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Class 3-8 Hybrid and Electric Vehicles Operating on North American Roads:

Supply Chain Assessment of Vehicles, Drive-Train Motors, Inverters, Converters and Batteries.

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Prepared for the US Department of Energy,
Office of Energy Efficiency and Renewable Energy,
Vehicle Technologies Office.

Approved for Public Release

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Review:

The information in this report has been developed based on an ongoing review by Synthesis Partners of structured and unstructured data from hundreds of anonymized, primary industry sources primarily during calendar year 2018, alongside thousands of secondary sources in 2018. Each primary source in particular is hereby acknowledged and thanked for their time and contributions to this effort. All errors and omissions remain the sole responsibility of Synthesis Partners.

To learn more about public information that is available about the sources and methods employed by Synthesis Partners in performing this and related research, please contact Mr. Christopher Whaling, P.I. at cwhaling@synthesispartners.com. Thank you.

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Table of Contents

Page No.

1.0 Introduction. ……………………………………………………………………………….......…..7

2.0 Relevant Prior Work. ………………………………………………………………….…8

3.0 Research Scope Details. ……………………………..…………………………….…9

4.0 Key Findings Regarding Class 3-8 HEV and PEV Counts. ….……..………………...11

4.1. Estimated Number of Class 3-8 HEV and PEVs Operating in North America (NA) in 2018. …………………………………………………………..………..11

4.2 Selected Component Suppliers For Whom Data Was Not Available at Time of Publication. ......………………………………………..…..19

5.0 Summary Gap Analysis. ……………………………..…………………..………………20

5.1 Selected Class 3-8 HEV and PEV NA Supply Chain Gap Analysis Conclusions. ………………………………………………………………………………………23

6.0 Selected Recommendations. ………………………………………………..……………..24

7.0 Selected Bibliography. ……………………………………………………………….....26

List of Figures, Tables, Charts and Diagrams

Page No.

Figure 1: Research Process to Assess Class 3-8 HEVs and PEVs on North American (NA) Roads and Their Suppliers. ……………………7

Figure 2: Types of Class 3-8 Vehicles. ……………………9

Figure 3: Statistics on Primary and Secondary Research. ……………………10

Chart 1: Estimated Number of Class 3-8 HEV and PEVs Operating in North America in 2018. ……………………11

Chart 2: Estimated Number of Class 3-8 HEV and PEVs Supplied, By Key Suppliers of Drive Train Components Operating in North America, as of 2018. ……………………12

Figure 4: Approximate Number of Class 3-8 HEV and PEV Trucks Operating on NA Roads in 2018, By Supplier. ……………………13

Figure 5: Approximate Number of Class 3-8 HEV and PEV Buses Operating on NA Roads in 2018, By Supplier. ……………………14

Figure 6: Approximate Number of Class 3-8 Up-Fitted or Converted HEV and PEVs Operating on NA Roads in 2018, By Supplier. ……………………15

Figure 7: Approximate Number of Class 3-8 HEV and PEVs Supplied By Motor Drive Suppliers Operating In NA, in 2018. …………………… 16

Figure 8: Approximate Number of Class 3-8 HEV and PEVs Supplied by Traction Drive Inverter and Converter Suppliers Operating in NA, in 2018. ……………………17

Figure 9: Approximate Number of Class 3-8 HEV and PEVs Supplied by Battery Suppliers Operating in NA, in 2018. ……………………18

Chart 3: Frequency of NA Class 3-8 HEV and PEV Supply Chain Gap Statements, By Main Topic: 2013 to Present. ……………………21

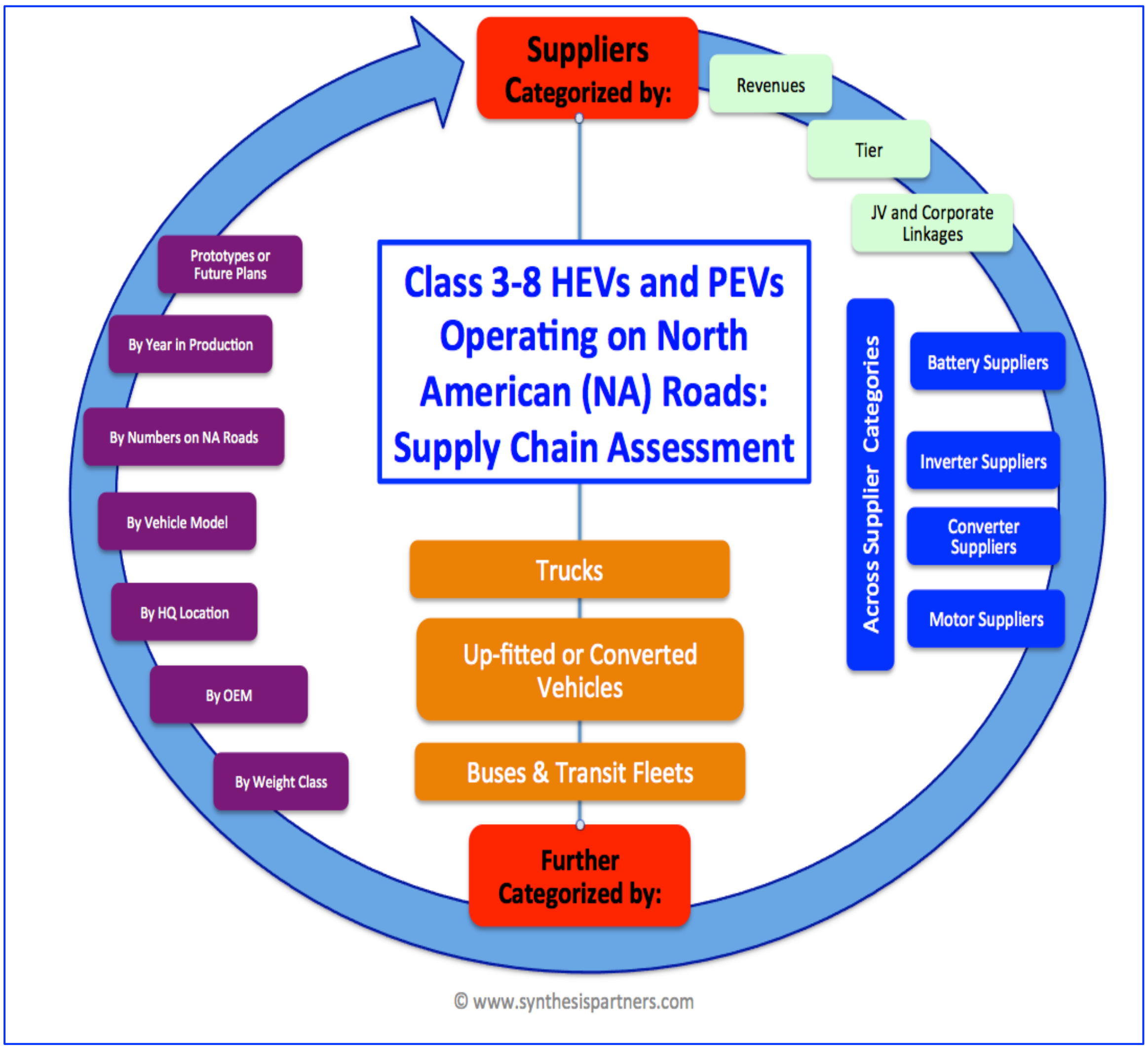
Figure 10: Drill Down Analysis of Gap Statements, By Top-Level Categories and Sub-Topic Frequency: 2013-July 30, 2018. ……………………22

1.0 Introduction

This report covers work completed by Synthesis Partners, LLC ("Synthesis") for the Department of Energy's Vehicle Technologies Office (VTO) under contract number DE-DT0006388, during fiscal year (FY) 2018.

