SCIENCE, TECHNOLOGY, AND PUBLIC POLICY PROGRAM

Increasing Manufacturing Capacity to Electrify Passenger Vehicles

Daniel R. Wohl
Daniel P. Schrag

HARVARD Kennedy School
BELFER CENTER

50 YEARS
OF RESEARCH, POLICY, AND LEADERSHIP

PAPER
DECEMBER 2023

Science, Technology, and Public Policy Program
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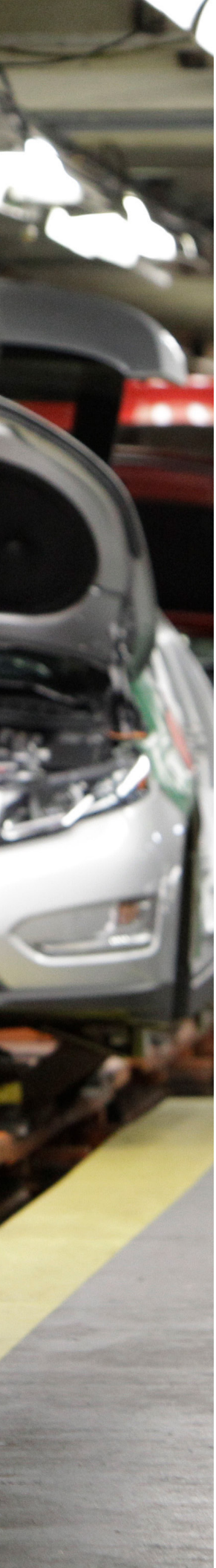
Assembly worker Julaynne Trusel works on a Chevrolet Volt at the General Motors Hamtramck Assembly plant in Hamtramck, Mich., Nov. 26, 2018 (AP Photo/Paul Sancya, File)



1. Executive Summary

In April 2023, the Biden Administration proposed greenhouse gas emissions regulation designed to result in 60% of new passenger vehicle sales in 2030 being plugin electric. Meanwhile, the 13 global automakers operating in North America have publicly committed to individual targets that, in aggregate, sum to 43% zero emission vehicle (ZEV) penetration in total North American passenger vehicle production volume by 2030, an implied 2.7M units below the Administration's 60% target. Despite industry's and governments' publicly announced ambitions, analysis of the industry's capital expenditures demonstrates that automakers have so far made investments in manufacturing capacity sufficient to achieve 31-39% ZEV penetration of new vehicle sales. Announced investments may not represent the totality of industry's privately planned or potential investments; however, this analysis quantifies industry's progress relative to pledges and demonstrates automakers must virtually double the capabilities enabled by current investments in order to achieve the federal target.

Based on the automakers' capital investments, 28 of 67 North American factories are on track to have ZEV production capacity by 2028. Of the 39 remaining legacy factories producing only internal combustion engine (ICE) vehicles, 24 of them were built over 30 years ago and will require business-as-usual upgrades to sustain operations. These older factories could be prime candidates for ZEV retrofits, where conventional facilities are upfitted with new ZEV manufacturing resources and equipment. Instead of promoting demand-side incentives like consumer tax credits, supply-side incentives focused on inducing ZEV retrofits of legacy factories or pushing automakers to invest in the long-term technoeconomic benefits of building new ZEV assembly plants from the ground up could accelerate the electrification of passenger transportation.

2. Introduction

In response to growing concern about anthropogenic climate change, shifting consumer preferences, and progress in zero emission vehicle (ZEV) technology, automakers and governments have submitted ZEV targets demonstrating their commitment to electrifying transportation. In 2021, the Biden Administration announced a goal for 50% of all passenger vehicle sales to be electric by 2030 and finalized greenhouse gas regulation through the Environmental Protection Agency (EPA) codifying an interim target of 17% for 2026.[1] In 2022, Congress passed the Inflation Reduction Act (IRA) which applied significant tailwinds likely to accelerate the deployment of numerous clean technologies including electric vehicles. Equipped with additional momentum, Biden's EPA then increased its proposed ZEV target for 2030 to 60%, along with a 67% target for 2032.[2] To be clear, neither of these targets are rigid requirements every automaker must individually achieve. Rather, EPA has produced analysis that illustrates a likely compliance pathway to its emissions regulation would involve 60% of new vehicles sales being plugin electric for its preferred option in the proposed 2030 rule and 17% for the finalized regulation applying to 2026.

Prior research has explored the speed at which vehicle fleet turnover occurs and proposed opportunities to accelerate turnover to achieve sustainable mobility goals; relatively little research, however, has evaluated whether the government's and automotive industry's annual targets are achievable. For example, Naumov, Keith, and Sterman (2022) demonstrate that increasing market share of ZEVs would still take decades to replace the existing fleet due lengthy useful lives that lengthen turnover times.[3] Meanwhile, Struben and Sterman (2008) have analyzed the consumer awareness required to generate adoption of ZEVs and other clean fuel vehicles.[4] Research by Bui, Slowik, and Lutsey (2021) has evaluated the U.S.-based commitments of automakers to scale ZEV production, but the analysis focuses on comparing U.S. capabilities to those in Europe and Asia, not in comparison to the targets set by U.S. federal authorities.[5]

Our research evaluates the automakers' potential to meet the U.S. federal government's ZEV penetration targets by forecasting annual ZEV production capacity (in units of vehicles) based on where automakers have committed capital expenditures to build new ZEV factories or retrofit legacy factories with ZEV capacity in North America. Automotive manufacturing is not a short time-scale

business, and automakers typically disclose the construction timelines and production capacity of their existing and planned factories. This means that ZEV factory capacity can be forecast out several years into the future with real announcements of capital investment. Using historical data regarding how long it takes automakers to ramp new factories to high volume production, we generate forecasts for both maximum ZEV factory capacity available to each automaker as well as the probable ZEV production volumes they could achieve based on those capital investments. The purpose of this paper is to analyze whether the North American ZEV manufacturing effort is on track meet its targets. We find the industry's current trajectory based on announced investments so far is significantly below the government's stated goals; by quantifying the remaining gaps between forecasted volumes and targets, we explore what policy interventions might improve the probability of achieving those goals.

3. Methods

Our approach relies upon forecasts for six volume scenarios utilizing the following methodologies.

First, "Total Volume (All Powertrains)" is provided by AutoForecast Solutions (AFS), an automotive consulting and research firm. AFS provides the historical and forecasted annual quantity of vehicles each automaker has produced or is projected to produce in North America across all propulsion types (all-electric, internal combustion engine, hybrid, etc.). AFS produces these volume forecasts by, in part, leveraging relationships with suppliers who have been contracted by the automakers to provide components and parts for future production.

Second, "ZEV + PHEV Volume" is also provided by AFS. These values are the annual quantity of plugin electric vehicles (both zero emission vehicles and plugin hybrid electric vehicles) that each automaker has produced and that AFS projects each will produce in North America through 2029.

Third, "Publicly Announced ZEV Targets" are tabulated based on the communications about electric vehicle ambitions from the 13 global automakers operating in North America. For example, GM has announced a 20% ZEV target for North America in 2025, while Ford has announced a target to build 2M ZEV units by 2026, approximately 33% of its global volume. The explicit or implicit percentage is applied to AFS's total North America volume forecast for each automaker's total volume to arrive at a numerical ZEV volume target for each automaker that has announced a target.

Fourth, the forecast includes two "U.S. Government Targets." The first is a 2026 target of 17% ZEV penetration. Models published by the US Environmental Protection Agency (EPA) indicate this level of penetration will be likely required to meet the Agency's finalized regulation for light-duty vehicle greenhouse gas emissions in Model Year 2026. The second target of 60% is the penetration EPA projects for its proposed but not-yet-binding regulation for 2030. These percent targets are translated into numerical volume targets by multiplying 17% and 60% against AFS' total volume forecasts for 2026 and 2030, respectively.

Fifth, we calculate "Max ZEV Production Capacity" using three inputs: a) publicly-disclosed production capacity of the 67 automotive assembly plants operated (or to be constructed) by the 13 global automakers with a North American presence, b) public disclosures from these automakers identifying the subset of those factories that have received or will receive capital investment to build ZEV manufacturing capacity, and c) applying the announced or implied ZEV capacity to the year that the same public disclosure indicates ZEV production will come online at those factories. In other words, this "bull case" scenario assumes that 100% of announced factory construction timelines are met, and capacity is instantly utilized at 100%.

Sixth, we calculate a "Probable ZEV Production Volume" scenario by delaying high volume production by 1 year from the automaker's announced start of production year and reducing annual factory output to 80% of capacity. Over the last 8 years, automakers have utilized 79% of North American factory capacity. In addition, conventional industry wisdom and data over this same period illustrate that automakers virtually always take at least 1 year to ramp up from the start of low volume production to high volume production in any assembly plant. These industry-wide averages are assumed to distribute evenly amongst the automakers and hold for the future relevant to this analysis.

Comparing these six forecasts against each other should illustrate how many ZEVs North America will produce in the medium-term based on the current level of capital investments it has made in manufacturing capacity. It should also quantify how the industry is tracking relative to its targets.

However, this analysis has limitations. First, constructing factory capacity does not guarantee production volume without the commensurate supply chain, labor force, and sales/logistics/delivery operations. For example, this analysis does not explicitly consider potential battery supply chain limitations. Second, national vehicle production is not the same as national vehicle deliveries due to importing and exporting. But historically 80% of North American production is delivered in the region. Furthermore, significant incentives in the Inflation Reduction Act are only available for North America-assembled ZEVs, which is likely to bolster the proportion of produced vehicles delivered domestically in the future.[6] Third, our approach does not incorporate younger automakers that do not have global presence and are not yet producing significant volumes of electric vehicles, like Rivian and Lucid, or more established international automakers that have not yet entered North America, like BYD.

