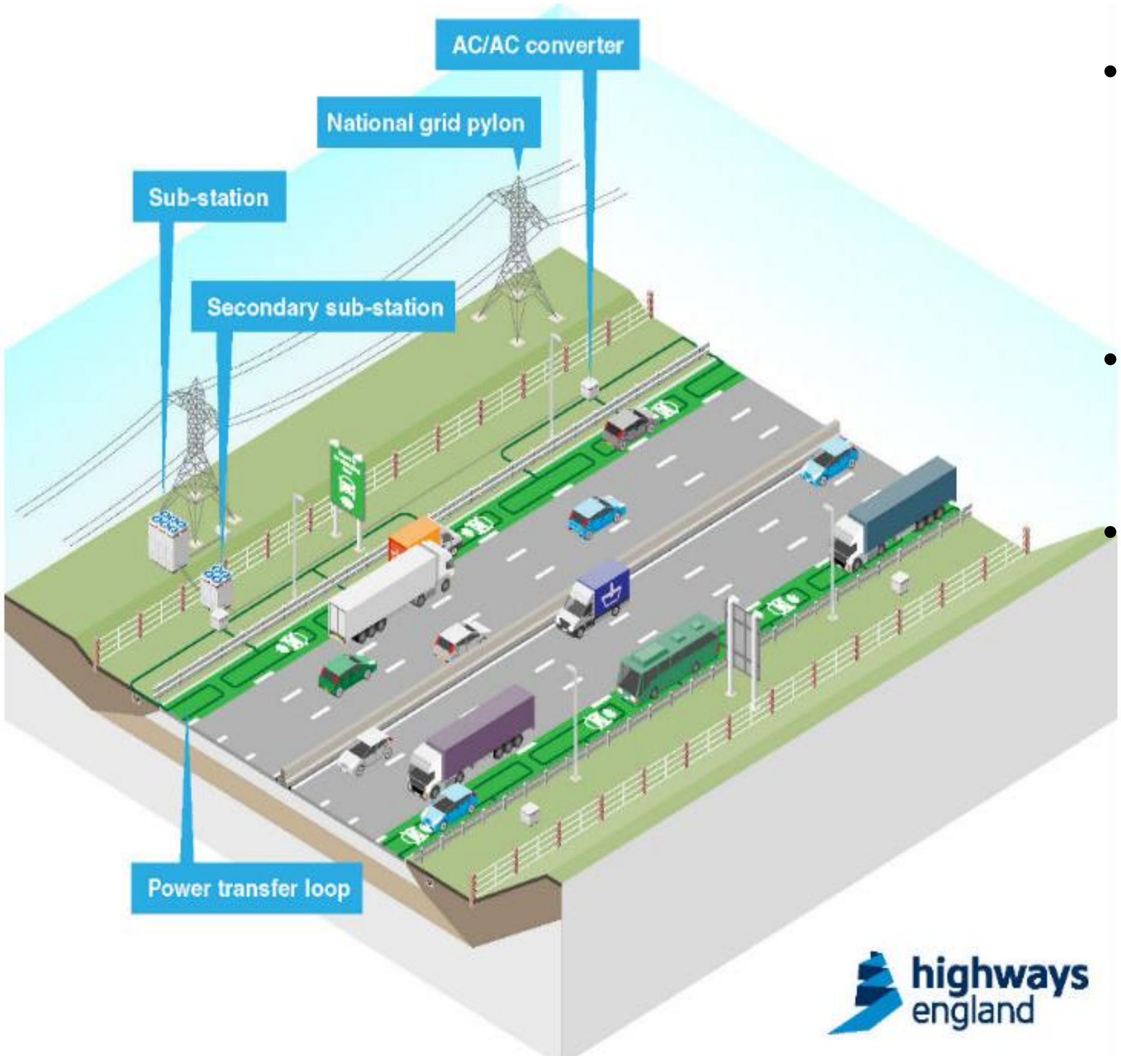
Class 8 Truck Inputs (33,000 lbs – 80,000 lbs)

Component	Model Characteristics
Aero Drag Coefficient (Cd)	0.6
Frontal Area (A: m2)	10
Tire Rolling Resistance (eta)	0.0065
Curb Weight Including Empty Trailer (kg)	15,700
Gross Vehicle Weight Rating (kg)	25,400 kg *
Transmission 10 Speed efficiency	98%
Axle Efficiency	98%
Electrical Accessories	4 kW
Motor Efficiency	94%
Inverter Efficiency	99%
Average mileages	500 miles/day 90,000 miles/year



