Tesla Motors, Inc. (TSLA)

Is the Model S Green? **April 5, 2013**

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Investment Highlights

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- *The total effective CO2, SOx and NOx emissions of a Tesla Model S are much higher than that of a large SUV*
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Research Analyst:

Nathan Weiss

Inquiries

Rob Hasting

(313) 530-4365

Executive Summary

The EPA tells us 51% of total CO2 emissions result from motor vehicle use. As a result, many environmentally-aware consumers buy hybrid and electric vehicles, including the Tesla Model S, in an effort to reduce their CO2 emissions. One can easily picture these consumers exclaiming "wealthy Republicans are destroying the planet!" when they find their Prius driving next to a 'one percenter' in a BMW.

According to the EPA, the Toyota Prius V generates 212g of tailpipe CO2 emissions per mile driven, while BMW offers a host of vehicles that generate less than 140g of CO2 per km (225g per mile) driven. In fact, there are now quite a few new vehicles on the road that emit between 240g and 280g of CO2 per mile driven, including the Chevy Cruze and the base model Honda Civic. Hop into a Honda Civic hybrid and your tailpipe CO2 emissions fall to just 202g per mile. So where does the Tesla Model S stand in terms of effective CO2 emissions?

Tesla Motors implies that the Model S sedan effectively emits 176g of CO2 per mile driven, although we believe the power consumption estimate Tesla uses for these calculations - 300 miles per 85 kWh consumed - is unrealistic. Furthermore, unlike gasoline-powered vehicles, electric vehicles utilizing lithium-based batteries suffer charging inefficiencies of roughly 10% to 20% and often consume meaningful amounts of energy when they sit idle - especially in cold weather. If we incorporate charging and idle losses, using data provided by Model S owners, we calculate that the effective CO2 emissions of an average Model S are roughly 394 g per mile. It gets worse: Other research shows the massive amounts of energy needed to create an 85 kWh lithium-ion battery results in effective CO2 emissions of 153g per mile over the life of a Model S battery, based on our assumptions. When the CO2 emitted during the production of the battery pack are incorporated, we believe the total effective CO2 emissions of an 85 kWh Model S sedan are 547g per mile - considerably more than a large SUV, such as a Jeep Grand Cherokee, which emits 443g per mile!

Despite the substantial effective CO2 emissions of the Model S sedan, Tesla received $465 mln of low-interest loans from the DOE and the $82,000 average list price luxury sedan benefits from a $7,500 Federal tax credit, as well as various state and local incentives - including a $2,500 tax credit in the state of California. In addition, government environmental credit schemes required other auto makers to pay Tesla more than $40 mln in 2012 to "offset" the emissions of their gasoline engine-equipped vehicles with credits from the more heavily polluting Model S.

Is The Tesla Model S Green?

Tesla Motors enjoys massive financial support from the Federal government, as well as various state and local governments: The Department of Energy (DOE) provided Tesla with $465 mln of low-interest loans under their Advanced Technology Vehicles Manufacturing Loan Program, buyers of the Tesla Model S luxury sedan gain $7,500 of Federal tax credits (at an annual cost to taxpayers of $150 mln at 'full output' of 20,000 Model S sedans per year) and state and local government incentives include a $2,500 rebate for Model S buyers in California, sales tax waivers, free parking, free charging and authorized travel in car pool lanes. Electric vehicle charging stations have also been subsidized, with Federal tax credits ranging from 30% of the cost of a home charger, up to a $1,000 tax credit, to $30,000 for the installation of commercial chargers. In addition, government environmental credit schemes forced other auto makers to pay Tesla more than $40 mln in 2012 to "offset" the CO2 produced by their gasoline engine-equipped vehicles with credits generated by Model S sales. All of these incentives are designed to help promote Electric Vehicles (EVs) and reduce CO2 emissions, saving the planet from the devastating effects of Global Climate Change. What if the Tesla Model S actually generated more CO2 than say, an efficient BMW? Even worse, what if effective Model S CO2 emissions are higher than most large SUVs?

How Much CO2 is Emitted to Generate One kWh of Electricity?

