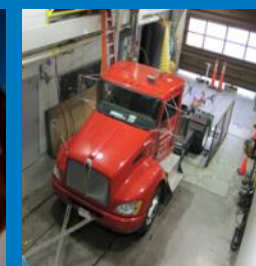
Analyzing Future Potential of Targeted In-Motion Wireless Power Transfer for Line Haul Trucks



L. Wang, J. Gonder, A. Brooker, E. Burton
and A. Konan

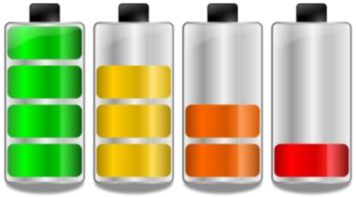
Conference on Electric Roads & Vehicles
February 10, 2015
Park City, Utah

Motivation-Why Consider Wireless Power Transfer (WPT)

The long-range operation of Class 8 truck makes plug-in vehicles not very practical. But hybrid electric vehicles (HEVs) combined with WPT might provide big benefits.

I. **The support of WPT in areas of high power demand makes engine downsize possible**
   A. Engine downsizing is generally not an option for heavy-duty HEVs because the battery depletes in long duration high power demand events.
   B. Most drivers only use engine peak power less than 1% of the time.

II. **Smaller and more affordable battery may realize fuel reduction similar to a larger battery plug-in vehicle**

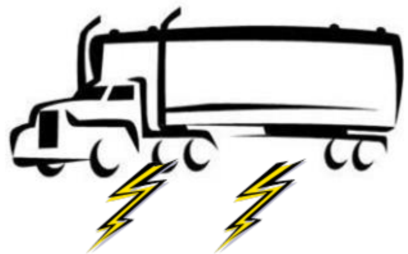


III. **Opportunity to achieve better cost effectiveness**

Objective

I. **Explore the fuel displacement opportunity WPT may offer to line haul trucks**

II. **Analyze the cost effectiveness for various implementation scenarios**



Source: KAIST

Source: Volvo Group

Source: Siemens

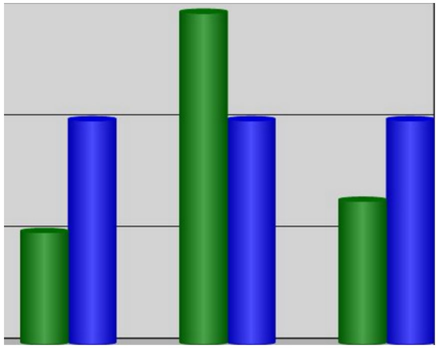
Outline

I. WPT roads selection

– WPT should be deployed at locations where large power demands happen most frequently.

II. Fuel economy (FE) comparison at various scenarios

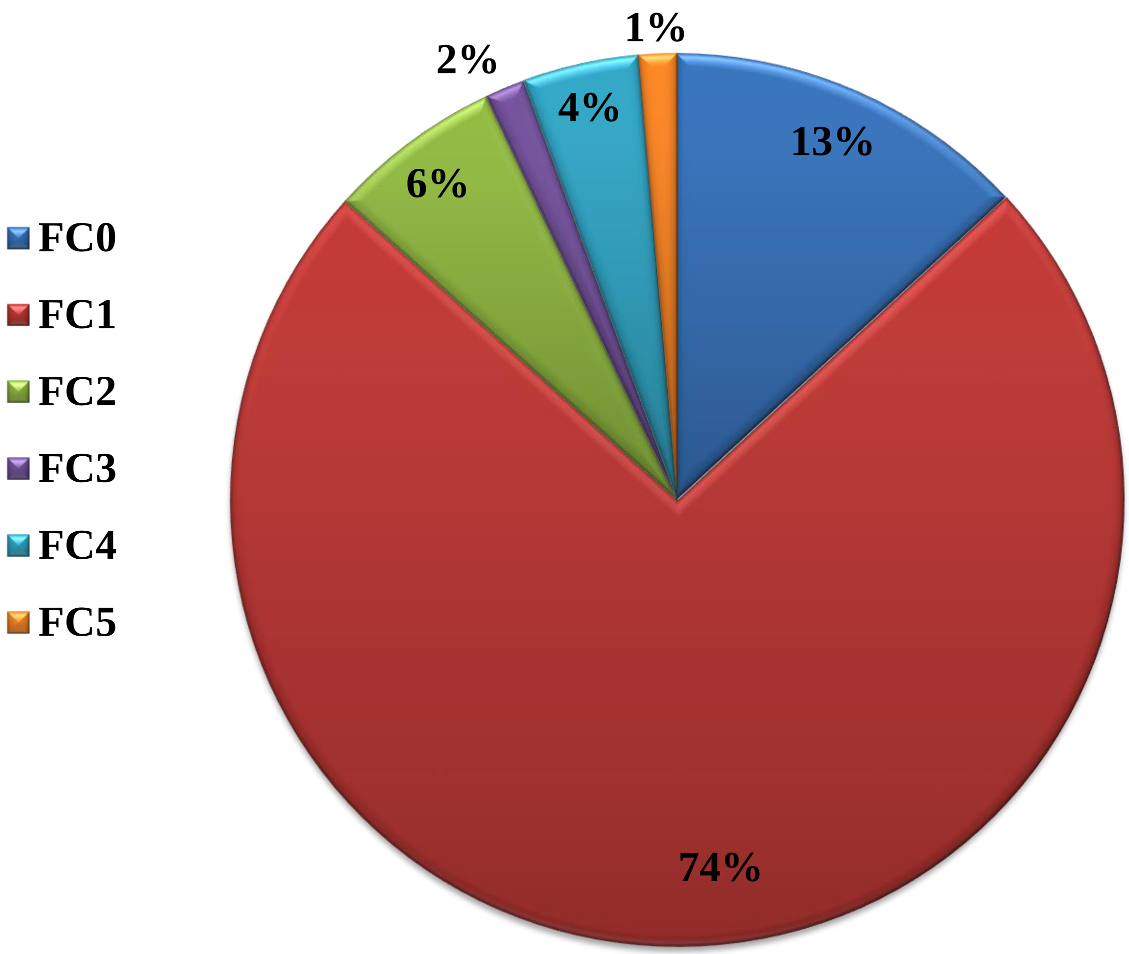
– Results include a baseline truck and a HEV truck with different levels of engine downsizing both with and without WPT.



