TEG On-Vehicle Performance & Model Validation

Doug Crane[1], John LaGrandeur[1], Vladimir Jovovic[1], Marco Ranalli[1], Martin Adldinger[1], Eric Poliquin[1], Joe Dean[1], Dmitri Kossakovski[1], Boris Mazar[2], Clay Maranville[3]

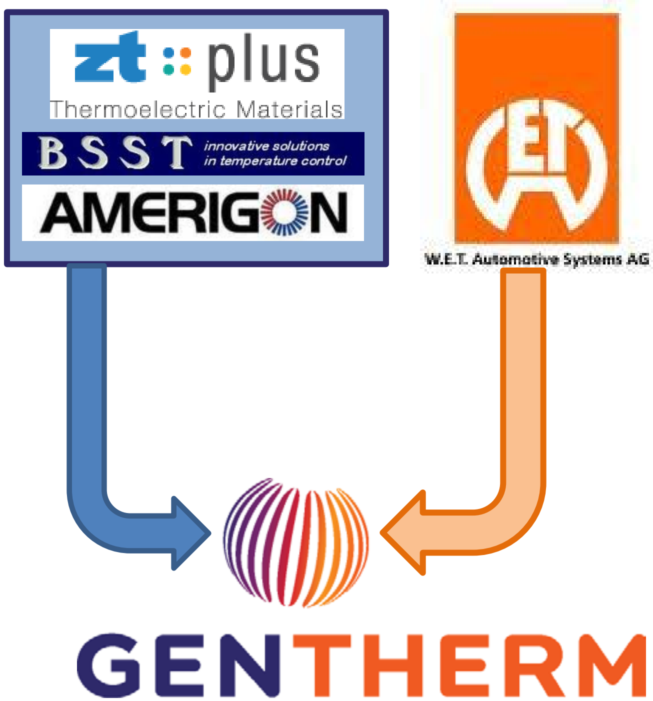
1. Gentherm
2. BMW Group
3. Ford Motor Company

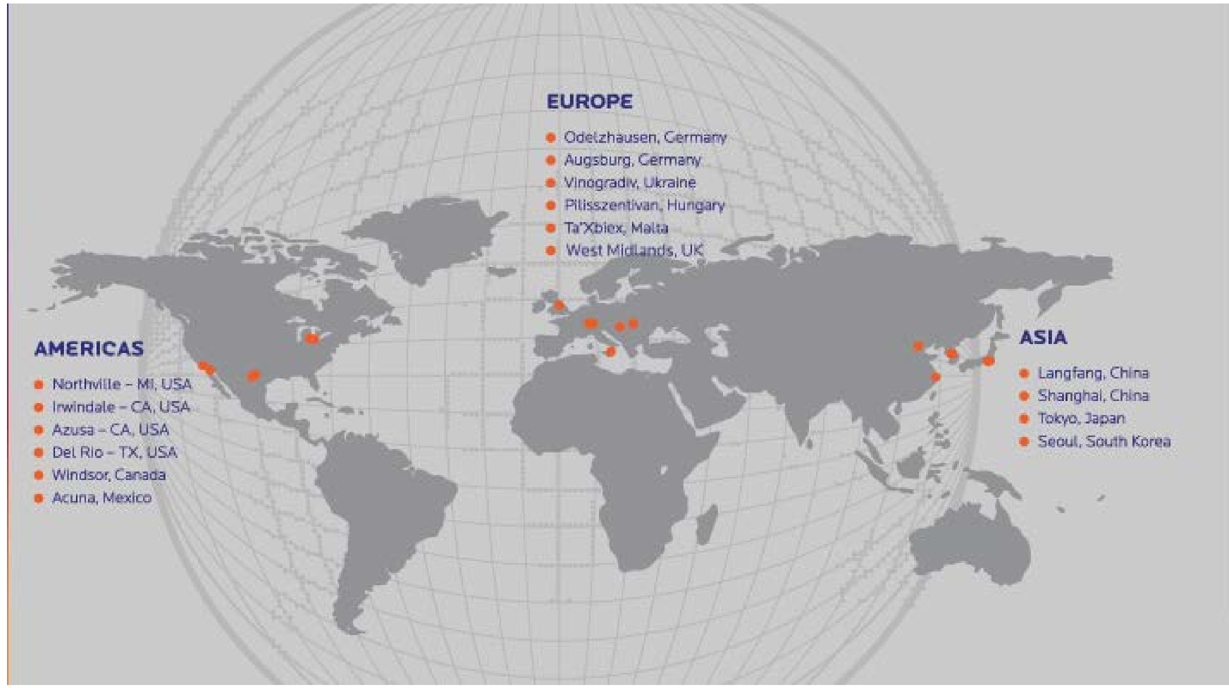
Directions in Engine Efficiency and Emissions Research (DEER)
Dearborn, MI
October 18, 2012

INSPIRING EFFICIENCY

GENTHERM

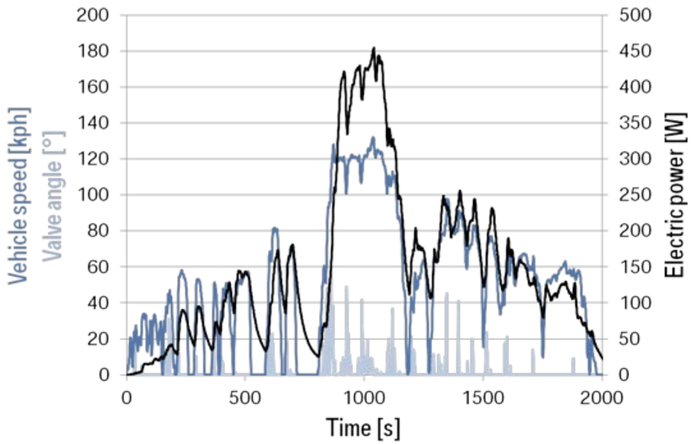
WHO WE ARE

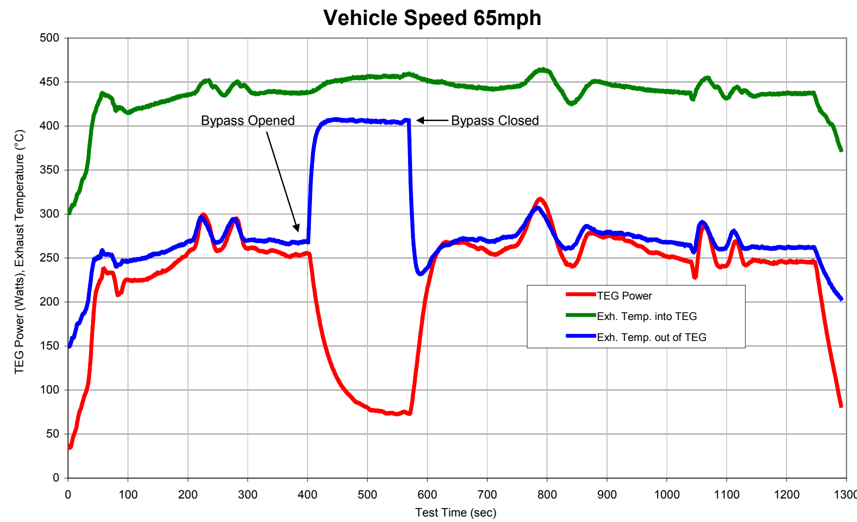




- Major supplier of thermoelectric products for automotive applications
- More than 5000 employees worldwide
- 3 manufacturing locations in the main regions
- 8 sales, development, R&D locations