4. Results

The methodology produces six volume outputs, with all values rounded to the nearest 10,000. The first (Table 1) and second (Table 2) list total vehicle production volume and plugin electric vehicle production volume. The consulting firm, AutoForecast Solutions (AFS), provided us with forecasts for total volume production in North America inclusive of all powertrains (internal combustion engine, battery electric, plugin hybrid electric, standard hybrid electric, etc.). Table 1 is typically used as the denominator when calculating ZEV penetration in subsequent results. However, AFS forecasts just 5% total volume growth over the full 7-year span of our analysis, a conservative growth rate that could produce an overestimate for ZEV penetration rate if the denominator in that fraction has been underestimated.

Table 1: Total Volume (All Powertrains)[1]

OEM	Line Item	2023	2024	2025	2026	2027	2028	2029
BMW	Total Volume (All Powertrains)	550,000	560,000	550,000	540,000	550,000	540,000	550,000
Ford Motor	Total Volume (All Powertrains)	2,470,000	2,430,000	2,450,000	2,480,000	2,560,000	2,600,000	2,610,000
Geely Group	Total Volume (All Powertrains)	60,000	140,000	170,000	180,000	170,000	160,000	170,000
General Motors	Total Volume (All Powertrains)	2,740,000	2,830,000	2,850,000	2,830,000	2,850,000	2,880,000	2,910,000
Honda Motor	Total Volume (All Powertrains)	1,650,000	1,730,000	1,710,000	1,720,000	1,720,000	1,770,000	1,750,000
Hyundai Motor	Total Volume (All Powertrains)	920,000	980,000	960,000	980,000	1,000,000	990,000	1,000,000
Mercedes-Benz Group	Total Volume (All Powertrains)	300,000	310,000	300,000	310,000	310,000	310,000	320,000
Renault-Nissan-Mitsubishi	Total Volume (All Powertrains)	1,140,000	1,120,000	1,130,000	1,130,000	1,140,000	1,140,000	1,110,000
Stellantis	Total Volume (All Powertrains)	2,170,000	2,010,000	2,160,000	2,260,000	2,290,000	2,290,000	2,310,000
Toyota Motor	Total Volume (All Powertrains)	1,980,000	2,050,000	2,020,000	2,020,000	2,030,000	2,030,000	2,040,000
Volkswagen	Total Volume (All Powertrains)	680,000	710,000	700,000	680,000	680,000	670,000	660,000
Subaru	Total Volume (All Powertrains)	290,000	300,000	290,000	310,000	300,000	300,000	290,000
Tesla	Total Volume (All Powertrains)	650,000	800,000	790,000	770,000	790,000	790,000	780,000
Total	Total Volume (All Powertrains)	15,610,000	15,940,000	16,080,000	16,210,000	16,370,000	16,470,000	16,490,000

Table 2: ZEV Volume

OEM	Line Item	2023	2024	2025	2026	2027	2028	2029
BMW	ZEV + PHEV Volume	90,000	100,000	100,000	120,000	130,000	140,000	150,000
Ford Motor	ZEV + PHEV Volume	210,000	240,000	350,000	470,000	580,000	600,000	660,000
Geely Group	ZEV + PHEV Volume	40,000	110,000	150,000	150,000	150,000	150,000	150,000
General Motors	ZEV + PHEV Volume	240,000	370,000	500,000	660,000	750,000	780,000	790,000
Honda Motor	ZEV + PHEV Volume	0	0	40,000	100,000	260,000	450,000	510,000
Hyundai Motor	ZEV + PHEV Volume	0	0	0	0	30,000	40,000	40,000
Mercedes-Benz Group	ZEV + PHEV Volume	120,000	140,000	140,000	140,000	140,000	150,000	160,000
Renault-Nissan-Mitsubishi	ZEV + PHEV Volume	10,000	10,000	60,000	80,000	80,000	80,000	80,000
Stellantis	ZEV + PHEV Volume	120,000	280,000	500,000	510,000	610,000	630,000	670,000
Toyota Motor	ZEV + PHEV Volume	20,000	30,000	60,000	70,000	70,000	70,000	70,000
Volkswagen	ZEV + PHEV Volume	90,000	110,000	110,000	100,000	110,000	100,000	140,000
Subaru	ZEV + PHEV Volume	0	0	0	0	0	0	0
Tesla	ZEV + PHEV Volume	650,000	800,000	790,000	780,000	790,000	790,000	790,000
Total	ZEV + PHEV Volume	1,590,000	2,200,000	2,800,000	3,190,000	3,700,000	3,980,000	4,220,000

1 OEM stands for original equipment manufacturer, another word for automaker. Also, note Geely Group is the parent company of Volvo and Polestar.

Table 3 is an aggregation of the latest public commitments that the 13 global automakers operating in North America have made. Note that automakers can and have adjusted their targets, but these figures represent the latest data available during the analysis. The figures in the table are the output of one of two approaches:

a. Multiplying an automaker's publicly committed "ZEV sales percentage in North America" to AFS's total volume forecast. For example, General Motors is targeting 20% ZEV sales penetration in 2025.[7] The 2025 figure for General Motors of 570,005 in Table 3 is the product of 20% and General Motors' value in 2025 in Table 1.

b. The global ZEV volume an automaker has stated they intend to produce by a given year multiplied by the percent of global sales that North America represents for that automaker. For example, in November 2021, Ford CEO Jim Farley tweeted that the automaker would produce 600,000 ZEV units globally in 2023. In typical, pre-pandemic years, Ford produced close to six million vehicles globally, so 600,000 units represents approximately 10% of its global volume. Therefore, the 2023 figure for Ford of 247,014 in Table 3 is the product of 10% and Ford's value in 2023 in Table 1.

Note that at the time of publication, Tesla and Subaru had not declared targets that could be extrapolated for North America volume.

Table 3: Publicly Announced ZEV Targets

OEM	Line Item	2023	2024	2025	2026	2027	2028	2029	2030
BMW	Publicly Announced ZEV Targets	110,000	-	140,000	-	-	-	-	270,000
Ford Motor	Publicly Announced ZEV Targets	250,000	-	-	830,000	-	-	-	1,170,000
Geely Group	Publicly Announced ZEV Targets	-	-	-	-	-	-	-	170,000
General Motors	Publicly Announced ZEV Targets	-	-	570,000	-	-	-	-	1,450,000
Honda Motor	Publicly Announced ZEV Targets	-	-	-	-	-	-	-	700,000
Hyundai Motor	Publicly Announced ZEV Targets	-	-	120,000	-	-	-	-	720,000
Mercedes-Benz Group	Publicly Announced ZEV Targets	-	-	150,000	-	-	-	-	320,000
Renault-Nissan-Mitsubishi	Publicly Announced ZEV Targets	-	-	-	-	-	-	-	440,000
Stellantis	Publicly Announced ZEV Targets	-	-	-	-	-	-	-	1,150,000
Toyota Motor	Publicly Announced ZEV Targets	-	-	-	-	-	-	-	410,000
Volkswagen	Publicly Announced ZEV Targets	-	-	-	-	-	-	-	360,000
Subaru	Publicly Announced ZEV Targets	-	-	-	-	-	-	-	-
Tesla	Publicly Announced ZEV Targets	-	-	-	-	-	-	-	-
Total	Publicly Announced ZEV Targets	360,000	-	980,000	1,800,000	-	-	-	7,170,000

The results presented in Table 4 follow a similar approach to the one used for the results in Table 3. The U.S. federal government has finalized or proposed targets for ZEV sales penetration. One is codified through EPA's Light-Duty Vehicle Greenhouse Gas Regulations and Standards for Model Years 2023-2026. The agency projects the standards "can be met with gradually increasing sales of plug-in electric vehicles in the U.S…to about 17 percent in MY [model year] 2026."[8] The Biden Administration has also proposed an emissions standard in its Light-Duty Vehicle Greenhouse Gas Regulations and Standards for Model Years 2027-2032 that it declares can be met by industry if 60% of new vehicle sales are ZEV by 2030.[9] Note that each individual automaker is not obligated to hit these specific targets – many may comply through pathways that involve banking and trading of credits they or other automakers have accumulated based on past performance. However, EPA has produced models illustrating 17% and 60% of new vehicle sales are likely to be plugin electric in order to comply with its emissions regulations. The results in 2030 in Table 4 are the product of 60% and the results in the 2029 column of Table 1 because AFS did not provide 2030 total volume projections.

