AMERIGON

Thermoelectric Generator Performance for Passenger Vehicles

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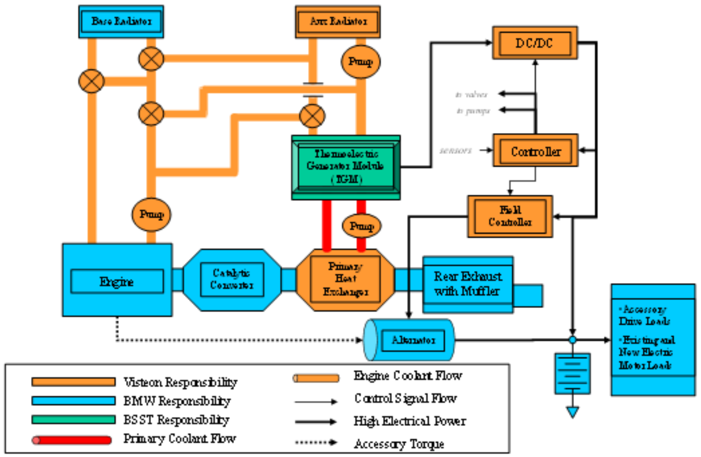
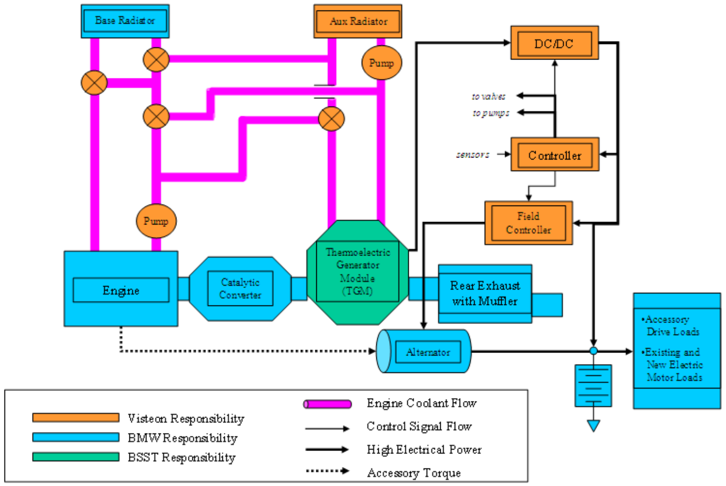
Program Overview

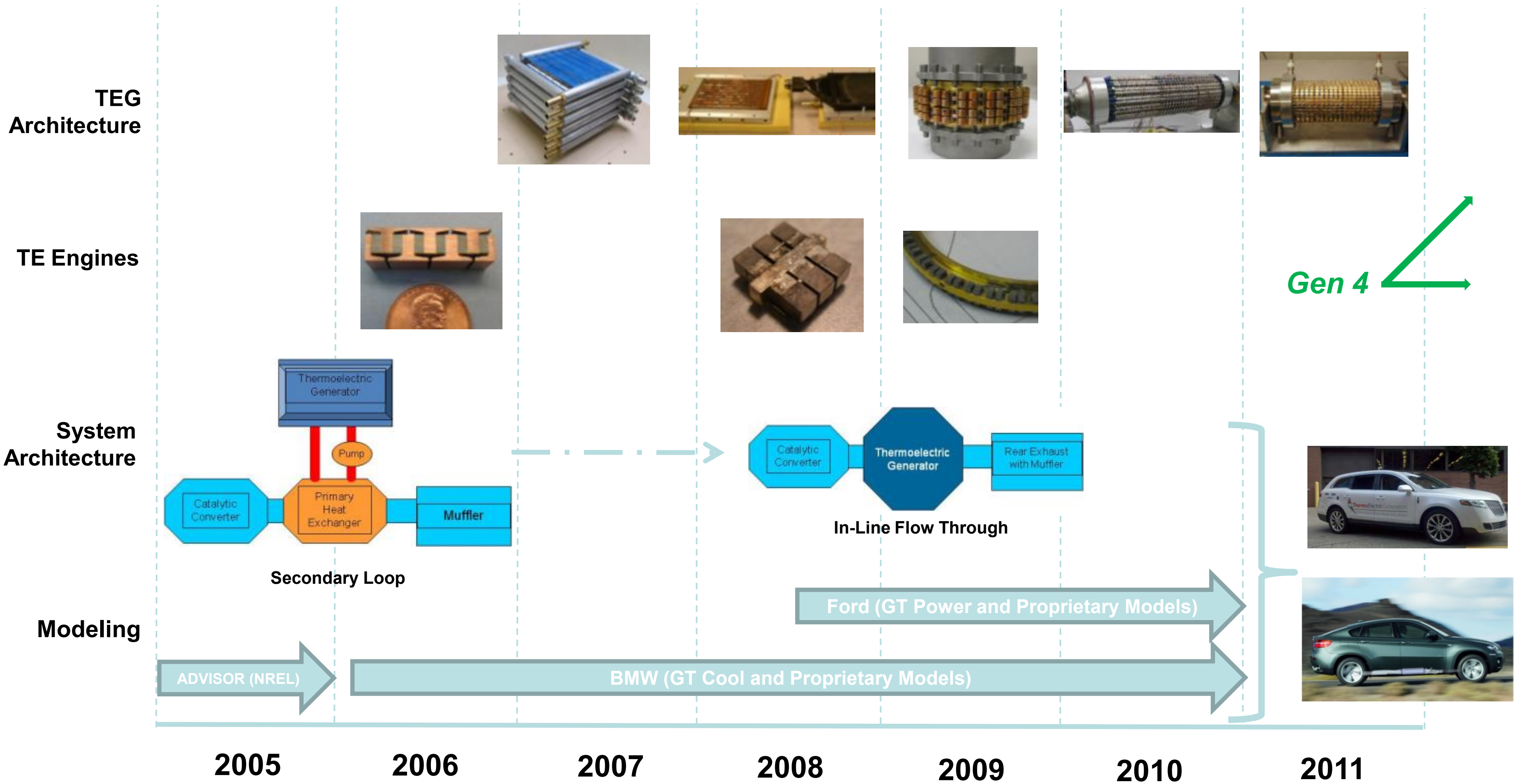
Amerigon recently completed a 7 year TEG program with partners BMW and Ford. The $10M program phases are described below:

- Phase 1: System modeling and architecture evaluation
- Phase 2: Subsystem design, build and bench test
- Phase 3: System integration. Planar configuration TEG with primary HEX and secondary loop, power converter
- Phase 4: Cylindrical TEG built and tested on test bench at Amerigon
- Phase 5: Improved cylindrical TEG built, installed, and tested on BMW X6 and Lincoln MKT vehicles





Technology Summary



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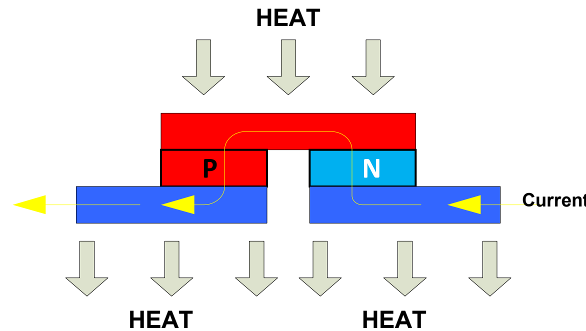
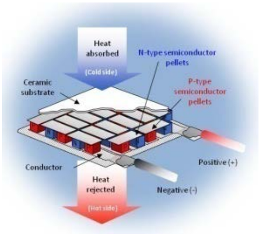
Stack Design TE Engine

Traditional TE module architecture consists of n & p type elements arranged in a planar array.

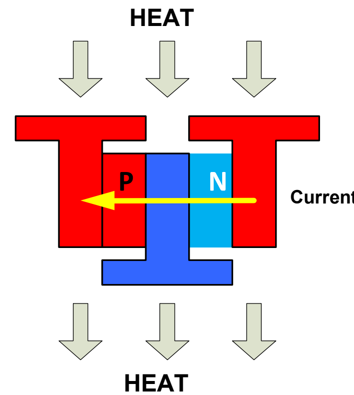
- Module size is constrained by thermally induced stress in the elements



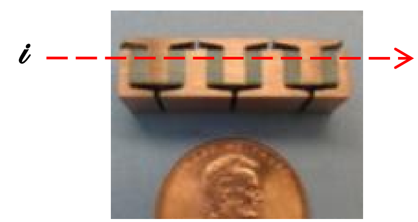
TRADITIONAL CONFIGURATION



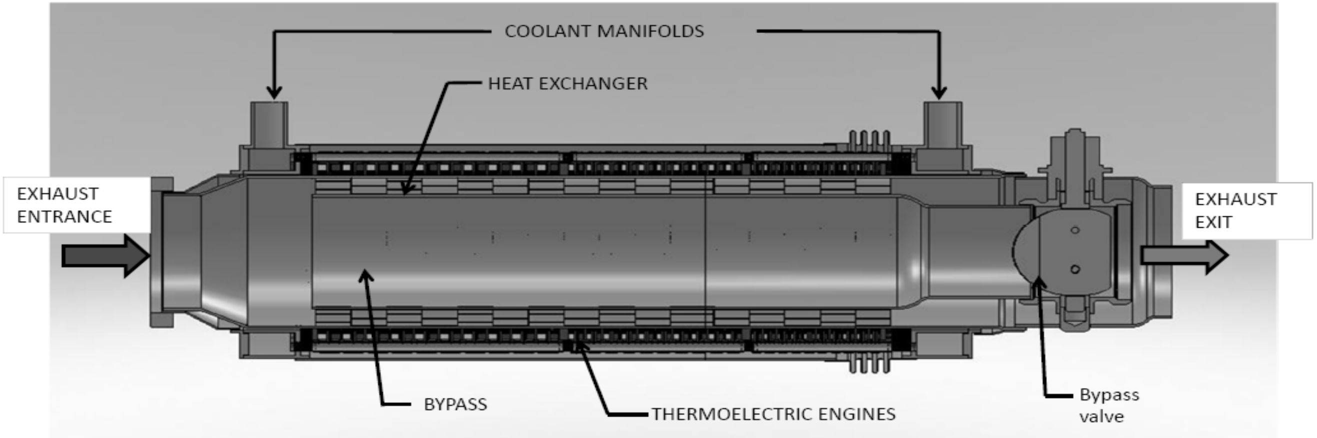
A stack design has been developed which enables shorter n & p leg lengths (less TE material = lower cost) and improved design flexibility.

