From Formula 1 via Formula E to OEM relevant EV/hybrid solutions

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MTS Systems Corporation
Advanced Technology Group
Electric Power Systems

engineexpo 2017
Open Technology Forum

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Presentation Outline

- MTS Systems Corporation
- Electric Power Systems
  - Trends
- Applications
- Questions

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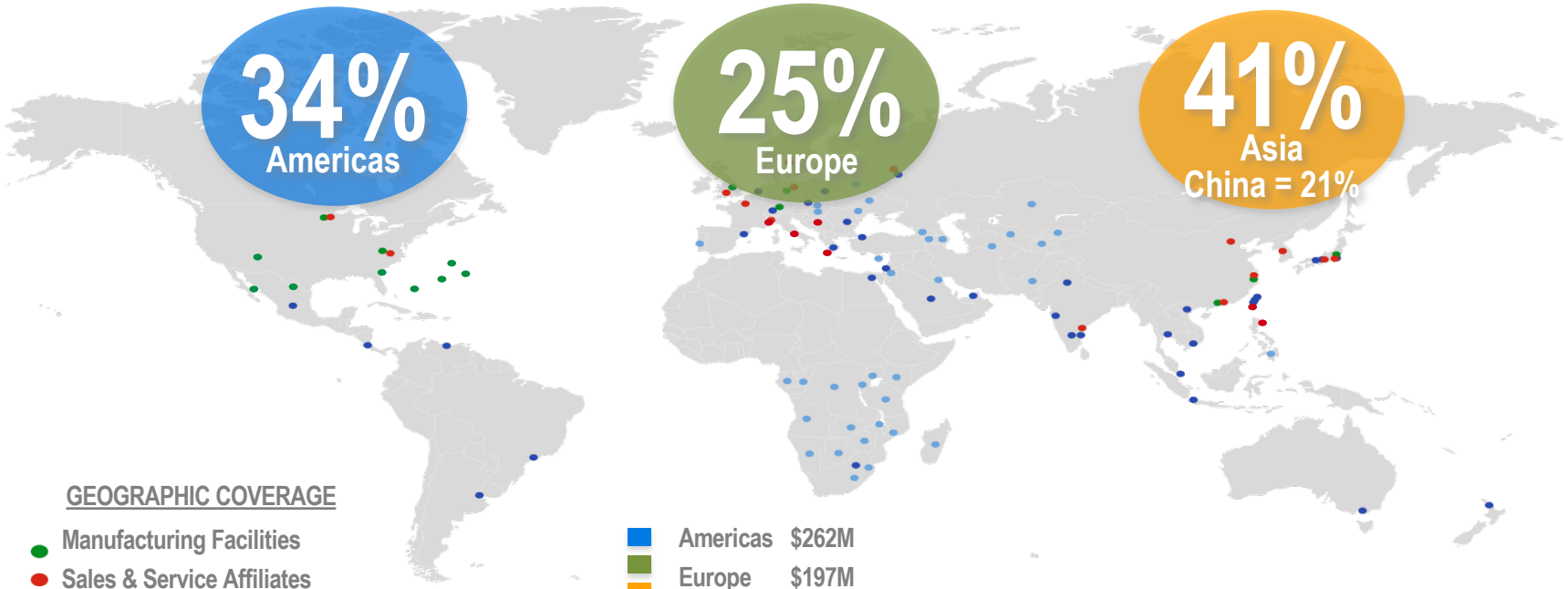
Strong global footprint to support geographically diverse customer base



GEOGRAPHIC COVERAGE

- Manufacturing Facilities
- Sales & Service Affiliates
- Business Partners
- BP Coverage

Americas	$262M
Europe	$197M
Asia	$159M
China	$164M

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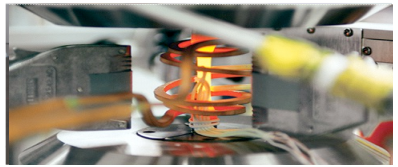
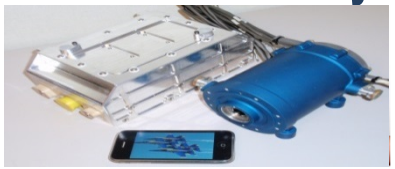
MTS Products, Systems and Services

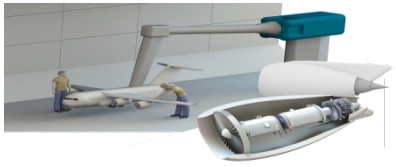
Test Vehicles, Structures, Materials



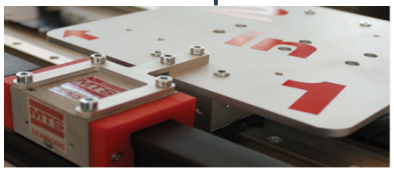
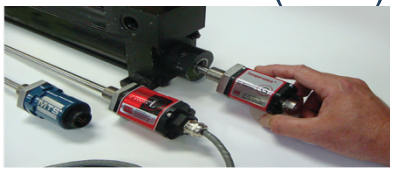



Electric Power Systems Vehicles, Industrial






Sensors position & acceleration (PCB)

