

# Fuel Consumption Improvement Study over combinations of technologies [Rev. 2]

## VOLPE vs. Autonomie (ANL)

For DOT/VOLPE

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Ehsan Sabri Islam, Ayman Moawad, Aymeric Rousseau  
*Argonne National Laboratory*



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# Table of Contents

- Introduction & Background
- Calculation
- Technology Decision Trees
  - Engine Technology Tree
  - Transmission Technology Tree
  - Vehicle Technology Tree
  - Hybridization Technology Tree
- IAV Engines
- Engine Technology Descriptions
- Results Summary & Comparison [Part 1]
  - Engine Technologies (ABS)
  - Engine Technologies (INC)
  - Transmission Technologies (ABS)
  - Transmission Technologies (INC)
  - Vehicle Technologies (ABS)
  - Vehicle Technologies (INC)
  - Hybridization Technology (ABS)
  - Hybridization Technology (INC)
- Plot Comparison Results [Part 2]
  - Absolute Improvement Result
    - Engine Technology
    - Transmission Technology2
    - Vehicle Technology
    - Hybridization Technology
  - Incremental Improvement Result
    - Engine Technology
    - Transmission Technology
    - Vehicle Technology
    - Hybridization Technology
- Summary of Plot Results [Part 3]
  - Engine Technology
    - Absolute Improvement Result
    - Incremental Improvement Result
  - Transmission Technology
    - Absolute Improvement Result
    - Incremental Improvement Result
  - Vehicle Technology
    - Absolute Improvement Result
    - Incremental Improvement Result
  - Hybridization Technology
    - Absolute Improvement Result
    - Incremental Improvement Result

# Introduction & Background

The objective of this report is to evaluate the impact of different technological advancements on fuel consumption improvements. The report further analyses the comparison between the results from VOLPE and Argonne National Laboratories (Autonomie).

## Calculation

Following is the detailed calculation process considered during this study:

- The reference technology was considered to be the root of each of the respective technology trees from VOLPE and IAV
- The reference fuel consumption was computed to be the fuel consumption corresponding to the reference technology
- Each of the fuel consumptions corresponding to the advanced technologies were computed to be compared to the reference fuel consumption.

- Absolute % increase in fuel consumption:

$$\frac{\text{Reference Fuel Consumption} - \text{Current Fuel Consumption}}{\text{Reference Fuel Consumption}} \%$$

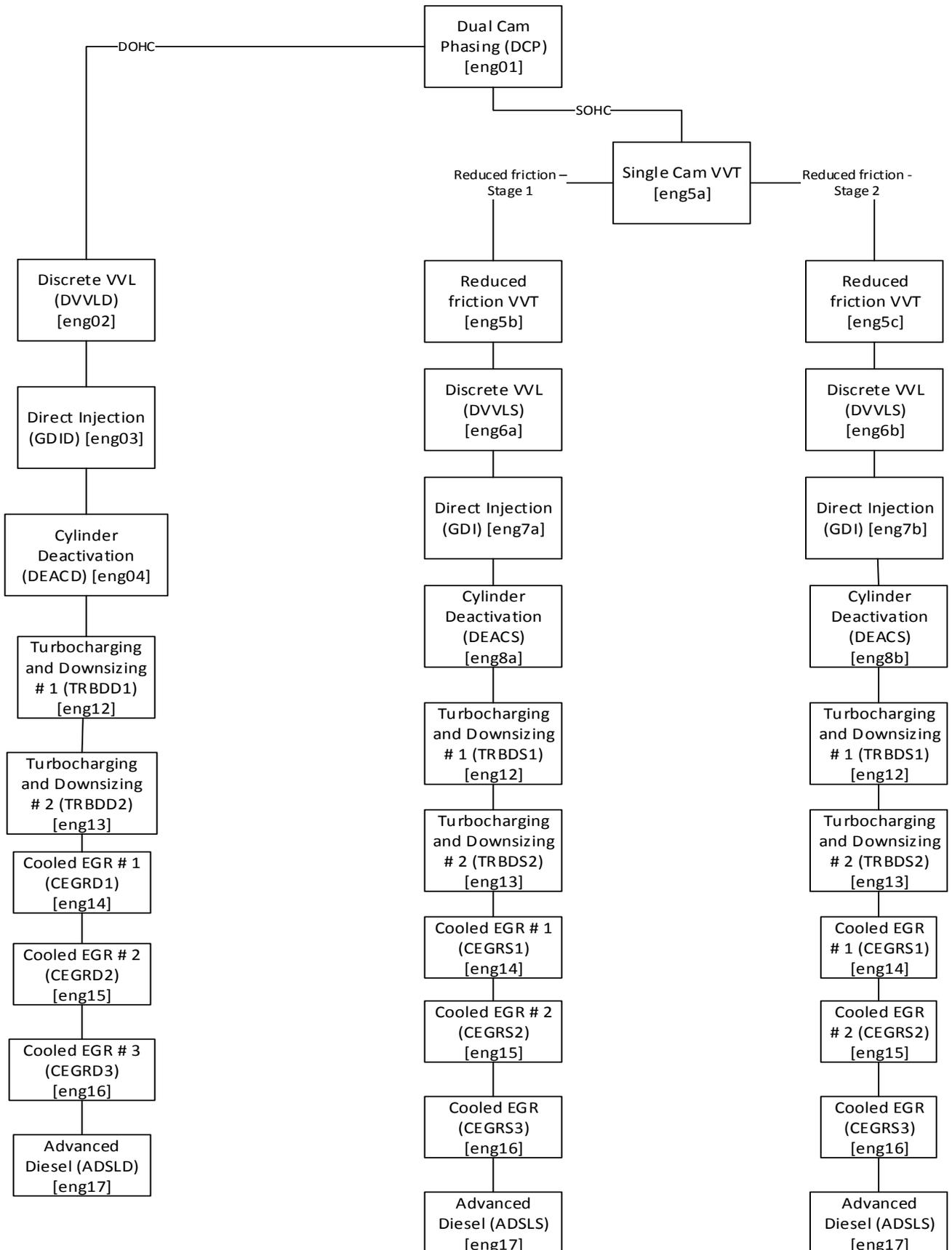
- Incremental % increase in fuel consumption:

$$\frac{\text{Previous Tech. Fuel Consumption} - \text{Current Tech. Fuel Consumption}}{\text{Previous Tech. Fuel Consumption}} \%$$

# TECHNOLOGY DECISION TREES

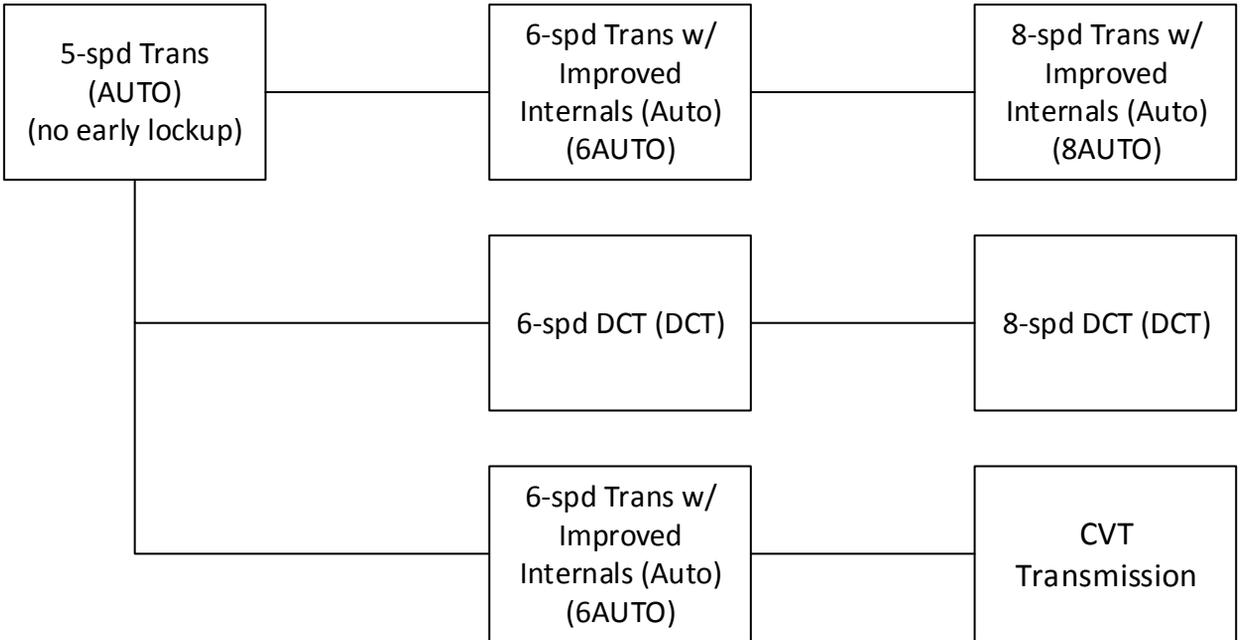


# Engine Technology Tree

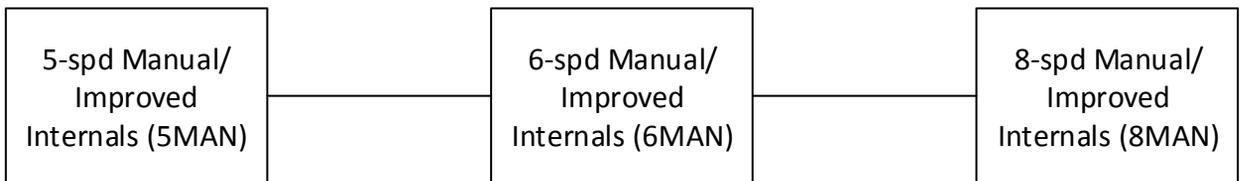


# Transmission Technology Tree

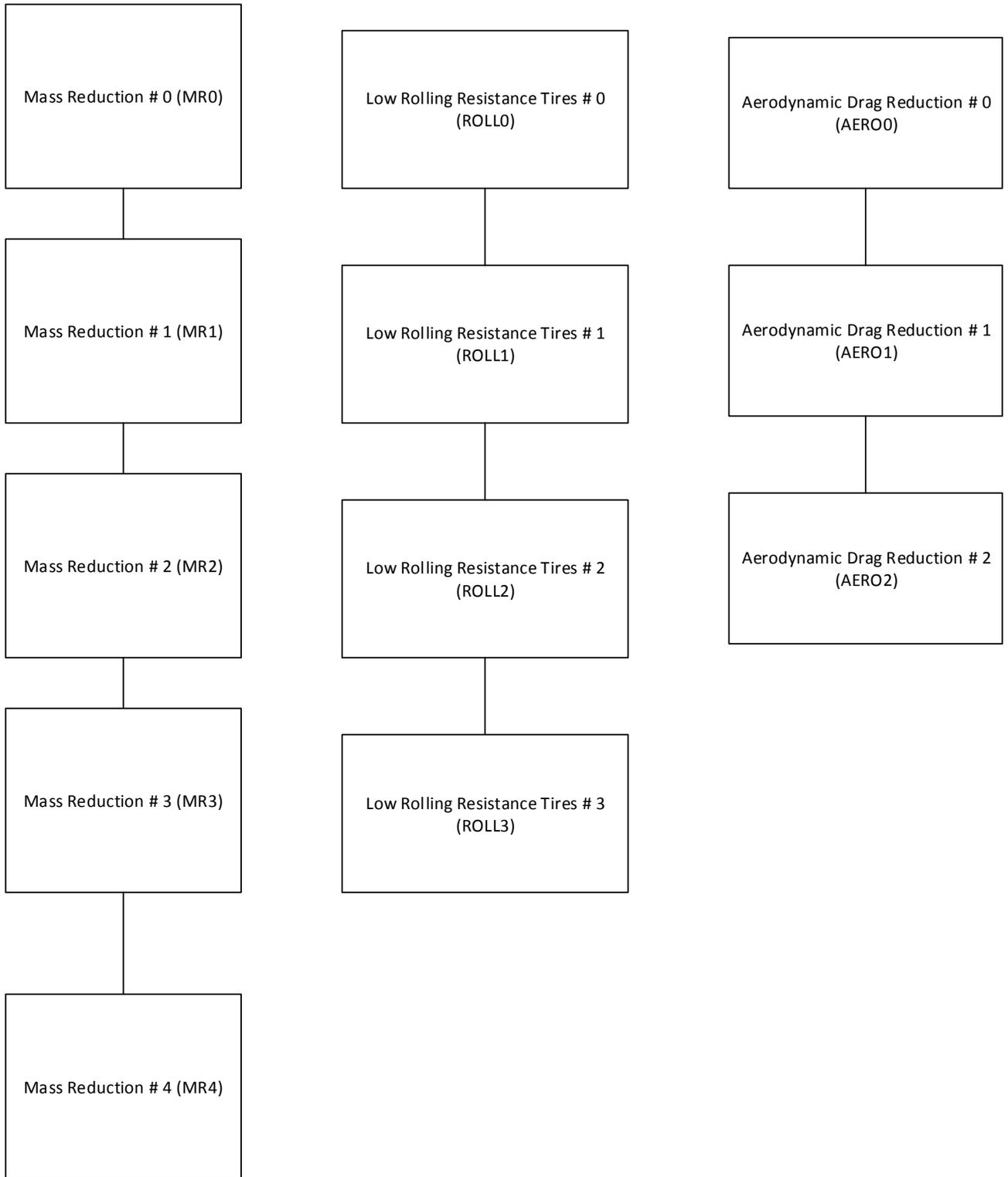
## Auto / DCT / CVT



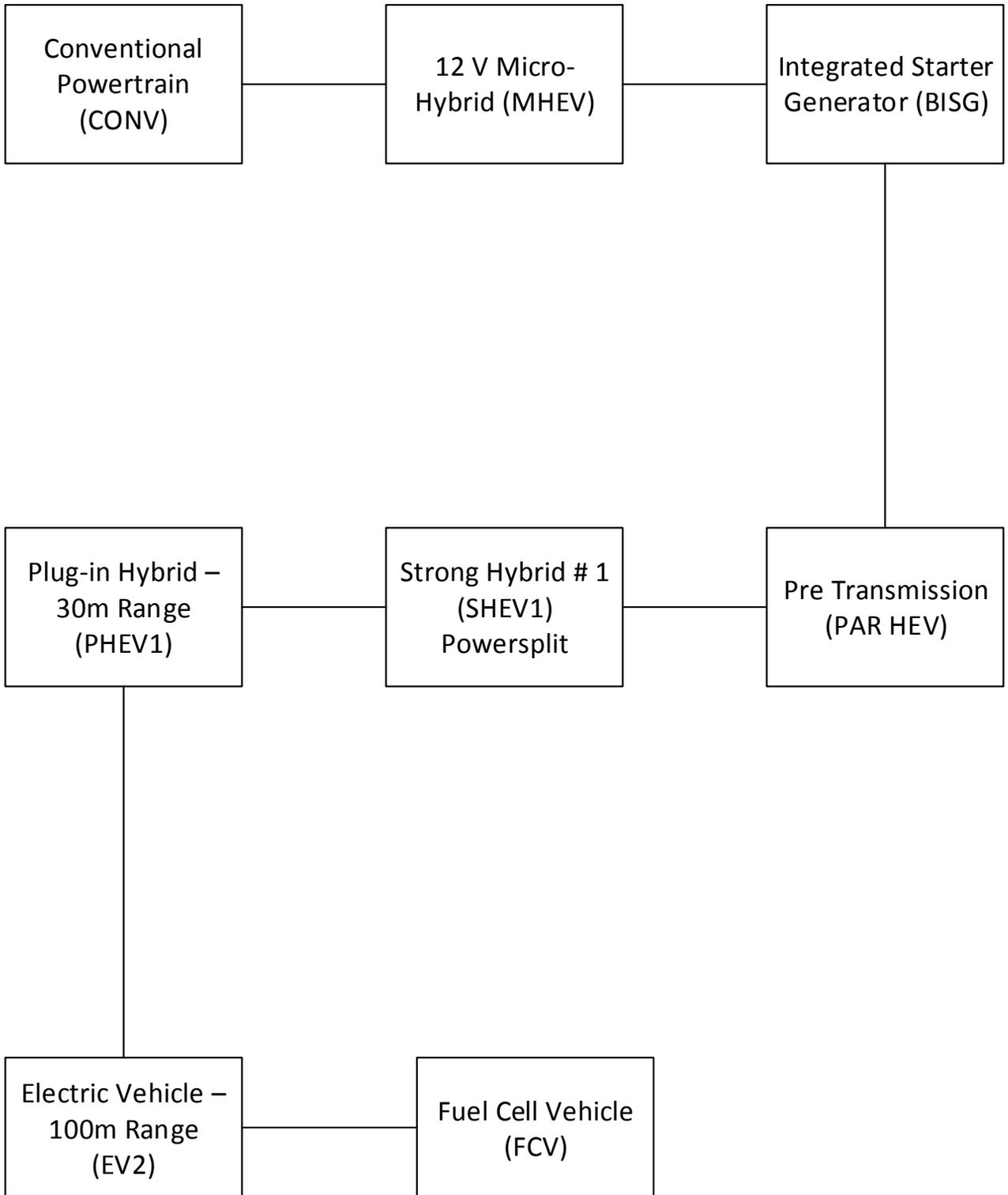
## Manual (MAN)



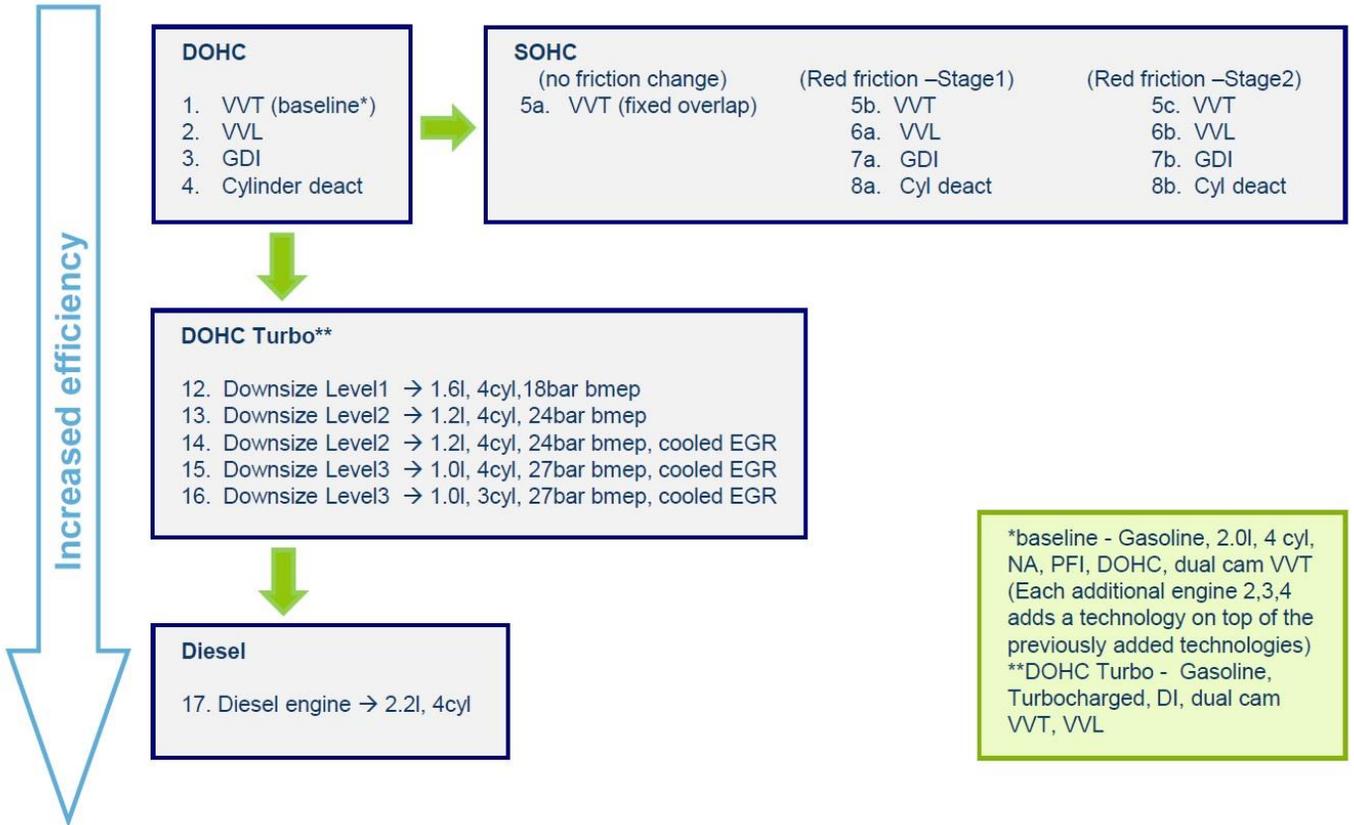
# Vehicle Technology Tree



# Hybridization Technology Tree



# IAV Engines



# Engine Technology Descriptions

- Eng1 - gasoline, 2.0l, 4 cyl, NA, PFI, DOHC, dual cam VVT
  - Calibrations fully optimized for best bsfc and maximum torque (comb. phasing, valve timing, lambda, etc)
- Eng2 - VVL system was added to the intake valves on Eng1
  - Valve lift and timing optimized
- Eng3 - Eng2 (PFI) converted to direct injection
  - Comp ratio raised from 10.2 to 11.0 and injection timing optimized
- Eng4 - Cylinder deactivation added to engine Eng3
  - Engine fires only 2 cylinders at low loads and at speeds below 3000 RPM by deactivating valves on 2 cylinders
- Eng5a - Eng1 converted to SOHC (gasoline, 2.0l, 4 cyl, NA, PFI, single cam VVT)
  - Valve timing optimized for fixed overlap camshaft with standard friction model from DOHC concepts
- Eng5b/ Eng6a/ Eng7a/ Eng8a - Reduced friction from Eng5a/ Eng2/ Eng3/ Eng4 respectively
  - Engine FMEP reduced by 0.1 bar over entire operation range to understand friction benefit from SOHC
- Eng5c/ Eng6b/ Eng7b/ Eng8b - Reduced friction from Eng5a/ Eng2/ Eng3/ Eng4 respectively
  - Engine FMEP reduced by 25% over entire operation range to understand potential of 'extreme' friction reduction (this is a "what if" study which doesn't necessarily represent what is currently possible)
- Eng12 - gasoline, 1.6l, 4 cyl, turbocharged, DI, DOHC, dual cam VVT, intake VVL
  - Calibrations fully optimized for best bsfc (comb. phasing, valve timing, lambda, etc)
- Eng13 - Eng12 downsized to 1.2l
  - Turbocharger maps scaled to improve torque at low engine speeds
- Eng14 - High pressure cooled EGR added to Eng13
  - Cooled EGR target set points optimized
- Eng15 - Eng14 downsized to 1.0l
  - Cooled EGR target set points re-optimized and turbocharger maps re-scaled
- Eng16 - Eng15 converted to 3cyl, 1.0l concept
  - Intake and exhaust piping scaled to account for larger mass flows through each cylinder and cooled EGR target set points re-optimized



# **RESULTS SUMMARY & COMPARISON [Part 1]**



## Engine Technologies (ABS)

Technology	Maximum Value (%)	Minimum Value (%)	Baseline vehicle (ANL) %	VOLPE Result, %
[eng02]	5.1733	1.72	4.20	3.6
[eng03]	7.0291	3.66	6.30	5.2
[eng04]	15.3143	1.18	12.57	N/A
[eng05a]	-0.6146	-3.37	-2.01	N/A
[eng05b]	1.6319	-0.82	0.97	N/A
[eng05c]	4.5855	0.99	3.78	N/A
[eng06a]	8.4759	4.00	7.07	3.6
[eng06b]	11.0201	6.89	9.66	3.6
[eng07a]	10.0811	5.82	9.08	5.2
[eng07b]	12.61	8.05	11.51	5.2
[eng08a]	18.61	4.79	15.36	N/A
[eng08b]	20.44	5.86	17.08	N/A
[eng12]	20.14	11.99	16.48	11.6
[eng13]	23.35	10.74	19.81	14.4
[eng14]	23.52	11.87	19.78	17.1
[eng15]	25.27	13.67	19.28	18.1
[eng16]	26.11	14.65	20.26	N/A
[eng17]	28.03	18.76	22.33	20.1

# Engine Technologies (INC)

Technology	Maximum Value (%)	Minimum Value (%)	Baseline vehicle (ANL) %	VOLPE Result, %
[eng02]_DOHC	5.17	1.72	4.20	3.6
[eng03]_DOHC	3.63	0.27	2.19	2.2
[eng04]_DOHC	9.33	-4.62	6.69	N/A
[eng12]_DOHC	14.15	3.33	4.47	7.5
[eng13]_DOHC	4.78	-2.76	3.98	3.5
[eng14]_DOHC	2.60	-1.40	-0.04	3.5
[eng15]_DOHC	3.49	-2.11	-0.62	1.4
[eng16]_DOHC	2.82	-1.76	1.21	N/A
[eng17]_DOHC	10.24	-0.05	2.59	2.8
[eng5a]_SOHC_01	-0.61	-3.37	-2.01	N/A
[eng5b]_SOHC_01	3.87	1.03	2.92	N/A
[eng6a]_SOHC_01	7.39	3.00	6.16	3.6
[eng7a]_SOHC_01	3.91	0.02	2.15	2.2
[eng8a]_SOHC_01	9.84	-3.41	6.91	N/A
[eng12]_SOHC_01	10.90	0.17	1.33	7.5
[eng13]_SOHC_01	4.73	-2.76	3.98	3.5
[eng14]_SOHC_01	2.60	-1.40	-0.04	3.5
[eng15]_SOHC_01	3.49	-2.11	-0.62	1.4
[eng16]_SOHC_01	2.82	-1.76	1.21	N/A
[eng17]_SOHC_01	10.24	-0.05	2.59	2.8

## Engine Technologies (INC) [Continued]

Technology	Maximum Value (%)	Minimum Value (%)	Baseline vehicle (ANL) %	VOLPE Result, %
[eng5c] _SOHC_02	6.65	2.73	5.68	N/A
[eng6b] _SOHC_02	7.09	3.62	6.11	3.6
[eng7b] _SOHC_02	3.53	-0.27	2.05	2.2
[eng8b] _SOHC_02	9.02	-3.9	6.29	N/A
[eng12] _SOHC_02	9.42	-1.77	-0.72	7.5
[eng13] _SOHC_02	4.73	-2.76	3.98	3.5
[eng14] _SOHC_02	2.60	-1.41	-0.04	3.5
[eng15] _SOHC_02	3.49	-2.10	-0.62	1.4
[eng16] _SOHC_02	2.82	-1.755	1.21	N/A
[eng17] _SOHC_02	10.24	-0.05	2.59	2.8

## Transmission Technologies (ABS)

Technology	Maximum Value (%)	Minimum Value (%)	Baseline vehicle (ANL) %	VOLPE Result, %
6-spd AUTO	8.22	-1.31	4.91	2
8-spd AUTO	11.14	-4.70	7.44	5.8
6-spd DCT	15.27	6.23	8.74	10
8-spd DCT	18.13	6.76	2.88	N/A
6-spd DM	3.71	0.87	3.25	2.4
8-spd DM	6.46	0.23	5.67	N/A
CVT	9.15	1.35	5.86	N/A

## Transmission Technologies (INC)

Technology	Maximum Value (%)	Minimum Value (%)	Baseline vehicle (ANL) %	VOLPE Result, %
6-spd AUTO	8.22	-1.31	4.91	2
8-spd AUTO	3.52	-5.32	2.66	4.6
6-spd DCT	15.27	6.23	8.74	4.1
8-spd DCT	5.06	-2.38	2.88	N/A
6-spd DM	3.71	0.87	3.26	2.4
8-spd DM	2.90	-1.13	2.49	N/A
CVT	5.97	-2.62	1.00	N/A

## Vehicle Technologies (ABS)

Technology	Maximum Value (%)	Minimum Value (%)	Baseline vehicle (ANL) %	VOLPE Result, %
MR1	2.64	-0.70	0.73	0.53
MR2	4.76	0.05	345	2.6
MR3	6.06	1.26	5.08	2.6
MR4	10.68	3.98	9.23	2.6
ROLL1	3.65	-1.11	0.72	1.9
ROLL2	4.70	-0.63	1.40	3.9
ROLL3	6.92	1.50	2.84	3.9
AERO1	5.81	0.66	1.99	2.3
AERO2	10.75	3.29	3.92	4.7

## Vehicle Technologies (INC)

Technology	Maximum Value (%)	Minimum Value (%)	Baseline vehicle (ANL) %	VOLPE Result, %
MR1	2.64	-0.70	0.73	0.5
MR2	4.03	-0.33	2.74	2.0
MR3	3.29	-0.98	1.69	0
MR4	6.68	0.68	4.37	0
ROLL1	3.38	0.64	0.72	1.9
ROLL2	4.07	0.25	0.69	2.0
ROLL3	3.89	0.80	1.45	0
AERO1	5.81	0.66	1.99	2.3
AERO2	5.86	0.72	1.97	2.5

## Hybridization Technology (ABS)

Technology	Maximum Value (%)	Minimum Value (%)	Baseline vehicle (ANL) %	VOLPE Result, %
Micro Hybrid (MHEV)	6.38	-2.17	5.05	6.80
BISG	14.52	2.84	9.76	6.80
Par HEV	35.70	11.56	35.00	N/A
SHEV1	48.23	43.90	44.75	48.60
PHEV1	76.14	71.86	72.75	69.5
EV2	80.9	78.44	79.01	90.4
FCV	65.16	61.58	62.24	90.4

## Hybridization Technology (INC)

Technology	Maximum Value (%)	Minimum Value (%)	Baseline vehicle (ANL) %	VOLPE Result, %
Micro-Hybrid (MHEV)	5.53	4.70	5.05	2.10
BISG	5.81	4.24	4.96	0.00
Par HEV	33.73	27.84	28.95	N/A
SHEV1	14.87	12.54	13.83	6.5
PHEV1	53.91	49.78	50.67	40.7
EV2	24.27	19.66	23.00	0
FCV	-78.20	-82.35	-79.92	0