As shown in Figure 1, this work assessed the number and type of Class 3-8 (medium- and heavy-duty) HEV and PEVs on North American (NA) roads, including analyzing information on the suppliers of traction drive inverters, converters, motors and batteries for Class 3-8 HEV and PEV vehicles operating on NA roads. VTO approved the work-plan that guided this work on 28 November 2017 and the collection phase of the work was completed on July 30, 2018.

Figure 1: Research Process to Assess Class 3-8 HEVs and PEVs on North American Roads and Their Suppliers.



As depicted in Figure 1, Synthesis executed integrated primary and secondary source research across thousands of English-language sources to develop a baseline for the most recent calendar year, of quantitative and qualitative data, on:

a) Number, make, model, manufacturer of Class 3-8 HEV & PEV commercial vehicles on the road in North America (NA: U.S., Canada, Mexico) for the most recent full year public data is available;

b) For the population of vehicles identified, for the same year, identify the suppliers of drive-train inverters, converters, motors, and batteries (which can include cells); and

c) Rank suppliers identified by revenue and numbers of units shipped (as publicly available, or reasonably inferred).

In addition, Synthesis employed the information and insights obtained in addressing the above questions to identify gaps, constraints and bottlenecks in the NA supply chain for traction drive components for Class 3-8 HEV and PEVs. This report provides a summary of information, which is the information that can be made publicly available from this work effort.

2.0 Relevant Prior Work

Synthesis performs targeted research to help inform VTO research and development (R&D) decision-making about critical technology bottlenecks, gaps or constraints in the US industrial base and supply chains. A gap is defined as a constraint or bottleneck that limits the growth of (e.g.) Class 3-8 HEV and PEV growth in NA – and which is based on factors that are largely under the control of R&D organizations (internal factors). For example, a gap may be a technology performance limitation or an engineering design issue that prevents needed technology from being available in a certain size, weight, cost and form factor. This report characterizes potential R&D gap topic areas that are relevant to the VTO's mission of energy affordability, efficiency and resiliency, and that can provide a path toward transitioning VTO R&D work into high-quality US-based jobs.

This research product builds directly on prior supply chain analyses by Synthesis. For example, during FY16 Synthesis assessed US export sectors relevant to electrical engineering in the automotive industry, in terms of relative size (by sales) and growth rates, in order to identify high strength or competitive US sectors. The top-ranked sectors identified are home to some of the most highly competitive and innovative US-based firms. These sectors were then reviewed to identify and assess potential new R&D areas, defined as technical areas in which the VTO has not previously engaged and where R&D investments could address a gap.

During FY17, Synthesis identified, characterized and prioritized gaps in current research activities in the field of autonomous and connected vehicles, focusing on:

- Light Detection and Ranging (LiDAR);
- Sensor system development; and
- Vehicle-to-vehicle (V2V) or vehicle-to-anywhere connectivity (V2X).

Synthesis specifically identified and characterized gaps in electric-drive, autonomous and connected vehicle technology that are promising VTO R&D areas, meaning that they were found to be:

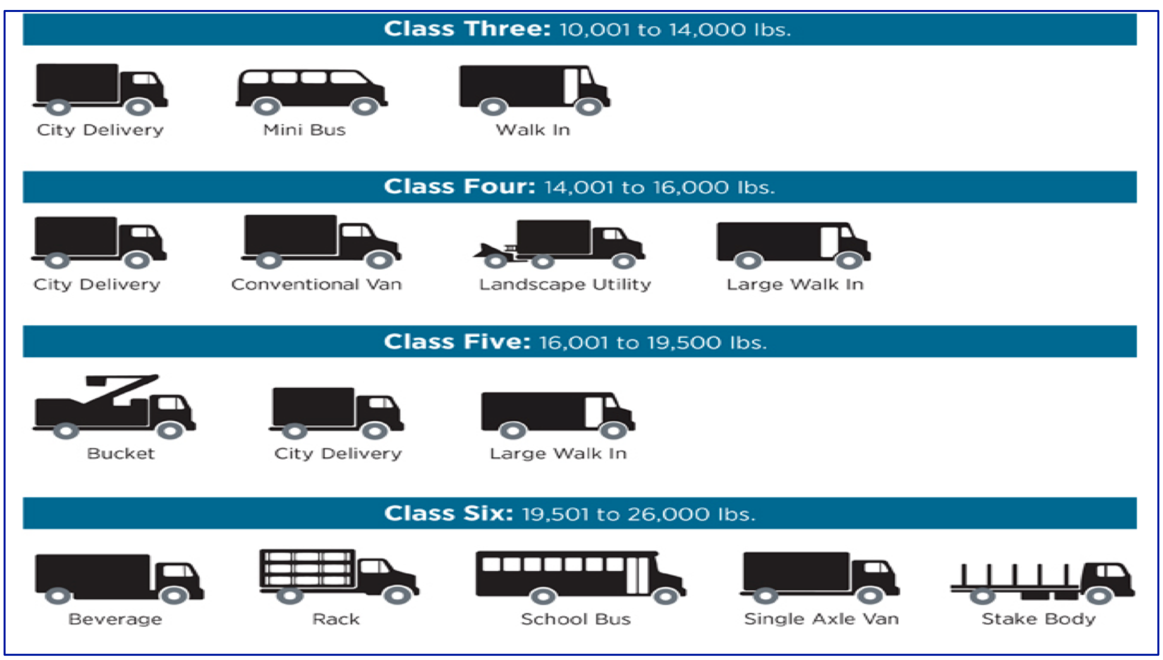
- Hardware-focused;
- US-based, or have the potential to be US-based and create US jobs;
- Could reach commercial vehicle markets in 5-10 years; and
- Has the capability to reduce costs, ideally by a significant (>50%) amount.

More details on the full range of reports regarding materials, component and vehicle supply chains that this research builds upon are available by contacting Mr. Christopher Whaling at cwhaling@synthesispartners.com.

3.0 Research Scope Details

Figure 2 depicts the types of vehicles (Class is determined by the gross vehicle weight rating (GVWR) of the vehicle) covered by this research.

Figure 2: Types of Class 3-8 Vehicles



Source: https://www.afdc.energy.gov/data/10381; Accessed 11/16/17.

Figure 3 provides a summary review of the sources accessed in FY18. The level of effort was executed to match the task requirements and results needed in the time available.

Figure 3: Statistics on Primary and Secondary Research

<table>
<tr><th>Source Details</th><th>Research Outcome Details</th></tr>
<tr><td>Secondary sources accessed February 2018 – July 2018.

