New paths for solving emergent problems of the EV sector -
John Paul MacDuffie
11/11/2022

Part I. Literature Citations


Part II. Recent News and Articles


Part III. Questions and Answers

James Womack (JW): There is a global expectation that zeros in on years 2035 and 2050 to achieve net zero CO2 levels. This creates panic for those who are worried that we are not getting to net zero fast enough. There seems to be an expectation that “making it” is a linear process. A linear process is pretty unlikely, and people may find this initially dismaying when we hit these years.

EV manufacturers have been engaged in a ‘range race,’ offering longer and longer ranges of travel, which presumes that the charging infrastructure is terrible. Do we need better charging or better batteries?

John Moavenzadeh (JM): JM: EVs are heavy because batteries are heavy. We are expending a lot of energy to move this battery. We are already taking a vehicle that is 10-20 times the weight of its occupants. When there is scarcity, it moves economic actors to increase supply - but the speed of auto vs. mines is different. Batteries may be in short supply with an increased demand of EVs.

Regarding vehicle architecture – is it a modular architecture or is it an integral architecture? Cars are more integral; and they are not computers. But what about now?

John Paul MacDuffie (JPMD): On scarcity and timing, companies did go into a range war without considering the complementarities with better-charging infrastructure. With innovation in battery chemistries, and packaging that reduce weight and increase power dynamics – I am hopeful (paraphrased).

On modularity vs. integration, there are more interdependencies in BEVs than ICEVs. All systems are being redesigned simultaneously to address battery life and efficiency concerns. So, they are more integrated than modular still.

Jinhua (J): Affordability - what is the dimension of affordability (rural vs. urban, car owner vs. non-car owners). Whose job is it to be responsible to engage along these different dimensions - and to address affordability?

JPMD: We will eventually have more used EVs. Plugin hybrids are an undervalued category today. Hybrids are a gateway into full electrification and accessible to people who don’t have ready access to charging infrastructure.

JM - Do you believe there will be a standardization of batteries and charging methods across different geographies?

JPMD: We are not headed toward standard batteries. Different chemistries are suited for different geographies, different vehicle sizes, and based on raw material availability and geopolitics and mineral access.
JM: Could you please explain how China and California have higher EV penetration due to regulatory incentives/penalties than the EU or the rest of the US? What are the top 2-3 drivers of EV adoption?

JPMD: Government policies are important at the state and country level. California has allowed them to pursue their own state goals in trying to reduce air pollution. China wanted to leapfrog and be a leader with EVs. This also boosts component leadership.

Norway has dedicated lanes, preferential parking, subsidies, and complementary policies. If you get consensus around this, you can use a host of policy levers to accelerate EV diffusion.

JM: Does EV propulsion change the performance of the automobile?

JPMD: EVs are silent, have incredible acceleration, and there’s no torque in acceleration. But back to the vehicle architecture - modularity isn’t happening. The fuel source is important, but there are so many subsystems that don’t change with EVs and still need to be part of the product development process. There are some visible parts that are different, but there is less revolutionary difference from the industry side (there is evolutionary difference). You can often even build EVs and ICEVs on the same assembly line! So that gives me confidence that the incumbent OEMs have a large role to play still from this standpoint.

JM: A recent study demonstrates that keeping older fuel-efficient ICEVs on the road longer reduces CO2 emissions significantly more than replacing them with EVs [Study citing Nakamoto]. Thoughts?

JPMD: There are wonderful ICEVs - the older dirtier ICEVs will be the entry point for low budget people. I see a lot of benefits to getting those models off the road and replacing with a BEV or a cleaner ICEV from a public health standpoint.

Part IV. Summary of Talk

John Paul took us through a deep dive into EV innovations - many of which will pave the way for more efficient energy use and increased EV adoption - all the while highlighting the upstream and downstream implications of using different battery chemistries.

Among these innovations were things like:
- New battery chemistries and extraction approaches to minerals
- New vehicle integration concepts (integration vehicle chassis with batteries)
- Circular recycling of materials
- More localized supply chains
- Decentralized grids aided by vehicles
- Multi-modal refueling

Re Battery Chemistries

Borrowing a summary from John Paul’s WSJ article:

“Most EV makers chose a nickel-manganese-cobalt combination for their lithium-ion batteries because it delivers the most power density, and hence longer range, for the buck. But it also relies
on two problematic minerals—nickel, for which supplies are limited, and cobalt, which is both scarce and plagued by unsafe mining and exploitation of child labour. NMC batteries also can [combust] under certain conditions.