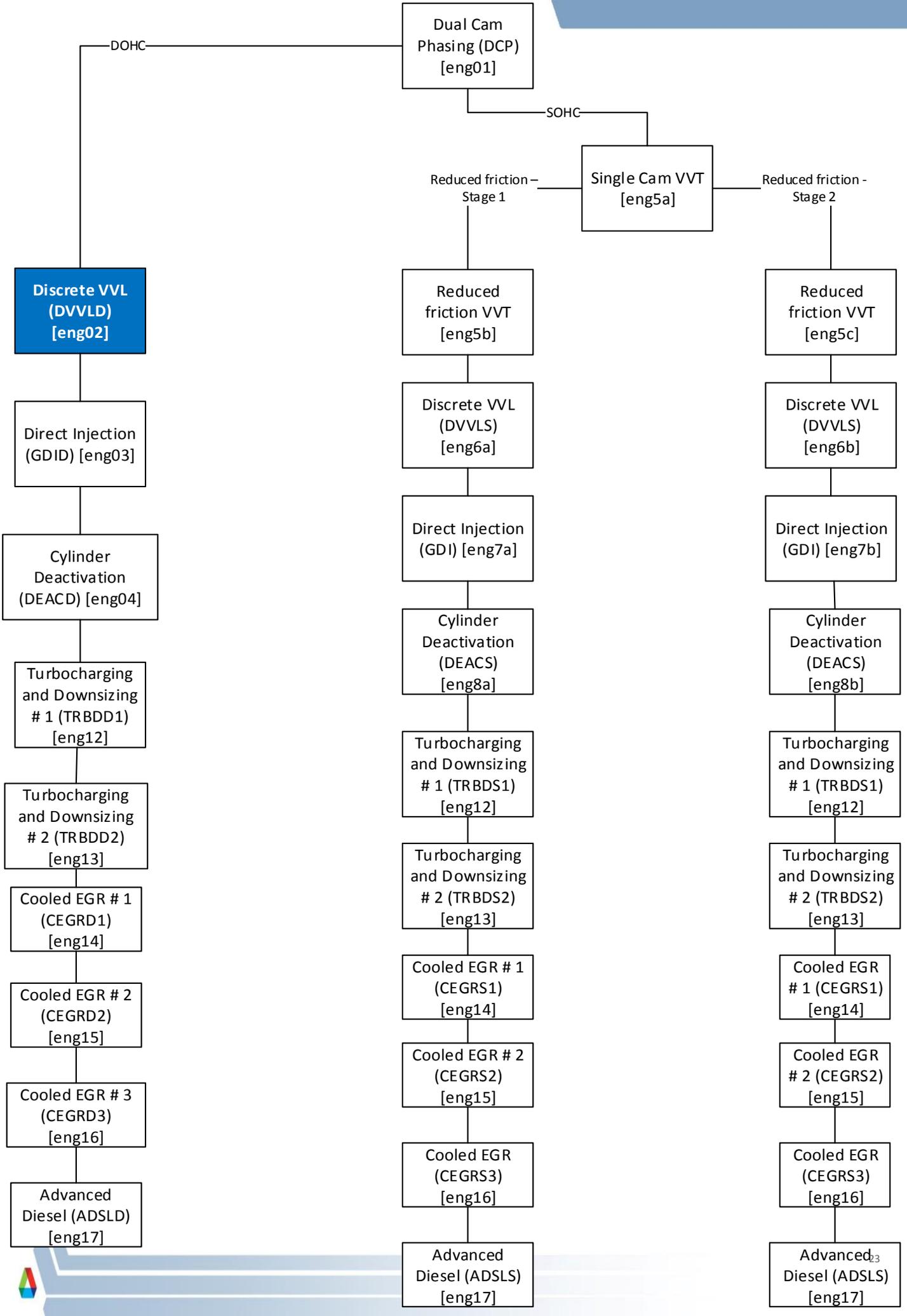
# **PLOT COMPARISON RESULTS [Part 2]**



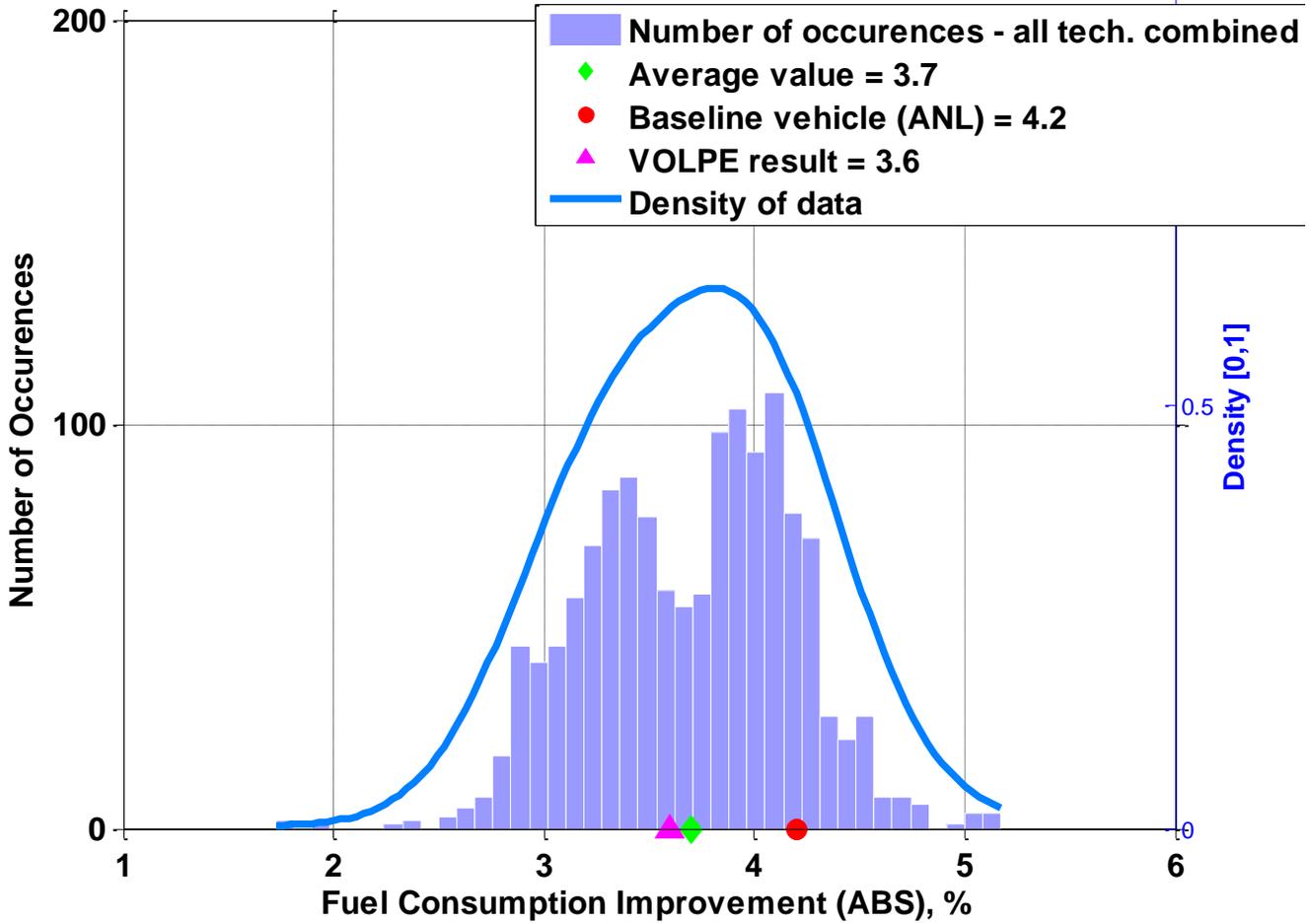
# **ABSOLUTE IMPROVEMENT RESULTS**

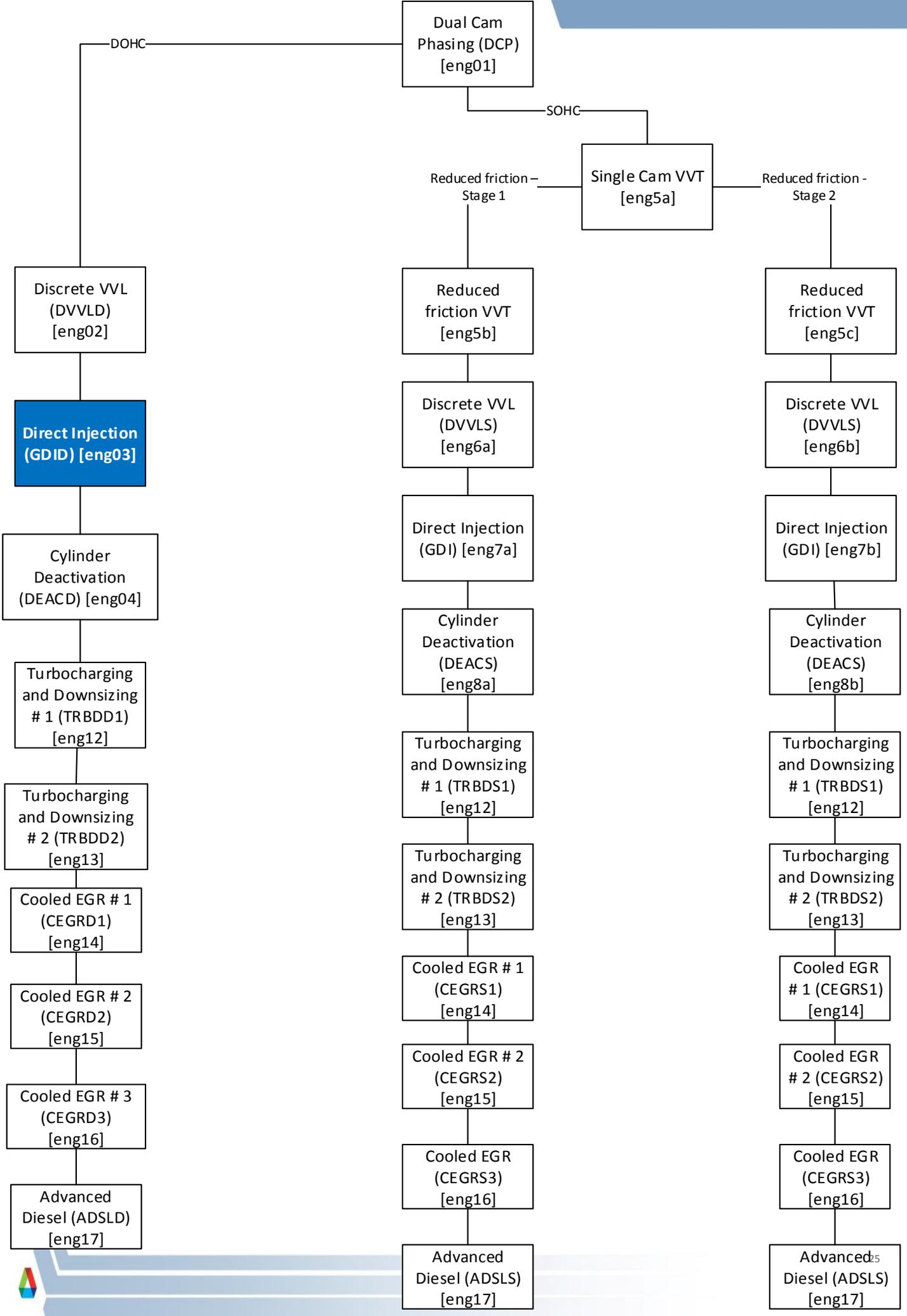


# ENGINE TECHNOLOGIES

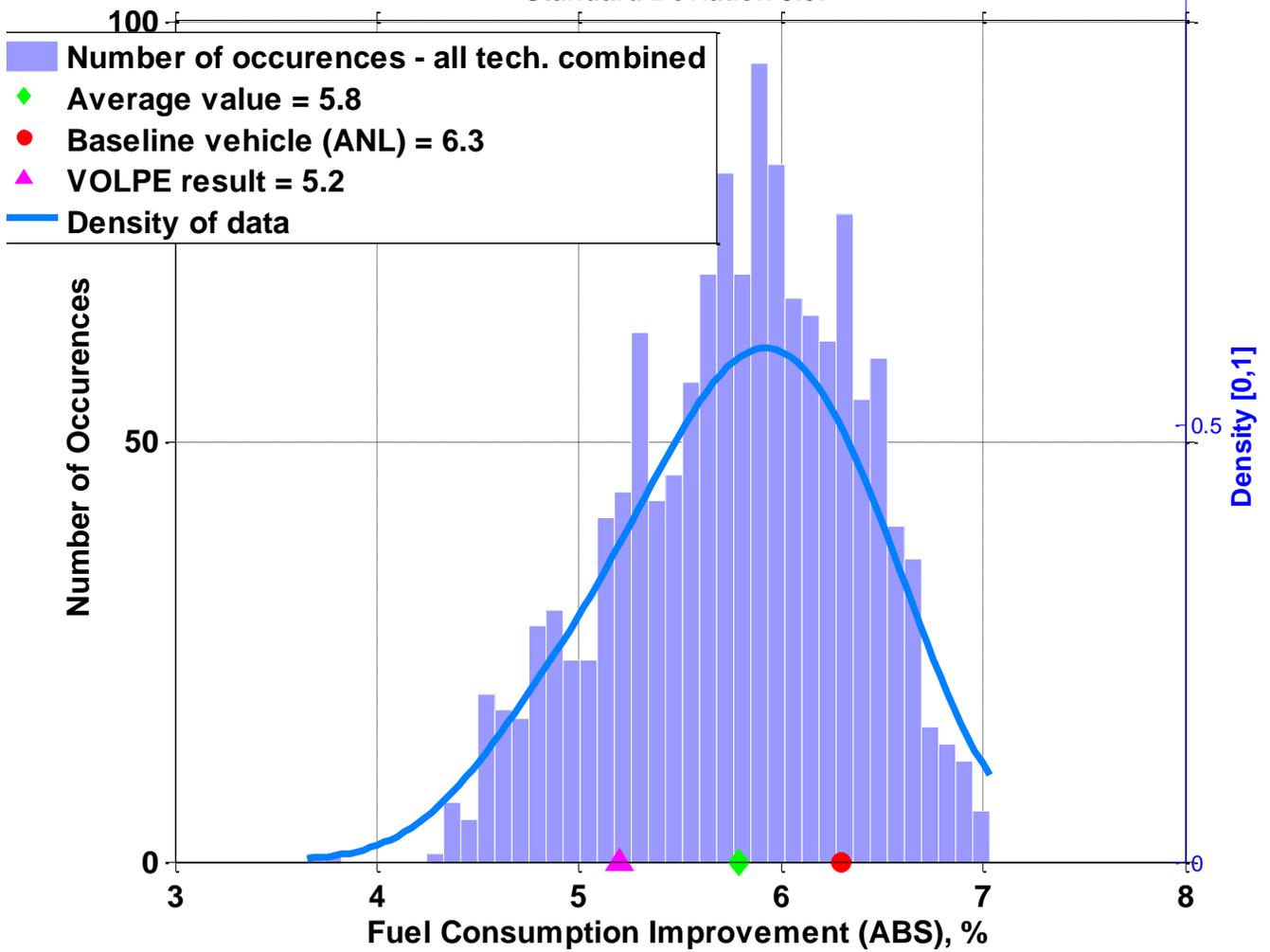


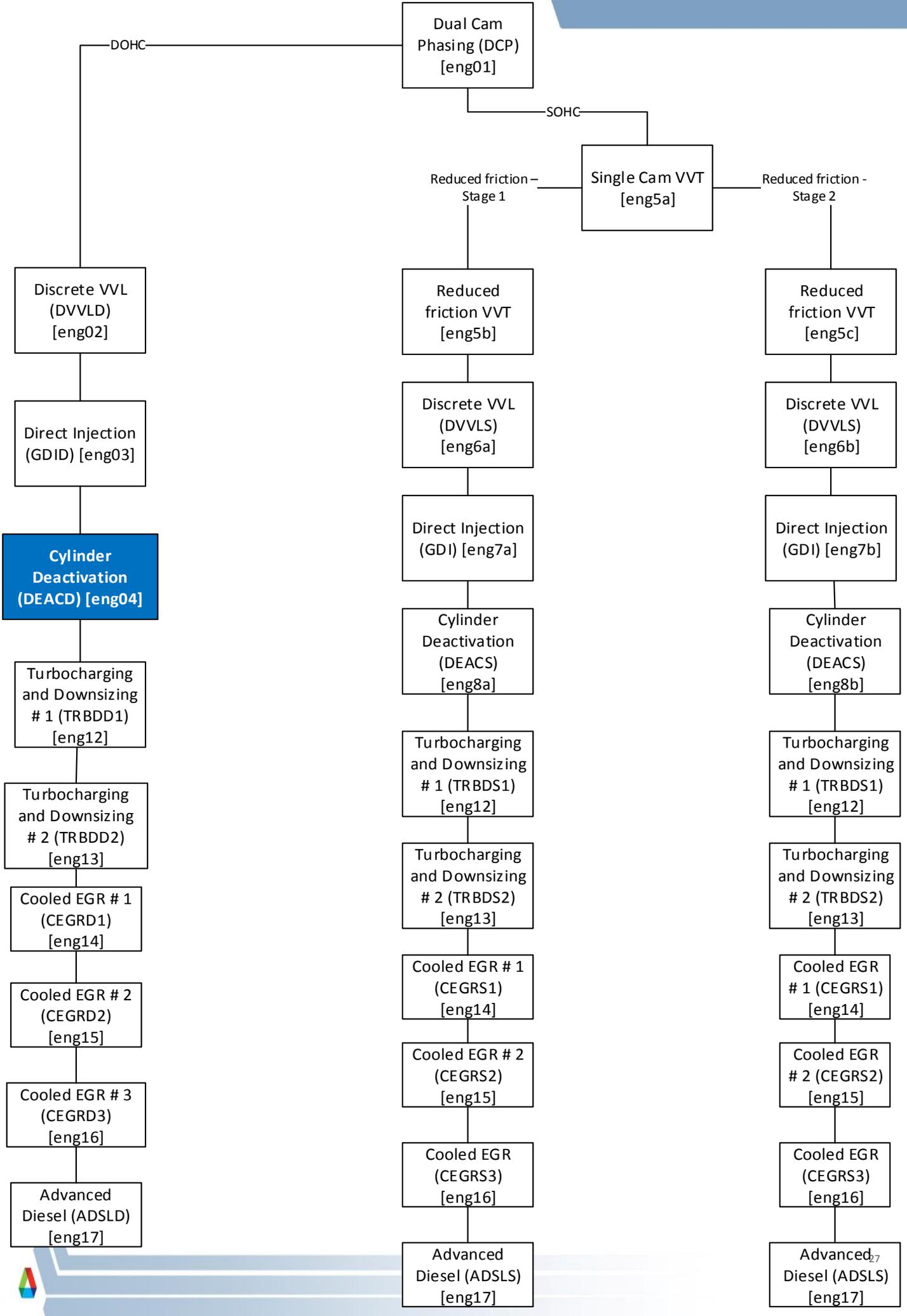
Distribution of Fuel Consumption for Eng02-Discrete VVL (DVVLD)  
 Absolute percentage compared with: Dual Cam Phasing(DCP) [eng01]  
 Standard Deviation 0.5:



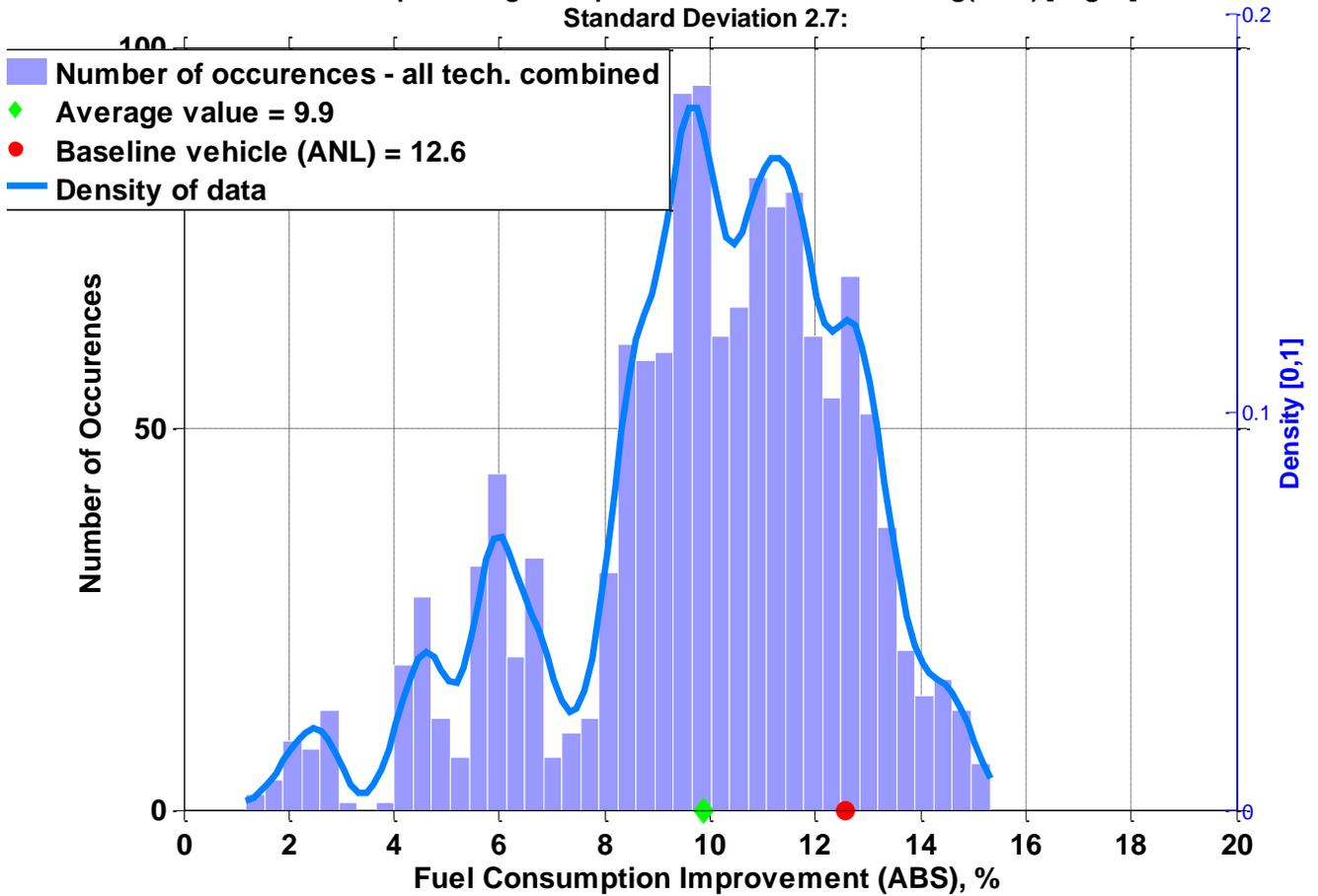


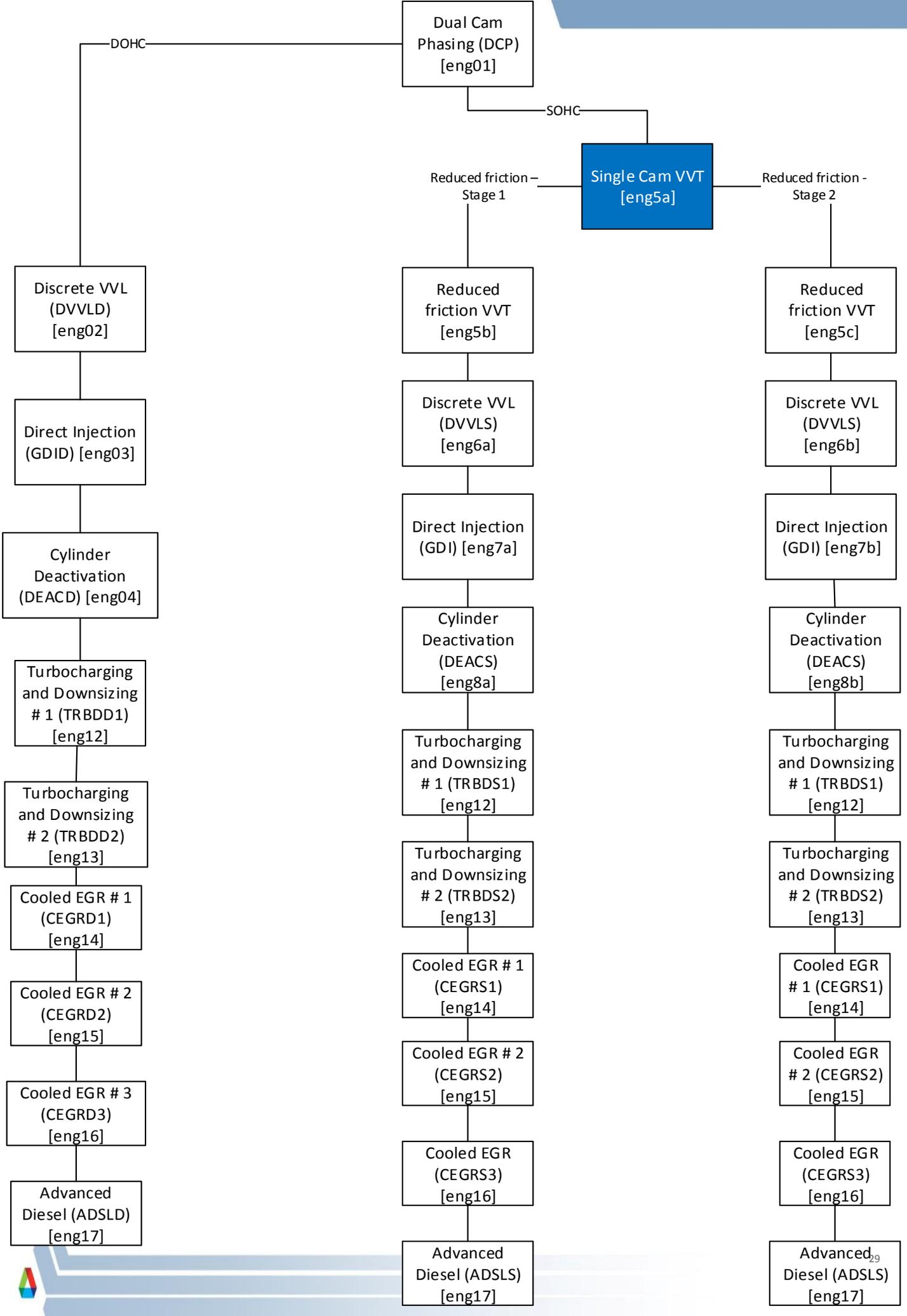
Distribution of Fuel Consumption for Eng03-Direct Injection (GDID)  
 Absolute percentage compared with: Dual Cam Phasing(DCP) [eng01]  
 Standard Deviation 0.6:



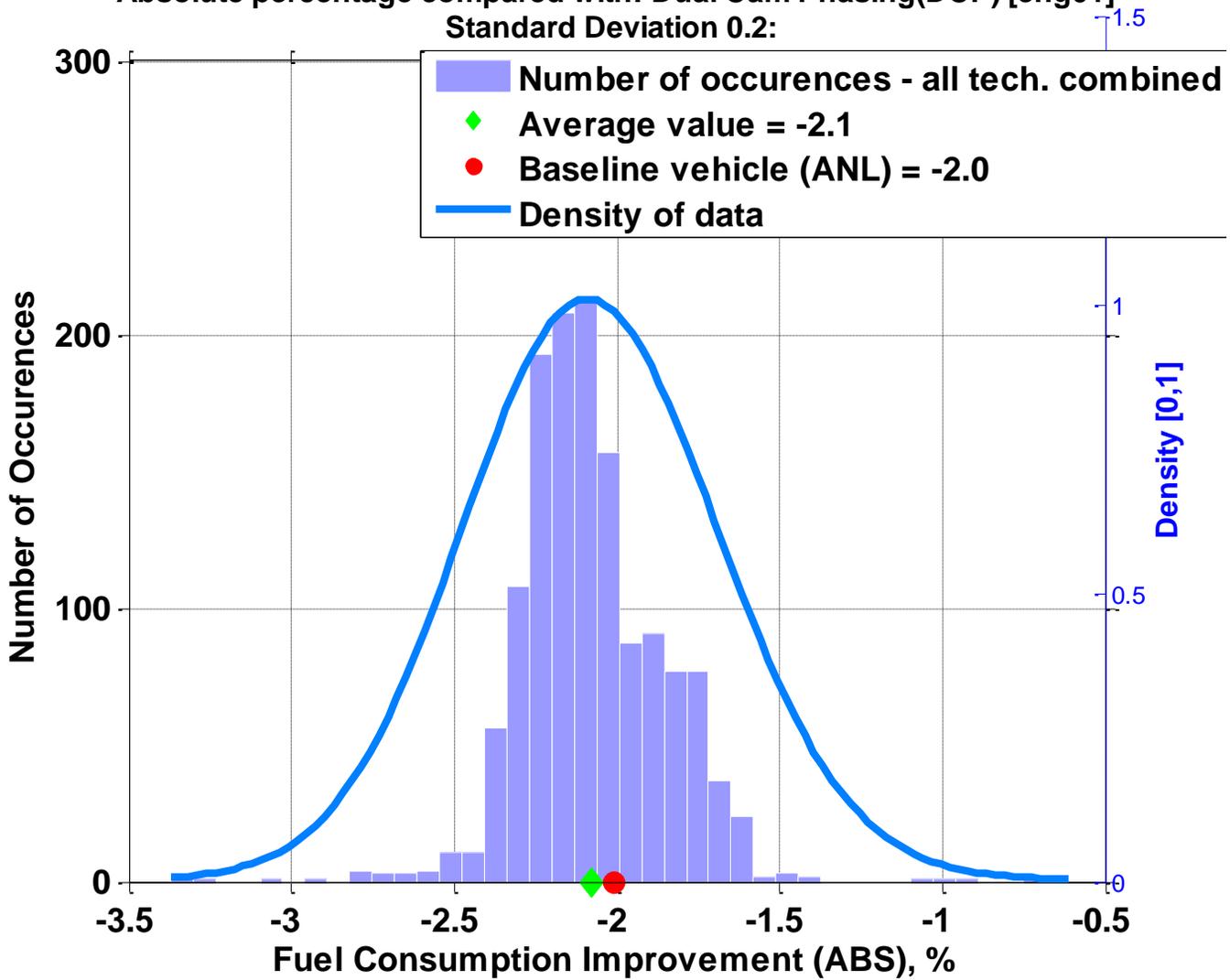


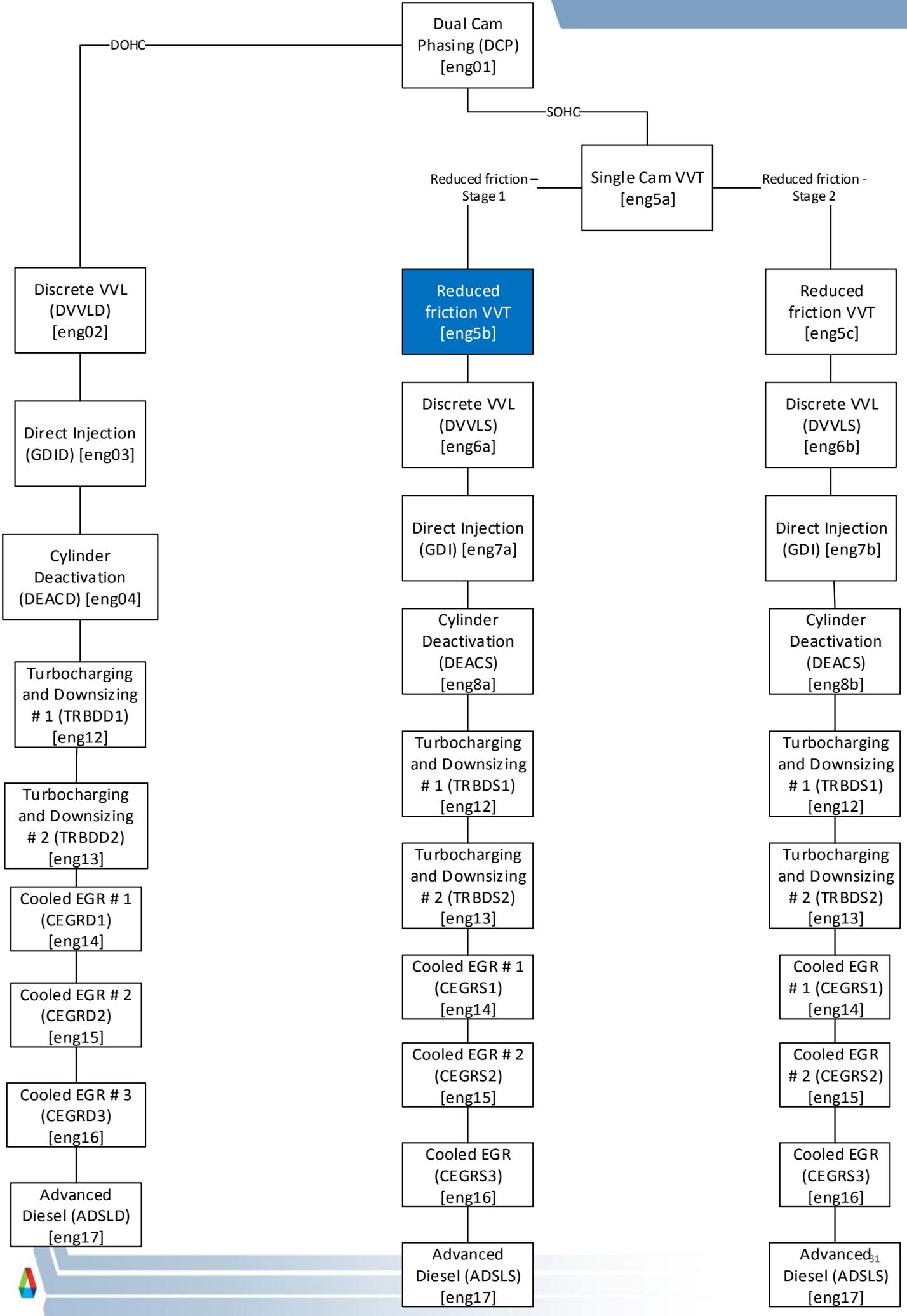
Distribution of Fuel Consumption for Eng04-Cylinder Deactivation (DEACD)  
 Absolute percentage compared with: Dual Cam Phasing(DCP) [eng01]  
 Standard Deviation 2.7:



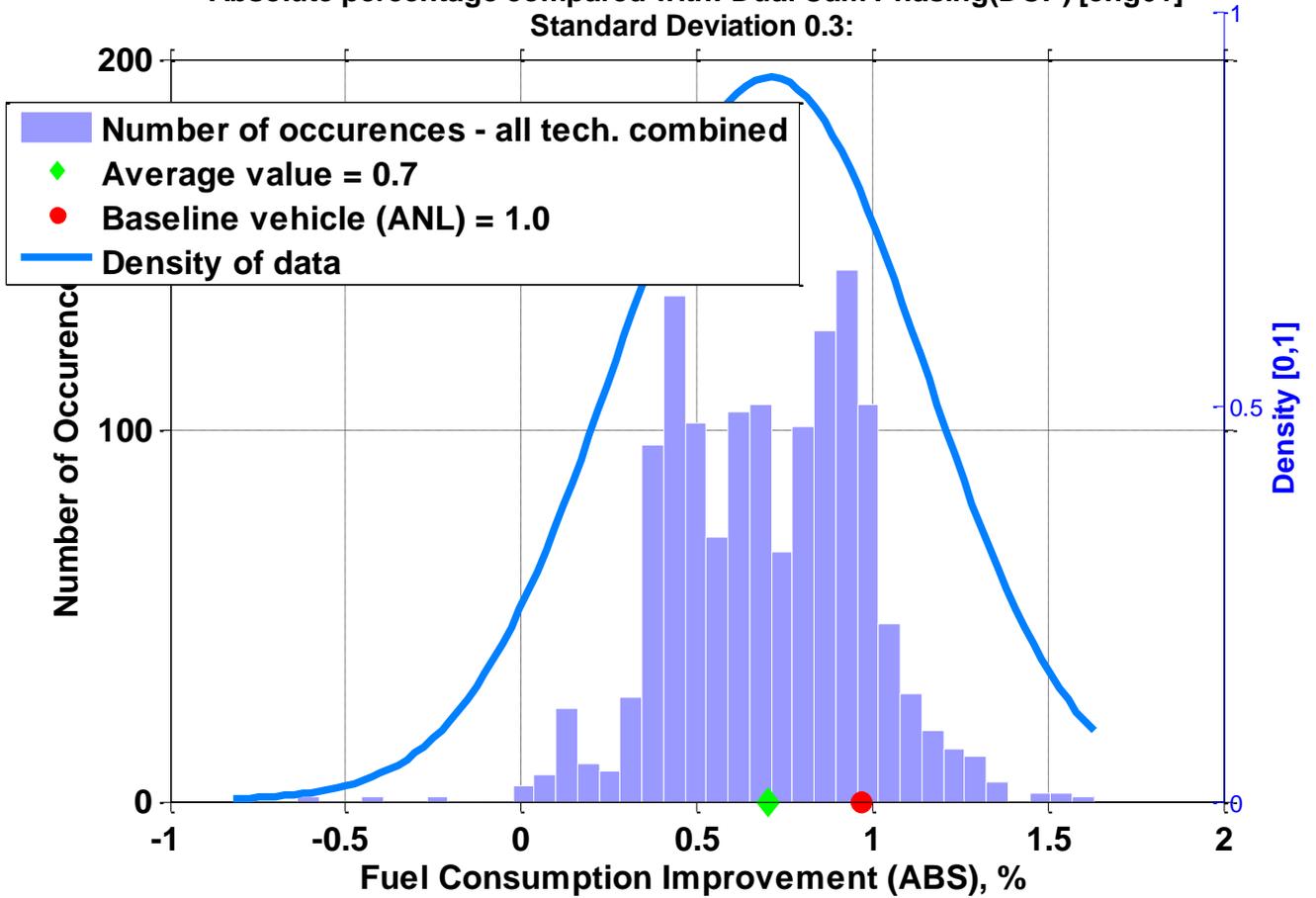


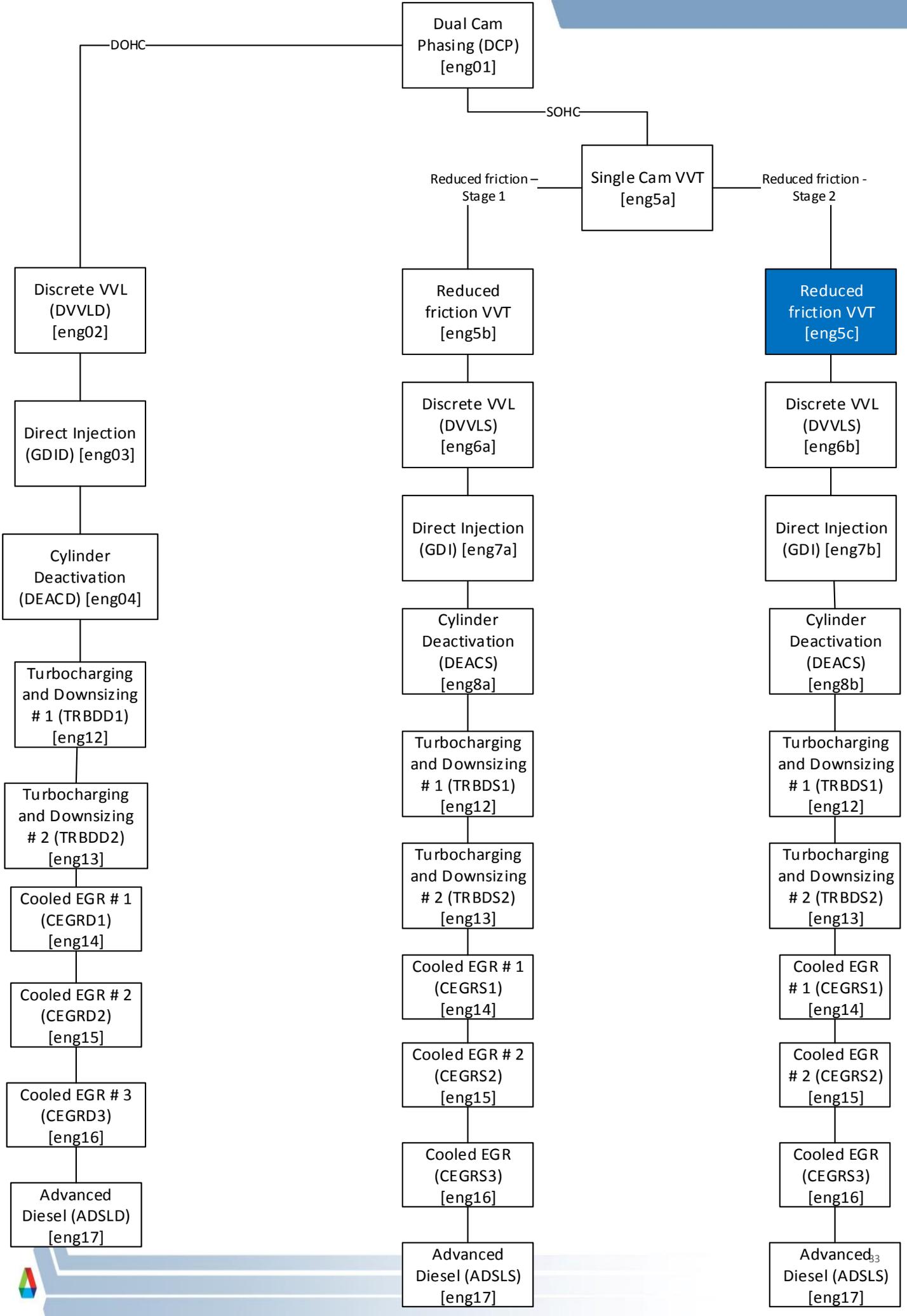
Distribution of Fuel Consumption for Eng05a-Single Over head cam  
 Absolute percentage compared with: Dual Cam Phasing(DCP) [eng01]  
 Standard Deviation 0.2:



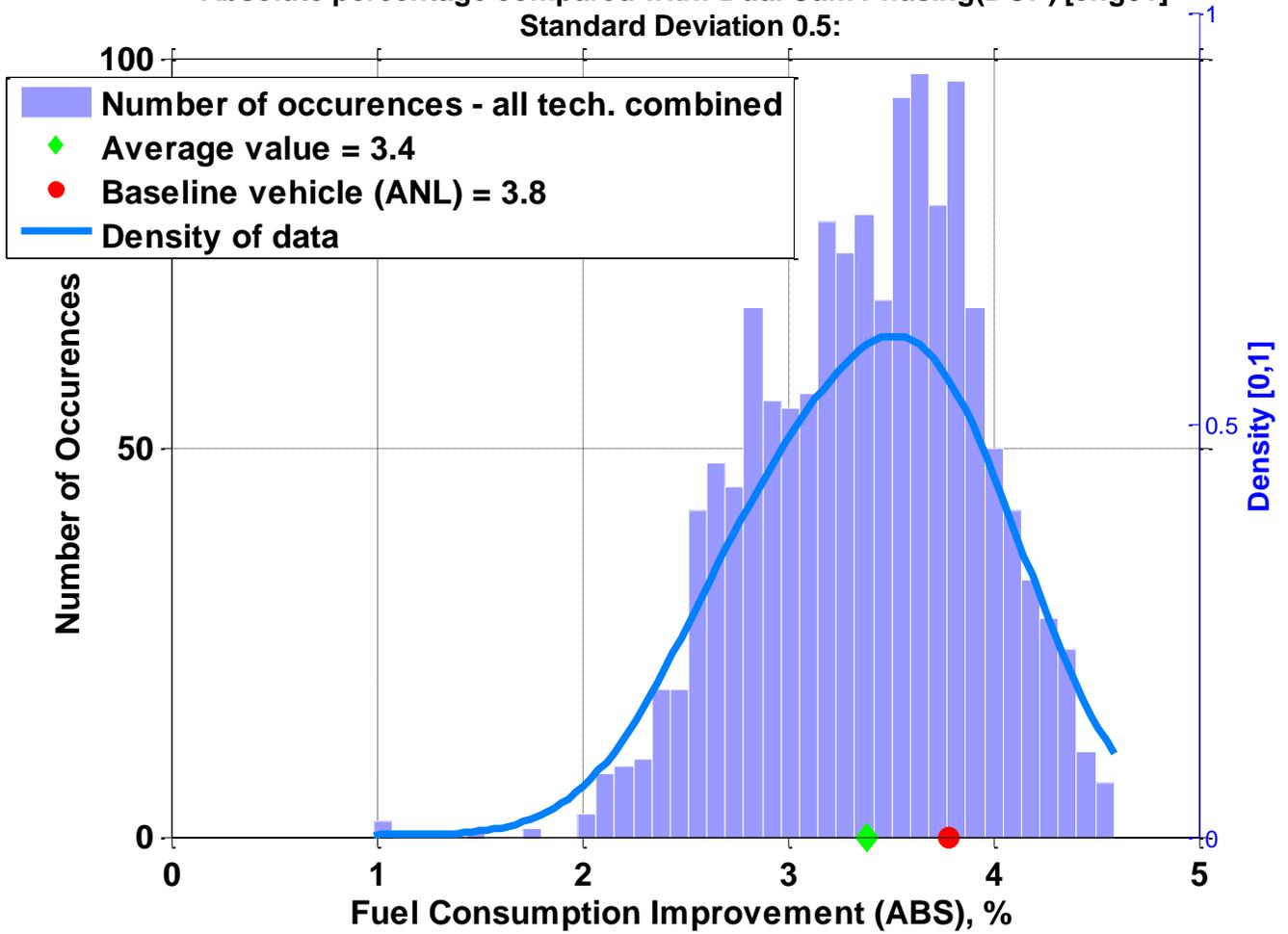


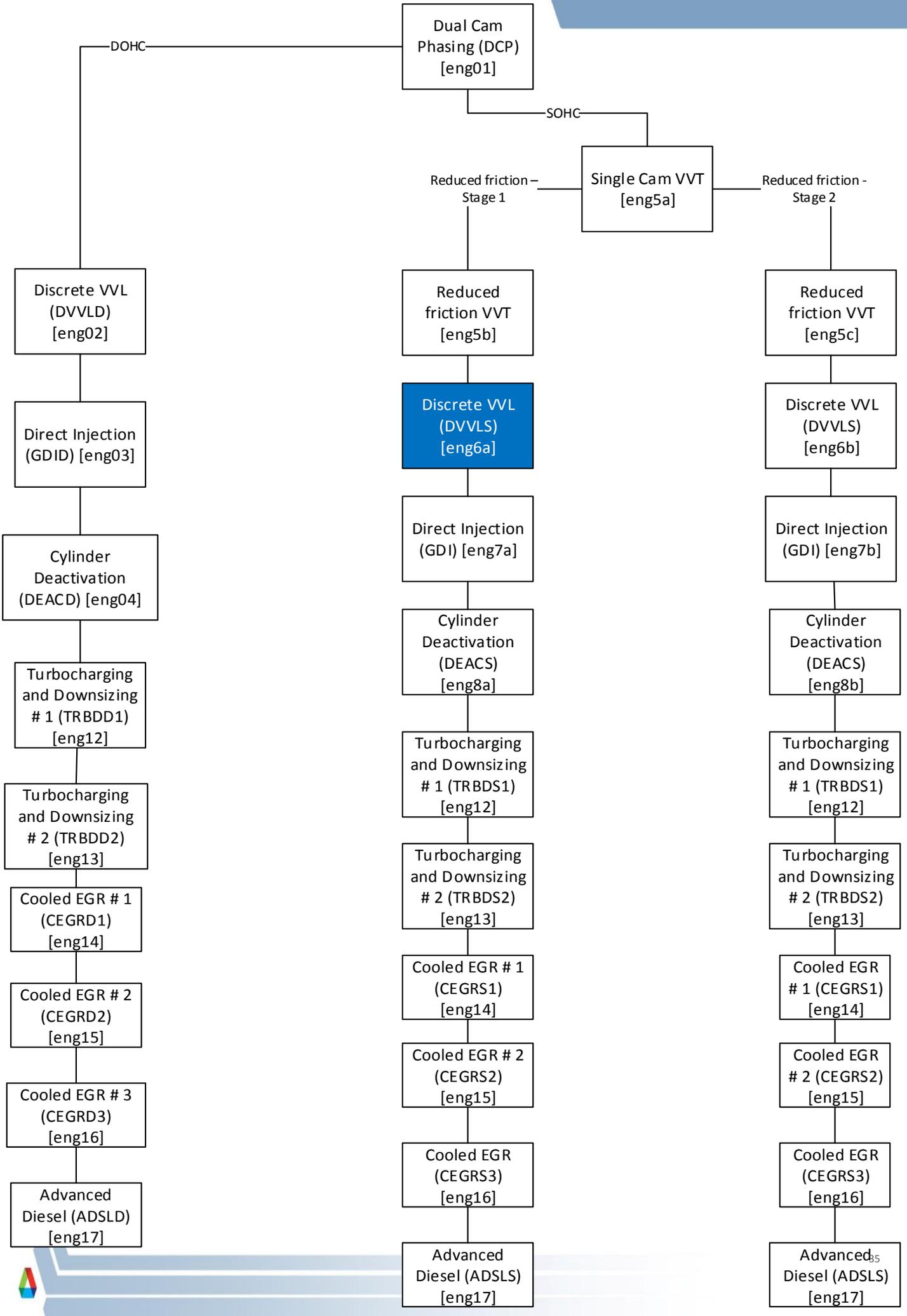
Distribution of Fuel Consumption for Eng05b-Reduced Friction VVT  
 Absolute percentage compared with: Dual Cam Phasing(DCP) [eng01]  
 Standard Deviation 0.3:



