EV Everywhere Grand Challenge

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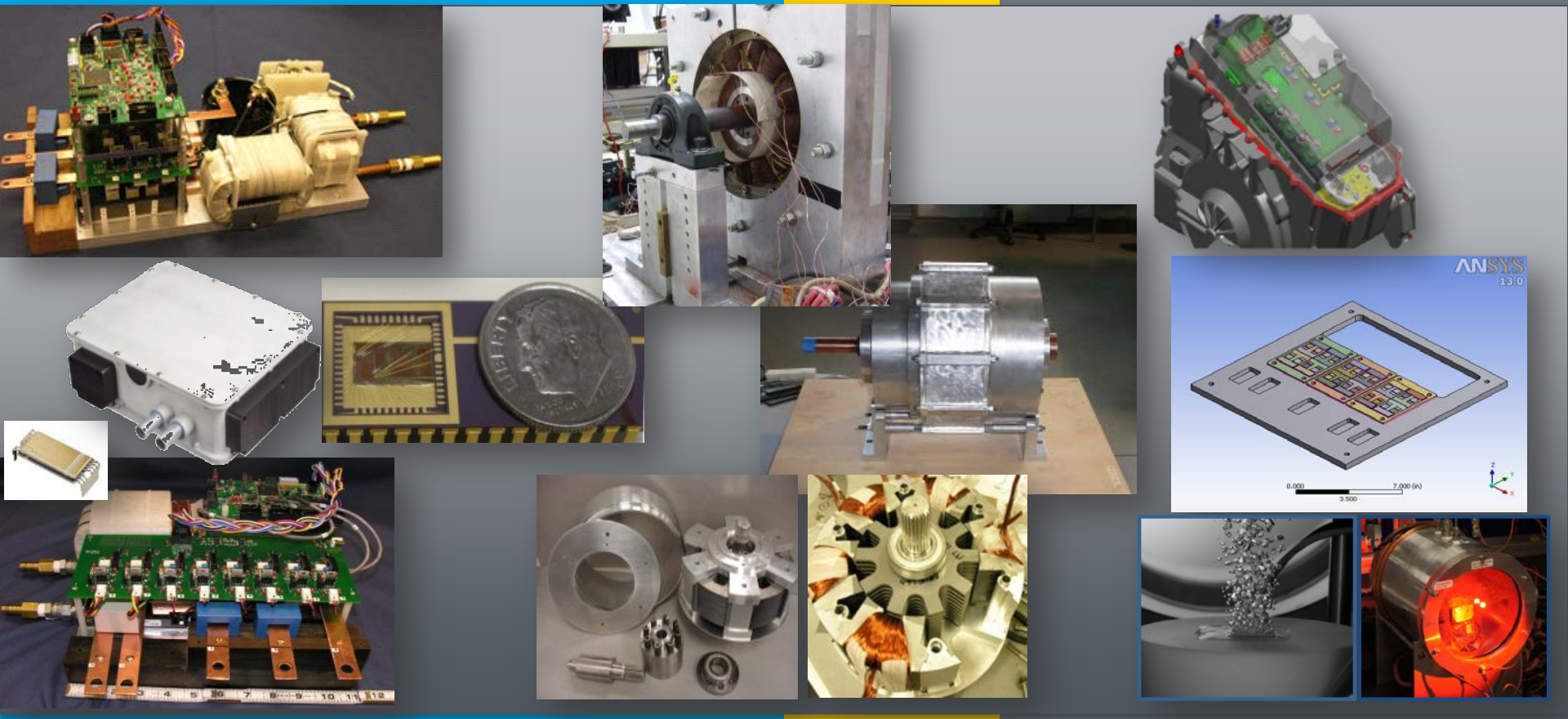