VEHICLE SUMMARY



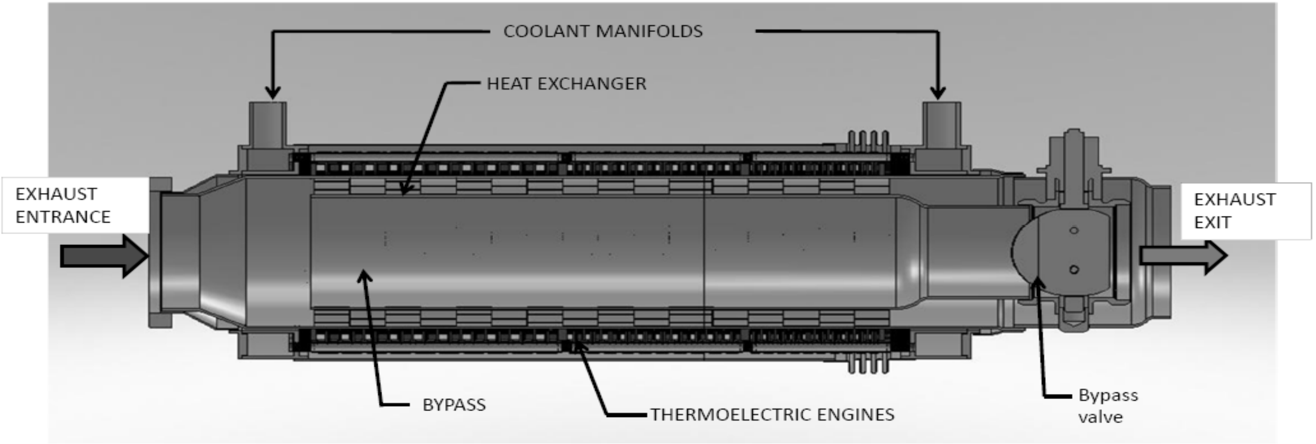


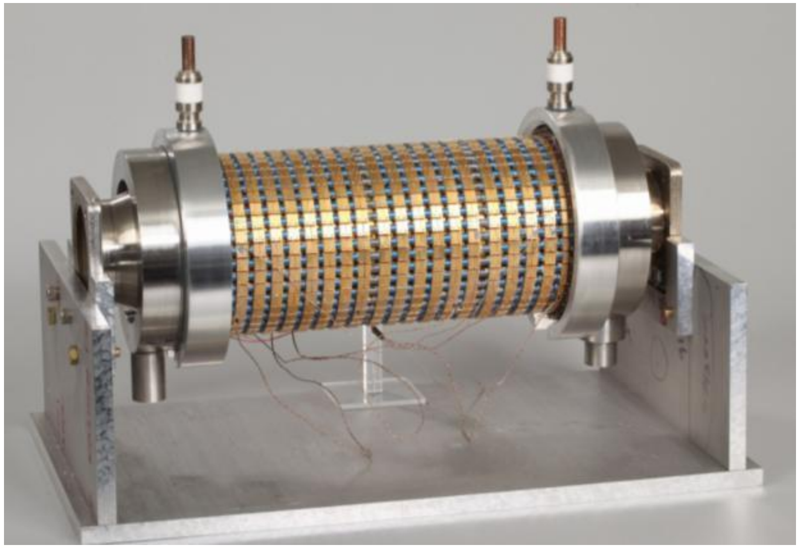
TEGs have been integrated into both BMW and Ford vehicles and have been in operation for over a year