While the Tesla Model S and other EVs generate "zero tailpipe emissions," a substantial amount of emissions are generated by the electric power plants that produce electricity to fuel EVs. The Environmental Protection Agency (EPA) calculated that in 2009, on average, each kWh of electricity generated in the United States resulted in the direct emission of 1.22 lbs of CO2 (551g), as reported in their eGRID report. To avoid the argument that the latest eGRID report (April 2012) uses data from 2009 that makes EVs look 'dirty,' we will update the estimated CO2 emissions per kWh using the EPA-reported average 2012 generation mix of 37.42% coal-fired generation (down from 44.44% in 2009) and 30.35% natural gas-fired generation (up from 23.31% in 2009), assigning 2.25 lbs of Co2 (1,021 g) per kWh of coal-fired generation and 1.14 lbs (517 g) per kWh of natural gas-fired generation. Ignoring the small amount of CO2 emissions resulting from petroleum coke and oil-fired electricity generation, as well as the minute CO2 output from nuclear and hydroelectric generation sources, we calculate that in 2012, 539g of CO2 were emitted by electric power plants for each kWh of electricity generated in the United States (.3742 X 1,021 + .3035 X 517). We then multiply our CO2 emissions estimate by the EPA-estimated 7% average transmission grid losses to determine that an average kWh of electricity provided to U.S. consumers in 2012 resulted in the emission of 577g of CO2.

Estimated Model S Driving Efficiency

Based on a weighted-average of the state-by-state CO2 emissions calculations shown in the "How is Electricity Generated" section of the Tesla Motors website (Tesla provides only state-level data for effective Model S CO2 emissions), the Model S sedan effectively emits 176g of CO2 per mile driven. According to the footnotes on Tesla's website, their calculations are based on a Model S consuming .283 kWh of electricity per mile driven - or 300 miles on a full charge for the most popular 85 kWh battery version of the Model S sedan. Using Tesla's assumptions for Model S power consumption and our estimate that in 2012, the average kWh of delivered electricity resulted in 577g of CO2 emissions, we calculate that the Model S effectively emits 163g of CO2 per mile driven (.283 x 577) - slightly lower than Tesla's calculations suggest.

Tesla's website also shows that a traditional gasoline-powered vehicle (or ICE vehicle - Internal Combustion Engine vehicle - as EV drivers like to call them) emits 400g of CO2 per mile driven based on average fuel efficiency of 22 MPG. We feel it is more appropriate to use the actual average of 27.4 MPG achieved by new passenger cars sold, resulting in average CO2 emissions of 321g per mile driven (ICE vehicles emit approximately 8,800g of CO2 per gallon of gasoline consumed). We should also point out that Tesla's CO2 calculations are not based on apples-to-apples comparisons as they use an energy consumption estimate for the Model S that is only likely to be achieved while driving (perhaps slowly) on the highway, then estimate the CO2 emissions of an average new ICE vehicle using (a low estimate of) the combined *city/highway* MPG rating.

Observed Model S Driving Efficiency

The EPA rated the 85 kWh version of the Model S sedan with a 265 mile combined city/highway range per charge using their five-cycle test, which includes various simulated vehicle speeds and conditions, including air conditioner usage. At a range of 265 miles per charge, the 85 kWh version of the Model S consumes .321 kWh of electricity per mile driven (85 / 265) and thus results in effective CO2 emissions of 185g per mile driven (.321 X 577), according to our estimates. Of course, the EPA five cycle test is just a simulation.

In the 'real world,' drivers of the Tesla Model S have reported higher energy consumption than Tesla and the EPA ratings suggest. For example, ***Motor Trend*** tested the range of the Model S on southern California highways in August. They hoped to travel 240 miles on a single charge, but after travelling 233.7 miles, they pulled into a charging station, short of their planned destination, with four miles of remaining range. In total, the range of the Model S sedan they tested (Tesla CEO Elon Musk's personal car) appeared to be 238 miles - under some favorable conditions: The two *Motor Trend* test drivers averaged roughly 48 mph during their five hour trip and used the cruise control, sparse braking, no A/C (on an August day in southern California) and drove with the air suspension lowered. Despite this, their test resulted in power consumption of .357 kWh per mile (85 / 238). *Motor Trend* was also kind enough to feature a photograph of the center console of Elon's Model S, showing that his sedan had travelled 3,150.1 miles, consuming 1,336.6 kWh of energy, or .424 kWh per mile - yielding an average realized range of 201 miles per 85 kWh.

While Elon's Model S may be driven hard, data taken from forum posts, articles and online videos show that on average, the Model S consumes roughly .375 kWh of energy per mile driven (227 miles per 85 kWh). Some of the more notable examples (due to the total miles traveled for the measurement) include forum posts by ModelS1079, who realized power consumption of .395 kWh per mile over 2,000 miles (215 miles per 85 kWh), another by ChadS, who also averaged .395 kWh of power consumption (215 miles per 85 kWh) on a recent multi-day, 2,386 mile road trip, and Dadaleus averaged .362 kWh per mile over 2,828.3 miles (234 miles per 85 kWh). The 'Lifetime Average Wh/Mile' thread in the Tesla forums reveals that the 48 owners of the 85 kWh Model S who posted to the thread realized average power consumption of .367 kWh per mile driven (232 miles per 85 kWh) over 175,629 total miles. Before their touchscreen went blank and needed to be replaced, the Model S purchased by *Edmunds* for testing achieved average energy consumption of .379 kWh per mile over 630.0 miles (224 miles per 85 kWh). Finally, *Consumer Reports* "broke in" their Model S (which, like *Edmunds*, they own) on a 176 mile road trip, averaging energy usage of .381 kWh per mile (223 miles per 85 kWh) in cold weather, which we will discuss further later in this report.

