North American Supply Chain for Traction Drive Motors and PE

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EDT032
For delivery Tuesday, June 7, 2016, 11:00AM at
US Department of Energy's Annual Merit Review (AMR) meetings.

Note: Nothing stated in this brief is an official viewpoint of the US Department of Energy or any other official US government entity.

Overview

1. This work is driven by DOE-VTO requirements, focusing on technical gaps in and R&D challenges facing the North American (NA) supply chain for traction drive power electronics (PE) and motors.

2. This work reflects five-plus years' work, including 100s of in-depth interviews, 1,000s of English and selected foreign language sources, technology-focused company case studies, numerous technical trend analyses and manufacturing cost assessments.

3. This presentation covers selected findings from our most recent public reports.

Core Questions We Address

- What core competencies are missing from the North American (NA) PE and motor supply chains?
- What might catalyze technology creation and job growth in the NA PE and motor supply chains?
- Is the NA technology supply chain prepared to support a significant increase in demand for advanced traction drive power electronics (PE) and motors? Why or why not?
- What specific R&D support may be helpful to accelerate development of the NA PE and motor supply chains?
- What specific manufacturing support may be helpful to accelerate development of NA PE and motor supply chains?

Our NA Supply Chain Intelligence Process

Public and Private NA Supply Chain Data*

- Private data employed:
  - Synthesis Partners' (SP) archive of 100s of interviews (2012-2016)
  - SP global network of experts.
  - SP network of industry sources (>330 companies).
  - SP company-data and market datasets.
  - Commercially available data-bases, extended and refined by SP.
- Public data employed:
  - Company annual reports and public filings.
  - Public market studies and literature.
  - Internet search (English, Chinese and Japanese).
  - Conferences and seminars.
  - Federal, state and local data-sets.

*This work has been underway for five years under DOE-VTO sponsorship.

Sources We Access and Work With

SP executes in-depth interviews with many types of supply chain organizations:

- Top global automotive OEMs
- 50s of global automotive Tier 1s
- 100s of automotive and related Tier 2-4s
- Universities and non-profit research organizations
- DOE National Labs (ORNL, NREL, Argonne, PNNL)
- USCAR Electrical and Electronics Tech Team (EETT)
- DOE and other USG executives
- Foreign experts and sources

Sample for illustration only:

Have we spoken to you? If not, please contact Chris Whaling at cwhaling@synthesispartners.

Diving into the Data

The following is an overview of our findings. Please see our most recent reports:

- NA Motors Supply Chain Analysis (March 2016)
- NA PE and Motors Supply Chain Assessment (January 2015)
- Review of Public Data on Costs of WBG Substrate Manufacturing (February 2015)

- *… and more than ten others since 2009.*

NA Motor* Supply Chain

Selection of organizations active in North America, provided for illustrative purposes only.

AC Propulsion Inc.
AK Steel Corp.
Apple, Inc.
Arnold Magnetic Technologies Corp.
BAIC Motor
BorgWarner, Inc.
BYD America Corp.
Continental Automotive Systems US, Inc.
Eurotranciatura USA LLC
Faraday Future
Fiat Chrysler Automobiles
Ford Motor Co.
GE Global Research
General Motors
Hitachi Automotive Systems America, Inc.
Hitachi Metals North Carolina, Ltd.
JFE Steel America, Inc.
Kienle+Spiess
Magna International of America, Inc.
Nippon Steel & Sumitomo Metal USA, Inc.
Nissan North America
Remy International, Inc.
Robert Bosch LLC
Superior Essex Inc.
TDK Ferrites Corp.
Tempel Steel Co.
Tesla Motors
Toshiba International Corp.
Toyota Motor, NA
US DOE, Oak Ridge National Laboratory
UQM Technologies Inc.
Wieland Copper Products LLC
Wolfspeed

* Focus is on automotive traction drive applications specifically.

NA PE* Supply Chain

Selection of organizations active in North America, provided for illustrative purposes only.