BMW X6

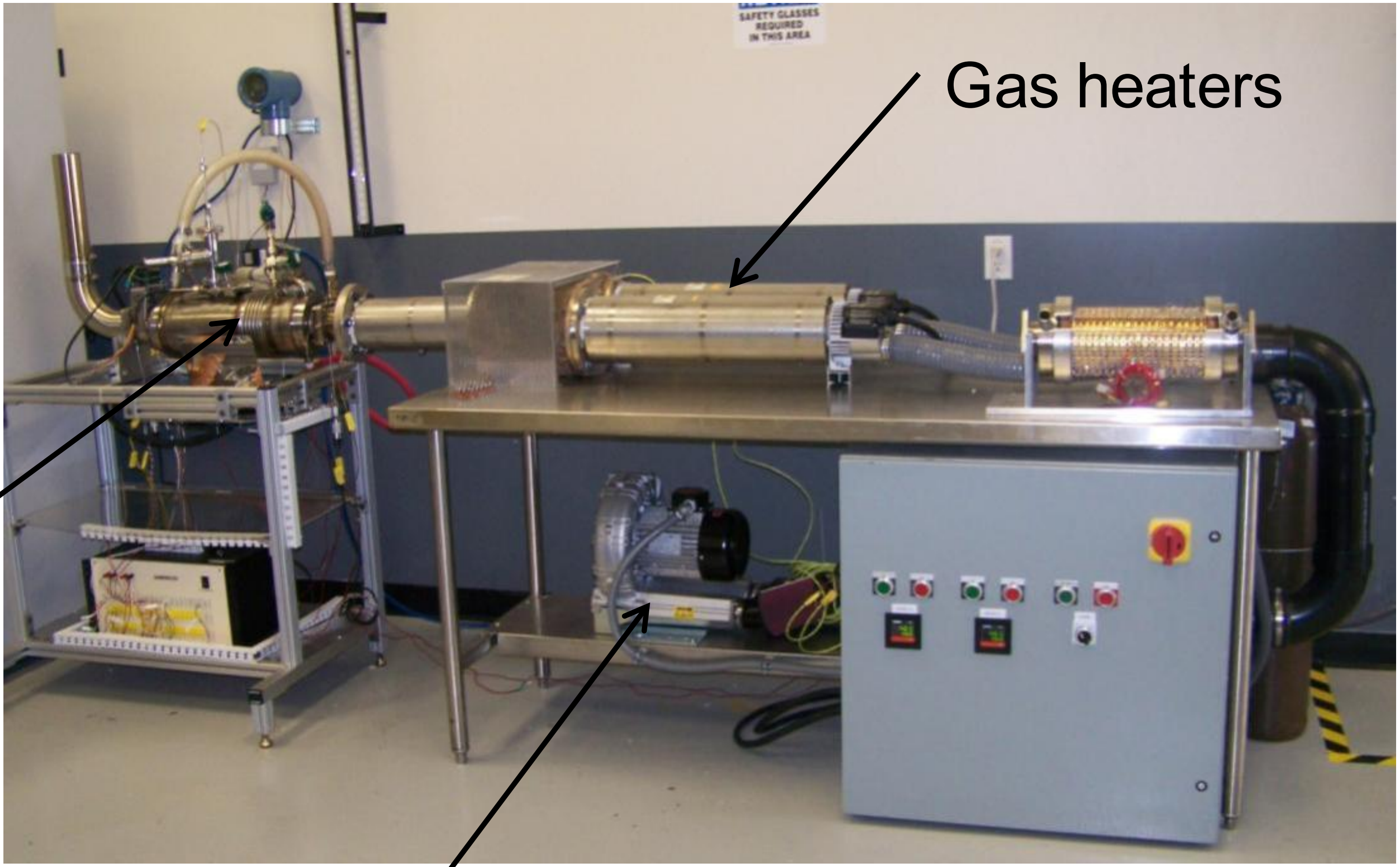
Ford Lincoln MKT

CYLINDRICAL TEG





BENCH TEST SETUP



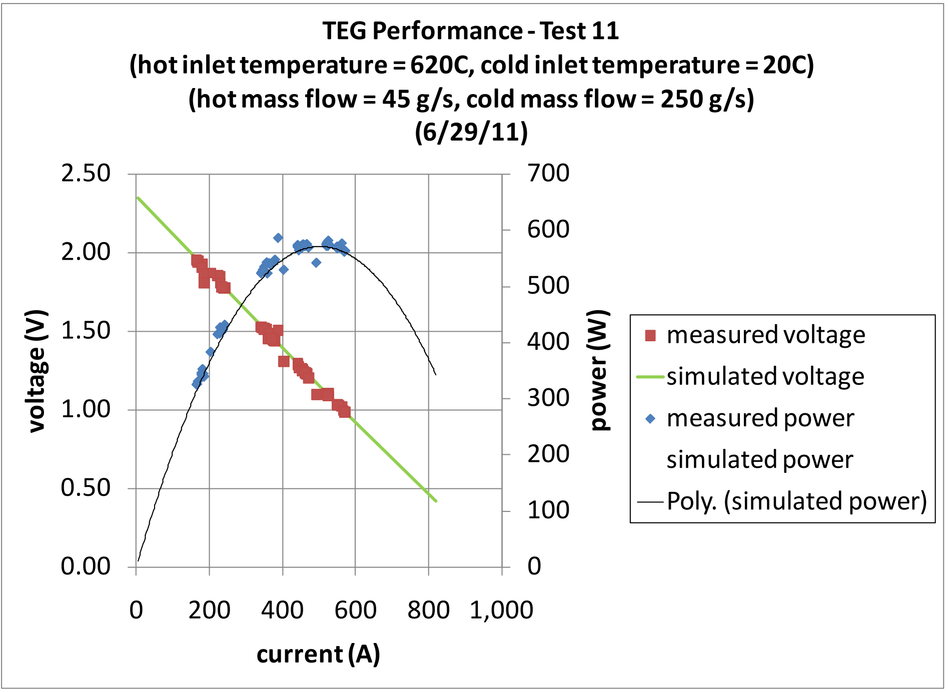
TEST CONDITIONS FOR TEG

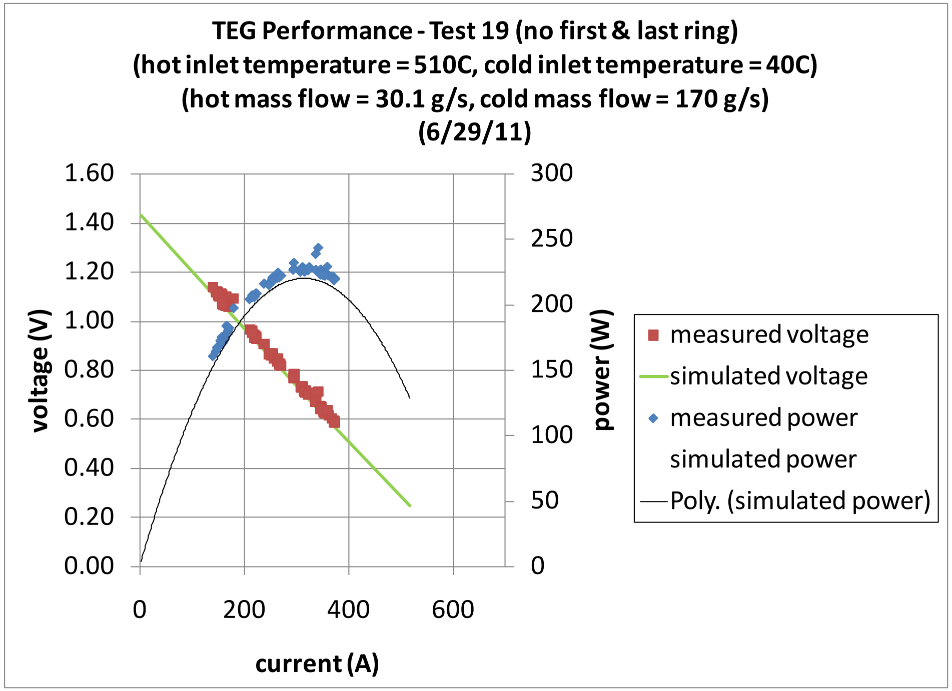
Test	1	2	3	4	5	6	7	8	9	10	11	12
Tfh,in (C)	390	390	390	425	425	425	510	510	510	620	620	620
Tfc,in (C)	20	20	20	20	20	20	20	20	20	20	20	20
vdot,h (g/s)	13.5	13.5	13.5	20.5	20.5	20.5	30.1	30.1	30.1	45	45	45
vdot,c (g/s)	170	250	330	170	250	330	170	250	330	170	250	330
max power output (W)	56.1	56.5	57.6	119	121	122	261	270	272	495	580	595

Test	13	14	15	16	17	18	19	20	21	22	23	24	25
Tfh,in (C)	390	390	390	425	425	425	510	510	510	620	620	620	620
Tfc,in (C)	40	40	40	40	40	40	40	40	40	40	40	40	20
vdot,h (g/s)	13.5	13.5	13.5	20.5	20.5	20.5	30.1	30.1	30.1	45	45	45	48
vdot,c (g/s)	170	250	330	170	250	330	170	250	330	170	250	330	330
max power output (W)	49.3	49.2	49.6	103	104	106	228	237	241	436	461	N/A	608

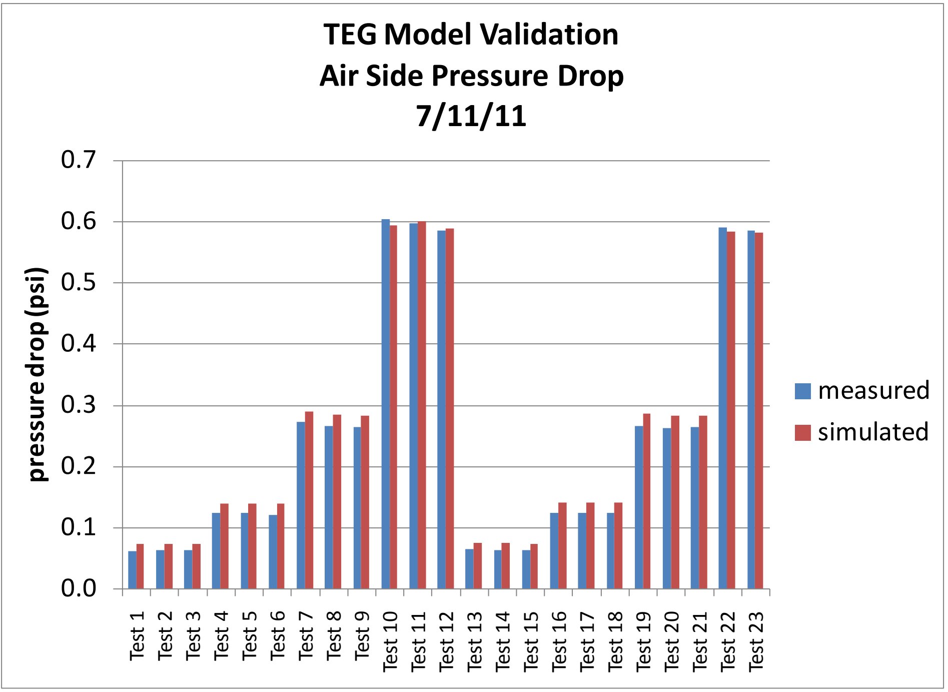
Note: Test 24 not completed due to the chiller overheating.