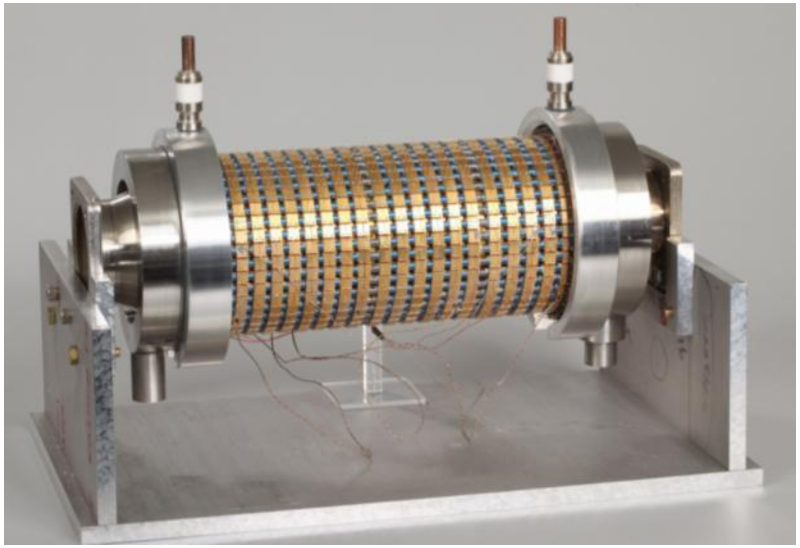


Amerigon Stack Design

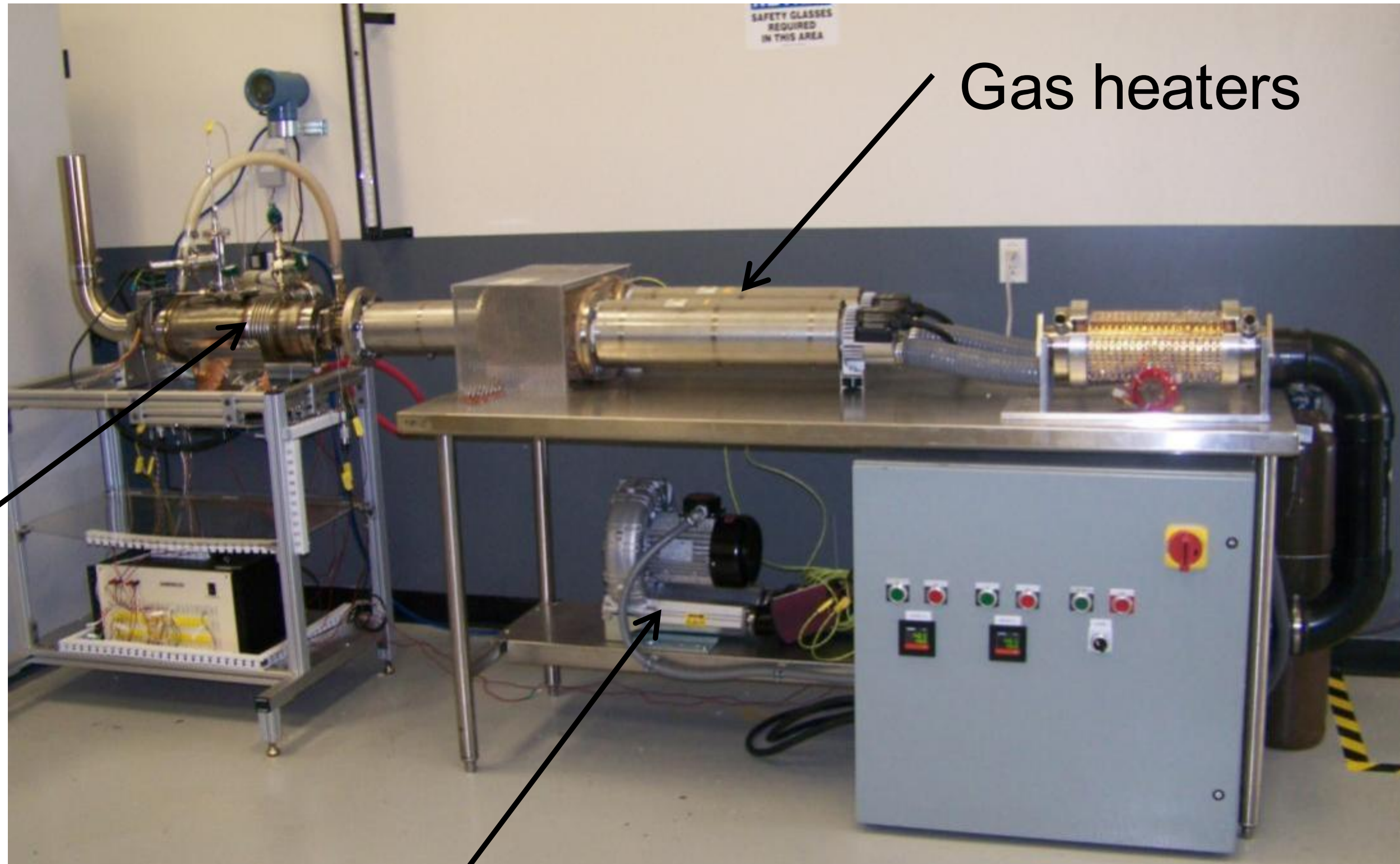


Cylindrical TEG





Bench Test Setup



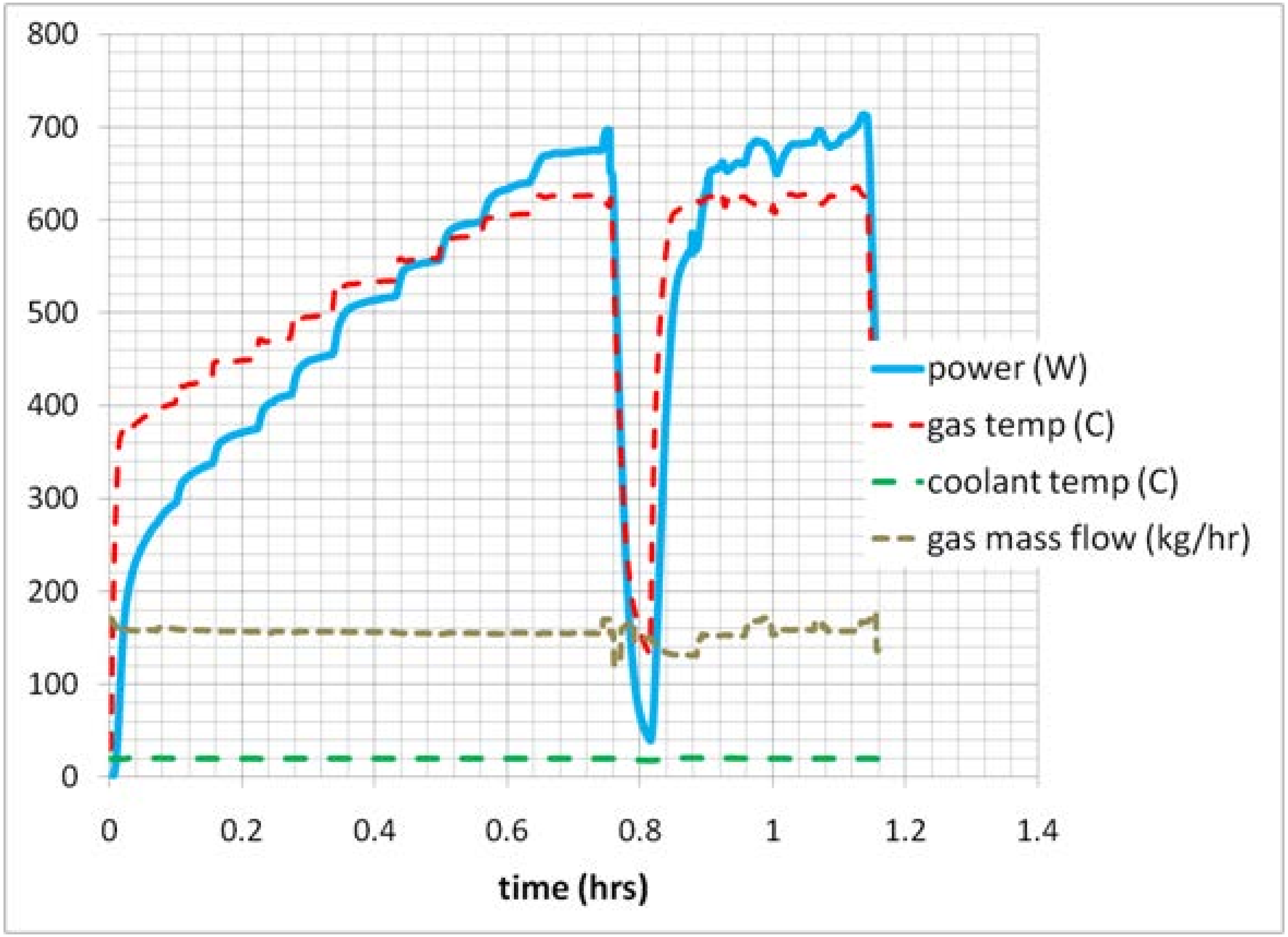
Test Conditions for Medium Temperature TEG