Some EV makers are now embracing an older, less-expensive battery technology known as lithium-iron-phosphate, or LFP... It draws entirely on cheap and abundant minerals and is less flammable”

John Paul highlighted that the scarcity and concentration of minerals like nickel and cobalt in certain countries can
a) lead to prices and the supply of these materials to trail geopolitical shocks in the regions to which they are part, as well as themself
b) become a source of geopolitical competition and conflict between nations vying for those minerals.

Other Innovations

John Paul went on to highlight innovations in batteries and components. Some examples include the integration of vehicle chassis and batteries in assembly and innovations in battery packaging. In terms of packaging, battery makers are creating larger cells for higher space utilization rather than creating modular cells. OEMs are also experimenting with packing the battery directly into the chassis (or vehicle frame). Both of these approaches conserve weight, save processing steps, and increase power density.

These innovations can help avoid what John Paul called a ‘weight spiral’ and in turn support the use of new battery chemistries.

Limitations

However, there are still some constraints to work through. By making the hardware more integrated, it makes battery replacement and second life uses more difficult. If a cell is faulty, a cell-to-chassis model would require the entire chassis to be replaced. Also, because the packs need to fit the chassis of a specific car size (e.g., a truck, SUV, sedan will also have different chassis), there is less economies of scale in production and cross-fitting between car models. The range of second life applications also drastically diminishes with cell-to-chassis integration.

Battery Management System (BMS)

Another key innovation that can increase battery efficient is the Battery Management System (BMS). The BMS works to monitor the utilization, charging and discharge rates, the thermal conditions, and timing of individual cells as well as the overall pack - thereby regulating how the battery is used and where energy can be saved. The BMS can implement different driving modes in varying operating conditions (e.g., performance, eco; towing).

When we redesign the BMS, we are able to software engineer an HVAC system to make it more efficient for the battery, as well as adjust the battery combination that is in engaged to make charging more efficient for the system as a whole.
OEMs are gaining additional efficiencies from producing/vertically integrating all of the stacks described above - i.e., battery packs, e-drive trains, BMS, and cell-to-chassis.

**Transitional Path**

John Paul describes all of these related innovations to argue that with the help of these technologies, LFP (Lithium Ferro-Phosphate) can replace NMC (Nickel Magnese Cobalt) chemistries, and that they should.

Some of the inherent advantages of LFP are it comes from cheaper, non-scare minerals, can support greater recharging cycles, have low toxicity, and are much safer (no fires). LFP's disadvantage of lower energy density at the cell level can be offset by packaging innovations to boost energy density at the system level, and via BMS adjustment to better regulate power use.

John Paul argues that the proliferation of BEVs is an integral step in meeting our climate goals, and these seem a bit more achievable with the falling price of renewable energy production and growing infrastructure subsidies. Yet, there is still much to be done when it comes to charging infrastructure - at home, at businesses and public buildings, as well as along the highway.

Calling on grid investments/enhancements, John Paul also advocates for policies to encourage off-peak EV charging and figuring out ways to distinguish between power used to charge EVs vs. for other uses. In California for example, it is better for EV owners to charge during the day rather than at night, since night energy requires more storage.

Going further, John Paul advocates that EVs can also support a decentralized smart grid, and if electrification of the home can be linked to visible cost savings, new and good jobs, political support will also grow.

**My Reflections**

This short talk provided several important topics to reflect on. Here I will add short commentary on the following topics broached by today’s talk:

1. Preparing America’s energy transition in the domestic market
2. Preparing for the same transition from a geopolitical standpoint
3. Placing greater emphasis on long term sustainable and circular supply chains

**1. Preparing America’s energy transition in the domestic market**

John Paul brought up several great points on this topic. The transition to BEVs is critical to meeting the U.S.’s climate objectives. However, U.S. private and public sector investment in EVs lags behind other countries, particularly China.

Over time, the U.S. needs to build a competitive domestic supply chain for EVs by investing in electric vehicles as it once did with combustion engine vehicles. This is obviously easier said than done, which requires a concerted effort to gradually transition an entire domestic labor force centered on the supply chain of ICEVs (including vehicle manufacturing, parts manufacturing, fuel extraction and refinement, petrochemicals, etc.) eventually to the same task around BEVs.
When we look at China, it has invested in every aspect of the EV supply chain with laser focus. According to Bloomberg, China’s share of global passenger EV sales has gone from 26% in 2015, to 48% in 2021, to 56% in first half of 2022.