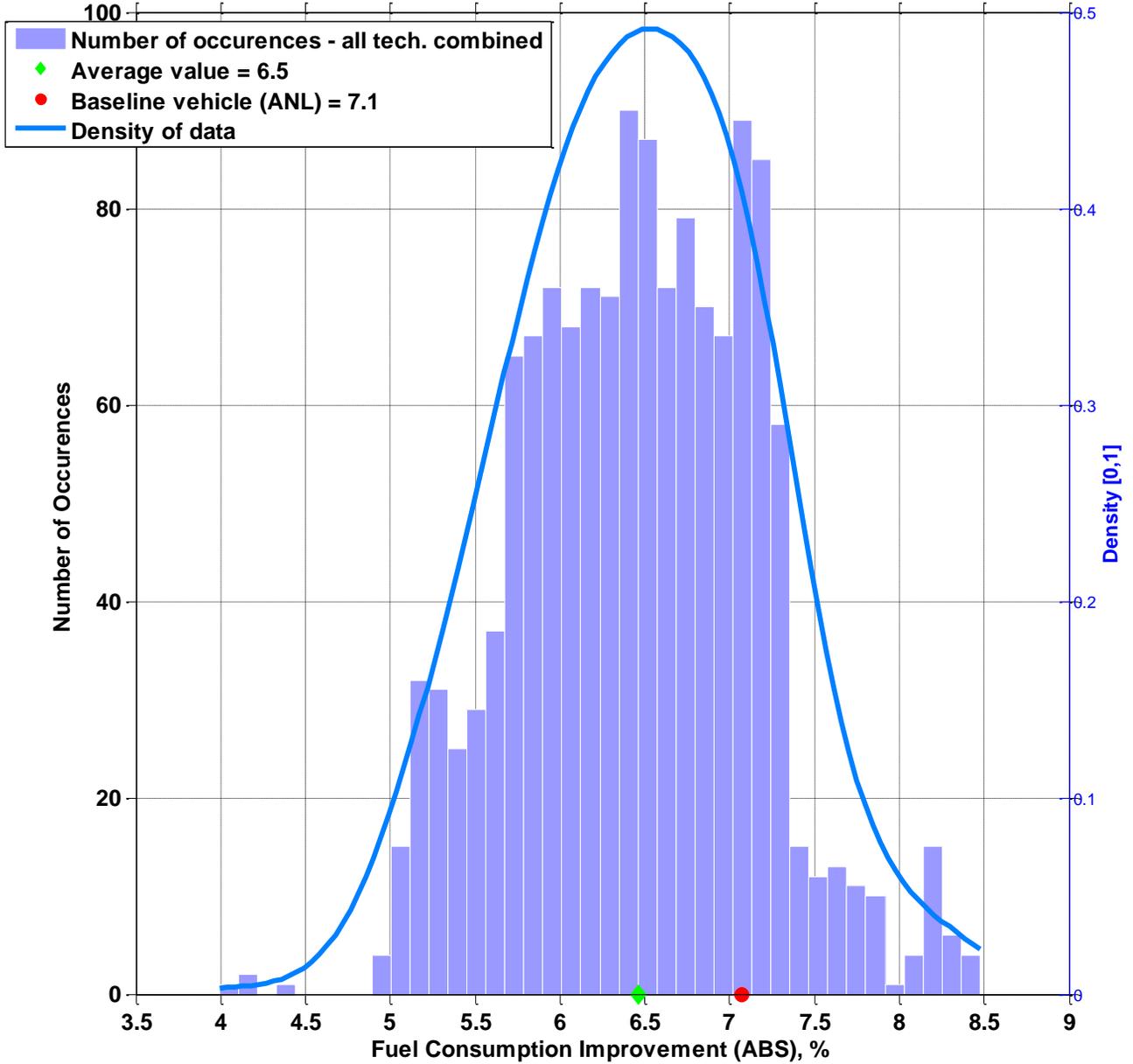


Distribution of Fuel Consumption for Eng05c-Reduced Friction VVT  
Absolute percentage compared with: Dual Cam Phasing(DCP) [eng01]  
Standard Deviation 0.5:



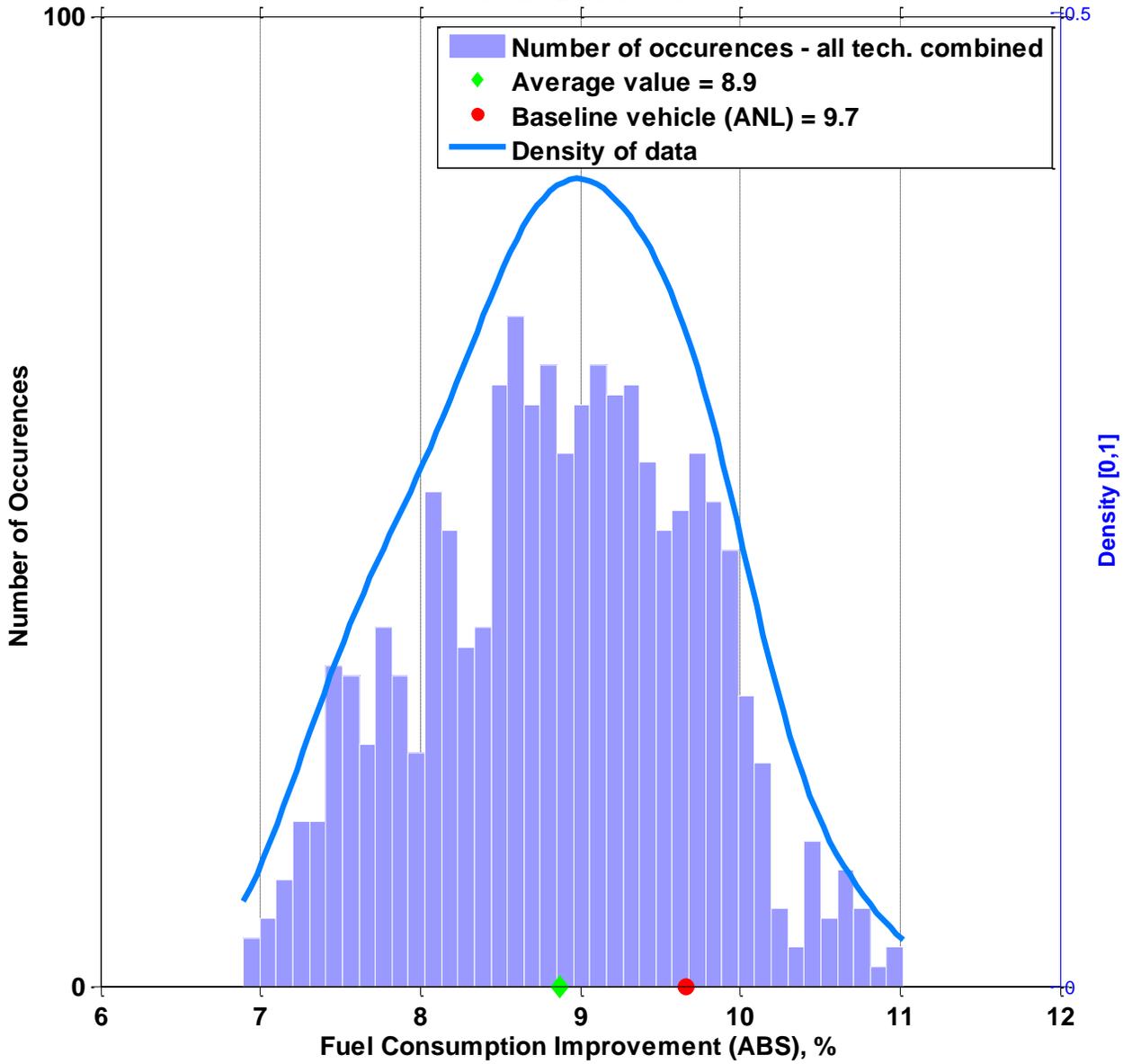


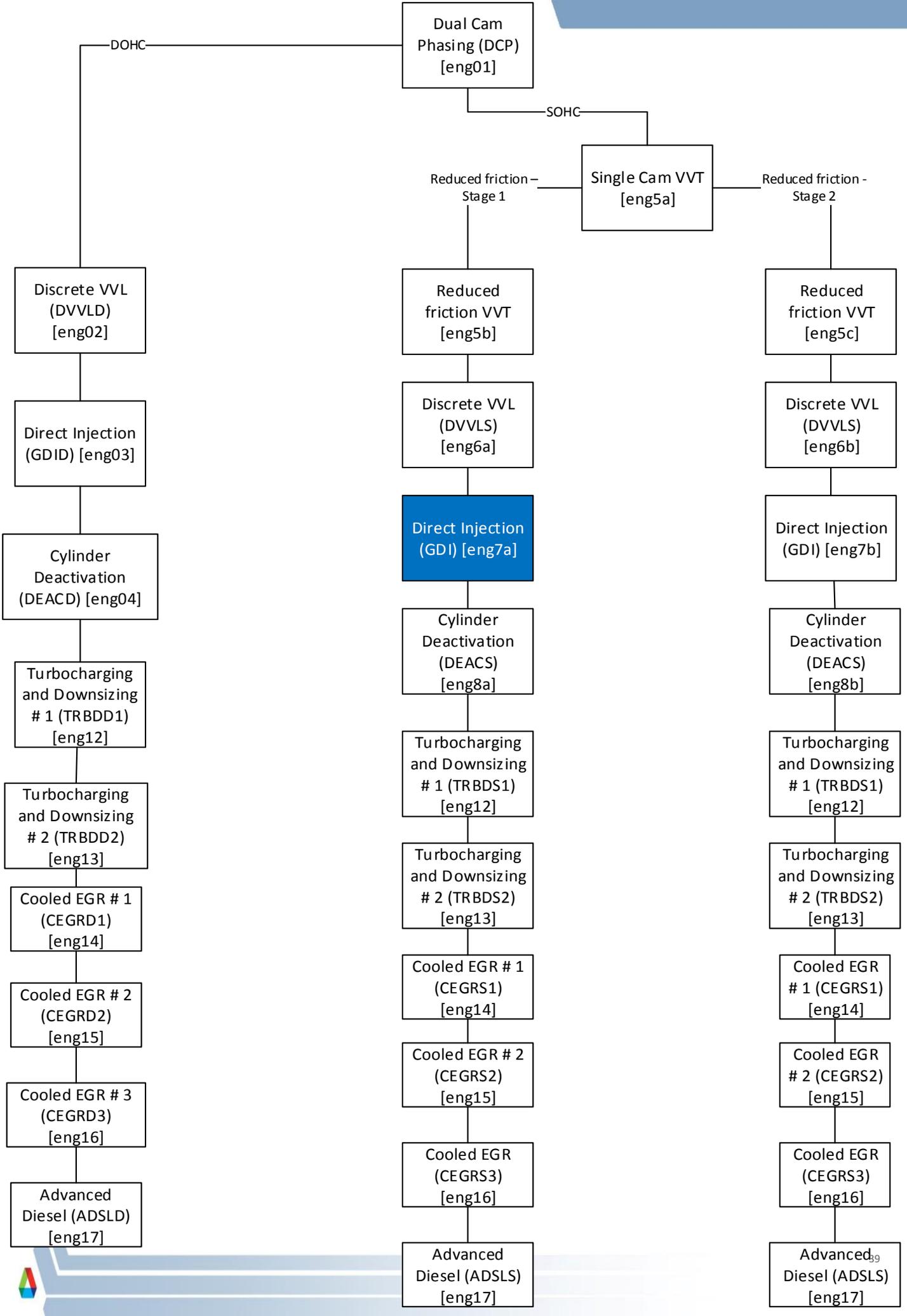
Distribution of Fuel Consumption for Eng06a-Dicrete VVL (DVVLS)  
 Absolute percentage compared with: Dual Cam Phasing(DCP) [eng01]  
 Standard Deviation 0.7:



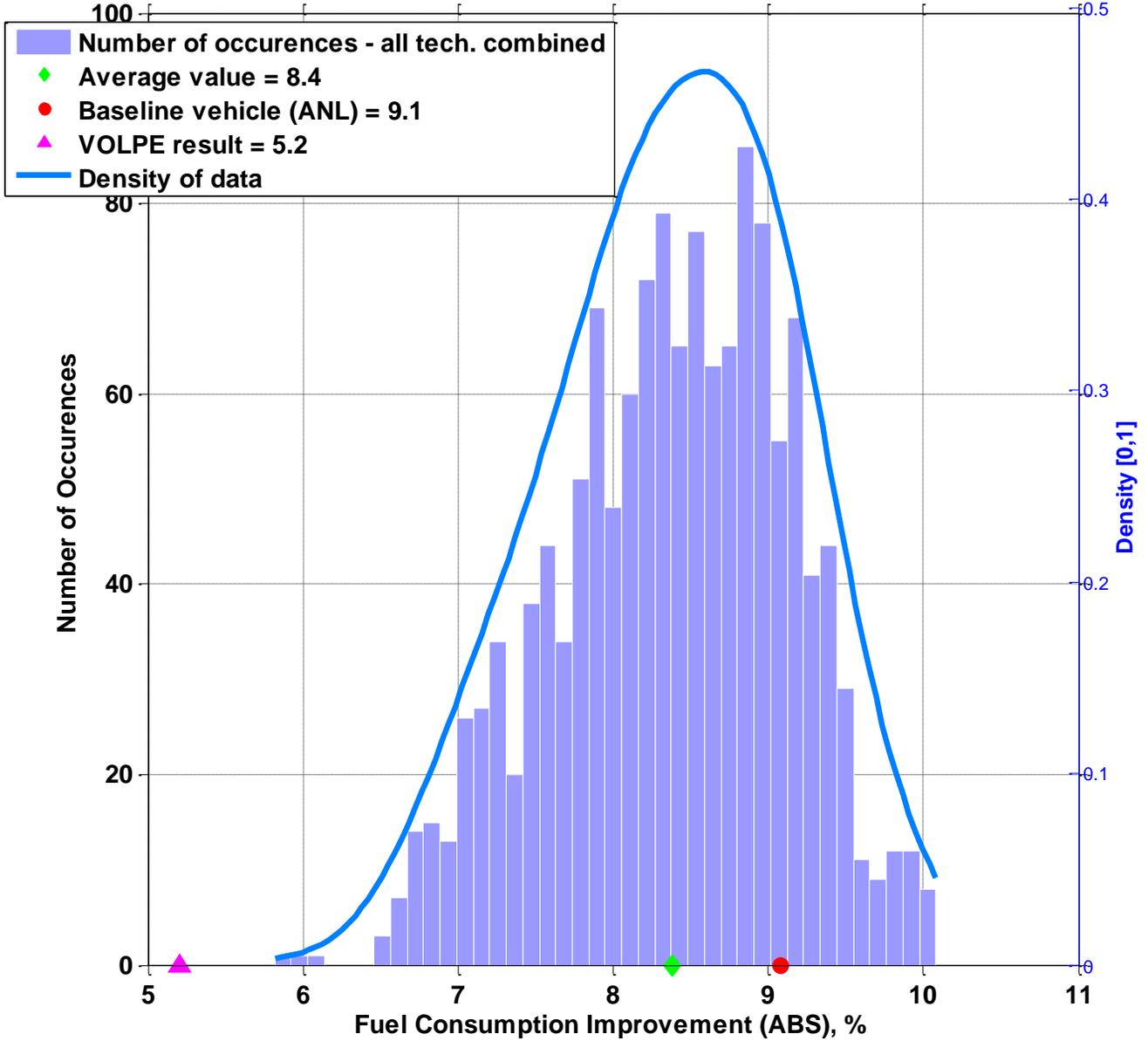


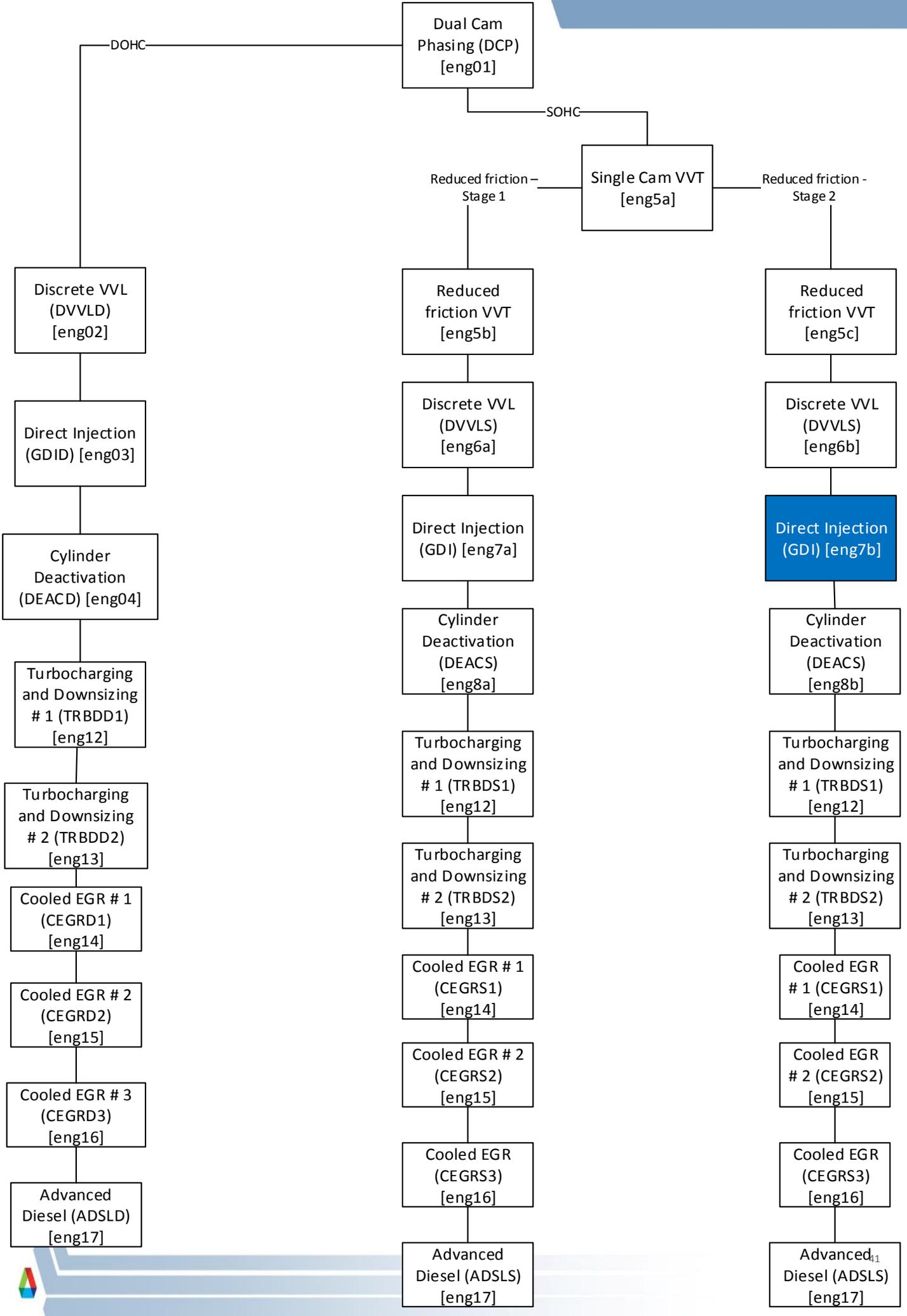
Distribution of Fuel Consumption for Eng06b-Discrete VVL (DVVLS)  
Absolute percentage compared with: Dual Cam Phasing(DCP) [eng01]  
Standard Deviation 0.8:



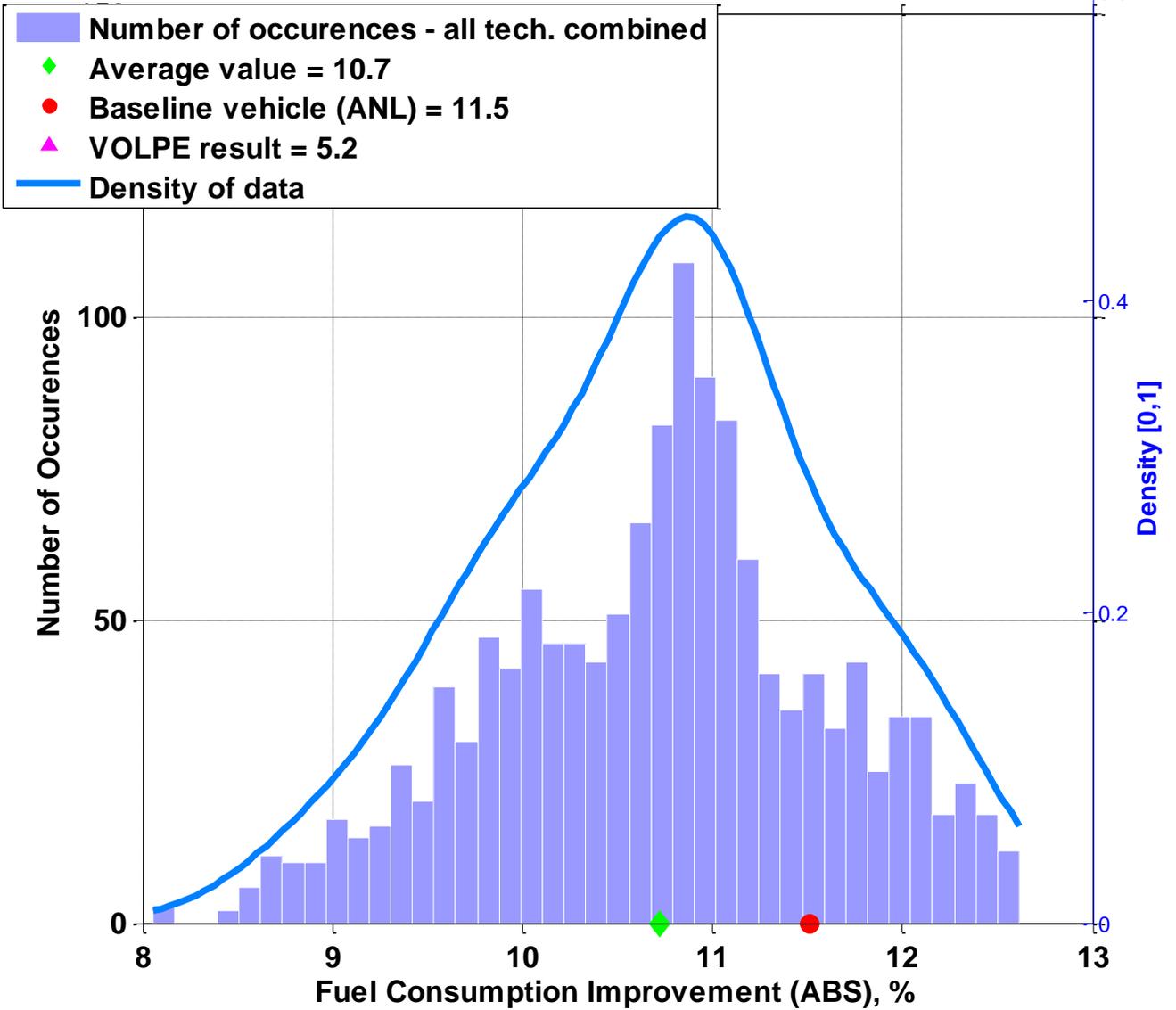


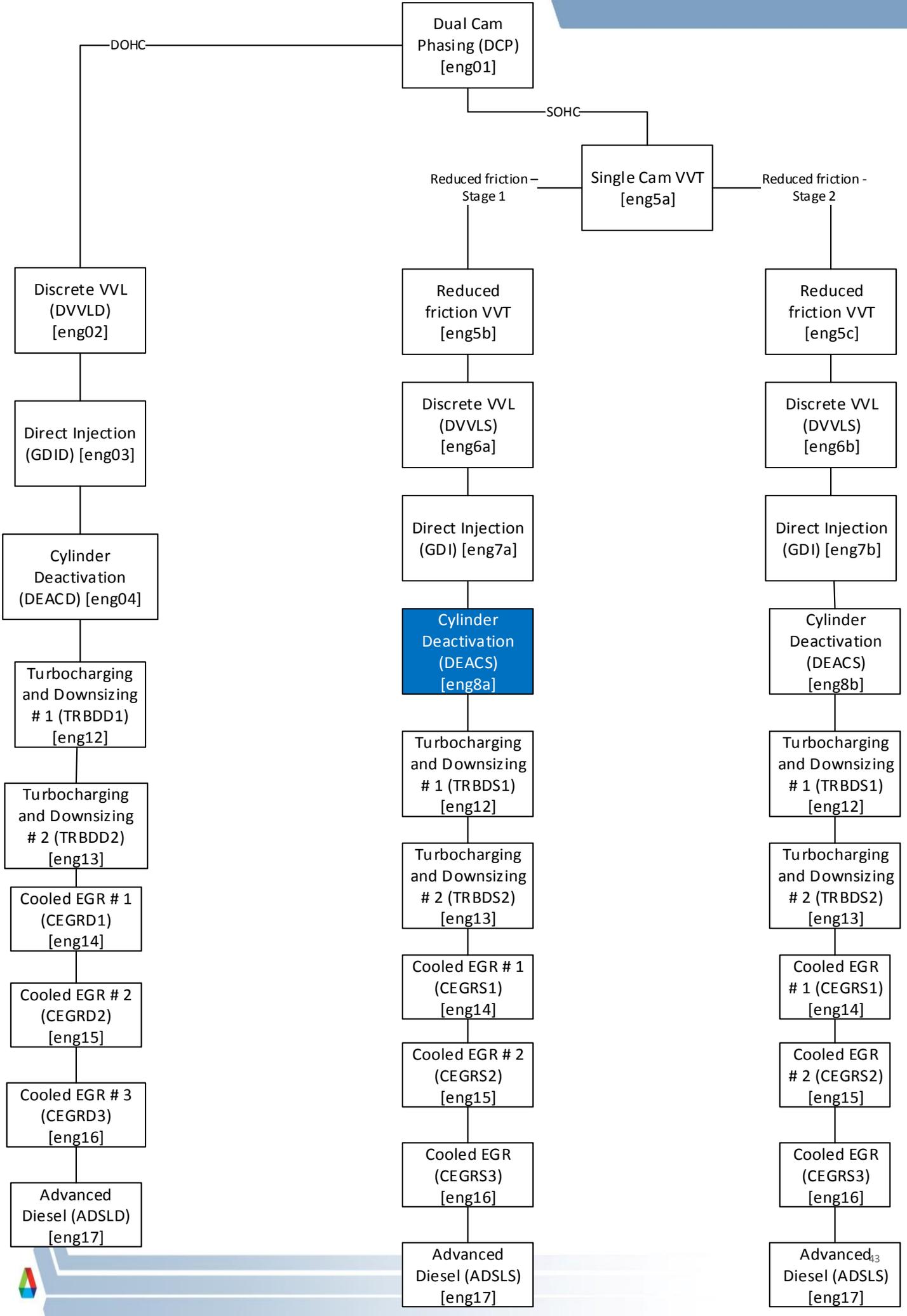
Distribution of Fuel Consumption for Eng07a-Direct Injection (GDIS)  
 Absolute percentage compared with: Dual Cam Phasing(DCP) [eng01]  
 Standard Deviation 0.8:



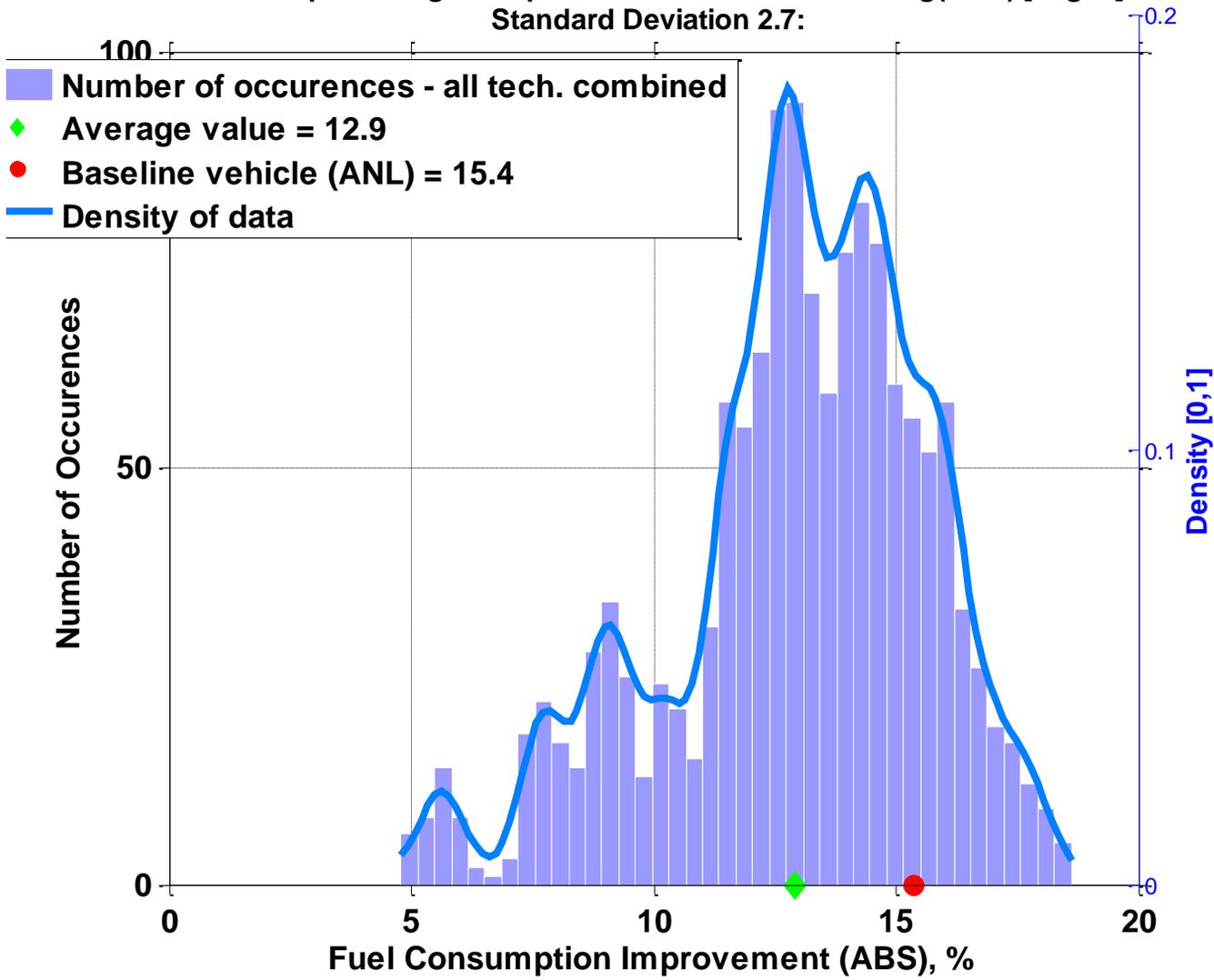


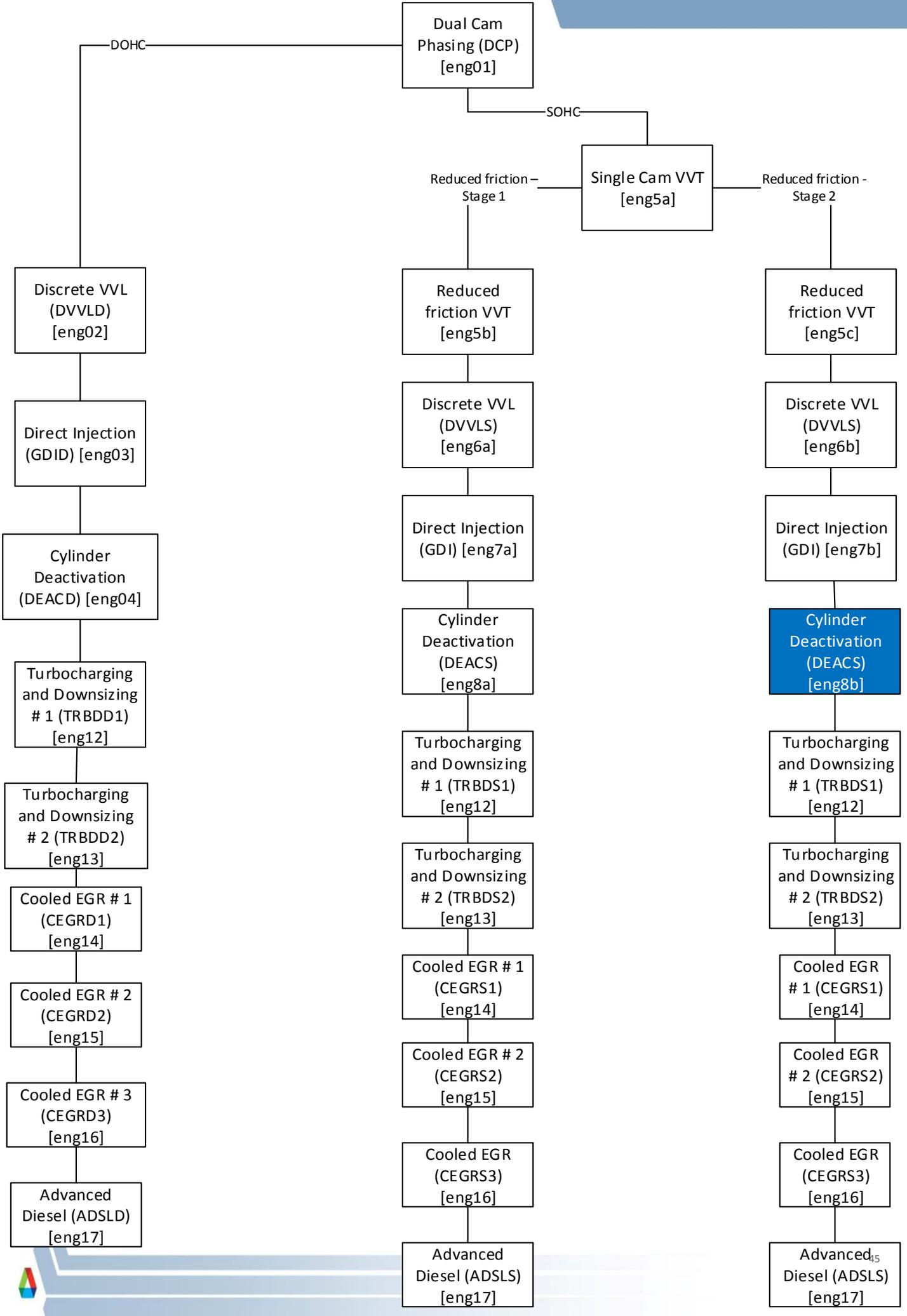
**Distribution of Fuel Consumption for Eng07b-Direct Injection (GDIS)  
 Absolute percentage compared with: Dual Cam Phasing(DCP) [eng01]  
 Standard Deviation 0.9:**