ELECTRIC DRIVE STATUS AND CHALLENGES

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Key DOE Technical Targets

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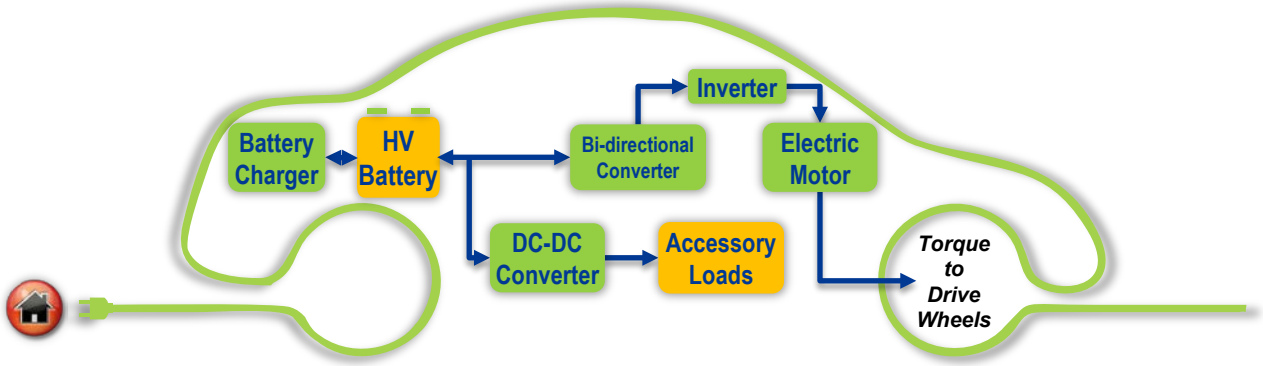

Traction Drive Requirements: 55 kW peak power for 18 sec; 30 kW continuous power; 15-year life

Traction Drive System

Impacts →	Reduce Cost	Reduce Weight	Reduce Volume	Reduce Energy Storage Requirements
Year	Cost ($/kW)	Specific Power (kW/kg)	Power Density (kW/l)	Efficiency
2010*	19	1.08	2.60	>90%
2012	17	1.12	2.86	>91%
2015	12	1.17	3.53	>93%
2020	8	1.44	4.00	>94%

Power Electronics

($/kW)	(kW/kg)	(kW/l)
7.9	10.8	8.7
7	11.2	10
5	12	12
3.3	14.1	13.4

Electric Motors

($/kW)	(kW/kg)	(kW/l)
11.1	1.2	3.7
10	1.24	4
7	1.3	5
4.7	1.6	5.7

* 2010 traction drive cost target achieved with development of the GM integrated traction drive project

EV Everywhere Electric Drive Targets

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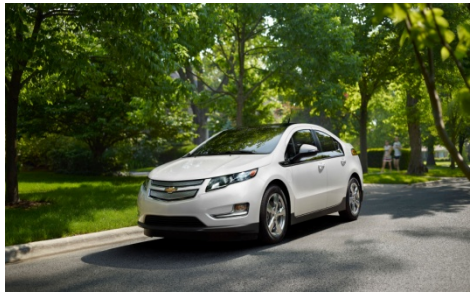
Traction drive cost reduction and performance improvements are necessary to achieve the *EV Everywhere* Grand Challenge

Chevy Volt



- ~40 mile electric range
- HEV: 32 mpg /300 miles
- 120 kW electric drive
- electric drive cost:~$2,400

Nissan Leaf

- ~75 mile electric range
- 80 kW electric drive
- electric drive cost:~$1,600

Tesla Model S

- ~ 250 mile electric range
- 270 kW electric drive
- electric drive cost:~$5,400

EV Everywhere Target Analysis		Current Status	PHEV 40	AEV 100	AEV 300
System Cost	$/kW	20	5	14	4
Motor Specific Power	kW/kg	1.2	1.9	1.3	1.3
PE Specific Power	kW/kg	10.5	16	12	16.7
System Peak Efficiency	%	90	97	91	98

On-board charging capability is essential to *EV Everywhere*

Current status and future targets are as follows:

3.3 kW Charger	2010	2015	2022
Cost	$900 - $1,000	$600	$330
Size	6-9 liters	4.0 liters	3.5 liters
Weight	9 -12 kg	4.0 kg	3.5 kg
Efficiency	90 – 92 %	93%	94%