** 70% of the rated load of 36,280 kg*

Dynamic Inductive Charging - Schematic

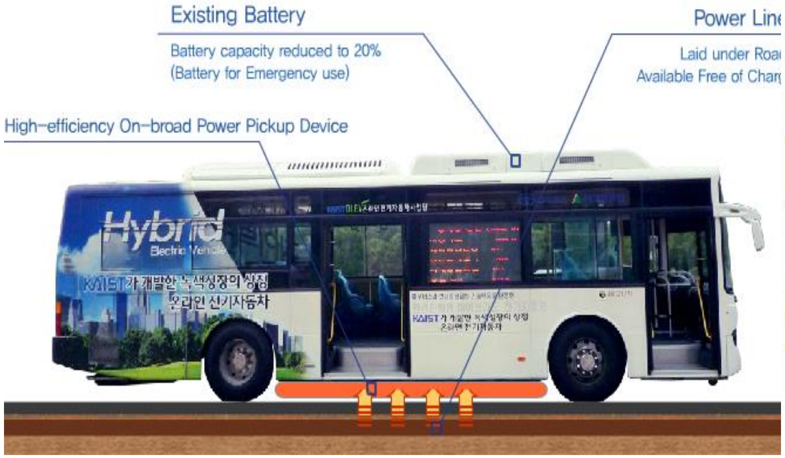


Dynamic charging schematic (source: England Highway Agency)

- A transmission substation steps down high transmission voltage and provides power to several traction substations
- A traction substation powers several inverters (power transmitters).
- An inverter provides power to several road segments with the primary coils embedded and also controls power on and off.

KAIST the Online Electric Vehicle (OLEV)

- The bus uses five 20 kW receivers to receive 100 kW electricity at an 85% maximum power transmission efficiency rate while maintaining a 17cm air gap between the underbody of the vehicle and the road surface. (80% efficiency at a 26-cm air gap).



(a) DWC-EV power track under construction (b) DWC-EV in operation

Catenary System - Status

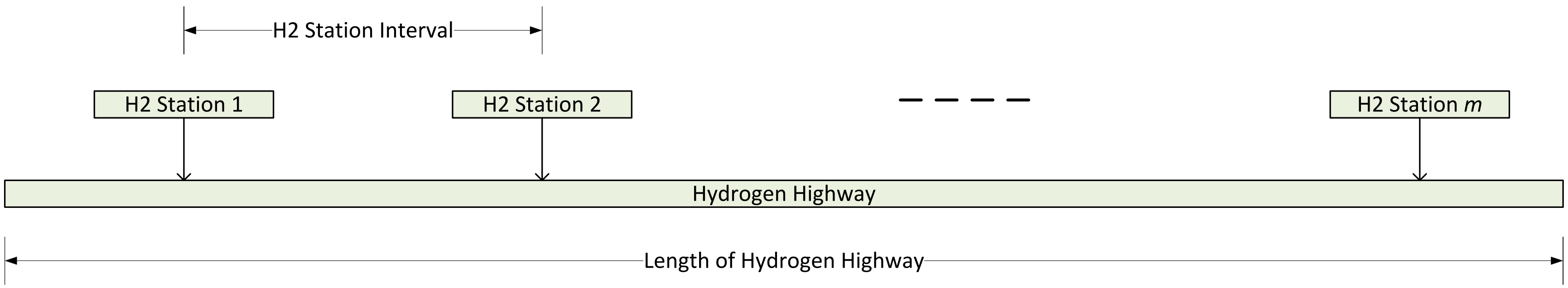
- Overhead catenary electric power supply is a mature and well understood technology.
- The same catenary that powers bus trolley lines and light rail transit trains, is used to provide power that is picked up by pantographs mounted on top of specially-equipped trucks.
- There are two major ongoing electric truck demonstrations for the overhead catenary system
  - Sweden's eHighway
  - California eHighway