III. Cost effectiveness analysis

– Cost effectiveness depends on many factors, including FE, diesel price and the cost of hardware and infrastructure.

Functional Class Distribution



FC1: Functional Class 1 corresponds to high-speed interstates

FC5: Functional Class 5 links to neighborhood streets

Distribution of Average Power Outputs vs. Grades

Grade Bin (%)	FC1 and FC2 Roads		FC3, FC4 and FC5 Roads	
	Average Power (kW)	Percent of Distance (%)	Average Power (kW)	Percent of Distance (%)
0~1.5	199	24.8	155	1.1
1.5~2	266	5.7	178	0.3
2~4	324	10.9	248	0.9
>4	368	4.7	295	1.1

21%

FASTSim

Future Automotive Systems Technology Simulator

- The average power is large when grades are larger than 1.5%.
- 21% of FC1 and FC2 roads have grades larger than 1.5%.
- 2% of FC3, FC4 and FC5 roads with grades larger than 1.5% are missing WPT.

Fuel Economy Comparison – 21.3% WPT @ FC1 & FC2 with Grade>1.5%

Scenarios	Engine Power (kW)	WPT Power (kW)	Total Fuel (Gallon)	FE (mpg)	Improvement (%)
Conventional Baseline Engine	391	0	145	5.50	N/A
Hybrid Baseline Engine	391	0	138	5.87	6.73
		100	125	6.49	18.00
Hybrid Downsize 1	350	0	135	5.93	7.82
		100	123	6.58	19.64
Hybrid Downsize 2	305	~~0~~	~~133~~	~~6.06~~	~~10.18~~
		100	121	6.69	21.64

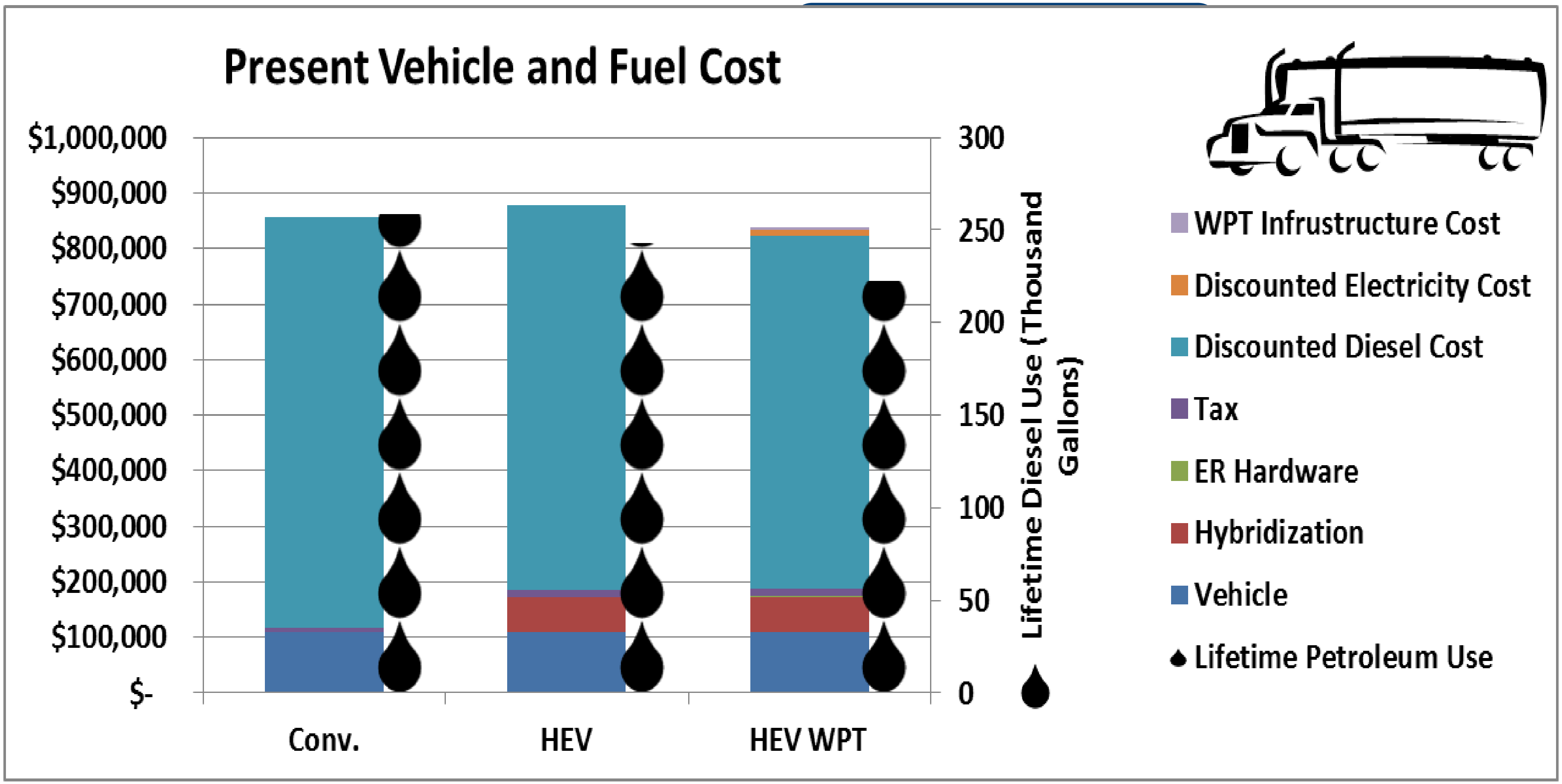
- The largest fuel savings potential is a HEV with its engine downsized to 305 kW and WPT on FC1 and FC2 roads with grades greater than 1.5%.
- Relative to the baseline conventional vehicle, this scenario achieved a 22% FE improvement. A 14% FE improvement was achieved relative to the HEV with no engine downsizing and no WPT.