With estimated average "real world" power consumption of .375 kWh per mile driven, the 85 kWh version of the Tesla Model S sedan generates effective CO2 emissions of 216g per mile driven using our previous calculations of CO2 emissions per delivered kWh of electricity (577g per kWh). This puts the effective CO2 emissions of the Model S just above that of the Honda Civic Hybrid (202 g per mile) and the popular Prius V (212 g per mile). Unfortunately, these calculations do not tell the whole story of the Tesla Model S.

Lithium-Ion Battery Charging Efficiency

Lithium-ion batteries store and release electricity through the movement of lithium ions between a cathode (typically lithium cobalt oxide, lithium iron phosphate or lithium manganese oxide) and an anode (generally graphite) inside the battery. Like any energy conversion process, there are inefficiencies, particular in the form of heat released while a lithium-ion battery is charged. It is commonly-accepted that lithium-ion batteries have 80% to 90% charge/discharge efficiencies, depending on the rate of charge and discharge (the higher the rate, the less efficient the process). These inefficiencies mean that the "per mile driven" power consumption rates touted by Tesla Motors and displayed by the Model S sedans themselves need to be inflated to account for power drawn from charging stations and electrical outlets, but consumed in the charging process and not available to power the Model S.

Fortunately, Model S owners are, in general, a pretty savvy bunch and several have noticed (and measured) the difference between the amount of electricity drawn from their home electrical systems and that which ended up being available to power their Model S sedans. One forum user, EarlyAdopter, found that 85% of the power drawn from his 120v charger ended up as usable energy in his Model S battery and that 87% of the power drawn from his 240v charger became usable charge in his Model S. Another post, by EngineerMom, includes a spreadsheet containing data from her home power monitor showing that her Model S retained 78.9% of the electricity drawn from her home. In addition, we know that the EPA rates the Model S with a 265 mile range per charge (.321 kWh per mile), but their window sticker disclaimer for the Model S shows that .38 kWh of energy is actually consumed per 100 miles driven (.380 kWh per mile) - indicating a 15.5% loss. While these charging losses are lower than that of other lithium-ion battery applications, likely due to the advanced battery composition and thermal-control system built into the Model S batteries, they increase the environmental burden of the Model S. In the footnotes of their Electric Vehicles Overview page, the U.S. Department of Energy states "Battery and battery charger efficiency are assumed to total 81% (roughly 90% each) based in part on estimates from published studies (Chae et. al., 2011; Gautam et. al., 2011)."

Based on a charging efficiency of 85%, 100 kWh of electricity is needed to result in 85 kWh of power available to drive a Model S. Put differently, due to charging losses, a Model S effectively consumes 17.6% more electricity than is consumed while driving the sedan. When we adjust our estimate of the effective emissions of the Model S upward by 17.6% to account for charging losses, we find that the Model S effectively emits 254g of CO2 per mile driven (216 X 1.176), increasing effective CO2 emissions from the equivalent of a Toyota Prius V (212g per mile) to slightly less than a standard 2013 Honda Civic (279g per mile).

Model S Idle Power Losses

Unfortunately, the inefficiencies of the Tesla Model S, and EVs in general, do not end there. Like all automobiles, the Model S consumes power while it is not being driven. Unlike other automobiles, however, the na-

ture of the Model S battery - which utilizes an estimated 9,000 type 8650 lithium-ion battery cells, most commonly used to power laptop computers - requires continuous monitoring and frequent thermal management (heating and cooling) to maintain both longevity and safety. Tesla has experimented with various software-induced 'sleep' states to conserve power when the Model S is not being driven, but owners have reported high power consumption while their Model S sedans sit idle using all versions of the software released by Tesla to date. Tesla has promised a new iteration of the 'sleep' state in a software release this summer, but past updates have not improved idle efficiencies significantly.

Tesla owners affectionately call their idle power losses the "Vampire Load." In warm weather (greater than 50 degrees F), the 85 kWh Model S sedan consumes roughly 3.5 kWh of electricity for every 24 hours the sedan sits idle, or 9.3 miles of driving range per day. Keep in mind that 3.5 kWh of idle losses require 4.1 kWh of electricity 'from the wall' to recharge due to the previously-discussed charging inefficiencies. Tesla's Power Drain While Idle (Vampire Load) forum thread has 408 posts and is filled with stories of lost driving range while users sedans sit idle, such as the 10 mile range loss per day reported by Dennis, as well as Andrew Wolfe, Islesowner, Dailydriver and more. We have also noticed that the idle power losses appear to be constant over multiple days, rather than declining after the first day as Tesla suggests.

