ELECTRIC VEHICLE BUILDOUT IMPLICATIONS by Willem Post; February 2, 2011
http://www.coalitionforenergysolutions.org/

INTRODUCTION

Automobile manufacturers in several nations have been developing hybrid, plug-in hybrids and all-electric vehicles. Among the hybrid vehicles, Toyota is the leader and has been mass producing the Prius for about 10 years and will soon be marketing several other Prius models, including plug-in Prius models. In this study plug-in hybrid and plug-in all-electric vehicles are designated as EV.

Tesla Motors is marketing its all-electric Roadster model, 2-dr, 2-passenger, 53 kWh Lithium-ion battery, using a 208/240-V, 70 A (draw) outlet the charging time is about 3.5 hours by a 16.8 kW wall-mounted, in-house charger, range 244 miles, sticker price $109,000, or $101,500 after federal tax credit, or 96,500 after California tax credit.

Nissan is marketing its all-electric Leaf model, a 4-dr, 5-passenger hatchback, 24 kWh Lithium-ion battery, using a 220/240-V, 40 A outlet the charging time is about 8 hours by the 3.3 kW on-board charger, range 100 miles, sticker price $32,780, or $25,280 after federal tax credit, or $20,280 after California tax credit.

General Motors is marketing its plug-in hybrid Volt model, a 4-dr, 5-passenger sedan, 16 kWh Lithium-ion battery, using a 220/240-V, 40 A outlet the charging time is about 4 hours by the 3.3 kW on-board charger, range 40 miles after which a 1.4 Liter, 4 cylinder gasoline engine provides power for another 340 miles, sticker price $41,000, or $33,500 after federal tax credit, or $28,500 after California tax credit.

Ford will be marketing its all-electric Focus model, a 4-dr, 5-passenger hatchback, 24 kWh Lithium-ion battery, using a 220/240-V, 40 A outlet the charging time is about 4 hours by the 6.6 kW on-board charger, range 100 miles, sticker price $33,000, or $25,500 after federal tax credit, or 20,500 after California tax credit.

An in-house charger, if needed, costs about $2,200 installed, or $1,100 after California tax credit. A house must have suitable electrical wiring capacity.

The EPA rating for the Nissan Leaf and the General Motors Volt is about 35 kWh/100 miles. Larger light-duty EV vehicles, using more kWh/mile, will also be needed. Medium EVs may use 50 kWh/100 miles and larger ones 65 kWh/100 miles.

The Leaf, Volt and Focus are small passenger vehicles. Because of their short range, people living in houses in the suburbs will likely be the early adopters and use them for short commutes and trips around town; because of their extended driving range the Tesla and Volt are more useful for longer commutes and trips than the Leaf and Focus.

http://money.cnn.com/2010/03/30/autos/nissan_leaf_pricing/index.htm
http://www.csmonitor.com/Environment/2010/0727/Chevy-Volt-vs.-Nissan-Leaf-the-electric-car-price-war

It is useful to make some calculations to obtain "ballpark" estimates of the capital costs and CO2 reduction of a mass adoption of EVs. This study assumes 50% of the passenger vehicles are replaced with EVs.

EV BUILDOUT, EV POWER, POWER CAPACITY REQUIRED, GRID IMPACTS AND CO2 REDUCTION

EV Buildout

The US has about 265 million passenger vehicles. Assuming a production rate of 5 million EVs/yr and a vehicle life of 10 years, it would take 10 years to have a maximum of 40 million EVs (some EVs will be in accidents, etc.), after which older EVs would be junked and replaced with newer ones, etc.
It would take about 20 years, or more, to achieve a production rate of 5 million EVs/yr.
It would take about 40 years, or more, to replace 50% of the current population of passenger vehicles with EVs.

EV Power

Assume each vehicle is driven 13,200 miles/yr, using 600 gal/yr @ 22 mpg. Gasoline has 114,000 Btu/gal. 1 kWh = 3,413 Btu. The DOE well-to-pump production factor = 0.83, i.e., it takes about 1.2 gallon of energy to have one gallon available at the pump.

The well-to-pump source energy of the existing gasoline-powered passenger vehicles = 1.2 production factor x 265 million veh x 600 gal/yr x 114,000 Btu/gal x 1 kWh/3,413 Btu = 6,373 TWh/yr. This compares with a source energy (coal at the mine, oil and gas at the well, etc.) of about 16,000 TWh/yr to produce about 4,000 TWh/yr of electric power consumed by the US.

Source energy, such as from a coal mine, is transported to a power plant that converts it to electric power which is carried via transmission and distribution, T&D, systems, and battery chargers to the batteries of the EVs. Because of various losses along this route, it takes about 4 kWh of source energy to have 1 kWh to the EV battery.