Services Consulting, Monitoring, Repair



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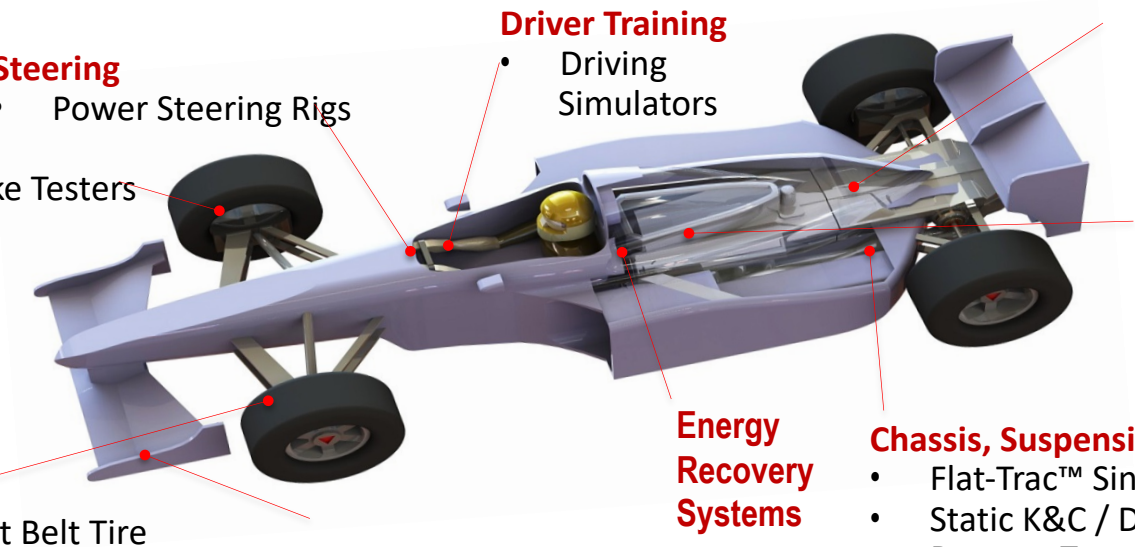
Motorsports Products



Steering
- Power Steering Rigs

Brakes
- Brake Testers

Driver Training
- Driving Simulators

Transmission, Clutch
- Transient Gearbox Dyno Rigs
- Lubrication Rigs
- Telemetry Torque Transducers

Engine
- Direct Drive Transient Dynos
- Single Cylinder Rigs
- Lubrication Rigs

Tires
- Flat Belt Tire Testers
- Flat-Trac™ Single Corner Roadway Simulators (SCRS)

Energy Recovery Systems

Chassis, Suspension
- Flat-Trac™ Single Corner Roadway Simulators
- Static K&C / Dynamic K&C
- Damper Testers
- Spindle Coupled Roadway Simulator
- Flat-Trac™ Roadway Simulators
- Integrated Wheel Force Transducers (SWIFT)

Aerodynamics (Wind Tunnels)
- Single-Belt Rolling Roads
- 5-Belt Rolling Roads
- Model & Wheel Support Systems
- Wind Tunnel Balances

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Wind Tunnel Rolling Roads

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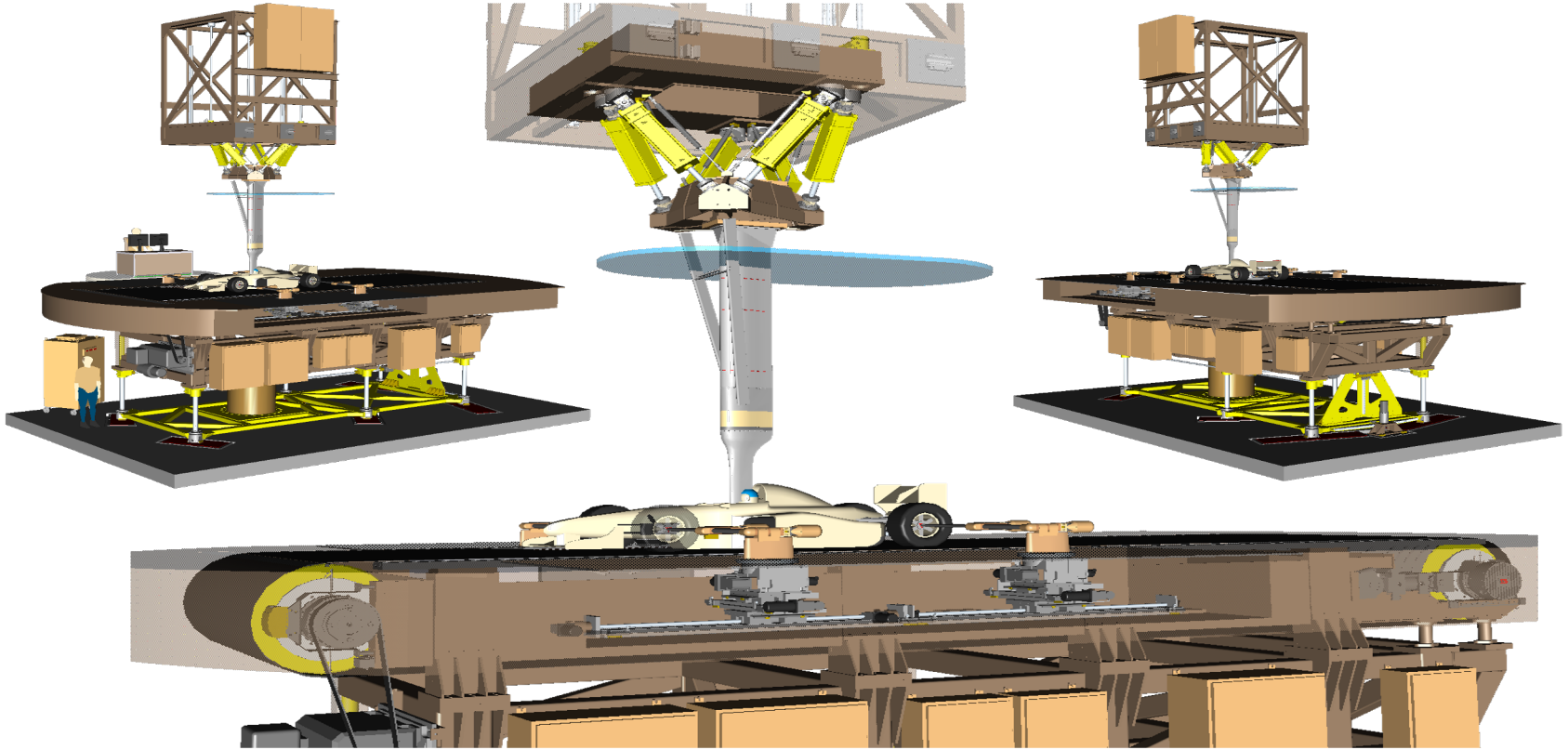
Wind Tunnel Rolling Roads & Model Support Systems