II-VI Advanced Materials
Alpha Advanced Materials (AAM)
Amphenol Interconnect Products Corp.
Analog Devices, Inc.
Arkansas Power Electronics International, Inc.
Bicron Electronics Co.
Bosch Rexroth
Calsonic Kansei North America, Inc.
FIAT (formerly Chrysler)
Cree, Inc.
Delphi Automotive LLP
DENSO Manufacturing Tennessee, Inc. (DMTN)
Dow Corning Electronic Solutions
Fabrico
Fairchild Semiconductor
Ford Motor
Freescale Semiconductor, Inc.
Fuji Electric Corp. of N.A.
General Motors
Hitachi Cable America Inc. (HCA)
Hitachi Automotive Systems America
Hitachi Metals North Carolina, Ltd.
Intersil
IXYS Corp.
Kemet Electronics Corp.
Kongsberg Automotive
Magmotor
Magna International of America, Inc.
Methode Electronics, Inc.
Mitsubishi Electric USA
ON Semiconductor
Positronic Industries Inc.
Powerex
Rinehart Motion Systems
Rogers Corp.
SBE, Inc.
Silicon Laboratories, Inc.
Superior Essex, Inc.
Tesla
Toshiba International

* Focus is on automotive traction drive applications specifically.

NA Motor Supply Chain Gaps

Top 10 categories of gaps discovered in the NA motors supply chain from primary source interviews, 2012-2015:*

•Strategic Investment Planning:	36%
•Situational Awareness: All Types:	18%
•Critical Materials Manufacturing Capacity:	10%
•Training and Engineering Skills:	7%
•Manufacturing Techniques and Tech.:	7%
•Standards Development:	5%
•Coordination and Collaboration:	5%
•Applied R&D:	3%
•Technology Transition Planning:	2%
•Multi-/Single-Industry Collaborative Eng.:	2%

* Gap categories ranked by percent of all NA motor supply chain gaps raised by primary sources, from 2012 to 2015. Percentages do not add up to 100 because there are several gaps outside the Top 10 that are not included (see report) and rounding. Source: Synthesis Partners, LLC (2015).

NA PE Supply Chain Gaps

Top Seven (7) categories of gaps discovered in the NA PE supply chain from primary source interviews, 2012-2014:*

•Strategic Investment Planning:	43%
•Situational Awareness: All Types	19%
•Capacity Development:	11%
•Coordination and Collaboration:	9%
•Modularization:	8%
•Training:	8%
•Technology Transition Planning:	3%

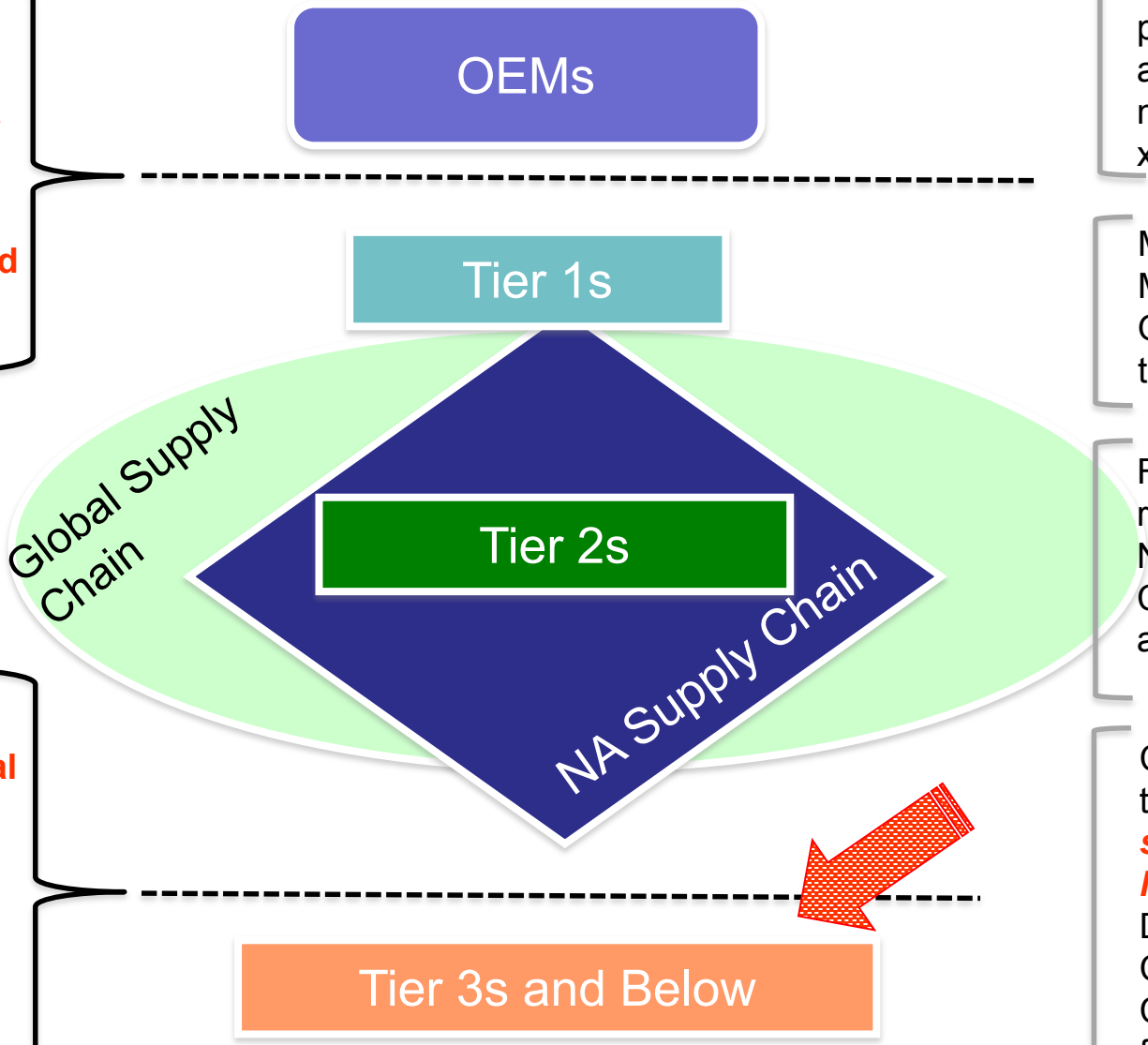
* Gap categories ranked by percent of all NA motor supply chain gaps raised by primary sources, from 2012 to 2014. Percentages do not add up to 100 because there are references to gaps that are not included (see report) and rounding. Source: Synthesis Partners, LLC (2015).