Hydrogen Fuel Cell Electric Trucks

Specification & performance comparison of Tyrano and Nikola One

Fuel Cell Trucks	Tyrano	Nikola One
Motor	320 kW	2 motors with power up to 1000 hp
Fuel Cell	65 kW	300 kW
Battery	130 kWh	320 kWh
Hydrogen Fuel	20 kg Compressed hydrogen at 350 bar	Not available (estimated 100 kg) in compressed or liquid hydrogen form
Refuel Time	10-15 min. at 430 bar	15 minutes (Nikola Stations)
Charging Port	Level 2	DC Fast
Range	200 miles	800 - 1,200 miles
Weight	Not available	2,000 lbs lighter than a diesel truck
Application	Class 8 short haul semi day cab	Class 8 long haul semi sleeper cab

Layout of hydrogen fueling stations



According to Caltrans 2015 annual average daily truck traffic data, the major freight corridors in California carry several thousand trucks with 5+ axles per day. A daily traffic flow of 5,000 Class 8 freight trucks with an average speed of 65 mph is considered in analyzing average infrastructure power demand and daily energy consumption.

Comparison of Truck Configuration and Power Demand and Energy Consumption

Table 2: Long-Haul Truck Configuration and Power Demand and Energy Consumption

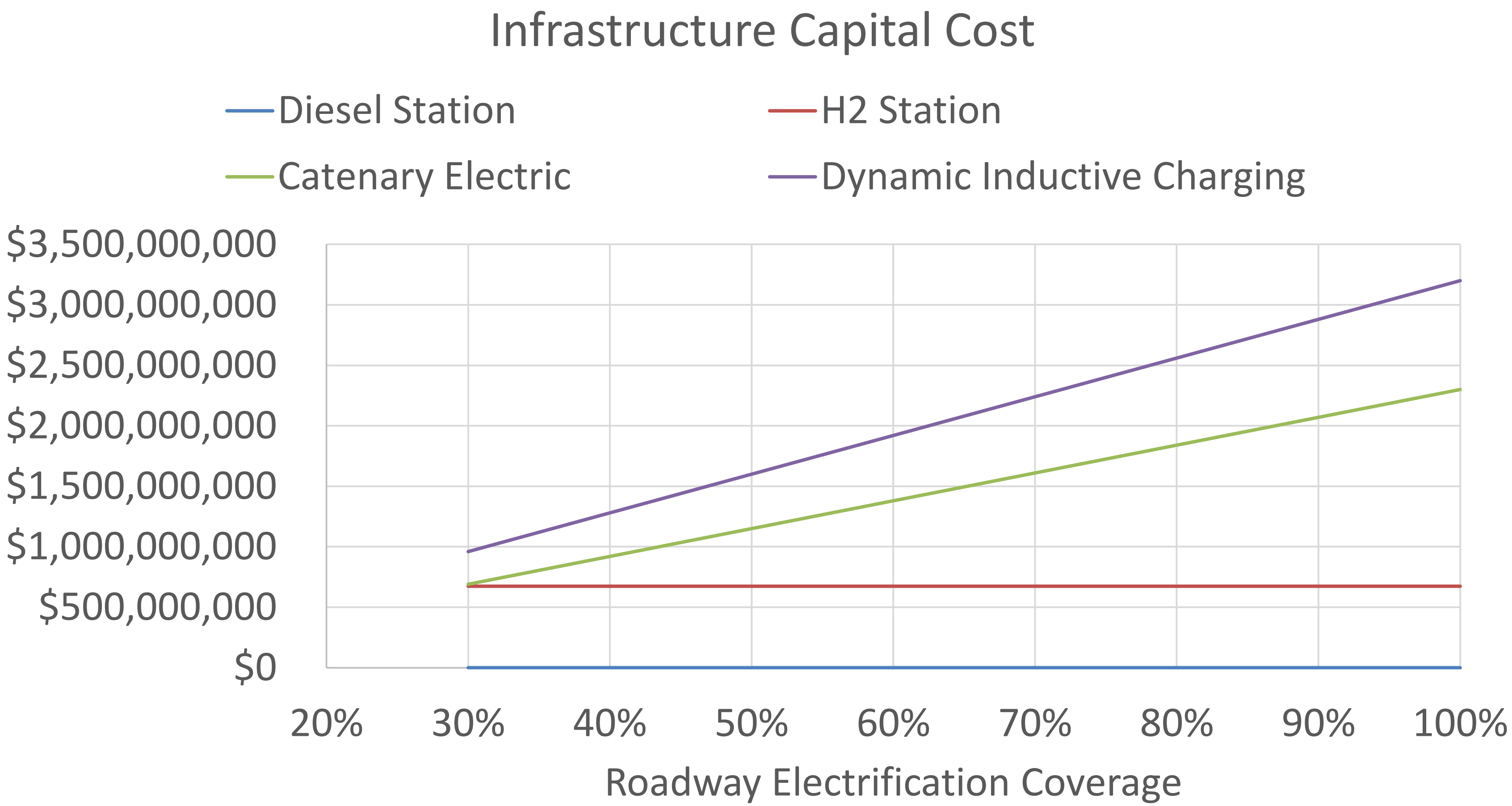
Long-Haul Truck Technology	Conventional Diesel	H2 Fuel Cell	Catenary electric	Dynamic Charging
Engine	300-450 kW	-----	-----	-----
Fuel Tank	125-300 gal	-----	-----	-----
Aftertreatment	SCR+DOC+DPF	-----	-----	-----
Transmission	10 speed	2 speed	2 speed	2 speed
Fuel Cell (kW)	-----	300	-----	-----
Hydrogen Storage (kg H2)	-----	72	-----	-----
Battery (kWh)	-----	50	100	100
Motor & Controller (kW)	-----	350	350	350
WPT Receiver Capacity (kW)	-----	-----	-----	320
Active Pantograph Capacity (kW)	-----	-----	320	-----
Range (miles)	500	500	500	500
Average traction power Request (kW)	160	160	160	160
Power Request to Grid (kW)	-----	-----	327	376
Truck energy Request (kWh/mi)	-----	-----	2.5	2.5
Energy Request to Grids (kWh/mi)	-----	-----	2.55	2.94
Diesel consumption @65mph (gal./mile)	0.1236	-----	-----	-----
H2 consumption @ 65mph (kgH2/mile)	-----	0.1155	-----	-----