The federal government can help by making direct investments into the domestic EV and components manufacturing sector, but it can also regulate requirements around future vehicle builds (as California is doing) and continuing to build out nationwide charging infrastructure - particularly along highways and between cities and towns. Governments can also incentivize consumer adoption with purchase subsidies or rebates. To have a sizeable impact, policies will also need to target long haul trucking, and logistics companies (including delivery companies) - to see where regulations vs. additional support is more appropriate to incentivize transition to EVs. As John Paul already pointed out, improving EV charging at government buildings as well as major private sector workplaces will make a difference as well.

2. Preparing America’s energy transition from a geopolitical standpoint

For more than three decades, the U.S. has led or been drawn into prolonged wars due to fears of energy security, including the Gulf Wars, Iraq, arguably Afghanistan, and conflicts in other strategically important geographies in the region. In order to not repeat this history, the U.S. should strategize long term in terms of its supply sources (minerals surrounding batteries but also other key components, such as aluminum and materials required for semi-conductors as vehicles become more computerized) and diversifying its reliance.

Moving from NMCs to LFPs is a key step in not building overreliance on scarce minerals produced in regions where the U.S. does not have significant control or influence presently. However, this move will not happen on its own - even with the concurrent development of battery innovations that John Paul outlines. As he said, it is U.S. consumer behavior and preference for longer battery life and the range war that has spawned that has led to embracing NMCs in the first place.

It is not clear what the pragmatic market-compatible long-term strategy is to assuage consumer range anxiety while charging infrastructure is built out. John Moavenzadeh and James Womack seemed to hint that average drivers really don’t need super long ranges (since long range trips are less frequent for urban dwellers) while John Paul seems to be saying that LFP combined with convergent innovations will make up the difference in range eventually. I am a bit skeptical on both these arguments. Yet do not have an appealing alternative proposal, and so will need to explore this topic and the supply chain more thoroughly in months to come.

To conclude this section, I would be interested to see more foreign policy commentators speak on how minerals essential to EVs can become tools for energy statecraft, leading to the U.S., China, or other power looking to control major choke points/routes of these minerals as a geopolitical tool, as well as how the U.S. can better position itself during this energy transition.

3. Placing greater emphasis on long term sustainable and circular supply chains

I fear that EV transitions in wealthy nations (e.g., U.S., EU countries, China, Korea, Singapore, etc.) will have undesired ripples in poorer nations in the absence of careful planning around vehicle lifecycles. As we eventually phase out ICEVs from our markets, what might this mean for the rest of the world without EV investment or infrastructure? Will OEMs and manufacturers still push to create fuel efficient and relatively cleaner ICEVs for global markets, and will many of our
second hand ICEVs end up in the streets of poorer nations (often with rapidly growing populations)? How can we prevent and mitigate a potential environmental divide between the rich and poor nations?

A few ideas here may be to

- Require that vehicle manufacturers and OEMs uphold similar rates of fuel efficiency and emission standard development of ICEVs as it has kept pace in the West before large scale EV transitions when exporting to other markets
- Regulate the export quantity and pace of ICEVs that pollute heavily
- Share EV infrastructure technology and knowledge, as well as providing international support where possible to encourage energy transitions where needed

All of the problems outlined above are complex, difficult challenges. There are no simple answers, and we will need to plan and work through these during the transition period so that we do more net good through the transition while avoiding some of the errors made during the petroleum revolution.

Part V. Other Material

Background Articles Originally Provided by Jinhua

1. Have Electric Vehicle Sales Reached a Tipping Point in the U.S.? (link)
2. Climate Change Technologies That Could Make All the Difference (summary) (full WSJ article)
EV Turning Point: Momentum Builds for U.S. Electric Vehicle Transition (link)
New Paths for Solving Emergent Problems of the Electric Vehicle (EV) Sector

MIT Mobility Forum, November 11, 2022

By: Prof. John Paul MacDuffie, Management Department
Director, Program for Vehicle and Mobility Innovation (PVMI)
Mack Institute for Innovation Management
PVMI: Its Roots in IMVP

The roots of the Program on Vehicle and Mobility Innovations (PVMI) are in the International Motor Vehicle Program (IMVP), founded in 1985 at MIT.