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

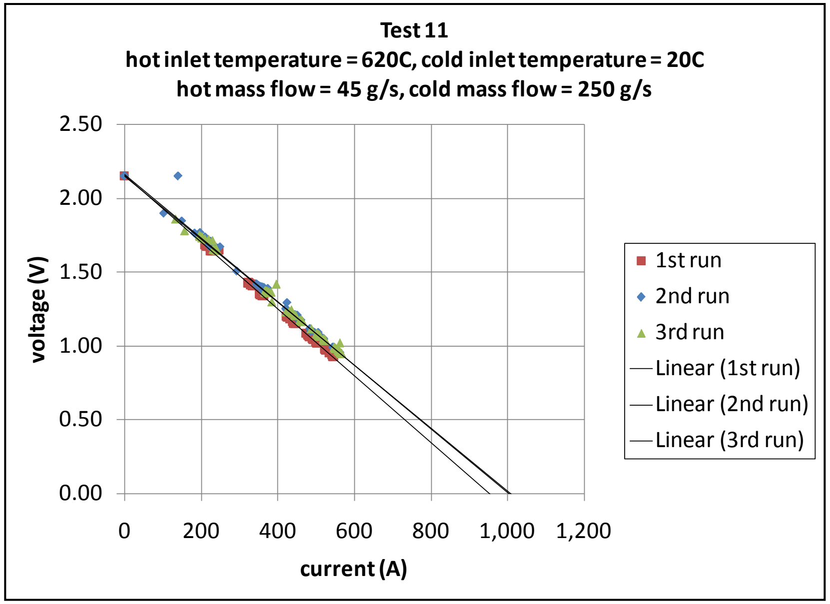
Test	13	14	15	16	17	18	19	20	21	22	23	24	25
Tfh,in (C)	390	390	390	425	425	425	510	510	510	620	620	620	620
Tfc,in (C)	40	40	40	40	40	40	40	40	40	40	40	40	20
vdot,h (g/s)	13.5	13.5	13.5	20.5	20.5	20.5	30.1	30.1	30.1	45	45	45	48
vdot,c (g/s)	170	250	330	170	250	330	170	250	330	170	250	330	330
max power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

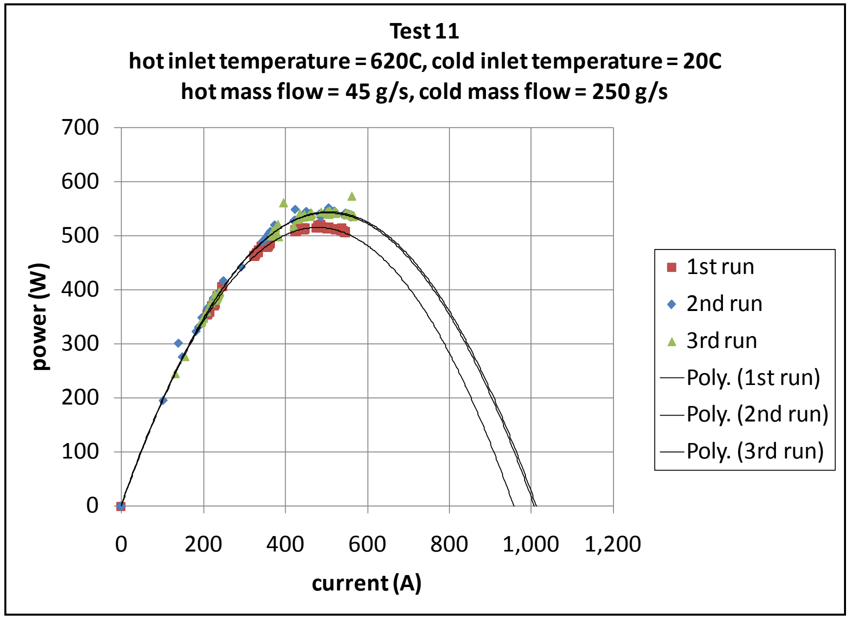
Note: Test 24 not completed due to the chiller overheating.