A few Model S owners have taken further steps to measure idle losses: Tesla Motors forum user Dennis used a Blink charger to monitor idle power losses when he was away for twelve days recently, finding that his Model S drew a total of 54 kWh "from the wall" (4.50 kWh per day) when his Model S sat in southern California temperatures ranging from 45 to 75 degrees. Incorporating 85% charging efficiency, his Model S consumed 3.82 kWh of energy per day (10.2 miles of range per day) while idle. Forum user Tezco installed metering equipment for his Aspen-based Model S, showing that at ambient temperatures of 50 degrees, the sedan drew roughly 3.2 kWh per day "from the wall", or 2.72 kWh of charge from the battery (7.3 miles of range per day). You can also see from Tezco's posts that idle losses become significantly larger as ambient temperatures decline: His Model S draws approximately 5.0 kWh per day "from the wall" when sitting idle in a 35 degree F garage. In colder weather, idle losses are significantly higher.

Model S Idle Power Losses in Cold Weather

The primary problem behind the now-famous Tesla Supercharger review by John Broder of the *New York Times* was that he parked his borrowed Model S outside on a cold, February night in Connecticut without plugging it in to a charger. When he parked the sedan before dinner, it had 90 miles of remaining range. After sitting overnight in 10 degree F weather, the remaining range was just 25 miles - a loss of 5.4 miles of range per hour (2.03 kWh per hour). The car ultimately left him stranded, unable to drive the 45 miles to the next Tesla 'Supercharger' station. Was this a one-time problem or does the Model S have a major flaw?

Based on the Tesla Model S reservation map, we estimate that 46% of North American Model S owners live in areas where winter temperatures routinely fall below freezing. This makes the cold weather idle losses a significant problem. Forum member Yobigd20, from New Jersey, wrote that in March, his Model S was consuming 2.76 miles of range per hour when left in the cold, or 1.04 kWh per hour, prior to charging losses. On the lower end of the spectrum, forum user Kevincwelch of Chicago reports 1 to 2 miles of driving range is lost every hour when his Model S sits idle in the cold, or .38 to .75 kWh of charge per hour. Reports of excessive

cold weather idle power losses come from outside the Tesla forums as well: David Nolan wrote in his review on *Green Car Reports* that his Model S was losing one mile of range (.375 kWh) for each hour the sedan sat idle in cold New York weather in early March (high temperatures averaged 46 degrees in NYC during the first two weeks of March). After Tesla told Mr. Nolan that the loses were fictitious due to the way the Model S calculates drivable range, he completed four tests using a power meter, averaging 4.5 kWh of idle power consumption "from the wall" per day (.159 kWh per hour at the car, or roughly ten miles of drivable range per day). *Consumer Reports* also joined the fray, testing their Model S in cold weather following the *New York Times* story, discovering that their rated-range declined by 75 miles after the sedan sat for seven hours in the cold, before recovering 20 miles of range over the first thirty miles travelled as the battery warmed. Their cold weather idle losses, net of range recovered when the battery warmed, appear to have been 7.8 miles of range per hour, or 2.93 kWh per hour - higher than the estimated cold weather idle losses of 2.05 kWh per hour suffered by Mr. Broder.

Tesla representatives told Mr. Nolan (as they told Mr. Broder) that all of the 'excess' (above 8 to 10 miles of rated driving range per day) cold weather idle power consumption is recovered once the Model S battery warms up, but the *Consumer Reports* experience, and reports from other owners, say otherwise. Model S owners are also reporting very high electricity consumption when their sedans are *plugged in* for extended periods of time in cold weather, meaning the power losses are real and not a figment of the sedan's driving range calculations: Tesla forum user Spurkey, who lives in Edmonton, Alberta was told by Tesla that his 110v, 12 amp charger (1.32 kWh per hour) was "just enough to keep the battery warm." In his first twenty four hours of charging on a 7 degree F day, his Model S actually lost 2km of range, indicating that his idle power losses were 31.7 kWh per day - nearly double the average California household electricity consumption of 18.3 kWh per day! This extremely high consumption rate likely results from the heating of the Model S battery prior to charging in order to improve the longevity of the battery. Model S owners in cold climates who follow Tesla's advice of charging nightly will likely face significant power consumption as their batteries are heated prior to and during charging.