“IMVP is an international network of faculty, Ph.D. students, and researchers delivering knowledge and insight about the global automotive industry.”

“IMVP organizes international teams of researchers to do collaborative research on topics throughout the automotive value chain.”

PVMI is the new name and provides the new direction for the IMVP network, and Wharton’s Mack Institute of Innovation Management is its new home.
“A Once-in-a Century Transformation”
Disruptive Technologies/Business Models: What Impact of CASE (separately and together)?

- **C**: “Connected car” – within-vehicle network; vehicle-to-vehicle (V2V); vehicle-to-infrastructure (V2I); infotainment services

- **A**: Autonomous vehicle – “driver assist” (Levels 1 & 2) to “primary vehicle control” (Level 3) to “full vehicle control” (Levels 4 and 5)

- **S**: Shared -- New mobility services, w/high asset utilization strategies (car-sharing/ ride-hailing) that reduce vehicle ownership

- **E**: Electric vehicles (BEVs) and recharging via electricity (from varied sources)
Many Identify Barriers to Diffusion of EVs

Goal: Achieving cost and performance parity with legacy ICEV technology

First, overcome these barriers:

• Need for battery innovations (range, cost, supply chain)
• Access to charging infrastructure
• Affordability
These Barriers Look Different Today Than 20, 10, 5 or even 3 Years Ago

- We’ve moved beyond questions of “whether” & “chicken and egg” debates
- Now the questions are “when and “how” -- around a set of still-thorny but more tractable problems.
- Expanding EV supply and multiple forces affecting EV demand are creating favorable conditions for a **swarm of innovations**
- Some are highly visible, others behind the scenes, from both private & public sectors
- *Taken as a whole, they yield promising paths for addressing these problems*
Disruptive Technologies Often Only Demonstrate Their Biggest Impact After a Swarm of Related Innovations

• For EVs, these innovations are occurring in:

  • Batteries → physical innovations, e.g., new chemistries; new extraction approaches; new vehicle integration concepts; deglobalized supply chains; circular recycling

  • Charging → electrification for decarbonization; new sources of electricity; public policies favoring clean energy; both decentralized and centralized grid enhancements; smart grid tools/incentives; multi-mode ‘refueling’

  • Affordability → public policy to speed cost parity; used EV and PHEV markets; physical innovations tied to vehicle market segments; more multi-mode mobility options; P2P vehicle sharing; remove “dirty” products
Battery Innovations
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Headlines On Shortages of EV Battery Materials Grow More Alarmed

- **COBALT** → Scarce, Concentrated (nearly 50% in Congo) Where Mining Is Linked to Human Rights Abuses

- **NICKEL** → Scarce, Concentrated (over 50% in Australia, Indonesia, South Africa, Russia and Canada), New Formulations Use More Nickel

- **GRAPHITE** → Not Scarce But Concentrated: “China accounts for about 60% of natural graphite production capacity and 90% of the synthetic variety” (Fortune)

- **LITHIUM** → Not Scarce, Supply Lags Demand Considerably, Price Up Dramatically (400-600% increase since January 2022), Surface Mining Method Has Negative Environmental Impacts

**Dominant battery chemistry is NMC (Nickel Manganese Cobalt) with Lithium (Li-ion in all chemistries for now) – and Graphite for anodes**

LITHIUM PRODUCTION AND RESERVES BY COUNTRY (USGS 2019)

![Lithium Production and Reserves by Country](chart.png)

Source: USGS 2019
Meanwhile, A Swarm of Physical Innovations in Batteries and Their Components – Plus Software

- Looking beyond cells
- Chemistry variants
- Packaging innovations
- Platform flexibility
- Battery management software (BMS)
Looking Beyond Cells

Innovations in cell design and manufacturing continue but:

Battery chemistries are now important strategically
Innovations in combining cells into modules and packs offer alternate paths to improvement
OEMs developing packaging innovations, battery platforms to support broad product portfolios
All are boosting vertical integration for batteries*
Employment impact: 2/3 of OEMs build battery modules and packs in their own plants*

*Source: Alochet, MacDuffie, & Midler, 2022
Different Battery Chemistries Offer Tradeoffs - and Supply Chain Solutions

Many chemistries that avoid or reduce need for cobalt (especially) and nickel

LFP  LMO, LMNO  NMC  2025-30

LG Chem’s new formulation: from 6-2-2- to 8-1-1
Packaging Innovations Are Crucial to Support New Battery Chemistries