Cylindrical TEG Performance



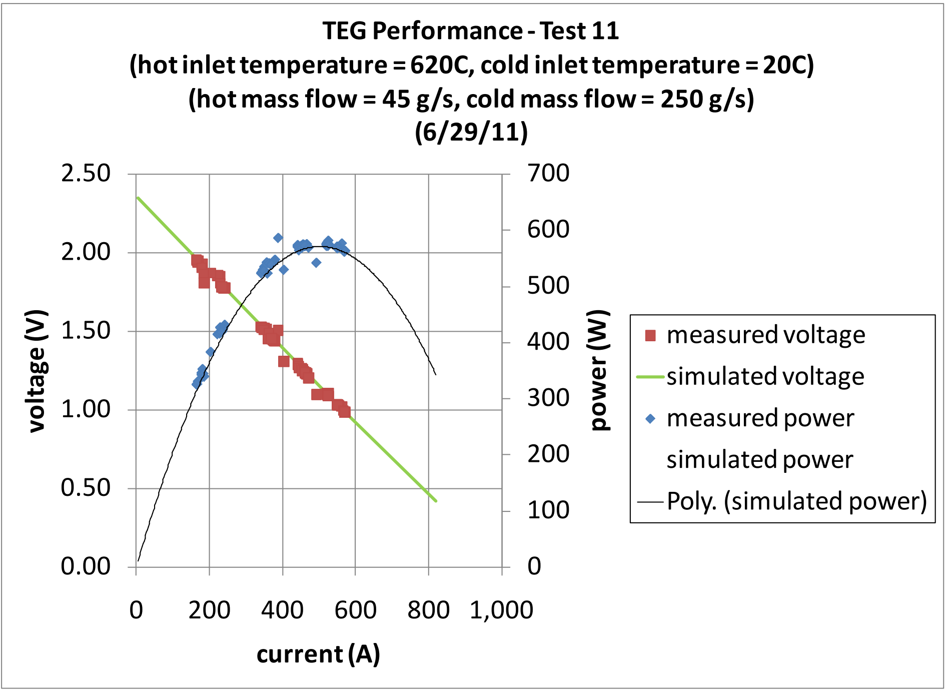
Run Repeatability

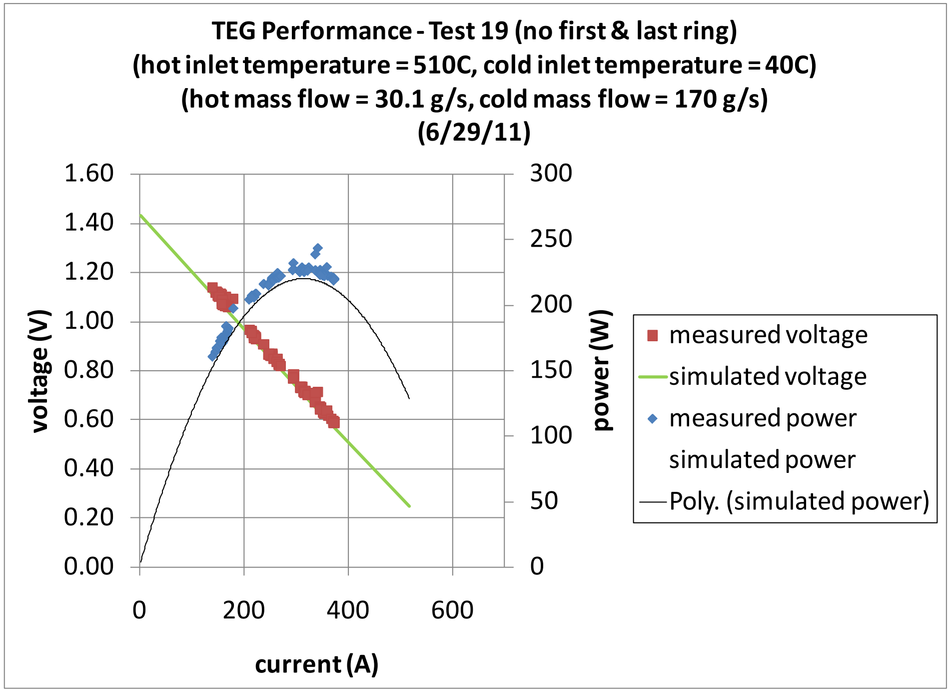




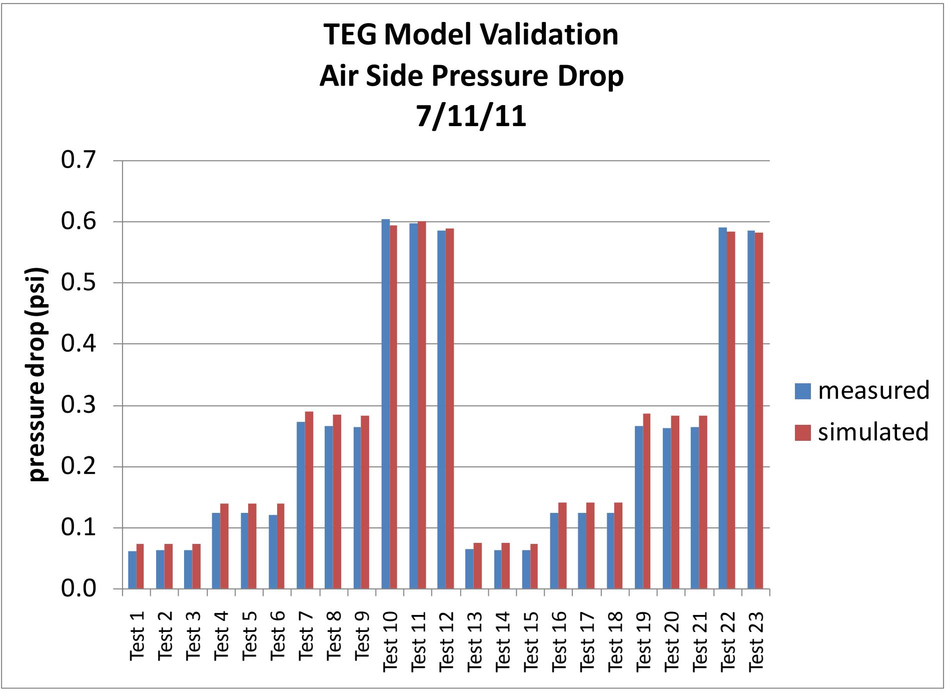
- The three runs were performed over a period of two weeks (over 25 hours of testing) and show good repeatability.
  - There is a 9% decrease in electrical resistance from run 1 to run 2 due to "settling in" of the device interfaces
  - This reduction in electrical resistance caused a 5% increase in peak power

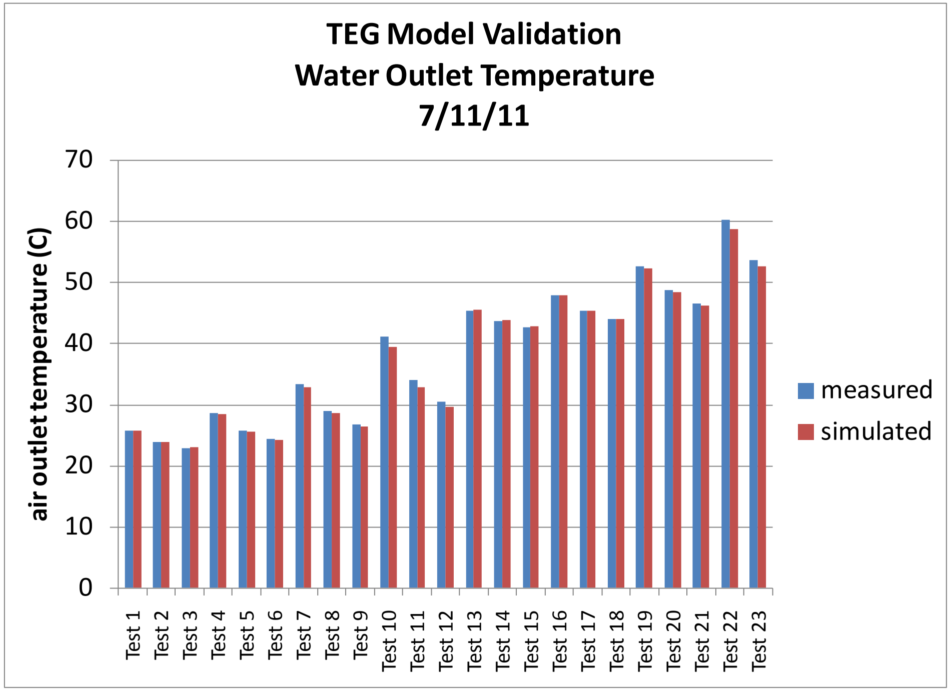
Power & Voltage Validation



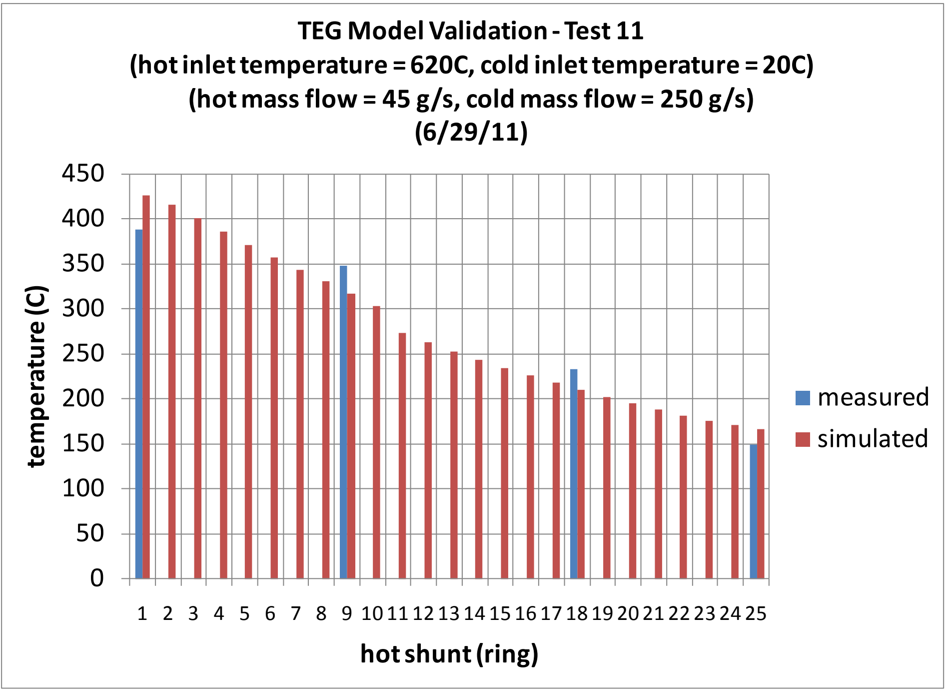


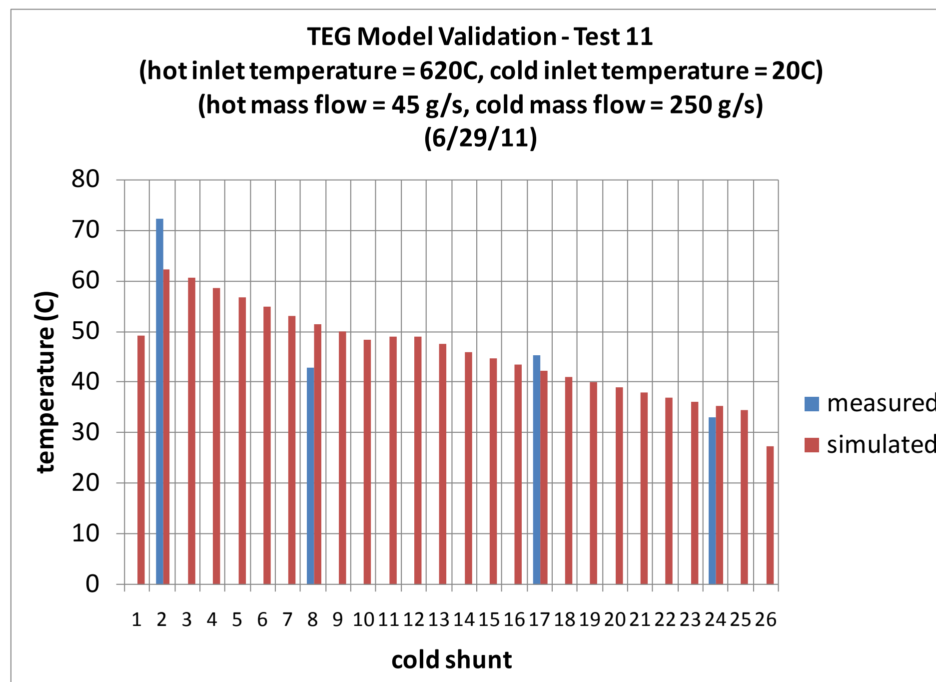
Air Pressure Drop & Water Outlet Temperature Validation