T&D systems are designed for daytime peak power demand, plus a margin. Power demand is much lower between 10 PM and 6AM; a good time for charging EVs. Power plants and T&D systems would be more fully utilized during these hours which would improve the economics of utilities, although utilities may need to sell this power at a discount to get consumers to charge their EVs during these hours, unless their is a mandate to do so.

If we assume the average EV uses 50 kWh/100 miles and is driven (13,200 miles)/(365 d) = 36 miles/d, then about 36/100 x 50 = 18 kWh/d needs to be replenished.

The in-house chargers would have a timer to turn them on from 10 PM-6 AM. The chargers would have a one hour ramp-up and and a one hour ramp-down function to minimize instantaneous changes in power demand on distribution systems. This would reduce the charging period from 8 to 7 hours. Average EV charging demand is 18 kWh/7 hr = 2.57 kW at a current of 2.57 kW/220 V = 11.7 Amps.

Power Capacity Required

EVs charging in time zones 1 (East Coast), 2, 3, 4 (West Coast) are assumed at 50 million, 25 million, 25 million and 32 million, repectively.

Approximate power for charging EVs:

Time zone 1: 50 million EVs x 2.57 kW/EV = 128,500 MW
Time zone 2: 25 million EVs x 2.57 kW/EV =   64,250 MW
Time zone 3: 25 million EVs x 2.57 kW/EV =   64,250 MW
Time zone 4: 32 million EVs x 2.57 kW/EV =   82,240 MW

Each day, EV power demand is ramping from zero, starting at 10 PM, to a maximum of 339,240 MW from 1 AM-3 AM, and ramping down to zero at 6 PM.

Demand peaks during the daytime on the East Coast in Time zone 1. Due to EVs charging, about 128,500 MW is added to normal nighttime demand. The grids in that time zone would need to be augmented as needed to accommodate this additional demand. An hour later the same happens in Time zone 2, etc.

There are losses of about 10% from the power plants, via the T&D systems and chargers, to the EVs, which means and additional 33,924 MW/average capacity factor 0.75 = 45,232 MW of existing coal, gas and nuclear plants are needed.

The EV demand, which is IN ADDITION of normal nighttime demands, would require the operation of 100,000 MW of new nuclear plants x capacity factor 0.90 + (332,320 MW + 45,232 MW losses) of exisitng coal, gas and nuclear plants x average capacity factor 0.75 = 373,164 MW of power plants from 1 AM-3 PM, and fewer plants from 10 PM -1 AM and 3 AM-6 AM.

The electric power needed to charge the EVs during the 10 PM-6 AM period: 132 million x 18 kWh/d = 2,376 million kWh/d, or 2,376 million kWh x 365 d/yr = 867 TWh/yr.
Note: About 4 times that energy would be source energy, such as from a coal mine or gas well.

http://en.wikipedia.org/wiki/File:LLNL_US_Energy_Flow_2009.png
http://www.fueleconomy.gov/Feg/co2.shtml

Grid Impacts

The charging of EVs will:

- cause the US to have daytime and nighttime demand peaks in each time zone.

- require greater levels of nighttime power generation in Time zones 1, 2 and 3, and greater exchanges of power between these time zones which means additional long distance transmission systems may be needed for nighttime exchanges of power.

- require greater levels of nighttime power generation in Time zone 4 (West Coast). Exchanges of power along the West Coast will continue to flow mostly north-south.

A typical local power distribution system serving an area with mostly houses and some businesses will have a given capacity. Adding to such an area hundreds of EVs charging from 10 PM-6 AM may overload the system, especially in summer when air conditioners, or in winter when electric heaters may be running as well.

- Demand control measures as part of "smart grids" and power distribution system upgrading may be needed to ensure continuous electric service.

- Utility rate schedules for EV charging that provide greatly reduced rates from 10 PM-6 AM and greatly increased rates at other times may be needed.

CO_2 Reduction

The US has about 265 million passenger vehicles. Assume each vehicle is driven 13,200 miles/yr, using 600 gal/yr @ 22 mpg. CO_2 produced = 265 million veh x 600 gal/yr x 20 lb of CO_2/gal x 1 metric ton/2,200 lbs = 1,445 million metric tons/yr.

Approximate CO_2 reduction from 50% EVs: 1,445/2 = 722.5 million metric tons/yr. This quantity will be less with increasing mileage of gasoline-powered vehicles, because EVs would be displacing higher mileage gasoline-powered vehicles.

Total power produced to charge EVs each day: (132 million EVs x 18 kWh)/0.90 loss factor = 2,640 million kWh which, for this study, is assumed to be allocated as follows:

Nuclear: 100,000 MW x 7 hrs x CF 0.90 = 630 million kWh; the US has 100,000 MW of nuclear plants
Coal: 180,000 MW x 7 hrs x CF 0.75 = 945 million kWh; the US has 310,000 MW of coal plants.
Gas: 203,000 MW x 7 hrs x CF 0.75 = 1,065 million kWh; the US has 440,000 MW of gas plants.