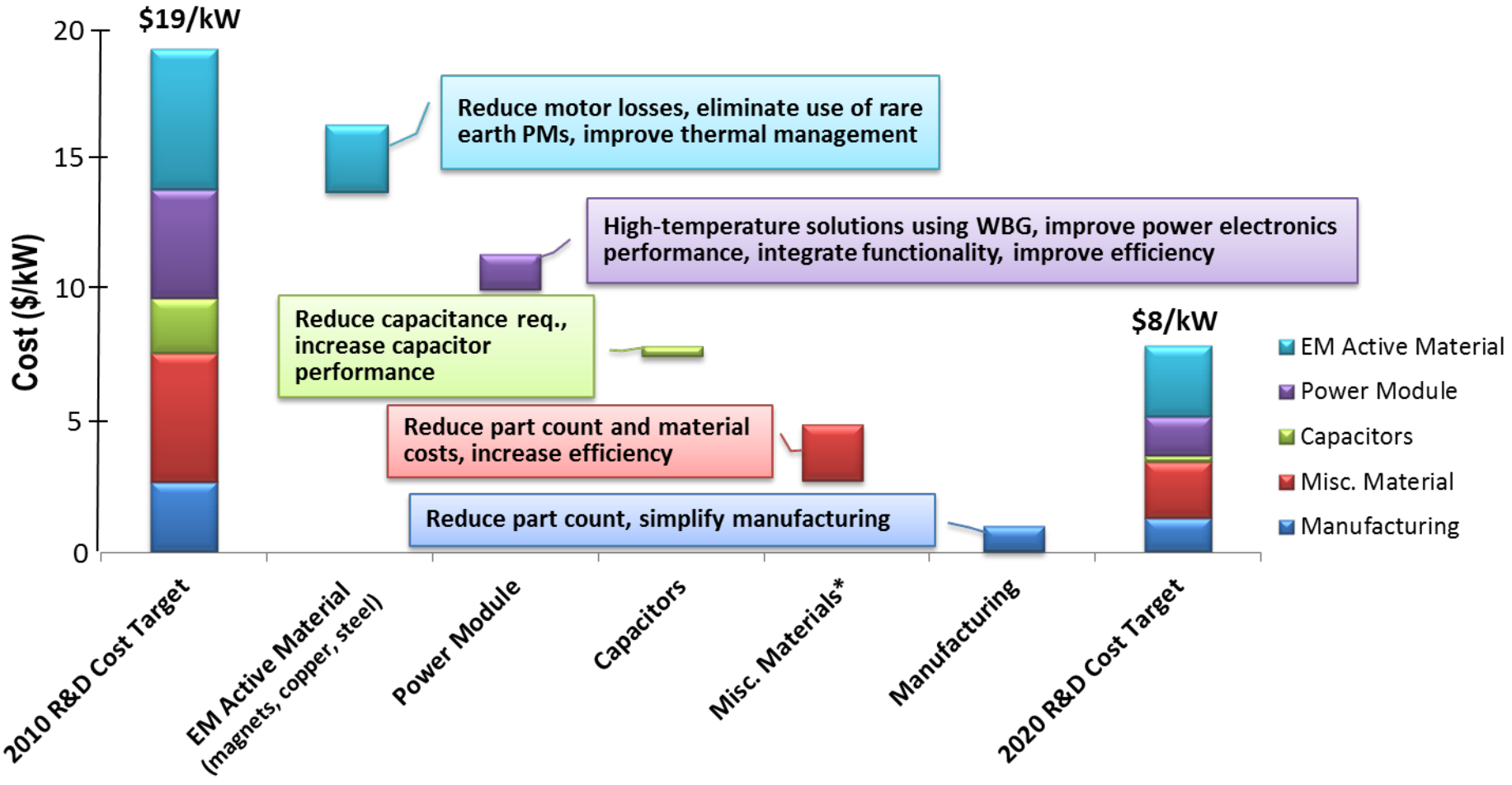
- **Cost is the most significant challenge**
- **Weight and volume reductions are necessary**
- **Traction drive and vehicle-level integration**
- **Integrated functionality is key**
- **Long-term solutions for fast charging and wireless power transfer**

