GASTone: an integral approach to maximize efficiency in heavy duty CNG engines

Alberto M. Merlo, **Alex Rinaldi** — *Centro Ricerche Fiat S.C.p.A.*
Stefano Golini, Francesco Tucci — *FPT Industrial*
Rainer Gietl, Andreas Schiessl — *Continental Automotive GmbH*
Estefania Hervas Blasco, Emilio Navarro Peris — *UPVLC*

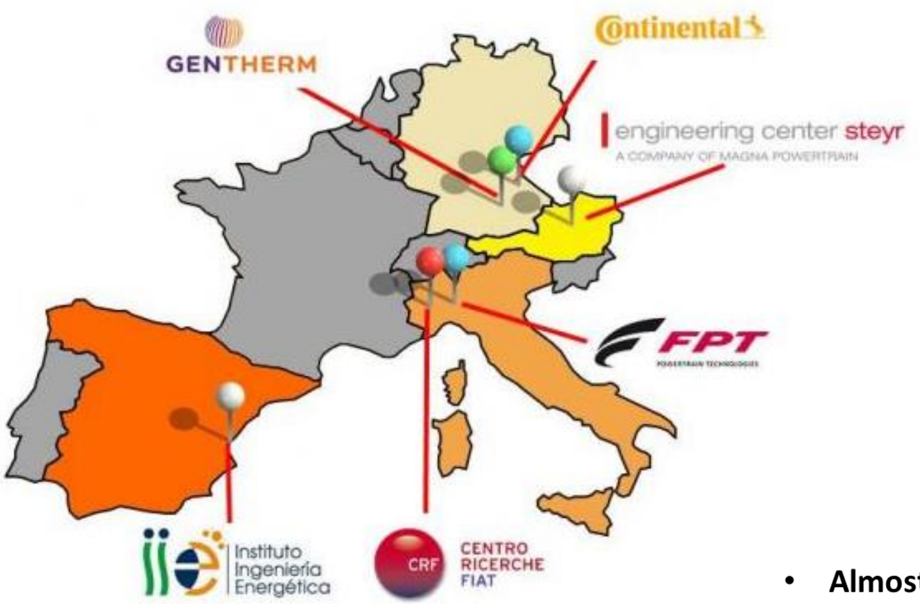
Summary

- GASTone Project
- Concept and Objectives
- Application Study
- System Validation
- Vehicle Simulations Results
- Exploitation

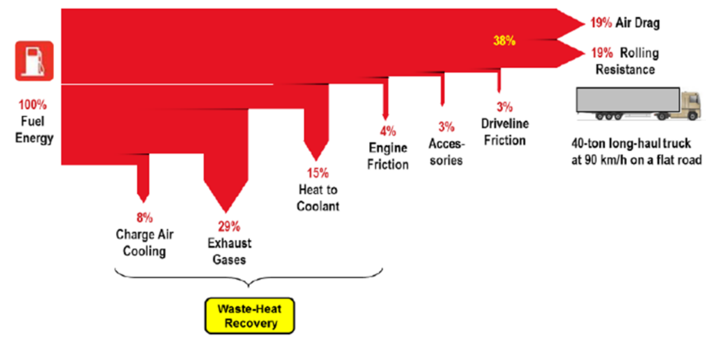
Project GASTone

CONSORTIUM

***GASTone** is a collaborative Project funded by the European Commission under the Grant agreement n° 605456 of the 7th Framework Program.*



MOTIVATION



- **Almost 2/3 of the fuel energy of a today long distance truck is dissipated energy available as heat:**
  - 1/3 a high temperature from the exhaust gas system
  - 1/3 dissipated to the coolant system
- **In addition, these vehicles often operate for long periods of time under pretty constant conditions:**
  - Energy recovery systems can be design to work regularly (beltless driven)
  - The electric energy generated would be used almost immediately

Concept and Objectives

OVERVIEW

The aim of the research was to develop an innovative high efficient energy conversion concept for a Natural Gas heavy duty engine focused on the integration of energy recovery devices, energy storage and engine auxiliaries electrification.