Infrastructure Cost for a 500-Mile Zero-Emission Highway Section

Long-Haul Highway Trucking Technology Scenarios	Conv. Diesel Truck	Hydrogen Highway	Catenary Electric Highway	Dynamic Inductive Charge Highway
Diesel station capital cost ($)	0	-----	-----	-----
Traction power distribution system				
Catenary system ($/route mile)	-----	-----	4,600,000	-----
Dynamic wireless charger ($/route mile)	-----	-----	-----	6,400,000
Hydrogen refueling stations (based on $21.8M /sta. for a 3000kg$H_2$/da. station)		672,530,000		
Daily fuel/electricity demand (DGE)	98,924	75,908	157,083	181,107
Daily h2 demand (kg) $4/kg H2		370, 200		
Daily electricity demand (kWh)			6,377,551	7,352,941
Total Electric power demand (kW)			261,643	301,659
Substation power rating (kW)			20,931	24,133
No. of Fuel Stations/Electrified Zones	10	10	13	13
Daily Station Diesel Supply (gallon/station)	9,892			
Daily Station H2 Supply (kg/station)		9,255		
Electric Power Demand (kW/electrified zone)			20,931	24,133
Infrastructure Cost (500 route miles)	**$0**	$673,661,680	$1,150,000,000	$1,600,000,000