We are yet to discover the idle power loss rate of the Model S in hot summer weather, when the battery will need to keep itself cool, but based on reports that the Model S consumes 3.5 kWh per day while sitting idle in moderate weather (between 50 and 80 degrees F) and a conservative 9.1 kWh per day (1 mile of range per hour) between 30 and 50 degrees F, we estimate that based on 46% of Model S owners living in states where temperatures fall below freezing four months per year, the average Model S spends 15% of its life in cold winter weather (.46 X .33). On this basis, the estimated average idle losses for all Model S sedans are 4.34 kWh per day (3.5 X .85 + 9.1 X .15), or 1,584 kWh per year, which require 5.10 kWh (1,863 kWh per year) to be drawn "from the wall" to replace due to the estimated 85% charging efficiency of the Model S battery and charger. This is more than four times the 450 kWh of electricity consumed each year by a 20 cubic foot, ENERGY STAR compliant refrigerator and 6.3X the electricity consumed in our 1,200 square foot offices (294 kWh last month, annualized).

The CO2 Footprint of Idle Losses

To calculate the effective Model S CO2 emissions per mile driven resulting from idle losses, we need to estimate the average miles driven per Model S sedan. Based on the number and timing of Model S sedan deliver-

ies to date (253 in Q3, 2,400 in Q4 and an estimated 4,750 in Q1) and Tesla's recent disclosure that 12 million total miles have been driven by Model S owners, we estimate the average Model S Sedan has been driven 644 miles per month (7,728 miles per year), or 21.17 miles per day. With an estimated efficiency of .375 kWh consumed per mile driven, a typical 85 kWh Model S sedan will consume 7.88 kWh of electricity driving 21 miles per day. If an additional 4.34 kWh is consumed each day, on average, while the sedan sits idle (again ignoring charging losses), the average total Model S energy consumption is actually 12.22 kWh per day - 55.07% higher than the reported consumption "per mile driven." Incorporating an estimated 85% charging efficiency, 14.37 kWh of electricity is drawn from a charger to drive an average Model S sedan 21 miles per day, or a stunning .684 kWh of total electricity consumption per mile driven.

Based on the estimated 577g of CO2 emitted for every delivered kWh of electricity, when we total the power consumed by a Tesla Model S while driving, as well as charging losses and idle losses, we calculate that an average Model S sedan effectively emits 394g of CO2 per mile driven (.684 X 577). This is more than a BMW 535 (374g per mile) or a Porsche 911 Carrera (384g of CO2 per mile drive).

Electric Bill Confirmation

Based on our calculations, we can create a simple formula to predict the estimated electricity consumption increase that should result from the purchase and use of a Model S sedan, allowing us to test our calculations: The average monthly Model S electricity consumption should be the combination of our estimated idle losses of 153 kWh per month (5.10 kWh per day) , including charging losses, and the estimated .441 kWh consumed per mile driven, also including charging losses (.375 / .85), making our electricity consumption forecast 153 + miles driven X .441. We can then compare the results of our (simple) formula to summaries of electric bills posted in forums. We have also privately secured electric usage data and bills, as well as driving distance and consumption data from Model S owners, which have helped to support our calculations.

Forum user **Meduri** shows he drove his Model S a stunning 2,500 miles in the first month of ownership. Based on our calculation, we would expect his monthly electricity consumption to increase by 1,255 kWh (153 kWh + 2,500 X .441) due to the demand from his Model S. His reported one-month electricity consumption increase was 1,102 kWh - from the three month average for September, October and November (we believe his December usage included a few days of Model S charging) of 1,358 kWh per month to the 2,460 kWh consumed during the 1/08 to 2/07 billing period. Keep in mind he lives in Georgia, so wintertime electricity consumption should decrease, although he does not show prior-year electricity consumption data. Meduri may have also charged his Model S away from home one or more times. Forum user **Teslaguy**, who lives in Pennsylvania, received his Model S in mid-December. He appears to drive an average of roughly 45 miles per day (1,350 miles per month), so we forecast that his monthly electricity consumption should increase by 748 kWh (153 kWh + 1,500 X .441). In the data he posted online, his electricity usage for the 12/27/12 to 1/29/13 period increased by 689 kWh versus the prior year. Forum user **Jandkw** reports that he drove 'about 900 miles' over the 29 days covered in his March electric bill - his first full monthly bill with his Model S. Based on our calculations, we would expect his monthly electricity consumption to have increased by 550 kWh (153 + 900 X .441). Jandkw reports that his electricity consumption increased from 678 kWh in the same period in 2012 to 1,229 kWh - an increase of 551 kWh.

The available electricity usage and miles driven statistics appear to roughly confirm our calculations of the power consumption, charging losses and idle losses of the Model S sedan. In addition, the home power consumption statistics likely understate the overall power consumption of a Model S sedan as owners sometimes charge their vehicles away from home, resulting in higher total electricity consumption than their home electricity bills suggest: One 50% charge away from home each week, incorporating charging losses, would reduce a Model S owner's home electricity usage by 196 kWh per month. An online poll asking forum members how often they charge their Tesla vehicle away from home each 1,000 miles (most likely 1.5 months) shows that only 9% never charge away from home.