This target was mainly reached based on the following three streams:

- The ***ENERGY RECOVERY*** from the exhaust gases heat with a cascade approach thanks to the adoption of two advanced devices:
  - ***THERMOELECTRIC GENERATOR (TEG)***
  - ***TURBO-GENERATOR (TBG)***
- The integration of a ***SMART KINETIC ENERGY RECOVERY SYSTEM*** to replace the alternator and generate electricity during decelerations ***IMPROVING THE EFFICIENCY OF THE ENGINE***.
- ***RE-USE OF THE GAINED ELECTRIC ENERGY*** within an advanced ***MULTILEVEL BOARD NET ARCHITECTURE OF ELECTRIC AUXILIARIES AND E-STORAGE***.

Application Study

REFERENCE VEHICLE AND ENGINE

Reference vehicle:

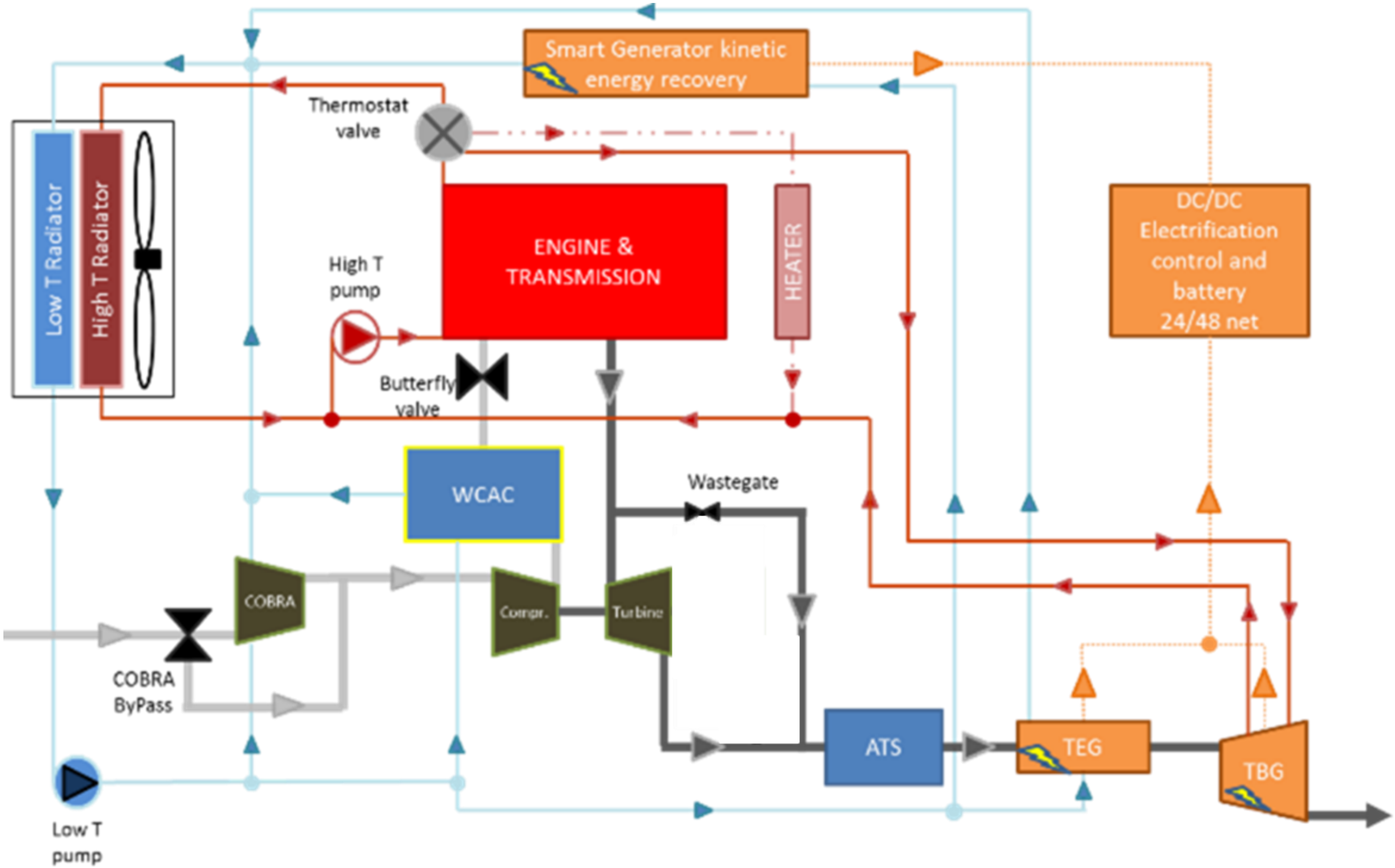
- **IVECO Stralis NG Euro VI MY2014**
  - Mission: Heavy duty truck, On-Road long haul
  - GTW: 44 tons ; GVW: 18 tons
  - Model: AT440S33T/P NG, Tractor 4x2 Artic
  - Gearbox: mechanical 16 speed