Approximate CO_2 increase from the power produced to charge the EVs: {0 lbs of CO_2 (nuclear) + 945 million kWh x 2.15 lb of CO_2/kWh (coal) + 1065 million kWh x 1 lb of CO_2/kWh (gas)} x 365 d/yr x 1 metric ton/2,200 lb = 514 million metric ton/yr.

Net CO_2 reduction: 722.5 - 514 = 208.5 million metric tons/yr; a big investment to achieve a small result when using existing CO_2-emitting power plants. As more nuclear plants and gas-fired, combined-cycle/gas-turbine, CCGT, plants and wind and PV solar facilities are built, the net CO_2 reduction becomes larger.

CAPITAL COSTS

The base-load capacity for charging EVs can be supplied by greater night-time utilization of the existing T&D systems and power sources, such as coal, gas and nuclear, augmented with wind and PV Solar (described below).

Capital Cost of New Nuclear Power Plants

Because the US needs to reduce its CO_2 emissions, it was decided, for this study, to use 100,000 MW of new nuclear plants to produce the power for the EVs. Wind and PV solar power, currently miniscule, would be phased in as they are built out.

The benefits of using new nuclear plants are:

- the CO_2 emission/kWh is among the lowest of all power sources.

- nuclear plants, not dependent on sun and wind, can be deployed throughout the US.

- the power is low-cost, steady, 24/7/365 and readily integrated into the existing electric grids.

- a percentage of older base-loaded nuclear and coal plants would be replaced with the new nuclear plants.

Capital cost of nuclear plants: 100,000 MW x $7,000,000/MW = $0.70 trillion; this cost would be significantly less if factory-built modular nuclear units are used.

http://theenergycollective.com/willem-post/47519/base-power-alternatives-replace-base-loaded-coal-plants

Extra Capital Cost of EVs

It took many decades for the world to achieve the mass production of today's complex passenger vehicles. It will take decades before a similar level of mass production is achieved for EVs. Subsidies for EVs will likely be with us for a long time.

Extra capital cost and/or subsidies for EVs: $4,000/EV x 132 million veh = $0.53 trillion.

Other Capital Costs

- facilities for a 5 million EV/yr production rate.
- augmented energy supply infrastructure for the new nuclear plants.
- augmented T&D systems to accommodate increased electric demand.

The rest of the world also has gasoline-powered vehicles and will have to make similar investments.

Capital Cost of Residential PV Solar Power and Battery Storage

Residential PV solar power will be a significant power source for charging EVs. Existing residential, grid-connected PV solar systems would need to be augmented with battery storage systems and new residential systems would have battery storage as standard equipment to provide power to EVs at night.

If a household has a 6 kW, south-facing, correctly-angled, fixed-axis, grid-connected PV solar system, it will produce about 6 kW x 4.3 avg peak sun hrs/d x 365 d/yr x 0.825 avg eff = 7,564 kWh/yr, or 20.7 kWh/d in Vermont which is poorly suited for PV solar power. In the US Southwest, highly suited for solar power, the kWh/d will be significantly higher. The kWh/d varies hourly, daily and with the seasons. In this study averages are used to simplify the analysis.

Residential PV systems cost about $4,500-$5,000/kW. PV panels are warranteed for 25 years; their rated output degrades about 0.5%/yr. Battery systems cost about $80/kWh of rated capacity. The batteries last about 6 years.

Average power use of a household is about 20 kWh/d, or 7,300 kWh/yr and of a medium-size EV about 18 kWh/d, or 6,570 kWh/yr, for a total of 13,870 kWh/yr, which means a household with a 6 kW PV solar system in Vermont purchases about 13,870-7,564 = 6,306 kWh/yr from the utility.

Household power usage starts at about dawn and continues into the later evening. On average, about 10 kWh/d of PV solar power would be used by the household during daylight hours, the rest, 10.7 kWh/d, would be stored in the batteries during daylight hours for charging an EV at night. The household would purchase power from the utility for household nighttime usage and to augment the 10.7 kWh/d to 18 kWh/d for charging an EV at night.

The battery storage capacity would need to be about 80 kWh (extractable 50 kWh) in mostly sunny areas, such as the US Southwest, and about 160 kWh (extractable 100 kWh) in mostly cloudy areas, such as New England, to ensure adequate power for charging an EV.

In New England, PV panels will be snow-covered at one time or another during winter, for a total of about 20 days, or more, or the weather may be cloudy for several days in a row at anytime during the year.

Note: A battery cannot be drawn down below a certain percentage of its rated capacity. In colder climates, batteries need to be kept warm for proper functioning.