Key Traction Drive Requirements & Targets

- ✓ Establish electric drive vehicle performance requirements
- ✓ Traction drive performance modeling and simulation
- ✓ Hardware-In-the-Loop and benchmark testing

Key Parameter	PHEV	AEV
Traction Drive Usage	Multiple modes	Full range
Peak Output Power	55 to 150 kW	
Continuous Output Power	20 to 85 kW	65 kW
Power Density	4 kW/l	
Specific Power	1.4 kW/kg	
Efficiency	94%	
Cooling Temperature	75°C	
Cost Target	$ 8/kW	

Opportunities to Achieve Traction Drive Cost Target

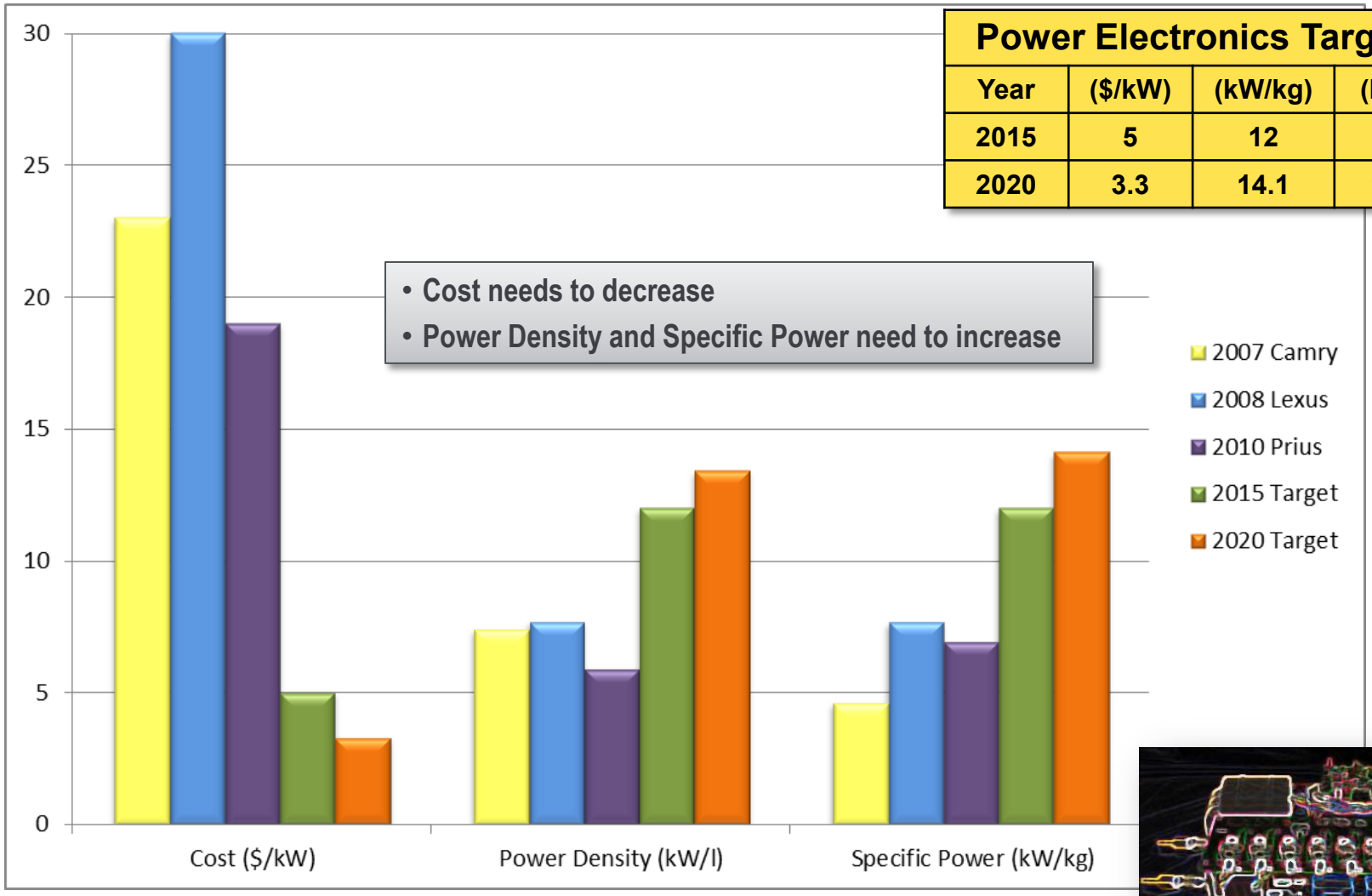


*** Inverter: cold plate, drive boards, thermal interface material, bus bar, current sensors, housing, control board, etc.**
Motor: bearings, housing, sensors, wire varnish and insulation, potting materials, shaft, etc.

Power Electronics for Traction Drive Applications

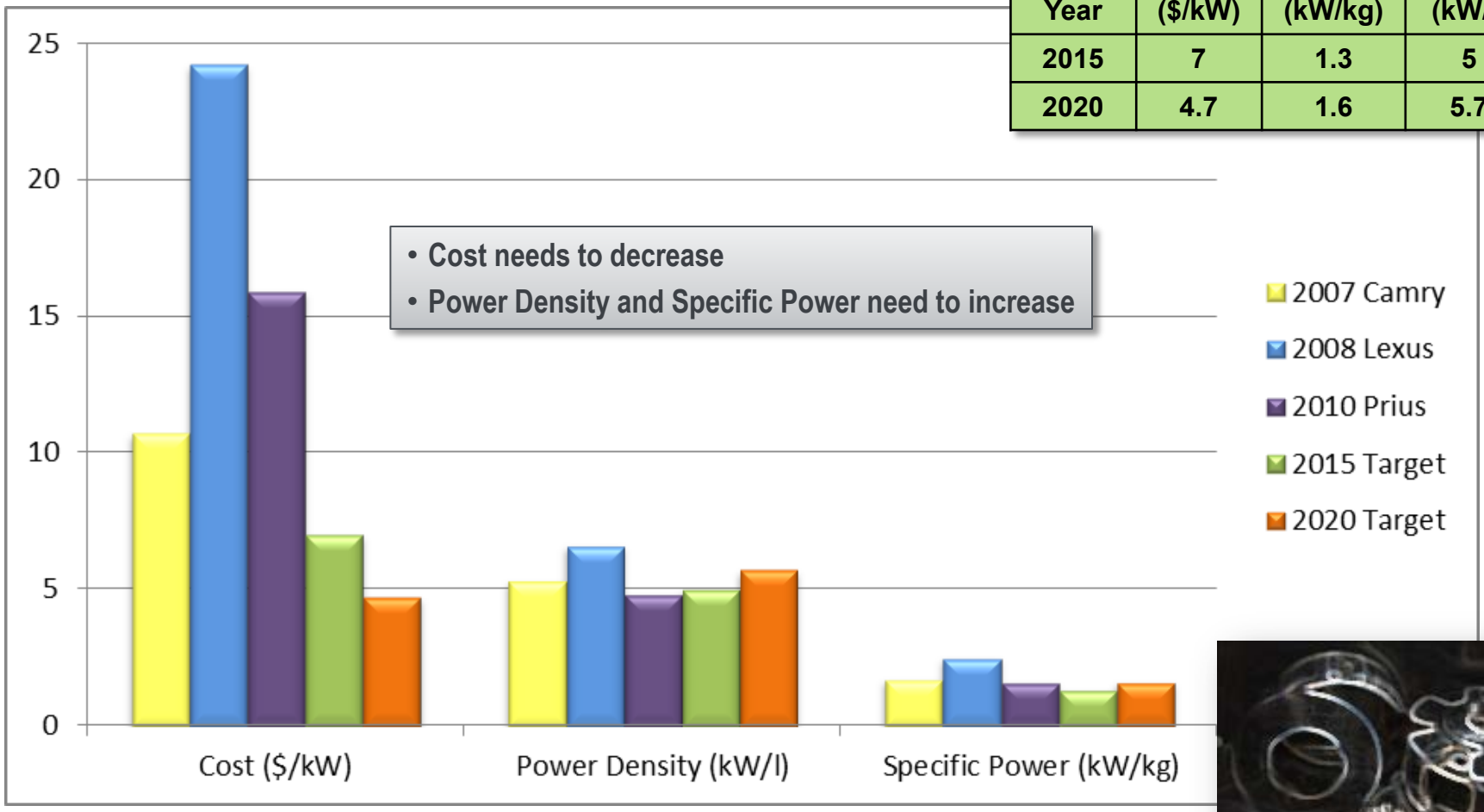
Power Electronics Targets			
Year	($/kW)	(kW/kg)	(kW/l)
2015	5	12	12
2020	3.3	14.1	13.4