Reference engine:

- **FPT Cursor8 NG Euro VI**
  - Displacement: 7.8l - 6 cylinders in line – 24 valves
  - Performance: 243kW@2000rpm / 1300Nm@1200rpm

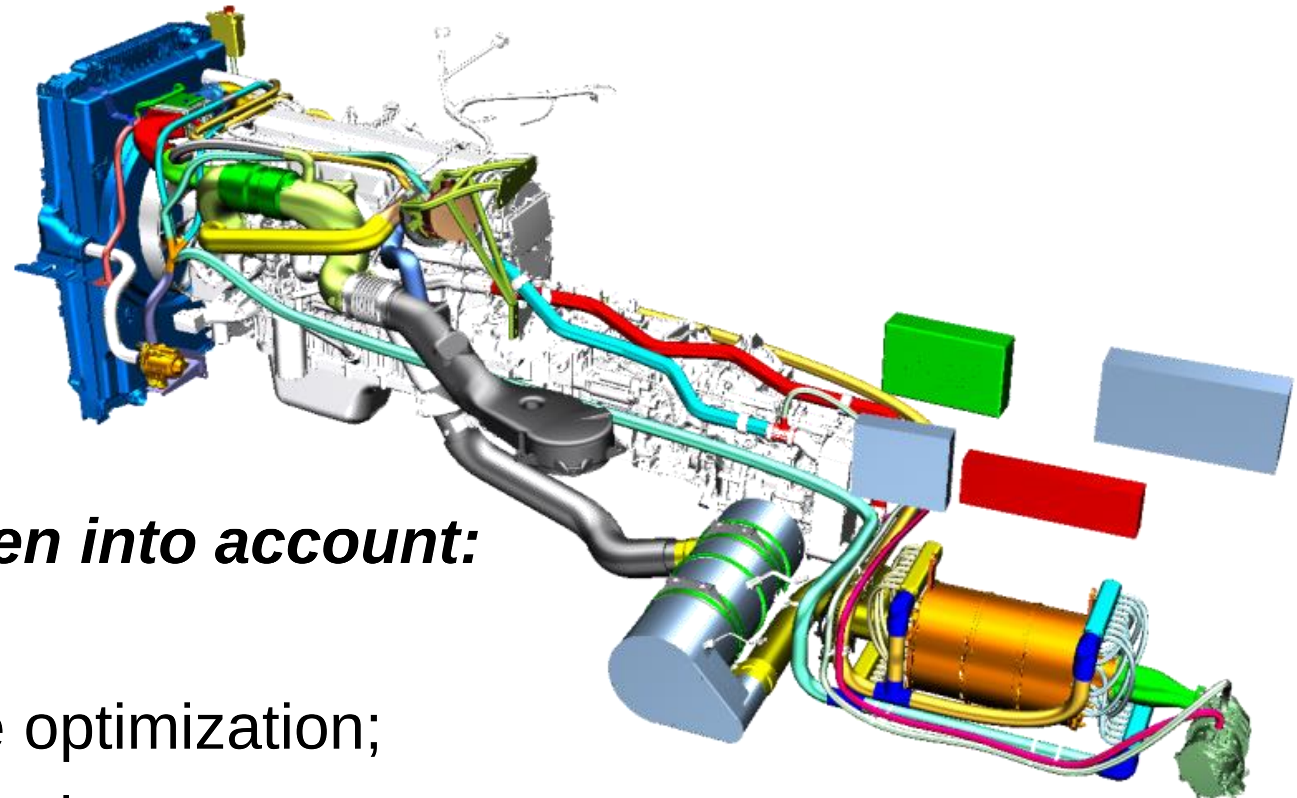
Application Study

OVERALL SYSTEM



Application Study

SYSTEM ON BOARD INTEGRATION