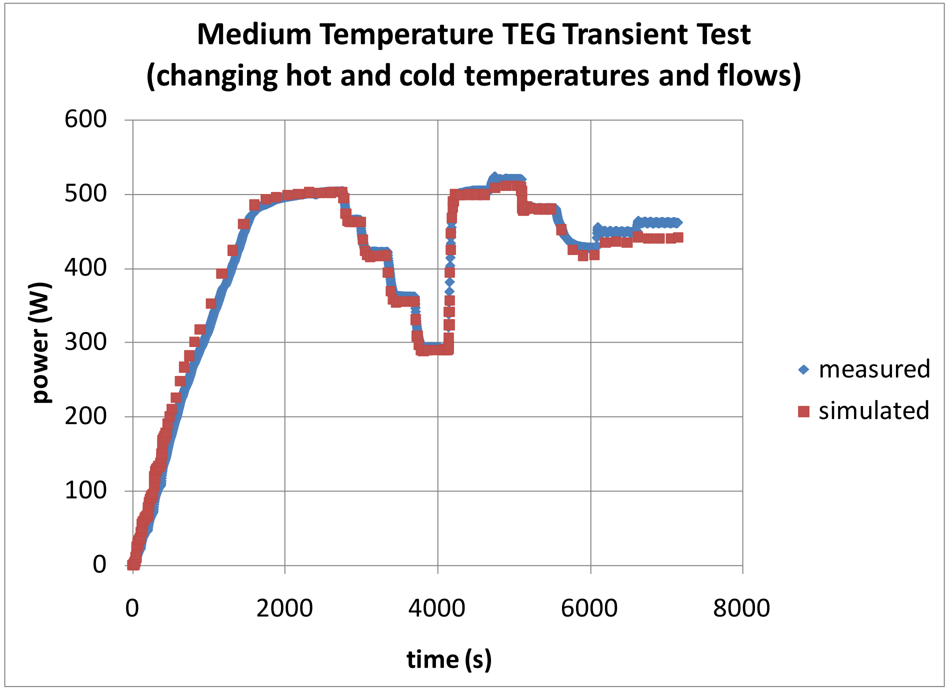


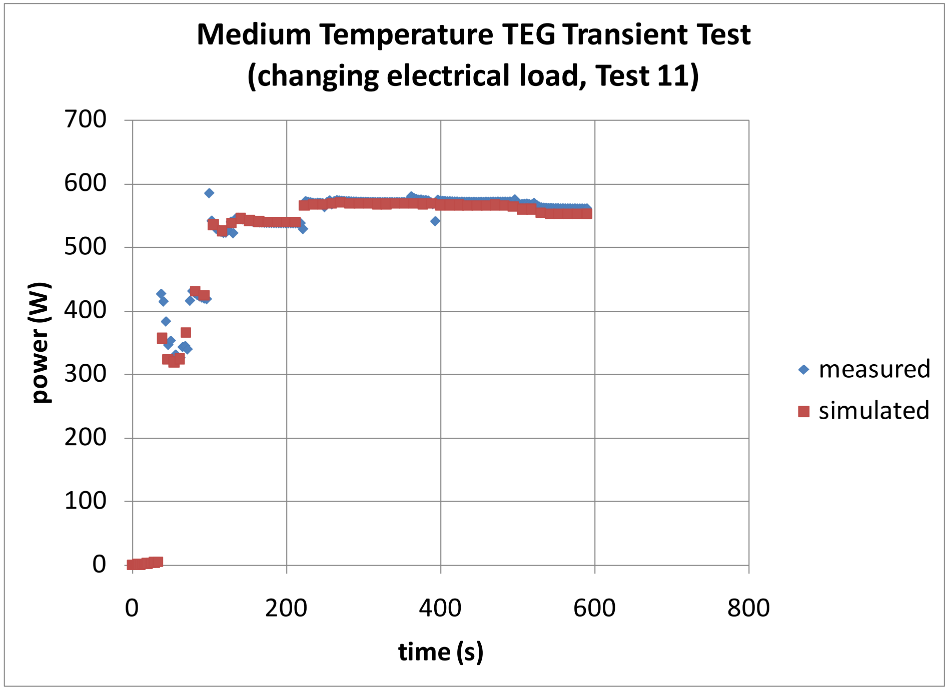
Hot & Cold Shunt Temperature Validation



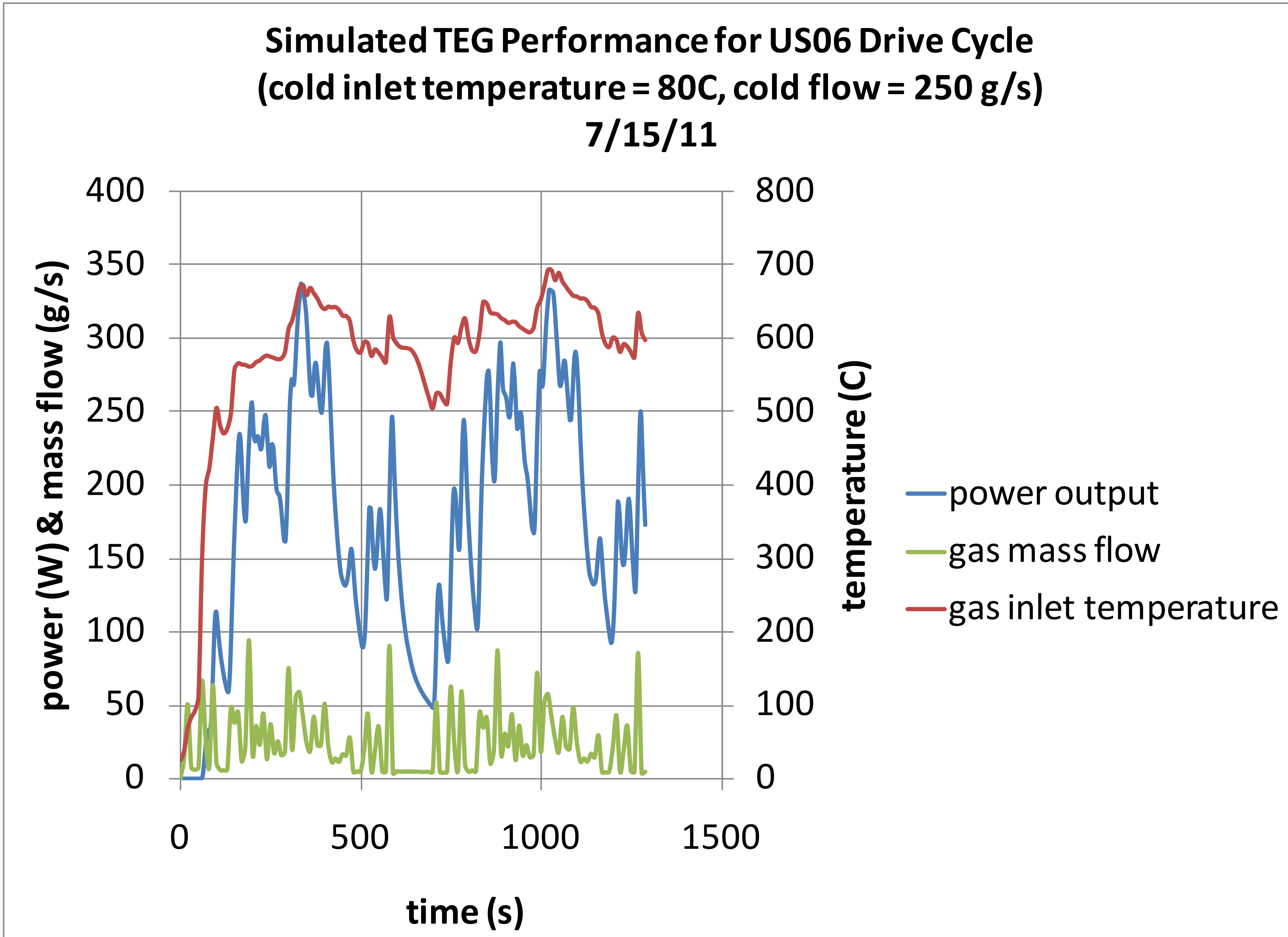


Medium Temperature TEG Transient Model Validation

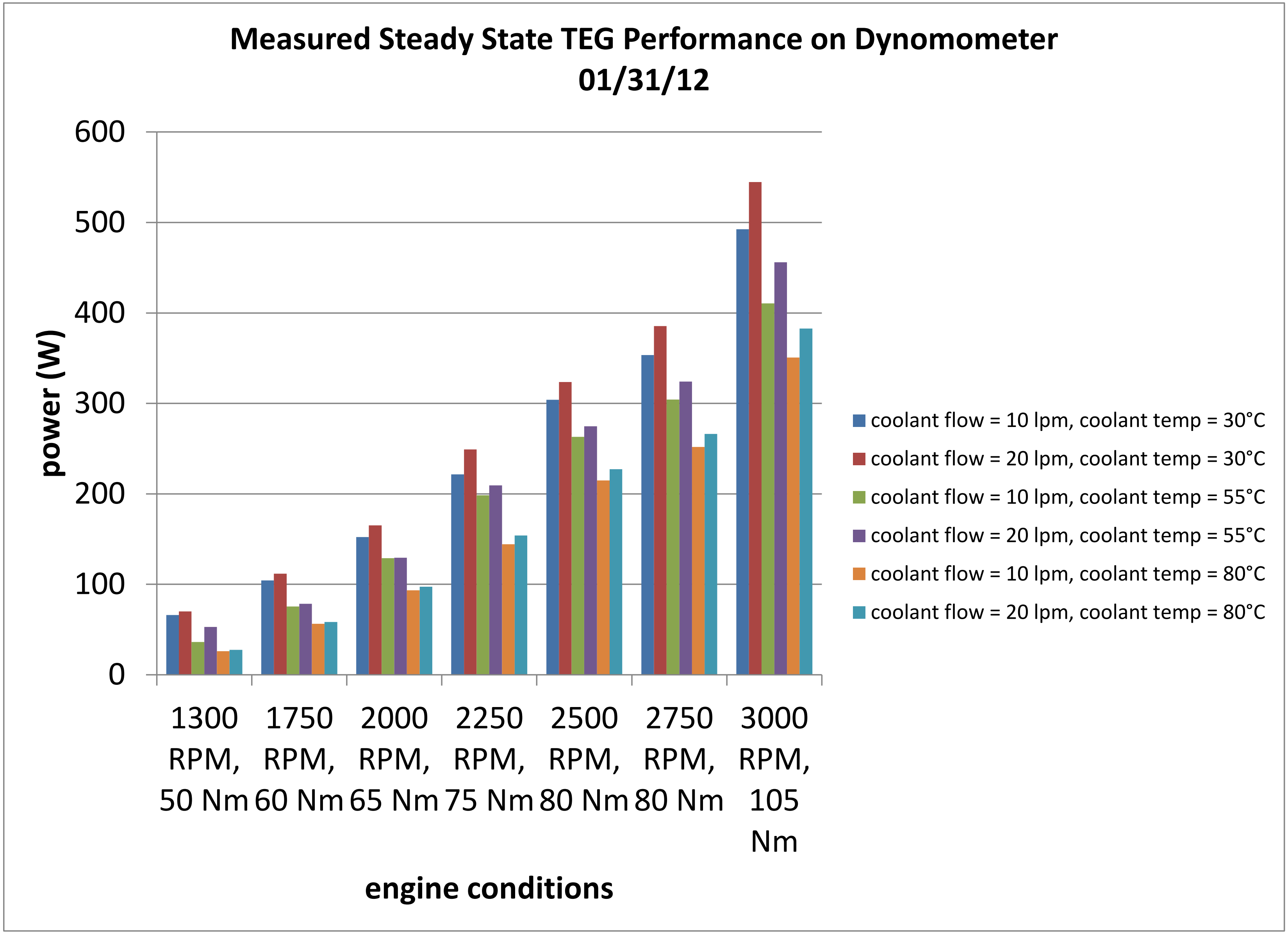




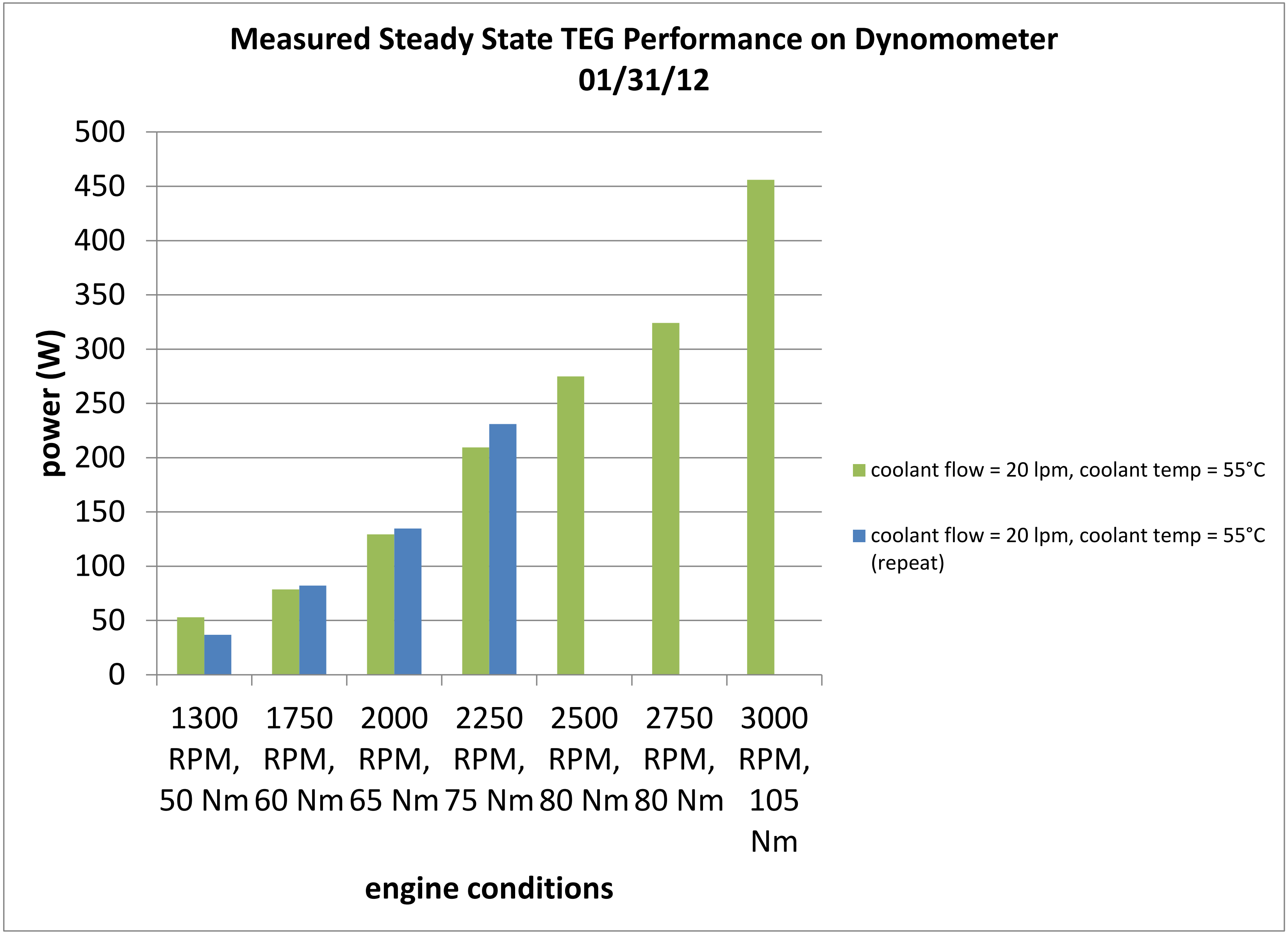
US06 Simulated TEG Performance



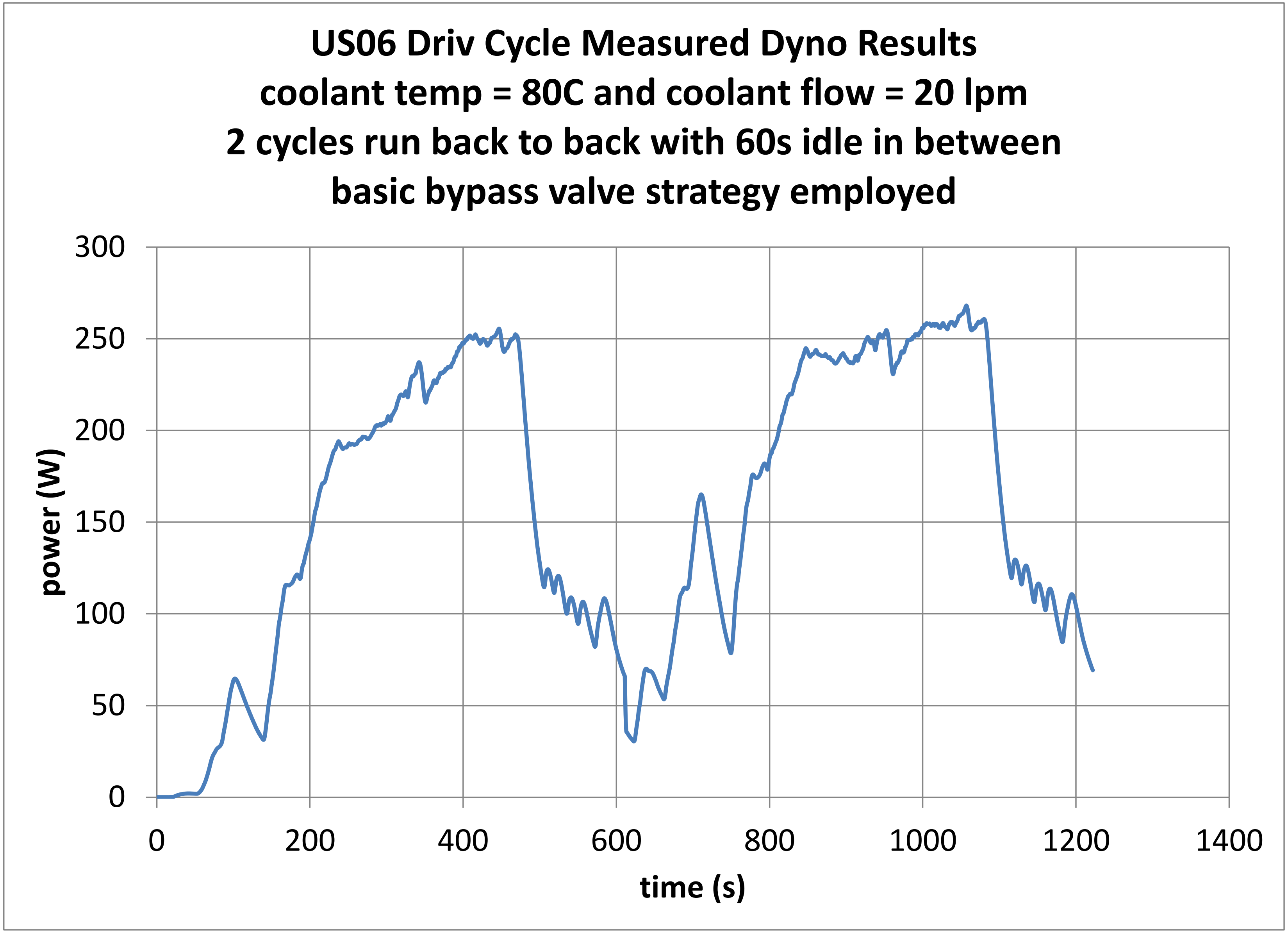
Steady State Power Vs Coolant Flow/Temp



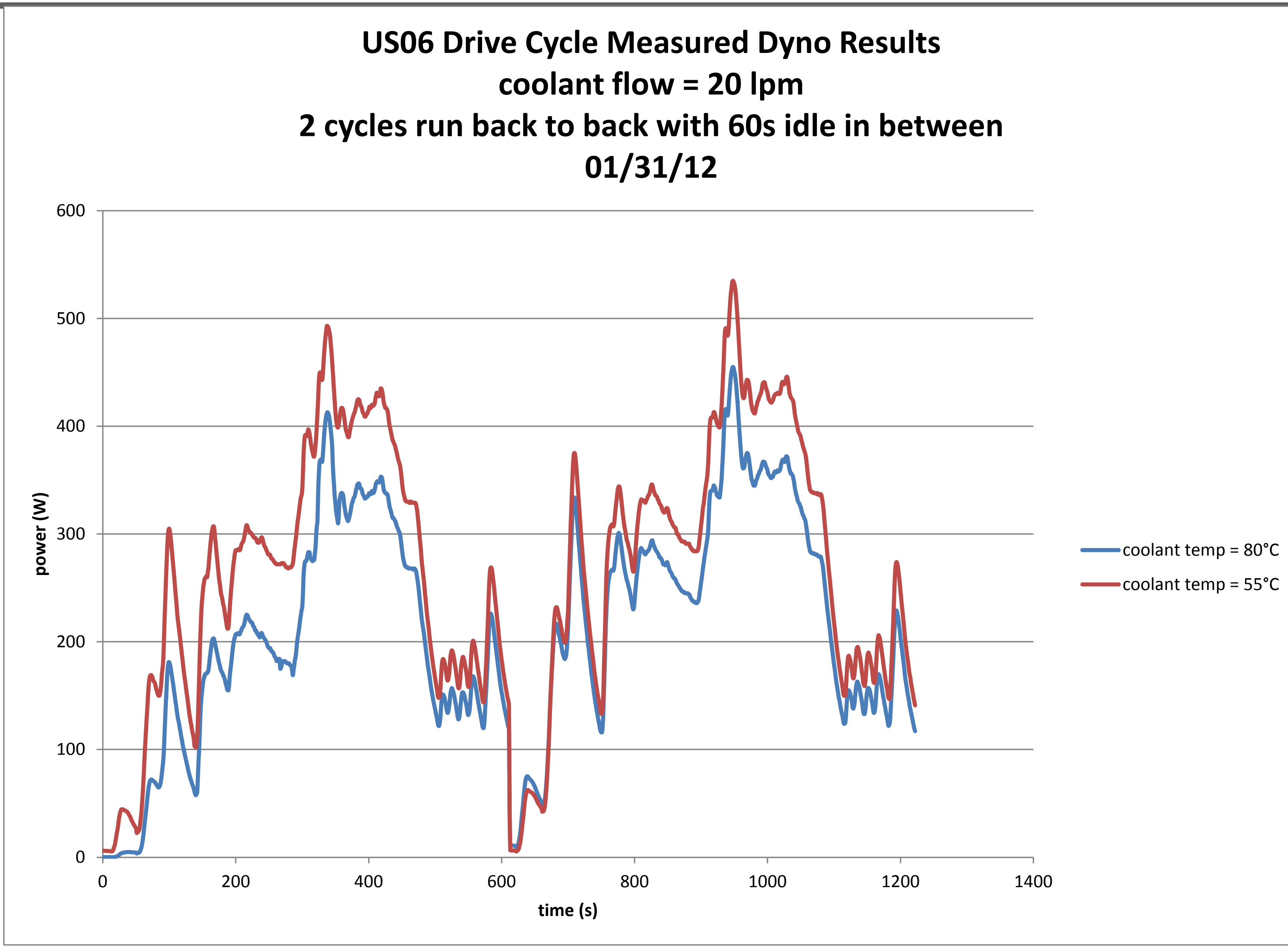
Repeatability: Steady State Power



Engine Dynamometer US06 Drive Cycle Results