- Cost needs to decrease
- Power Density and Specific Power need to increase



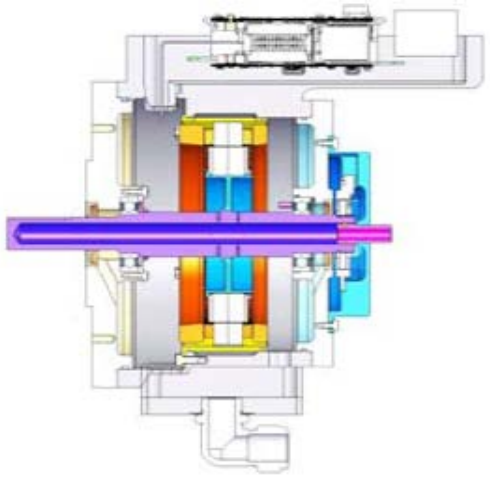
Electric Motors for Traction Drive Applications

Motor Targets			
Year	($/kW)	(kW/kg)	(kW/l)
2015	7	1.3	5
2020	4.7	1.6	5.7

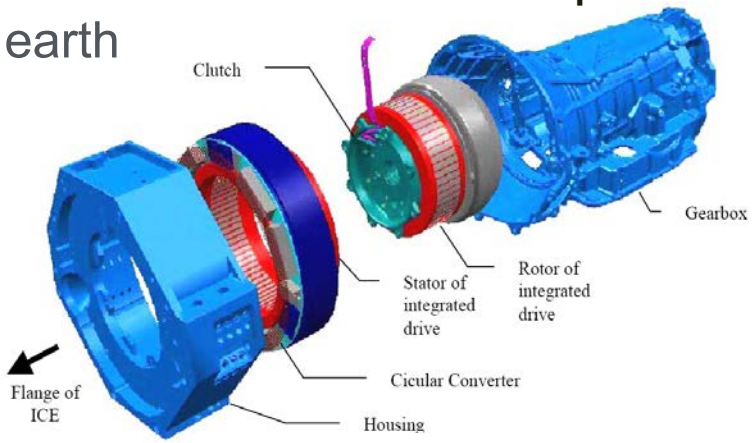


Traction Drive Challenges & Issues

- **Cost is the biggest challenge**
  - What is the most cost effective solution?
  - Are integrated systems worth the tradeoffs?
- **Packaging improvements are needed**
  - At device and component levels
  - Higher temperature and manufacturability
- **Advanced materials and designs**
  - High temperature silicon vs. WBG devices
  - Low-cost, high-temperature bus capacitors
  - Motors with reduced or eliminated rare earth content
- **Reliability**
  - Simultaneous vibration & temperature
  - Service life requirements
- **Thermal management**
  - Reduce heat generation
  - Improve heat transfer
  - System and vehicle-level integration