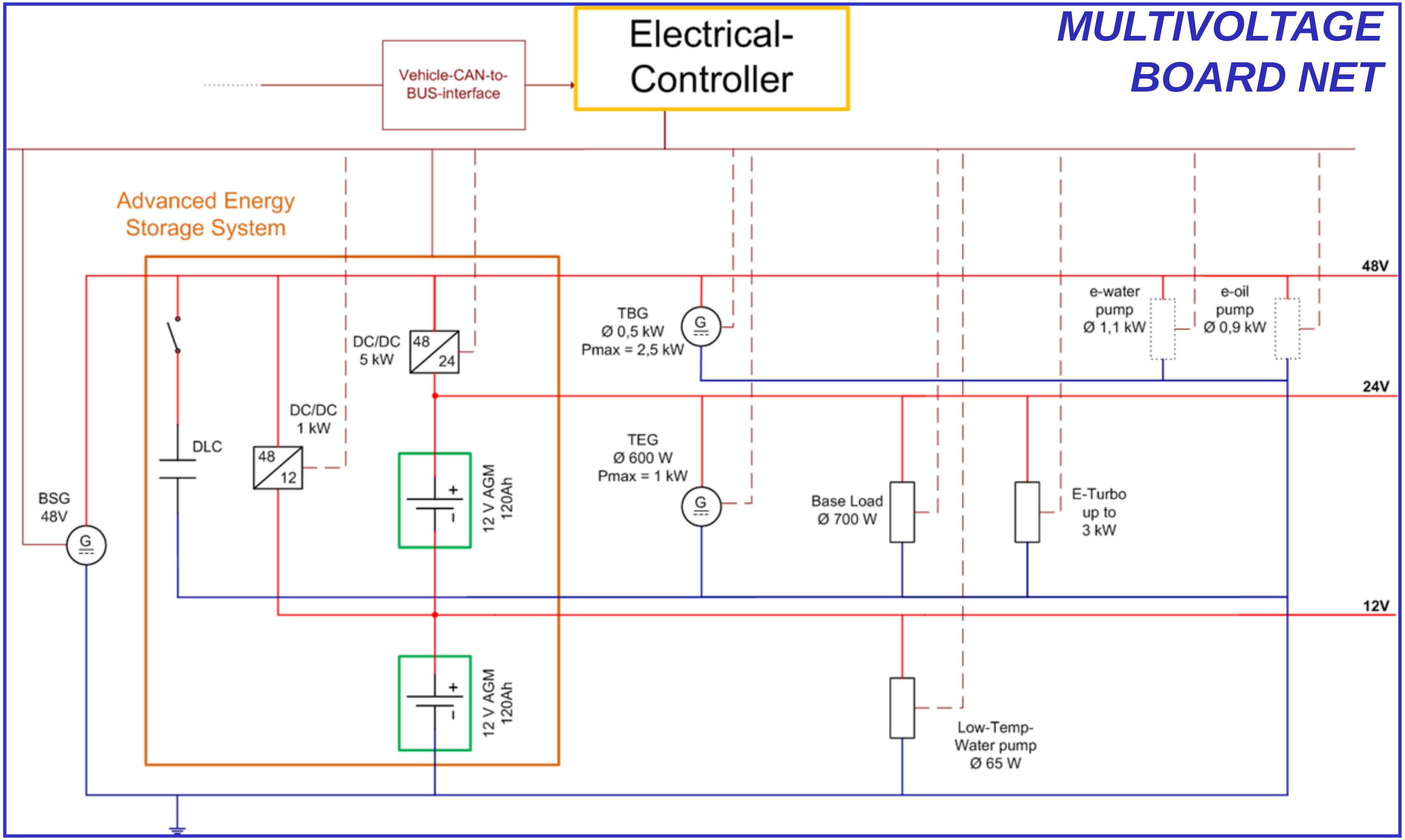


Installation criteria taken into account:

- engine behavior;
- device performance optimization;
- vehicle layout constraints;
- supplier/producer installation constraints;
- regulation for CNG fuel systems.