Table 4: U.S. Government Targets

OEM	Line Item	2023	2024	2025	2026	2027	2028	2029	2030
BMW	U.S. Government Targets	-	-	-	90,000	-	-	-	330,000
Ford Motor	U.S. Government Targets	-	-	-	420,000	-	-	-	1,560,000
Geely Group	U.S. Government Targets	-	-	-	30,000	-	-	-	100,000
General Motors	U.S. Government Targets	-	-	-	480,000	-	-	-	1,740,000
Honda Motor	U.S. Government Targets	-	-	-	290,000	-	-	-	1,050,000
Hyundai Motor	U.S. Government Targets	-	-	-	170,000	-	-	-	600,000
Mercedes-Benz Group	U.S. Government Targets	-	-	-	50,000	-	-	-	190,000
Renault-Nissan-Mitsubishi	U.S. Government Targets	-	-	-	190,000	-	-	-	660,000
Stellantis	U.S. Government Targets	-	-	-	380,000	-	-	-	1,390,000
Toyota Motor	U.S. Government Targets	-	-	-	340,000	-	-	-	1,220,000
Volkswagen	U.S. Government Targets	-	-	-	120,000	-	-	-	400,000
Subaru	U.S. Government Targets	-	-	-	50,000	-	-	-	180,000
Tesla	U.S. Government Targets	-	-	-	130,000	-	-	-	470,000
Total	U.S. Government Targets	-	-	-	2,760,000	-	-	-	9,890,000

As described in the methodology and data section, the results presented in Table 5 utilize three key inputs:

a. Publicly disclosed production capacity of the 67 automotive assembly plants operated (or to be constructed) by the 13 global automakers with a North American presence

b. Public disclosures from these automakers identifying the subset of those factories that have received or will receive capital investment to build ZEV manufacturing capacity

c. Applying the announced or implied ZEV capacity to the year the same public disclosure indicates ZEV production will come online at those factories

For example, Hyundai Motor currently manufactures in North America out of two assembly plants, one in Montgomery (AL) and one operated in West Point (GA) by Kia Motors, a brand within the Hyundai Group. The facilities have maximum production capacities of 400,000 and 340,000, respectively.[10] Hyundai has announced that it will begin producing an electric version of its Genesis GV70 model in Montgomery in 2023.[11] Hyundai produces approximately 50,000 units of the GV70 annually, so we assume that this announced investment will contribute 50,000 units of ZEV capacity in Montgomery. In addition, Hyundai has announced plans to invest $5.5B in Bryan County, GA to build a full electric vehicle and battery manufacturing facility with 300,000 units of capacity set to come online in 2025.[12] So in this forecast, we project Hyundai's maximum ZEV production capacity of 50,000 units for 2023 and 2024 and then add 300,000 units for a total of 350,000 starting in 2025.

Table 5: Maximum ZEV Production Capacity

OEM	Line Item	2023	2024	2025	2026	2027	2028	2029	2030
BMW	Max ZEV Production Capacity	80,000	80,000	80,000	80,000	260,000	260,000	260,000	260,000
Ford Motor	Max ZEV Production Capacity	600,000	600,000	1,300,000	1,300,000	1,300,000	1,300,000	1,300,000	1,300,000
Geely Group	Max ZEV Production Capacity	-	150,000	150,000	150,000	150,000	150,000	150,000	150,000
General Motors	Max ZEV Production Capacity	450,000	1,040,000	1,040,000	1,040,000	1,040,000	1,040,000	1,040,000	1,040,000
Honda Motor	Max ZEV Production Capacity	60,000	60,000	60,000	60,000	60,000	60,000	60,000	60,000
Hyundai Motor	Max ZEV Production Capacity	50,000	50,000	350,000	350,000	350,000	350,000	350,000	350,000
Mercedes-Benz Group	Max ZEV Production Capacity	90,000	90,000	90,000	90,000	90,000	90,000	90,000	90,000
Renault-Nissan-Mitsubishi	Max ZEV Production Capacity	30,000	30,000	230,000	230,000	230,000	230,000	230,000	230,000
Stellantis	Max ZEV Production Capacity	60,000	170,000	460,000	460,000	460,000	460,000	460,000	460,000
Toyota Motor	Max ZEV Production Capacity	420,000	420,000	420,000	420,000	420,000	420,000	420,000	420,000
Volkswagen	Max ZEV Production Capacity	60,000	60,000	60,000	60,000	260,000	260,000	260,000	260,000
Subaru	Max ZEV Production Capacity	-	-	-	-	-	-	-	-
Tesla	Max ZEV Production Capacity	1,100,000	1,850,000	1,850,000	1,850,000	1,850,000	1,850,000	1,850,000	1,850,000
Total	Max ZEV Production Capacity	2,990,000	4,590,000	6,080,000	6,080,000	6,460,000	6,460,000	6,460,000	6,460,000

Table 6 presents results for Probable ZEV Production Volumes. As described, automakers take at least one year to ramp from start of commercial production to high volume production. And the industry, on average, utilizes 80% of its production capacity even before the COVID-19 pandemic. Therefore, the results in Table 6 simply delay the production capacities announced in Table 5 by one year and project that 80% of full capacity will be utilized at that time. They demonstrate that, so far, the industry has committed capital expenditures to produce 5.2M ZEV units in 2028, or 31% of total production volume.

Table 6: Probable ZEV Production Volume

OEM	Line Item	2023	2024	2025	2026	2027	2028	2029	2030
BMW	Probable ZEV Production Volume	60,000	60,000	60,000	60,000	60,000	200,000	200,000	200,000
Ford Motor	Probable ZEV Production Volume	110,000	480,000	480,000	1,040,000	1,040,000	1,040,000	1,040,000	1,040,000
Geely Group	Probable ZEV Production Volume	-	-	120,000	120,000	120,000	120,000	120,000	120,000
General Motors	Probable ZEV Production Volume	-	360,000	830,000	830,000	830,000	830,000	830,000	830,000
Honda Motor	Probable ZEV Production Volume	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000
Hyundai Motor	Probable ZEV Production Volume	-	40,000	40,000	280,000	280,000	280,000	280,000	280,000
Mercedes-Benz Group	Probable ZEV Production Volume	-	70,000	70,000	70,000	70,000	70,000	70,000	70,000
Renault-Nissan-Mitsubishi	Probable ZEV Production Volume	20,000	20,000	20,000	180,000	180,000	180,000	180,000	180,000
Stellantis	Probable ZEV Production Volume	50,000	50,000	140,000	370,000	370,000	370,000	370,000	370,000
Toyota Motor	Probable ZEV Production Volume	-	340,000	340,000	340,000	340,000	340,000	340,000	340,000
Volkswagen	Probable ZEV Production Volume	50,000	50,000	50,000	50,000	50,000	210,000	210,000	210,000
Subaru	Probable ZEV Production Volume	-	-	-	-	-	-	-	-
Tesla	Probable ZEV Production Volume	880,000	880,000	1,480,000	1,480,000	1,480,000	1,480,000	1,480,000	1,480,000
Total	Probable ZEV Production Volume	1,220,000	2,390,000	3,670,000	4,870,000	4,870,000	5,170,000	5,170,000	5,170,000

Finally, Tables 7 and 8 summarize the totals from key tables at two key periods, 2026 and 2030. Table 7 presents how each automaker and the industry overall are tracking to perform based on their current investments slated to unlock ZEV manufacturing capacity in 2026. Table 8 presents the same for 2030. Note that Tesla's implied ZEV penetration (Probable ZEV as % of Total Volume) is greater than 100% because all of their production is 100% ZEV and our analysis suggests they will produce more total units than AFS has forecast.

Table 7: Summary at 2026

OEM	2026						
	Total Volume	*Publicly Announced ZEV Target	U.S. Government Target	Max ZEV Production Capacity	Probable ZEV Production Volume	Probable ZEV as % of Total Volume	Probable ZEV as % of Gov't Target
BMW	540,000	140,000	90,000	80,000	60,000	11%	67%
Ford Motor	2,480,000	830,000	420,000	1,300,000	1,040,000	42%	248%
Geely Group	180,000	-	30,000	150,000	120,000	67%	400%
General Motors	2,830,000	570,000	480,000	1,040,000	830,000	29%	173%
Honda Motor	1,720,000	-	290,000	60,000	40,000	2%	14%
Hyundai Motor	980,000	120,000	170,000	350,000	280,000	29%	165%
Mercedes-Benz Group	310,000	150,000	50,000	90,000	70,000	23%	140%
Renault-Nissan-Mitsubishi	1,130,000	-	190,000	230,000	180,000	16%	95%
Stellantis	2,260,000	-	380,000	460,000	370,000	16%	97%
Toyota Motor	2,020,000	-	340,000	420,000	340,000	17%	100%
Volkswagen	680,000	-	120,000	60,000	50,000	7%	42%
Subaru	310,000	-	50,000	-	-	0%	0%
Tesla	770,000	-	130,000	1,850,000	1,480,000	192%	1138%
Total	16,210,000	1,800,000	2,760,000	6,080,000	4,870,000	30%	176%

*2026 Publicly Announced ZEV target uses 2025 figures for companies that have not disclosed 2026 targets