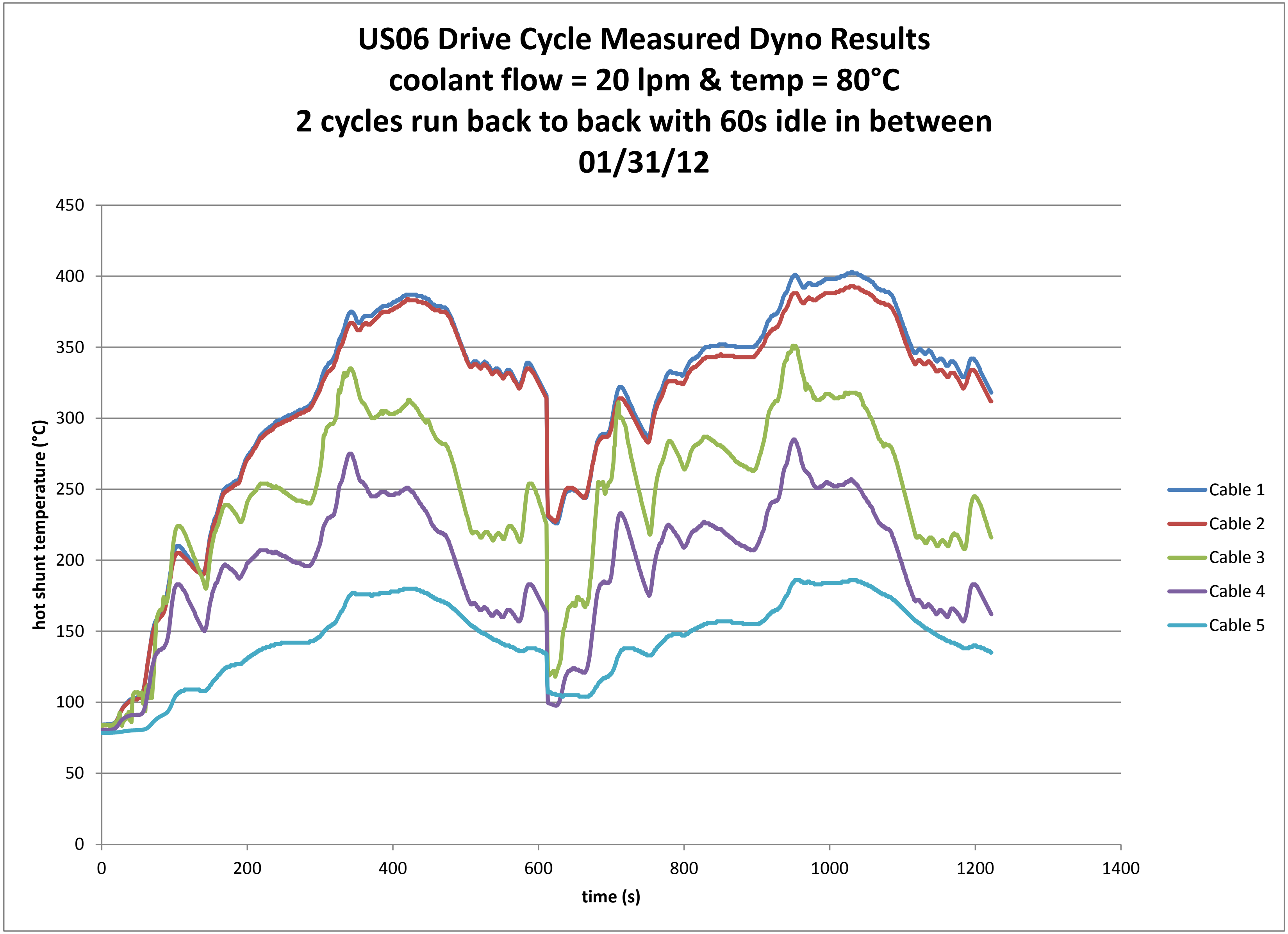


Engine Dynamometer US06 Drive Cycle Results

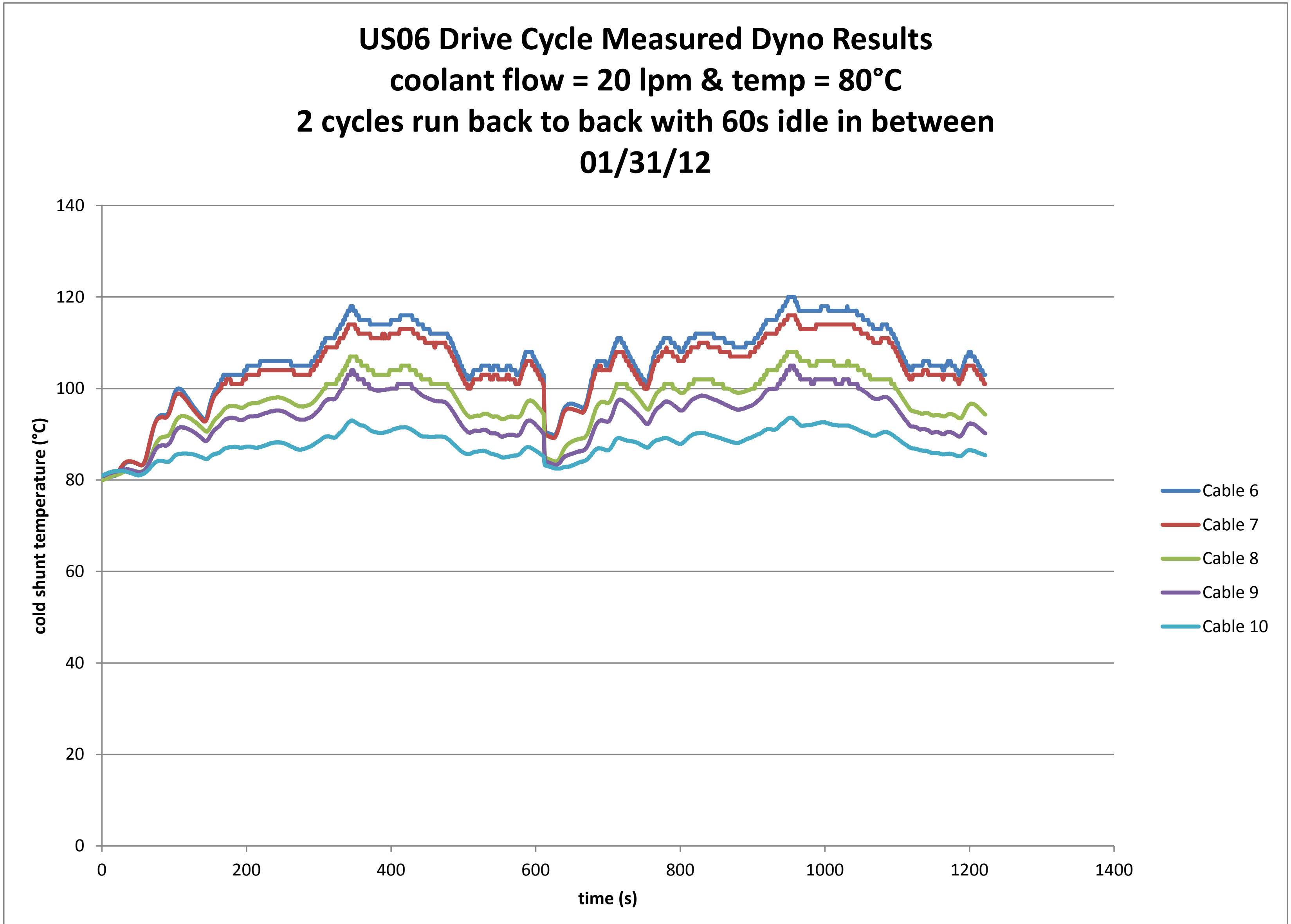


Note: Bypass valve closed for cycle

TE Mat'l Surface Temperatures (Hot) Vs US06



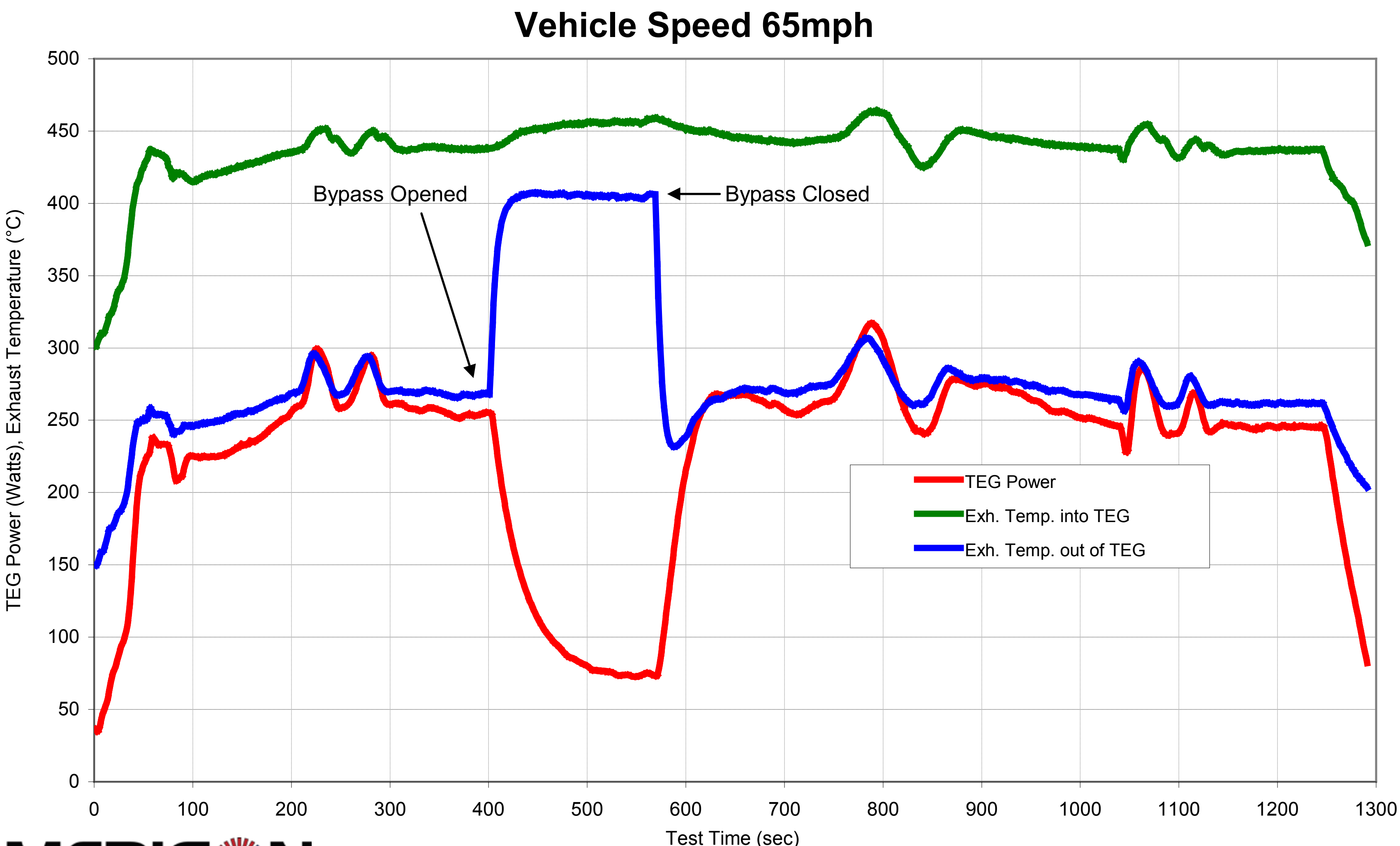
TE Mat'l Surface Temperatures (Cold) Vs US06



Ford Lincoln MKT AWD

Vehicle Integration

Vehicle On-Road Test Results



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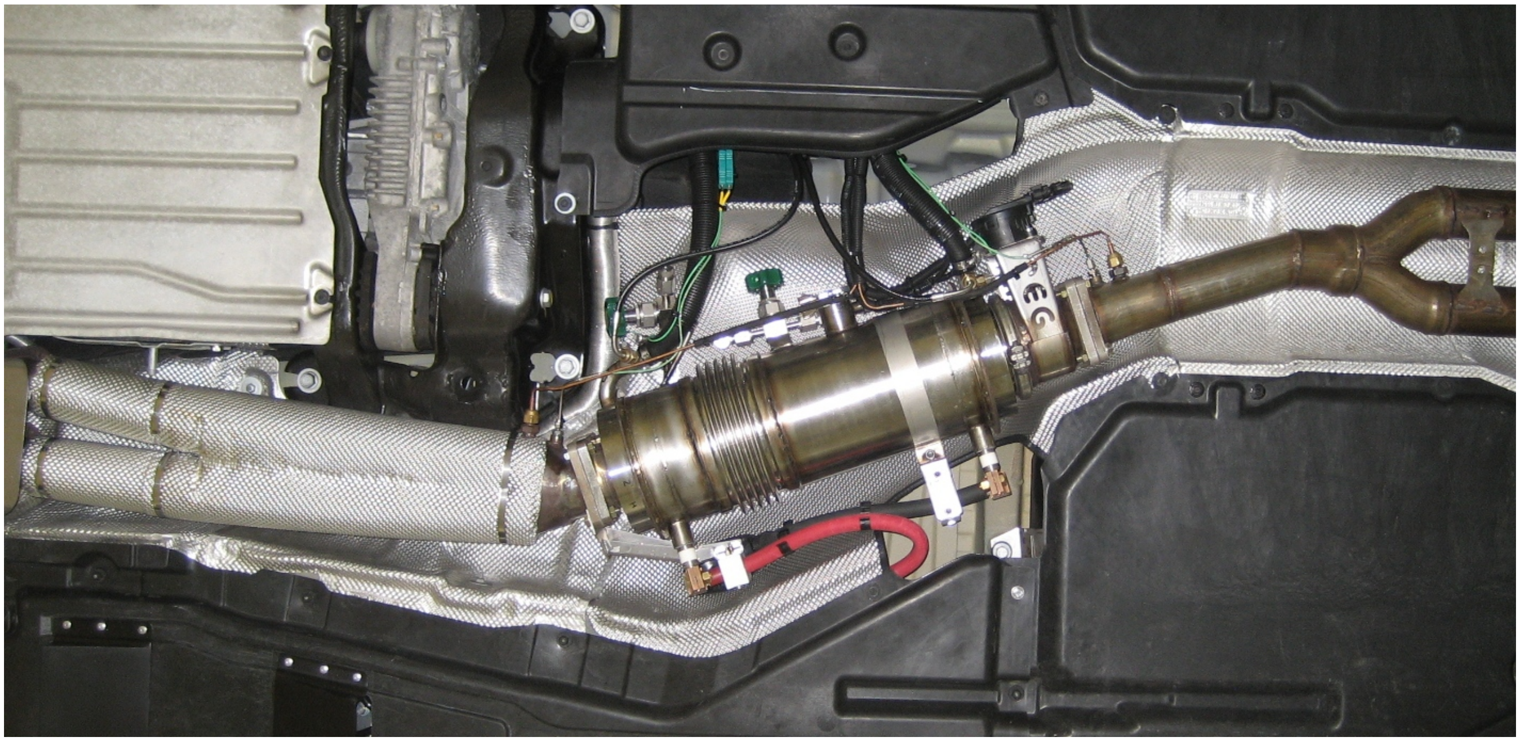
BMW X6

BMW X6 Installation



Summary

TEGs have been built and bench tested with over 700W of power output achieved with air inlet temperatures up to 620C.

TEGs were installed in a BMW X6 and Lincoln MKT with at least 450W of power output achieved in road tests for both vehicles.

Repeatable performance has been achieved in bench and engine dynamometer testing. Repeatable performance still being achieved in over 6 months of vehicle testing.

Steady state model has been validated to within 10% error for a wide range of operating conditions and load resistances for power, voltage, temperatures, and pressure drops for TEGs with varying TE material

Transient model has been validated to within 10% error for a wide range of operating conditions and load resistances for TEGs with varying TE material

Validated transient model has been used to simulate automotive drive cycles such as the US06

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
- FE Benefits Vs regulatory and customer drive-cycles

The partnership between BMW, Ford, and Amerigon 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

Acknowledgements

US Department of Energy: John Fairbanks

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