• Battery makers are eliminating modules in cell-to-pack designs

• OEMs are experimenting with packing cells directly into the chassis (cell-to-chassis)

• Both save weight, processing steps, and increase power density, helping support new battery chemistries

• Great way to avoid the “weight spiral”
Cell-to-Chassis = Structure with a Double Function

• Analogy that Tesla uses: Like using airplane wings to hold fuel
• First step: Design the fuel tanks in the shape of the wings
• Analogous step: Design the chassis with a battery pack-shaped cavity
• Next innovation: New glues that add structural strength to adhesive bonds that keep cells and plates together

“The ultimate battery pack would be one that consists of 100 percent active material. That is, every part of the battery pack stores and releases energy,” Euan McTurk
Battery Platforms Offer Flexibility to Support Broad Product Portfolio

Ultium Module Flexibility

- Battery packs are custom tailored for energy and range
- Packs can contain 6, 8, 10, 12 modules, or can be double stacked to hold up to 24 modules
Cell-to-Chassis and Configurable Platforms Solve Some Problems and Create Others

- Replacing faulty cells will be far more difficult w/cell-to-chassis

- Idiosyncratic pack shapes won’t fit in other models → Loss of scale economies? Less repair or replacement flexibility?

- Limits range of “second-life” applications when the car is scrapped

- Larger battery sizes in cell-to-pack and cell-to-chassis designs may limit them to grid-storage applications
Battery Management System (BMS): “DNA of EVs”

Monitors parameters of individual cells and overall battery pack

Controls charging and discharging rates and timing

Regulates thermal conditions (affects safety and efficiency)

Evaluates overall capability, over time and in different operating conditions

Enacts different driving modes (performance; eco; towing)
Leapmotor’s “Intelligent Power System”

“We integrate our electric motors, gearboxes and MCUs into our proprietary electric drive system, Heracles. We expect to mass-produce a more advanced oil-cooling electric drive system, PanGu, which features an industry-leading maximum efficiency up to 94.6%. We develop our own battery pack and battery management technologies. With the delivery of the C01 in the third quarter of 2022, we expect to become the world’s first pure-play EV company to apply cell-to-chassis (“CTC”) technology in mass production.”

• Vertical integration of the entire e-drive train; battery pack and BMS; and now cell-to-chassis
• This is the same approach being taken by most incumbent OEMs and de novo EV startups
Who Does What in Battery Manufacturing  
(*Alochet, MacDuffie, & Midler, 2022*)

Nearly all OEMs (incumbent ICEV and *de novo* BEV), buy cells.

In contrast, 2/3 of OEMs make battery modules and packs at or near EV assembly plants.

These assembly jobs can be done by existing workers, after training.

1/3 ally with one battery partner.

**OEMs do Battery Management System (BMS) on their own or write specs for software specialist**

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Taken As a Whole: LFP Can Replace NMC

LFP (Lithium Ferro-Phosphate) was applied first in scooters and small EVs.

“The big Chinese battery makers (BYD, CATL and Lishen — each one larger by itself than any other battery company that’s not in China) -- have been making LFP cells for 10 years.”*

For a time, displaced by NMC (Nickel Manganese Cobalt) – but no longer.

LFP Advantages: Cheaper (non-scarce) materials, more recharging cycles, much safer (no fires), low toxicity

LFP Disadvantage of lower energy density at cell level can be offset by:

- Packaging innovations (cell-to-pack; cell-to-chassis) that boost energy density
- BMS adjustments (less acceleration speed, slower HVAC temperature adjustments, less range) that reduce energy demand

* Lou Schick, director of investments at Clean Energy Ventures
Shortage of Raw Materials Not Easily Solved...

Out of Power?
A shortage of raw materials means there may not be batteries available for all the EVs automakers say they plan to sell.