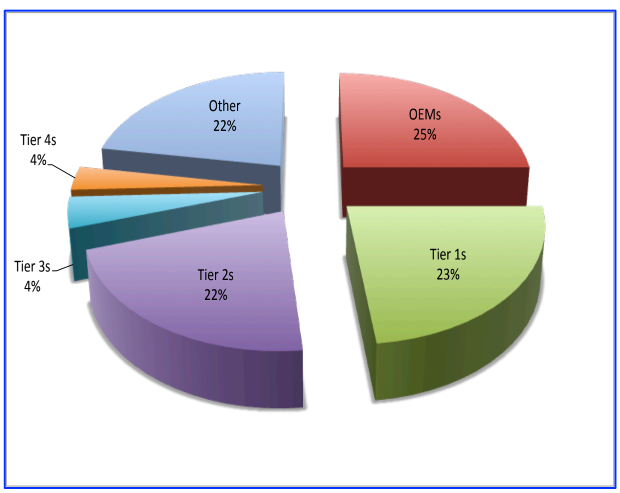
Approximately 1,600 websites, news articles, press releases and research papers were reviewed for original data and to identify the most appropriate primary, 3rd party market research and other organizational sources.</td><td>Prioritized search, along with a review of Synthesis' internal proprietary database of nearly 1,000 primary sources. Result: approximately 400 highly relevant companies, associations, laboratories or individuals were identified for close examination.

Nine (9) 3rd party market research reports were assessed in-depth and 17 organizations were identified as having valuable data for follow-up.</td></tr>
<tr><td>High-Relevance Contacts

Approximately 400 executive and other contacts were identified as highly relevant, including:
• Sr. Execs = 165
• Mid-Level Execs = 165
• Other (Researchers, State, Federal or Non-Profit) = 70
.</td><td>Approximately 900 unique, custom contacts made via telephone and email to the 400 high-relevance contacts.

From the telephone and email primary source contacts, 35 in-depth interviews were completed.

In addition, approximately 50 additional in-person conversations were executed during APEC 2018 in San Antonio.</td></tr>
<tr><td>Distribution of High-Relevance Contacts


</td><td>Distribution of high-relevance contacts:

• OEMs = 25%
• Tier 1 = 23%
• Tier 2 = 22%
• Tier 3 = 4%
• Tier 4 = 4%
• RD&E = 7%
• Other* = 22%

*Other includes: Academic, Associations, Consultants, Dealers, Distributors, Federal Government, Fleet Operators, Integrators, Investors, State and Local Government, Market Research Firms, Publications, RD&E Entities, Repair/Service Orgs. and Software Firms.</td></tr>
</table>

4.0 Key Findings Regarding Class 3-8 HEV and PEV Counts

4.1 Estimated Number of Class 3-8 HEV and PEVs Operating In North America in 2018

The following charts provide a summary of the quantitative data collected, which is now integrated into an original Class 3-8 NA database at Synthesis. We provide an assessment and ranking of the supply chain gaps identified by sources in the section that follows.

Chart 1: Estimated Number of Class 3-8 HEV and PEVs Operating in North America in 2018.

Type of Class 3-8 HEVs and PEVs:	Estimated Number in Operation in North America in 2018
Class 3-8 Trucks Only	11,909
Class 3-8 Buses and Transit Fleets Only	13,826
Class 3-8 Converted/Up-Fitted Vehicles Only	3,187
Sum Total: Class 3-8 HEV and PEVs Operating in North America	**28,922**

Chart 1 provides the first public, detailed estimate of the count of Class 3-8 HEV and PEV vehicles on the road in NA. This information represents an integration of market study information, primary source information, the Federal Transit Agency's (FTA) Revenue Vehicle Inventory database regarding Class 3-8 HEV and PEVs on the road in NA, and other source information. The Synthesis database includes information on each model of vehicle, including classes based on reported or inferred gross vehicle weight rating (GVWR).

The suppliers of motors, batteries, inverters and converters to Class 3-8 HEV and PEVs in NA did not provide information on the exact number of vehicles supplied that are operating in NA only. These same suppliers however did supply information on numbers of Class 3-8 HEV and PEVs supplied that are in operation *globally.* This data is summarized in Chart 2 below. This information is provided for readers to review and extend. Please note that Chart 2 is not intended to provide an accurate count of all Class 3-8 HEV and PEVs in operation globally, as the global market was expressly not the focus of this study.

Chart 2 below provides one view on the estimated global scale of the motor, inverter, converter and battery Class 3-8 markets, of which NA is a large part.

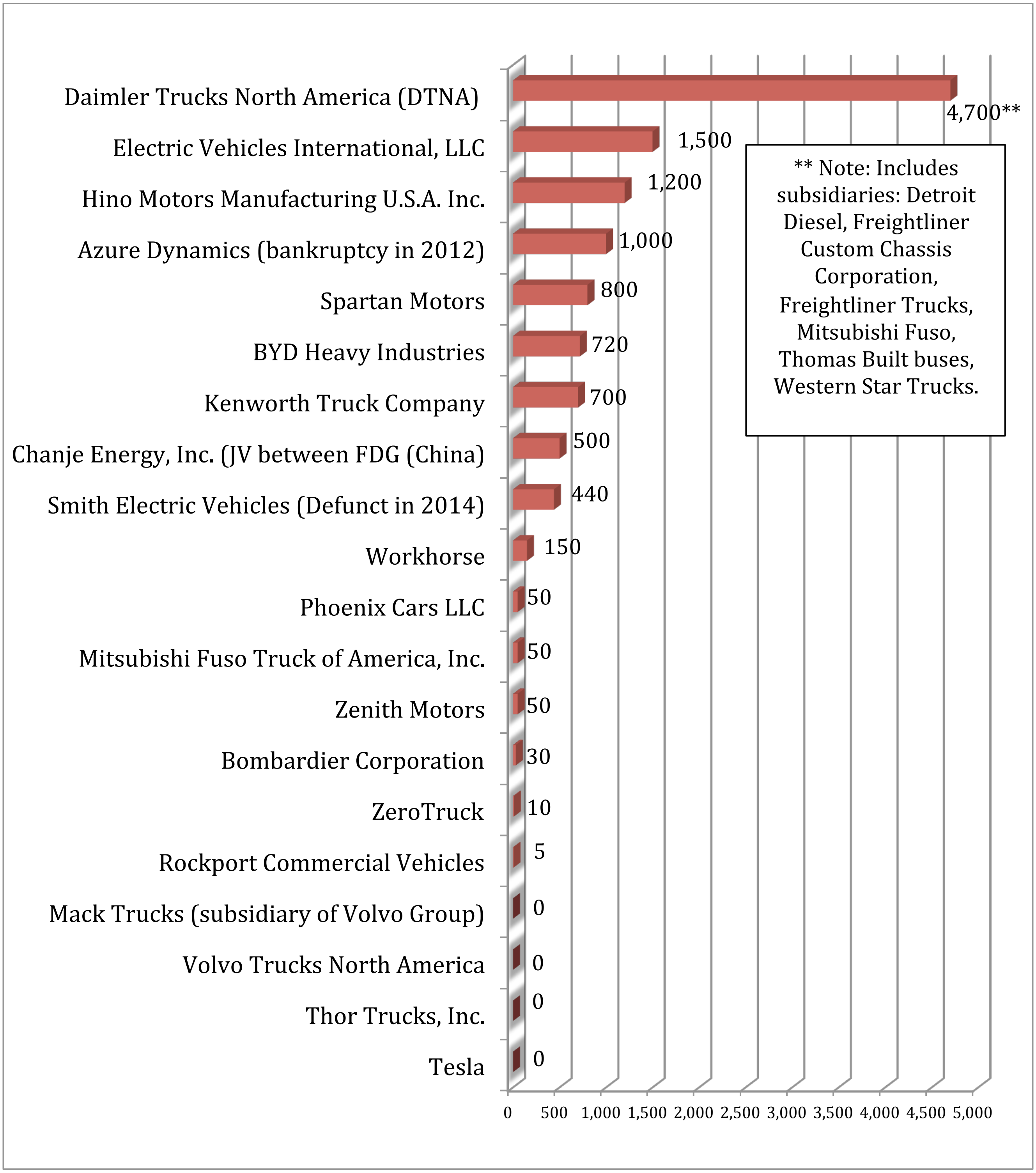
Chart 2: Estimated Number of Class 3-8 HEV and PEVs Supplied, By Key Suppliers of Drive Train Components Operating in North America, as of 2018.