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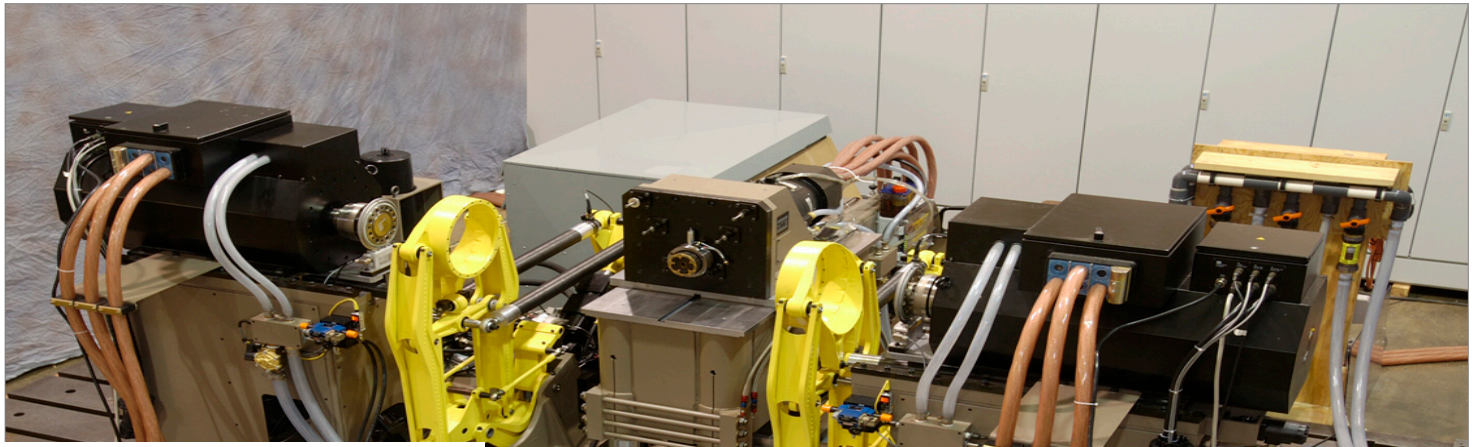
F1 Transmission Test System



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F1 TTS Input Dynamometer Motor Evolution

Dynamometer Parameters	V10	V8	V6	"1000HP" V6
Peak power	710 kW	610kW	628 kW	742 kW
Maximum Speed	22,000 rpm	24,000 rpm	15,000 rpm	15,000 rpm
Peak Torque	400 Nm	330 Nm	700 Nm	750 Nm
Inertia	0.014 kg-m^2	0.010 kg-m^2	0.018 kg-m^2	0.018 kg-m^2
Maximum acceleration rate	270,000 rpm/s	315,000 rpm/s	370,000 rpm/s	400,000 rpm/s

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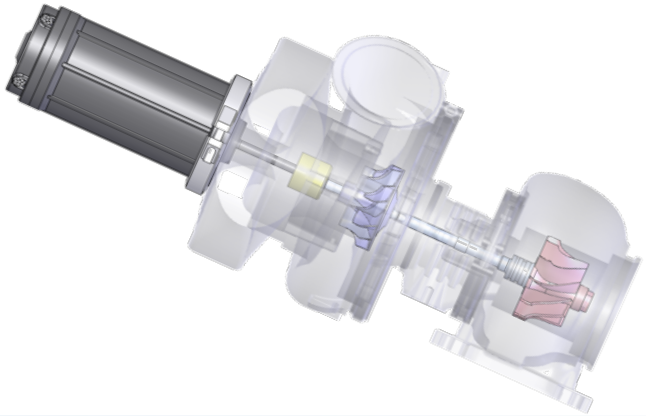
Motor Applications …



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EPS – Electric Power Systems

Develop and manufacture high performance electric motors and controls with optimization of

- Power Density
- Efficiency
- Inertia

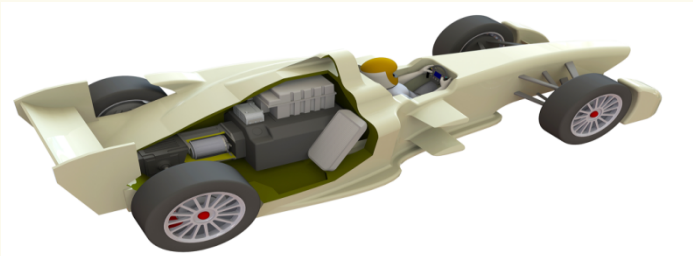
Portfolio

- Traction motors
- ERS
- Dynos
- Industrial solutions
- Power generation
- Oil and gas exploration
- Aerospace applications

Formula 1 Energy Recovery System

» Kinetic energy recovery
» Heat energy recovery

Formula E drive System



» Traction drive
» Kinetic energy recovery

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EPS Core strengths

- High Power Density
  - Relevant for mobile or space constrained applications
- Minimum Inertia
  - Relevant for highly dynamic applications (e.g. testing and e-turbo)
- High Efficiency
  - Relevant for mobile (electric vehicle), industrial applications (compressors, spin rigs, etc.)
- Simulation capabilities
  - Can predict performance with high accuracy prior to building hardware
- Complete offer: motors, power electronics, control boards
  - Broad portfolio of applications from 1 kW to 1 MW