- Estimated number of EVs automakers say they plan to sell.
- LFP* batteries that can be made with expected supplies of lithium
- NMC811** batteries that can be made with expected supplies of lithium
- NMC811** batteries that can be made with expected supplies of nickel

Projected sales of EVs, per Wood Mackenzie

*60 kWh LFP batteries
**90 kWh NMC811 batteries
Sources: Wood Mackenzie, BloombergNEF, BATPaC
...But Shortages Drive Expanded Supply, Substitutive Innovations, and More Recycling

• Lithium production is just scratching the surface of available reserves

• New methods of lithium extraction are gaining ground (e.g., direct extraction from brine rather than evaporation)

• NMC (Nickel Manganese Cobalt) is shifting from 6-2-2 to 8-1-1

• LFP (Lithium Ferro (Iron) Phosphate) avoids nickel and cobalt altogether

• Economics of battery recycling grow more attractive as raw material prices increase – boost for “circular economy” investments and public support
Investment Is Pouring Into EV Recycling

Higher raw material prices drives more investment in recycling. If recycling capacity grows sufficiently, it helps reduce dependence of EV industry on new mining.
Charging Innovations
Disruptive Technologies Often Only Demonstrate Their Biggest Impact After a Swarm of Related Innovations

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  • Batteries → physical innovations, e.g., new chemistries; new extraction approaches; new vehicle integration concepts; deglobalized supply chains; circular recycling

  • Charging → electrification for decarbonization; new sources of electricity; public policies favoring clean energy; multi-mode ‘refueling’; both decentralized and centralized grid enhancements; smart grid tools/ incentives

  • Affordability → public policy to speed cost parity; used EV and PHEV markets; physical innovations tied to vehicle market segments; more multi-mode mobility options; P2P vehicle sharing; remove “dirty” products
Electrification Is Urgently Needed for Transportation

“Mobility Becomes Electric,” J.P. MacDuffie, report for Engine No. 1

Figure 1.1: Transportation is the Leading Source of Greenhouse Gas Emissions in the US

Source: EPA Greenhouse Gas Inventory Explorer
Drop in Price of Alternative Sources of Electricity Has Dramatically Changed the Playing Field

• “In 2009-10, solar PV cost 10x what they cost now - and onshore wind farms cost 3x what they cost now.”

• “Put differently, 90% drop in solar PVs -- and in cost per kWh of lithium-ion batteries. 70% decline in the cost of wind.”

• “That changes the playing field for climate policy. What it would cost to have 10x the political will - that is what we unlocked by driving down solar PV and Li-ion costs by factor of 10.”

• “10x easier to take action for a given amount of political will.”

• “All before the new U.S. legislation. (Infrastructure Bill; CHIPS Act; Inflation Reduction Act)”

Jesse Jenkins, NetZero Project, Princeton on Ezra Klein podcast, 9/20/22
Q: “How Do These New Bills Make Scaling Clean Energy Easier?”

• “Focuses on making clean energy cheaper” - subsidies via tax credits, rebates for weatherizing, loans to towns. “Put thumb on the scale for clean vs dirty energy.”

• “Many countries subsidized deployment of those technologies when they were expensive and created the early markets that drove innovation and cost declines.”

• “Not pricing carbon but decarbonizing energy production. Economists want product prices to represent their true cost. But making fossil fuels more expensive is politically impossible.”

• “Alternative is less economically efficient but much more likely to succeed. Cleaner energy develops public goods – less emissions, less air pollution, better public health, fewer extreme weather event – hence worth subsidizing.”

• “Move cost of clean energy off households and onto the progressive tax structure of the federal government - 15% corporate tax plus go after tax cheats.”

Jesse Jenkins, NetZero Project, Princeton on Ezra Klein podcast, 9/20/22
Between now and 2030, increasing diffusion of BEVs is the surest path to electrifying transportation. 

“Mobility Becomes Electric,” J.P. MacDuffie, report for Engine No. 1
“The Tesla Is Not Enough”: Incumbent Automotive OEMs Are Needed To Speed the EV Future

“Mobility Becomes Electric,” J.P. MacDuffie, report for Engine No. 1

Tesla’s most optimistic forecast is selling 20 million/year by 2030. That’s double the current size of Toyota or VW. And would still only be 1 out of 5 vehicles sold annually worldwide.
Charging Infrastructure Is Now An Urgent Matter – And, in the U.S., Has Gained New Subsidies

**Home**
- Actor: Homeowner; Landlord
- Charging Hours: Overnight
- Charging Duration: 8-12 hours
- Financed by: EV Owner
- Other Benefits: Home Grid System

**Around Town**
- Actor: Municipalities; Businesses
- Charging Hours: Daytime
- Charging Duration: 0.5-8 hours
- Financed by: Charger Lease/Purchase
- Other Benefits: "Customer" Perk