The PV solar approach to charge EVs appears somewhat complicated and less applicable in cities than in suburbs and rural areas. If such an approach is adopted nationwide, new housing roofs must be correctly-angled and true-south oriented for maximum solar power collection which is not the case with the roofs of most existing houses.

The above illustrates how residential PV solar power might be used for EV charging; it is an expensive way to go, unless PV solar systems, MPPT charge controllers and battery systems become a lot less costly.

Capital Cost of Wind Power and Storage

Wind power will become a significant power source for charging EVs, except ERCOT, the manager of the Texas grid, counts the capacity value of wind power in Texas, a big wind state, at about 8.7% of the installed wind capacity; hardly something to rely on for next day's commute without backup from other power sources, such as the big three: coal, gas and nuclear.

Wind power facilities paired with pumped-storage hydro plants, as practiced by Denmark, Spain, Portugal, Hydro-Quebec and the Bonneville Power Authority appears to be lowest cost and lowest CO_2 approach to integrate higher percentages of wind power into the grid.

Absent such hydro plants, inexpensive, large-scale power storage systems (not yet invented) or transmission system overlays, as envisioned by the Eastern Wind Integration and Transmission Study and the ISO-NE Wind Integration Study, will be needed.

http://theenergycollective.com/willem-post/46977/impacts-variable-intermittent-power-grids
http://theenergycollective.com/willem-post/47519/base-power-alternatives-replace-base-loaded-coal-plants

CONCLUSION

The above indicates an enormous increase in power production would be required to accommodate:

- future economic growth.

- an increasing population.

- an increasing population of EVs.

Given current circumstances, it is likely the world will not make such enormous investments and global warming will continue unabated. This means people must learn to live with much more heat, a la Middle East, India, etc., and gradually move away from low-lying land near water to higher ground.

Some less costly and quicker measures to reduce CO_2 are:

- improving worldwide mpg of future gasoline-powered vehicles. This is an on-going effort that should be accelerated with subsidies. Cars with high mpgs usually are small and low-cost. If tens of millions/yr are sold worldwide, it will have a major impact on reducing CO_2.

- increasing energy efficiency. See details below.

- a new annual gas-guzzler use tax on vehicles that get less than 25 mpg would get many of them to the junkyard and replaced with higher mileage vehicles or EVs; the lower the mileage, the higher the tax. The tax would be paid at the time of registration renewal.
Note: a significant increase in the federal gasoline tax was considered, but rejected, because it is too regressive.

The tax could be used to subsidize:

- EVs and higher mileage vehicles that get more than 35 mpg (this mpg should be gradually increased with time); the higher the mileage, the greater the subsidy.

- the necessary expansion and conversion of the US power system.

- implement increased energy efficiency.

http://green.blogs.nytimes.com/2010/09/23/the-hockey-stick-lives/

https://solutions.mckinsey.com/climatedesk/getfile.aspx?uid=166ff77f-2a92-4ea1-a462-7f42baf125f5&fp=design%2fDownloads%2fPathwayToLowCarbonEconomy_ExecutiveSummary.pdf&ru=default%2fen-us%2fhidden%2fduplicatedownload.aspx

www.mckinsey.com/globalGHGcostcurve

http://www.wwf.se/source.php/1226616/Pathways%20to%20a%20Low-Carbon%20Economy,%20Executive%20Summary.pdf

PathwayToLowCarbonEconomy_ExecutiveSummary[1].pdf

INCREASED ENERGY EFFICIENCY

This section is included, because energy efficiency will have a much bigger role in the near future, as energy system analysts come to realize that tens of trillions of dollars will be required to reduce CO_2 from all sources and that energy efficiency will reduce CO_2 at a lesser cost and more effectively.

Energy efficiency projects:

- will make the US more competitive, increase exports and reduce the trade balance.

- usually have simple payback periods of 6 months to 5 years.

- reduce the need for expensive and highly visible transmission and distribution systems.

- reduce two to five times the energy consumption and greenhouse gas emissions and create two to three times more jobs than renewables per dollar invested; no studies, research, demonstration and pilot plants will be required.

- have minimal or no pollution, are invisible and quiet, something people really like.

- are by far the cleanest energy development anyone can engage in; they often are quick, cheap and easy.

- have a capacity factor = 1.0 and are available 24/7/365.

- use materials, such as for taping, sealing, caulking, insulation, windows, doors, refrigerators, water heaters, furnaces, fans, air conditioners, etc., that are almost entirely made in the US. They represent about 30% of a project cost, the rest is mostly labor. About 70% of the materials cost of expensive renewables, such as PV solar, is imported (panels from China, inverters from Germany), the rest of the materials cost is miscellaneous electrical items and brackets.

- will quickly reduce CO_2 at the lowest cost per dollar invested AND make the economy more efficient in many areas which will raise living standards, or prevent them from falling further.

- if done before renewables, will reduce the future capacities and capital costs of renewables.