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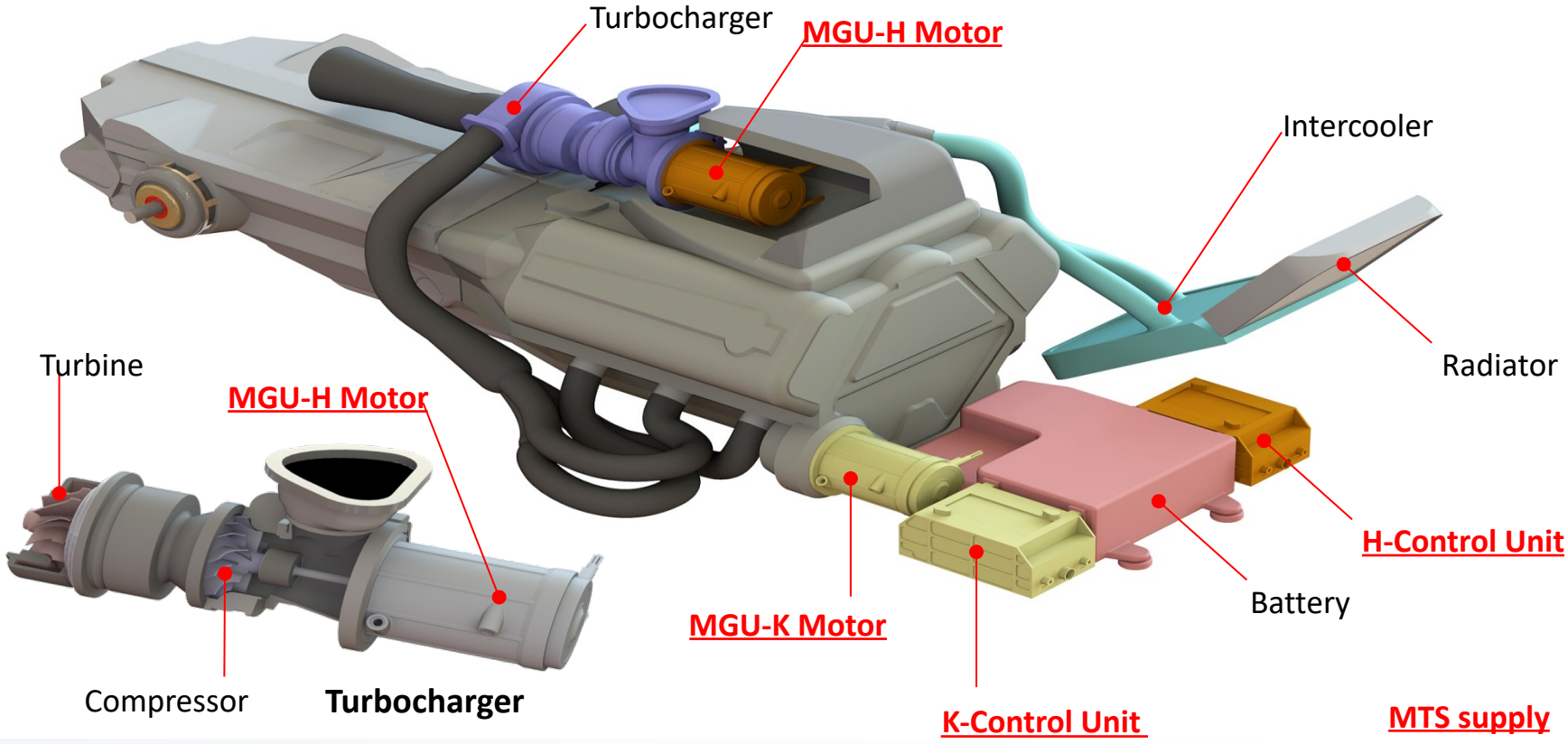
Formula 1 ERS System



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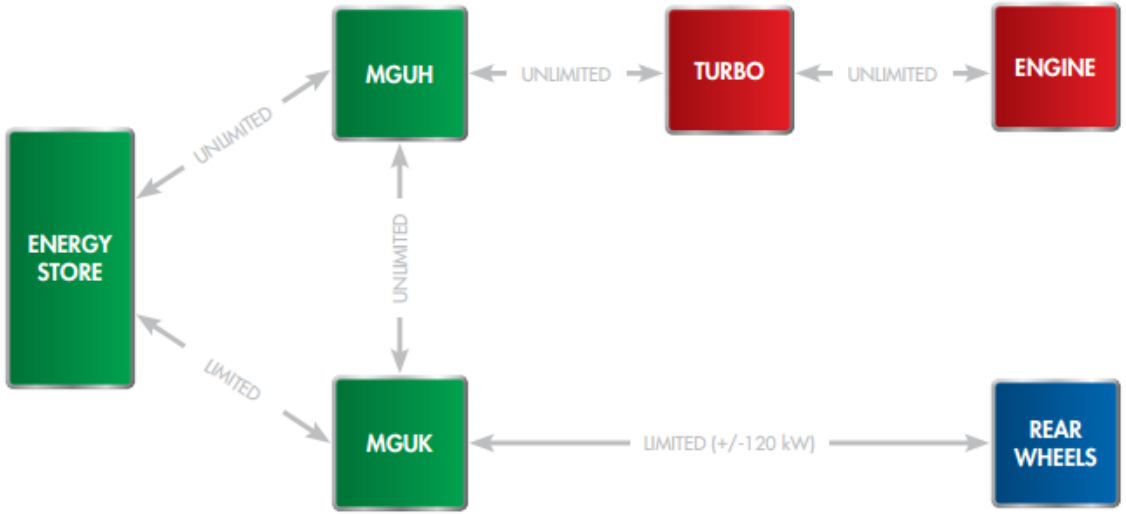
F1 FIA allowable Power Unit Energy Flow



Source:
https://www.fia.com/sites/default/files/publication/file/FIA%20F1%20Power%20Unit%20leaflet.pdf

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MTS ERS + Traction Drive Technology History

- 2008 Formula 1 KERS MGU-K & CU prototype development
- 2009 and onward supply of MGU-K & CU to one Formula 1 team
- 2010 LMP1 KERS component supply
- 2014 and onward supply of MGU-H & CU to one Formula 1 team
- 2015 MGU-K & CU system supply for LMP1 KERS
- 2015 Formula E, Season 3-4, traction motors and CUs
- 2016 MGU-H for Commercial Vehicle Development with Turbo Supplier
- 2017 Formula E, Season 5, traction motors and CUs

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Typical F1 Specifications

KERS MGU		
Power	60 kW	120 kW
Diameter	98 mm	106 mm
Length	160 mm	185 mm
Mass	4.0 kg	6.5 kg
Torque	20 Nm	45 Nm
Speed	40,000 RPM	40,000 RPM
Power Density	50 kW/liter	74 kW/liter
KERS Control and Power Electronics (KCU)		
Maximum Power	60 kW	120 kW
Physical size	200 x 130 x 100 mm	200 x 165 x 110 mm
Mass	2.5 kg	3.5 kg
Battery voltage	200 Volts	350 Volts