Class 3-8 HEV and PEV Drive Train Component Suppliers Operating in NA.	Estimated Number of Class 3-8 HEV and PEVs Supplied, By Selected Drive-Train Component Suppliers Operating in NA, as of 2018.
Motor System Suppliers	47,406
Drive Train Inverter and Converter Suppliers	38,071
Battery Suppliers	32,381
Average Number of Vehicles Supplied in 2018, Across Above Component Suppliers	**39,286**

Given the scope of this research, not every vehicle that is supplied by a motor, inverter or battery supplier is confirmed to be operating on the road, nor may be a unique vehicle. Chart 2 provides the most recent information obtained by Synthesis during this work depicting relative size of the global Class 3-8 HEV and PEV market from a component supplier's point of view.

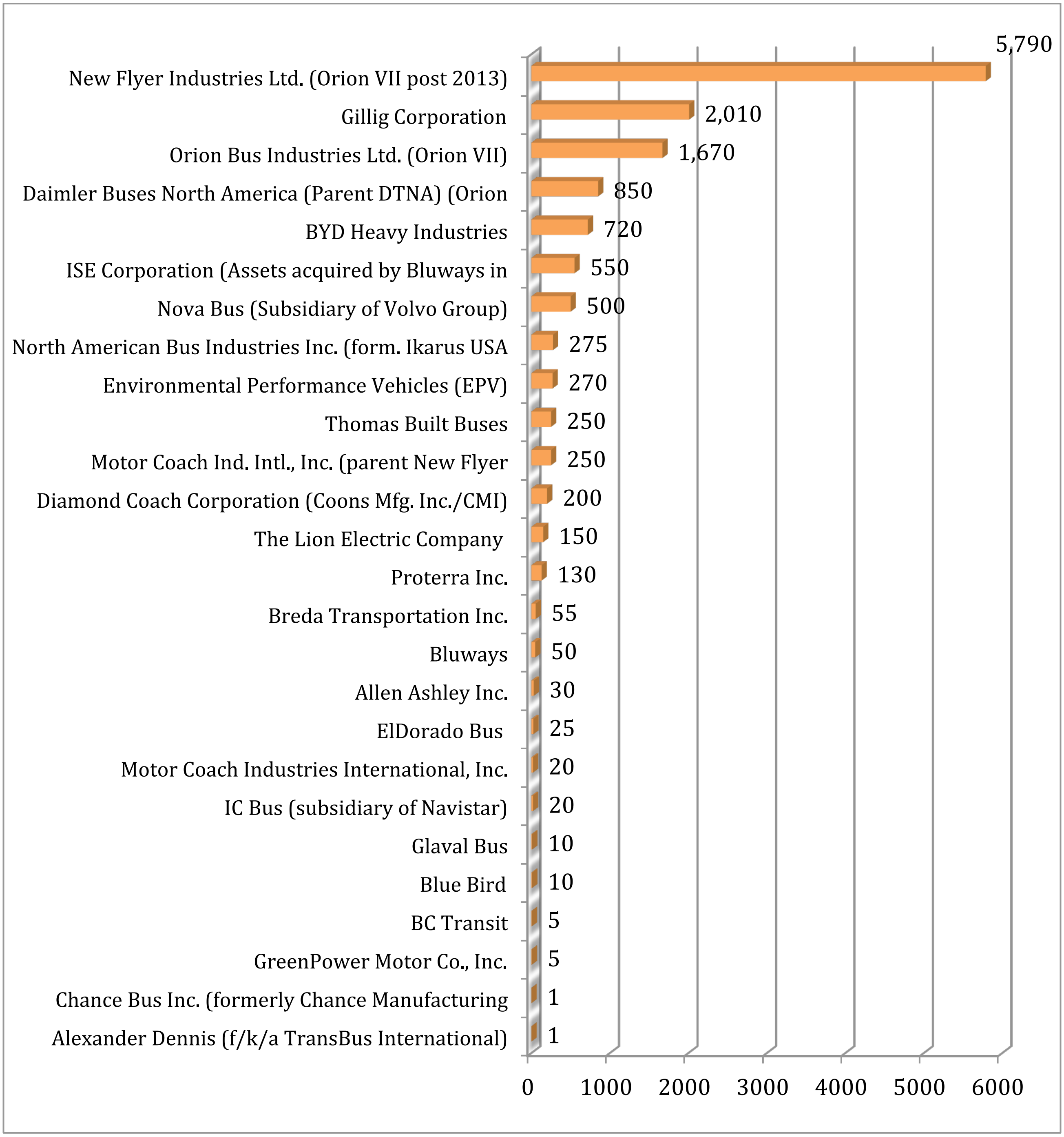
The next series of Figures depict the number of HEV and PEVs in operation in *NA*, by type of vehicle (e.g., by Truck, Bus or Fleet Vehicle, or Up-fitted vehicle class) and by main component supplier (e.g., by Motor, Inverter and Converter, or Battery supplier). Additional information on each supplier and vehicle counted is contained in the Synthesis Class 3-8 HEV and PEV database.

Figure 4: Approximate Number of Class 3-8 HEV and PEV Trucks Operating on NA Roads in 2018, By Supplier.