The Cost of Driving a Tesla Model S

We believe that the average Model S sedan travels 630 miles per month, requiring 431 kWh of electricity, including charging and idle losses. Based on average electricity rates of $.129 per kWh and $.03 per kWh average distribution/tax/environmental fees, the total electricity cost for a Model S sedan would be $68.53 per month (431 X $.159). As we referenced earlier, an average new gasoline-powered car achieves a combined city/highway 27.4 MPG, which would result in monthly fuel costs of $83.69 at 630 miles traveled per month and average fuel costs of $3.64 per gallon. Step into a Honda Civic, which achieves a combined 32 MPG, and estimated monthly fuel costs decline to $71.66 - not substantially different from our estimated electricity costs to drive a Model S the same distance.

In order to achieve a lower monthly fuel cost driving a Model S versus driving a gasoline-powered car, the owner must drive a lot of miles: At 1,250 miles per month (15,000 miles per year), we estimate that an average Model S will require 704 kWh of electricity (153 + 1,250 X .441), for a total cost of $111.94, while our average gasoline-powered car (27.4 MPG, $3.64 per gallon) would cost the owner $166.06 per month. Switch to a Honda Civic, and the fuel costs resulting from driving 1,250 miles per month fall to $142.19.

Of course, electricity costs vary by state, although the states with large numbers of Model S owners (like California, New York, New Jersey, Massachusetts) tend to have the highest electricity costs. In some cases, the purchase of the Model S sedan has led consumers to switch electricity rate plans and move to Time Of Use (TOU) metering, reducing their electric bills, but these changes could have been made independently of purchasing a Model S. In other regions, such as California, electricity costs can actually increase as total usage increases: Pacific Gas and Electric recently issued a press release showing estimated residential electric bills at various usage levels based on January 2013 rates. At 550 kWh per month, average usage in California, their estimated average electric bill was $91.60, or $.167 per kWh. At usage of 850 kWh per month, the estimated bill increases to $188.05 per month ($.221 per kWh) and usage of 1,200 kWh per month increases the monthly bill to $307.13 per month, or $.256 per kWh. At these rates, a household starting with monthly electricity consumption of 550 kWh that then buys a Model S sedan, increasing their consumption to 1,200 kWh per month (which would equal an estimated 1,127 miles driven per month, or 13,523 miles per year), would face a $215.53 monthly increase in their electric bill, from $91.60 per month to $307.13 per month. This is more than the estimated $149.72 it would cost to drive a conventional gasoline-powered car 1,127 miles per month at 27.4 MPG and $3.64 per gallon gasoline prices.

In addition to the electricity costs resulting from owning and driving a Tesla Model S, the lithium ion batteries need to be replaced every few years. Tesla offers Model S buyers a pre-paid battery replacement option under which buyers pay Tesla Motors $12,000 today to receive a new 85 kWh battery eight years from now. Spread over eight year, and ignoring the time value of paying the money up front, the battery replacement option costs buyers $125 per month - nearly double the average estimated electricity costs of $68.53 per month that we calculated on the previous page (based on 630 miles per month). The combined monthly battery and electricity costs of $193.53 are also substantially higher than the estimated $83.69 of monthly fuel costs to drive a gasoline-powered vehicle a similar distance each month (630 miles). To Tesla's credit, their four year maintenance plan costs buyers $2,400, compared to total estimated four year maintenance costs of $4,200 for other high-end automobiles, although some makers, such as BMW, Jaguar and Volvo now offer free maintenance.

The Carbon Cost of Lithium Ion Batteries

Lithium Ion batteries require massive amounts of energy to produce, as several studies and articles have pointed out, including the recent ***Wall Street Journal* report by Bjorn Lomborg**. The *Journal of Industrial Ecology* research report, on which the *Wall Street Journal* report was based, **Comparative Environmental Life Cycle Assessment of Conventional and Electric Vehicles** by Troy R. Hawkins, Bhawna Singh, Guillaume Majeau-Bettez, and Anders Hammer Strømman, estimated that a 24 kWh EV driving 150,000 km over its lifetime resulted in CO2 emissions of 91g of CO2 per KM, 48g per km above the 43g per km of effective CO2 emissions resulting from the construction of an Internal Combustion Engine (ICE) vehicle. We will ignore the fact that the Model S has an aluminum body that is roughly six times more energy intensive to produce than a steel body. Multiplying the additional 48g of CO2 per KM of effective emissions resulting from the construction of an EV by the 150,000 km expected useful EV battery life on which their study was based, the CO2 emissions resulting from the construction of an EV total 7.2 mln g for a 24 kWh battery-equipped EV, or 300,000 g per kWh of capacity. Other studies, such as **Life cycle assessment of lithium-ion batteries for plug-in hybrid electric vehicles – Critical issues** by Mats Zackrissona, Lars Avellána, and Jessica Orleniusb estimate 180,000 to 280,000g of CO2 emissions per kWh of lithium ion battery capacity, depending on the production process and location. If we use the lowest estimate, 180,000g of CO2 released per kWh of capacity when constructing a lithium-ion battery, the production of the lithium-ion battery for an 85 kWh Model S generates 15.3 mln grams of CO2.