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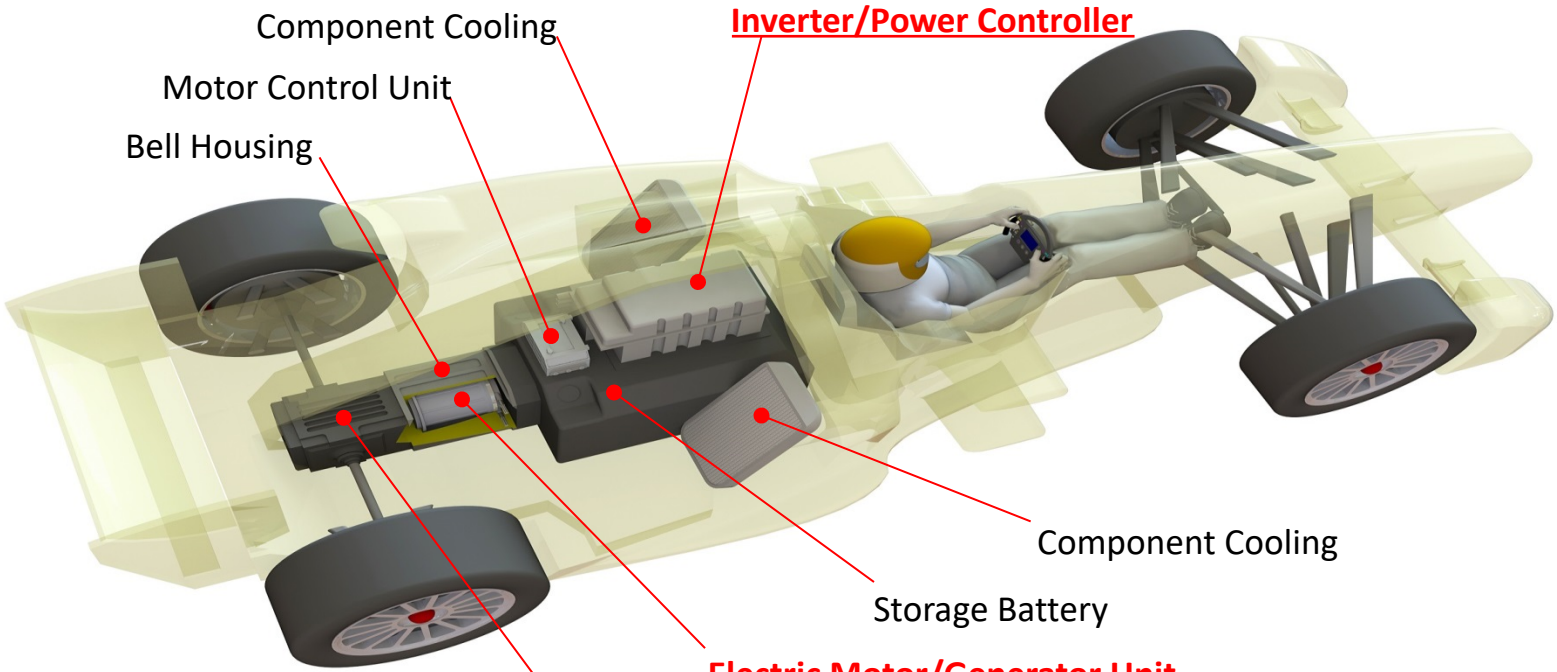
Formula E Seasons 3 -5



MTS Supply

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RoadMap S1- S5

	S1	S2	S3	S4	S5
Battery	28 kWh	28 kWh	28kWh	28kWh	54 kWh
Max Power Release QUALY	200 kW	200 kW	200 kW	220kW	250 kW
Max Power Release RACE	150 kW	170 kW	170 kW	180kW	200 kW
Max Power Release FanBoost	180 kW	200kW (100kj)	200 kW	220kW	250 kW
Max Power Regen	Free	100 kW (0.7)	150 kW (0.75)	200 kW (0.8)	250 kW
E Diff / 1 MGU per wheel / TRQ Vect	No	No	No	No	No
Braking system	Classic	Classic	Classic	Classic	Active
Transmission	RWD	RWD	RWD	RWD	RWD
aero	Standard wing profile	Standard wing profile	Standard wing profile	Standard wing profile	Spec Chassis and bodywork
Tyres	5Fr/5Re/Drv /race	5Fr/5Re/Drv / race	Michelin	Michelin	Michelin
Weight with driver	896 kg	888 kg	880 kg	880 kg	888 kg