Comparison of Infrastructure Capital Cost

Infrastructure capital costs vary with road electrification coverage

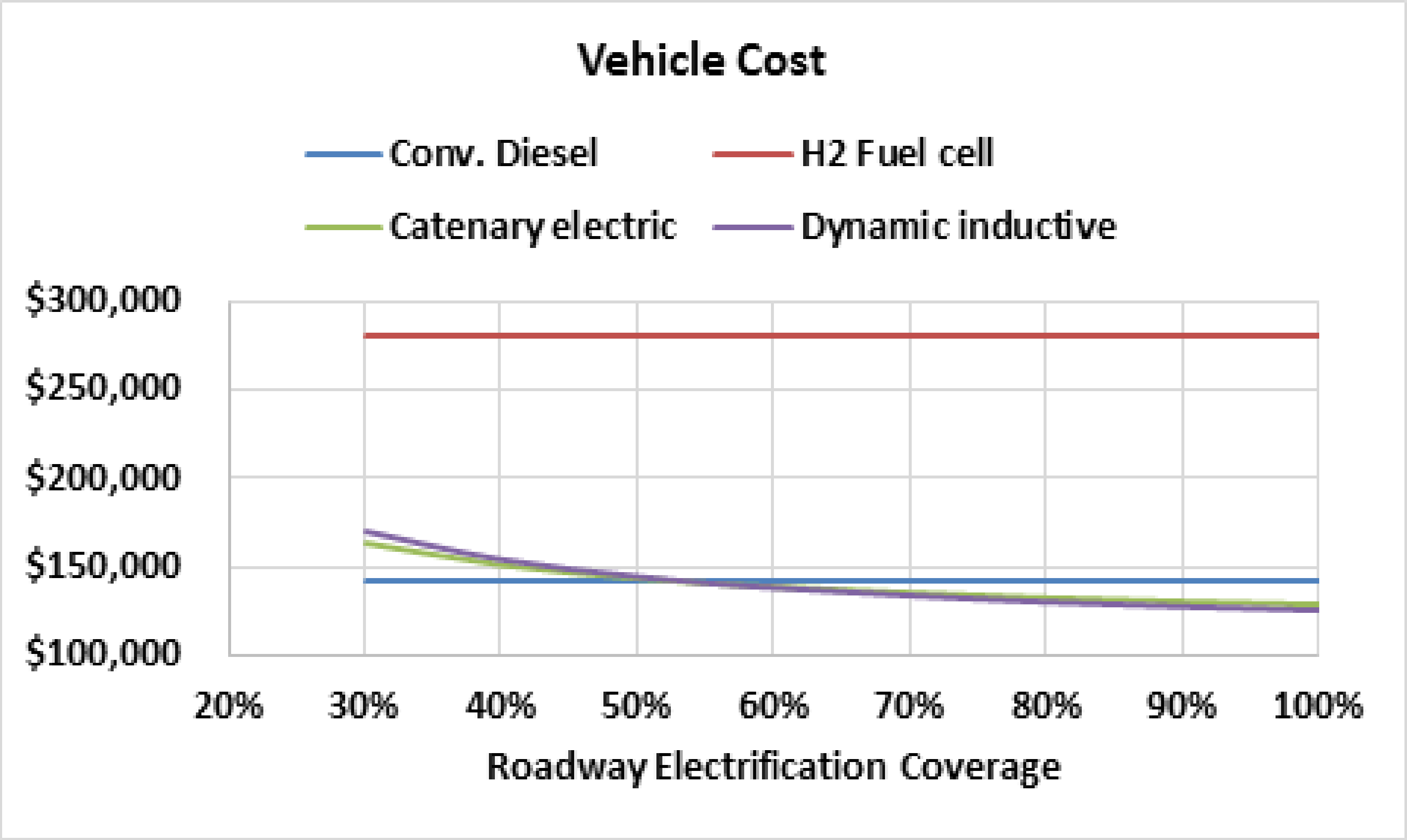


Vehicle Component Cost (2025)

Fuel_Cell_Cost	**80**	**$/kW**
H2_Storage_Cost	**500**	**$/kgH2**
Battery_Cost	**300**	**$/kWh**
Motor_Cost	**15**	**$/kW**
Motor_Ctrl_Cost	**10**	**$/kW**
WPT_Receiver_Cost	**25**	**$/kW**

Projected Truck Cost for 2025

Long-Haul Trucking Technology	Conv. Diesel	H2 Fuel Cell	Catenary Electric	Dynamic Charging
Glider	$95,539	$95,539	$95,539	$95,539
Engine	$21,881	-----	-----	-----
Aftertreatment	$15,750	-----	-----	-----
Transmission	$8,549	$2,000	$2,000	$2,000
Fuel cell	-----	$24,000	-----	-----
Hydrogen storage	-----	$36,000	-----	-----
Battery	-----	$15,000	$30,000	$30,000
Active pantograph & converter	-----	-----	$6,500	
wireless charge receiver	-----	-----	-----	$8,000
Motor and controller	-----	$8,750	$8,750	$8,750
Truck Cost	**$141,719**	**$181,289**	**$142,789**	**$144,289**


Vehicle Cost
Conv. Diesel
H2 Fuel cell
Catenary electric
Dynamic inductive
$300,000
$250,000
$200,000
$150,000
$100,000
20%
30%
40%
50%
60%
70%
80%
90%
100%
Roadway Electrification Coverage

Conclusions

- **Electrified highway truck costs are lower than fuel cells, but infrastructure costs are much higher**
- **Highway electrification costs are not substantially different for catenaries or inductive charging, and either/both types of costs could come down relative the assumptions used here.**
- **For fuel cells, the economics depends on lowering the cost of hydrogen storage onboard the vehicle and demonstrating the required durability of heavy-duty fuel cells.**

Thank You!