Integrated Motor and Inverter Concepts*

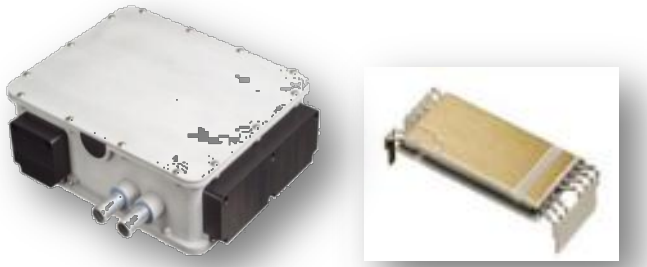


Circular Converter*

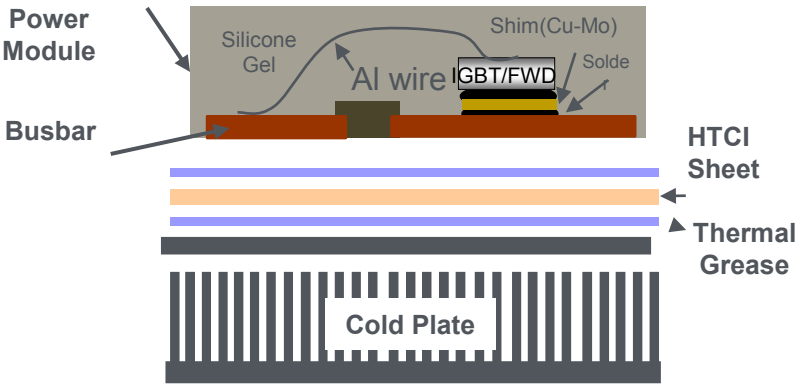
***ORNL/University of Wisconsin-Madison**

Power Electronics Challenges & Issues

- **Cost is the biggest challenge**
  - Power module and passive components
  - Emphasis on modular, scalable designs
- **Volume and mass reductions are needed**
  - Driven by passive devices
  - Packaging issues exist-at all levels
- **Packaging and Advanced materials required**
  - Higher temperature capability
  - Increase thermal conductivity
- **Reliability**
  - Wirebonds, die and substrate attach, solders, & connectors
  - Substrates and epoxies
- **Thermal Management**
  - Liquid cooling to air
  - Single sided or double sided
- **Efficiency**
  - Idle or quiescent loads



55 kW Delphi Inverter with Viper Power Module



Nissan LEAF Power Module

Wide Bandgap Device

Electric Motor Challenges & Issues

- **Costs are the biggest challenge**
  - Rare earth costs and uncertainty
  - Uncertainty of copper prices
- **Volume and mass reductions are needed**
  - Higher operating speeds
  - Low loss laminations
  - Higher slot fill
- **Thermal Management**
  - Temperature limitations of existing materials
  - Improve heat transfer
- **Packaging and Advanced materials required**
  - Higher temperature capability
  - Increase thermal conductivity
- **Reliability**
  - Stake-welds, solders, connectors, insulation
  - Epoxies
- **Efficiency**
  - System level component matching

GE 55 kW IPM Motor

UQM IPM Motor

Cost Reduction

Combining the battery charger, inverter, inverter controls, electric motor, and thermal management into one integrated traction drive will enable cost reduction.

Challenges exist with advanced materials and devices:

- WBG switches and diodes
- Non-rare earth magnets
- Small, high temperature passive devices
- Innovative packaging and advanced designs
- High reliability to meet service life and warranty
- High voltage insulation systems

Information Sources

- **DOE VTP FY 2011 Advanced Power Electronics and Electric Motors Annual Progress Report**
  - http://www1.eere.energy.gov/vehiclesandfuels/pdfs/program/2011_apeem_report.pdf
- **USDrive Electrical and Electronics Technical Team Roadmap**
  - http://www1.eere.energy.gov/vehiclesandfuels/pdfs/program/eett_roadmap_12-7-10.pdf
- **DOE Vehicle Technologies Multi-year Program Plan 2011-2015**; Section 2.2.1
  - http://www1.eere.energy.gov/vehiclesandfuels/pdfs/program/vt_mypp_2011-2015.pdf

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