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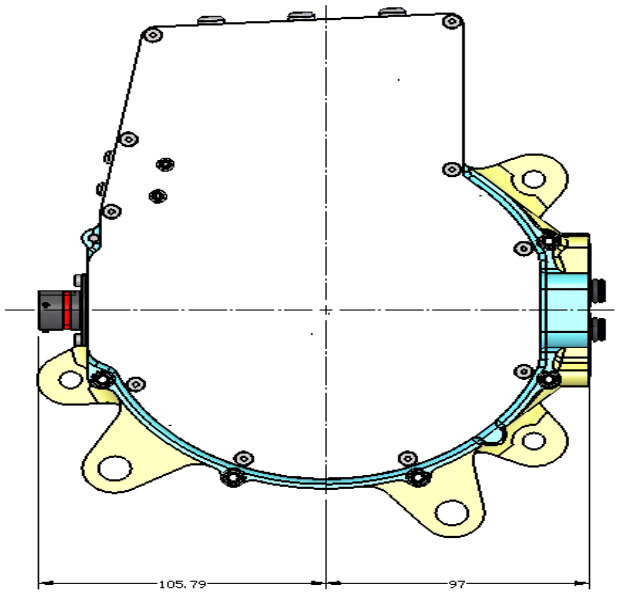
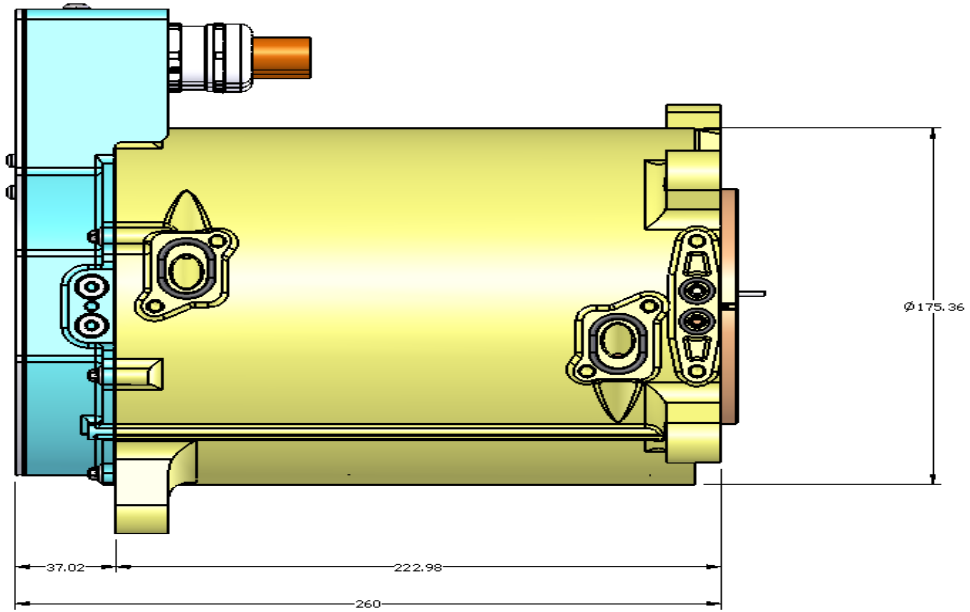
MTS Formula E S3-S4 Traction Motor Layout





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MTS Formula E S3-4 Motor Specifications

Parameters	Units	Specification
Power	[kW]	200
Maximum Speed	[rpm]	20,000
Motor Peak Torque	[Nm]	300
Water cooling flow (nominal)	[l/min]	10
Stator weight	[kg]	16.2
Weight of rotor	[kg]	5.7
Motor weight (w/o connector)	[kg]	26
Rotor inertia	[kg-m^2]	Less than 0.006
Power Density	[kW/liter]	32

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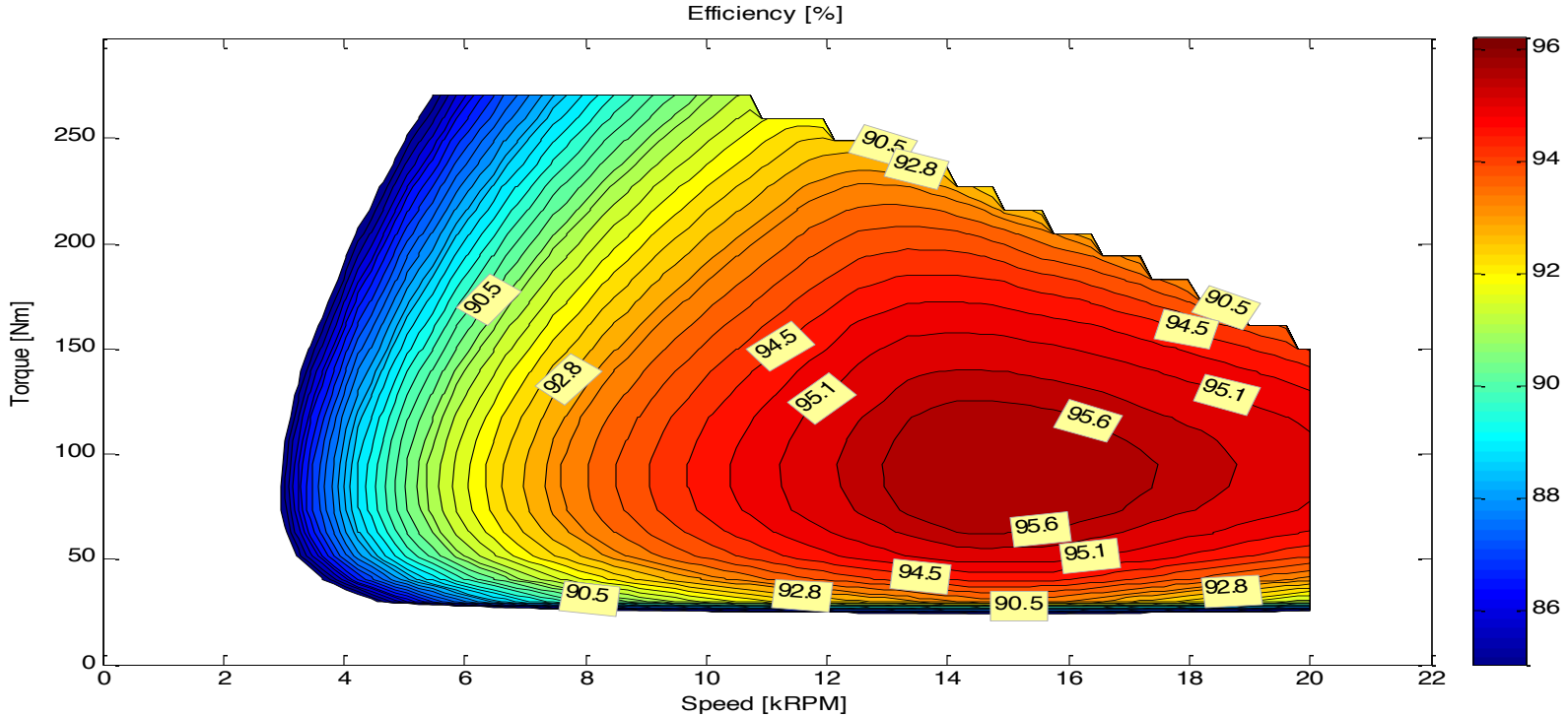
MTS S3-S4 Total Efficiency Map