The 85 kWh Model S battery has an eight year, unlimited mileage warranty and the 60 kWh battery has an eight year, 125,000 mile (whichever comes first) warranty. As we mentioned previously, Model S owners are currently driving an annualized average of less than 8,000 miles per year, which is not surprising given that the typical Model S owner has more than one vehicle and high-end automobiles are generally driven fewer miles than an average automobile - perhaps offset by the fact the EVs are likely to be driven more than ICE vehicles. At 8,000 miles per year, the eight year Tesla warranty would run out at 64,000 total miles driven. Given that lithium ion batteries degrade more due to their age and the **total number of charging cycles** than the total electricity throughput of the battery (and Tesla advises owners to plug their vehicle in every night), the duration of the battery warranty is much more important than the total miles covered. If we give Tesla the benefit of doubt and assume the average Model S battery will end up being driven for 100,000 miles before being replaced (10,000 miles per year for ten years), the estimated 15.3 mln grams of CO2 generated by the production of the 85 kWh lithium ion battery averages 153g of CO2 per mile driven by the Model S.

Total Effective CO2 Emissions for an 85 kWh Model S

As we previously discussed, we estimate that driving an 85 kWh Model S results in effective CO2 emissions of 254g per mile (.441 X 577), including charging losses and idle power consumption, plus additional effective CO2 emissions of 140g per mile driven due to idle losses - for a total of 394g of effective CO2 emissions per mile travelled. If we add the estimated 153g per mile of CO2 effectively released over the life of an 85 kWh Model S battery resulting from the production of the battery, we find that the total effective CO2 emissions of an 85 kWh Tesla Model S sedan are a stunning 547g per mile - considerably more than a large SUV, such as a Jeep Grand Cherokee, which emits 443g per mile, and close to that of the massive Ford Expedition, which emits 556g of CO2 per mile driven!

Other Pollutants Matter

If the Tesla Model S does not make sense as a CO2-reducing vehicle, perhaps the benefits come from the reduction of other pollutants. The U.S. Environmental Protection Agency is required by the Clean Air Act to set standards for six common pollutants: Ozone, Particulate Matter, Carbon Monoxide, Nitrogen Oxides, Sulfur Dioxide and Lead. Now that unleaded gasoline is common-place, the primary pollutants covered under the Clean Air Act and produced by gasoline-powered motor vehicles are Nitrogen Oxides, Sulfur Dioxides and the resulting Ozone. Nitrogen Oxides (NOx) are byproducts of combustion that contribute to ground-level ozone, acid rain and fine particle pollutants that cause smog and lung irritation. In 2000, the Environmental Protection Agency introduced their Tier 2 vehicle standards, phased in between 2004 and 2009, requiring vehicle manufacturers realize fleet-wide average NOx emission levels of .07g per mile. The EPA reports in their eGRID report, which we previously referenced, that 1.122 lb of NOx are emitted by power generators per MWh of electricity produced, or 508.75g per MWh (.509g per kWh). If a Tesla Model S travels 227 miles per 85 kWh charge, consuming .375 kWh per mile, the sedan's effective national average NOx emissions are .18g per mile driven (.375 X .509) - more than 2.5X the EPA Tier 2 limit for gasoline-powered vehicles. Adding in our estimated charging and idle losses, the 85 kWh Model S sedan effectively consumes .684 kWh of electricity per mile driven, effectively generating .35g of NOx per mile driven (.684 X .509) - 5X the EPA Tier 2 NOx limit. Keep in mind that this calculation ignores the emissions resulting from the energy required to produce the lithium batteries used in the Model S.