Sample Drill-Down on *One* NA Motor Supply Chain Gap:

Critical materials and related materials manufacturing know-how.

NA Motor Supply Chain is Brittle

Divergence between OEMs and Tier 1s on the existence of gaps in NA in training, coordination and collaboration.



Insufficient NA-domiciled critical materials, processes and motor mfg. capabilities for globally competitive motors mfg.

Motor design and prototyping; Final assembly of motors into xEVs.

Motor fabrication; Mfg.; Assembly; QC and delivery to OEM.

Fabrication of rotors; Stators; NdFeB magnets; Copper windings, and Packaging.

Copper winding techniques***; E-steel; E-steel laminations;*** Low-Dy magnets; Copper die casting; Copper/ Al. rotor fabrication.

E-Steel: A Critical Materials Gap

- Silicon Steel (Si- or E-Steel) sourcing is an issue with strong, competing viewpoints and high-value supply chain implications.
- Si steel manufacturers see the ~25% per year growth rate in specialty steels anticipated for HEV/EV motors as key growth market.
- Given the current and expected growth rate in the hybrid and electric vehicle market in the U.S., there may be a shortage of high quality E-steel 4-5 years out.

Major E-Steel Companies (alpha-order)

E-Steel Supplier	City, Country of HQ Location	Relevant xEV Customer	Comments (Updated regularly based on SP analysis, industry representatives and public sources.)
AK Steel	West Chester Township, OH	Not identified to-date.	xEV motor applications not identified to-date. Public source: http://www.aksteel.com.
Bao Steel	Shanghai, China	Tempel	Tempel buys steel from Bao, JFE, POSCO and others for use in e-steel laminations for HEV electric motors.
China Steel Corp./ CSC	Kaohsiung, Taiwan	Tesla	CSC supplies e-steel to Tesla. CSC was expected to start a new production line by the end of 2014 for 0.15 mm-thick non-oriented silicon-steel sheets to be used as core material for motors of electric vehicles such as Tesla Motors. Annual capacity will be 150,000 metric tons. Public source: SP analysis and "China Steel Expects Orders to Rise", Fanny Liu, Market Watch, 03-03-14, http://www.marketwatch.com/story/china-steel-expects-orders-to-rise-2014-03-03, accessed 06-22-15.
Cogent Surahammars Bruk	Surahammar, Sweden	AntriebsTechnik und Entwicklungs GmbH (ATE)	ATE Motors uses Cogent's Hi-Lite e-steel in ATE electric motors. Public source: http://hi-lite.se, accessed 10-20-15.
Eurotranciatura	Baranzate, Italy	Nissan-Renault, Fiat-Chrysler	Eurotranciatura manufactures electrical steel laminations for use by Nisaan and Fiat.
Hitachi	Tokyo, Japan	GM	Hitachi supplies electrical steel to GM for the Chevy Bolt, Malibu, Silverado Hybrid, and Spark, as well for the Buick LaCrosse E-Assist and Buick Regal.
JFE Steel	Tokyo, Japan	Tempel, Japanese OEMs.	The xEV motor applications of Tempel's e-steel have yet to be identified. It is understood that JFE supplies (though not through Tempel) one or more Japanese xEV OEMs.