Application Study

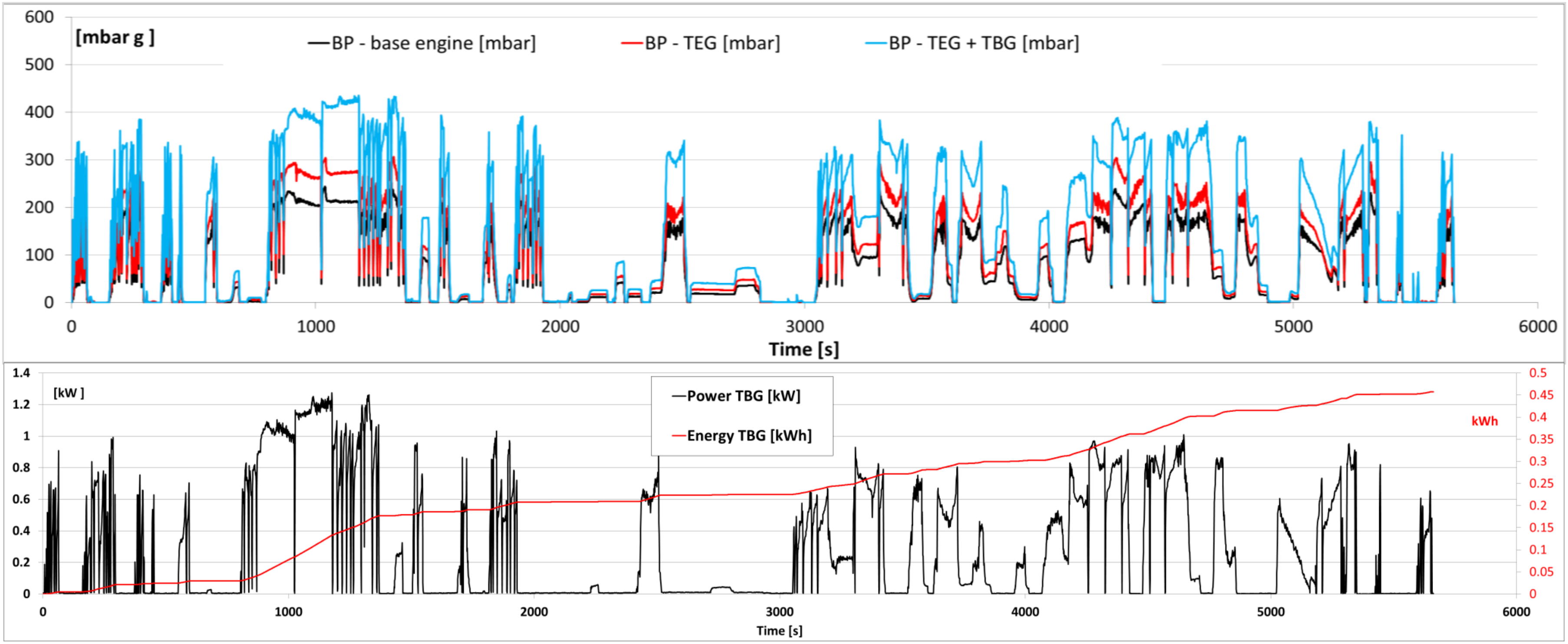
POWERPACK INTEGRATION AND CALIBRATION



System Validation

BENCH TESTING: TEG + TBG

The addition of TBG causes an high backpressure increase that leads to a higher FC by 0.37%; energy production is about 0.46 kWh.

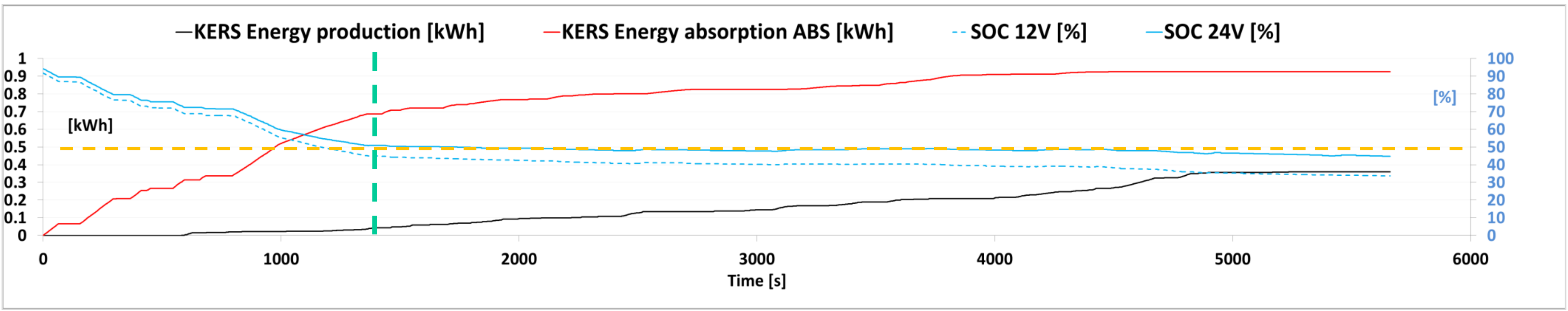


Description	DELTA BSFC [%]	DELTA fuel consumption/cycle [kg]	Delta fuel Energy [kWh]	Delta Mechanical Energy [kWh]	TBG energy production [kWh]
Base engine + TEG + TBG	0.376	0.139	1.751	0.609	+0.457