Assumptions for Vehicle Inputs and Economic Conditions

Inputs	Assumption
Vehicle Life (years)	19
Beginning of Life Annual Travel (mile)	120,000
Miles of Highways (mile)	194,600 [1]
Annual highway fuel consumption (gallon)	169 billion [2]
Conventional Vehicle Cost	$110,000 [3]
Hybridizing Cost Increment	$61,450 [3]
Additional WPT Cost per Vehicle	$10,000 [3]
Diesel Cost	$3.88 /gal [4]
Electricity Cost	$0.08 /kW [4]
WPT Cost	$3,000,000/mile
Discount Rate	4.2% [3]
Percent of WPT Roads	14% [5]
WPT infrastructure life (year)	8

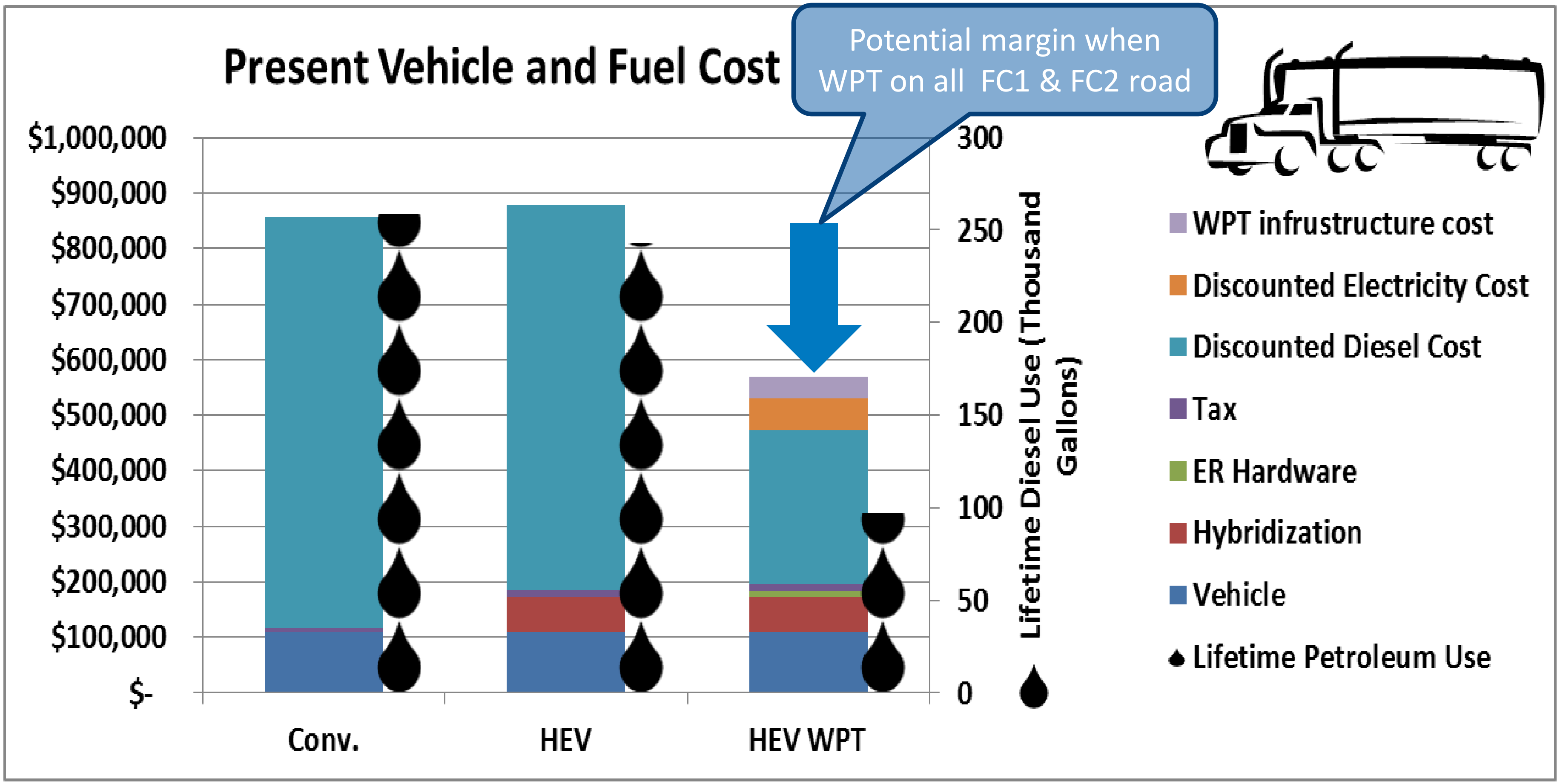
- Optimistic assumption: all vehicles using the WPT infrastructure and only one lane is electrified.
- The national NAVTEQ road data indicated that roughly 14% of FC1 and FC2 nationwide miles have grades greater than 1.5%. For the cost effectiveness analysis, we therefore reduced the estimated FE improvement from 14% to 9%.