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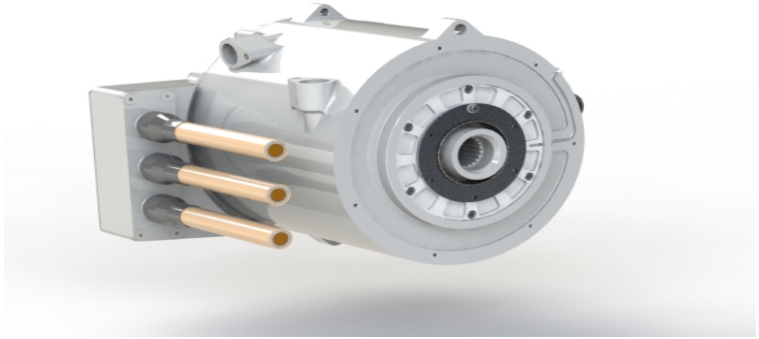
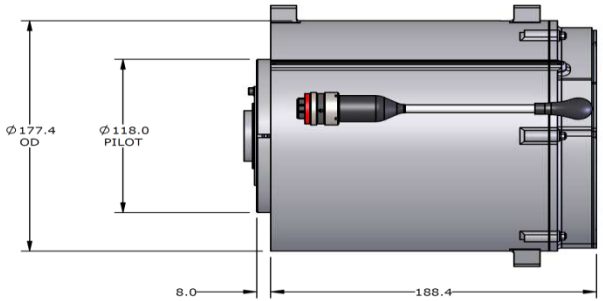
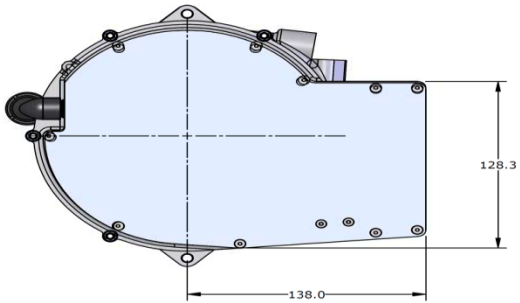
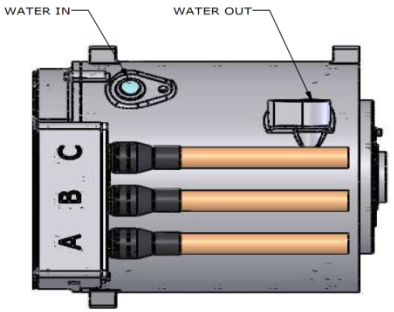
Season 5 : MGU

- Basic OD: 177.4
- Overall Length: 188.4
- Mass Dry: 22.13 kg









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S5 FE MGU

Parameters	Units	Specification
Power	[kW]	250
Maximum Speed	[rpm]	27,000
Motor Peak Torque	[Nm]	220
Torque at max speed	[Nm]	88.4
Motor Length	[mm]	188.4
Motor Basic OD	[mm]	177.4
Motor weight (dry)	[kg]	22.13
Rotor inertia	[kg-m^2]	Less than 0.006
Power Density	[kW/liter]	54

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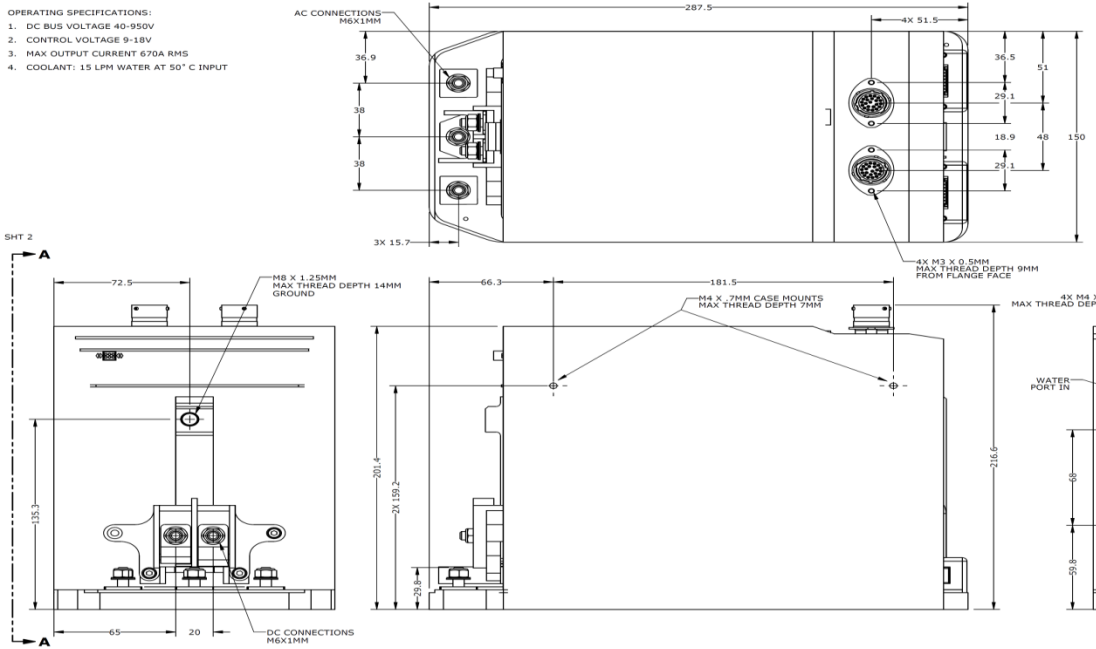
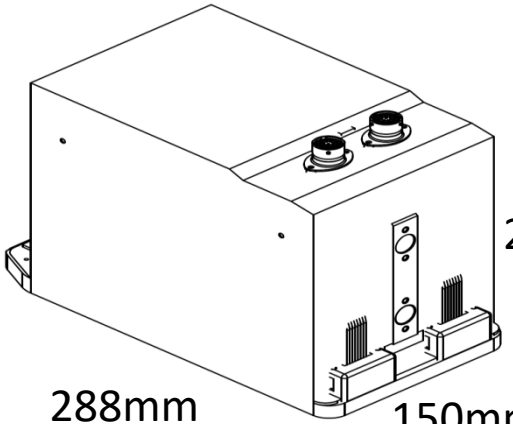
Season 5: Inverter Core