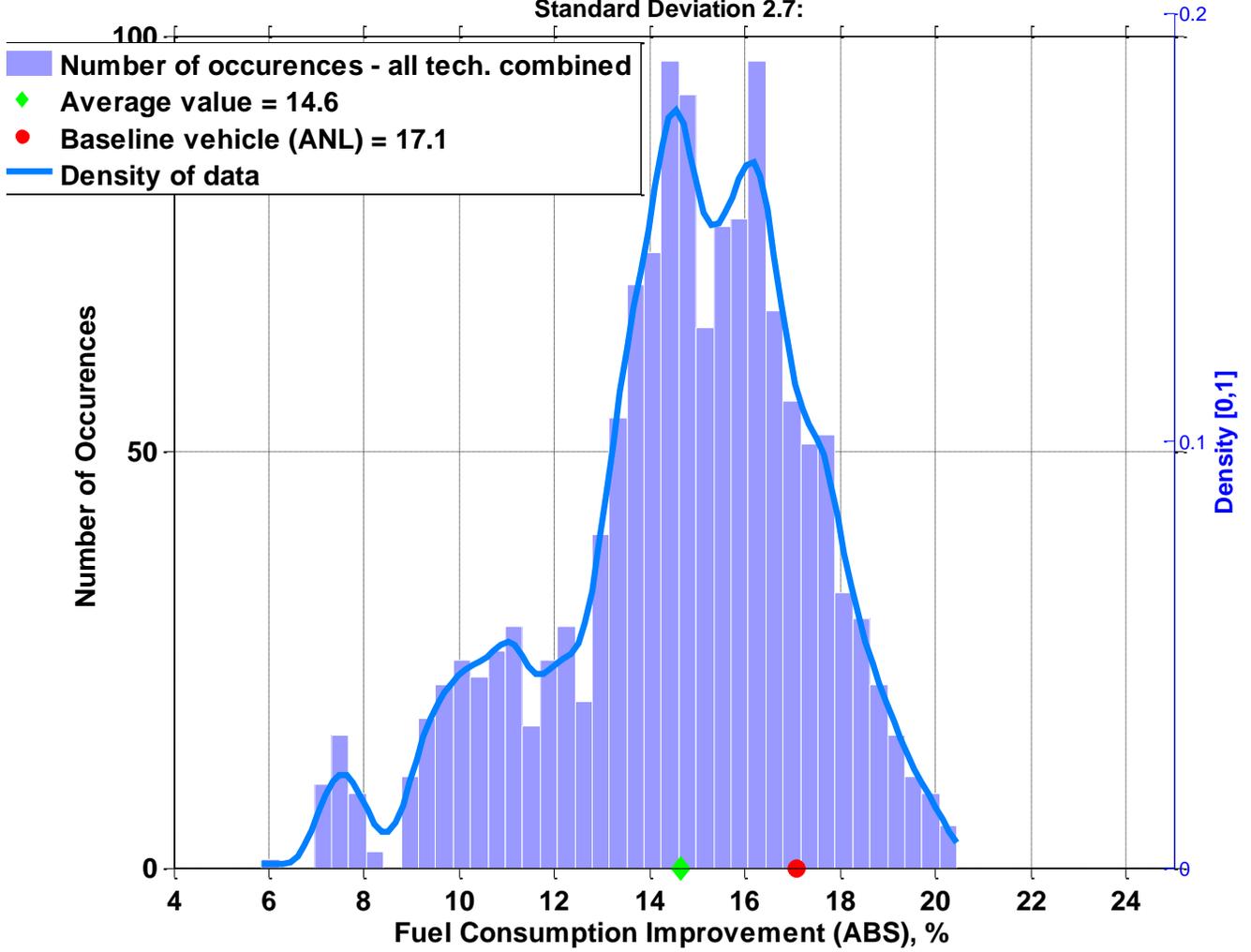


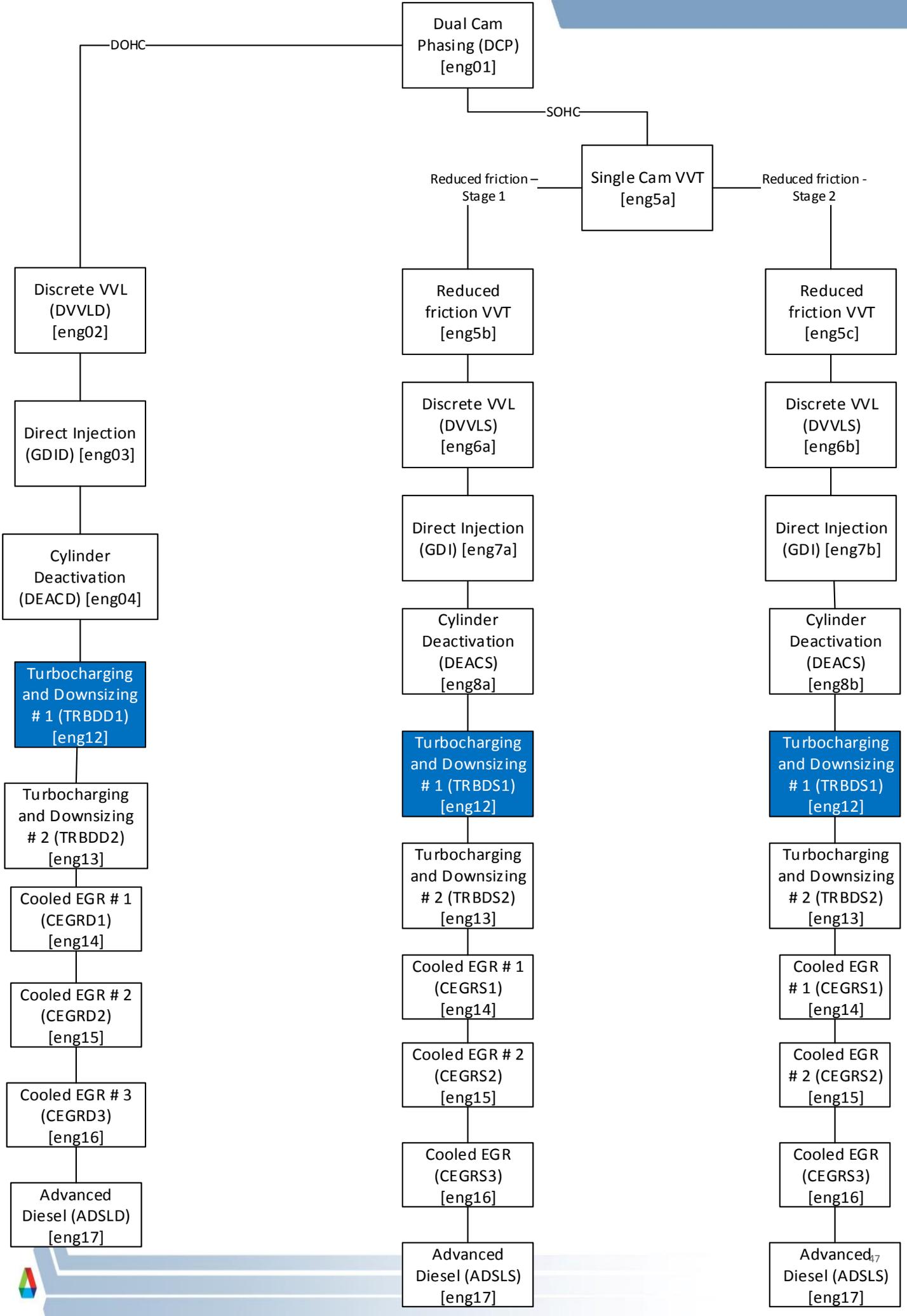
Distribution of Fuel Consumption for Eng08a-Cylinder Deactivation(DEACS)  
 Absolute percentage compared with: Dual Cam Phasing(DCP) [eng01]  
 Standard Deviation 2.7:



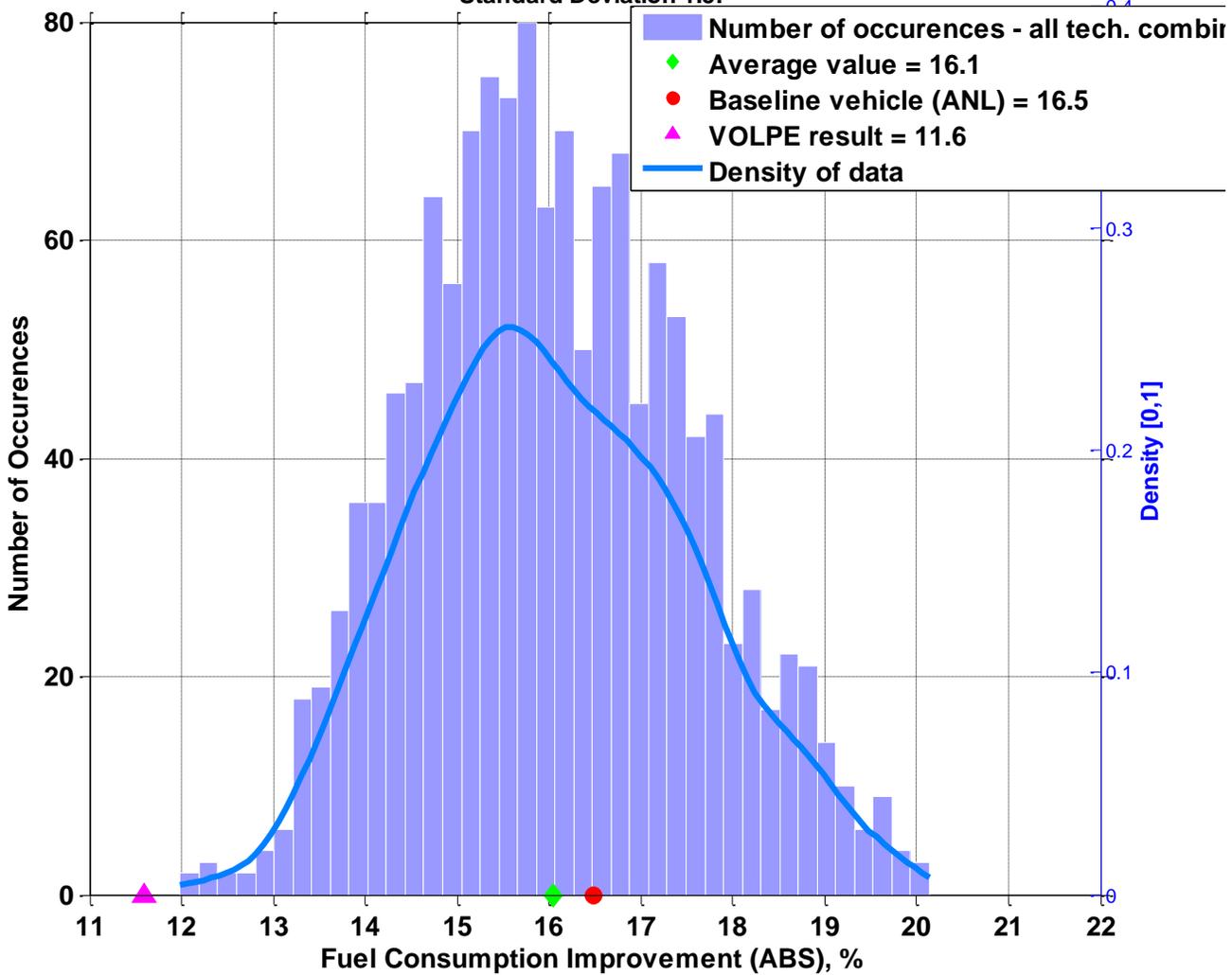


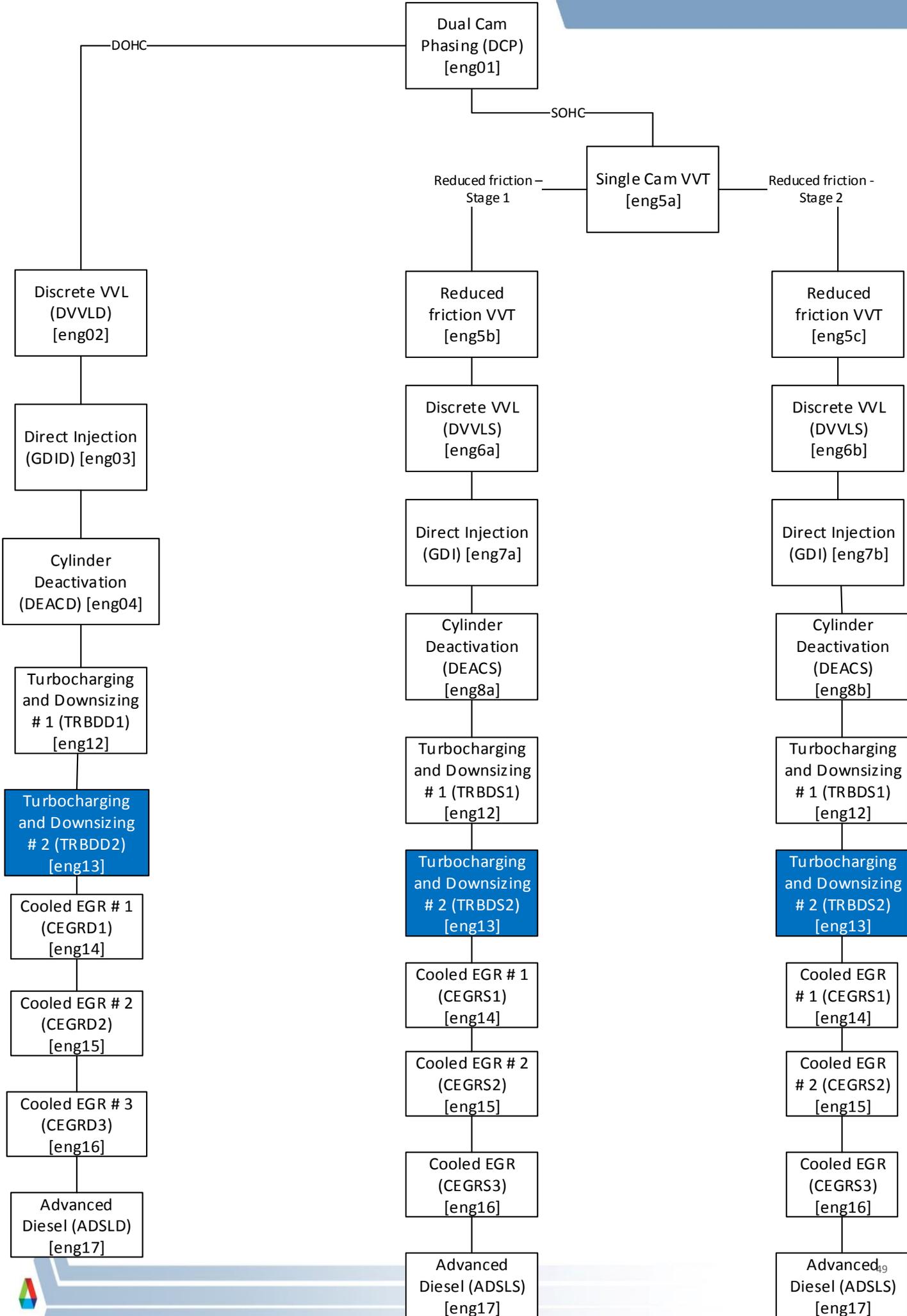
Distribution of Fuel Consumption for Eng08b-Cylinder Deactivation (DEACS)  
 Absolute percentage compared with: Dual Cam Phasing(DCP) [eng01]  
 Standard Deviation 2.7:



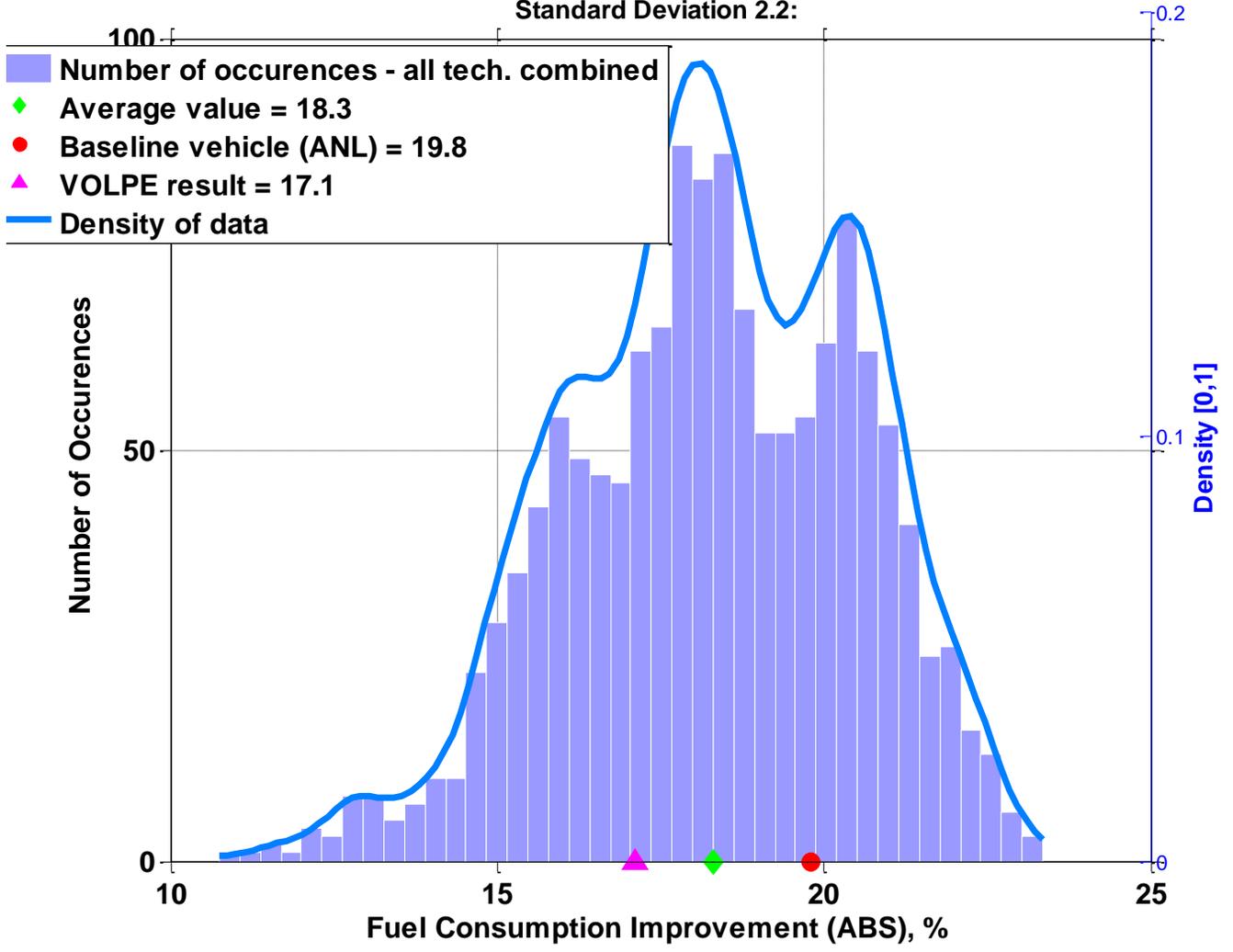


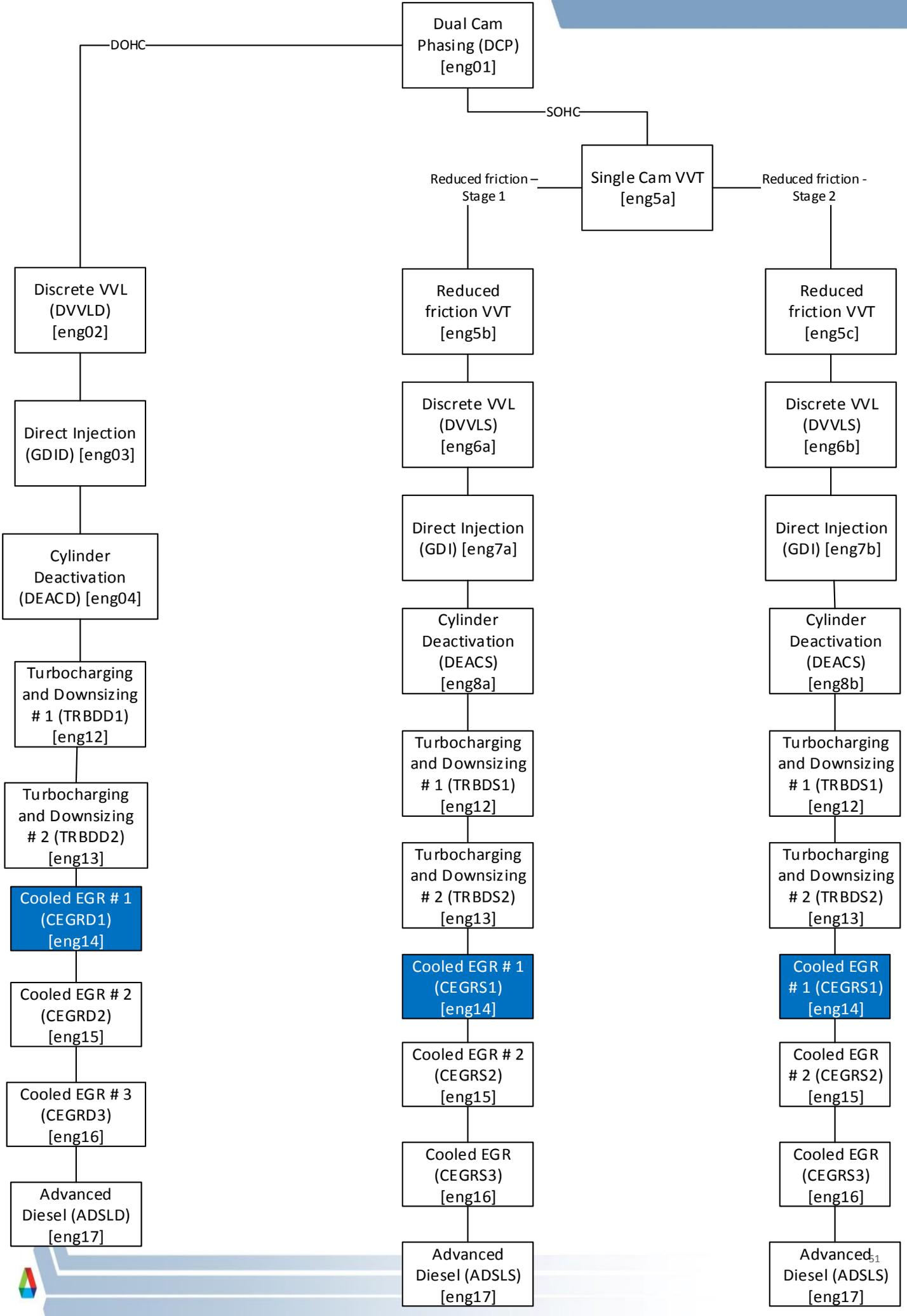
Distribution of Fuel Consumption for Eng12-Turbocharging and Downsizing # 1 (TRBD1)  
 Absolute percentage compared with: Dual Cam Phasing(DCP) [eng01]  
 Standard Deviation 1.5:



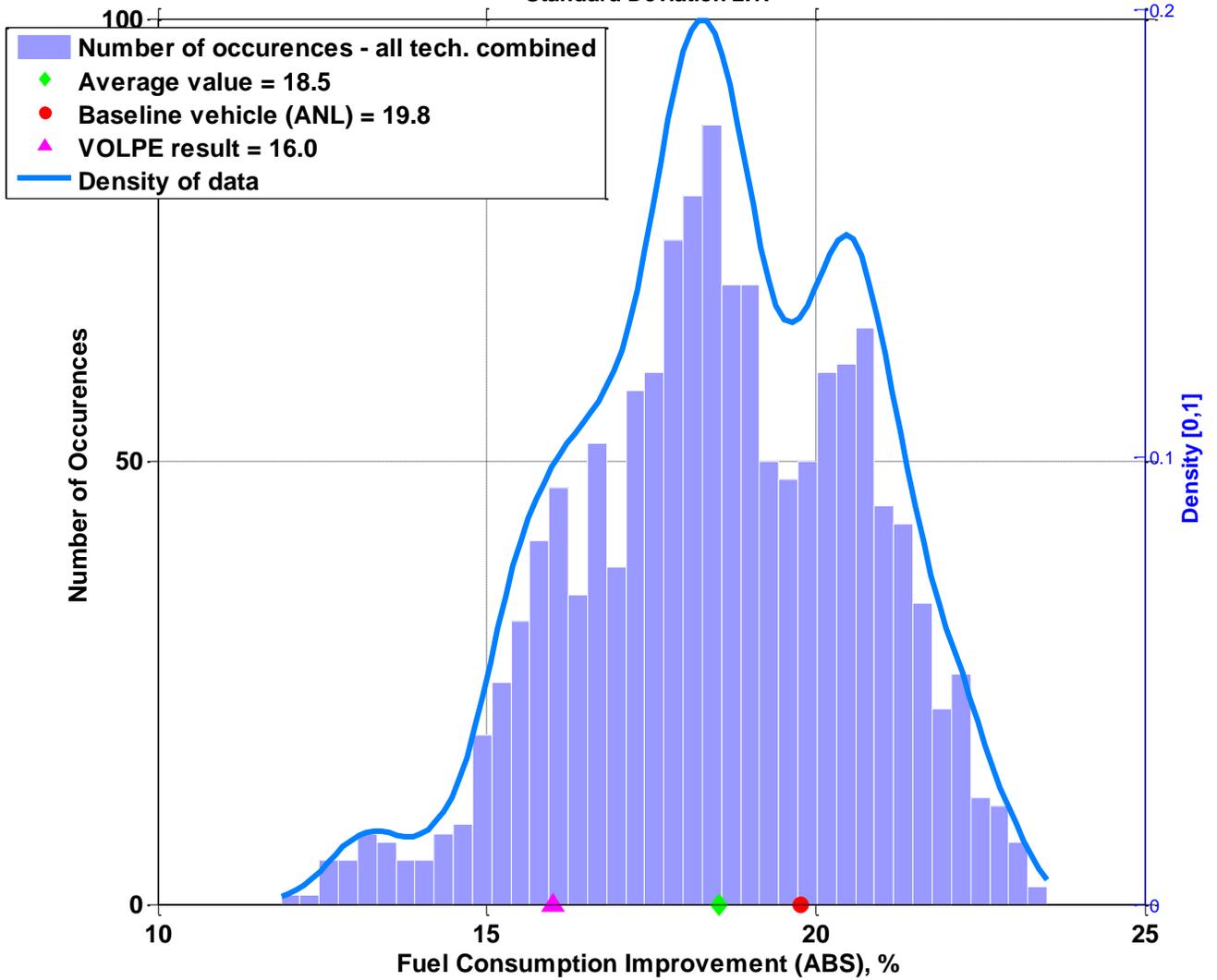


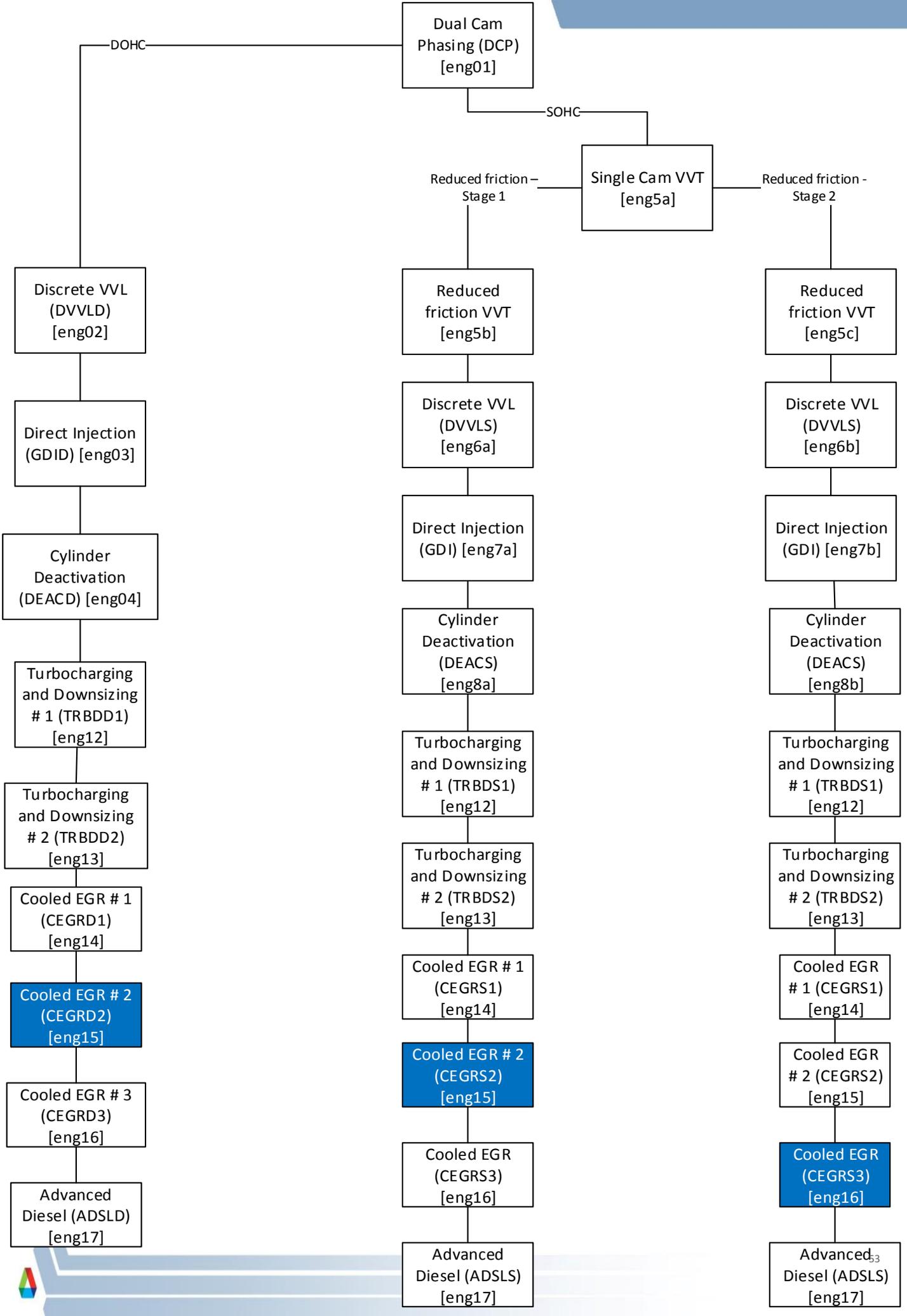
Distribution of Fuel Consumption for Eng13-Turbocharging and Downsizing #2 (TRBD2)  
 Absolute percentage compared with: Dual Cam Phasing(DCP) [eng01]  
 Standard Deviation 2.2:



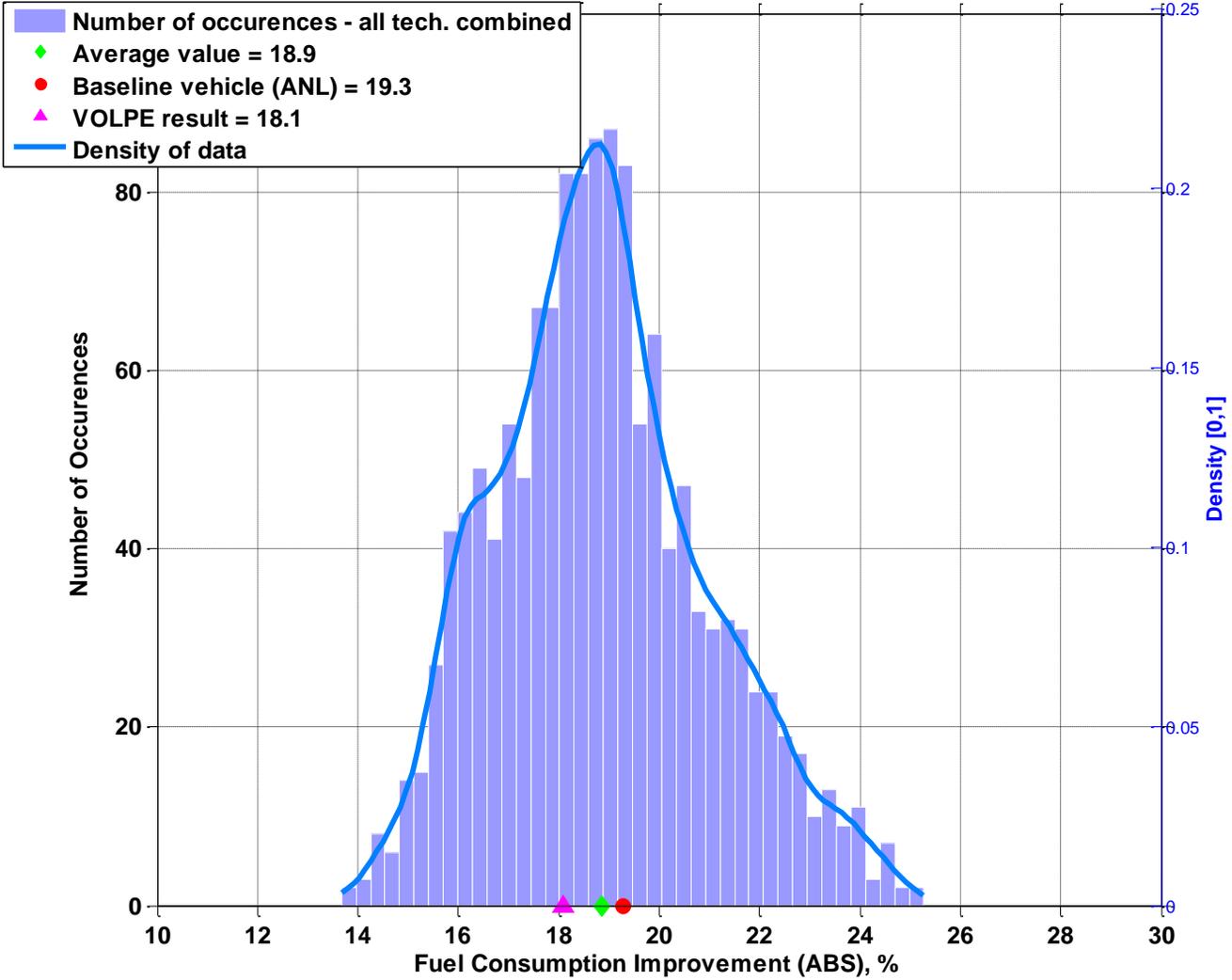


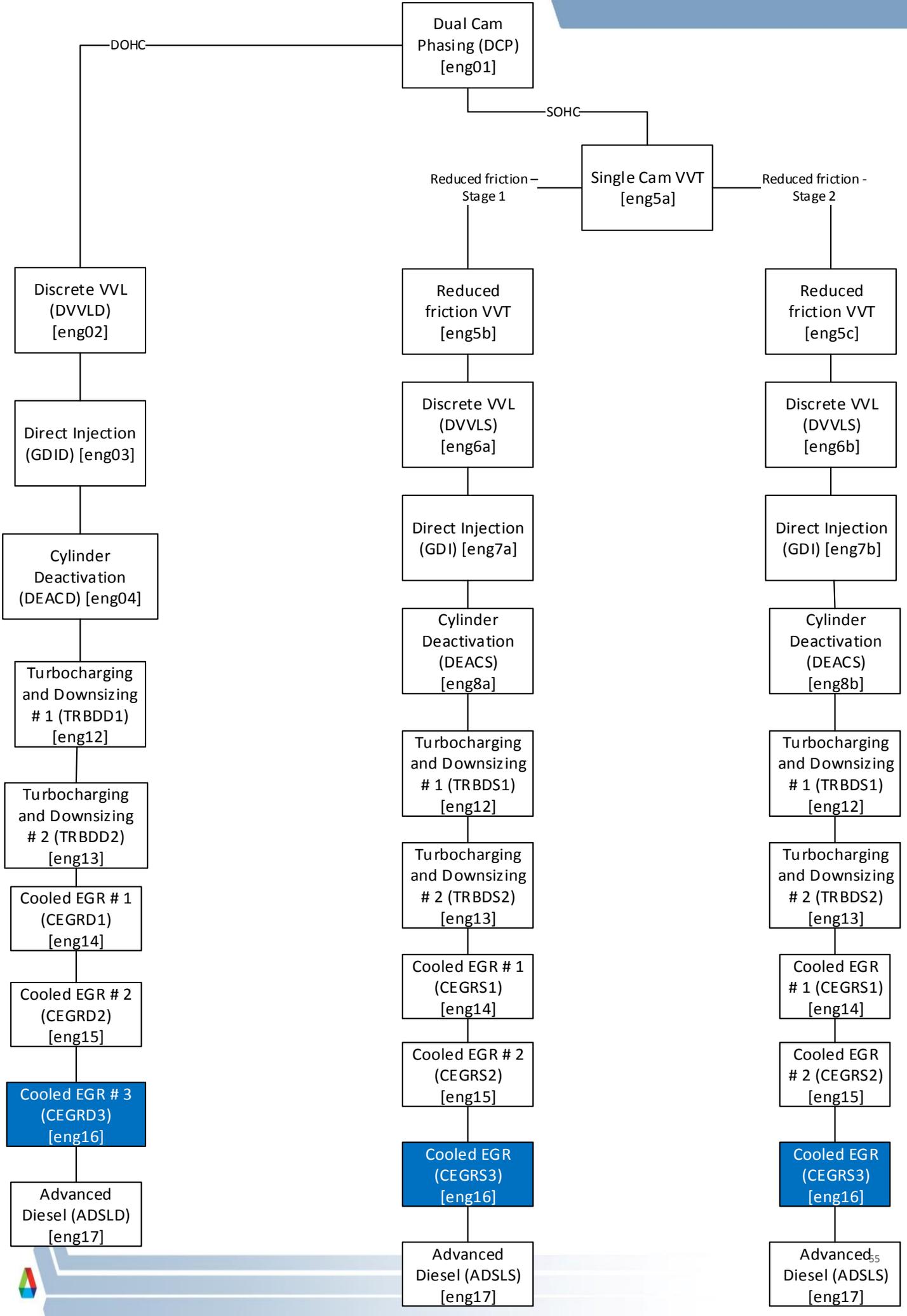
Distribution of Fuel Consumption for Eng14-Cooled EGR#1 (CEGR1)  
 Absolute percentage compared with: Dual Cam Phasing(DCP) [eng01]  
 Standard Deviation 2.1:



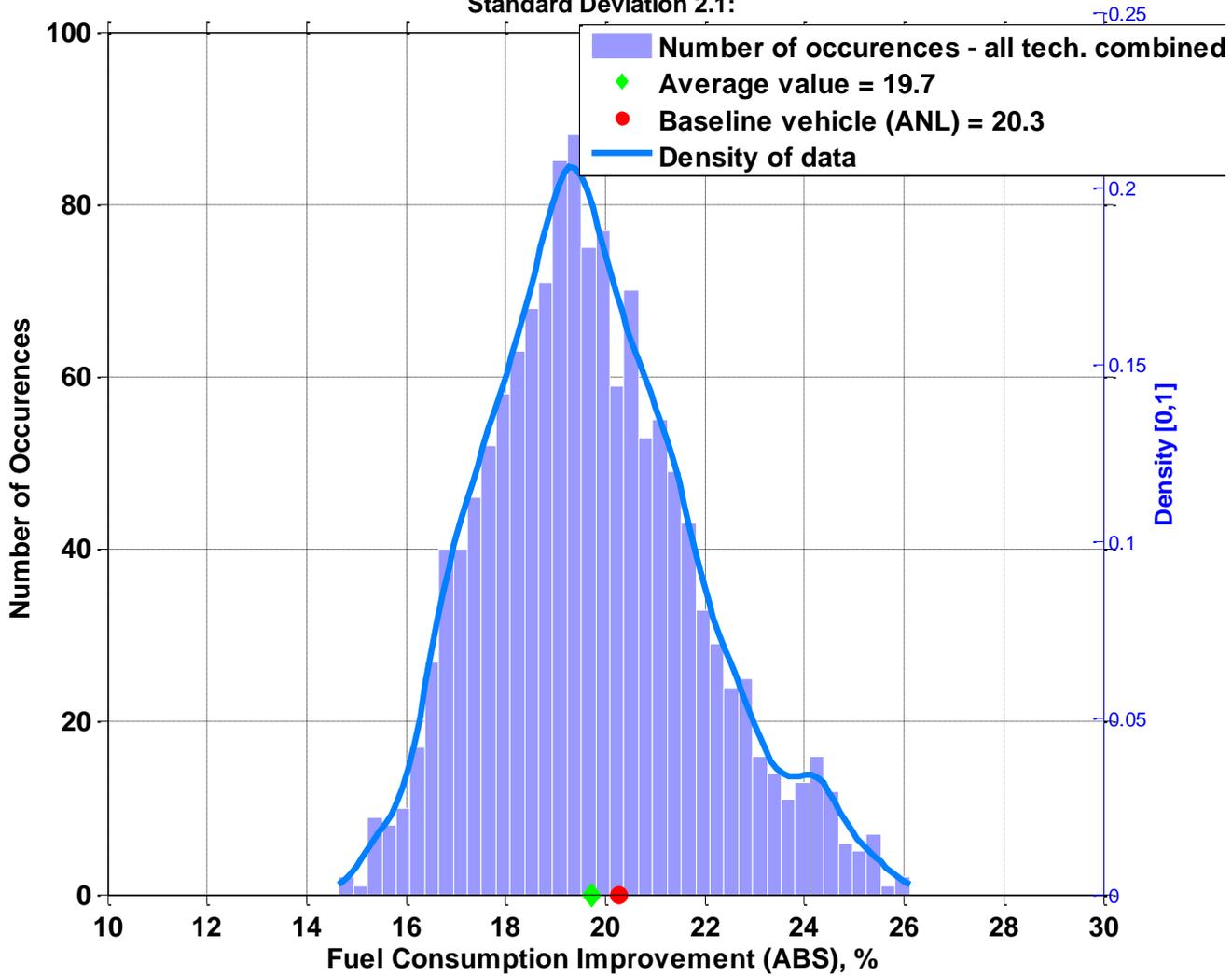


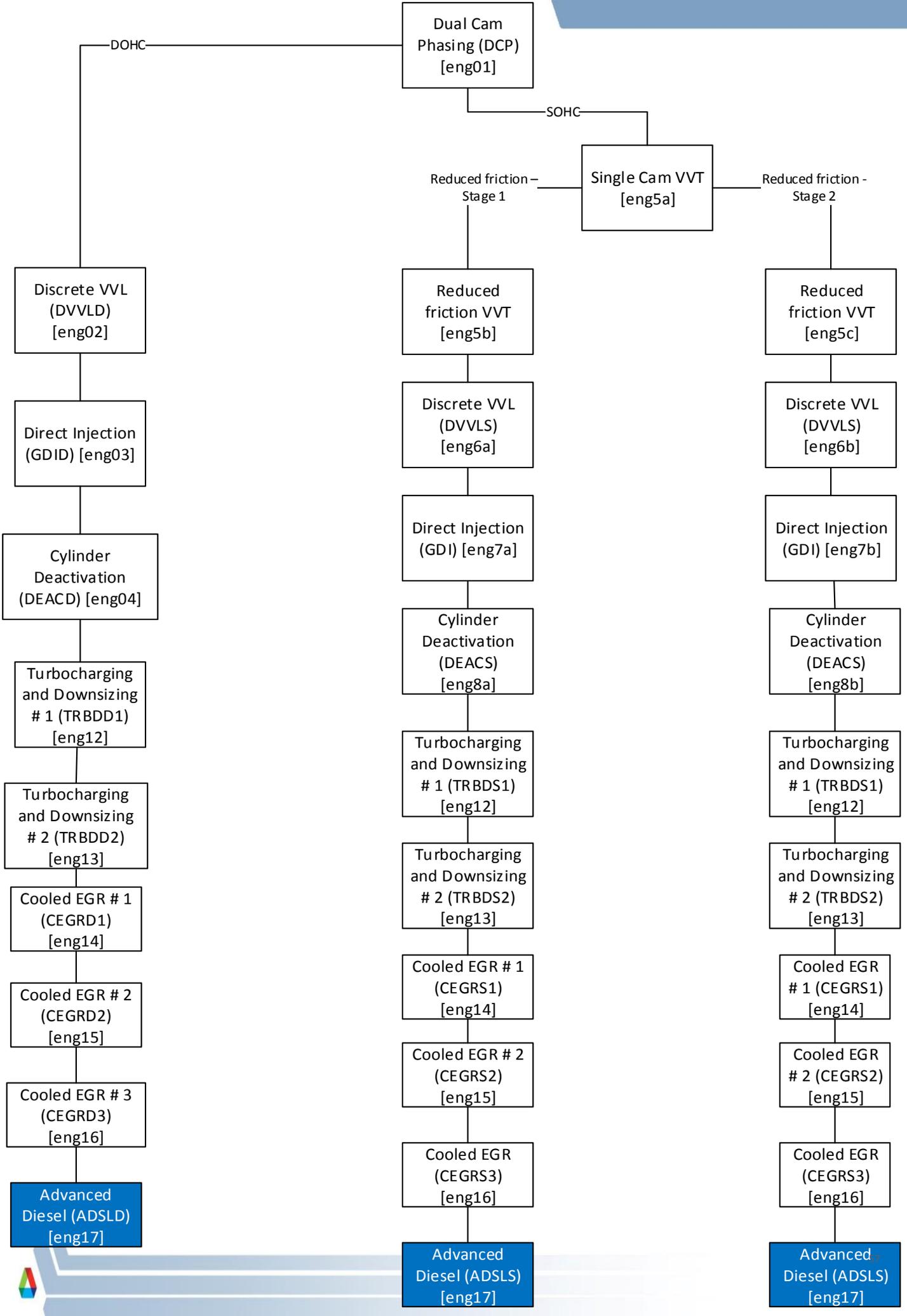
Distribution of Fuel Consumption for Eng15-Cooled EGR#2 (CEGR2)  
 Absolute percentage compared with: Dual Cam Phasing(DCP) [eng01]  
 Standard Deviation 2.1:



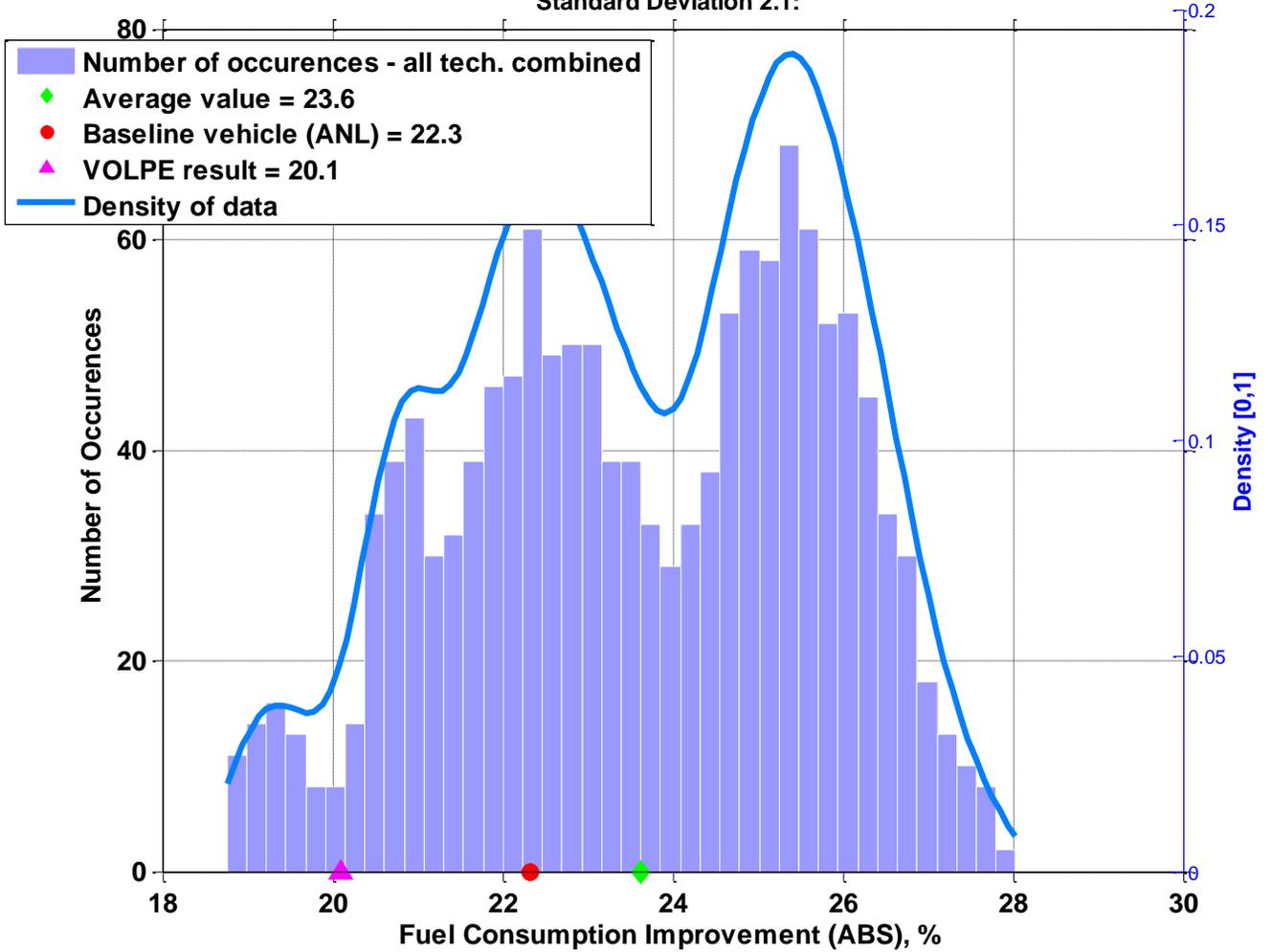


Distribution of Fuel Consumption for Eng16-Cooled EGR (CEGR3)  
 Absolute percentage compared with: Dual Cam Phasing(DCP) [eng01]  
 Standard Deviation 2.1:





Distribution of Fuel Consumption for Eng17-Advanced Diesel(ADLS)  
 Absolute percentage compared with: Dual Cam Phasing(DCP) [eng01]  
 Standard Deviation 2.1:



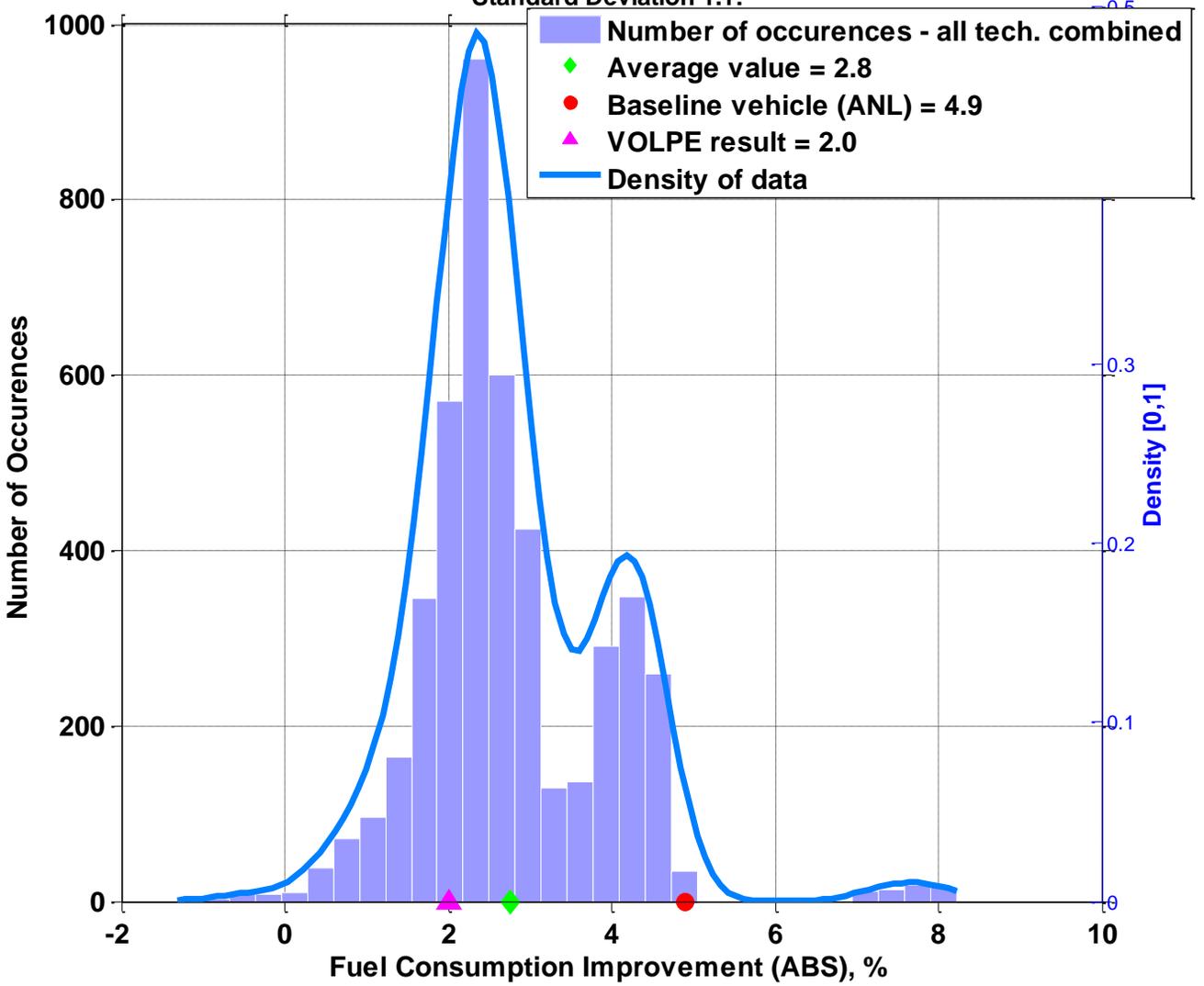
# TRANSMISSION TECHNOLOGY

5-spd Trans (AUTO)

6-spd Trans w/Improved  
Internals (Auto) (NAUTO)

8-spd Trans (AUTO)

Distribution of Fuel Consumption for Transmission-AUTO-(early lockup)-6-spd  
 Absolute percentage compared with: AUTO-5spd (no early lockup)  
 Standard Deviation 1.1:



5-spd Trans (AUTO)

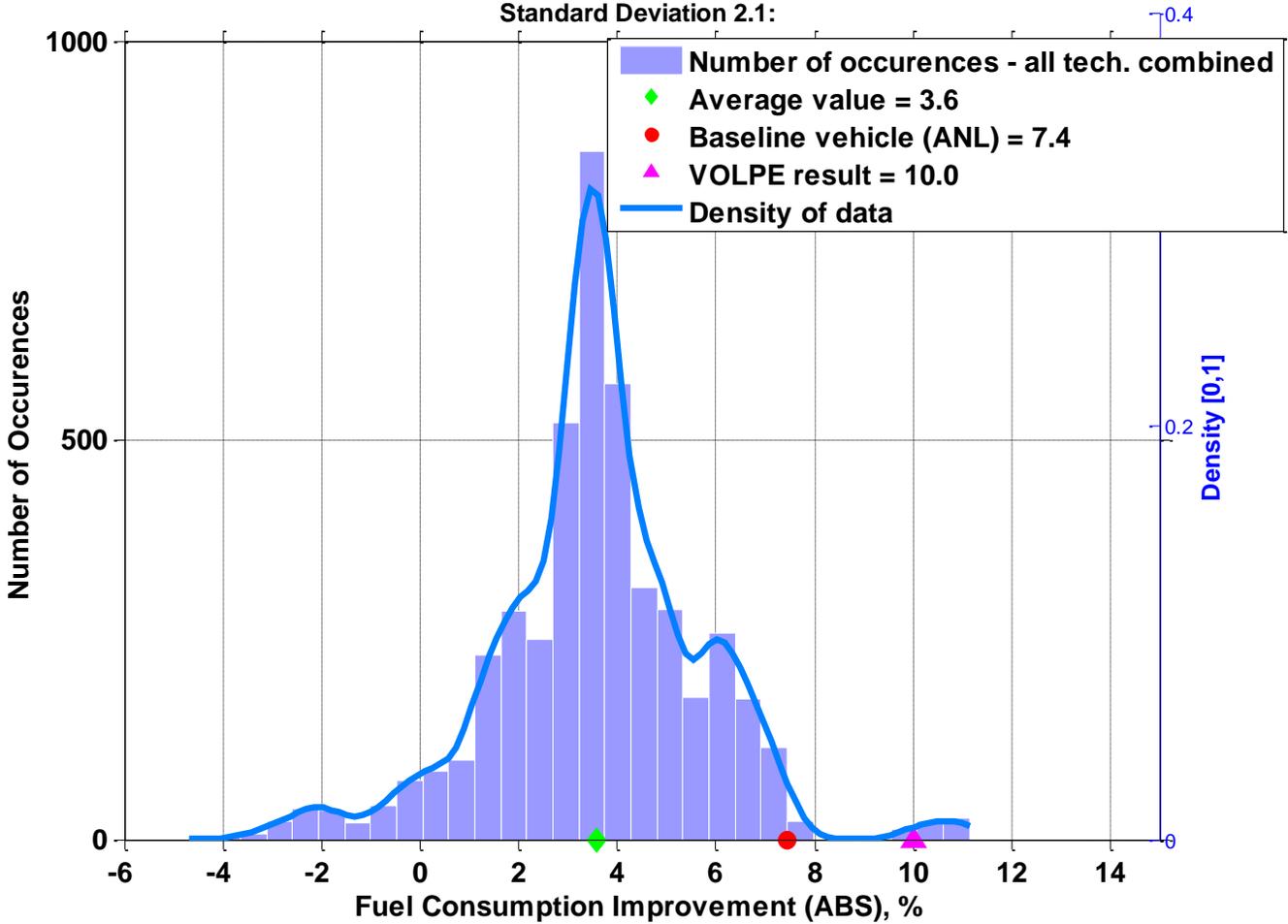


6-spd Trans w/Improved Internals (Auto) (NAUTO)



8-spd Trans (AUTO)

Distribution of Fuel Consumption for Transmission-AUTO-(early lockup)-8-spd  
 Absolute percentage compared with: AUTO-5spd (no early lockup)  
 Standard Deviation 2.1:



5-spd Trans (AUTO)

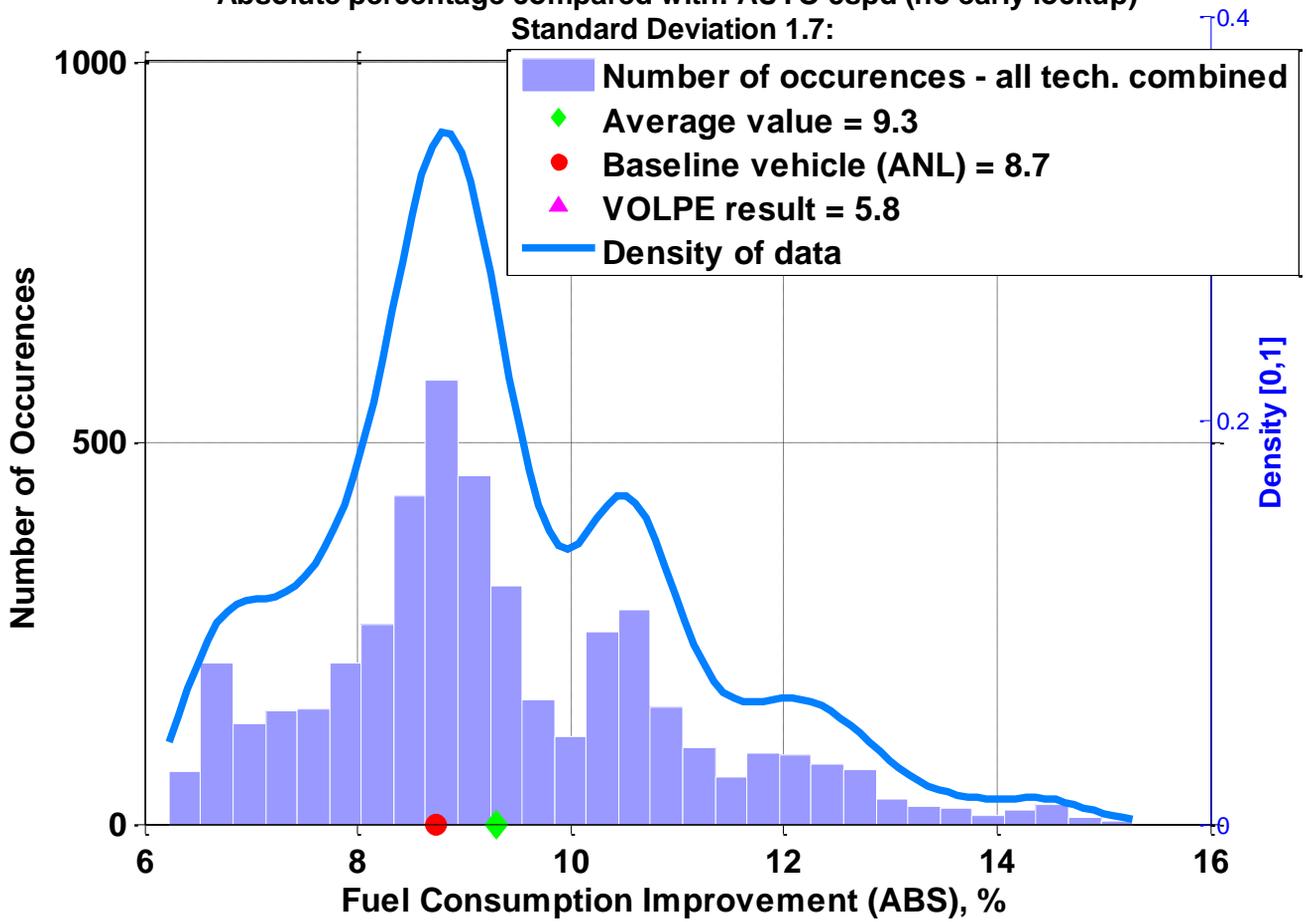


6-spd DCT (DCT)



8-spd DCT (DCT)

Distribution of Fuel Consumption for Transmission-DCT-6-spd  
 Absolute percentage compared with: AUTO-5spd (no early lockup)  
 Standard Deviation 1.7:



5-spd Trans (AUTO)

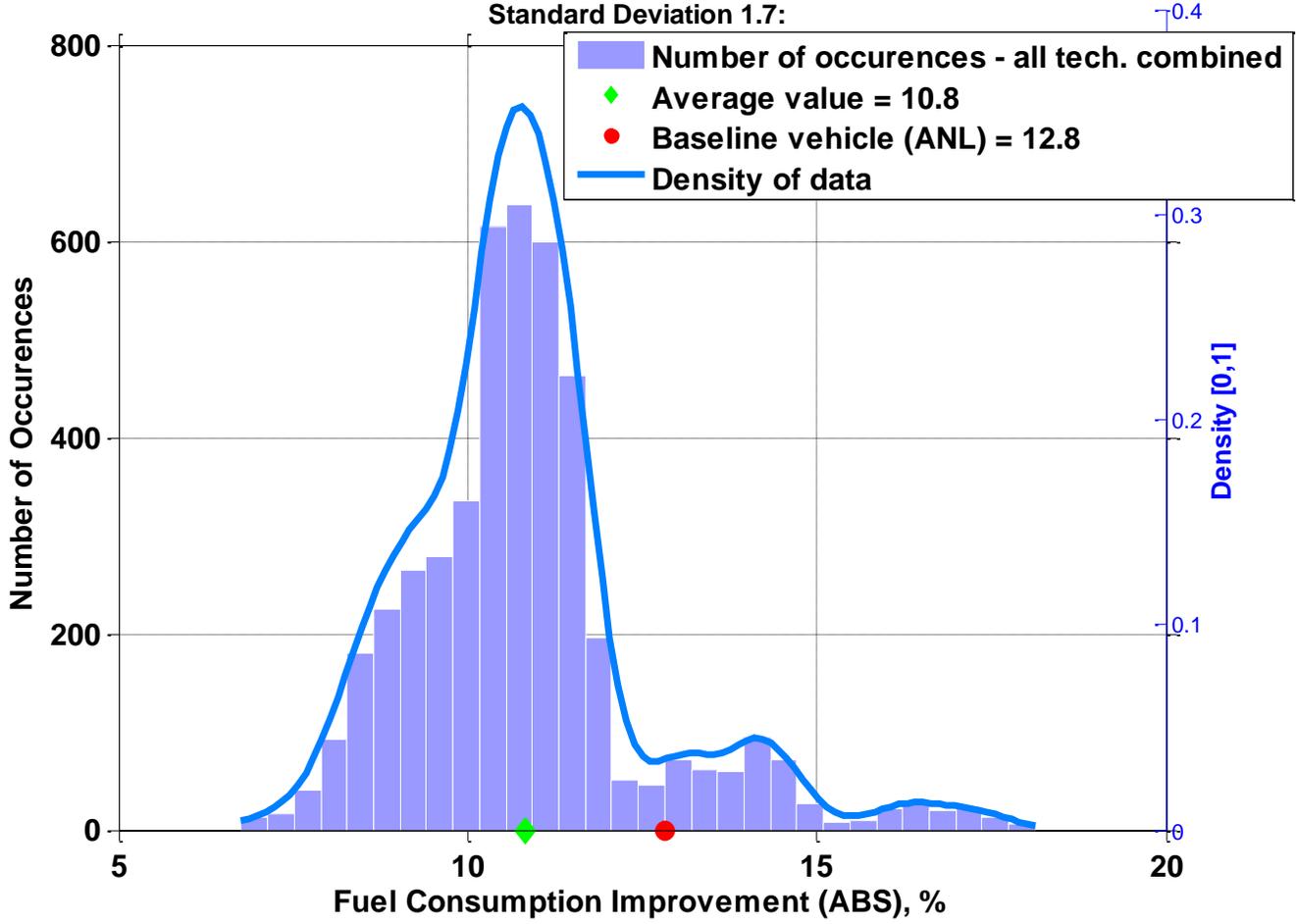


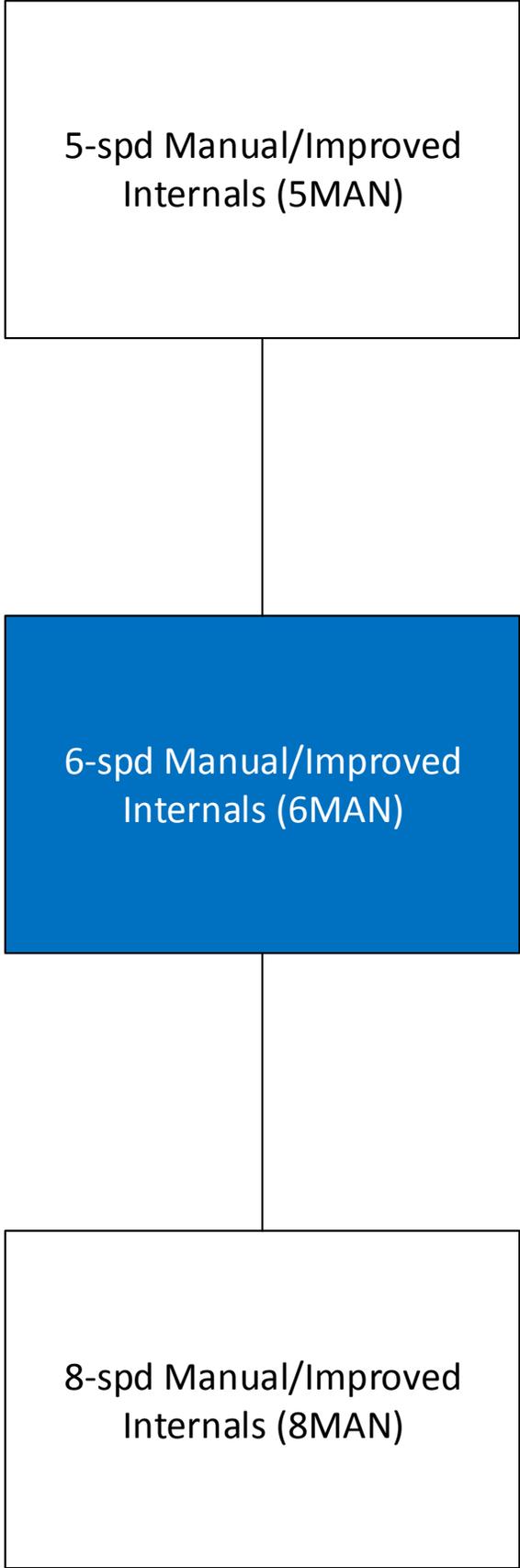
6-spd DCT (DCT)



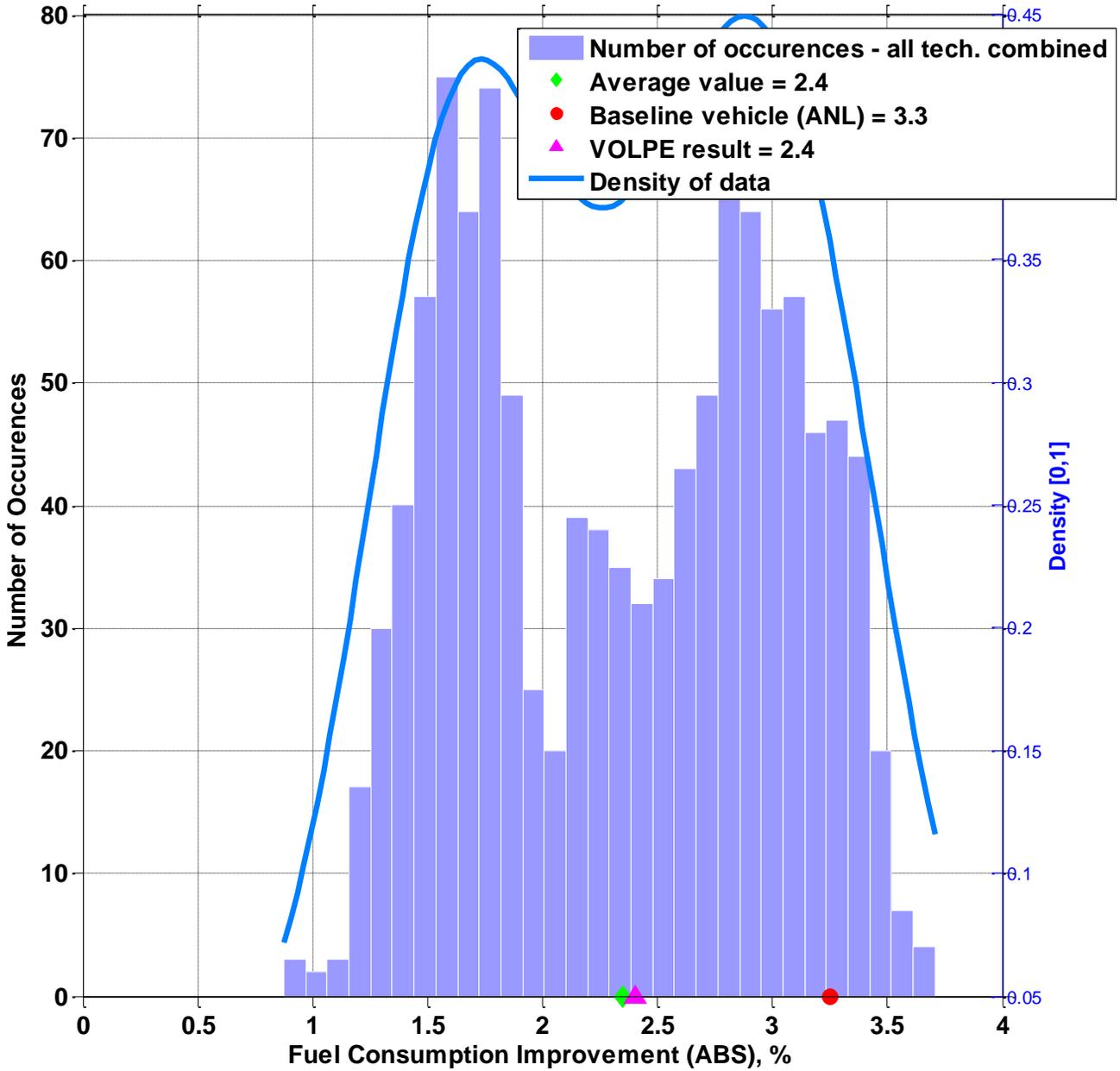
8-spd DCT (DCT)

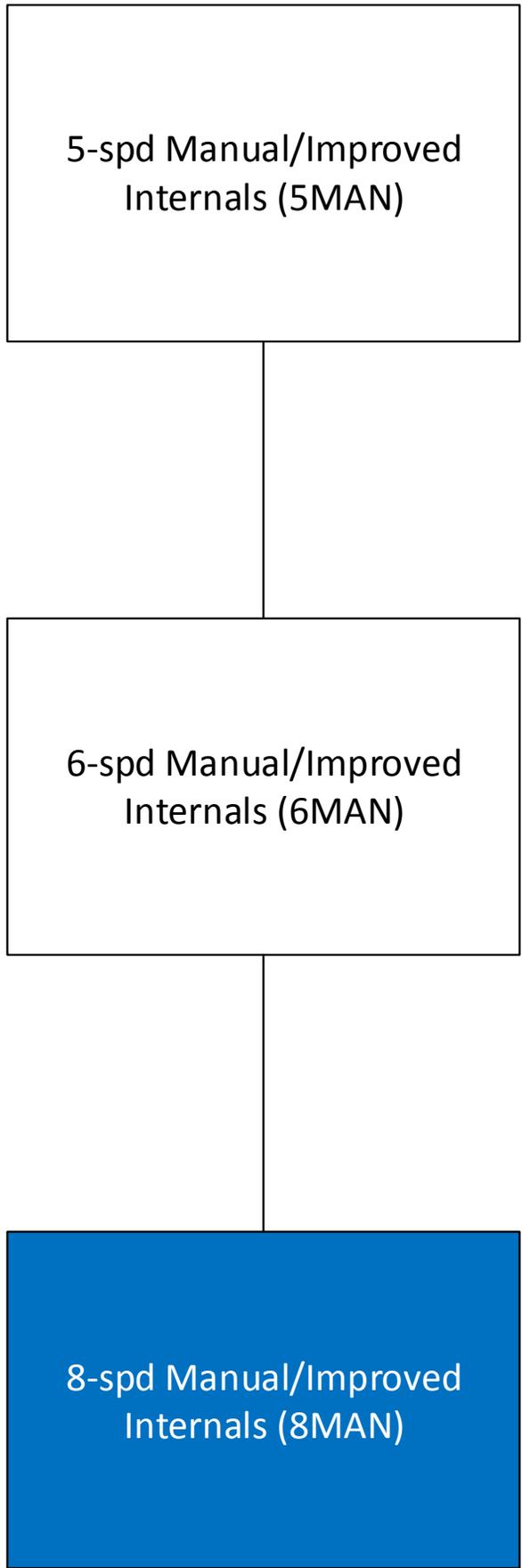
Distribution of Fuel Consumption for Transmission-DCT-8-spd  
 Absolute percentage compared with: AUTO-5spd (no early lockup)  
 Standard Deviation 1.7:



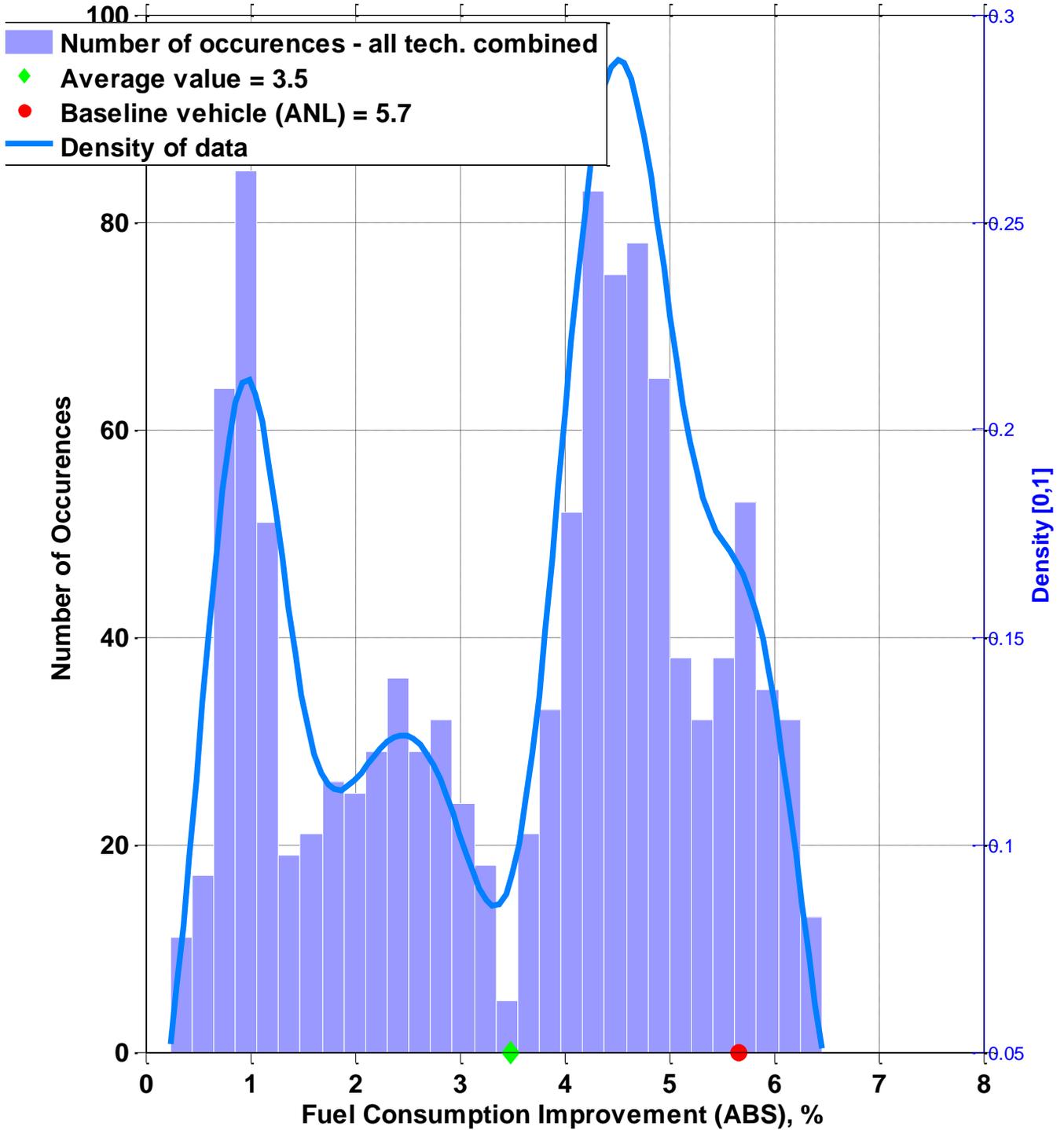


Distribution of Fuel Consumption for Transmission-DM-6-spd  
 Absolute percentage compared with: DM-5spd  
 Standard Deviation 0.7:





Distribution of Fuel Consumption for Transmission-DM-8-spd  
 Absolute percentage compared with: DM-5spd  
 Standard Deviation 1.8:

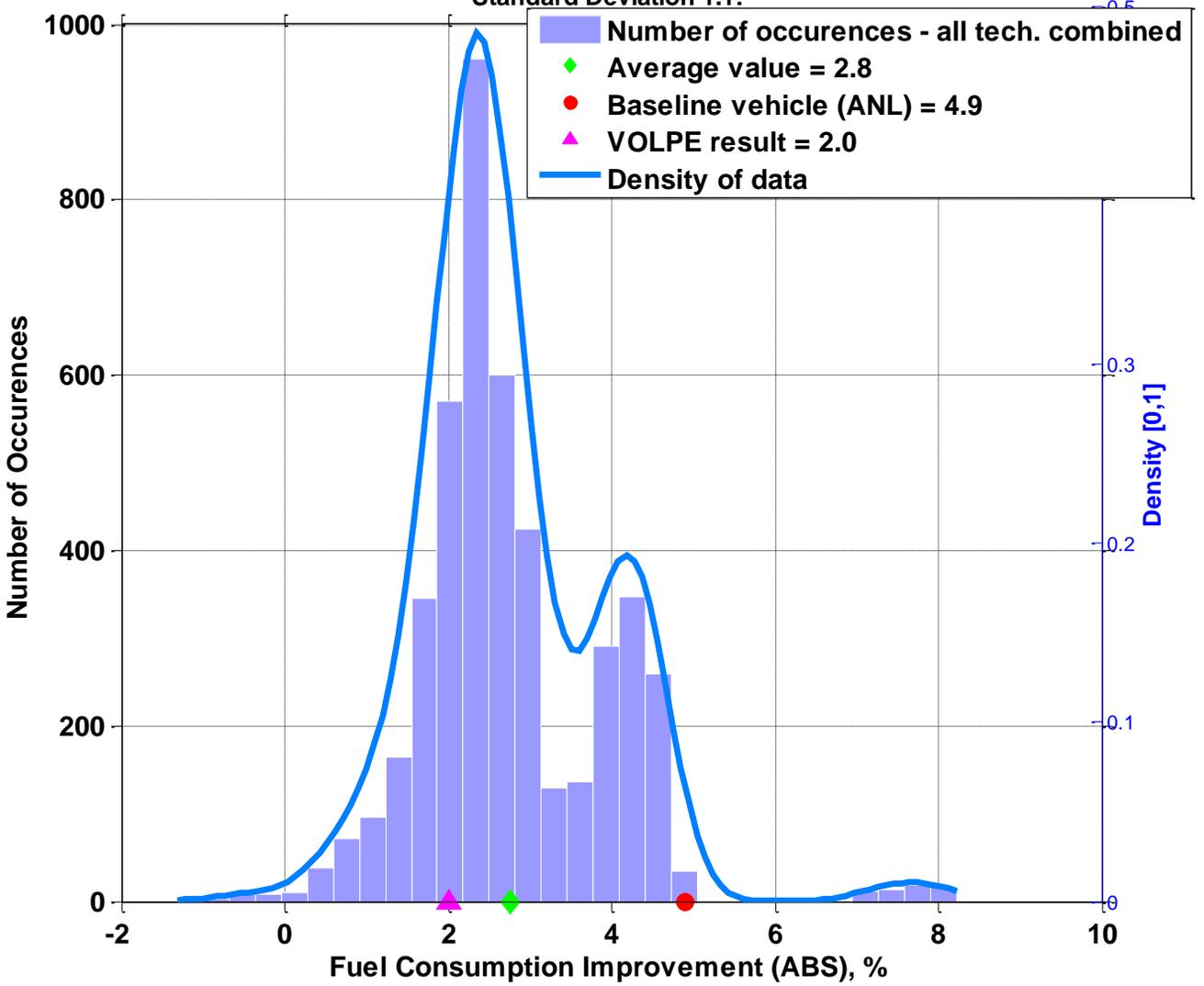


5-spd Trans (AUTO)  
(no early lockup)

6-spd Trans w/  
Improved Internals  
(Auto) (6AUTO)

CVT Transmission

Distribution of Fuel Consumption for Transmission-AUTO-(early lockup)-6-spd  
 Absolute percentage compared with: AUTO-5spd (no early lockup)  
 Standard Deviation 1.1:

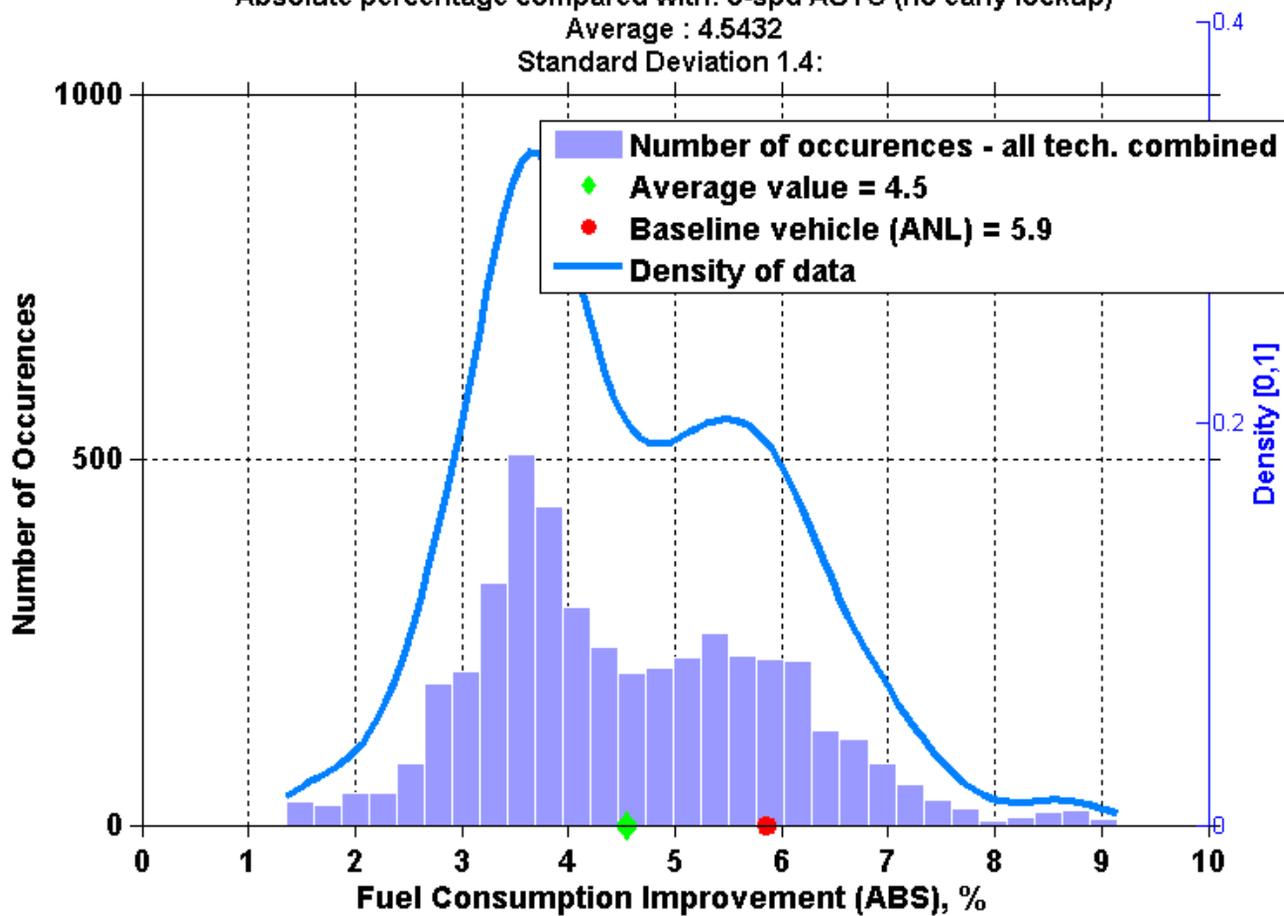


5-spd Trans (AUTO)  
(no early lockup)

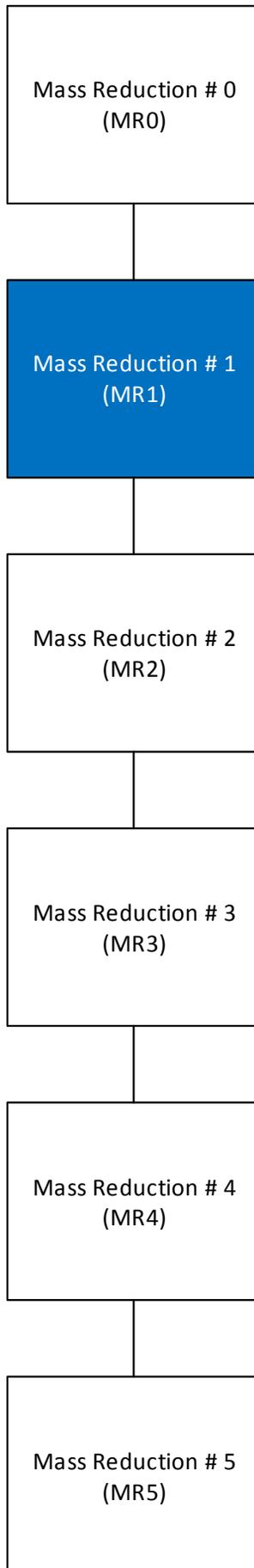
6-spd Trans w/  
Improved Internals  
(Auto) (6AUTO)

CVT Transmission

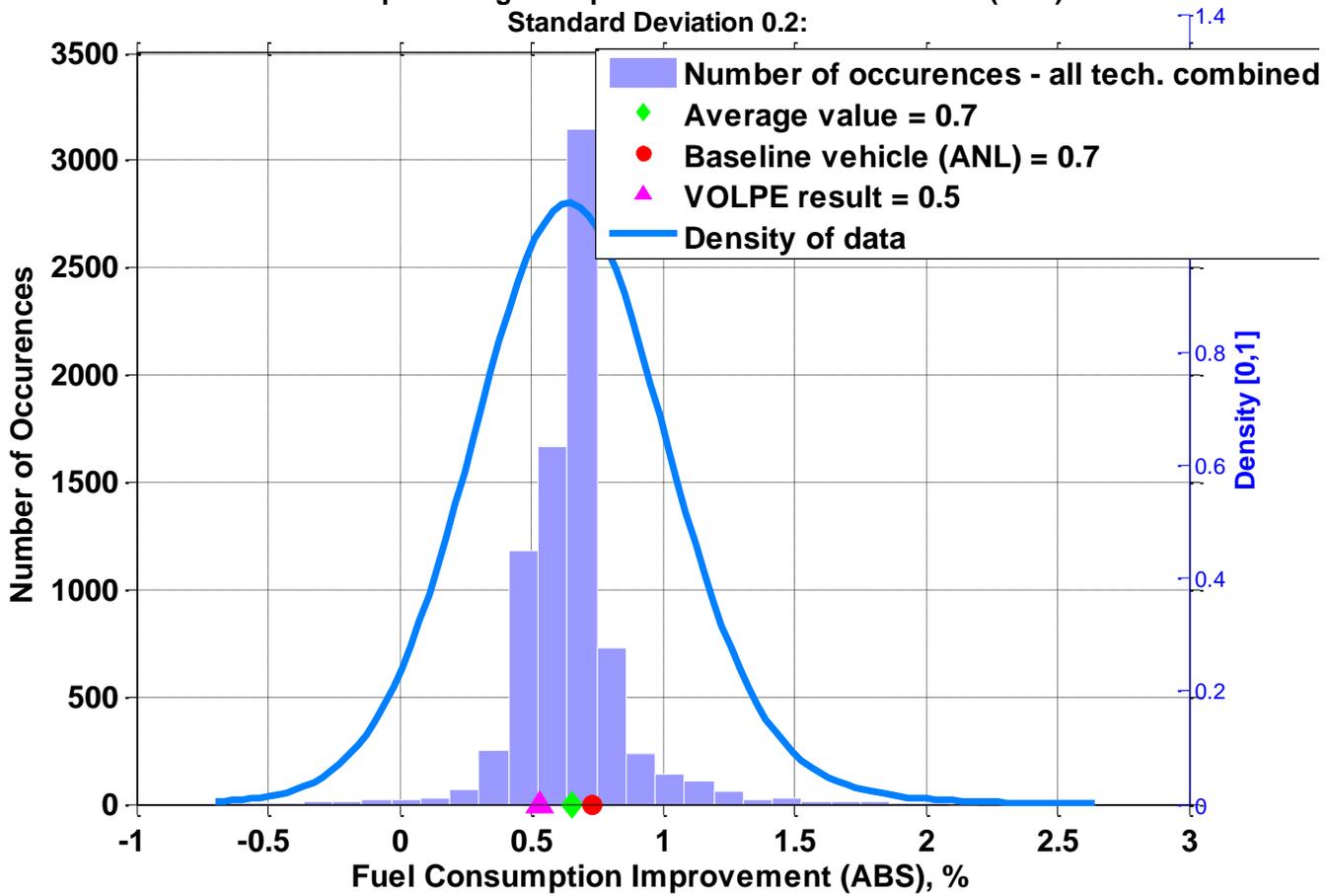
Distribution of Fuel Consumption for Transmission-CVT  
 Absolute percentage compared with: 5-spd AUTO (no early lockup)  
 Average : 4.5432  
 Standard Deviation 1.4:



# VEHICLE TECHNOLOGIES



Distribution of Fuel Consumption for Vehicle Technology-Mass Reduction#1 (MR1)  
 Absolute percentage compared with: Mass Reduction#0 (MR0)  
 Standard Deviation 0.2:



Mass Reduction # 0  
(MR0)

Mass Reduction # 1  
(MR1)

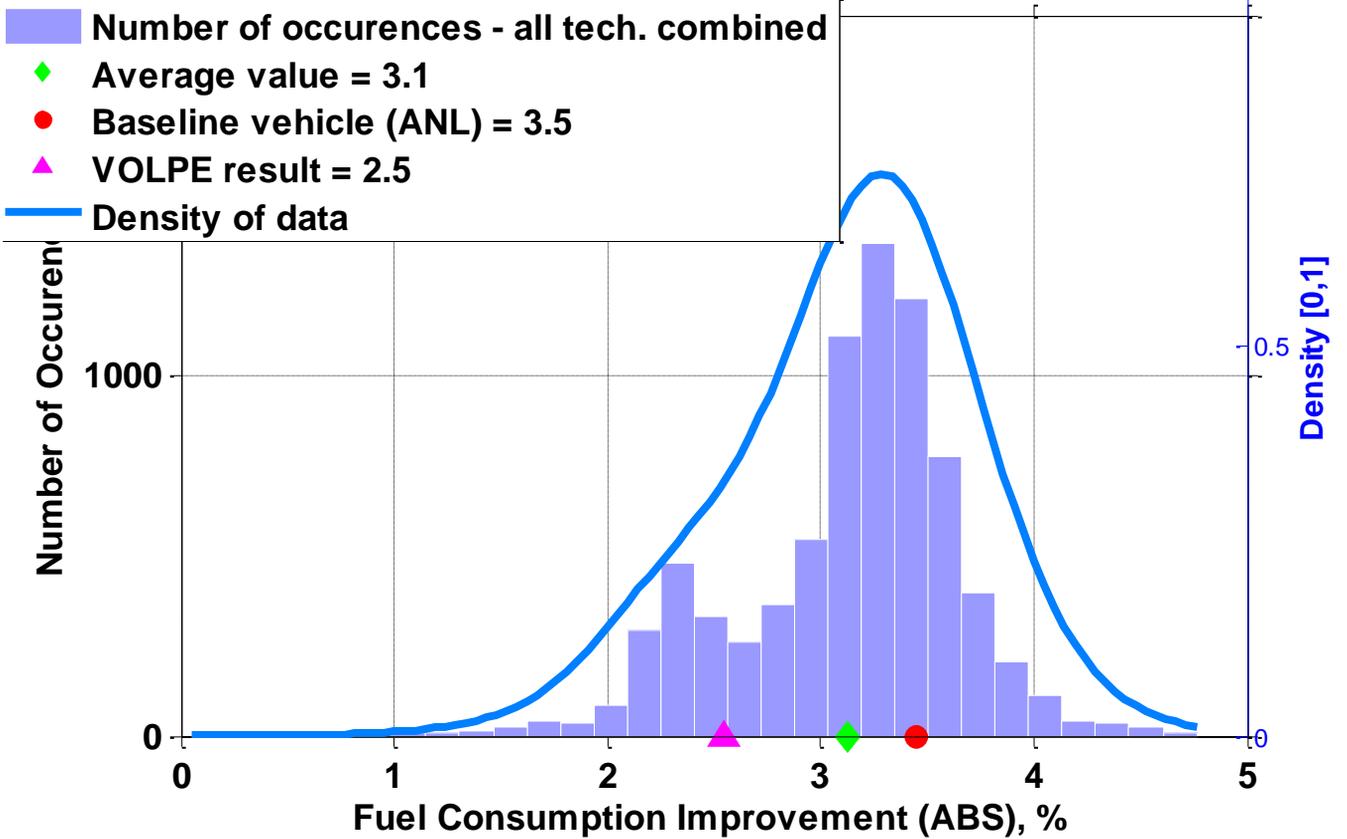
Mass Reduction # 2  
(MR2)

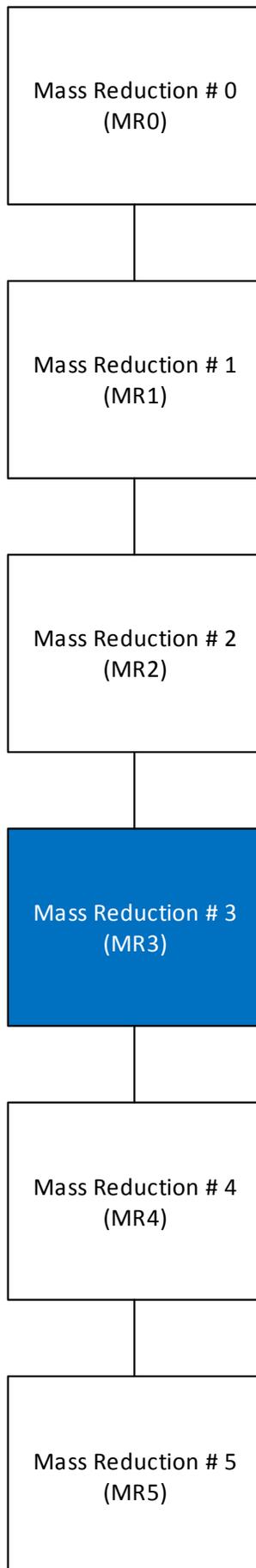
Mass Reduction # 3  
(MR3)

Mass Reduction # 4  
(MR4)

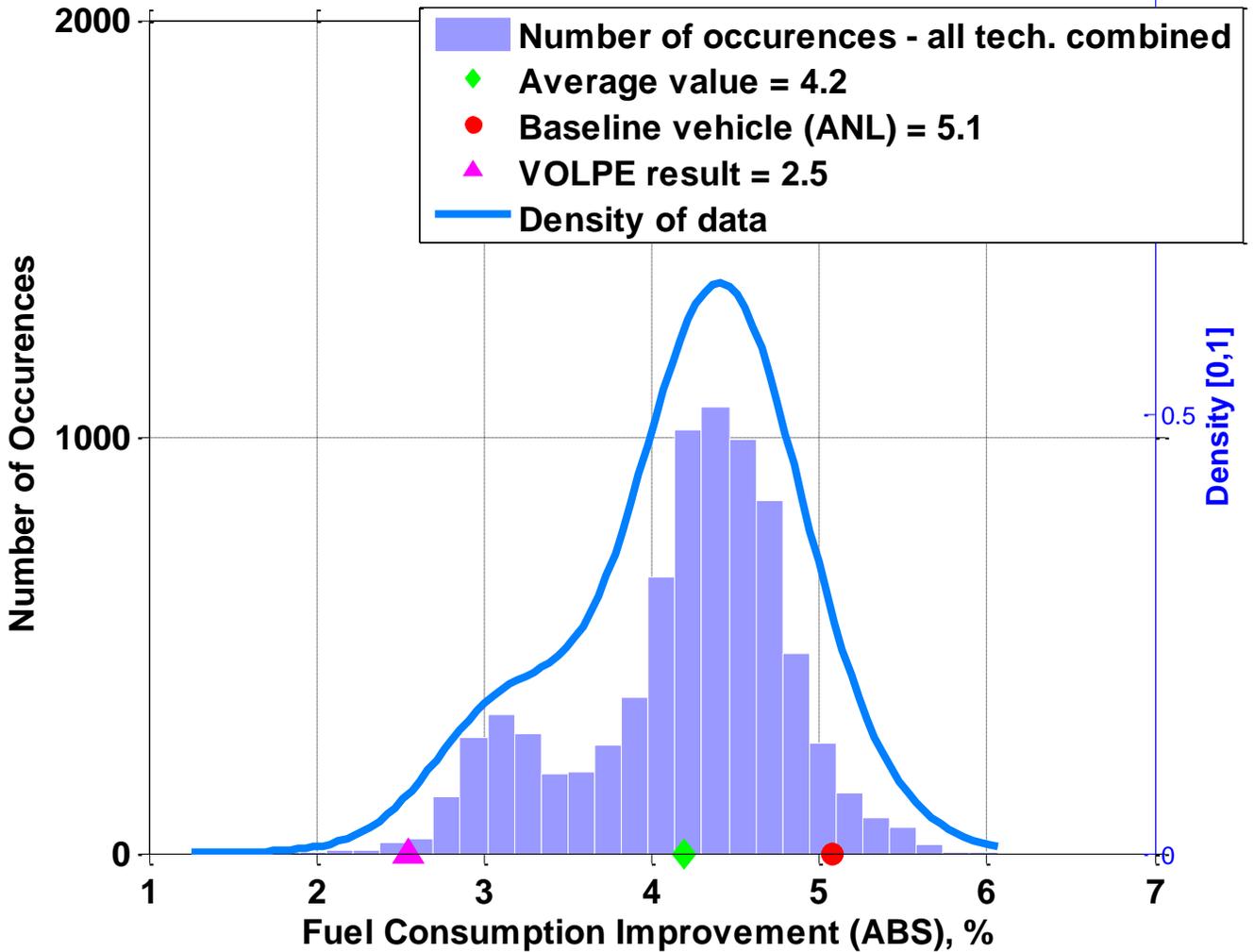
Mass Reduction # 5  
(MR5)

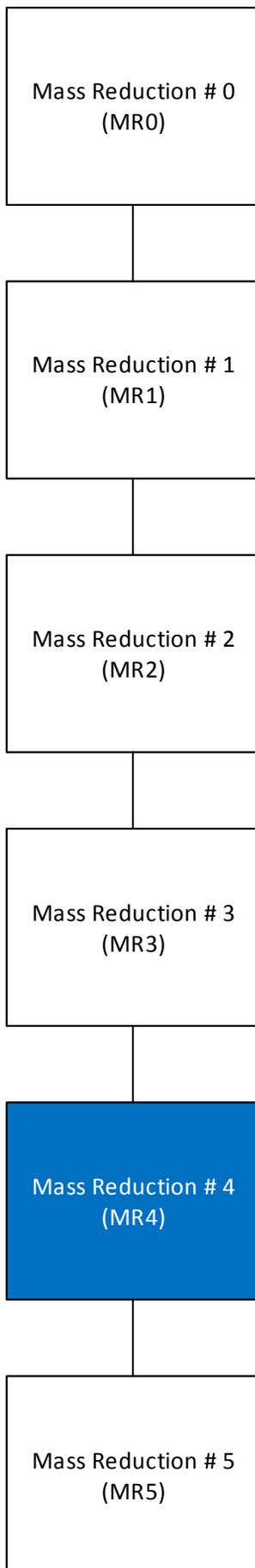
Distribution of Fuel Consumption for Vehicle Technology-Mass Reduction#2 (MR2)  
 Absolute percentage compared with: Mass Reduction#0 (MR0)  
 Standard Deviation 0.5:



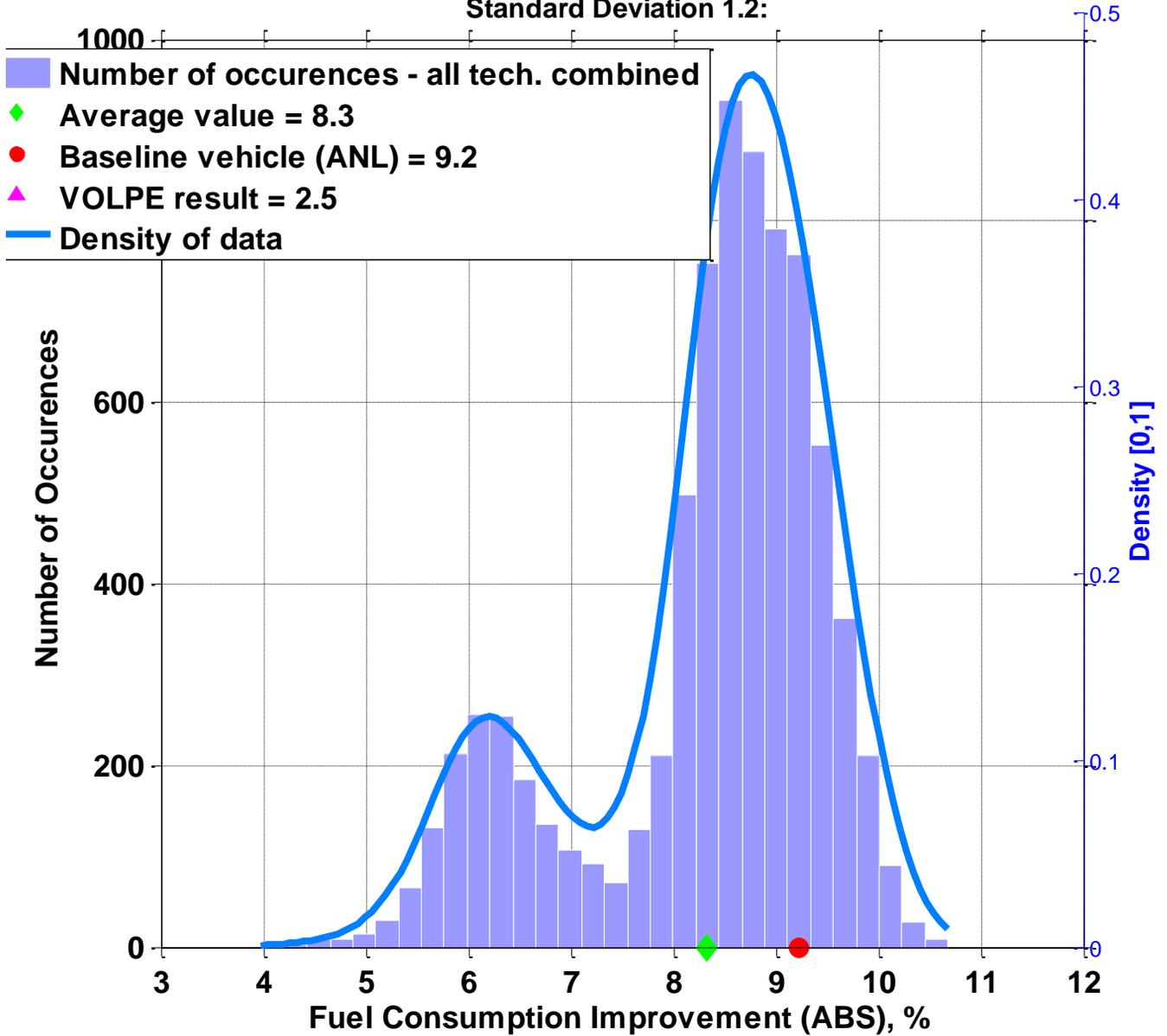


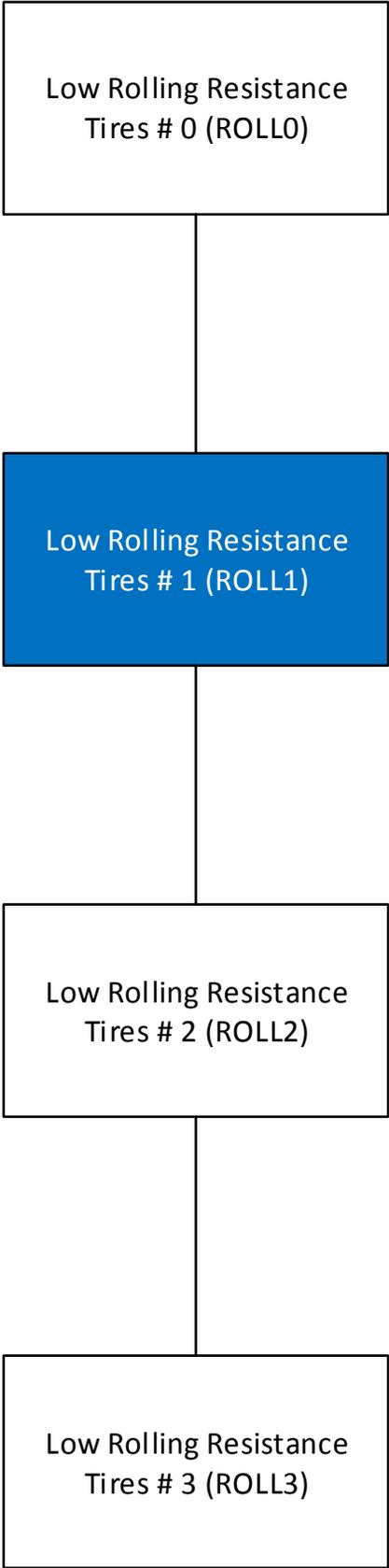
Distribution of Fuel Consumption for Vehicle Technology-Mass Reduction#3 (MR3)  
 Absolute percentage compared with: Mass Reduction#0 (MR0)  
 Standard Deviation 0.6:



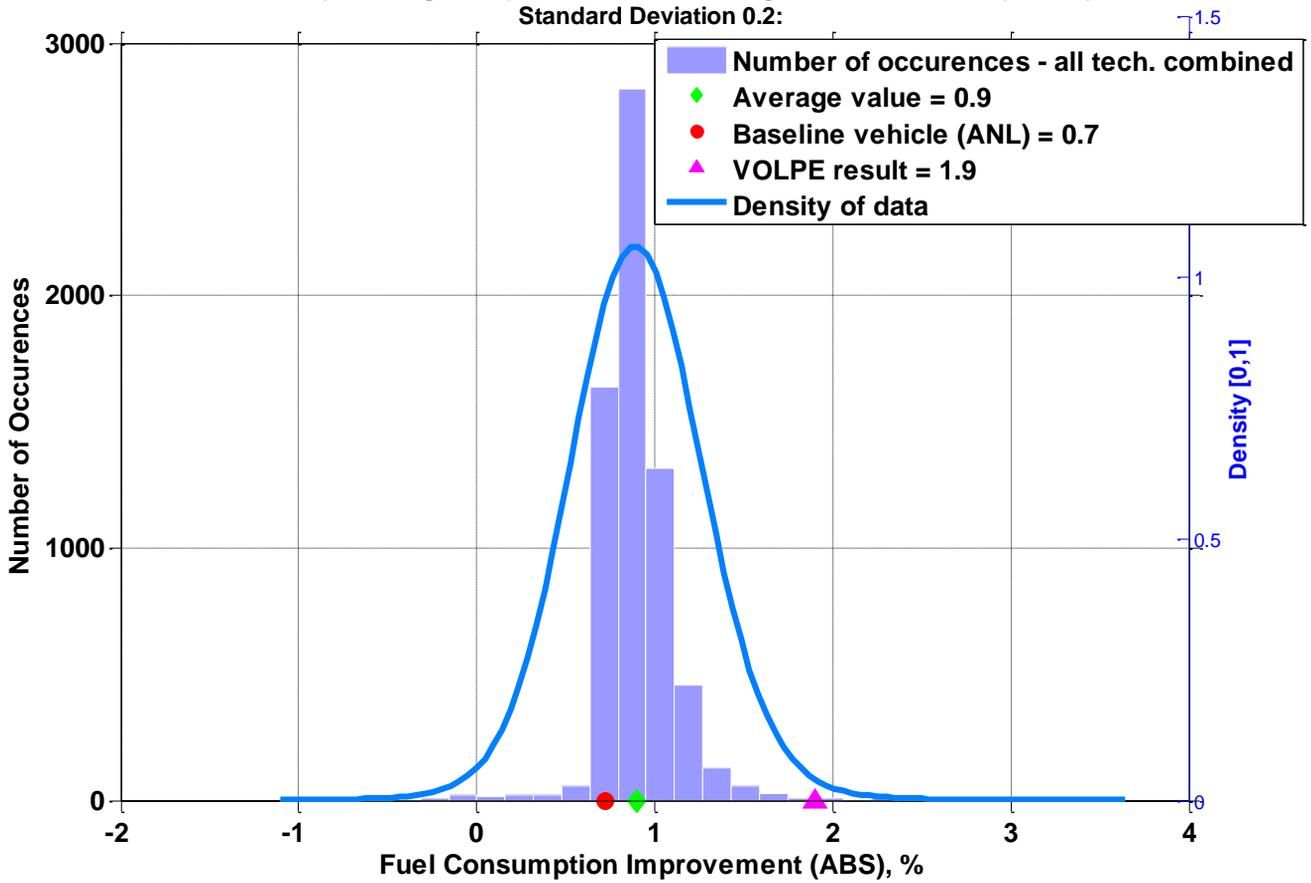


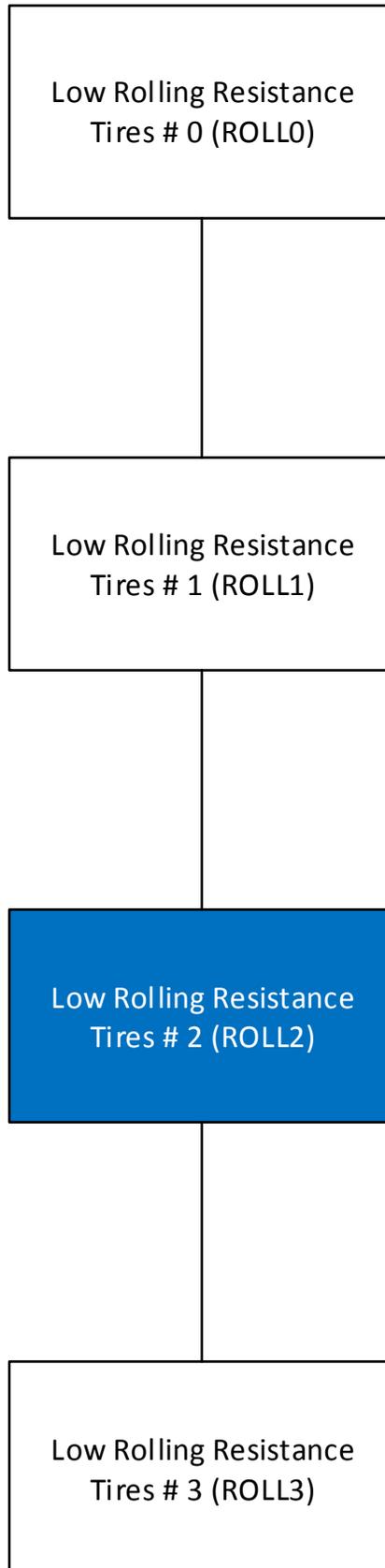
**Distribution of Fuel Consumption for Vehicle Technology-Mass Reduction#4 (MR4)**  
**Absolute percentage compared with: Mass Reduction#0 (MR0)**  
**Standard Deviation 1.2:**