Sulfur Dioxide and Sulfur Oxides (SO2 and SOX) cause adverse respiratory impacts, including asthma flair-ups and increased hospitalizations and increases atmospheric particulates. In addition, Sulfur Dioxides (and Nitrogen Dioxides) cause acid rain. The EPA also included sulfur content regulations in their Tier 2 regulatory package, requiring motor vehicle fuel to contain less than 30 ppm (.038g/gallon). At the new vehicle average fuel efficiency of 27.4 mpg, motor vehicles emit 1.39 mg of sulfur per mile if 100% of the sulfur is released into the atmosphere. Electric power plants generate an estimated 73% of Sulfur Dioxide in the United States (http://www.epa.gov/air/sulfurdioxide/), so it is not surprising that the EPA eGRID report states that 3.08 lb of SO2 is emitted per MWh of electricity generated in the United States, or 1,397.05g per MWh (1,397mg per kWh). If a Tesla Model S travels 227 miles per 85 kWh charge, consuming .375 kWh per mile, the sedan's effective national average sulfur emissions are 524mg per mile driven (.375 X 1,397) - approximately 376X the EPA Tier 2 emissions resulting from the gasoline sulfur content limitations. Adding in our estimated charging and idle losses, the 85 kWh Model S sedan consumes .684 kWh of electricity per mile driven , effectively generating 956mg of sulfur per mile driven (.684 X 1,397) - 688X the effective EPA Tier 2 sul-

fur content limit. The size of these emissions are staggering: If 20,000 Model S sedans are sold each year, they will effectively release as much SO2 as 13.76 mln new gasoline-powered vehicles - nearly every automobile sold in the United States each year.

Even worse, the EPA recently proposed the reduction of gasoline sulfur content from 10 ppm to 3 ppm, among other reductions - a proposal that the American Petroleum Institute said **will cost refiners close to $10 bln to realize**. We applaud the move, but point out that the Tesla Model S will generate the equivalent of 2,063X the sulfur emissions of traditional gasoline-powered cars (688 X 3) at 3 ppm gasoline sulfur content. This staggering multiple means that 20,000 Model S sedans produced per year will have the effective sulfur emissions of 41.26 mln gasoline-powered automobiles.

In many states, including California, if a smog testing center could measure the effective emissions of a Tesla Model S through a tailpipe, the owner would face fines, penalties or the sale of the vehicle under state "clunker buyback" programs. Instead, legislators have set up systems such as Zero Emissions Vehicle credits (ZEVs) that force other automakers to buy credits from Tesla when their fleet-average emissions do not meet mandated levels.

The Grid is Becoming Greener

While the electric power generation grid is likely becoming greener over time, so is motor vehicle fuel. The new "Tier 3" EPA standards propose to reduce sulfur content in gasoline by more than 60% and reduce nitrogen oxides by 80%, beginning in 2017, by requiring standards already in place in California to be met by all states. When combined with the latest CAFÉ standards, requiring 35.5 MPG for all passenger cars by 2016 (resulting in average CO2 emissions of 248g per mile), emissions will be significantly reduced. Despite less focus on EVs, Europe is making even greater strides to reduce passenger vehicle emissions: On March 21, Prof. Dr. Martin Winterkorn, chairman of the Executive Board of Volkswagen Aktiengesellschaft, met with Greenpeace Chief Executive Director Brigitte Behrens in Hanover to discuss Volkswagen's commitment to reduce emissions to the EU target of 95g of CO2 per km by 2020, or 153g per mile. The pace of emissions reductions from gasoline engine-powered vehicles is likely to far exceed the reduction in effective EV emissions resulting from an increasingly green electric generation infrastructure for the foreseeable future.

Conclusion

Tesla Motors implies that the Model S sedan effectively emits 176g of CO2 per mile driven, although we believe the power consumption estimate Tesla uses for these calculations - 300 miles per 85 kWh consumed - is unrealistic. Furthermore, unlike gasoline-powered vehicles, electric vehicles utilizing lithium-based batteries suffer charging inefficiencies of roughly 10% to 20% and often consume meaningful amounts of energy when they sit idle - especially in cold weather. If we incorporate charging and idle losses, using data provided by Model S owners, we calculate that the effective CO2 emissions of an average Model S are roughly 394 g per mile. It gets worse: Other research shows the massive amounts of energy needed to create an 85 kWh lithium-ion battery results in effective CO2 emissions of 153g per mile over the life of a Model S battery, based on our assumptions. When the CO2 emitted during the production of the battery pack are incorporated, we believe the total effective CO2 emissions of an 85 kWh Model S sedan are 547g per mile - considerably more than a large SUV, such as a Jeep Grand Cherokee, which emits 443g per mile!

The effective NOx and Sulfur emissions of a Model S are even more startling. We believe that many states would take the Model S off the road if they could measure the effective emissions of the sedan from a tailpipe. Our hope is that this report will help our clients provide more pressure for Tesla to reduce the idle losses, or the "vampire load" of the Model S and work the reduce the power consumption of the sedan. In addition, we would really like to see other journalists confirm (or disprove) our work. While Tesla Motors is unlikely loan vehicles to let journalists confirm our data (and my wife still will not let me buy one for testing), we know that *Consumer Reports* and *Edmunds* each own a Model S sedan and we challenge them to install metering equipment to measure the actual amount of electricity consumed by their Model S sedans under varying temperatures and driving conditions.

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