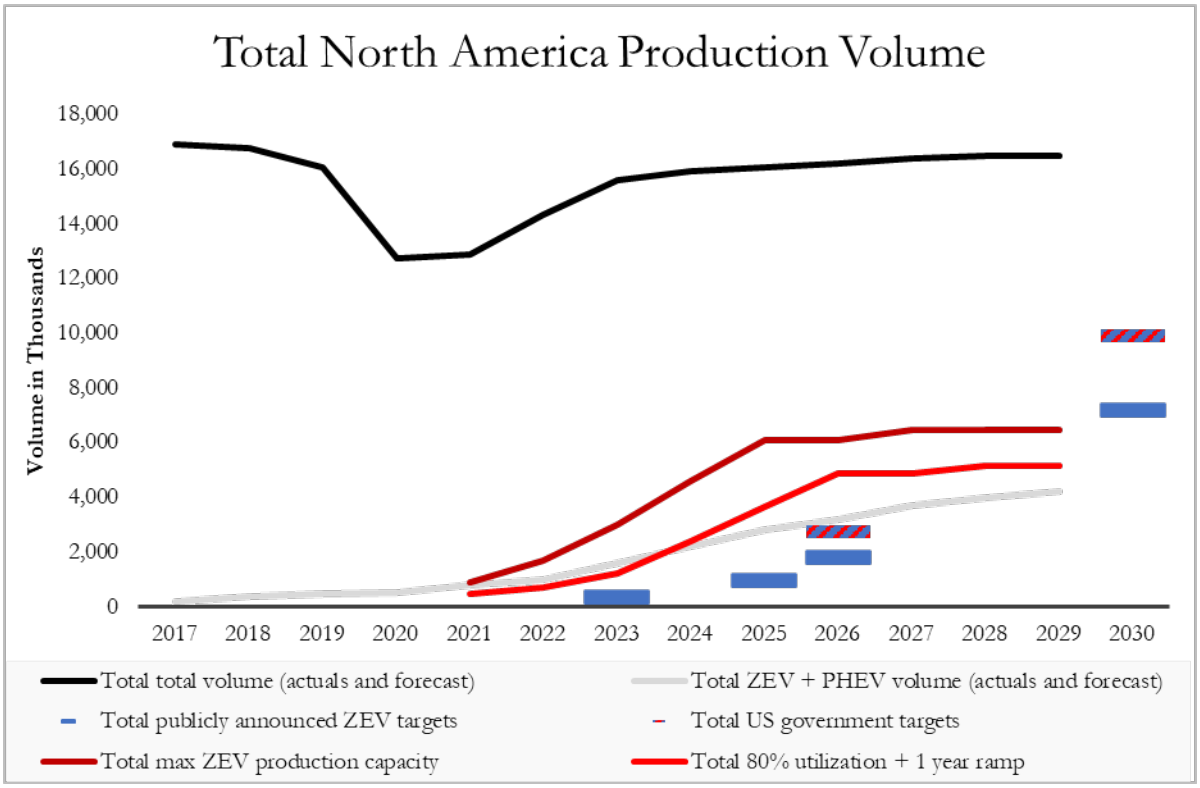
Table 8: Summary at 2030

OEM	2030						
	*Total Volume	Publicly Announced ZEV Target	U.S. Government Target	Max ZEV Production Capacity	Probable ZEV Production Volume	Probable ZEV as % of Total Volume	Probable ZEV as % of Gov't Target
BMW	550,000	270,000	330,000	260,000	200,000	36%	61%
Ford Motor	2,610,000	1,170,000	1,560,000	1,300,000	1,040,000	40%	67%
Geely Group	170,000	170,000	100,000	150,000	120,000	71%	120%
General Motors	2,910,000	1,450,000	1,740,000	1,040,000	830,000	29%	48%
Honda Motor	1,750,000	700,000	1,050,000	60,000	40,000	2%	4%
Hyundai Motor	1,000,000	720,000	600,000	350,000	280,000	28%	47%
Mercedes-Benz Group	320,000	320,000	190,000	90,000	70,000	22%	37%
Renault-Nissan-Mitsubishi	1,110,000	440,000	660,000	230,000	180,000	16%	27%
Stellantis	2,310,000	1,150,000	1,390,000	460,000	370,000	16%	27%
Toyota Motor	2,040,000	410,000	1,220,000	420,000	340,000	17%	28%
Volkswagen	660,000	360,000	400,000	260,000	210,000	32%	53%
Subaru	290,000	-	180,000	-	-	0%	0%
Tesla	780,000	-	470,000	1,850,000	1,480,000	190%	315%
Total	16,490,000	7,170,000	9,890,000	6,460,000	5,170,000	31%	52%

*2030 Total Volume target uses 2029 figures because AFS did not provide 2030 total volume projections

Based on capital expenditures that have been publicly committed towards electric vehicle assembly and typical construction and utilization behaviors within the industry, our analysis projects North America could manufacture 4.9M ZEV units (30%) in 2026 and 5.2M units in 2028 (31%) with the capital expenditures publicly committed so far. These volumes should be sufficient to achieve the 2026 EPA target of 17% ZEV penetration but present a significant gap to the industry's public commitments for 2030 (43%), and the federal government's goals for the same year (60%). These various scenarios and the distance between them are illustrated in Figure 1.

Figure 1



5. Discussion

With standard construction and production lead times and historical factory utilization rates in the automotive industry, we can forecast the ZEV production capacity in North America that will be unlocked by publicly disclosed capital investments. While the industry has time to invest and build additional capacity to hit the 2030 target, this analysis captures how much more must come online to hit the broad-based targets. Since most automakers take roughly five years to plan a new model, most have understandably not yet committed capital expenditures dedicated to the back end of the 2020s. Our analysis demonstrates they must double ZEV production capacity enabled by the current round of capital expenditures to successfully reach the 60% 2030 target.

There are several factors that could discourage automakers from making these additional investments to achieve these targets within the 2030 timeline. First, the expansion of ZEV sales depends critically on the buildout of charging infrastructure. The IRA and bipartisan Infrastructure Investment and Jobs Act passed the in 2021 contain several incentives for new charging infrastructure, but it remains to be seen whether the construction of new charging stations will keep up with the rapid expansion of ZEV sales anticipated over the next five years. Limited access to public charging stations in cities, for example, remains a disincentive for customers to choose ZEV models. A second obstacle to substantial new investments in ZEV production capacity is the recent rise in interest rates, affecting both large capital investments by automakers and new car purchases by consumers. After a decade of near-zero interest rates for many new car loans, higher interest rates could cause drivers to delay purchasing new cars, slowing down the turnover of vehicles and delaying the transition towards ZEVs, even if there is no recession. Finally, the transition to new ZEV production is bringing along labor challenges, as many of the new ZEV factories have been or will be built in "right to work" states that prohibit forcing all production workers to join the union representing the facility. Indeed, the transition towards ZEVs was a major issue in the recent United Automobile Workers strike and may remain a significant challenge for some automakers as they expand production. It remains unclear whether any of these obstacles will pose major challenges for new ZEV investment, but taken together, it remains highly uncertain that significant acceleration of new investments by automakers will occur before 2030.

Under these recent pressures, many automakers have been signaling an intention to adjust medium-term targets. Ford has extended its 2023 target into 2024 and abandoned its 2026 target.[13] And GM has abandoned previous 2023 and 2024 targets but reaffirmed its 2025 target.[14] While other automakers have also commented on their ZEV futures, none have specifically adjusted targets like Ford and GM did. Others like Geely and Hyundai have even doubled down on their commitments, and longer term 2030 targets appear unchanged across the board.[15] It is possible that these medium-term pullbacks are part of an industry political negotiation to secure greater EV subsidies or to influence EPA to finalize rules less stringent than those proposed in April 2023. Ultimately, 2030 targets may remain intact. But given that a doubling of current investment will be required to meet the proposed 60% target, the medium-term adjustments could play a factor.

There are some offsetting state and federal efforts that may drive more investment by automakers in the years ahead. In addition to the Administration's 60% target for 2030, California, New York, and Oregon have all committed to a 100% ZEV target in 2035 by effectively prohibiting the sale of internal combustion engine passenger vehicles starting in that year or the one before.[16] To achieve these targets, the IRA provides numerous incentives meant to expand ZEV adoption in the United States. The flagship electric vehicle policy included in the legislation is the return of a federal tax credit offered to motorists who purchase an electric vehicle. Formally known as the clean vehicle credit, this $7,500 tax credit is split into two halves: a vehicle is eligible for the first $3,750 if the vehicle has battery components manufactured or assembled in North America and is eligible for the second $3,750 if its battery contains critical minerals that were extracted, processed, or recycled in the United States or countries with which the United States has a free trade agreement.[17] In effect, the policy ties the demand side stimulus of a $7,500 tax credit to eligibility criteria that can only be met through establishing a domestic battery supply chain. Only vehicles that are assembled in North America and purchased by motorists under income thresholds qualify for the credit.

However, these incentives do not directly increase the industry's capabilities to manufacture ZEVs, or to increase vehicle supply. Until recently, consumers behavior suggested ZEV demand exceeded supply, with some reports noting every electric model faces an order backlog of 6 months or more.[18] The constraints of undersupply are beginning to loosen as the macroeconomic environment becomes

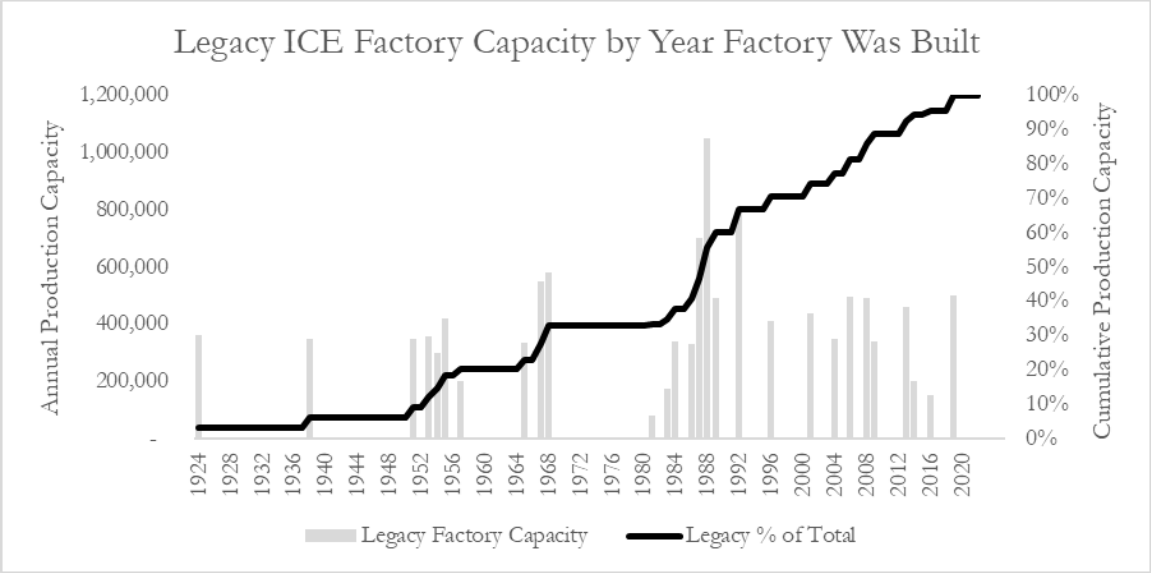
less consumer-friendly, and dealer inventories start to grow, but they remain below pre-pandemic and longtime industry norms.[19] In a demand-constrained environment, tax credits are unlikely to change consumer behavior. But because the automotive market is competitive, automakers will strive to meet battery criteria required for consumers to realize the full incentive, thereby strengthening the domestic industry for critical mineral mining and refining and battery manufacturing. Generating sufficient battery cells, modules, and packs will establish the floor for ZEV production volume: automakers cannot produce vehicles without requisite batteries.[II] However, assembly plant factory capacity establishes the ceiling. Automakers cannot manufacture more ZEVs than their factories can assemble.