Major E-Steel Companies (alpha-order)

E-Steel Supplier	City, Country of HQ Location	Relevant xEV Customer	Comments (Updated regularly, based on SP analysis, industry representatives and public sources.)
Nippon Steel & Sumitomo Metal	Tokyo, Japan	Denso, Hitachi, Furukawa and Sumitomo	Nippon Steel & Sumitomo Metal e-steel are each assumed to supply xEV vehicles via their respective customers, e.g. via Denso to Toyota, via Hitachi to GM, and via Furukawa to Tesla. Further information is needed to independently validate this assumption.
POSCO	Pohang, South Korea	GM, Kia Motors, Tempel Steel, Tesla	POSCO supplies e-steel to GM for the Chevy Spark, to Kia for the Soul EV, and to Tesla for the Model S. Public source: "POSCO Growth Engine - New Chairman of POSCO Paying Attention to Electric Vehicle Industry", 03-14-14, http://www.businesskorea.co.kr/english/news/industry/3685-posco-growth-engine-new-chairman-posco-paying-attention-electric-vehicle-industry#sthash.mLAFl4db.dpuf, accessed 11-10-15.
Tata Steel	Mumbai, India	None identified to date.	xEV motor customers not yet identified. Public source: http://www.tatasteelautomotive.com/en/
ThyssenKrupp Electrical Steel GmbH	Gelsenkirchen, Germany	None identified to date.	xEV motor customers not yet identified. Public source: http://www.tkes.com/web/tkeswebcms.nsf/$All/60F861C62E65929AC1257734004EF0FA/$FILE/NGO_020610.pdf, accessed 10/20/15.

E-Steel and Single String Dependencies

- Si-steel requires a very specific manufacturing pattern/process – not possible to transition from motor laminated steel to Si-steel in the same plant without an extensive recapitalization effort.
- It takes 12-24 months to install production equipment for thin steels, so companies need to move to address this potential gap.
- In addition to US domestic steel manufacturers, French and Austrian steel producers are looking at the potential market in NA, esp. because Asian producers are subject to recent ITC tariff.
- Si-Steel points to one of several critical single-string dependencies in critical materials and mfg. know-how needed to produce magnets, windings, new high-temperature laminates and other key components for motors.

Sample Drill-Down on *One* NA PE Supply Chain Gap:

Strategic Investment

The PE Strategic Investment Gap

- Need for strategic, system-wide understanding of WBG (noting that the lack of such understanding serves as a constraint on the competitiveness of NA automotive and other industries).

- Need for a comparative analysis of US vs. German vs. Japanese on WBG manufacturing process capabilities and cost, including approaches to die-attach, plating, interconnects, and other basic manufacturability issues.

- Need to focus DOE funding on a fewer number of high-priority NA supply chain gaps, esp. regarding manufacturability, to include increased supply of custom integrated circuits (ASICs) and smarter IGBTs including new design paths for waste-heat power recovery.