Cost Effectiveness Analysis: WPT on FC1 & FC2 Roads with Grade>1.5% @$3.88/gallon, FE=6.4 mpg



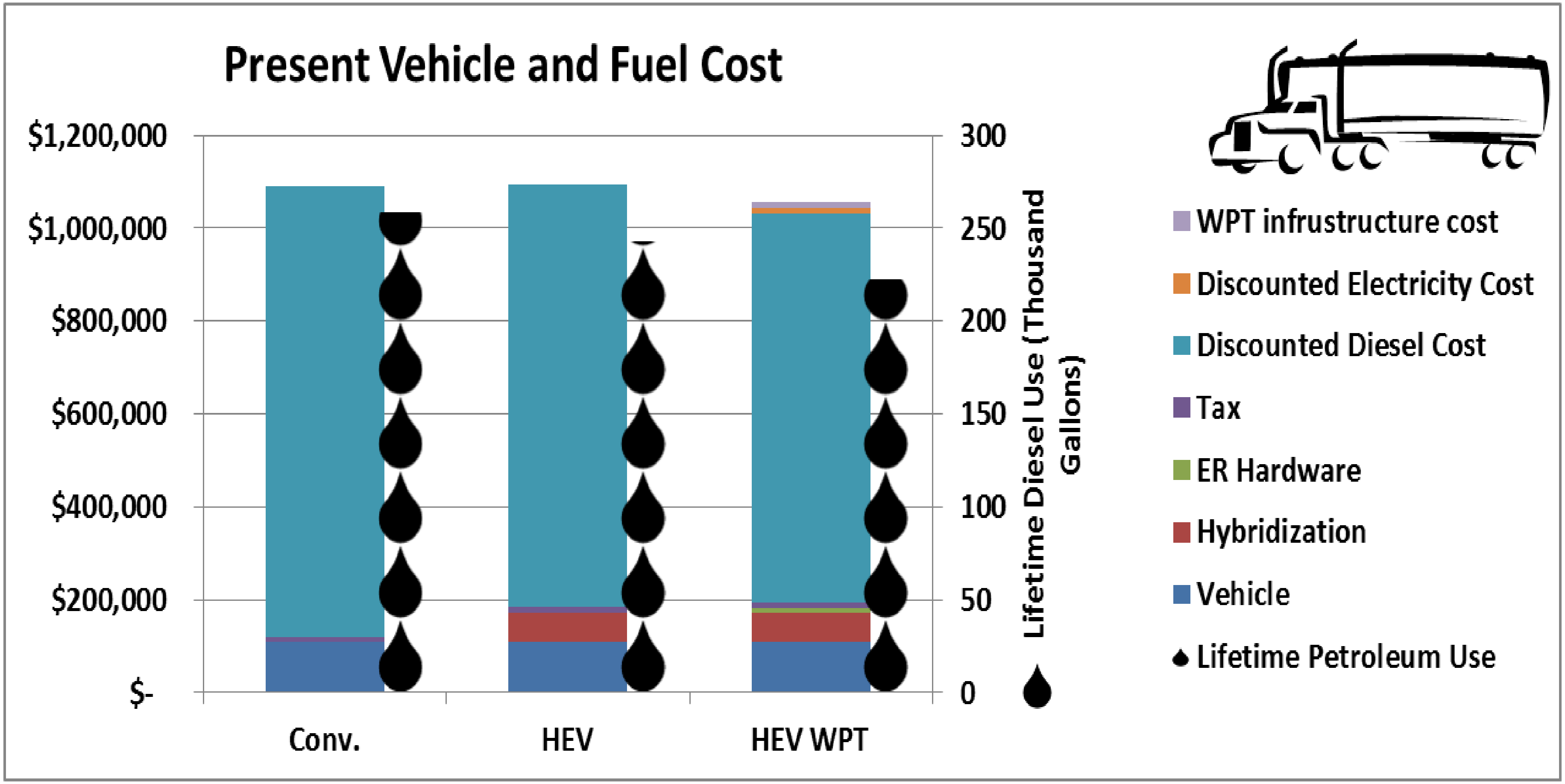
- The results suggest fuel consumption for such a strategy could be 9% lower than for a baseline HEV.
- An cost-benefit analysis indicates that the savings could be achieved with a roughly equivalent lifetime cost as for a conventional truck.