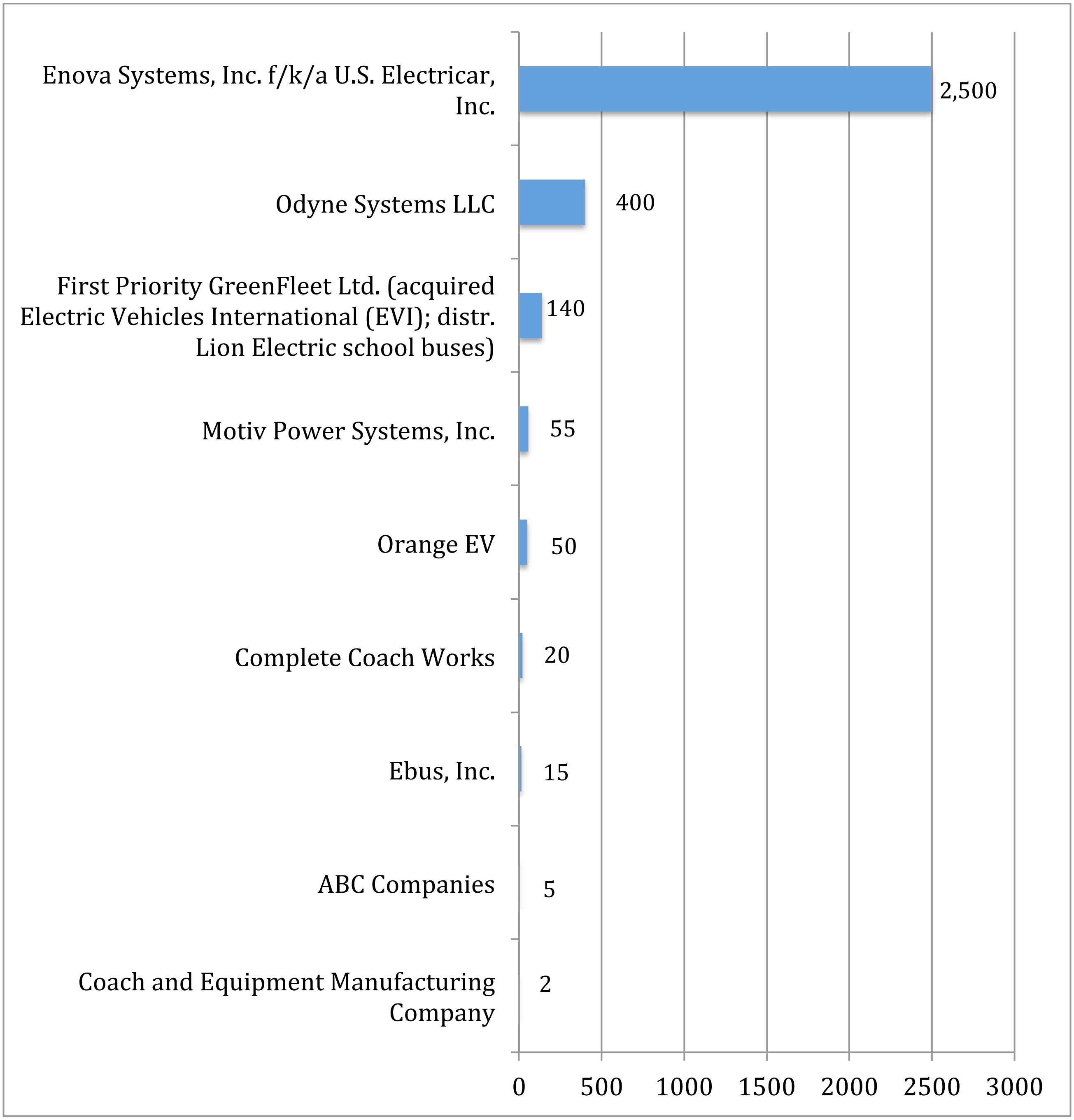
Sum Total: The sum total number of Class 3-8 HEV or PEV trucks in operation in NA in 2018 was estimated at 11,909.

Figure 5: Approximate Number of Class 3-8 HEV and PEV Buses Operating on NA Roads in 2018, By Supplier.



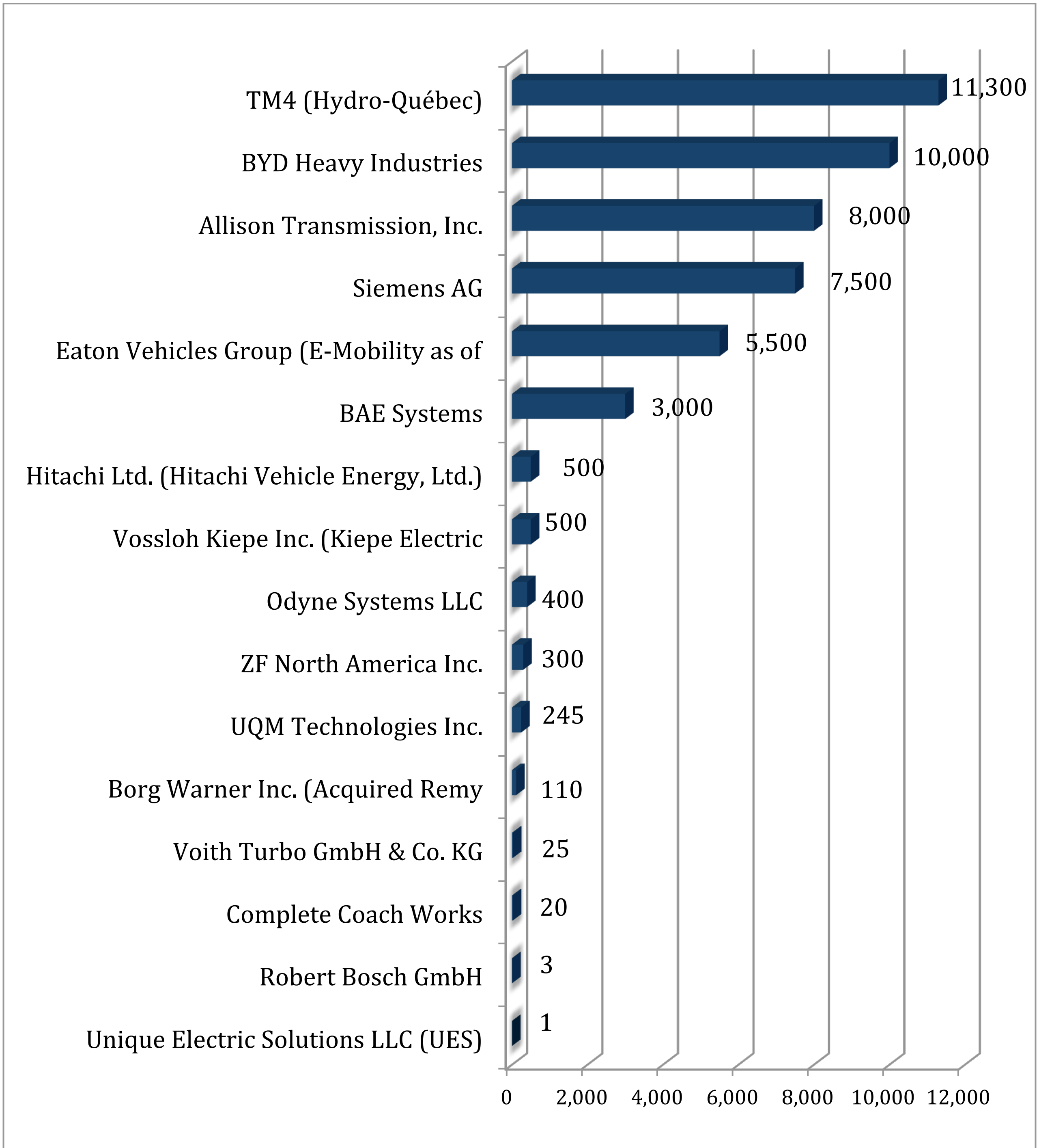
Sum Total: The sum total number of Class 3-8 HEV or PEV buses in operation in NA in 2018 was estimated at 13,826.

Figure 6: Approximate Number of Class 3-8 Up-Fitted or Converted HEV and PEVs Operating on NA Roads in 2018, By Supplier.