Incentivizing ZEV retrofits for older legacy factories could accelerate the expansion of ZEV manufacturing capacity required to achieve the 60% penetration target. Of the 63 existing vehicle assembly plants in North America operated by the 13 global automakers, our review identifies 23 have received ZEV investment, as indicated by a publicly announced capital expenditure that will retrofit an existing factory with ZEV manufacturing capability.[III] Therefore, 40 factories remain that only produce legacy ICE vehicles, and these plants possess nearly 12M units of combined annual production capacity (approx. 75% of the 16M units of total production capacity in North America). Just under 8M units of this legacy ICE production capacity is concentrated in 22 facilities that were all constructed at least 30 years ago, before 1993 and represented in Figure 2. Business-as-usual upgrades should prompt automakers to invest in retrofits that modernize these aging facilities regardless of desires to transition from ICE to ZEV. There is an opportunity to accelerate the industry's path towards electrification by encouraging automakers to implement ZEV capacity through these business-as-usual retrofits.

II There are also other limiting factors on the supply side like charging infrastructure to relieve range anxiety and technician labor required for vehicle assembly and service.

III Two more greenfield factories are currently slated to come online by 2025: Blue Oval City (Ford) and Bryan County (Hyundai).

Figure 2



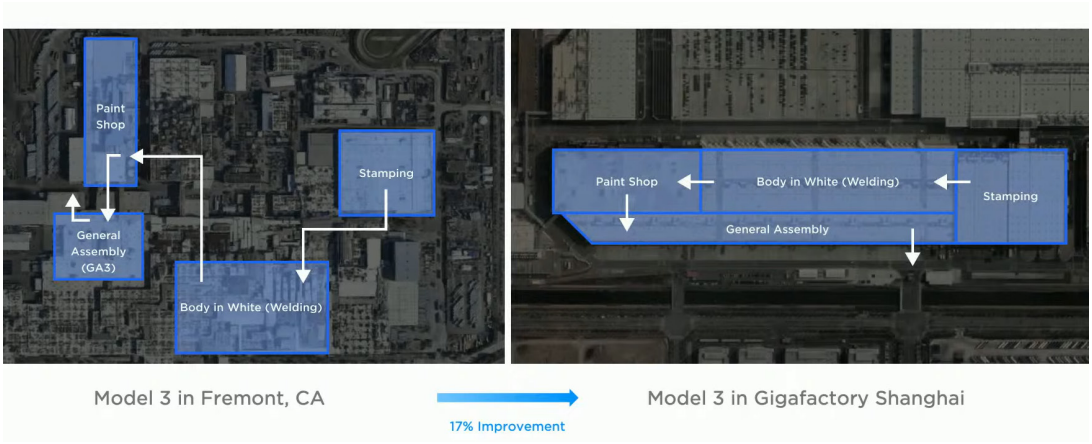
The IRA and White House appear to recognize the opportunity to promote the anticipated factory investments but may not provide sufficient support to unleash it. The IRA allocates $2B through 2031 for "Domestic Manufacturing Conversion Grants" to "retool existing auto manufacturing facilities to promote for domestic production of clean vehicles, including hybrids, plug-in hybrids, EVs, and hydrogen fuel cell vehicles."[20] Yet $2B is immaterial compared to what will be required for the industry. GM's retrofit to unlock 200,000 units of annual ZEV capacity in Spring Hill (TN) will consume $2B of capital expenditures alone. More recently, the White House announced another $10B in subsidized loans to be made available for automakers to retrofit conventional assembly plants through the Department of Energy's Loan Program Office (LPO).[21] This is a strong, positive step forward, especially if this debt catalyzes significant follow-on private capital. Nonetheless, the scale of capital expenditures required to transition the conventional ICE production complex to a ZEV production complex should require additional interventions.

Policymakers, automakers, unions, and other stakeholders invested in the ZEV transition could benefit from an array of other incentives including accelerated

depreciation tax benefits for aging facilities undergoing ZEV retrofits, tax credits that can be applied against the procurement of ZEV equipment, more subsidized loans and grants to fund ZEV retrofits, or local incentives targeting individual facilities ripe for a retrofit.

ZEV retrofits retain advantages over building new ZEV factories through less intensive construction and installation investment, prevailing siting and zoning, a legacy trained labor force, and existing supply chain infrastructure; however, steady state high volume production in a retrofit facility could be constrained compared to building new ZEV factories from scratch. Low volume, legacy facilities receiving retrofits may suffer from endemic utilization rate issues even in an updated ZEV status. Building factories from the ground up unlocks opportunities to implement innovative designs optimized for ZEV production efficiency. For example, Tesla's assembly plant in Shanghai, China, constructed as a new facility, is a single monolithic factory with a straightforward flow shown in Figure 3. This layout could not be implemented in Tesla's first North American assembly plant in Fremont, CA, a retrofit of a legacy ICE facility jointly operated by GM and Toyota. Due to the original architecture of the Fremont plant Tesla inherited, the retrofit facility's flow is more complex, and that factory has proved less efficient than Shanghai. Other advanced improvements like unboxed manufacturing – in which different parts of the vehicle are assembled simultaneously rather in series to ultimately reduce capex and improve output per unit – require building from the ground up in order to implement.

Figure 3[22]



Building new factories requires greater initial capital expenditures – Ford has committed $5.6B to build a new ZEV factory in Blue Oval City (TN) compared to $1.8B for a ZEV retrofit at an existing factory in Oakville (ON). But those expenditures are usually amortized over such a long period of time that they can end up being an insignificant portion of the cost per vehicle produced. Assuming Blue Oval City and Oakville both follow 30-year depreciation schedules and produce 200k annual units in their steady state, then Oakville's cost savings could amount to just $633 per vehicle, or 2% of a vehicle that hypothetically costs $30k to manufacture. These economics incorporate no new factory advantages granted by optimal factory designs or updated labor agreements.

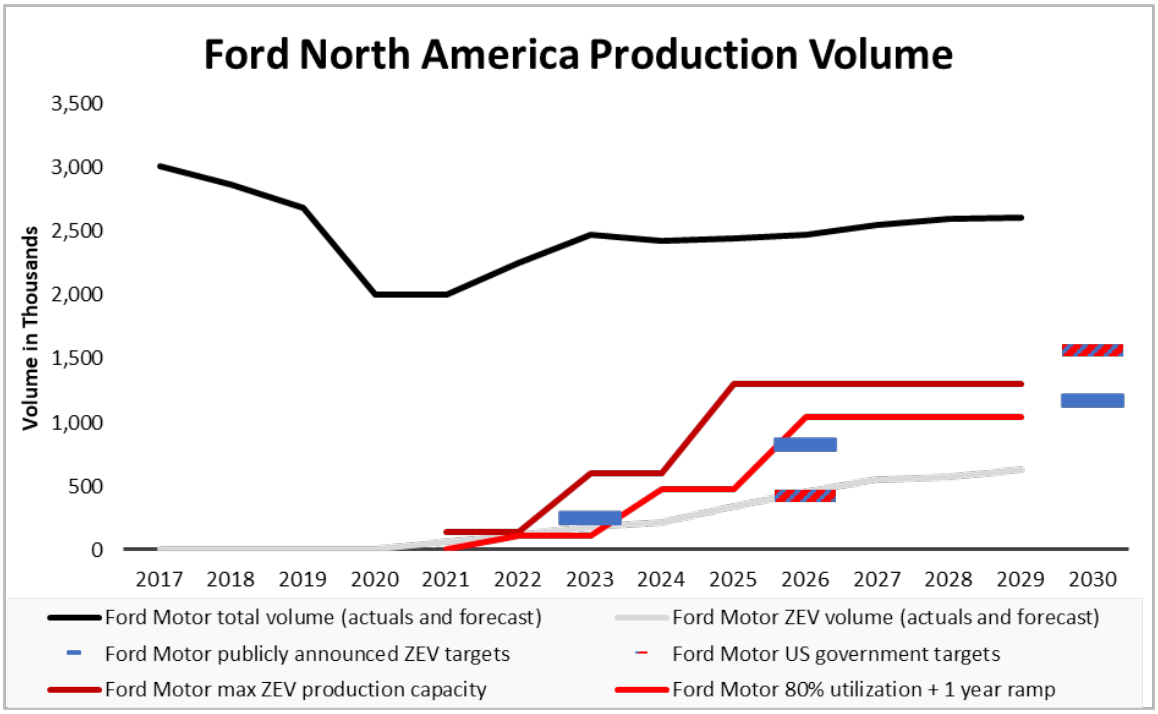
Automakers pursuing retrofits benefit from access to their skilled legacy labor force, but new ZEV sites offer a chance to reset labor relations and cost structures. When retrofitting a facility, some automakers remain beholden to historical labor union agreements. While initial IRA tax credit proposals provided incremental incentives to vehicles manufactured with union labor, the final legislation dropped those requirements.