Cost Effectiveness Analysis: WPT on All FC1 & FC2 Roads @$3.88/gallon, FE=14.6 mpg



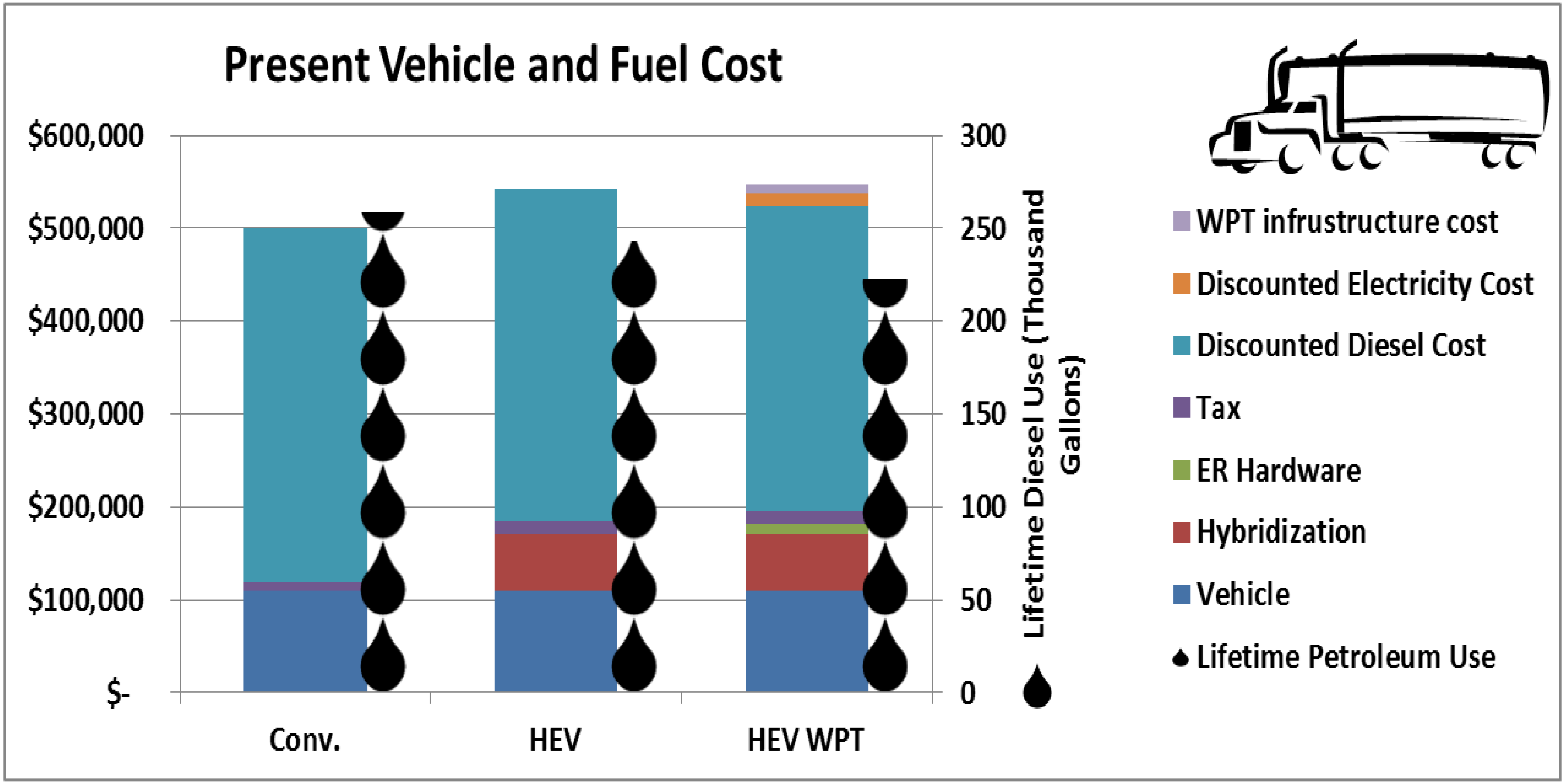
- High sensitivity: 35% lower than a conventional truck