System Validation

BENCH TESTING: TEG + BSG

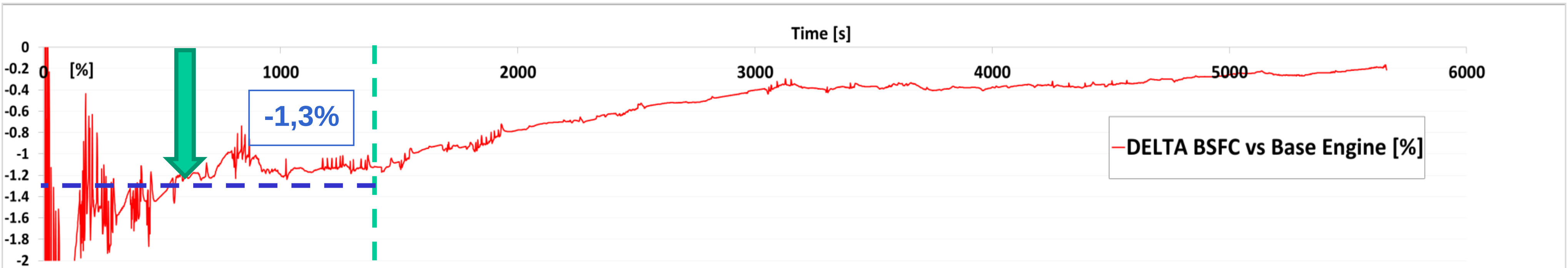
BSG produces electrical energy during deceleration periods (fuel cut-off) and when battery state of charge (SOC) is < 50%.



System Validation

BENCH TESTING: TEG + BSG

When battery state of charge is > 50%, BSG can be used as motor and FC reduction (-1,3%) is achieved (during the first 1500 sec of ACEA cycle).



Description	DELTA BSFC on BASE engine [%]	Delta Electrical energy [kWh]	Kers energy production [kWh]	Kers energy absorption [kWh]	TEG Electrical production [kWh]
Base engine	0.000	0.000	0.000	0.000	0.0
Base engine + TEG + BSG	-0.212	-0.056	+0.36	-0.926	+0.51

System Validation

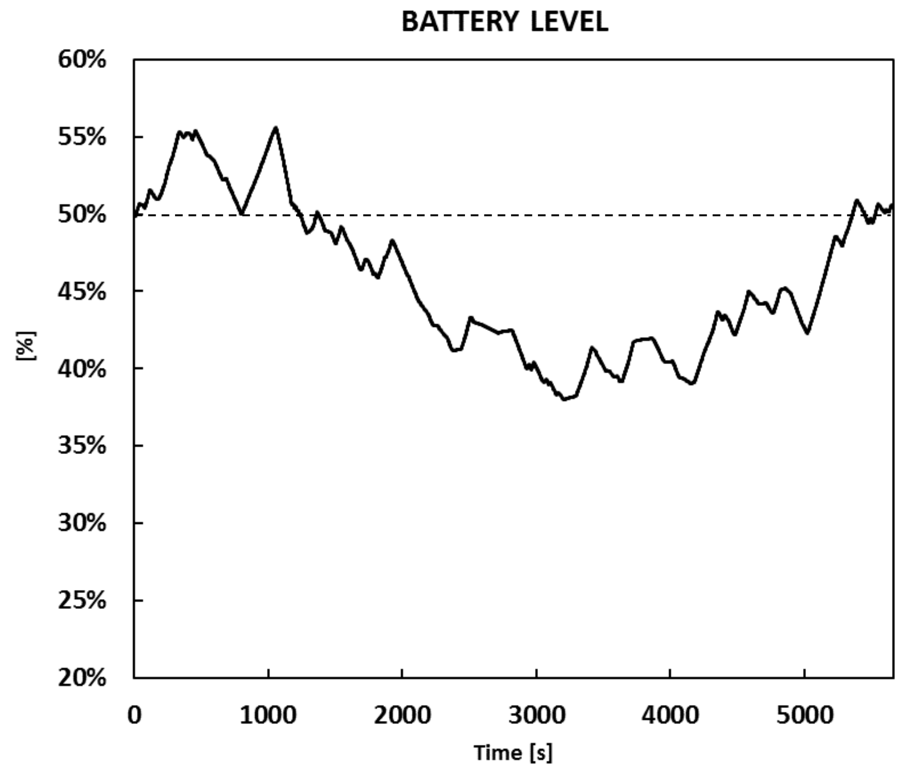
STORAGE SYSTEM STRATEGY: ZERO BALANCE @CYCLE ENDING