6. Conclusion

The automotive industry has declared aggressive goals for passenger vehicle electrification. By 2030, the U.S. federal government targets 60% ZEV penetration, and our review of public statements by each of the 13 global automakers operating in North America identifies cumulative commitments reaching 43% penetration by the same date. However, the capital expenditures committed by these automakers reveals the industry has thus far announced investments in about half of the required factory capacity necessary to manufacture enough vehicles reach the government's ZEV targets. In the most probable scenario, North America could manufacture 4.9M ZEV units (30%) in 2026 and 5.2M units in 2028 (31%). Therefore, automakers must virtually double the factory capacity enabled by the current set of committed investments by 2030 in order to reach the target of 60% ZEV penetration.

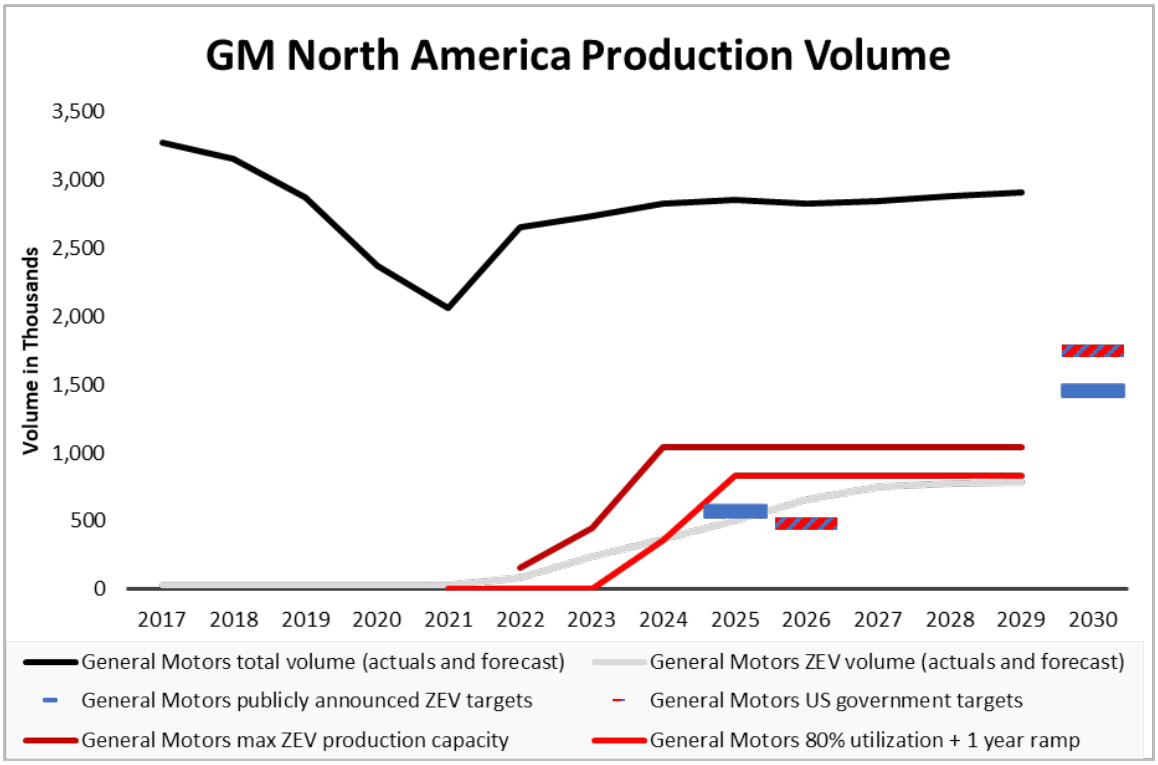
Interventions that increase ZEV capacity could come in many forms. Ultimately, supply-side incentives for factory retrofits or new ZEV factory construction may be more likely to increase ZEV penetration than the current regime of demand-side tax credits for motorists buying ZEVs in a supply-constrained market. Retrofitting existing factories offers near-term expedience through lower capital expenditures, access to a trained labor force, existing supply chain infrastructure, and grandfathered zoning and siting. Of the 12M units of manufacturing capacity in North America still dedicated to ICE-vehicle production alone, 8M units is concentrated in 22 factories constructed over 30 years ago. The auto industry could unlock ZEV production capacity if business-as-usual upgrades for these aging facilities incorporated ZEV retrofitting. Long-term, building new ZEV factories benefit from factory designs optimized for ZEV manufacturing as well as updated labor agreements. Due to the long useful lives of automotive assembly plants, the greater upfront capital expenditures required to build new ones are amortized over so many units of production over such a lengthy period that those costs could become inconsequential on a per vehicle basis.

Appendix



Ford Motor is projected to have maximum ZEV production capacity of 1M units (35%) by 2025 based on committed capital expenditures.

1. Publicly announced ZEV targets
    a. 2023: 10% (600k units, which is equivalent to 10% of the company's global volume)[23]
    b. 2026: 33% (2M units globally)[24]
    c. 2030: "40% to 50%"[25]
2. Committed capital expenditures towards ZEV expansion
    a. 2023: $420M to expand Cuautitlan (MX) from 140k to 200k units,[26] $2B for Detroit Electric Vehicle Center (MI) to begin production at 80k units with expansion to 160k in 2024,[27] $850M for Flat Rock (MI) retrofit with existing 240k unit capacity[28]
    b. 2025: $5.6B for Blue Oval City (TN) production to begin at 500k units,[29] $1.8B Oakville (CN) to retrofit to 200k units[30]
3. Ford has utilized 81% of its factory capacity over last 8 years.

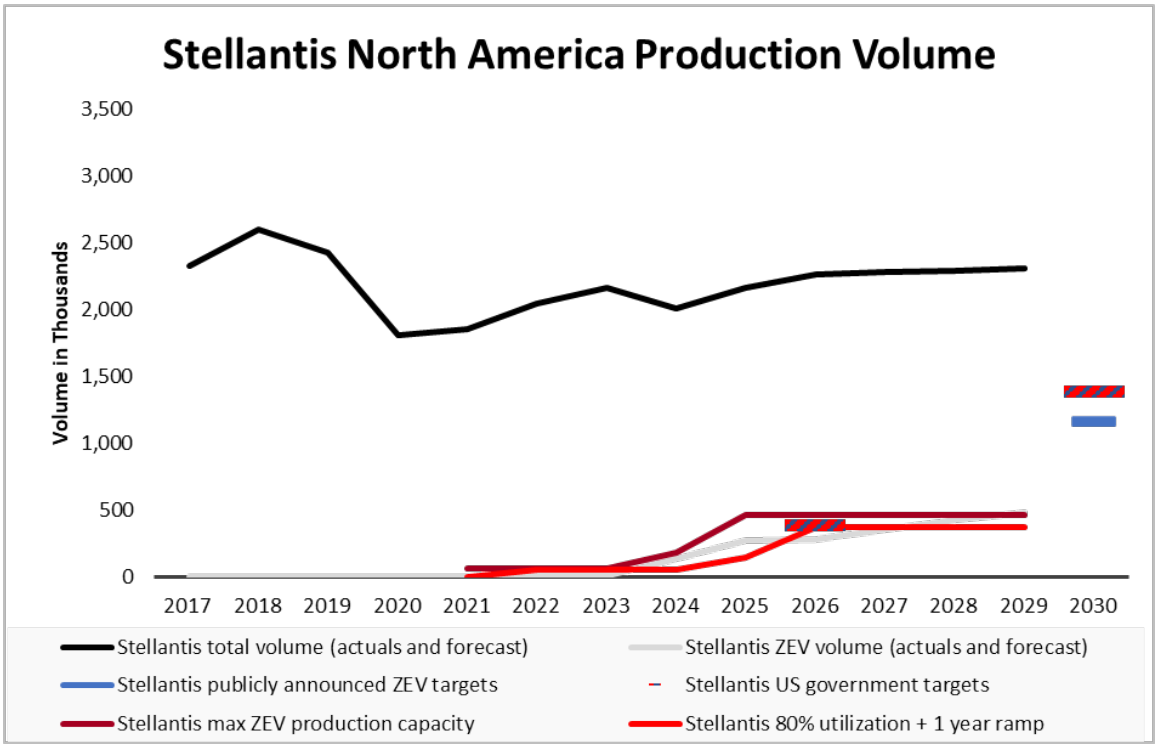


General Motors is projected to have maximum ZEV production capacity of 1M units (37%) by 2024 based on committed capital expenditures.

1. Publicly announced ZEV targets
    a. 2025: 20%[31]
    b. 2030: 50%[32]
    c. 2035: 100%[33]
2. Committed capital expenditures towards ZEV expansion
    a. 2022: $2.2B to build Factory Zero (MI) at 100k units and 2024 expansion to 250k units[34]
    b. 2023: $2B to retool Spring Hill (TN) to 200k units[35]
    c. 2024: $4B to expand Orion (MI) to 350k units,[36] $1B to retool Ramos Arizpe (MX) at 240k units[37]
3. GM is communicating (and this analysis assumes) 600k unit combined capacity at Factory Zero and Orion, but current capacity is 260k and 2021 utilization was just 40k.