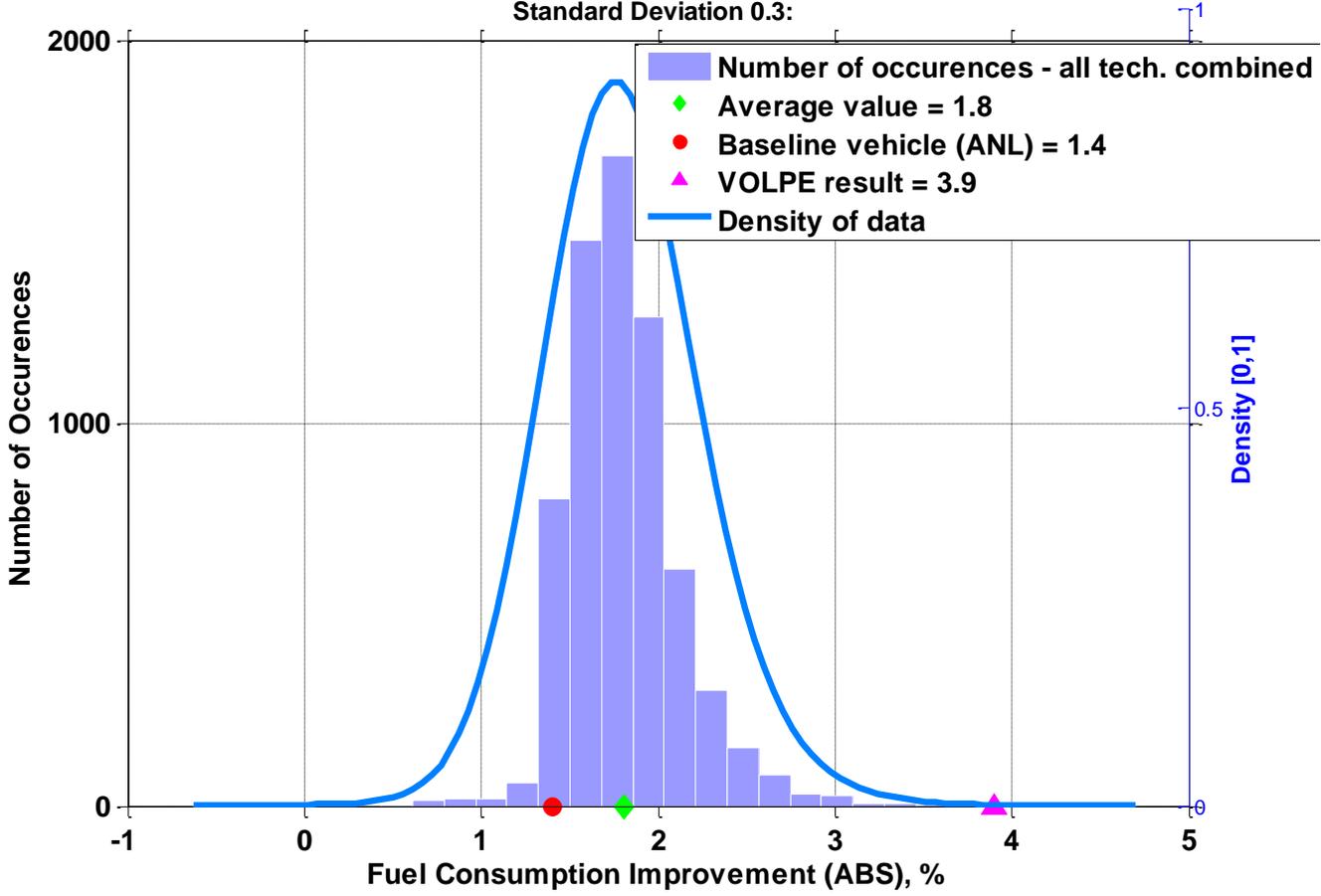


Distribution of Fuel Consumption for Vehicle Technology-Low Rolling Resistance Tires#1(ROLL1)  
 Absolute percentage compared with: Low Rolling Resistance Tires#0(ROLL0)  
 Standard Deviation 0.2:





Distribution of Fuel Consumption for Vehicle Technology-Low Rolling Resistance Tires#2(ROLL2)  
 Absolute percentage compared with: Low Rolling Resistance Tires#0(ROLL0)  
 Standard Deviation 0.3:



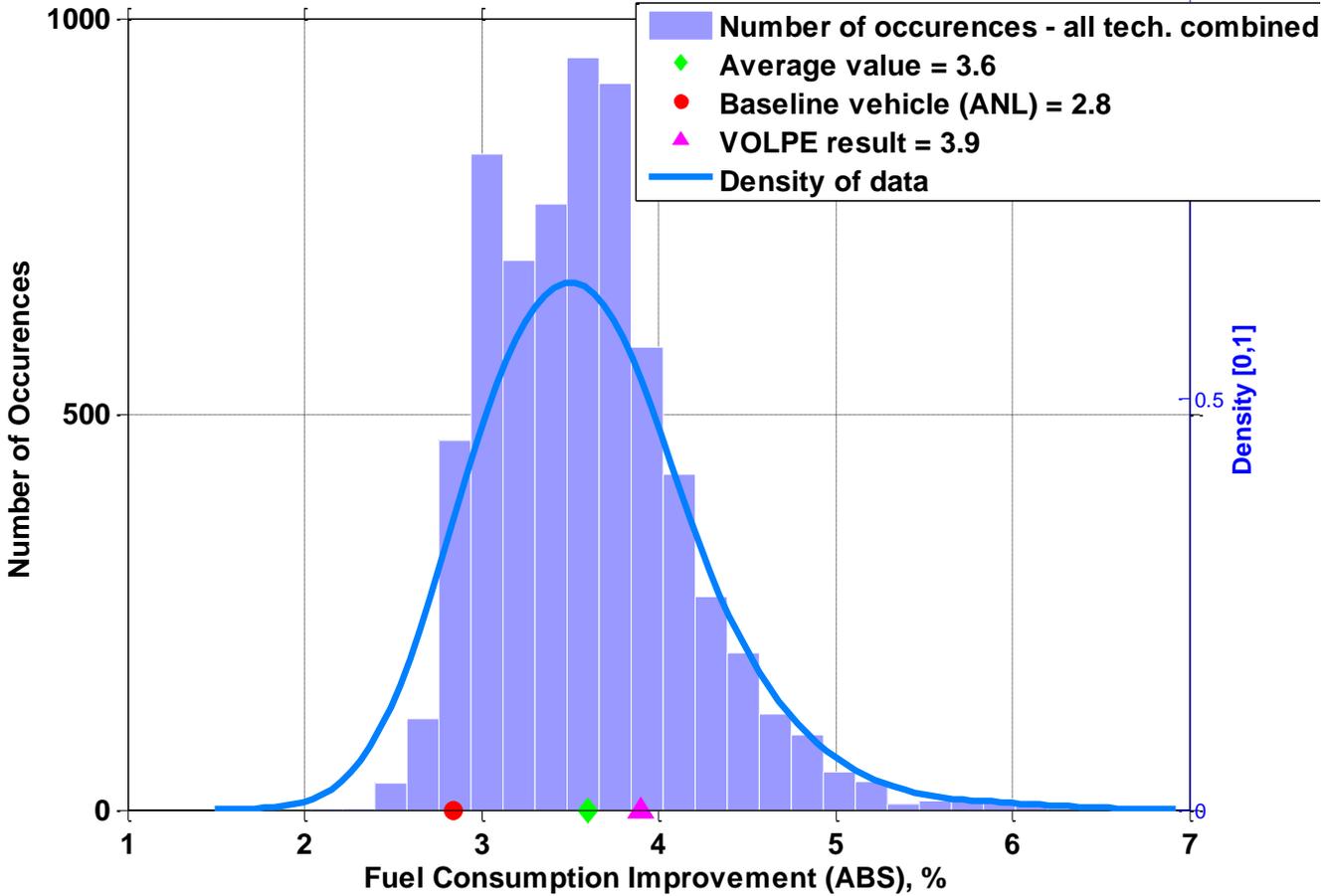
Low Rolling Resistance  
Tires # 0 (ROLL0)

Low Rolling Resistance  
Tires # 1 (ROLL1)

Low Rolling Resistance  
Tires # 2 (ROLL2)

Low Rolling Resistance  
Tires # 3 (ROLL3)

Distribution of Fuel Consumption for Vehicle Technology-Low Rolling Resistance Tires#3(ROLL3)  
 Absolute percentage compared with: Low Rolling Resistance Tires#0(ROLL0)  
 Standard Deviation 0.6:

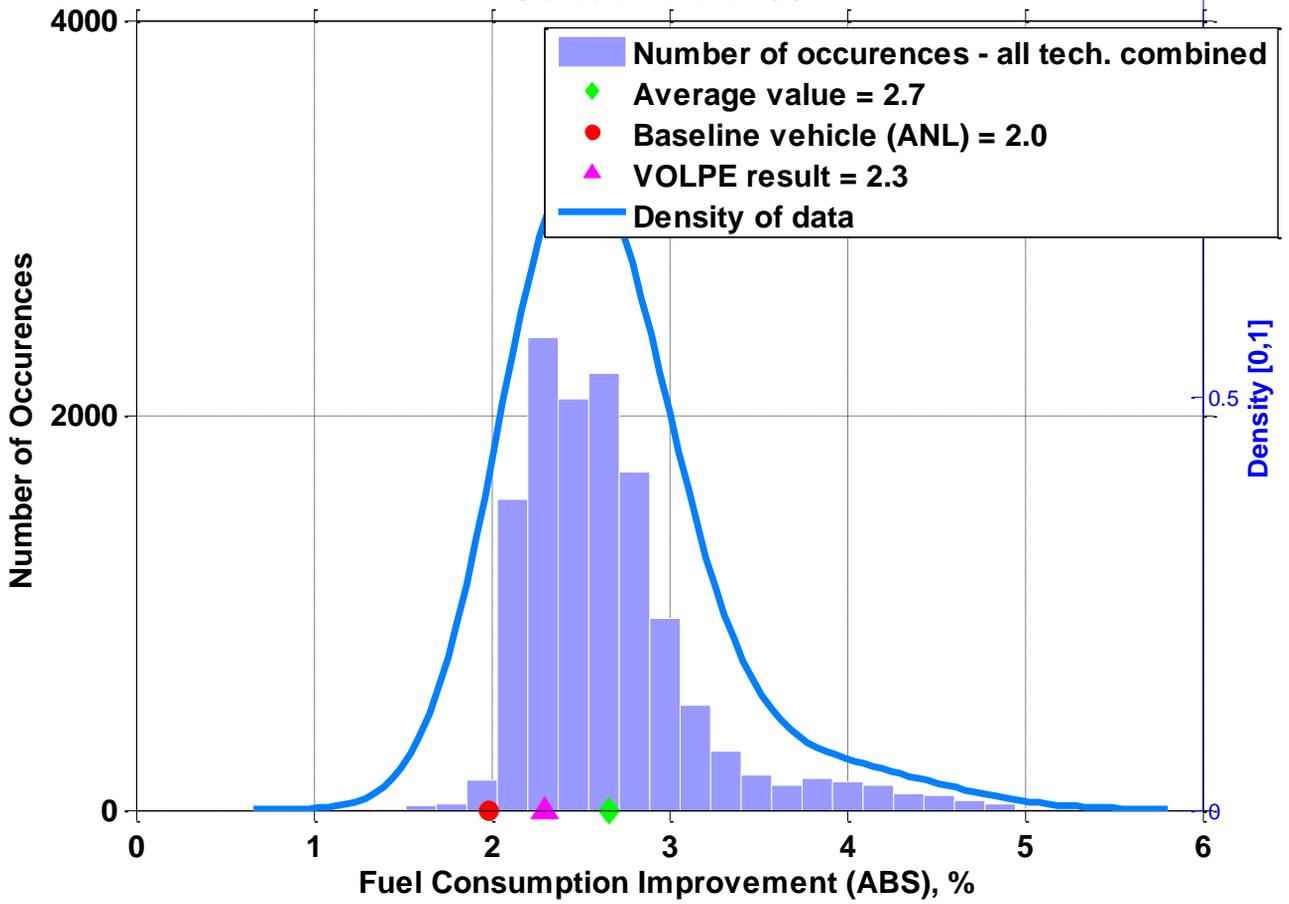


Aerodynamic Drag  
Reduction # 0 (AERO0)

Aerodynamic Drag  
Reduction # 1 (AERO1)

Aerodynamic Drag  
Reduction # 2 (AERO2)

Distribution of Fuel Consumption for Vehicle Technology-Aerodynamic Drag Reduction#1 (AERO1)  
 Absolute percentage compared with: Aerodynamic Drag Reduction#0 (AERO0)  
 Standard Deviation 0.5:

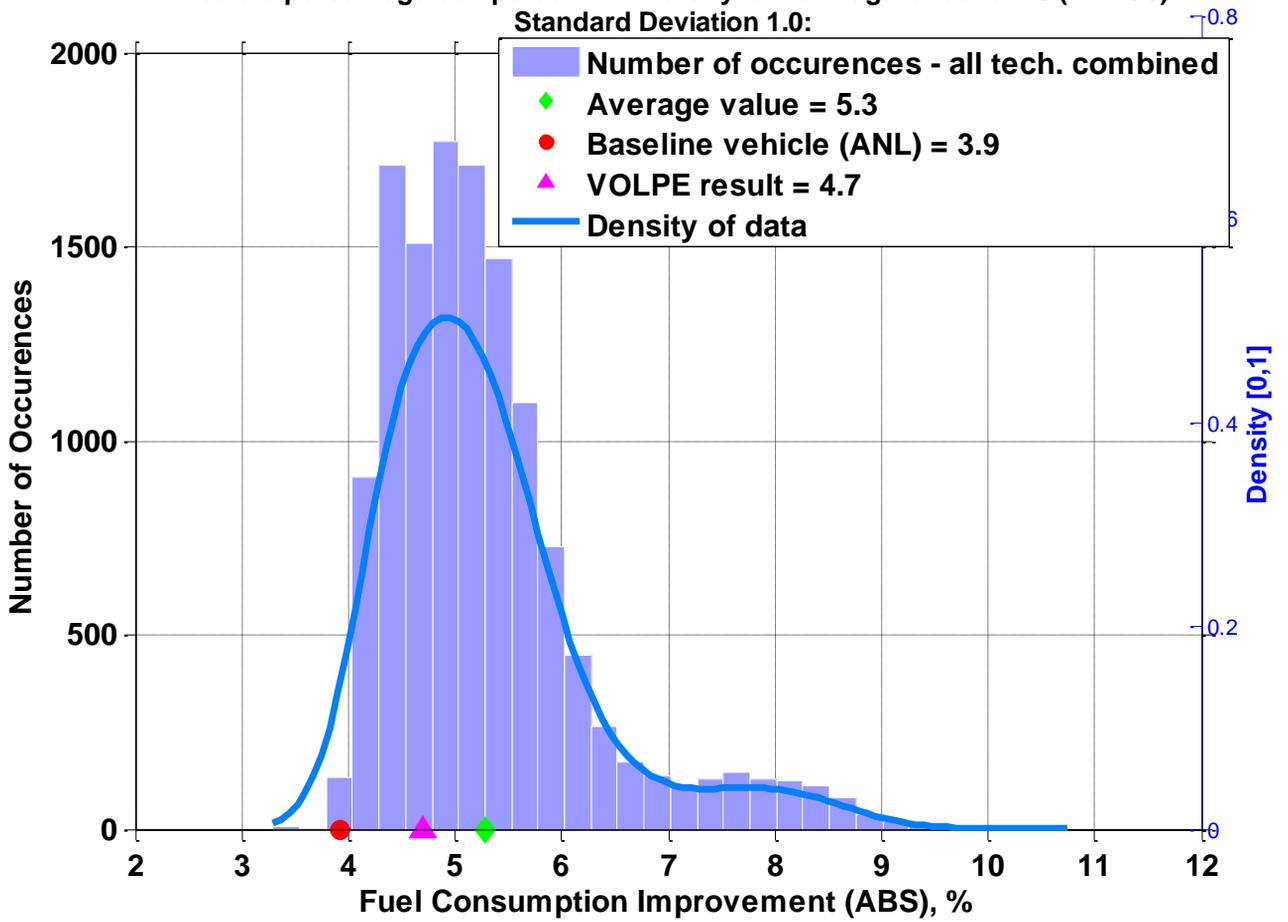


Aerodynamic Drag  
Reduction # 0 (AERO0)

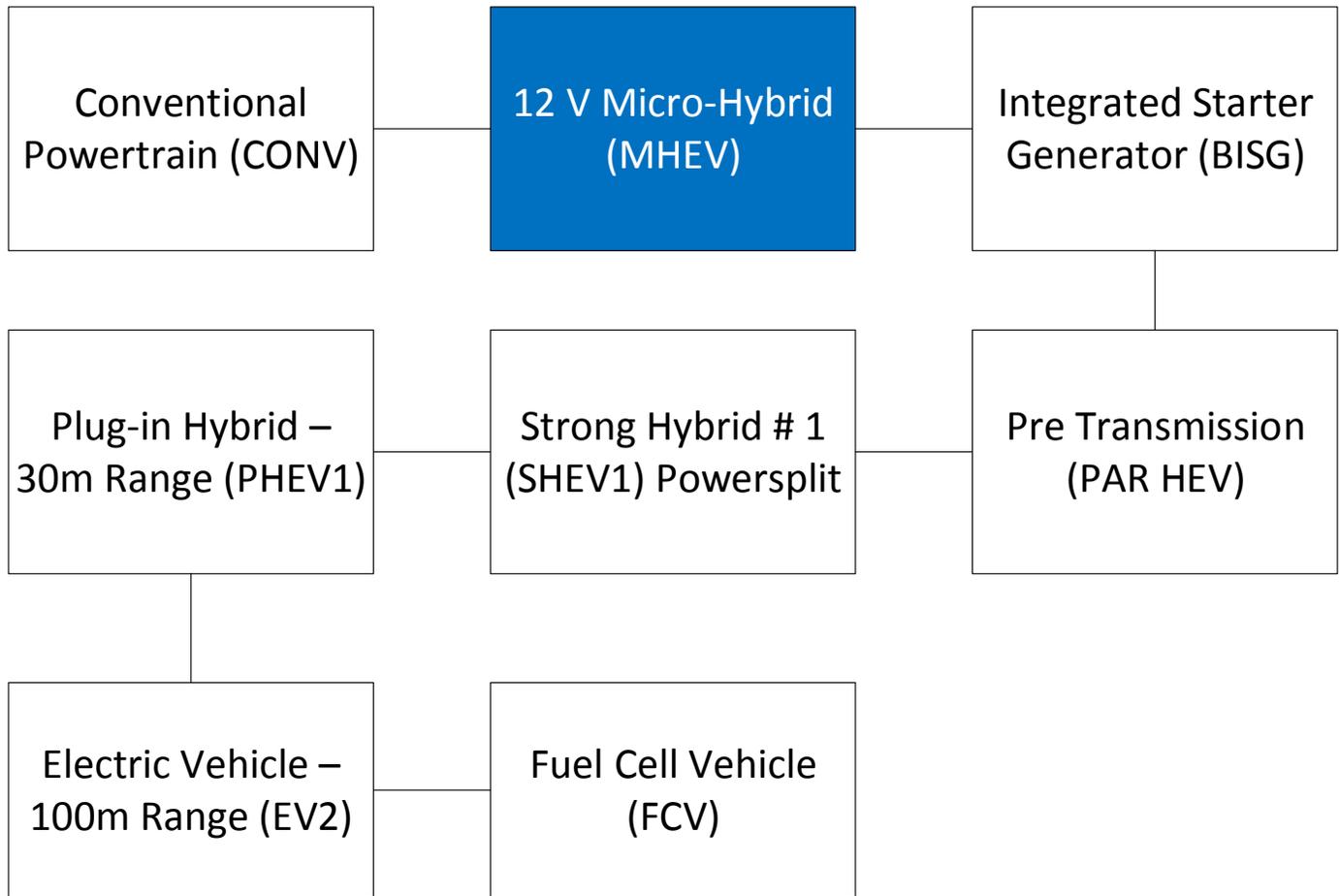
Aerodynamic Drag  
Reduction # 1 (AERO1)

Aerodynamic Drag  
Reduction # 2 (AERO2)

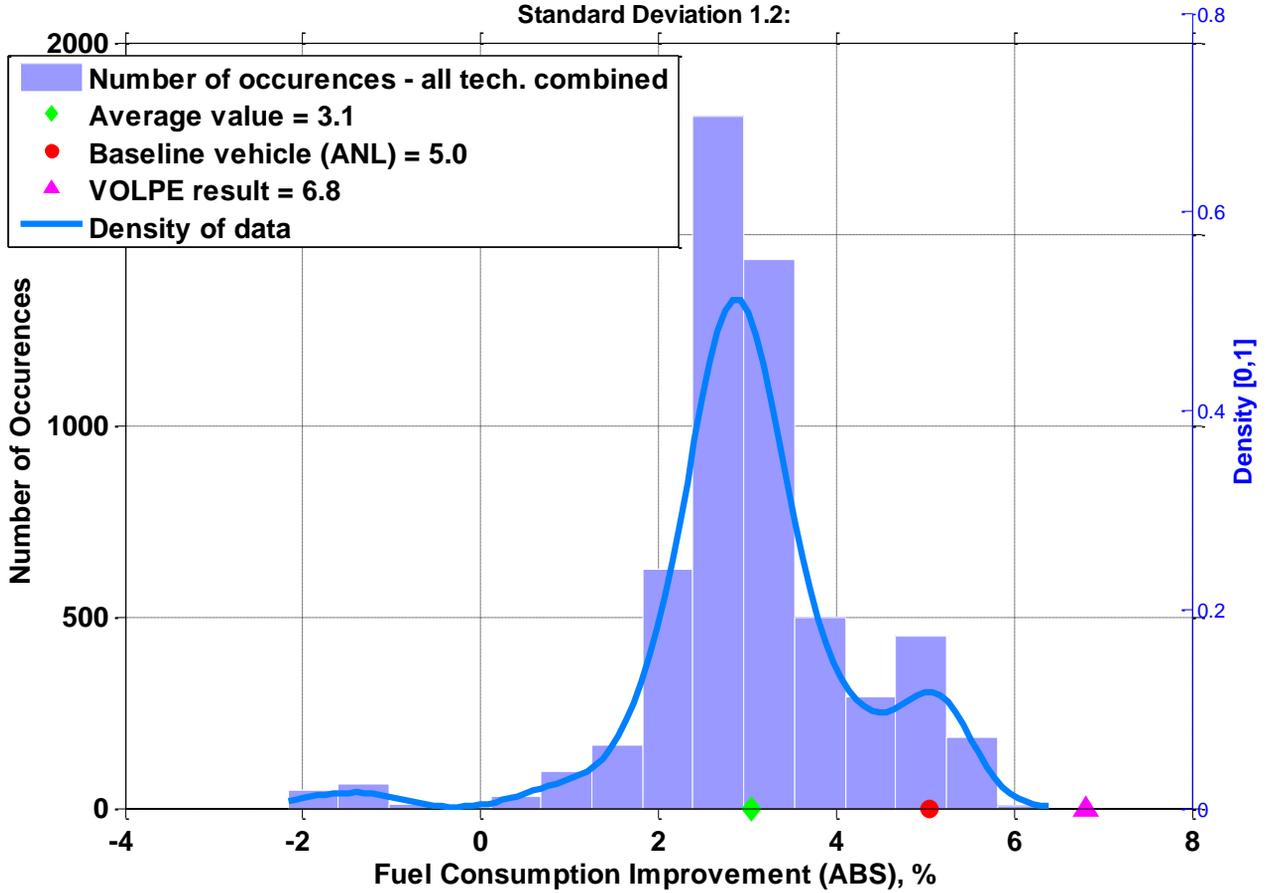
Distribution of Fuel Consumption for Vehicle Technology-Aerodynamic Drag Reduction#2 (AERO2)  
 Absolute percentage compared with: Aerodynamic Drag Reduction#0 (AERO0)  
 Standard Deviation 1.0:

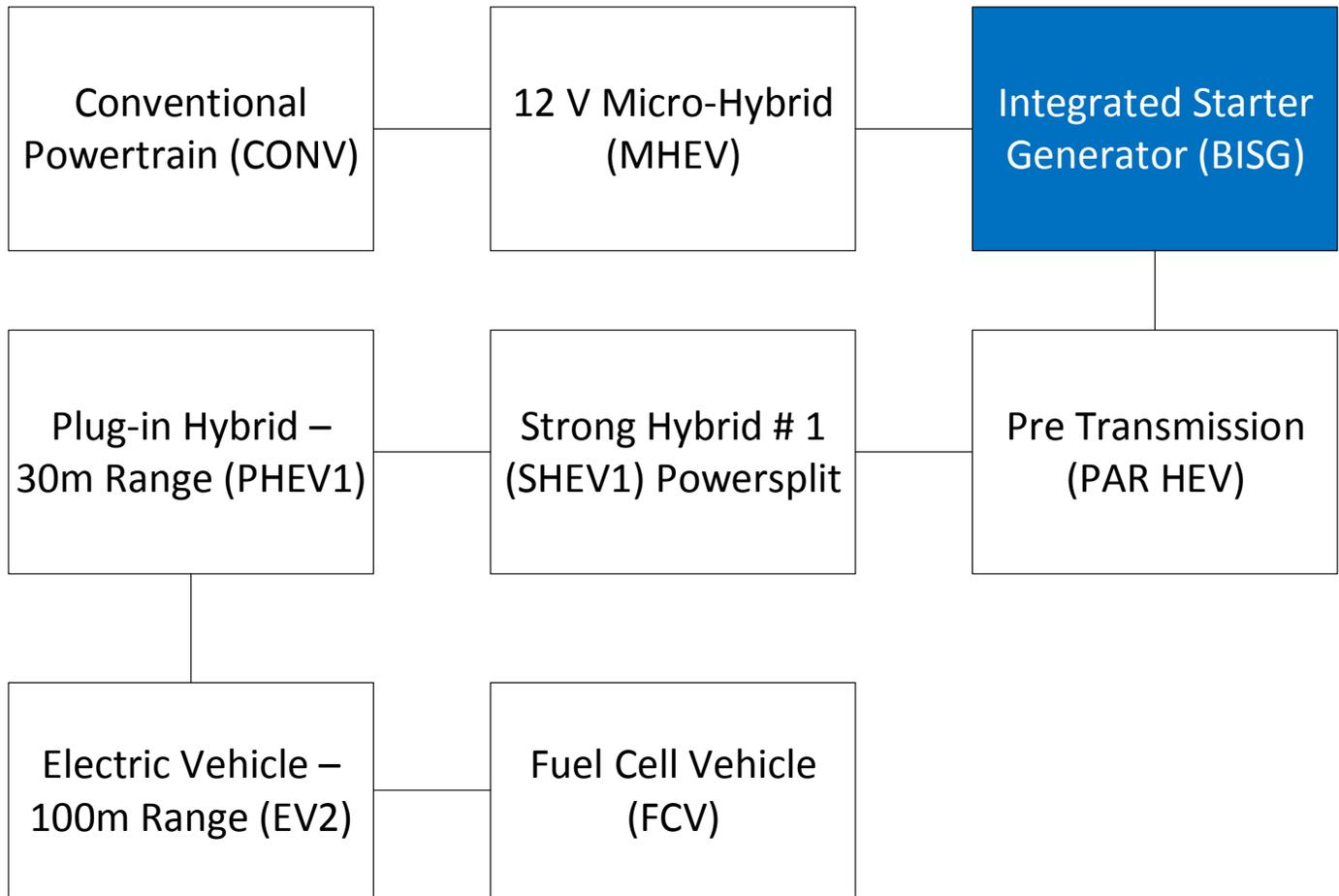


# HYBRIDIZATION TECHNOLOGY

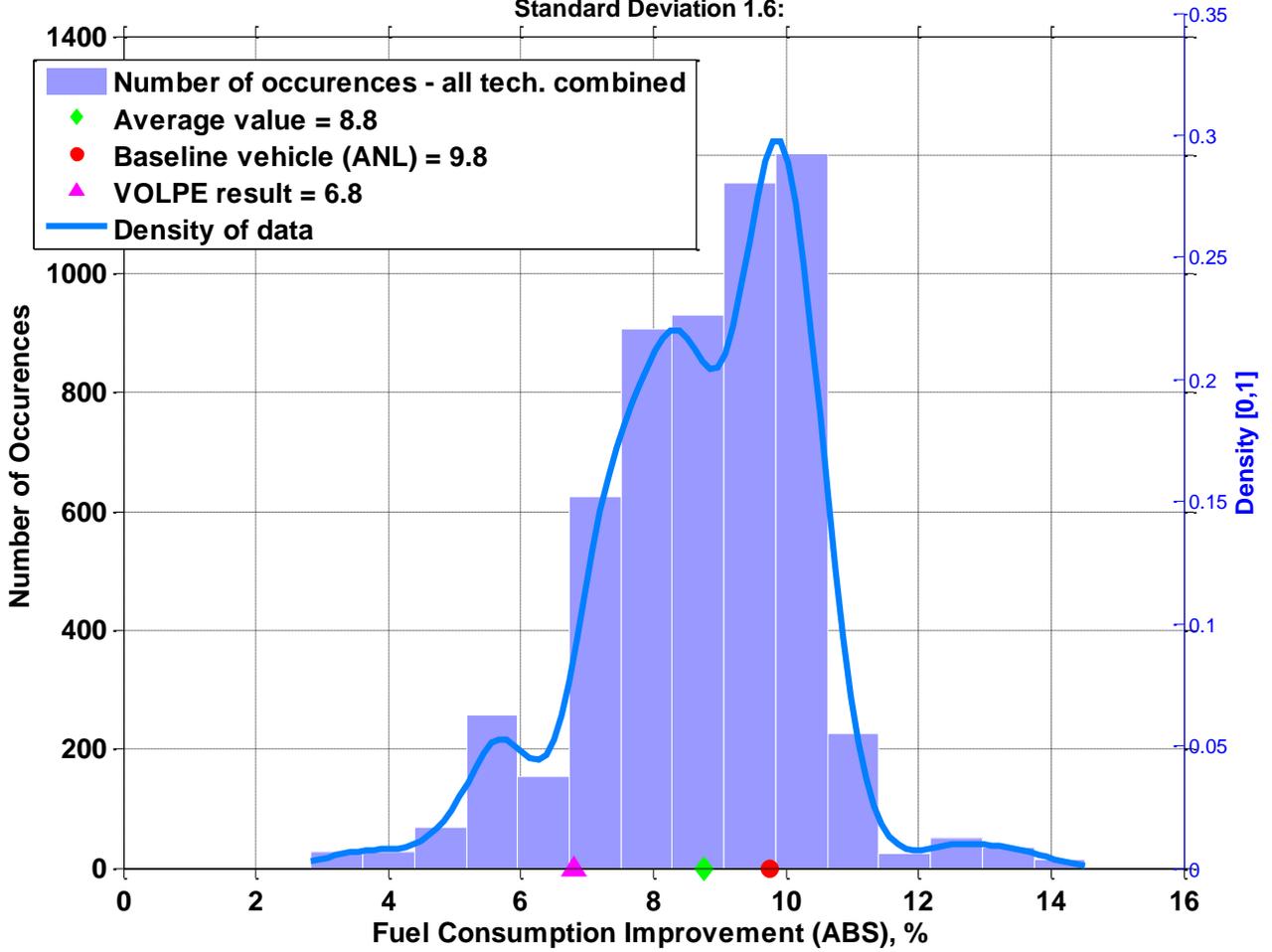


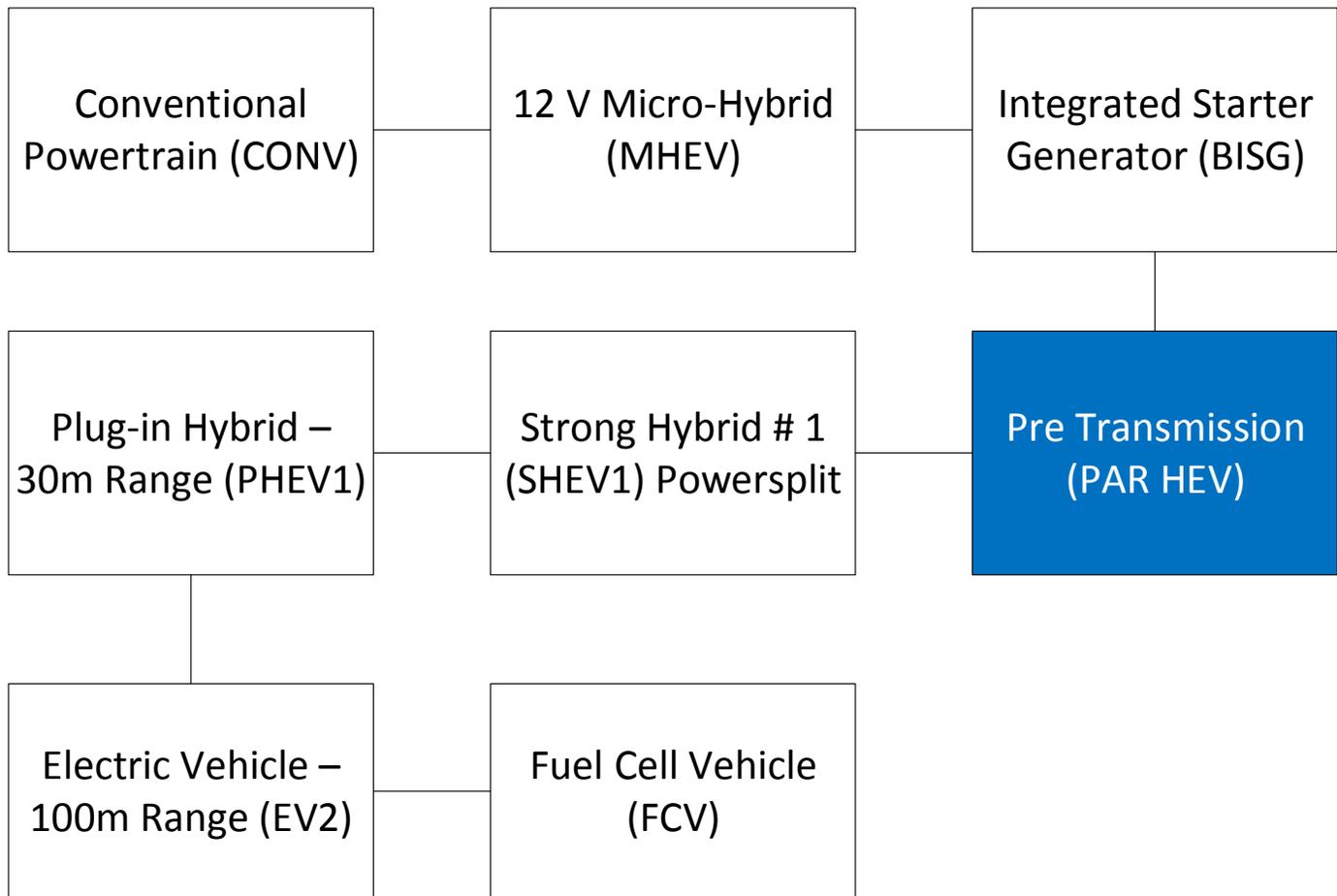
Distribution of Fuel Consumption for Hybrid-12V Micro-Hybrid(MHEV)  
Absolute percentage compared with: Conventional Powertrain  
Standard Deviation 1.2:



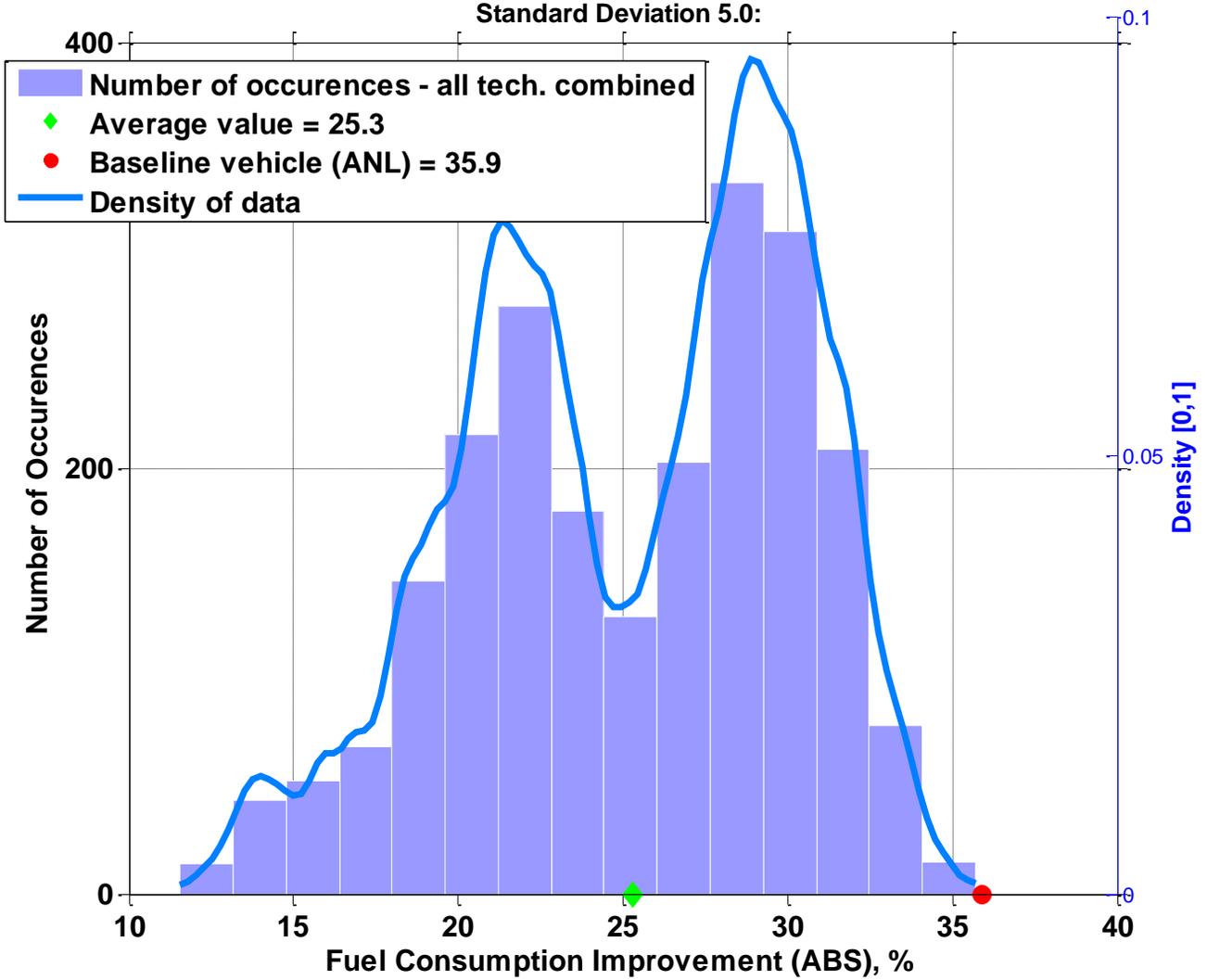


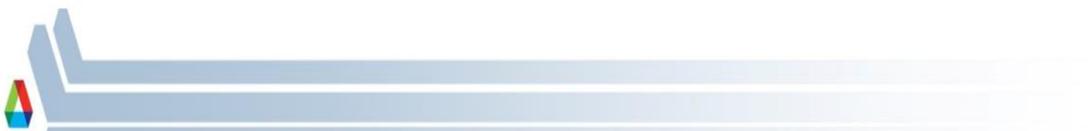
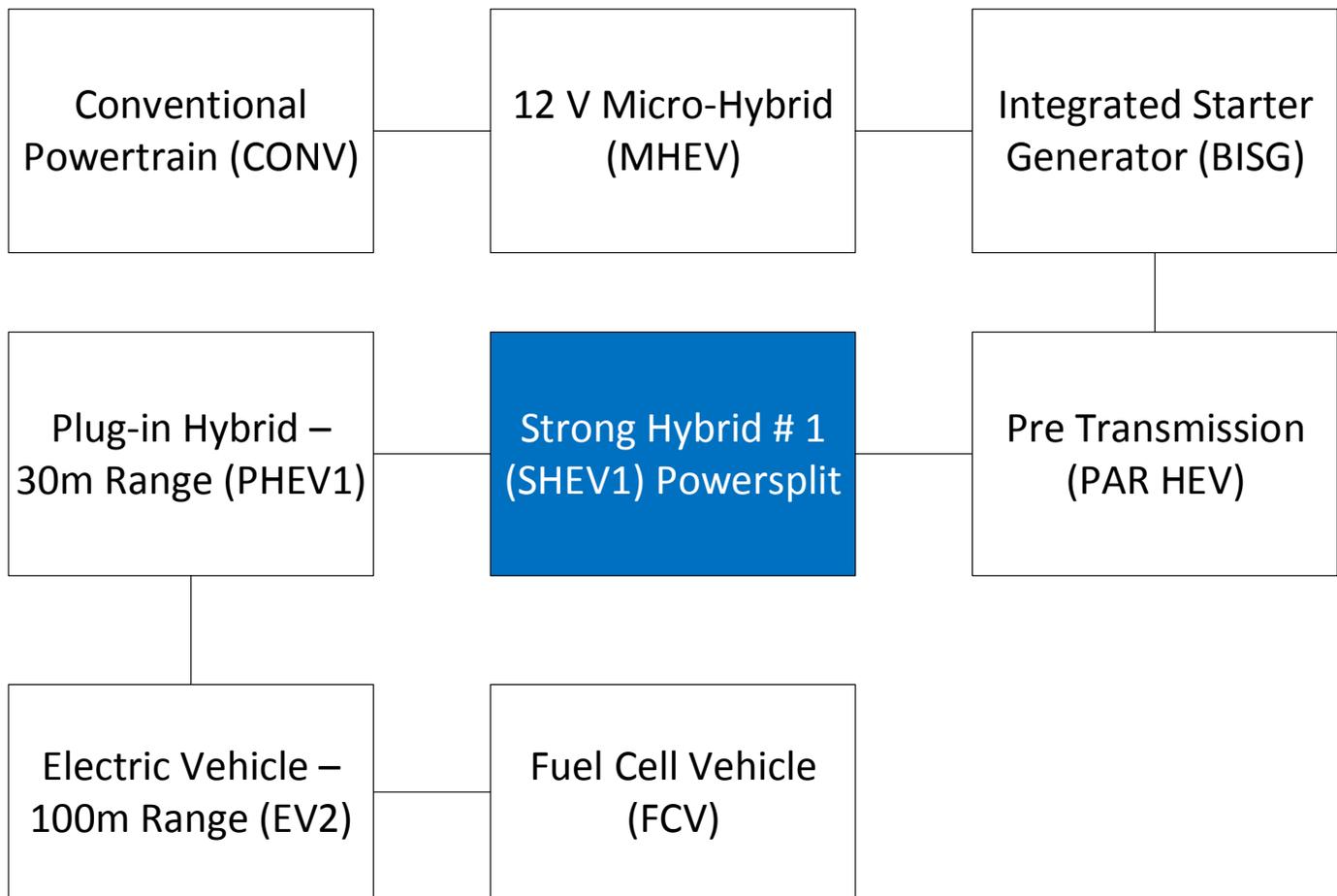
Distribution of Fuel Consumption for Hybrid-Integrated Starter Generator (BISG)  
 Absolute percentage compared with: Conventional Powertrain  
 Standard Deviation 1.6:



