Autos, Trucks, and Advanced Mobility

Tesla Truck Withstands Scrutiny (w/ Caveats) Based on v3.0 of EV Payback Model

CONCLUSION

Tesla says electric trucks can tackle long-haul applications. Essentially all of our other covered companies disagree. It's easy to say, "the batteries are too heavy!" or "the batteries are too costly!" and declare the incumbents victorious - but such back-of-the-envelope rebuttals aren't good enough in this case. The implications of misunderstanding the EV debate are wide-ranging, not just for truck-oriented companies and their investors, but for market participants across the industrial spectrum. With this in mind, we have spent the past few months speaking with contacts, studying online physics tutorials, and creating a new version of our EV truck payback model. After completing this latest version - which is a substantial improvement vs. our past efforts - we still think EV trucks will succeed.

- **The Tesla truck could achieve a 2-year payback - but read the fine print, because assumptions matter.** Investors were understandably surprised - and perhaps a bit skeptical - when they saw the purported selling price, specs, and operating costs of Tesla's semi. Every fleet is different, and without knowing all of the details underlying Tesla's assertions, it's impossible to stress-test the company's claims. With this in mind, we are attempting to be as transparent as possible in our EV payback analysis. Clients can view all of our assumptions on pages 2-4, and if they wish, they can obtain a copy of the model and replace our assumptions with their own.

- **Cost (not weight) is the biggest x-factor; Tesla's scale in the car market will help.** In our view, investors are too focused on the physical limitations of EVs. We aren't concerned about weight or other performance-related characteristics. We have examined weight and its impact on energy efficiency, and we think fleets can minimize any negative impact by right-sizing the battery and spec'ing lightweight parts. But cost is a bigger unknown. For instance, we don't know how cheaply Tesla can make its battery packs, motors, or power electronics. Given the truck's (shockingly low) price point of $150k-$200k, we think Tesla must be expecting its scale in the car market to enable installed battery costs of ~$100/kWh (or lower), along with cheap motors and inverters.

- **There's still room to improve our payback model.** We will attempt to address remaining uncertainties in future versions of our model. For instance, will fleets need to replace batteries (at a substantial cost) in response to eventual range degradation, or will they be able to re-deploy older trucks to lower-mileage routes? Will there be unforeseen maintenance costs or other reasons for downtime? How much will hot or cold weather impact efficiency? Will service costs be insourced, and if so, how much will it cost to hire/train technicians? What will be the residual value of a used Tesla semi? Why can't diesel competitors mimic Tesla's impressive drag coefficient, and if they do, will it become harder to deliver a payback vs. diesel? Can Tesla really deliver $0.07/kWh electricity?

- **Stock implications.** We are Neutral or Underweight on many truck stocks, owing partially to inflated cyclical valuations and partially to the risk of disruption. Neutral-rated stocks include CMI, PCAR, and NAV, while ALSN remains our highest-conviction Underweight (though the assumptions highlighted on pages 2-4 are less relevant for ALSN, given the company's focus on vocational fleets). To varying degrees, we think Overweight-rated stocks like TSLA, WBC, and MTOR are sheltered from secular threats.

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Related Companies:	Share Price:
ALSN	45.31
CMI	181.96
MTOR	23.77
NAV	43.86
PCAR	74.83
TSLA	333.69
WBC	149.82

INDUSTRY RISKS

Production delays, real-world performance shortfalls, warranty claims, high-profile accidents, competition, increasingly efficient diesel technologies, raw material shortages and/or price spikes, cheaper oil