**Highway**
- Actor: Federal Government
- Charging Hours: Road Trips!
- Charging Duration: 0.5-1 hour
- Financed by: Federal Government
- Other Benefits: Range Anxiety
Many Grid Investments and Enhancements Are Needed – and Smarter Grid Policy – e.g.,

• How to apply incentives for off-peak EV charging based on actual charging time?
• Need to distinguish between electricity used to charge an EV and power used simultaneously for other purposes by the same customer – aka load disaggregation.
• Con Edison and GM are working together on accurate smart meter measures of this.
• Reliable load disaggregation encourages participation in off-peak EV charging incentive programs. Con Edison, 10/12/22

• At what times should EV owners be encouraged to charge?
• In California, not at home.
• Cheapest prices for electricity from wind and solar are late morning and early afternoon.
• Nighttime requires storage.
• Best to incentivize daytime charging – while at work or around town. Stanford U News, 9/22/22
Ideas and Politics Will Matter

• As (if) electrification for home and transportation is understood, accepted, and supported, home charging for EVs will become subsumed in a broader idea of developing a decentralized smart grid – and support will grow.

• As (if) electrification for home and transportation is also linked to visible cost savings, new and good jobs, support will grow.

• Electrification – and all climate policies – can be politicized.

• Jurisdictional disputes (municipal, state, federal) over installing charging infrastructure and grid enhancements can also be a barrier.

• The hope: streamlined & facilitated permitting; training for the new jobs; and visible changes in the built infrastructure will build political support.
Affordability Innovations
Disruptive Technologies Often Only Demonstrate Their Biggest Impact After a Swarm of Related Innovations

• For EVs, these innovations are occurring in:

  • Batteries ➔ physical innovations, e.g., new chemistries; new extraction approaches; new vehicle integration concepts; deglobalized supply chains; circular recycling

  • Charging ➔ electrification for decarbonization; new sources of electricity; public policies favoring clean energy; multi-mode ‘refueling’; both decentralized and centralized grid enhancements; smart grid tools/ incentives

  • Affordability ➔ public policy to speed cost parity; used EV and PHEV markets; physical innovations tied to vehicle market segments; more multi-mode mobility options; P2P vehicle sharing; remove “dirty” products
Affordability Is One Aspect of Accessibility (and What I Cover Here)

• Accessibility to EVs is a broader question than affordable prices.

• Urban vs. suburban vs. rural is another crucial dimension.

• Accessibility is heavily intertwined with charging infrastructure; affordability is less so

• Indeed, one key affordability issue is ”gateway” access to BEVs through PHEVs – can be charged but also has ICE backup when needed

• I emphasize the growth/evolution of used EV vehicle markets, BEV and PHEV
With Lower Operational Costs, Primary Barrier is Front-End Purchase

• EVs have lower “fuel” price; lower operational expenses and maintenance needs --> **lower lifetime ownership costs than ICEVs**

• Purchase prices for EVs have stayed high – and current high demand and limited supply limits price competition

• Current tax credits only apply when filing your taxes – and no longer apply to the most popular models

• EV “sticker shock” when seeking to purchase is high
Inflation Reduction Act Subsidies Are Well-Designed to Help (Though Not Immediately)

- Allows point-of-sale incentives
- Removes vehicles-per-manufacturer cap.
- Creates purchase price and income limits:
  - Extends the tax credit to pre-owned EVs.
  - **PHEVs are included** - important because they can be owned by people without ready access to charging
Inflation Reduction Act Subsidies Are Well-Designed to Help (Though Not Immediately)

• Allows point-of-sale incentives starting in 2024. Purchasers will be able to apply the credit (up to $7,500) at the dealership, reducing sticker shock.

• Removes 200,000 vehicle-per-manufacturer cap. Brings back the tax credit for some popular and affordable EVs, which should attract new buyers.

• Creates income and purchase price limits:
  • SUVs, vans, and pickup trucks priced under $80,000, and all others (e.g. sedans) under $55,000.
  • For new vehicles, AGI cap on purchaser income: $150K for individuals; $300K for a joint filer.

• Extends the tax credit to pre-owned EVs.
  • Purchase price can not exceed $25,000
  • Model year must be at least two years earlier than the calendar year of the purchase
  • Tax credit for 30% of the sale price up to $4,000.
  • The AGI cap for pre-owned EVs is $75,000 for individuals and $150,000 for a joint filer.