4. GM imposed a global recall on all Chevrolet Bolts produced from 2017-2022, its signature ZEV product over the past decade, due to battery defects.[38]

5. GM has utilized 76% of its factory capacity over the last 8 years.



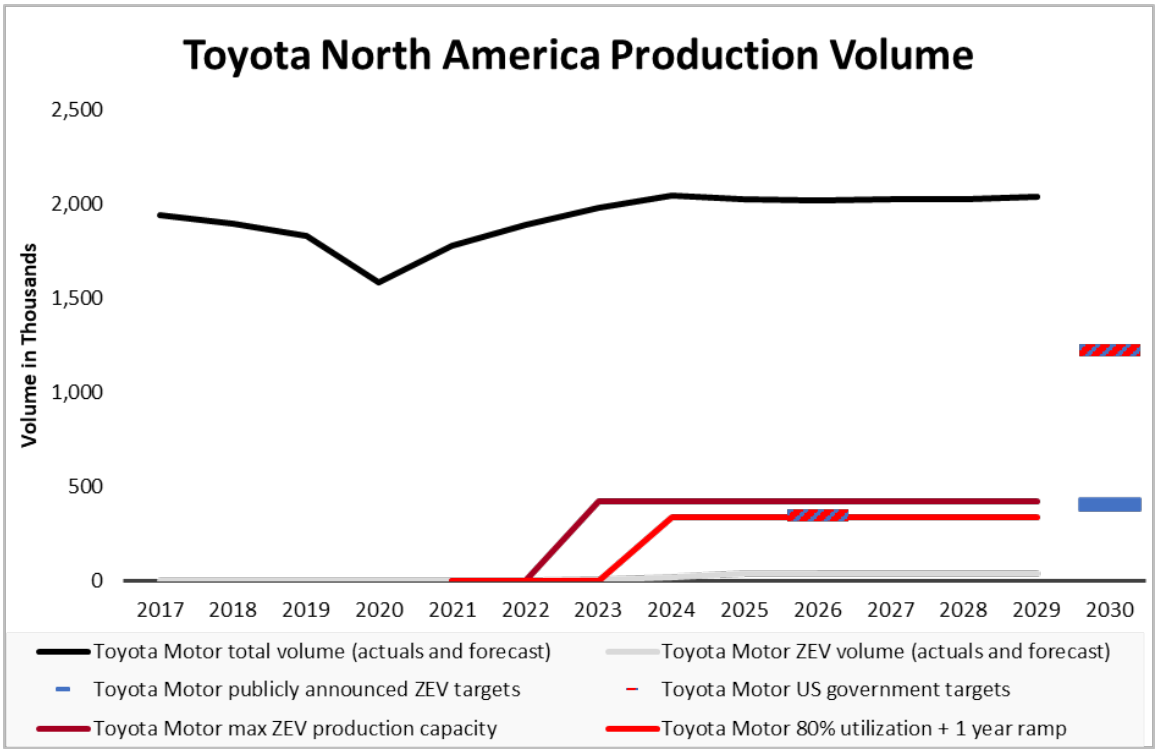
Stellantis has set no interim targets pre-2030 and not committed to a ZEV vs hybrid approach.

1. Publicly announced ZEV targets
    a. 2030: 50%[39]
2. Committed capital expenditures towards ZEV expansion
    a. 2021: Toledo North (OH) currently producing 60k Jeep PHEVs per year
    b. 2024: $2.8B for Windsor (CN) to replace current annual production of 100k ICE units with a BEV[40] and for Brampton (CN) to be retooled in 2024 with EV production resuming in 2025 at 285k unit capacity[41]

3. Stellantis' announcements have been vague regarding whether they are pursuing a ZEV versus hybrid approach to electrification.

4. Despite its laggard approach in North America, Stellantis led all automakers in Europe in the second quarter of 2022 in total all-electric deliveries; however, their strategy there is focused on sedans (i.e. Fiat 500e), a small market unlikely to translate to high volume sales in North America.[42]

5. Stellantis has utilized 78% of its factory capacity over the last 8 years.



Toyota has a 20% ZEV target for 2030 and made no commitments to ZEV over hybrid so far. With projected maximum ZEV production capacity of 420k ZEV units (21%) by 2023, the automaker is tracking to its target that significantly trails competitors' and government targets.

1. Publicly announced ZEV targets
    a. 2025: 40% to be "electrified"[43]
    b. 2030: 20%[44]

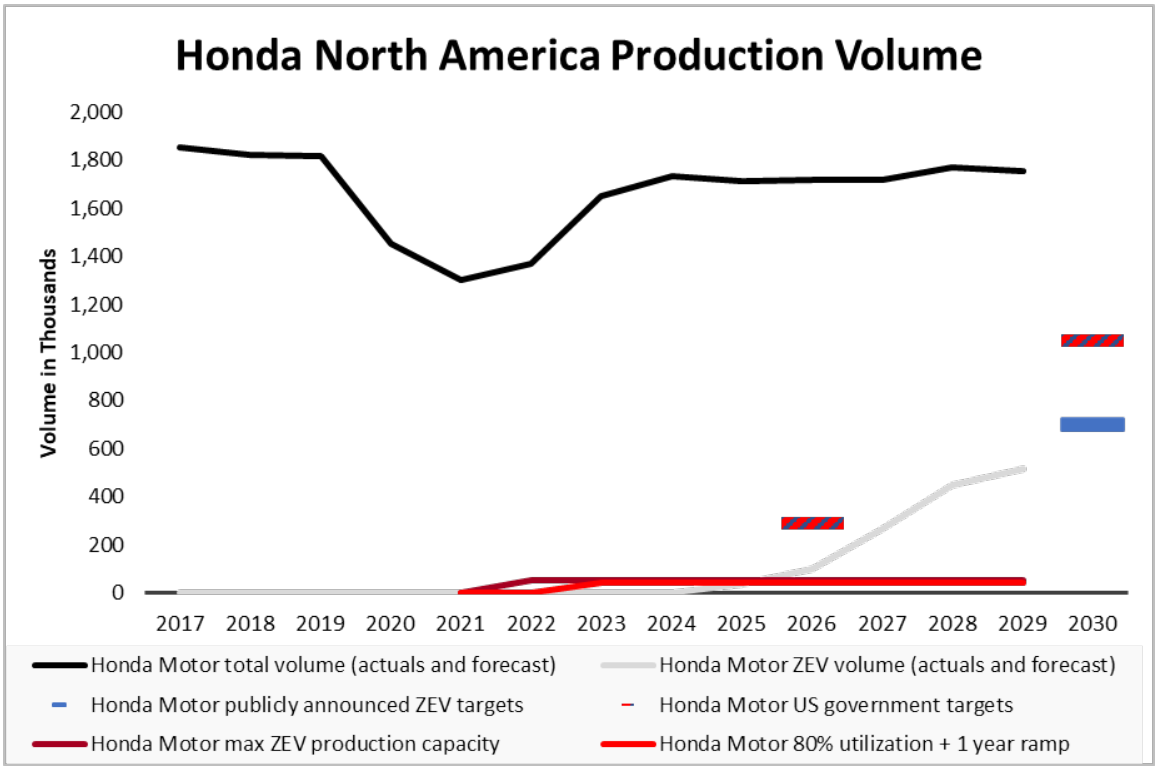
2. Committed capital expenditures towards ZEV expansion

    a. 2023: $803M investment to produce two "electrified" models at Princeton (IN) with existing capacity of 420k units[45]

3. Toyota has not specified if it will pursue to ZEV vs hybrid technology at Princeton or if it will shut down existing ICE assembly lines meaning actual ZEV production is unlikely to be 420k units.

4. Toyota has indicated 15 BEV models will be available by 2025, but it has not invested to expand North American factory capacity.

5. Toyota has utilized 93% of its factory capacity over the last 8 years.



Honda has committed nearly nothing to ZEV factory capacity in North America, with a projected maximum production capacity of 55k ZEV units (3%) by 2022 based on committed capital expenditures.

1. Publicly announced ZEV targets[46]

    a. 2030: 40%

    b. 2035: 80%

    c. 2040: 100%

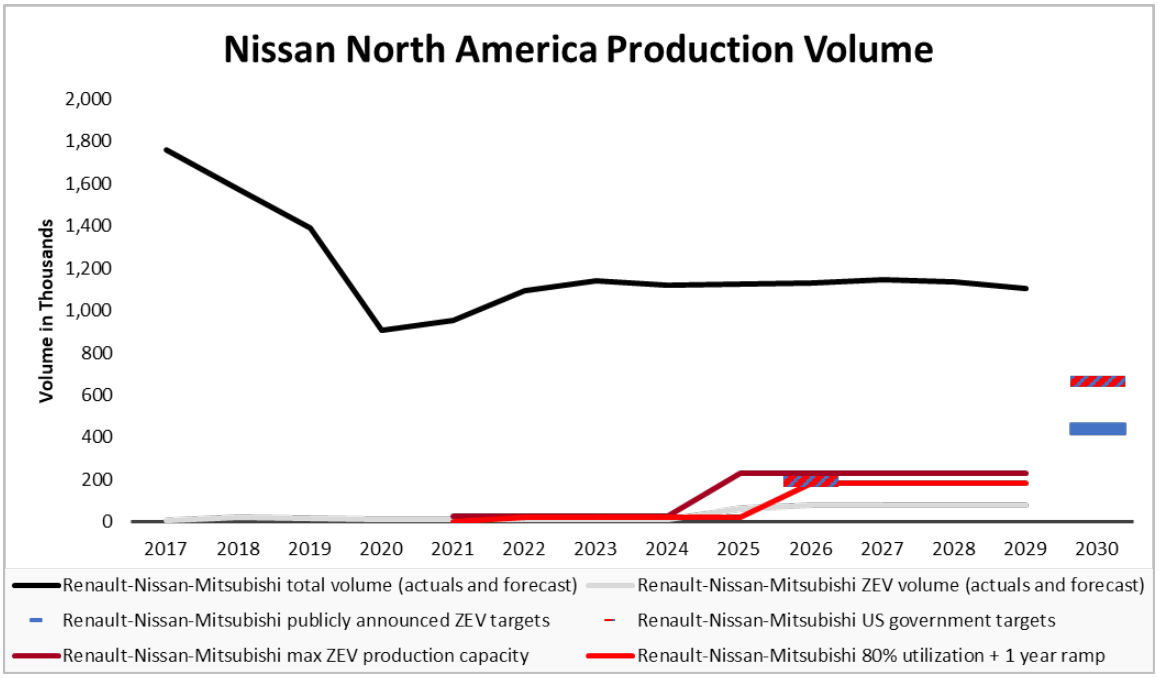
2. Committed capital expenditures towards ZEV expansion

    a. 2019: invested $30M for electric retrofit of one line in Marysville (OH) with 55k capacity[47]

    b. 2024: paying GM to use their factory capacity to build yet-to-be announced BEV (non-additive to total industry ZEV capacity)

3. Honda is publicly exploring a factory investment for 2027 low-cost ZEV, but capital has been committed yet.

    a. Honda has a 90% factory utilization rate over the last 8 years.