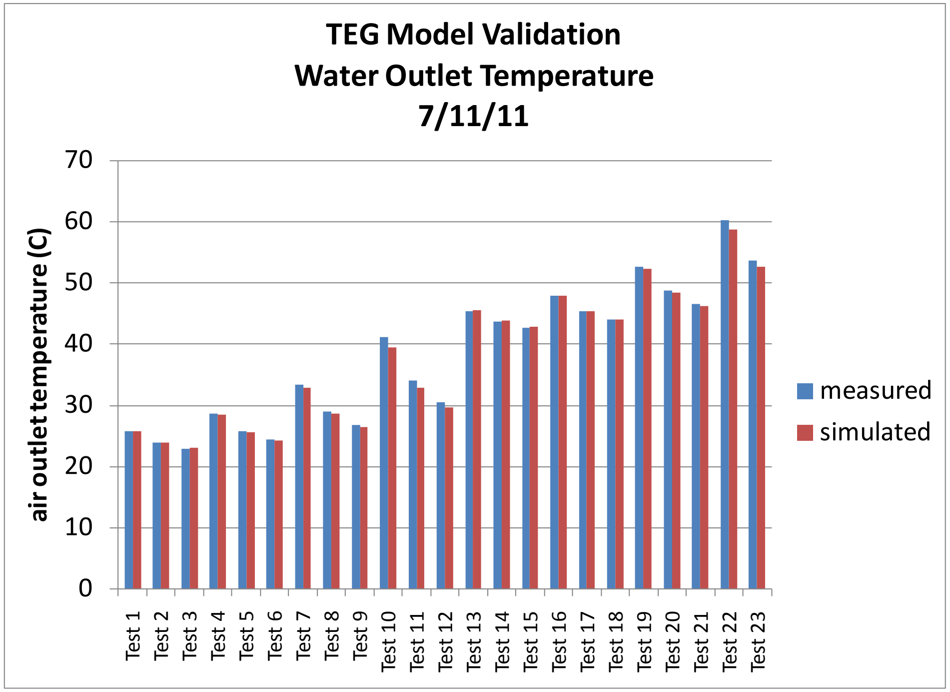
POWER & VOLTAGE VALIDATION



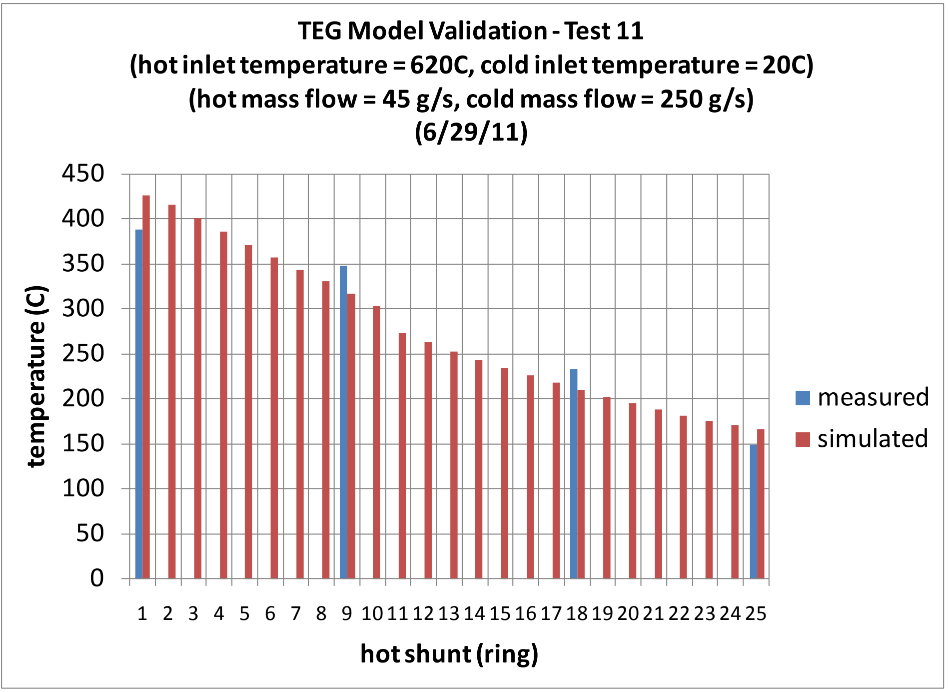


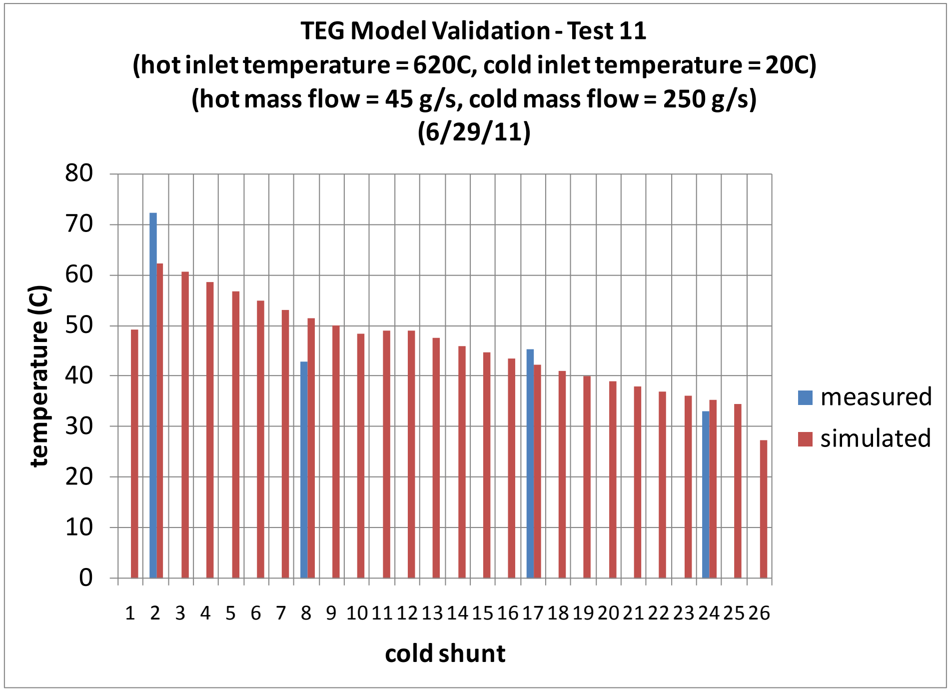
AIR PRESSURE DROP & WATER OUTLET TEMPERATURE VALIDATION