• **PHEVs are included** - important because they can be owned by people without ready access to charging
Used EV Market Will Grow

• Used vehicles are already the most common purchase of income-constrained buyers

• Longevity of modern vehicles (average of 13-14 years in U.S.) means potential for multiple owners

• With mostly older Tesla models available, used EV prices are high

• Proliferation of new EV models will, in time, provide lower-price options

• Used EV tax credit (in IRA) won’t cover many models at first

• PHEVs will get the tax credits, boosting this type of hybrid (over HEV)
Recurrent Price Index

Includes:
- 2017 Chevy Bolt
- 2017 BMW i3
- 2017 Tesla Model S
- 2018 BMW 530e
- 2018 Nissan LEAF
- 2018 Honda Clarity
- 2019 Audi e-tron
- 2019 Tesla Model 3
- 2019 VW e-golf

Recurrent.com, Q4 2022 report
Few Current Used EVs (12%) Will Be immediately Eligible for the Tax Credit

- **September Used EV Inventory**
  - Just 12% of Used EVs Would Qualify for Tax Credit Today
  - **< $25k**: 12.1%
  - **$25 - $40k**: 18.2%
  - **$40 - $80k**: 31.9%
  - **$60 - $80k**: 28%
  - **above $80k**: 9.8%

- **Used Plug-in Hybrids Will Lead Tax Credit Eligibility in 2023**
  - Top Inventory in Sub-$27K Range
  - **Chevy Volt (PHEV)**: 22.4%
  - **Nissan Leaf**: 19.8%
  - **Ford Fusion Energi (PHEV)**: 14.2%
  - **Fiat 500e**: 5.1%
  - **Chevy Bolt EV**: 5.3%
  - **Ford C-Max (PHEV)**: 4.8%
  - **VW e-Golf**: 4%
  - **Toyota Prius Prime (PHEV)**: 3.1%
  - **All Other**: 0.2%

*Note that some BMW i3 have a gasoline range extender.*
To get federal tax credit, used EV purchase price must be under $27,500 (blue bar)
Mandates at State Level Will Boost EV Sales—and (Soon) Supply of Used EVs

California’s mandate is the most ambitious/aggressive

Other states that follow CA’s standards for emissions may choose similar mandates

Politically complex – but could speed transition to electrification and path to more affordable EVs
Other trends that will help w/ affordability

- LFP batteries work well in smaller vehicles – and can be cheaper
- Imports of smaller and cheaper EVs may grow (though won’t qualify for full tax credits under current rules)
- China very much wants its EV manufacturers to be global exporters (though current US-China dynamics may impose constraints)
- Peer-to-Peer business models – private owners renting out their vehicles for use – could make EVs more affordable (Tesla promises this)
- Urban dwellers with many low-emissions mobility options – e-bikes, e-scooters, EV taxis – may buy a small EV/PHEV (or forego ownership)
The Most Affordable Vehicles Will Continue to Be Used ICEVs

• Problematic because they have the most emissions, lower miles per gallon, less safety equipment

• “Cash for clunkers” programs to get the oldest, dirtiest vehicles off the road have a mixed history

• Well-designed policies could be critical to speeding the transition to affordable EVs for those currently relying on these vehicles

• For a thoughtful examination of what these polices would be, see a recent study by MIT System Dynamics faculty [here](#)
Staying Alert to the Swarm of Innovations Underway Will Help Identify the Paths Forward

• We’ve moved beyond questions of “whether” & “chicken and egg” debates
• Now the questions are “when and “how” -- around a set of still-thorny but more tractable problems.
• Expanding EV supply and multiple forces affecting EV demand are creating favorable conditions for a swarm of innovations
• Some are highly visible, others behind the scenes, from both private & public sectors
• *In my view, taken as a whole, they yield promising paths for addressing these problems*
Innovations Will Support EV Momentum – and Also Reveal New Problems

• New problems are also tractable but involve tough tradeoffs:
  
  • Batteries $\rightarrow$ more battery-vehicle integration and some new chemistries make second-life applications and recycling for raw materials more difficult

  • Charging $\rightarrow$ jurisdictional and permitting complexity that slows rollout of multi-mode refueling options, constraining demand

  • Affordability $\rightarrow$ used ICEVs will be a primary choice for many due to affordability; removal of the dirtiest will help; value of PHEVs as gateway to BEVs (esp. used) but supply is (will be) low
Questions?