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ORANGE CELLS: user inputs

Duty Cycle Assumptions - Class 8 Tractor					
Miles traveled per day	275	miles/day	Time spent at each red light	1.5	mins/stop
Days in operation per week	5.0	days/week	Total time spent idle at red lights	35.1	mins/day
Annual miles traveled	71,696	miles/yr	# of planned stops per day	5	stops/day
% of miles on highways	60.0%	%	Time spent at each planned stop	30	minutes
% of miles in suburbs	35.0%	%	Time spent idle at planned stops	150	mins/day
% of miles in urban areas	5.0%	%	Time spent idle at ALL stops (mins)	185	mins/day
# of miles on highways	165.0	miles/day	Time spent idle at ALL stops (hours)	3.1	hrs/day
# of miles in suburbs	96.3	miles/day	Speed when driving on highways	60	miles/hr
# of miles in urban areas	13.8	miles/day	Speed when driving in suburbs	35	miles/hr
# of red lights per mile: highways	0.00	stops/mile	Speed when driving in urban areas	10	miles/hr
# of red lights per mile: suburbs	0.10	stops/mile	Time spent in motion: highways	2.8	hrs/day
# of red lights per mile: urban areas	1.00	stops/mile	Time spent in motion: suburbs	2.8	hrs/day
# of stops at red lights: highways	0.0	stops/day	Time spent in motion: urban areas	1.4	hrs/day
# of stops at red lights: suburbs	10	stops/day	Total driver time spent working	10.0	hrs/day
# of stops at red lights: urban areas	14	stops/day	Total daily # of stop/start cycles	28	cycles/day
Total # of stops at red lights	23	stops/day	Avg. vehicle speed while in motion	40.0	miles/hr

Diesel Vehicle Specs & Cost Assumptions		
Drivetrain power requirement (kW)	336	kW
Drivetrain power requirement (hp)	451	hp
Engine mfg cost per kW	$40	$/kW
Engine manufacturing cost	$13,440	$
Engine margin & warranty[1]	15.0%	%
Installed cost: engine	$15,456	$
Engine size (6.7L, 9L, 12L, 13L, 15L)	12.0	Liters
Emission control parts mfg. cost	7,460	$
Parts margin/warranty[1]	15.0%	%
Installed cost: emission control parts	$8,579	$
Max. range given fuel tank capacity	1,316	miles
Extra range buffer vs. daily range needs	379%	%
Transmission mfg. cost	$5,000	$
Transmission margin/warranty[1]	15.0%	%
Installed cost: transmission	$5,750	$
Installed cost of other misc. parts[2]	$2,500	$
Weight of parts[3] before light-weighting	5,270	lbs
Truck maker margin & warranty	15.0%	%
Installed cost: parts not needed on EV	$37,128	$

[1]use 0% if manufactured in-house by vehicle manufacturer
[2]e.g. fuel tanks, pb-acid batteries, alternator, starter, clutch, belt-driven auxiliary parts
[3]we assume the frame rails, cross members, and cab can be built with lighter-weight materials (for a cost)

Electric Vehicle (EV) Specs & Cost Assumptions		
Drivetrain power requirement (kW)	768	kW
Motors, pwr electronics mfg cost/kW	$10	$/kW
Motors, power electronics mfg cost	$7,680	$
Motors, pwr elec margin & warranty[1]	0.0%	%
Installed cost: motors + pwr electronics	$7,680	$
Lithium-ion battery pack capacity	545	kWh
Battery pack mfg cost-per-kWh	$100	$/kWh
Battery pack manufacturing cost	$54,500	$
Battery pack margin/warranty[1]	0.0%	%
Installed cost: battery pack	$54,500	$
Max range given battery capacity	300	miles
Extra range buffer vs. daily range needs	9%	%
Gearbox (0 if no gearbox)	$0	$
Gearbox margin/warranty[1]	0.0%	%
Installed cost: gearbox	$0	$
Installed cost of other misc. parts[2]	$5,000	$
Weight of parts[3] after light-weighting	4,320	lbs
Impact of light-weighting	950	lbs
Cost-per-lb of light-weighting	$5	$/lb
Installed cost of light-weighted parts	$4,750	$
Truck maker margin & warranty	15.0%	%
Installed cost: new parts needed on EV	$82,720	$