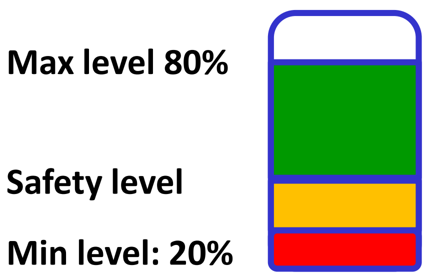
Initial charge: 50%

Operating storage range: [20-80]%

Strategy: technologies recovering energy produce always at maximum (within the backpressure limit)

Final charge: 50%





Vehicle Simulation Results

ACEA ACHIEVEMENTS – CNG ENGINES

Benefit at a vehicle level by technologies:

Technology considered	Fuel saved (%)	Ker_prod (kWh)	Teg_prod (kWh)	Tbg_prod (kWh)
None (Reference vehicle)	0	0	0	0
KER (deceleration)*	2.954	2.059	0	0
TEG*	0.2986	0	0.613	0
TBG* (total back <300mbar)	0.208	0	0	0.694
KER + TBG	3.647	2.076	0	0.6745
KER + TEG	3.705	2.077	0.605	0
TEG + TBG*	0.584	0	0.6175	0.57
KER + TEG + TBG (GASTone)	4.011	2.102	0.6056	0.5563

* There is not enough electric production to handle all the consumption during the ACEA cycle. Only the electrical energy available at the moment of production is used in these cases, while not harvesting energy the behavior of these devices is similar to a mechanical load.

Vehicle Simulation Results

ACEA ACHIEVEMENTS – DIESEL ENGINES

Benefit at a vehicle level by technologies:

Technology considered	Fuel saved (%)	Ker_prod (kWh)	Teg_prod (kWh)	Tbg_prod (kWh)
None (Reference vehicle)	0	0	0	0
KER (deceleration)*	2.157	2.045	0	0
TEG*	-0.56	0	0.228	0
TBG* (total back <300mbar)	0.503	0	0	1.163
KER + TBG	3.76	2.11	0	1.139
KER + TEG	1.913	2.065	0.225	0
TEG + TBG*	0.09	0	0.229	1.107
KER + TEG + TBG (GASTone)	3.222	2.113	0.2242	1.09

* There is not enough electric production to handle all the consumption during the ACEA cycle. Only the electrical energy available at the moment of production is used in these cases, while not harvesting energy the behavior of these devices is similar to a mechanical load.

Vehicle Simulation Results

CONSIDERATIONS ON ACHIEVED RESULTS

- ***KER*** → *most profitable technology*
- ***TEG*** → *provides constant moderate power* (advances in thermoelectric research may further increase the TEG's benefits)
- ***TBG*** → *highest peak production* (highest backpressure penalty)
- ***CNG*** engine:
  - ***FUEL SAVING RATE*** at a vehicle level: *4.01%*
- ***DIESEL*** engine:
  - *~ 50% more of exhaust gas mass flow* than CNG engine
  - *~ 300ºC lower exhaust temperature*

  → ↑ Energy ↓ Quality
  - ***FUEL SAVING RATE*** at a vehicle level: *18% lower than in CNG*

Exploitation

- ***CRF***
  - *waste heat recovery knowledge consolidation*
  - *48V technologies investigation*
- ***ECS***
  - *TE modules integration in complete TEG systems*
  - *full implementation in the design process of the gained knowledge*
- ***THRM***
  - *develop and engage TEG technologies in the heavy duty market*
- ***FPT***
  - *investigate in innovative energy recovery approach to achieve fuel economy improvement*
- ***CONTI***
  - *48V technologies investigation and multi-voltage systems*
  - *production of electrified auxiliaries*

Thank you for your attention!

Alex Rinaldi

CRF

EMEA Product Development – Engine and Thermal Systems Innovation

Office: *+39 011 00 42 682*

Email: *alex.rinaldi@crf.it*