Tracking the Global Elite:

Top 10 Traction Drive Motor and PE Suppliers

Top 10 Traction Drive Motor Suppliers

Rank	Traction Drive Motor Supplier	HQ City	HQ Country	5 Year Total (Number of xEVs into which OEM installed motors, 2011-2015; rounded to nearest 100.)
1	Toyota	Aichi	Japan	5,267,700
2	Honda	Tokyo	Japan	1,211,400
3	Toshiba	Tokyo	Japan	363,800
4	Hyundai Mobis	Seoul	South Korea	307,500
5	Aisin	Aichi	Japan	280,300
6	Renault/Nissan	Amsterdam	The Netherlands	280,000
7	Continental	Hanover	Germany	249,600
8	Valeo	Paris	France	242,400
9	MELCO	Tokyo	Japan	207,300
10	Hitachi	Tokyo	Japan	193,800

Selected Findings About Top Motor Suppliers

- Top three traction drive motor producers account for 70% of all (not just Top 10) production, for 2011-2015.
- The #1 motor supplier (Toyota) had 40% larger market share than the #2 motor supplier (Honda) (equivalent to ~4m xEVs supplied), for 2011-2015.
- The #2 motor supplier (Honda) had ~9% larger market share than the #3 motor supplier (Toshiba) (equivalent to ~1m xEVs supplied), for 2011-2015.
- Among companies ranked below #3, less than 0.5% separates the market shares of each successive supplier, for 2011-2015.
- Outside the Top 10 (for 2011-2015), companies are not positioned for low cost automotive scale (greater than 100,000 xEVs supplied per annum).

Top 10 Traction Drive Inverter Suppliers

Rank	Traction Drive Inverter Supplier	HQ City	HQ Country	5 Year Total (Number of xEVs into which OEMs installed inverters, 2011-2015; rounded to nearest 100.)
1	Toyota	Aichi	Japan	4,125,600
2	Denso	Aichi	Japan	1,485,900
3	MELCO	Tokyo	Japan	1,360,800
4	Continental	Hanover	Germany	427,100
5	Hitachi	Tokyo	Japan	425,400
6	Toshiba	Tokyo	Japan	384,400
7	Hyundai Mobis	Seoul	South Korea	307,500
8	Valeo	Paris	France	242,400
9	Bosch	Gerlingen	Germany	232,100
10	Calsonic Kansei	Saitama	Japan	174,200

Selected Findings About Top Inverter Suppliers

- Top three traction drive inverter producers account for 71% of all (not just Top 10) production, for 2011-2015.
- The #1 inverter supplier (Toyota) had 27% larger market share than the #2 inverter supplier (Denso) (equivalent to ~2.7m xEVs supplied), for 2011-2015.
- The #2 inverter supplier (Denso) had just ~1.5% larger market share than the #3 inverter supplier (MELCO) (equivalent to ~100,000 xEVs supplied), for 2011-2015.
- Among companies ranked below #3, less than 1% separates the market shares of each successive supplier, for 2011-2015.
- Outside the Top 15 (for 2011-2015), companies are not positioned for low cost automotive scale (greater than 100,000 xEVs supplied per annum).

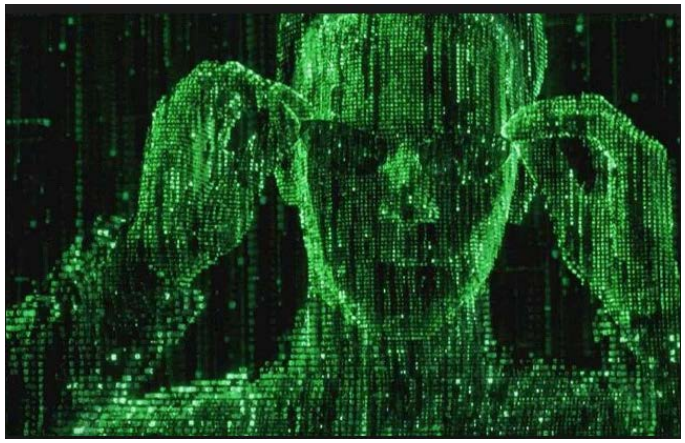
Next Steps

The following topics are framing our current collection and analysis activities on behalf of VTO.

Next Steps

- Integrating public PE and motors supply chain data for electronic access and delivery.
- Pursuing new data and analysis to help to identify R&D efforts that may have greater likelihood of transition and growth in the US.
- Assessing how supply chain intelligence can be produced and used in new ways to define and characterize R&D topics, gap impacts and potential gap-filling trade-spaces.
- Guidance on partnering to help drive R&D investments that catalyze the NA PE and motors supply chain to achieve increased strength and resilience.

Thank you.



Source: http://news.filehippo.com/2013/11/googles-deep-learning-computers-smart-creators/

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