[1]use 0% if manufactured in-house by vehicle manufacturer
[2]e.g. wiring harness and electric (non-belt-driven) AC, compressor, power steering
[3]we assume the frame rails, cross members, and cab can be built with lighter-weight materials (for a cost)

Diesel Vehicle Opex Assumptions		
Per-gallon diesel cost	$2.90	$/gal
Yearly gallons of diesel consumed	8,717	gal/year
Yearly spending on diesel	$25,280	$/year
Per-mile repair & maintenance costs	$0.15	$/mile
Yearly spending on repair, maintenance	$10,396	$/year
Yearly spending on fuel, repair, maint.	$35,676	$/year

Electric Vehicle (EV) Opex Assumptions		
Cost of electricity	$0.07	$/kWh
Yearly kWh of electricity consumed	130,120	kWh/year
Yearly spending on electricity	$9,108	$/year
Per-mile repair & maintenance costs	$0.07	$/mile
Yearly spending on repair, maintenance	$5,198	$/year
Yearly spending on fuel, repair, maint.	$14,306	$/year

Incremental Spending & Opex Savings: EV vs. Diesel		
Incremental price: EV truck vs. diesel	$45,592	$/year
Annual opex savings: EV truck vs. diesel	$21,370	$/year

SIMPLE PAYBACK TIME: EV vs. DIESEL
2.1 YEARS

Source: Piper Jaffray Research

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ORANGE CELLS: user inputs

Diesel Vehicle Energy Consumption		
Vehicle mass (GVW, in lbs)	64,062	lbs
Vehicle mass (GVW, in kg)	29,058	kg
Velocity during highway driving	26.8	m/s
Velocity during suburban driving	15.6	m/s
Velocity during urban driving	4.5	m/s
Kinetic energy during highway driving	10.5	MJ
Kinetic energy during suburban driving	3.6	MJ
Kinetic energy during city driving	0.3	MJ
Engine efficiency during acceleration	25.0%	%
Driveline efficiency	95.0%	%
Energy used per start cycle (highway)	44	MJ
Energy used per start cycle (suburbs)	15	MJ
Energy used per start cycle (urban)	1	MJ
Energy for starting after red lights	161	MJ/day
Energy for starting after planned stops	264	MJ/day
% of kin. energy recaptured (braking)	0.0%	%
Kin. energy recaptured at red lights	0.0	MJ/day
K.E. recaptured during planned stops	0.0	MJ/day
Assumed density of air	1.225	kg/m^3
Vehicle (trailer) height	162	inches
Vehicle (trailer) width	102	inches
Vehicle (trailer) cross sectional area	16,524	in^2
Square meters per square inch	0.000645	m^2/in^2
Vehicle (trailer) cross sectional area	10.7	m^2
Vehicle+trailer drag coefficient	0.70	N/A
Distance driven on highways	265,541	m/day
Distance driven in suburbs	154,899	m/day
Distance driven in urban areas	22,128	m/day
Kin. energy of displaced air (highway)	873	MJ/day
Kin. energy of displaced air (suburbs)	173	MJ/day
Kin. energy of displaced air (urban)	2	MJ/day
Engine efficiency at highway speed	44.7%	%
Engine efficiency at suburban speed	43.4%	%
Engine efficiency at urban speed	28.4%	%
Energy needed to offset air drag	2,486	MJ/day
Coefficient of rolling resistance (μ_{RR})	0.0065	N/A
Acceleration due to gravity	9.81	m/s^2
Force due to rolling resistance (F_{RR})	1,852	N ($kg{\cdot}m/s^2$)
Work needed to offset rolling resist.	820	MJ/day
Average engine efficiency	43.4%	%
Energy needed to offset rolling resist.	1,988	MJ/day
Fuel energy consumed	4,899	MJ/day
Gallons diesel per MJ	0.00683	gal/MJ
Watt-hours per MJ	278	Wh/MJ
Fuel consumption (gallons diesel)	33	gal/day
Fuel consumption (liters diesel)	127	L/day
Fuel consumption (watt-hours)	1,360,844	Wh/day
Fuel economy measure #1	8.2	MPG
Fuel economy measure #2	28.6	L/100km
Fuel economy measure #3	4,949	Wh/mile