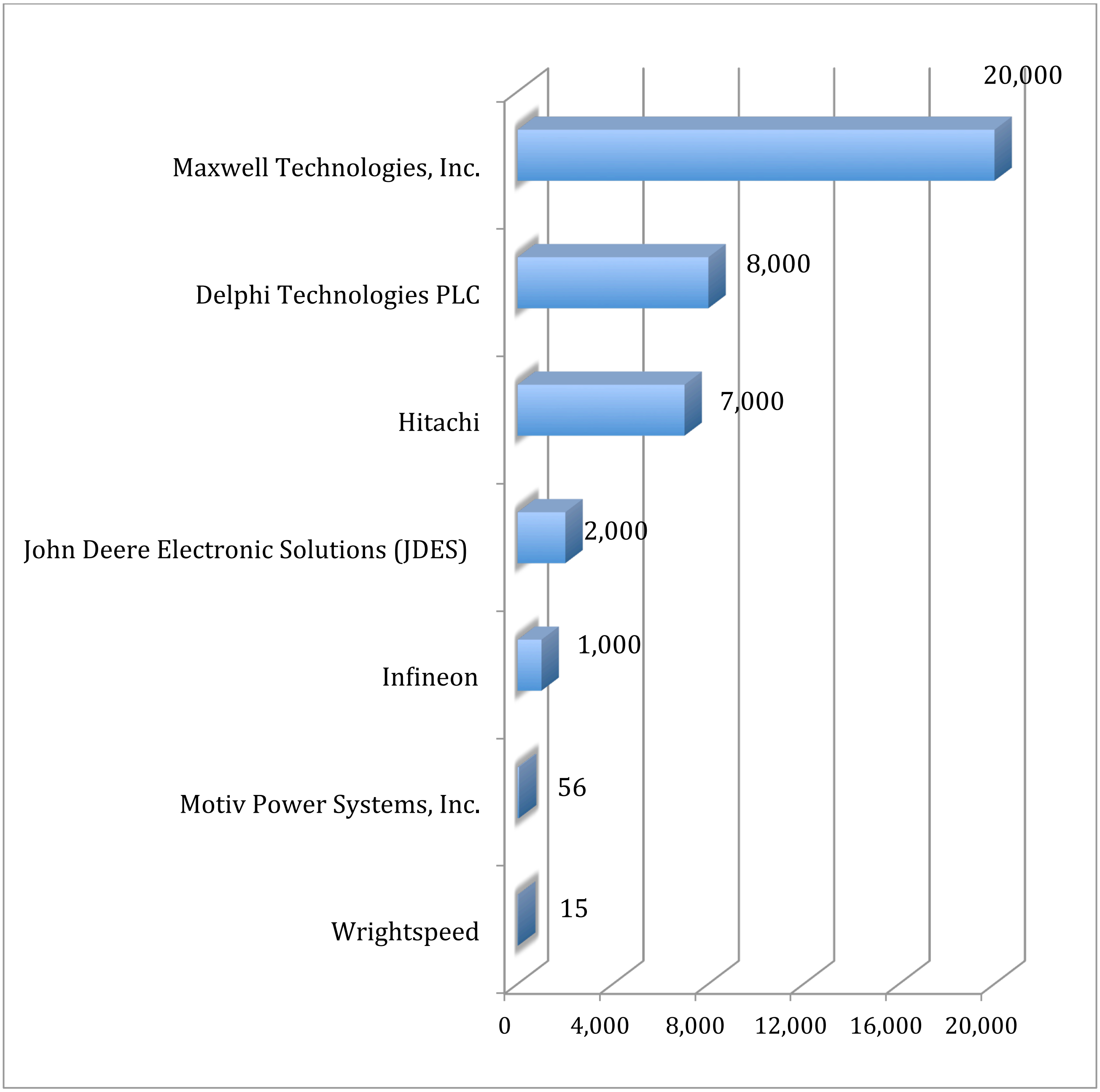
Sum Total: The sum total number of Class 3-8 HEV or PEV converted vehicles in operation in NA in 2018 was estimated at 3,187.

Figure 7: Approximate Number of Class 3-8 HEV and PEVs Supplied By Motor Drive Suppliers Operating In NA, in 2018.



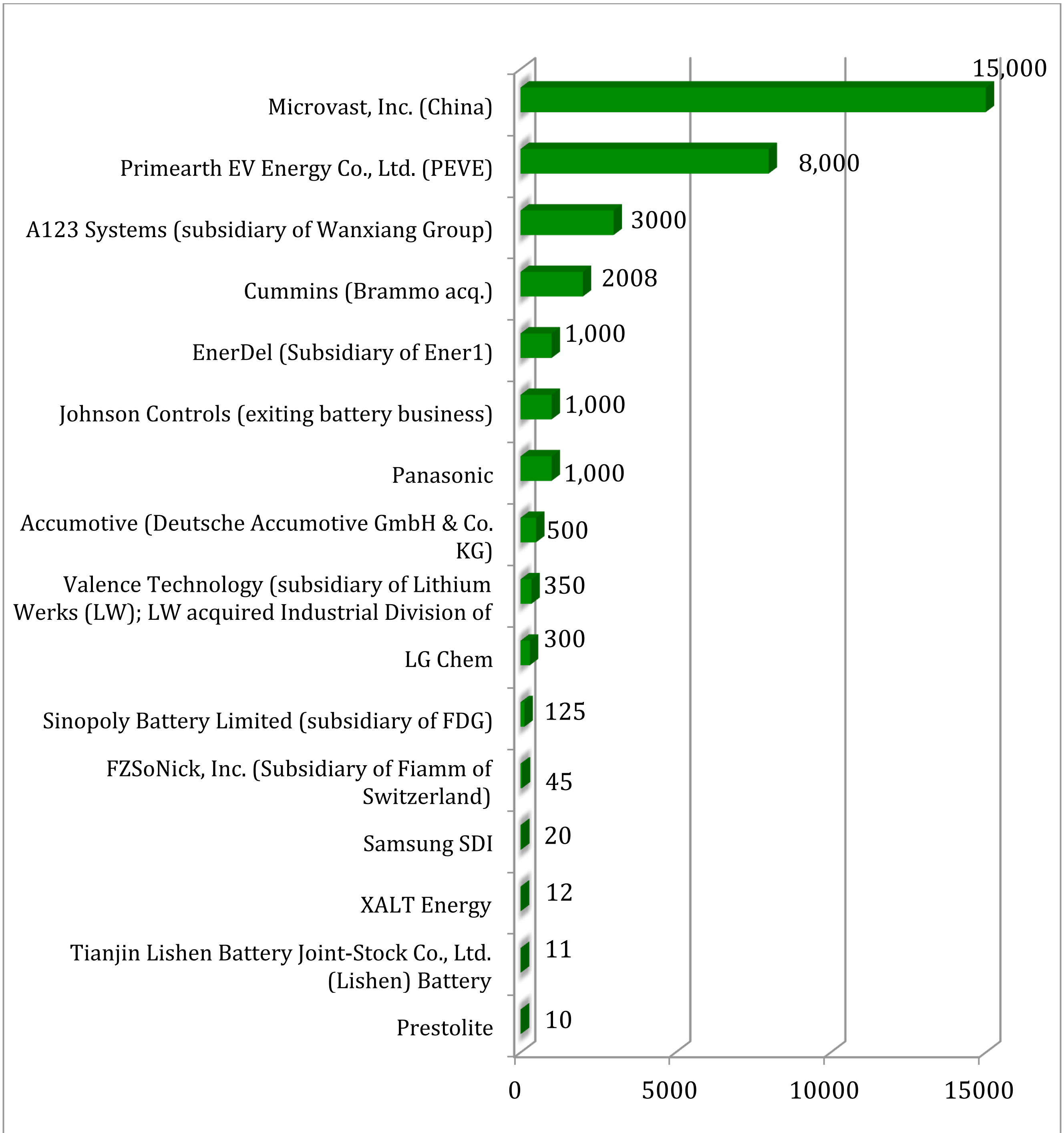
Sum Total: The sum total number of Class 3-8 HEV or PEVs in operation globally in 2018, which are supplied by the listed motor drive suppliers, was estimated at 47,406.