Cost Effectiveness Analysis: @$5.10/gallon



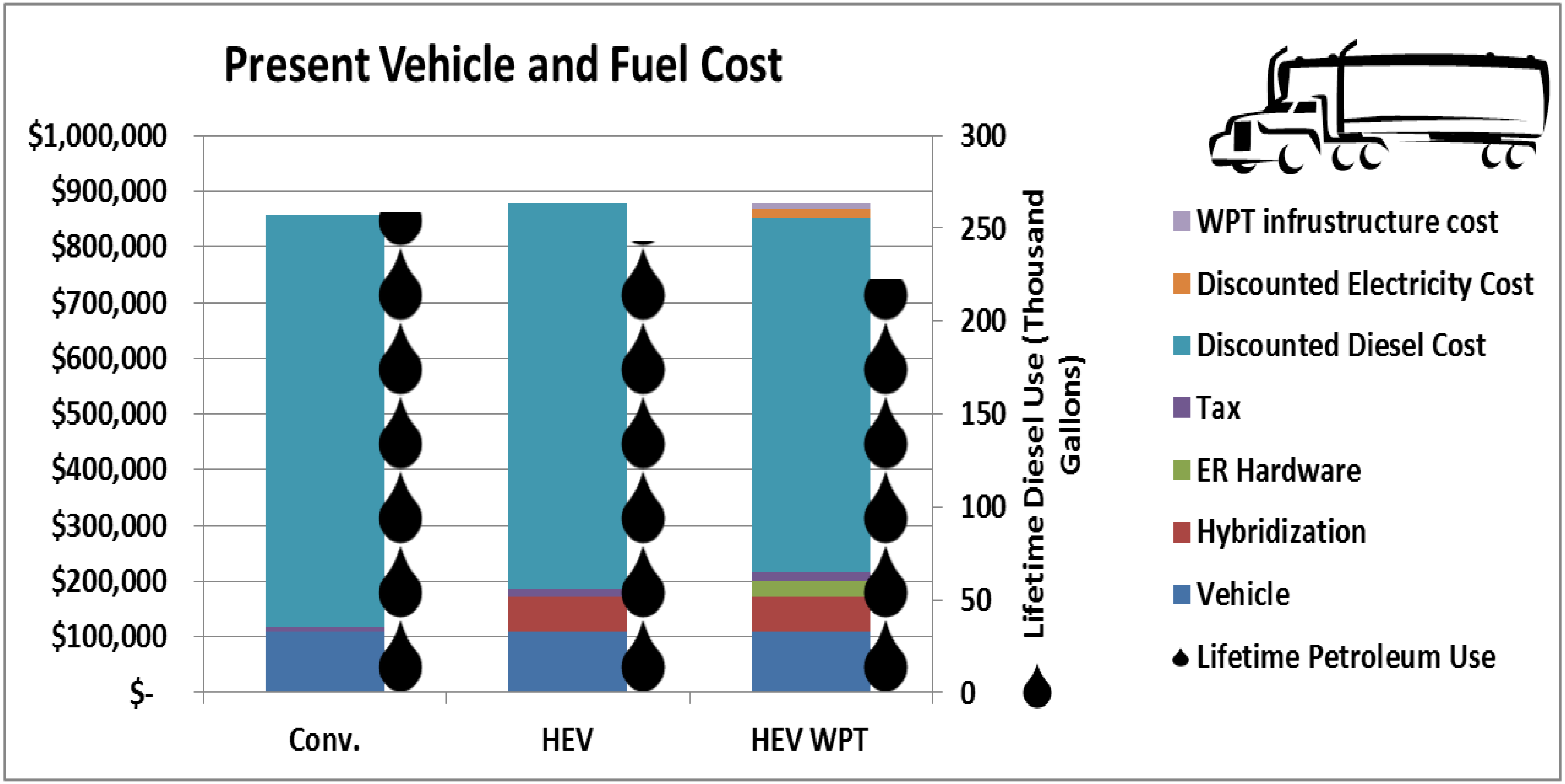
➢ High sensitivity: 3% lower than a conventional truck

Cost Effectiveness Analysis: @$2.00/gallon



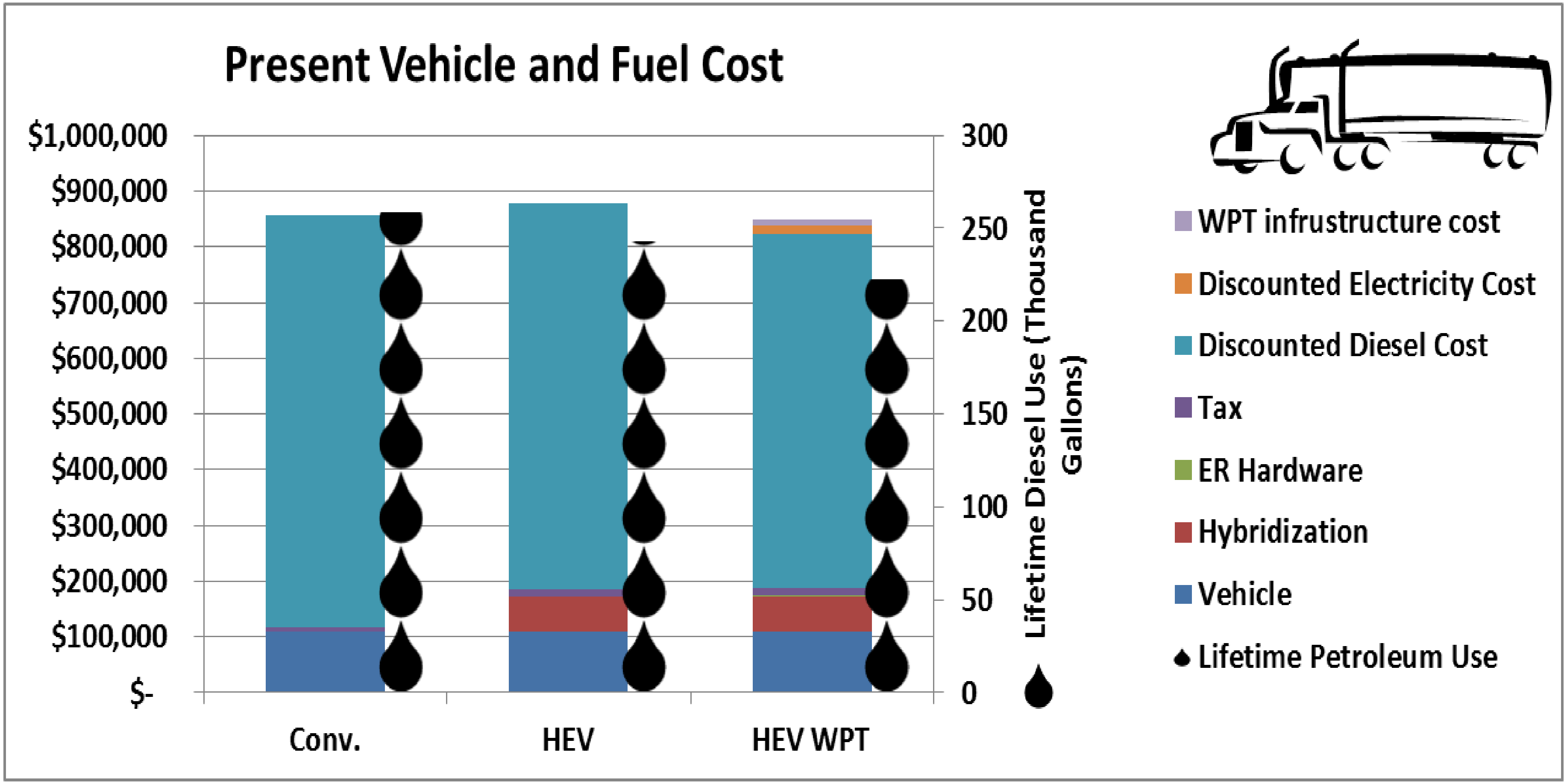
- ➢ High sensitivity : 10% higher than a conventional truck.