Electric Vehicle (EV) Energy Consumption		
Vehicle mass (GVW, in lbs)	64,819	lbs
Vehicle mass (GVW, in kg)	29,402	kg
Velocity during highway driving	26.8	m/s
Velocity during suburban driving	15.6	m/s
Velocity during urban driving	4.5	m/s
Kinetic energy during highway driving	10.6	MJ
Kinetic energy during suburban driving	3.6	MJ
Kinetic energy during city driving	0.3	MJ
Battery efficiency	98.0%	%
Motors, power electronics efficiency	81.0%	%
Energy used per start cycle (highway)	13	MJ
Energy used per start cycle (suburbs)	5	MJ
Energy used per start cycle (urban)	0	MJ
Energy for starting after red lights	49	MJ/day
Energy for starting after planned stops	80	MJ/day
% of kin. energy recaptured (braking)	55.0%	%
Kin. energy recaptured at red lights	21.3	MJ/day
K.E. recaptured during planned stops	34.9	MJ/day
Assumed density of air	1.225	kg/m^3
Vehicle (trailer) height	162	inches
Vehicle (trailer) width	102	inches
Vehicle (trailer) cross sectional area	16,524	in^2
Square meters per square inch	0.000645	m^2/in^2
Vehicle (trailer) cross sectional area	10.7	m^2
Vehicle+trailer drag coefficient	0.36	N/A
Distance driven on highways	265,541	m/day
Distance driven in suburbs	154,899	m/day
Distance driven in urban areas	22,128	m/day
Kin. energy of displaced air (highway)	449	MJ/day
Kin. energy of displaced air (suburbs)	89	MJ/day
Kin. energy of displaced air (urban)	1	MJ/day
Battery+drivetrain efficiency (highway)	79.4%	%
Battery+drivetrain efficiency (suburbs)	79.4%	%
Battery+drivetrain efficiency (urban)	79.4%	%
Energy needed to offset air drag	679	MJ/day
Coefficient of rolling resistance (μ_{RR})	0.0065	N/A
Acceleration due to gravity	9.81	m/s^2
Force due to rolling resistance (F_{RR})	1,874	N ($kg{\cdot}m/s^2$)
Work needed to offset rolling resist.	829	MJ/day
Average drivetrain efficiency	79.4%	%
Energy needed to offset rolling resist.	1,045	MJ/day
Fuel energy consumed	1,797	MJ/day
Gallons diesel per MJ	0.00683	gal/MJ
Watt-hours per MJ	278	Wh/MJ
Fuel consumption (gallons diesel)	12	gal/day
Fuel consumption (liters diesel)	46	L/day
Fuel consumption (watt-hours)	499,089	Wh/day
Fuel economy measure #1	22.4	MPG(eq)
Fuel economy measure #2	10.5	L(eq)/100km
Fuel economy measure #3	1,815	Wh/mile

Assumed Engine Efficiency at Various Average Vehicle Speeds																
Average speed (mph)	9.7	12.9	16.4	19.1	22.2	27.0	31.8	34.9	37.3	40.2	43.2	46.2	49.2	52.6	54.9	56.1
Diesel engine efficiency	28%	34%	34%	37%	40%	40%	41%	43%	44%	44%	44%	44%	44%	45%	45%	45%