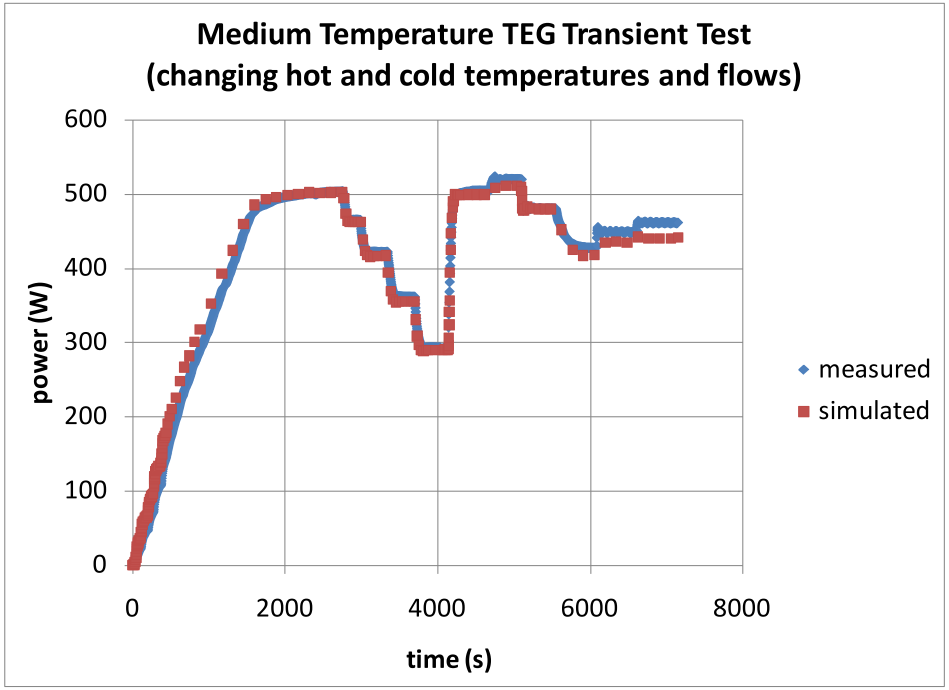


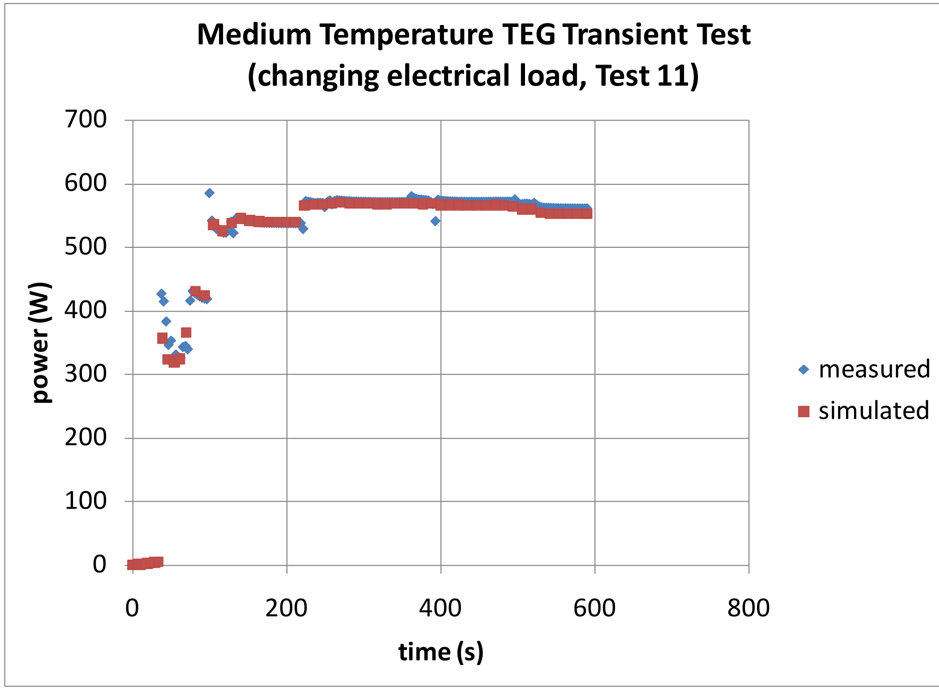
HOT & COLD SHUNT TEMPERATURE VALIDATION





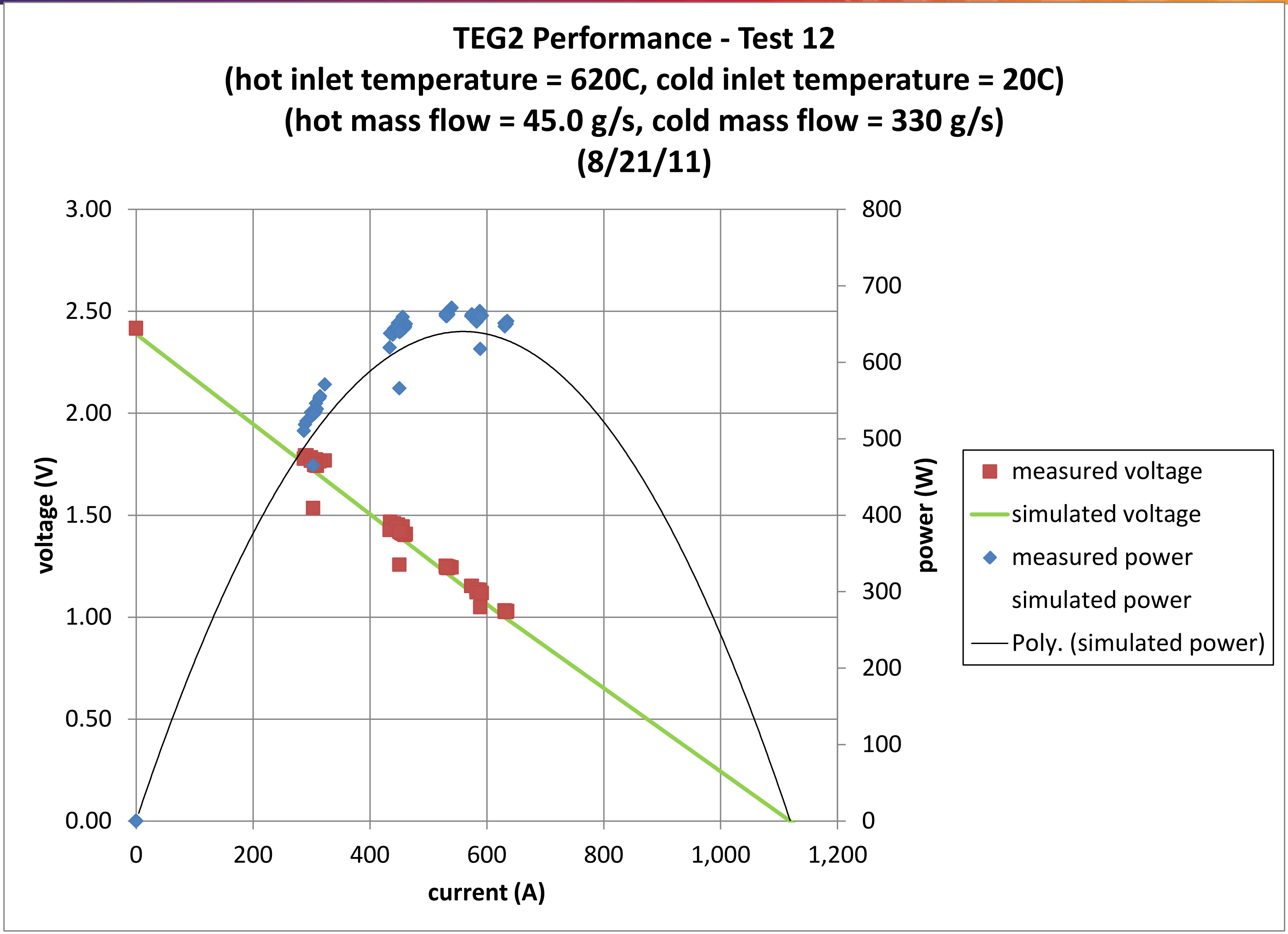
TEG TRANSIENT MODEL VALIDATION



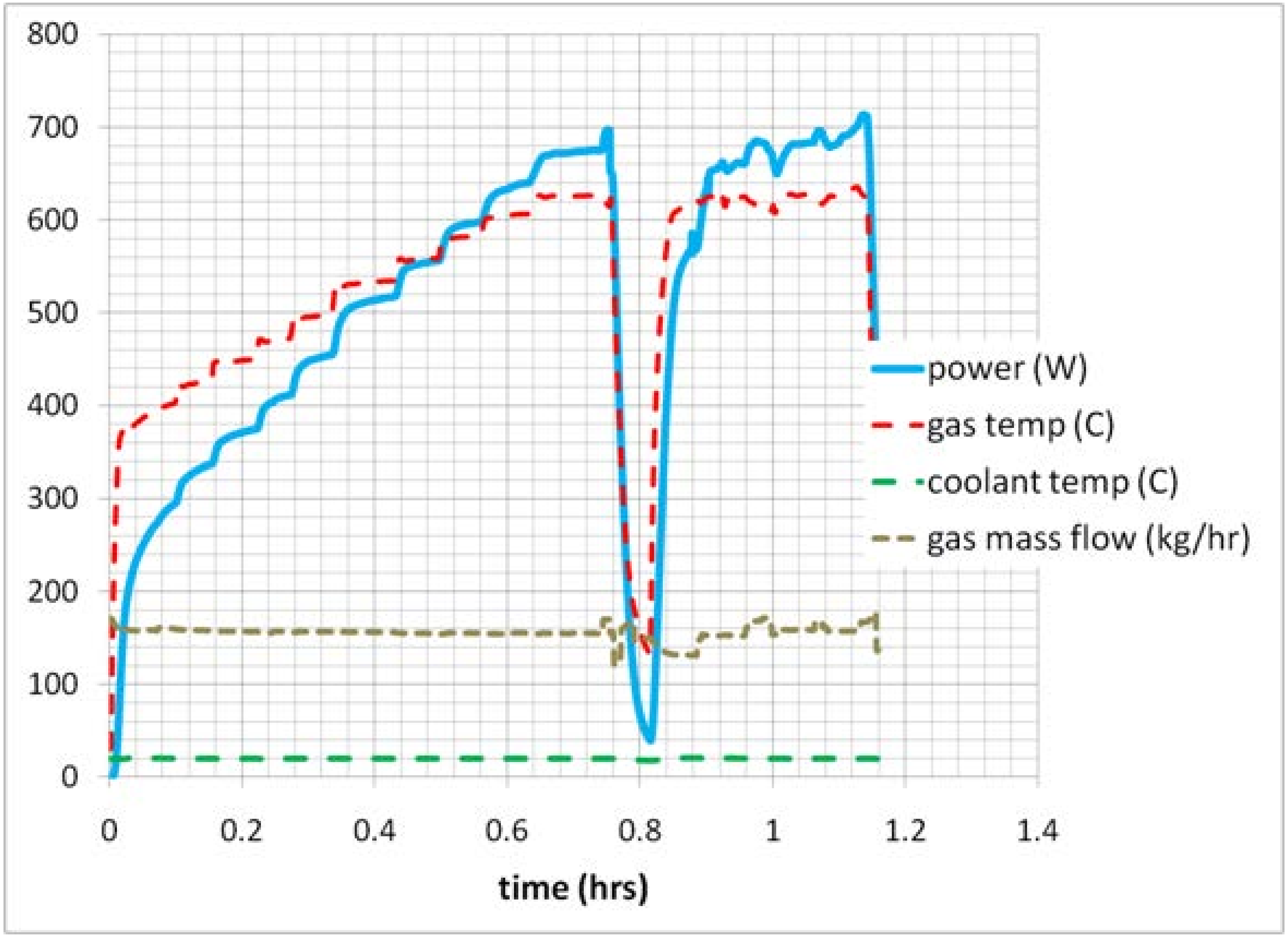


GENTHERM INSPIRING EFFICIENCY

SECOND TEG RESULTS & MODEL VALIDATION

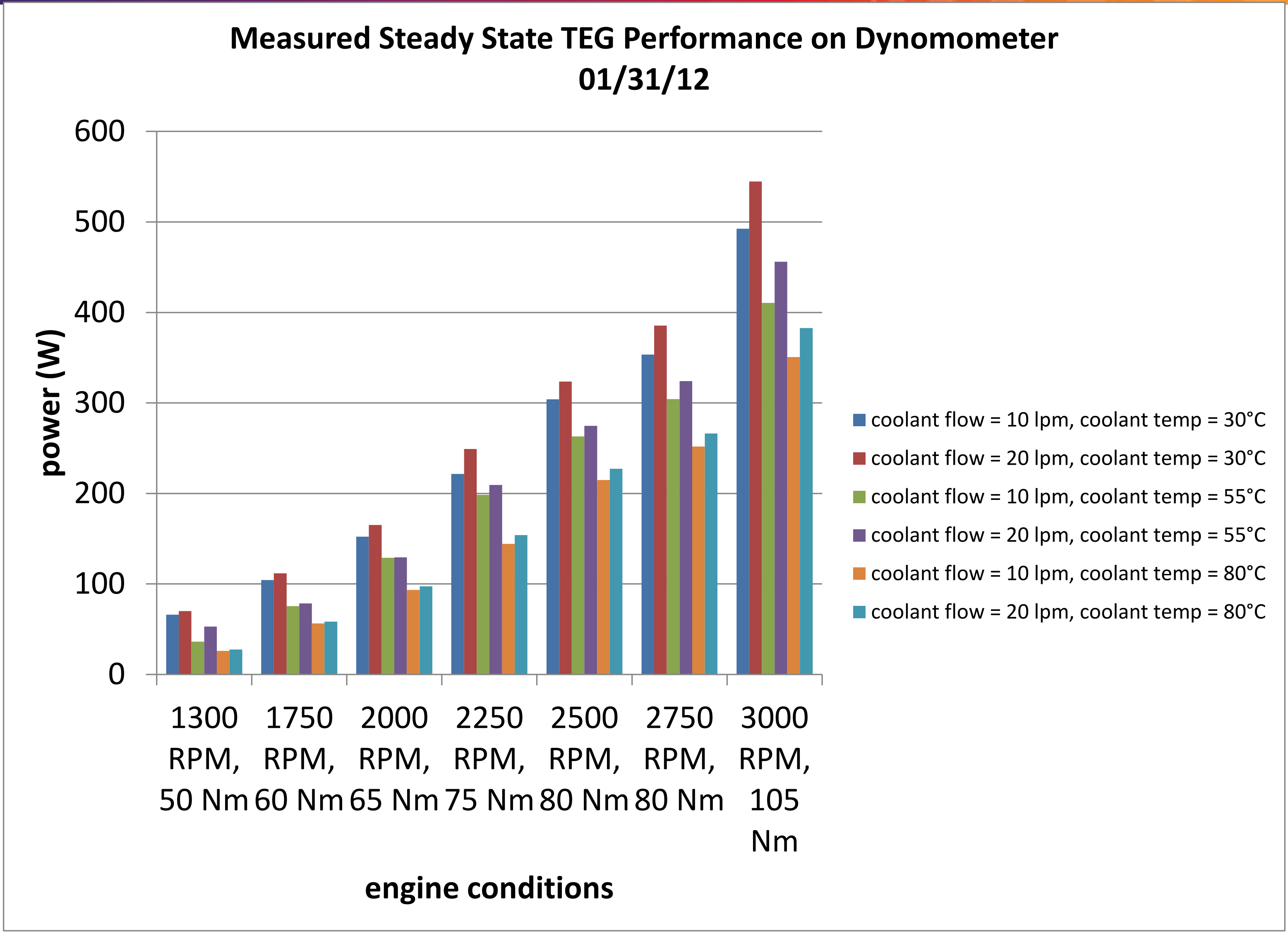


CYLINDRICAL TEG PERFORMANCE

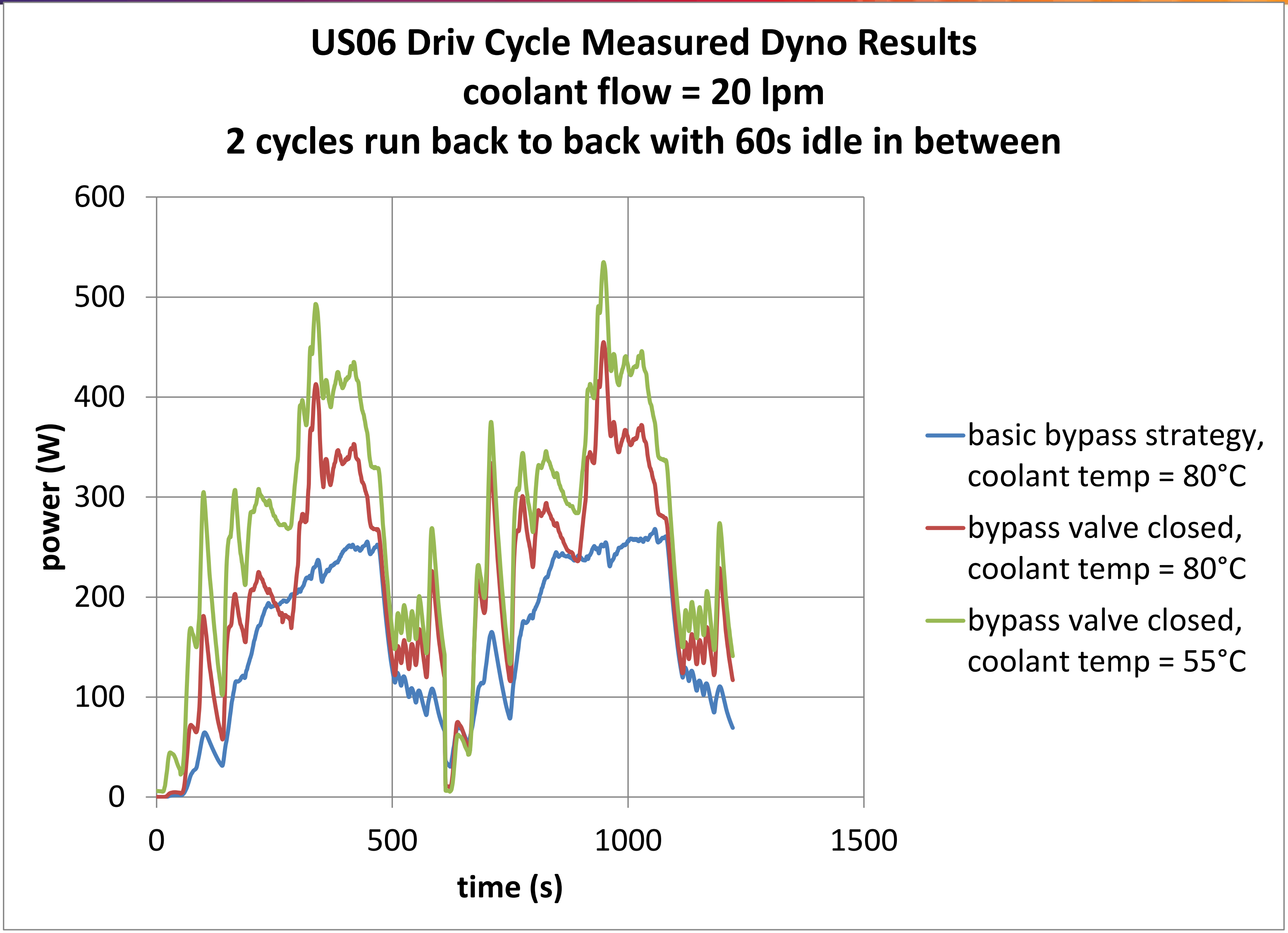


49 W/L (based on flange to flange dimension including outer shell and internal bypass)
1280 W/kg of TE material used

STEADY STATE POWER VS COOLANT FLOW/TEMP

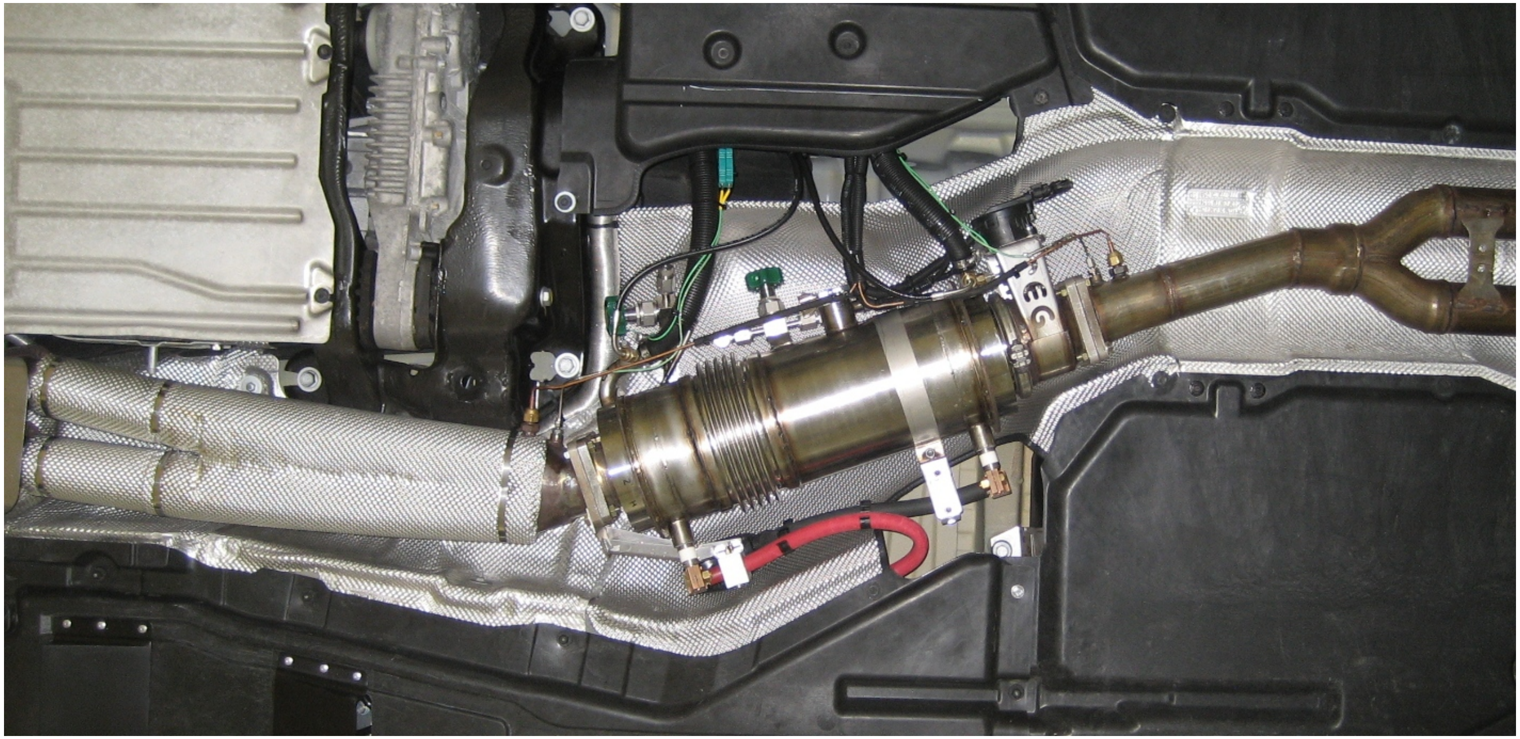