Cost Effectiveness Analysis: @$30,000 Hardware Device Cost



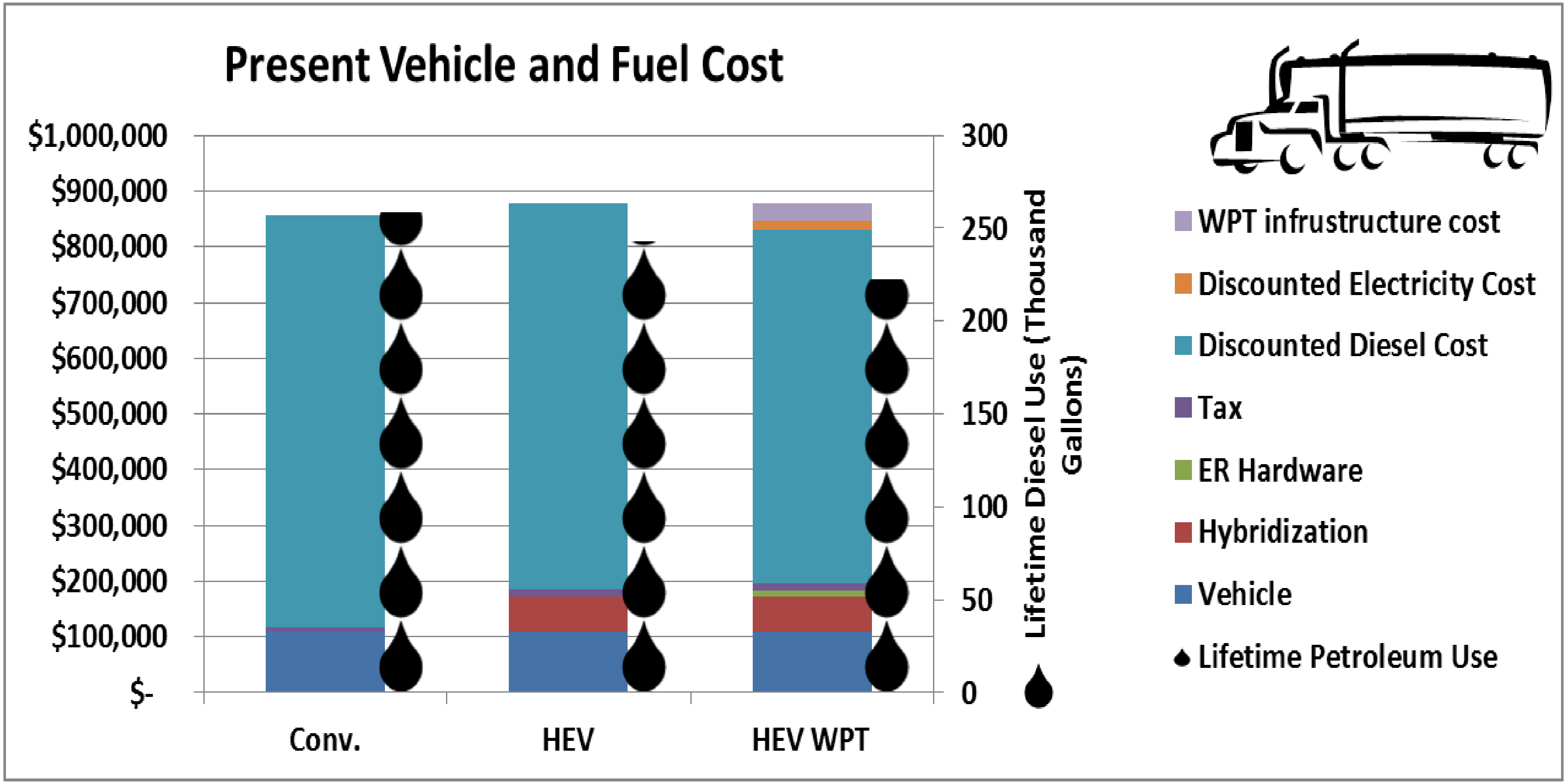
- Low sensitivity: 2% higher than a conventional truck