Nissan has set no interim ZEV targets before 2030 but is tracking to sufficient capacity to meet the 2025 federal target, with projected maximum production capacity of 230k ZEV units (21%) by 2025 based on committed capital expenditures.

1. Publicly announced ZEV targets

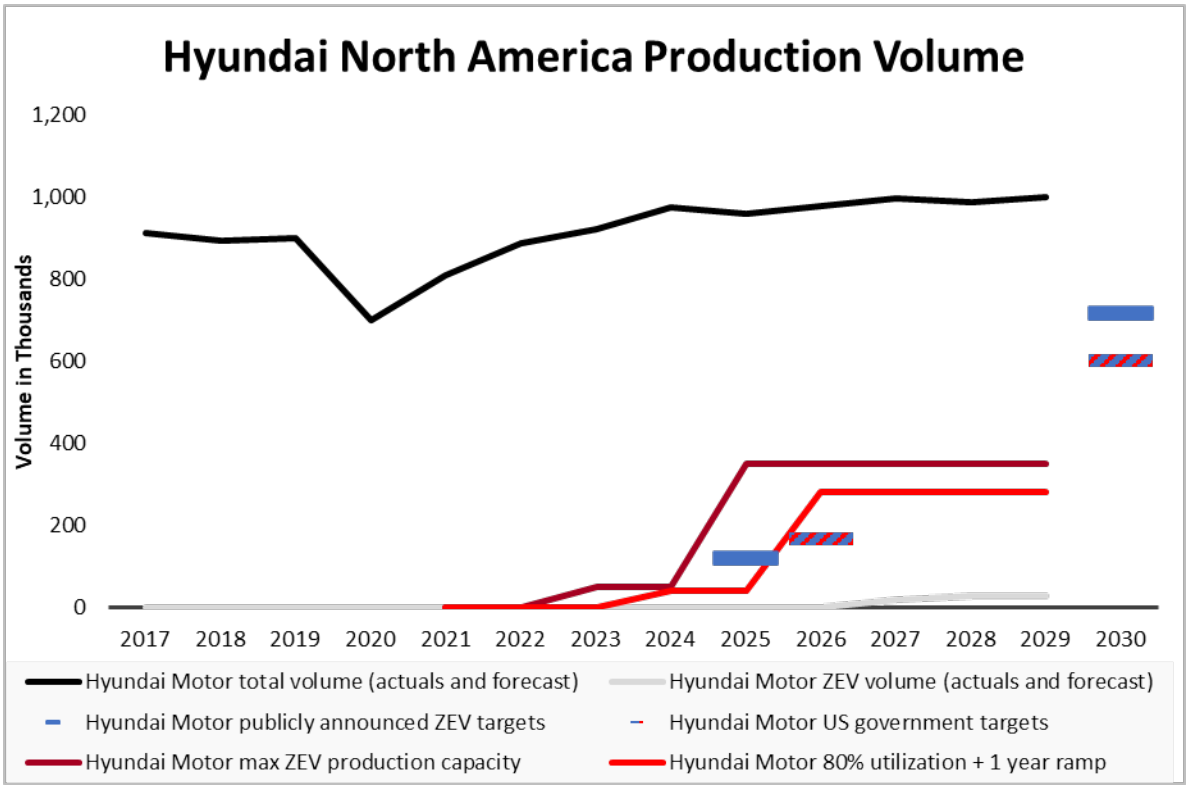
    a. 2030: 40%[48]

2. Committed capital expenditures towards ZEV expansion

    a. 2025: $500M to retool one of two assembly lines in Canton (MS) for 200k max capacity[49]

b. Nissan is already currently producing 25k ZEV units (Nissan Leaf) annually at Smyrna (TN) with no commitment to expand, yet.

c. Nissan has utilized 81% of its factory capacity over the last 8 years.

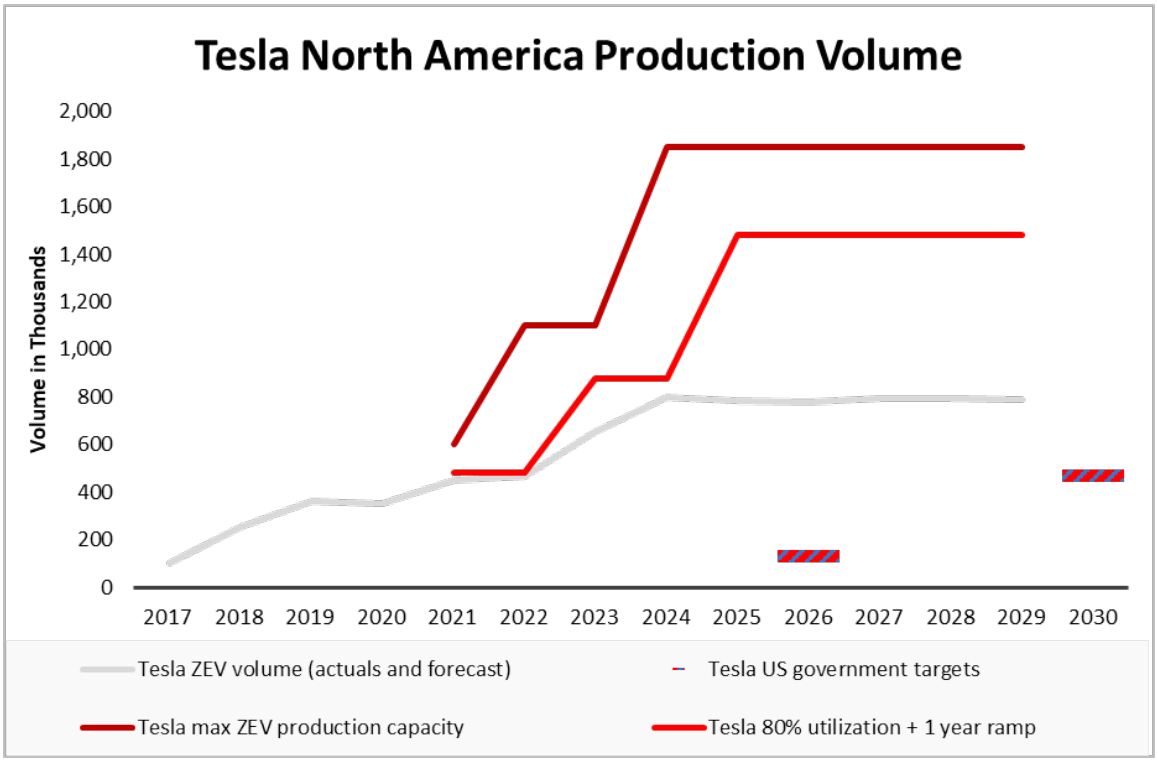


Hyundai is projected to have a maximum production capacity of 350k ZEV units (36%) by 2025 based on committed capital expenditures.

1. Publicly announced ZEV targets
    a. 2025: 12% (560k units globally)[50]
    b. 2030: 72% (3.2M units globally)[51]
2. Committed capital expenditures towards ZEV expansion
    a. 2023: $300M to add 50k units of ZEV capacity in Montgomery (AL) for Genesis brand[52]
    b. 2025: $5.5B to build 300k units of ZEV capacity and battery manufacturing in Bryan County (GA)[53]

3. Hyundai updated its 2030 target from 42% in March 2022 to 72% in May 2022, before the IRA passed.

4. Hyundai has utilized 88% of its factory capacity over the last 8 years.



Tesla, as a ZEV-only manufacturer, prioritizes growth in total volume over ZEV penetration, with maximum production capacity of 1.9M ZEV units (100%) by 2024 based on committed capital expenditures.

1. Publicly announced ZEV targets
    a. Soft guidance to global volume growth of 50% year-over-year in quarterly earnings call with 20M unit global annual capacity goal
2. Committed capital expenditures towards ZEV expansion
    a. 2021: Estimated $10B to develop 500k units of capacity in Austin (TX)[54]
    b. 2024: developing rumored 1M units of capacity in Monterrey (MX), though assuming 750k units in this analysis because no factory in the world produces 1M units and Tesla's largest to date (Shanghai) has 750k of capacity[55]

3. Tesla took approximately 10 years to ramp from first production ZEV in 2008 (Roadster) to high volume ZEV in 2018 (Model 3).
4. Tesla has utilized just 35% of its factory (all in Fremont) capacity during this ramp from zero to high volume production.
5. Tesla total volume is not shown because Tesla total volume = ZEV volume

Lower-volume OEMs not individually presented (Volkswagen, BMW, Subaru, Geely, and Mercedes-Benz).

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