Source: Piper Jaffray Research

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ORANGE CELLS: user inputs

Diesel Vehicle Weight Assumptions		
# of aluminum wheels + tires (on cab)	10	wheels
Weight of one wheel+tire pairing	170	lbs/wheel
Total weight of wheels+tires (on cab)	1,700	lbs
Weight of frame rails, cross members	1,860	lbs
5th wheel weight (0 if no 5th wheel)	180	lbs
Steer axle weight (incl. suspension)	603	lbs
# of drive axles	2	axles
Weight of each drive axle	850	lbs
Total weight of drive axles	1,700	lbs
# of dead axles (excl. steer axle)	0	axles
Weight of each dead axle	400	lbs
Total weight of dead axles	0	lbs
Driveshaft weight	160	lbs
Rear suspension system weight	550	lbs
Cab, hood, fairings, interior, glass	3,230	lbs
Engine weight	2,050	lbs
Aftertreatment system weight	191	lbs
Transmission weight	850	lbs
Engine cooling system weight	730	lbs
Amount of coolant in cooling system	8.0	gal
Per-gallon coolant weight	8	lbs/gal
Total weight of on-board coolant	64	lbs
Diesel tank #1 size (150, 100, 80, 50)	80	gal
Diesel tank #1 weight	135	lbs
Diesel tank #2 size (0 if no 2nd tank)	80	gal
Diesel tank #2 weight	135	lbs
Total weight of empty diesel tanks	270	lbs
Total fuel capacity	160	gal
Average diesel fill rate	50.0%	%
Gallons of onboard fuel	80	gal
Per-gallon weight of diesel fuel	6.943	lbs/gal
Total weight of onboard diesel fuel	555	lbs
# of lead-acid (Group 31) batteries	4	batteries
Weight per lead-acid battery	65	lbs
Total weight of lead-acid batteries	260	lbs
DEF tank capacity (9.5, 16, or 23)	23	gal
Weight of DEF tank (w/ brackets)	80	lbs
Per-gallon weight of DEF	9.00	lbs/gal
Total weight of onboard DEF	207	lbs
Weight of exhaust system (excl. SCR)	1,132	lbs
Curb weight - vehicle only	16,372	lbs
Driver weight	190	lbs
Passenger weight	0	lbs
Curb weight - trailer (0 if no trailer)	12,500	lbs
Weight of onboard cargo	35,000	lbs
Total gross vehicle weight (GWR)	64,062	lbs

Electric Vehicle (EV) Weight Assumptions		
# of aluminum wheels + tires	6	wheels
Weight of one wheel+tire pairing	217	lbs/wheel
Total weight of wheels+tires (on cab)	1,300	lbs
Frame rails, cross members, 5th wheel	960	lbs
5th wheel weight (0 if no 5th wheel)	130	lbs
Steer axle weight (incl. suspension)	603	lbs
# of e-axles	2	axles
Weight per e-axle (excl. motor)	850	lbs
Total weight of e-axles (excl. motor)	1,700	lbs
# of dead axles (excl. steer axle)	0	axles
Weight of each dead axle	400	lbs
Total weight of dead axles	0	lbs
Driveshaft weight (0 if no driveshaft)	0	lbs
Rear suspension system weight	550	lbs
Cab, hood, fairings, interior, glass	3,230	lbs
Total drivetrain power requirement	768	kW
Gearbox weight (0 if no gearbox)	0	lbs
# of traction motors+inverters	4	motors
Per-motor power requirement	192	kW
Traction motors: weight per kW	1.25	kg/kW
Weight per traction motor (kg)	240	kg
Pounds per kg	2.20	lbs/kg
Weight per traction motor (lbs)	529	lbs
Total weight of traction motors	2,116	lbs
Total battery capacity	545	kWh
Lithium-ion battery pack density	12	lbs/kwh
Lithium-ion battery pack weight	6,540	lbs
Curb weight - vehicle only	17,129	lbs
Driver weight	190	lbs
Passenger weight	0	lbs
Curb weight - trailer (0 if no trailer)	12,500	lbs
Weight of onboard cargo	35,000	lbs
Total gross vehicle weight (GWR)	64,819	lbs

Source: Piper Jaffray Research

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