Figure 8: Approximate Number of Class 3-8 HEV and PEVs Supplied by Traction Drive Inverter and Converter Suppliers Operating in NA, in 2018.



Sum Total: The sum total number of Class 3-8 HEV or PEVs in operation globally in 2018, which are supplied by the listed traction drive inverter and converter suppliers, was estimated at 38,071.

Figure 9: Approximate Number of Class 3-8 HEV and PEVs Supplied by Battery Suppliers Operating in NA, in 2018.



Sum Total: The sum total number of Class 3-8 HEV or PEVs in operation globally in 2018, which are supplied by the listed battery suppliers, was estimated at 32,381.

In conclusion, based on just this NA-based research (focusing on key suppliers in operation in NA), the suppliers of critical components to the Class 3-8 HEV and PEV fleet supply somewhere between 32,381 and 47,406 Class 3-8 HEV and PEVs. The average estimate of total number of Class 3-8 HEV and PEVs supplied by the listed component suppliers is 39,286.

4.2 Selected Component Suppliers For Whom Data Was Not Available at Time of Publication.

Not all suppliers provided information at the time of publication. The following suppliers are highlighted because they did not provide any or sufficient information on their role in the supply chain, but they should be included in any comprehensive list of companies that may be part of the Class 3-8 HEV and PEV supply chain in NA. Specifically, public information that Synthesis could independently validate was not available at the time of publication from the following selected, potential Class 3-8 HEV and PEV suppliers.

Inverter or Converter Suppliers:
- TDK-EPC Corporation (Tokyo, Japan)
- Mitsubishi Electric US, Inc. (Cypress, CA)
- ABC Companies (Faribault, MN)
- US Hybrid Corp. (Torrance, CA)
- EPC Power (Poway, CA)

Battery Suppliers:
- Automotive Energy Supply Corp. (AESC) (Zama City, Kanagawa Prefecture, Japan) (Note: AESC was to be acquired by Chinese private equity firm GSR Capital in August 2017, but deal was stopped in July 2018 by Nissan.)
- Hitachi Vehicle Energy, Ltd. (Hitachi-naka City, Ibaraki Prefecture, Japan)
- BASF (Ludwigshafen, Germany; (Florham Park, NJ (main US HQ))
- Contemporary Amperex Technology (CATL)
- Saft Group S.A. (Levallois-Perret, France)
- JD Power Co. Ltd. (New Taipei City, Taiwan)
- Altair Nano (moved mfg. to China in 2013) (Reno, NV)
- FDG Electric Vehicles Ltd. (China) (Hong Kong and Hangzhou, China) (Note: Chanje is U.S. sales subsidiary.)

The above list of selected component suppliers may not be inclusive.

5.0 Summary Gap Analysis

This section summarizes the results of an analysis of 100s of expert source statements about gaps relevant to the Class 3-8 HEV and PEV NA supply chain developed through interviews by Synthesis from 2013 through July 2018.

The 2013 starting date range is selected in order to avoid single-year bias as well as to employ the broadest base possible for a quantitative view on the underlying in-depth qualitative market research.

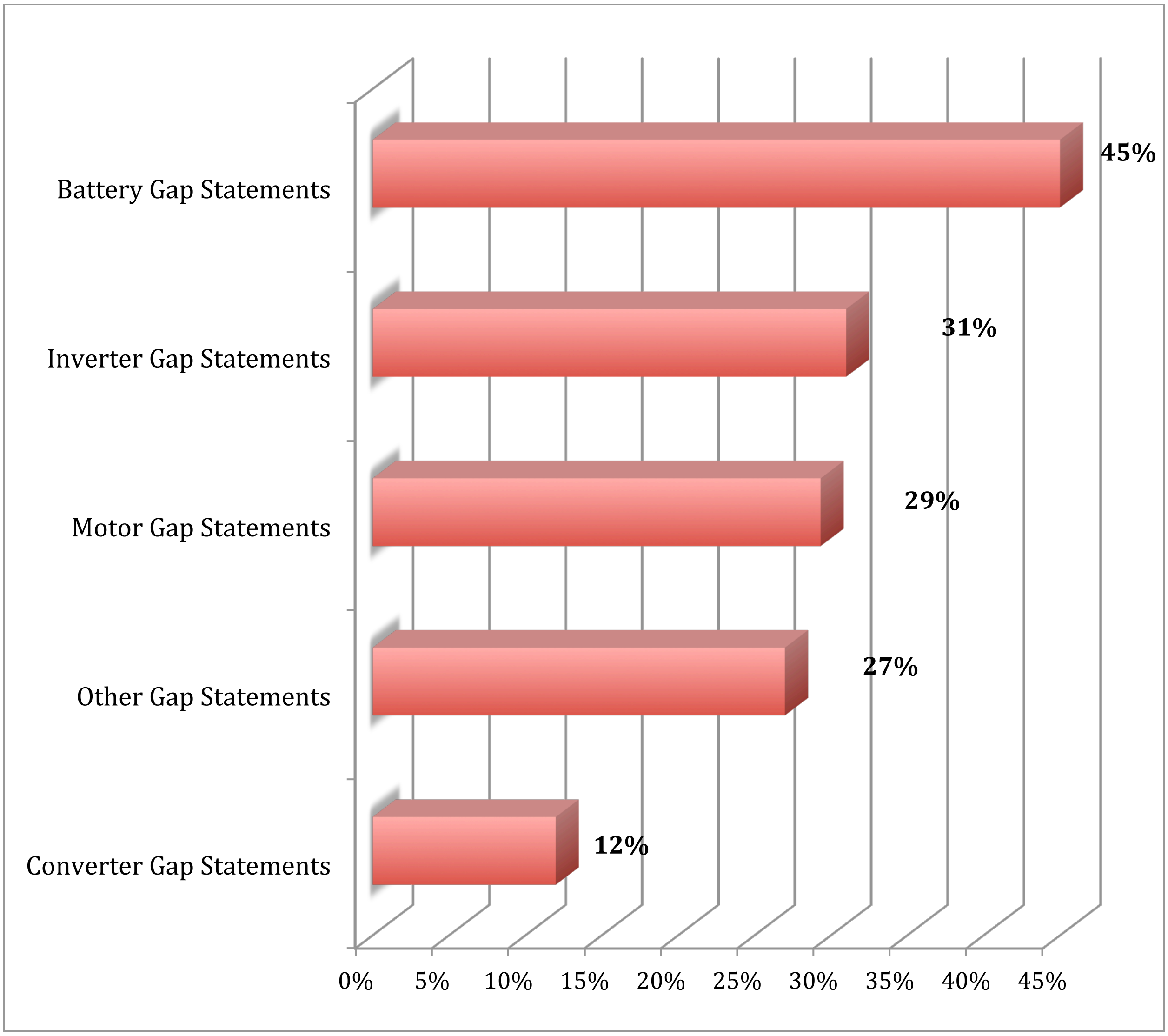
Chart 3 below depicts the distribution of gap statements obtained from 100s of open-ended conversations with sources from 2013 through July 2018.

A few caveats in interpreting the data in Chart 3: a) double counting occurs because individual gap statements by sources may cover more than a single category; and b) the percentages add up to more than 100% because gap statements can cover more than a single category.