Cost Effectiveness Analysis: @$3,000 Hardware Device Cost



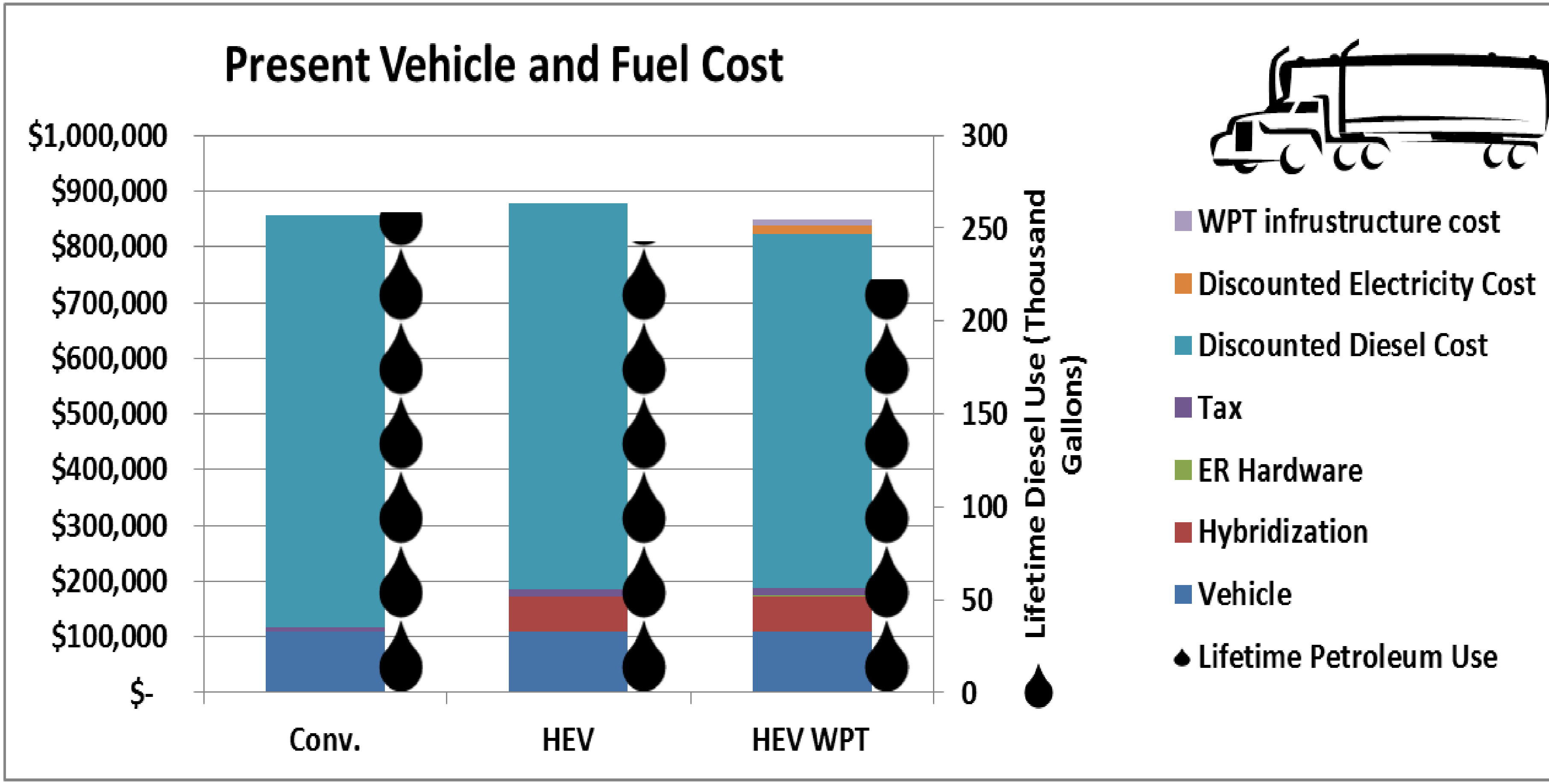
- Low sensitivity : 1% lower than a conventional truck.

Cost Effectiveness Analysis: @$10M/mile Infrastructure Cost



- Low sensitivity: 2% higher than a conventional truck.

Cost Effectiveness Analysis: @$ 1.5M/mile Infrastructure Cost



- Low sensitivity: 1% lower than a conventional truck.

Summaries

I. **WPT scenarios selection:**
   A. Applying WPT on FC1 and FC2 roads with grades greater than 1.5%.
   B. Downsizing an HEV engine to 305 kW.

II. **Performance Results:** Assuming 14% of the interstate roads have WPT, which is less than 0.2% of the roads in the nation, petroleum use was reduced by 9% and the vehicle's net cost was similar to a conventional vehicle.

III. **Cost effectiveness sensitivity analysis**:
   A. High sensitivity to the amount of infrastructure and fuel price
   B. Low sensitivity to the cost of hardware device and infrastructure.

Questions?

References

1. NREL’s Fleet DNA Project website, www.nrel.gov/vehiclesandfuels/fleettest/research_fleet_dna.html.
2. NAVTEQ 2011 Q3 NAVSTREETS SDC Data Dictionary.
3. Summary Report on Cost/Benefit Analysis for Roadway Electrification with Commercial Trucks and On Support Provided to VSATT, the TSDC and RWDC: Advanced Vehicle Modeling and Simulation Milestone.
4. U.S. Energy Information Administration (EIA) website, www.eia.gov/.
5. The national NAVTEQ/Nokia/HERE Road Layer Data

Appendix