- Core Mass: 7.8 kg
- Optional Aluminum Cover Mass: 1.7 kg





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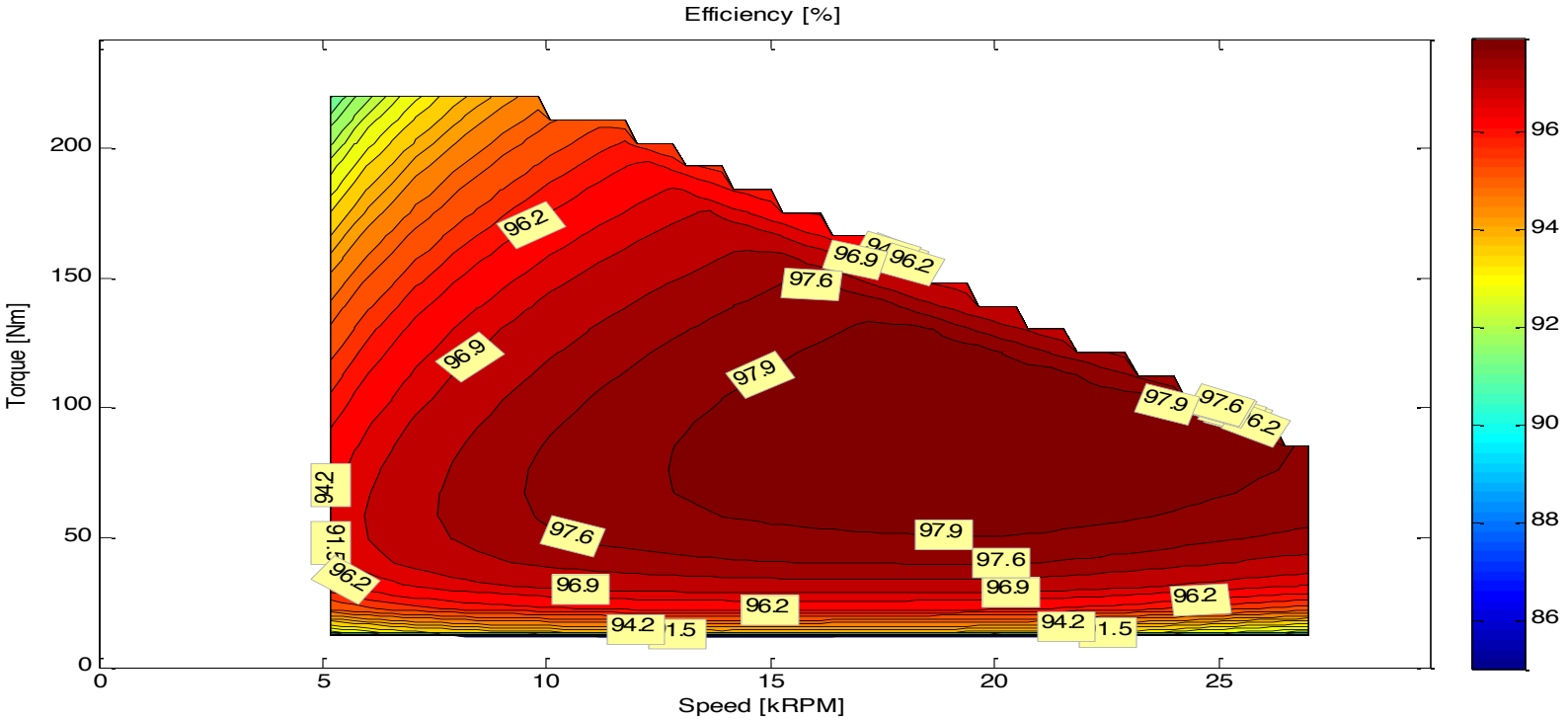
Motoring - Combined Efficiency



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Applications beyond Motorsport

Automotive Applications of our technology:

- Hybrid drive systems with Energy Recovery
  - Traction (KERS)
  - E-Turbo
- Full Electric vehicles

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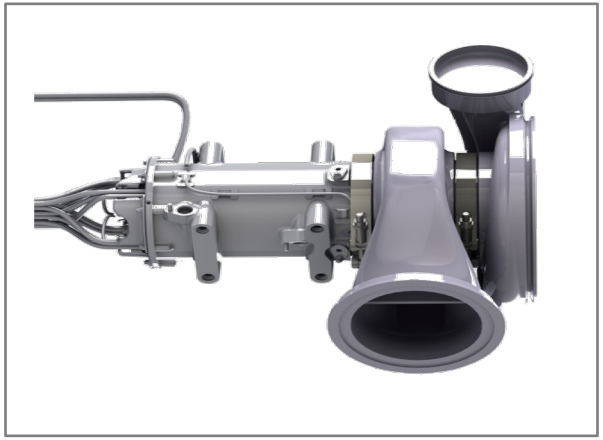
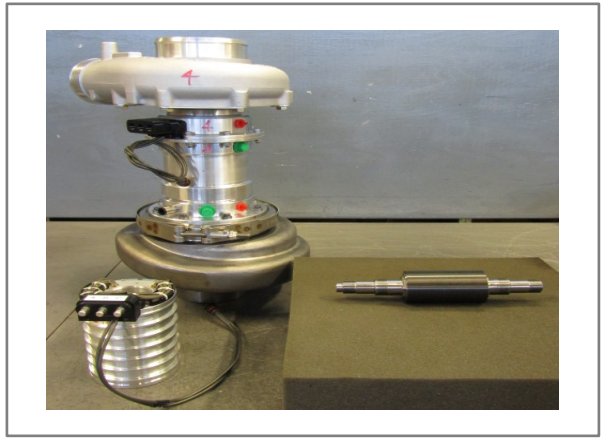
Electrical Turbo Compounding Technology

Commercial vehicle E-turbo with MTS MGU



Ferrari Formula 1 E-Turbo (2014)



Commercial Vehicle E-turbo, 2016

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Questions Please ?

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