Synthesis has endeavored to ensure every source statement about a supply chain concern or gap is represented in every category that it is relevant to. Statements by sources were not forced to fit into any pre-set categories, but rather were applied to as many relevant categories as considered reasonable.

Additional information regarding Synthesis' in-depth interviews, communications with sources and corresponding gap research is available for VTO use, consistent with source confidentiality agreements.

Chart 3: Frequency of NA Class 3-8 HEV and PEV Supply Chain Gap Statements, By Main Topic: 2013 to Present.



Based on frequency of occurrence, Batteries represent the most important category of gaps, followed by topics that are essentially equal based on frequency of occurrence: Inverters, Motors and "Other" gap statements.

The "Other" category addresses gap statements about manufacturability, public incentives and subsidies, regulation, standards, costs, materials and software (among other topics).

A further assessment of the gap statements is provided in Figure 10. It shows how each main gap category includes several sub-topics, which are raised by sources with varying frequency. Figure 10 is the basis of the summary conclusions reported on gaps in the NA Class 3-8 HEV and PEV supply chain.

Figure 10: Drill Down Analysis of Gap Statements, By Top-Level Categories and Sub-Topic Frequency: 2013-July 30, 2018*.

Battery gap statement analysis, by highest to lowest frequency sub-topic:

- 51 relate to Other;
- 41 relate to Engineering;
- 37 relate to Costs;
- 25 relate to Materials;
- 17 relate to Standards; and
- 6 relate to Software.

Motor gap statement analysis, by highest to lowest frequency sub-topic:

- 19 relate to Engineering;
- 17 relate to Costs;
- 15 relate to Other;
- 7 relate to Standards;
- 6 relate to Materials; and
- 6 relate to Software.

Inverter gap statement analysis, by highest to lowest frequency sub-topic:

- 27 relate to Other;
- 13 relate to Engineering;
- 8 relate to Costs;
- 8 relate to Standards;
- 7 relate to Software; and
- 2 relate to Materials.

Converter gap statement analysis, by highest to lowest frequency sub-topic:

- 10 relate to Engineering;
- 10 relate to Other;
- 6 relate to Standards;
- 5 relate to Software;
- 4 relate to Costs; and
- 0 relate to Materials.

* See Notes below.

Figure 10 Notes:

- Gap statements can refer to information about several gaps in one statement.
- Quantification of gap statements is only approximate and can be different depending on the analyst that analyzes the gaps.
- Synthesis used two analysts to review all gap statements for relevance and type, and integrated the results to produce findings here.
- The “Other” sub-topic includes discussion of public incentives and subsidies, regulation and other cross-disciplinary topics.

5.1 Selected Class 3-8 HEV and PEV NA Supply Chain Gap Analysis Conclusions.

The following findings are considered to be plausible based on the comprehensive gap statement data reviewed during this work. Synthesis analysts based these conclusions on qualitative judgments of the underlying quantified data.

Specifically, the analysis below is based on the understanding that significance of gaps can be valued based on frequency of source statements. This does not mean that individual, low frequency gap statements were not given careful consideration. In certain contexts, the significance of less frequently occurring gap statements can be high. Synthesis analysts weighed all of the information collected about every gap statement (e.g., including source, context, specificity, timing, relevance to other gaps) in order to reach a reasonable and approximately accurate result as outlined below.

Findings:

1) Batteries appear to be the most important field of gaps in the Class 3-8 HEV and PEV NA supply chain.

2) After Batteries, the next priority category of gaps includes Inverter, Motor and Other Gap statements. These three fields of gap statements appear to be similar in significance based on frequency.

3) Converter gap statements emerge as the least significant in terms of frequency of occurrence.

4) Drilling down within the Battery gap category, one finds that the majority of concerns or gap statements relate to “Other.” To help clarify “Other” gap statements include statements such as:
    a. “Lithium-ion manufacturing continues to be based on the same equipment used originally for the manufacture of cassette tapes”;
    b. "Battery plants are of much greater scale, depressing prices ever further”; and
    c. "Engineering and infrastructure firms need to be given significant roles in innovating solutions."

5) Across all major components – Batteries, Motors, Inverters and Converters – the existence of many "Other" gap statements reflects the diffuse and deep range of gap topics and suggests the need for more attention on such "Other" statements to help define, develop and execute a proactive and strategic response.

6) Materials represent an important category of gaps in Batteries and reflect the ongoing need for fundamental materials science for better catalysts and electrolytes.

7) Across Batteries, Motors, and Inverters, the core question of how to engineer solutions that maximize performance at competitive costs remains the topic of most general concern. This is reflected in the data that shows across all main topic areas except Converters, the Engineering and Cost gap topics are represented with highest or near-highest frequency.

8) In Motors, Inverters and Converters, the least important topics are Standards, Software and Materials. This suggests that with regard to HEV and PEV Class 3-8 suppliers of Motors, Inverters and Converters, the first priority gaps they are addressing relate to Engineering, Costs and/or Other topics.

9) Finally, in Batteries the role of Standards is considered a worthy area of attention as a gap, though certainly not as significant as Engineering, Costs, Materials and Other areas in the battery development domain.

Synthesis has found there to be many sources ready to voice concrete, pragmatic concerns as gap statements. The opportunity going forward is to quickly produce actionable supply chain intelligence based on new, current or related sources, especially if narrowly defined sub-topics within gaps are determined to be of high significance.

6.0 Selected Recommendations

This work produced a new baseline of publicly available quantitative and qualitative information regarding the NA supply chain for Class 3-8 HEV and PEVs on the road in NA. The research also provided a comprehensive view about gaps of concern to participants in the Class 3-8 HEV and PEV NA supply chain.

Based on this research, several recommendations emerge and are placed below for discussion.

1) Refine and improve the data presented. For example, it is understood that Class 2 HEV and PEVs represent a class that is larger than Class 3-8 HEV and PEVs combined, and is therefore a gap in the current research and an important topic for future research and study.

2) Determine whether the detailed information on Class 3-8 HEV and PEV usage provided here should be updated and refined each year, and further transformed into a user-accessible database.

3) Extend the current data sets to wider geographic regions, or link it to other data sets of special value, for example in power electronics R&D, battery or motor component supply chain developments, or other fields – to efficiently and effectively produce added value.

4) Leverage the data sets produced here to analyze topics of public policy significance, which are dependent both upon the Class 3-8 HEV and PEV supply chain conditions and other concrete (technological) aspects in NA mobility competitiveness. For example, further study on questions regarding: a) autonomous mobility in logistics employing Class 3-8 HEV and PEV systems; b) acceleration of Class 3-8 HEV and PEV battery development to make US mobility energy storage markets more competitive, and c) new materials for low-cost light-weighting of Class 3-8 HEV and PEVs specifically.

5) Leverage the source relationships developed through this work to continue to identify and rapidly develop awareness about emerging weaknesses and strengths within the NA supply chain.

6) Seek new, broad R&D pathways to support next-generation medium- and heavy-duty HEV and PEV vehicle growth, with a focus on building resilience and capacity for technology innovation in the US supply chain.

7) Map NA supply chain gaps across mobility categories, to include passenger vehicle, light duty, medium- and heavy duty commercial, rail, off-road and marine transportation elements, and seek out common hardware components, technology processes and materials that are needed across these categories to support transformational logistics.

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