ENGINE DYNAMOMETER US06 DRIVE CYCLE RESULTS

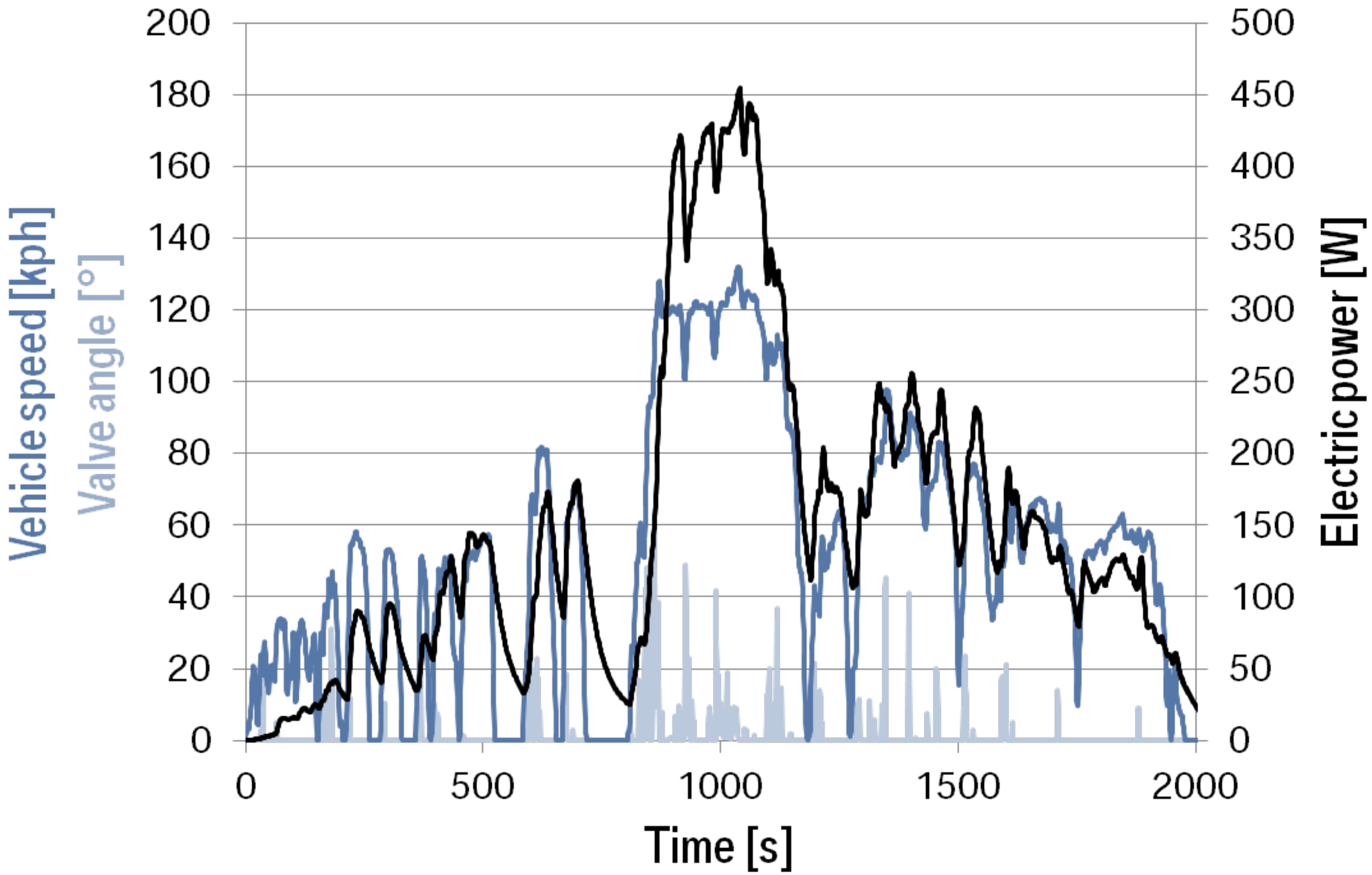


BMW X6

BMW X6 INSTALLATION

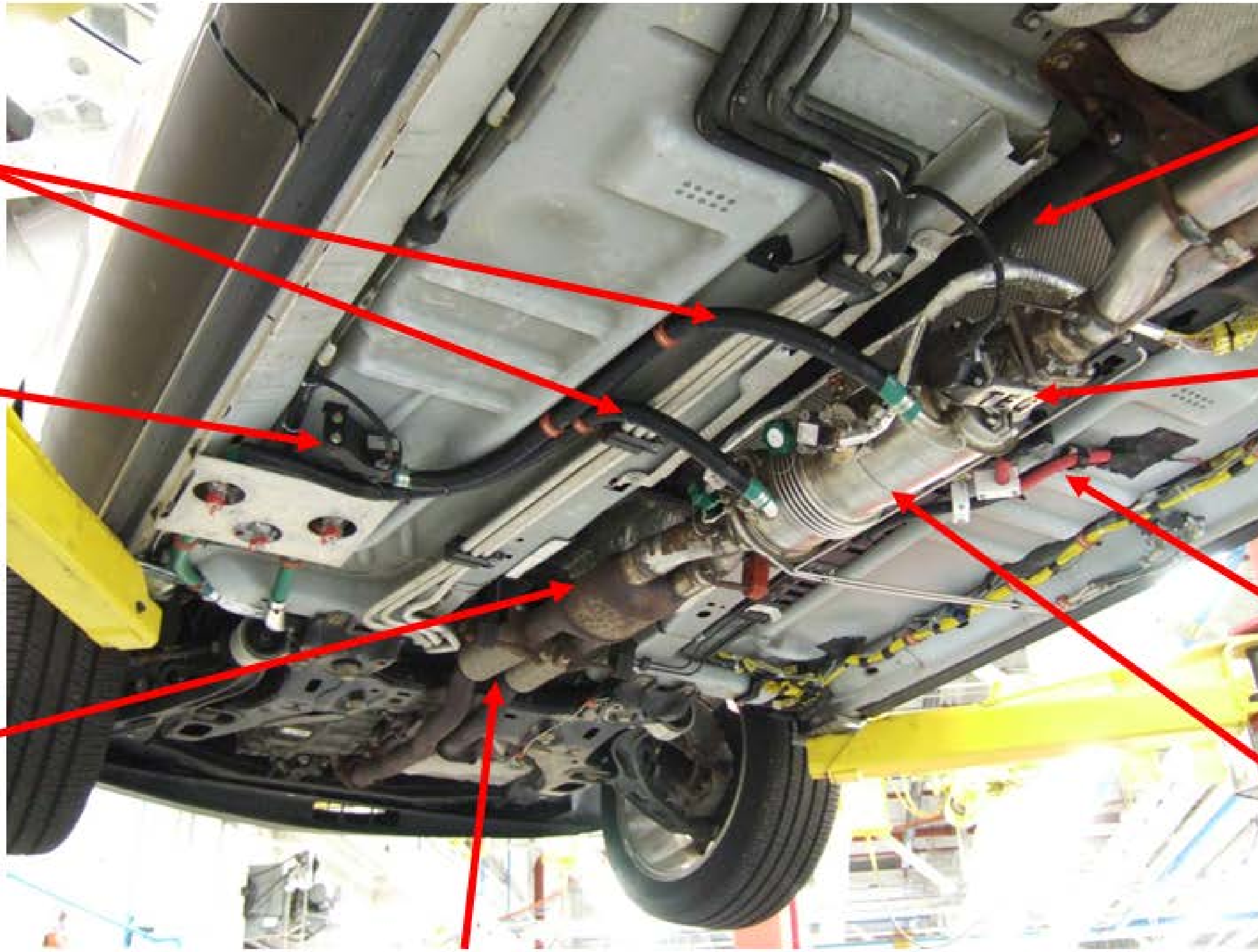


VEHICLE ON-ROAD TEST RESULTS

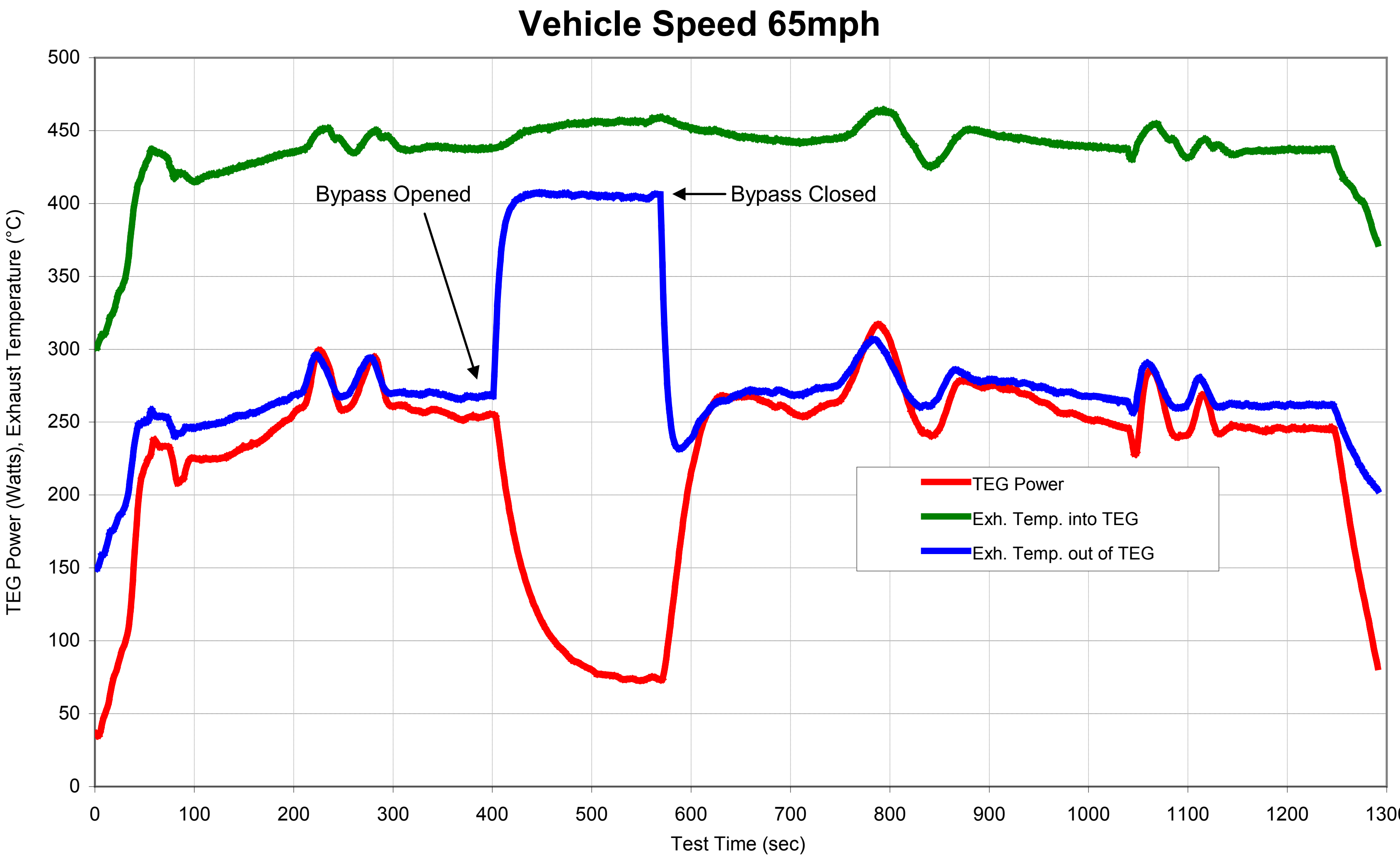


FORD LINCOLN MKT AWD

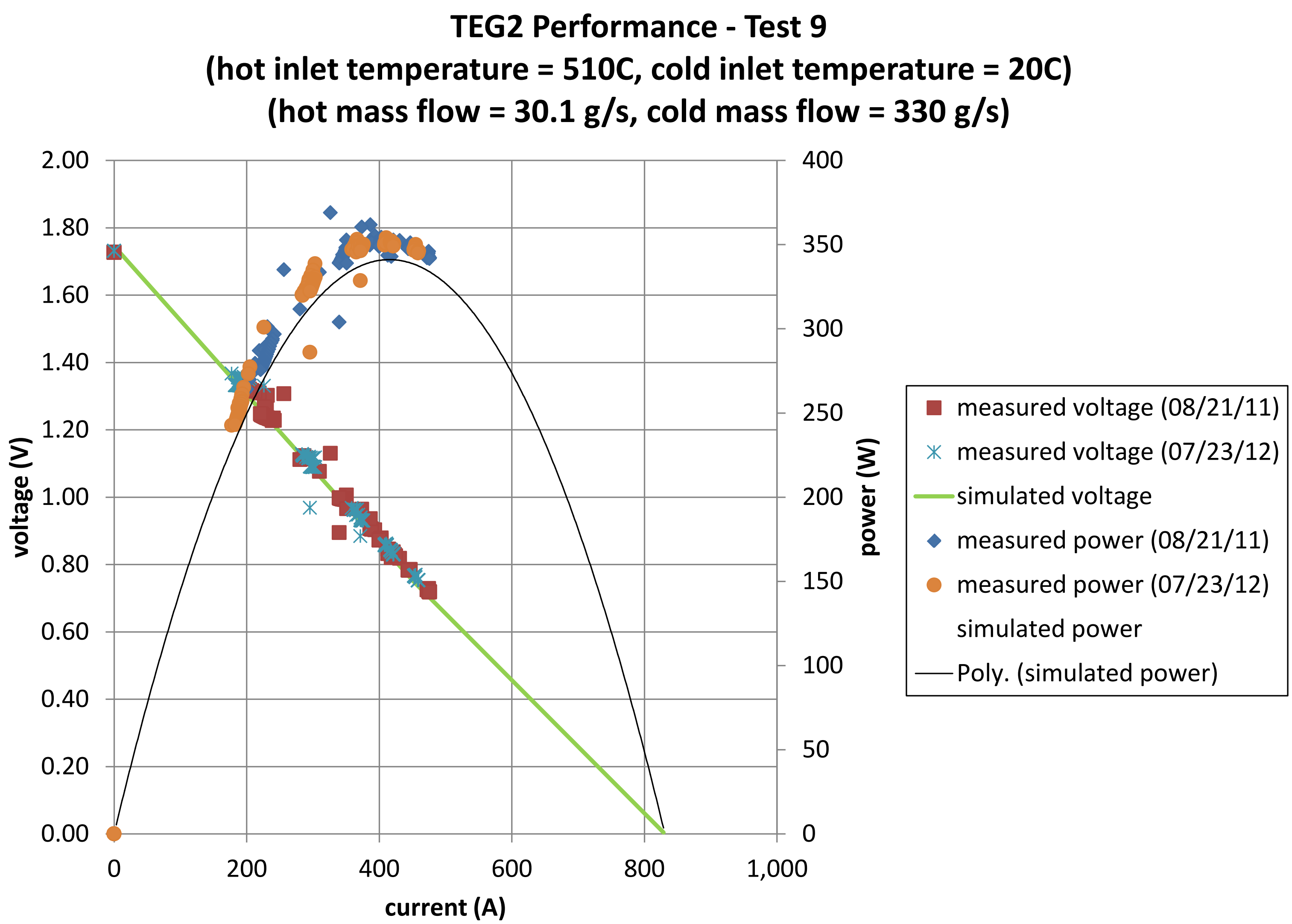
FORD VEHICLE INTEGRATION



VEHICLE ON-ROAD TEST RESULTS



TEG PERFORMANCE REPEATABILITY



SUMMARY

TEGs have been successfully integrated and tested on a BMW X6 and a Lincoln MKT with over 600W of power produced in vehicle tests and over 700W produced in bench tests.

Models have been created that can successfully capture TEG performance in both steady state and transient conditions.

These models have been integrated into vehicle system level models as well.

With the validation of the models against experimental data, the simulation tools can be used to optimize the geometries and operating schemes of the TEG designs.

A cylindrical TEG technology platform has been developed which is on a path to commercialization by the end of this decade.

OUTLOOK AND FURTHER WORK

Further work is required to address technical and economic risks for TEG commercialization:

- Material and system costs
- Design robustness and performance
- In automotive, FE Benefits Vs regulatory and customer drive-cycles

The partnership between BMW, Ford, Tenneco and Gentherm will continue in a follow-on DOE TEG program with the following key objectives:

- 5% FE gain for a passenger vehicle measured over the US06 drive cycle
- Economic feasibility defined for 100K/annum manufacturing volume
- Integrating TEG with 15L diesel engine in Bradley Fighting Vehicle program

ACKNOWLEDGEMENTS

US Department of Energy: John Fairbanks

DOE NETL: Carl Maronde

BMW: Boris Mazar, Andreas Eder, and Carsten Spengler

Ford Motor Company: Clay Maranville, Dan Demitroff, and Quazi Hussain