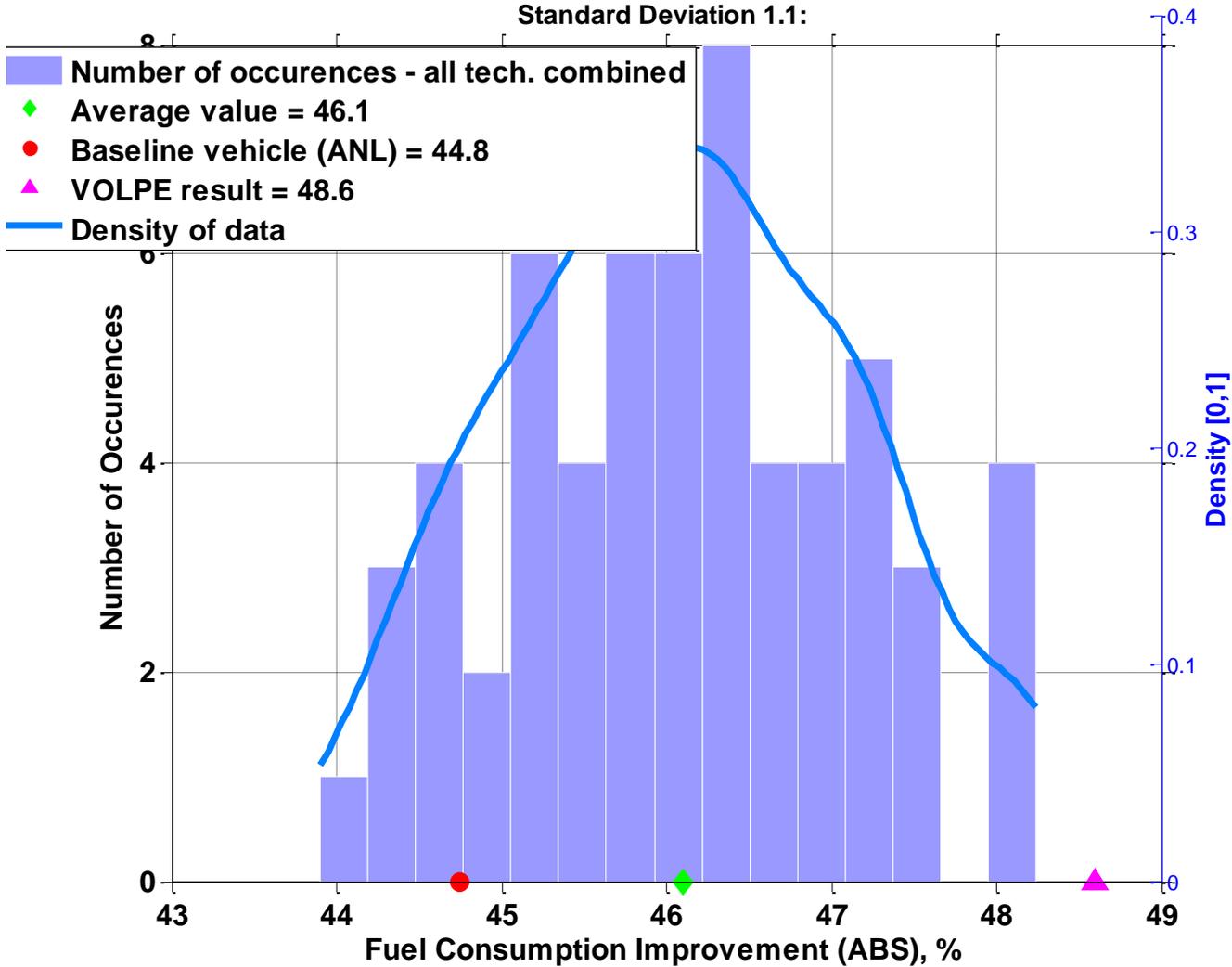


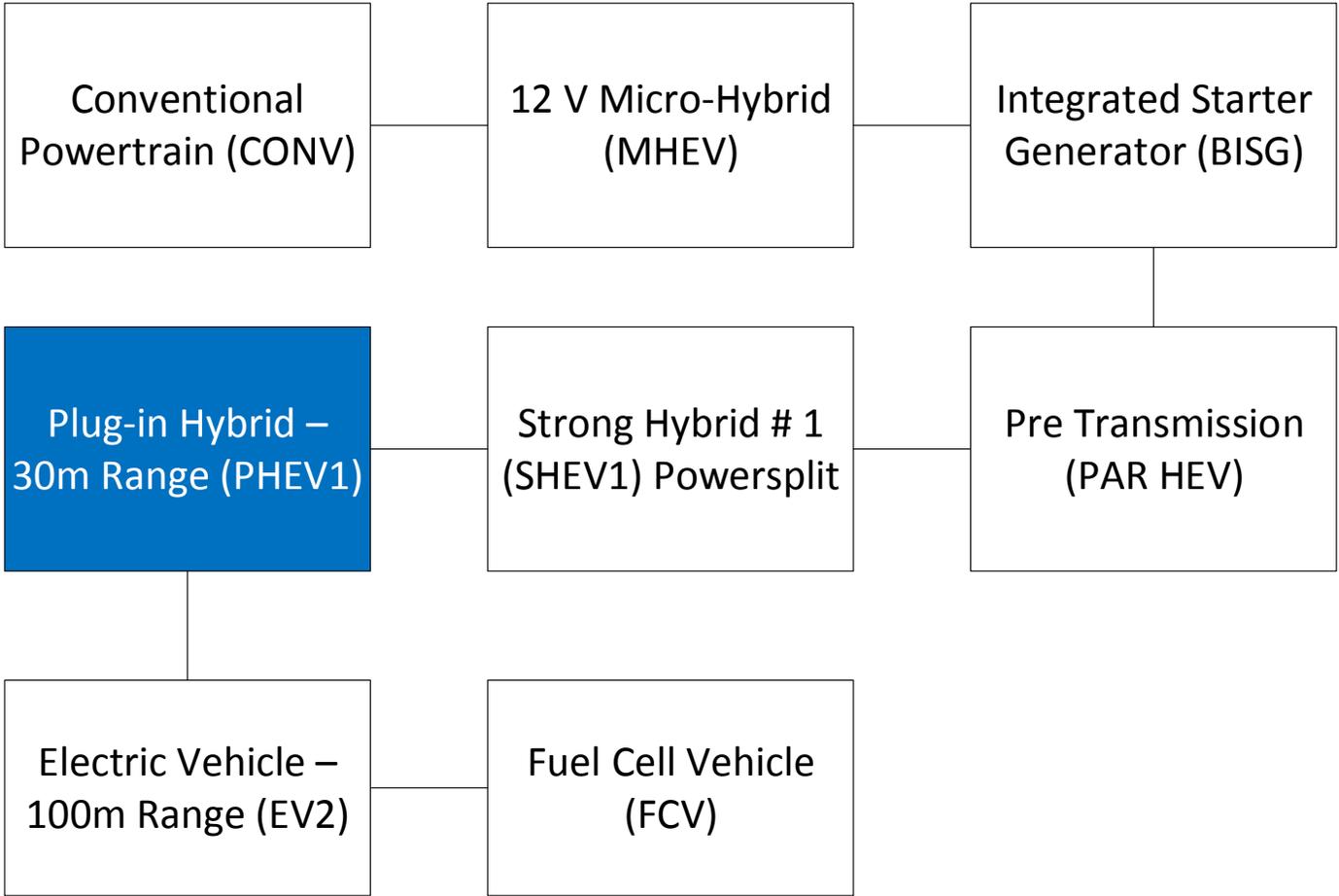
**Distribution of Fuel Consumption for Hybrid-Pretransmission Hybrid  
Absolute percentage compared with: Conventional Powertrain  
Standard Deviation 5.0:**



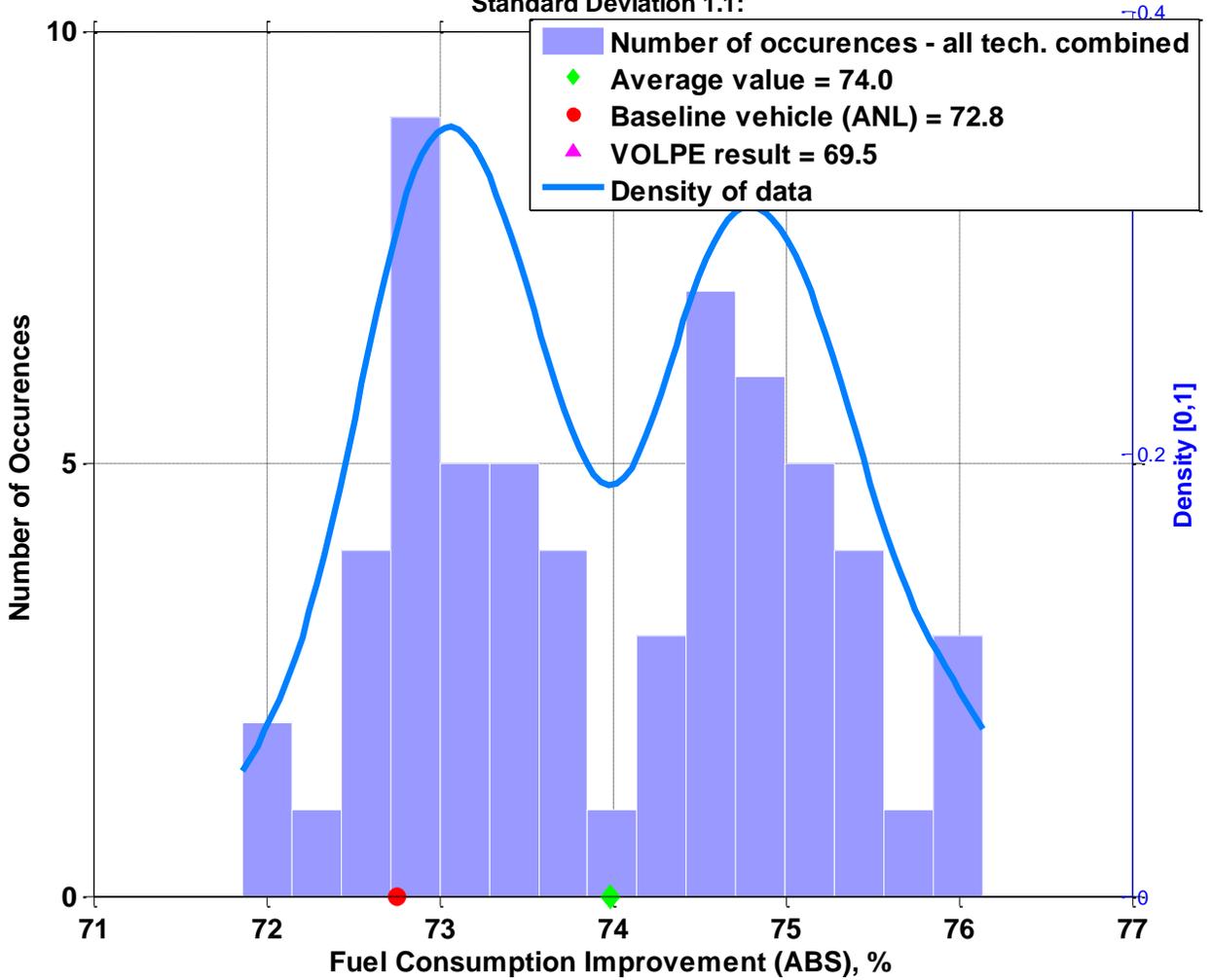


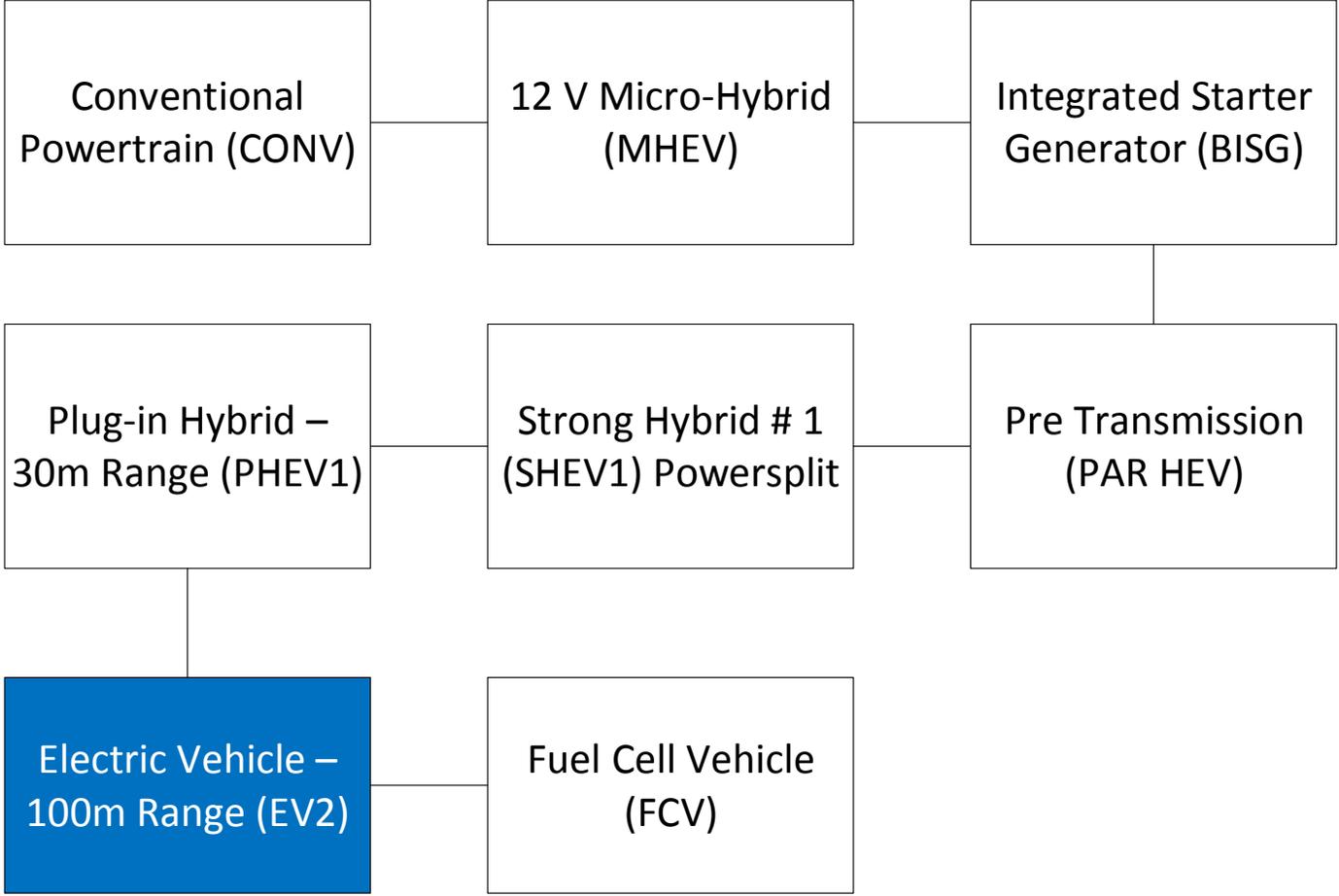
**Distribution of Fuel Consumption for Hybrid-Strong Hybrid#1 (SHEV1)**  
**Absolute percentage compared with: Conventional Powertrain**  
**Standard Deviation 1.1:**



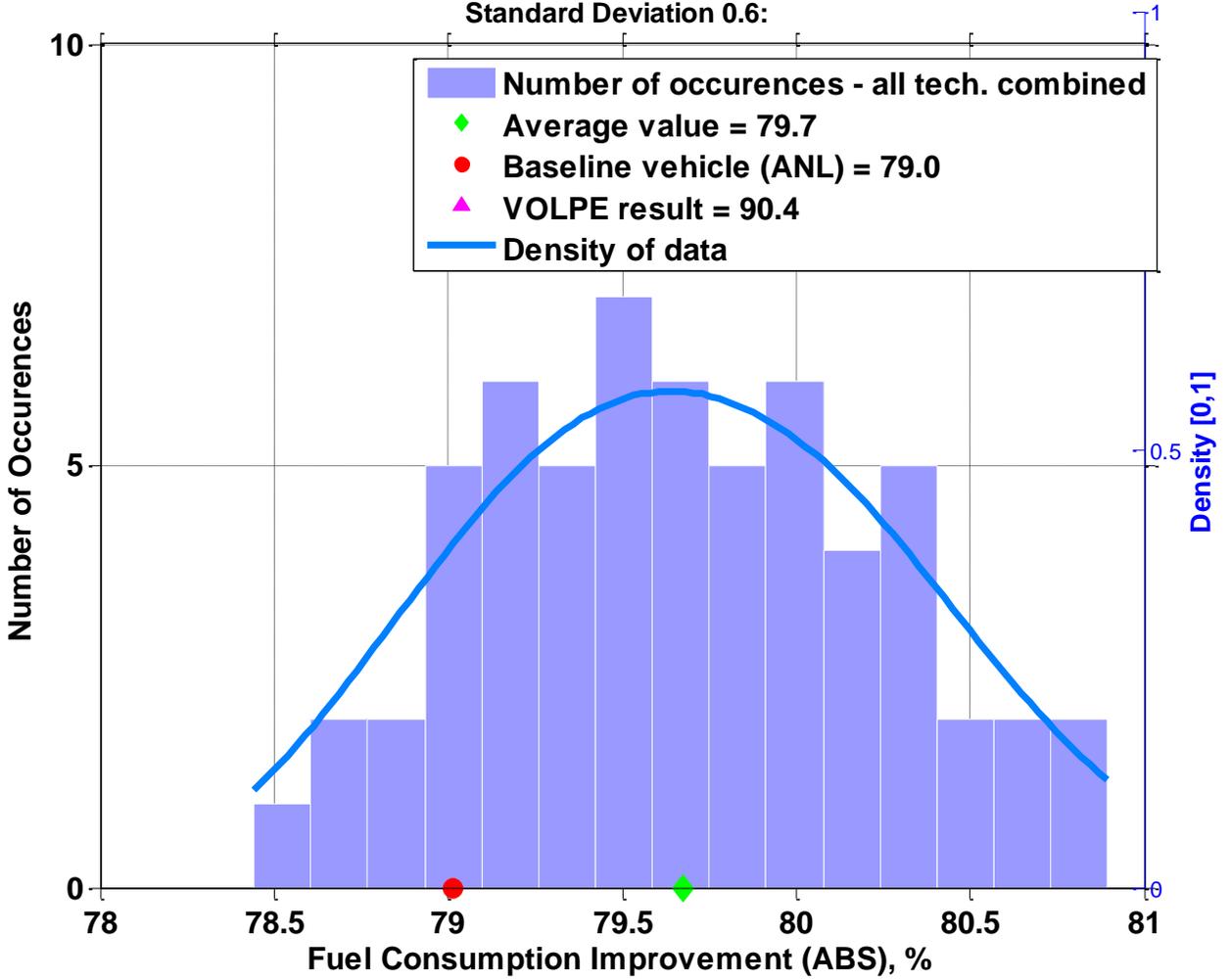


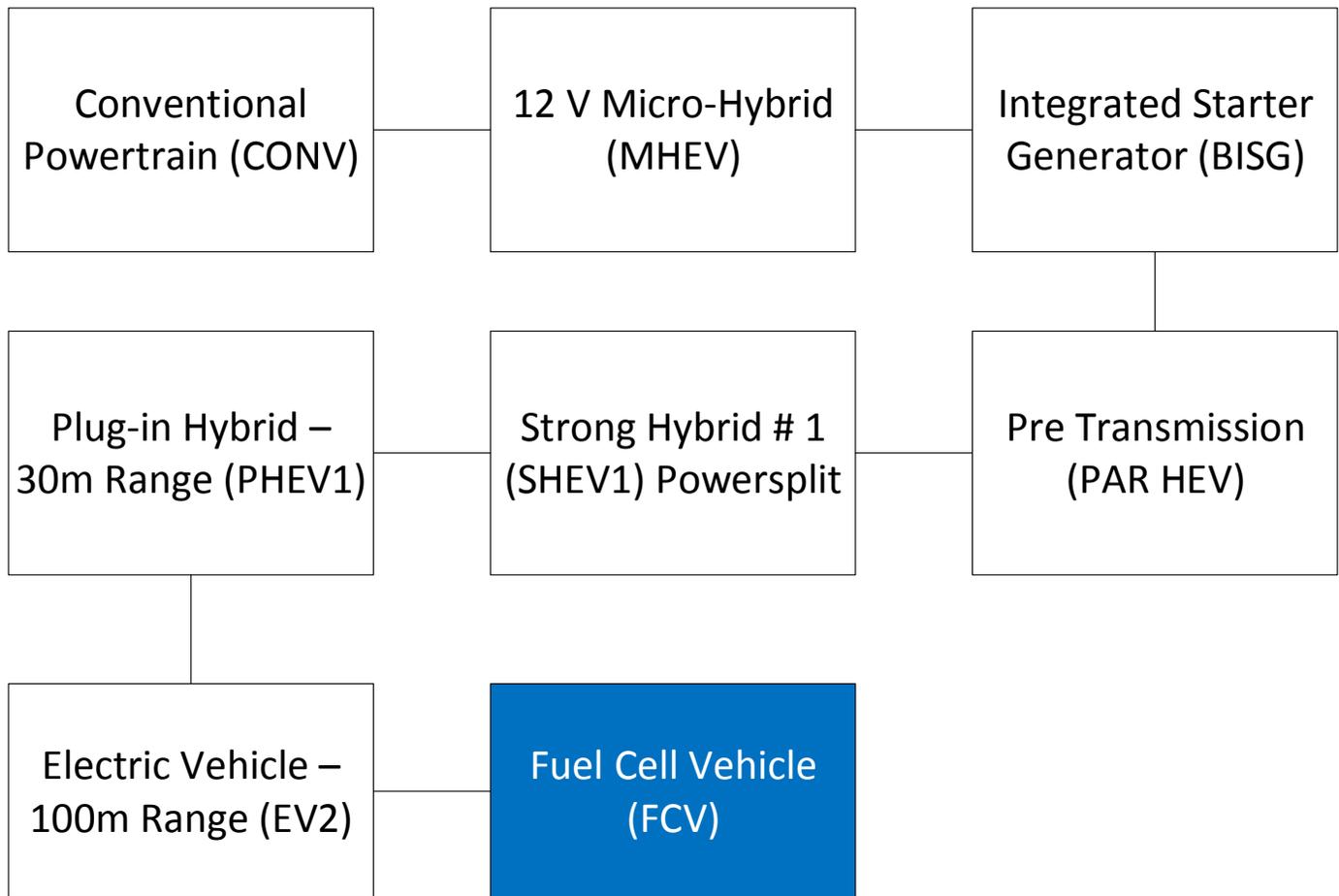
Distribution of Fuel Consumption for Hybrid-Plug-in Hybrid 30m Range (PHEV1)  
 Absolute percentage compared with: Conventional Powertrain  
 Standard Deviation 1.1:



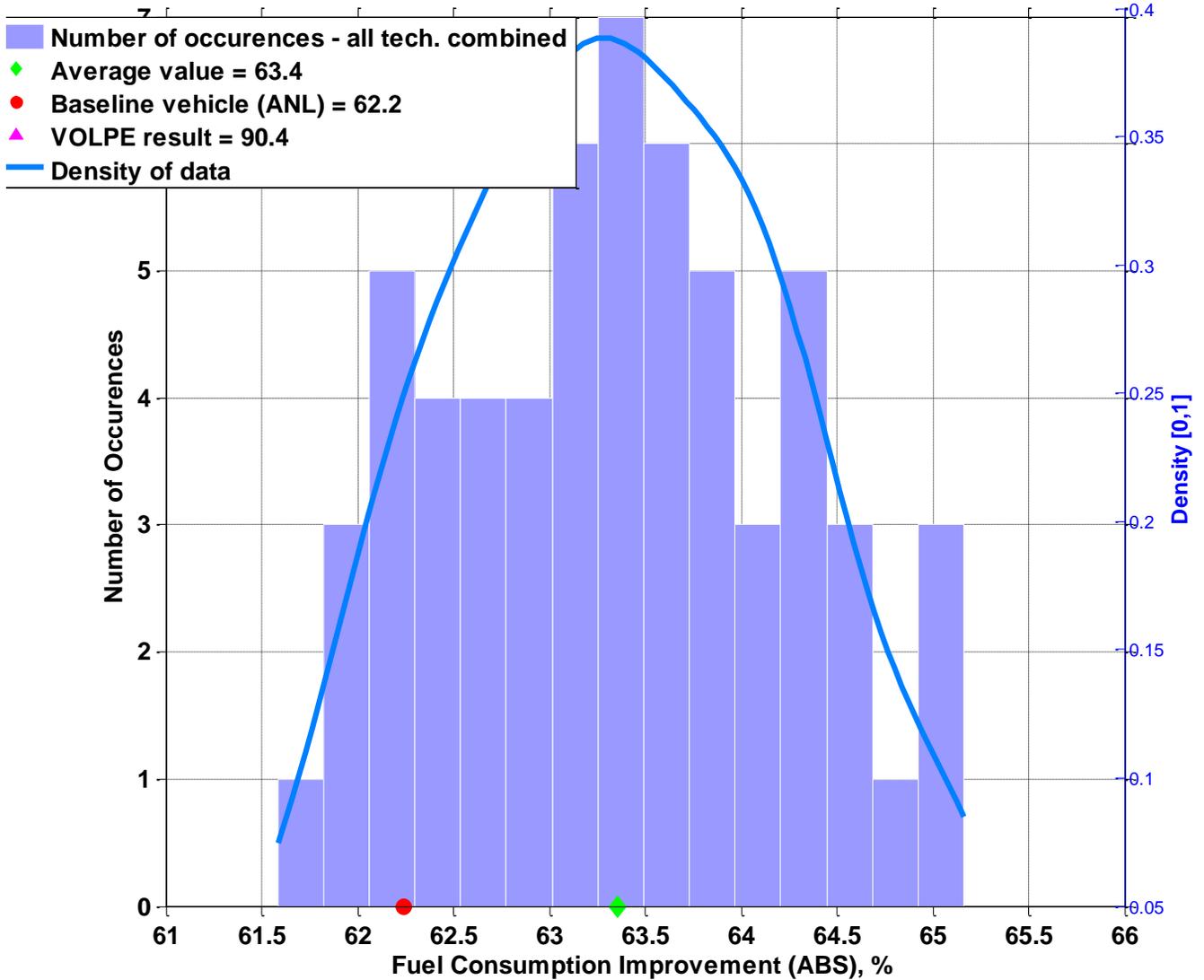


Distribution of Fuel Consumption for Hybrid-Electric Vehicle - 100m Range (EV2)  
 Absolute percentage compared with: Conventional Powertrain  
 Standard Deviation 0.6:





**Distribution of Fuel Consumption for Hybrid-Fuel Cell Vehicle (FCV)**  
**Absolute percentage compared with: Conventional Powertrain**  
**Standard Deviation 0.9:**

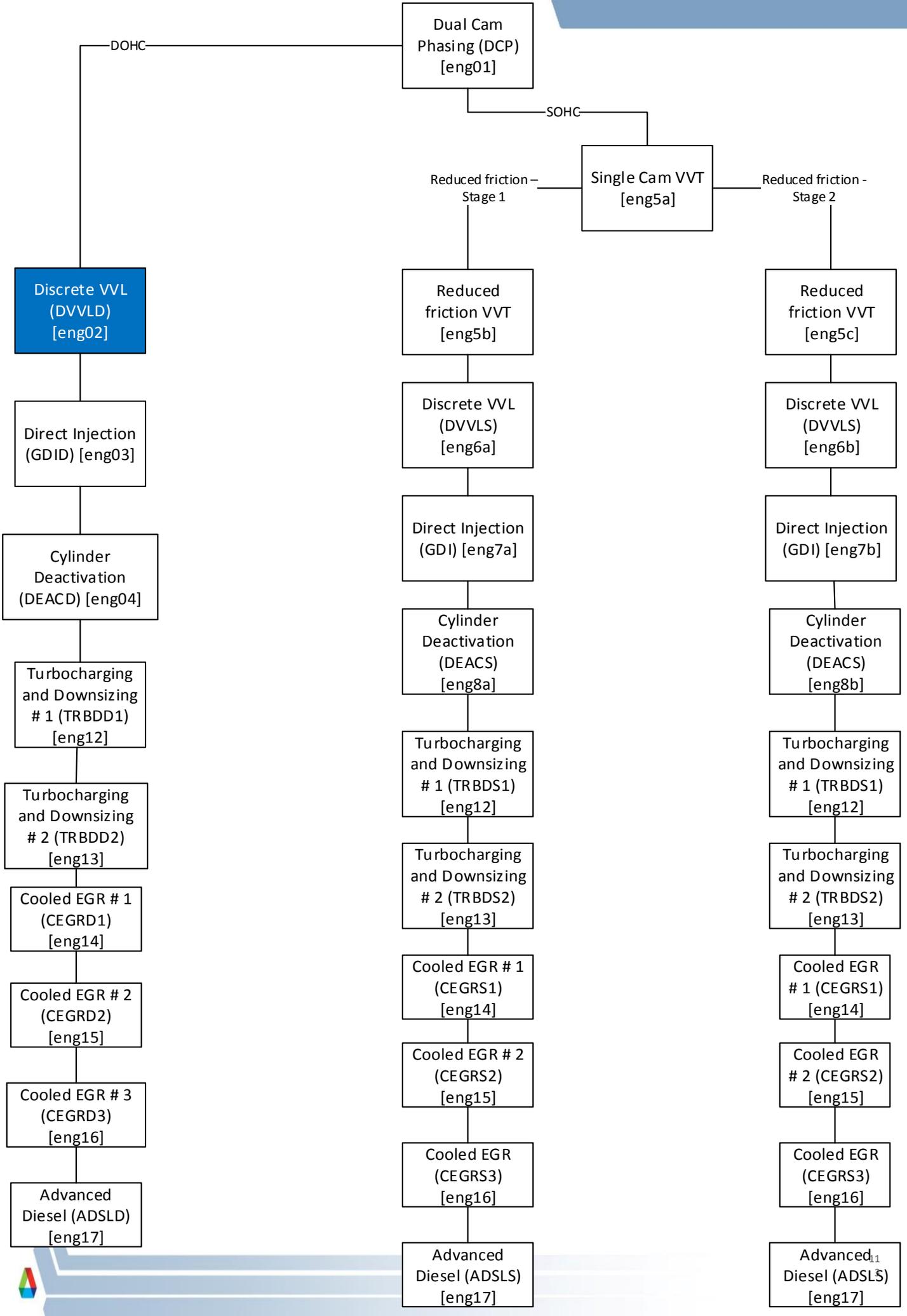




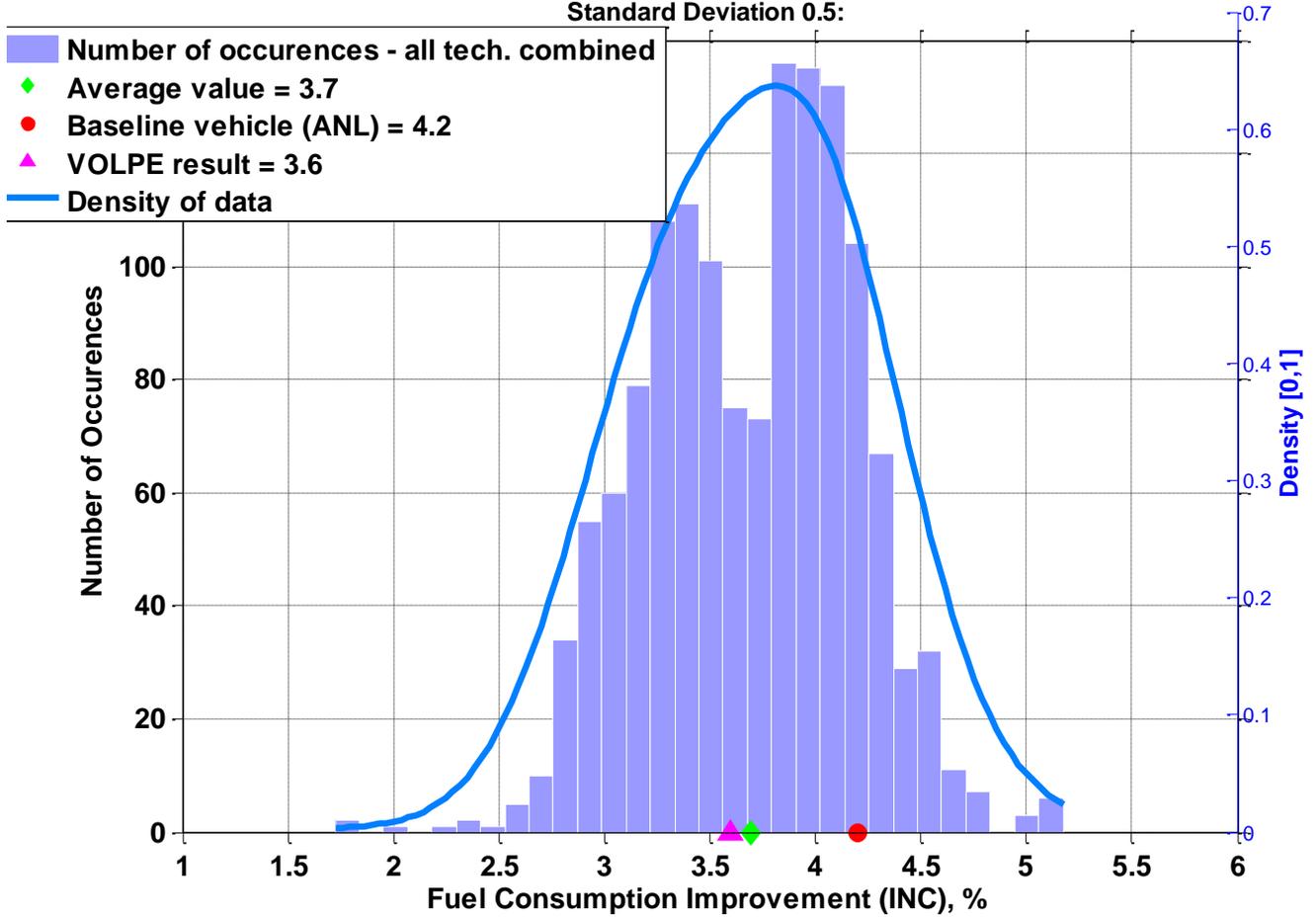
# INCREMENTAL IMPROVEMENT RESULTS

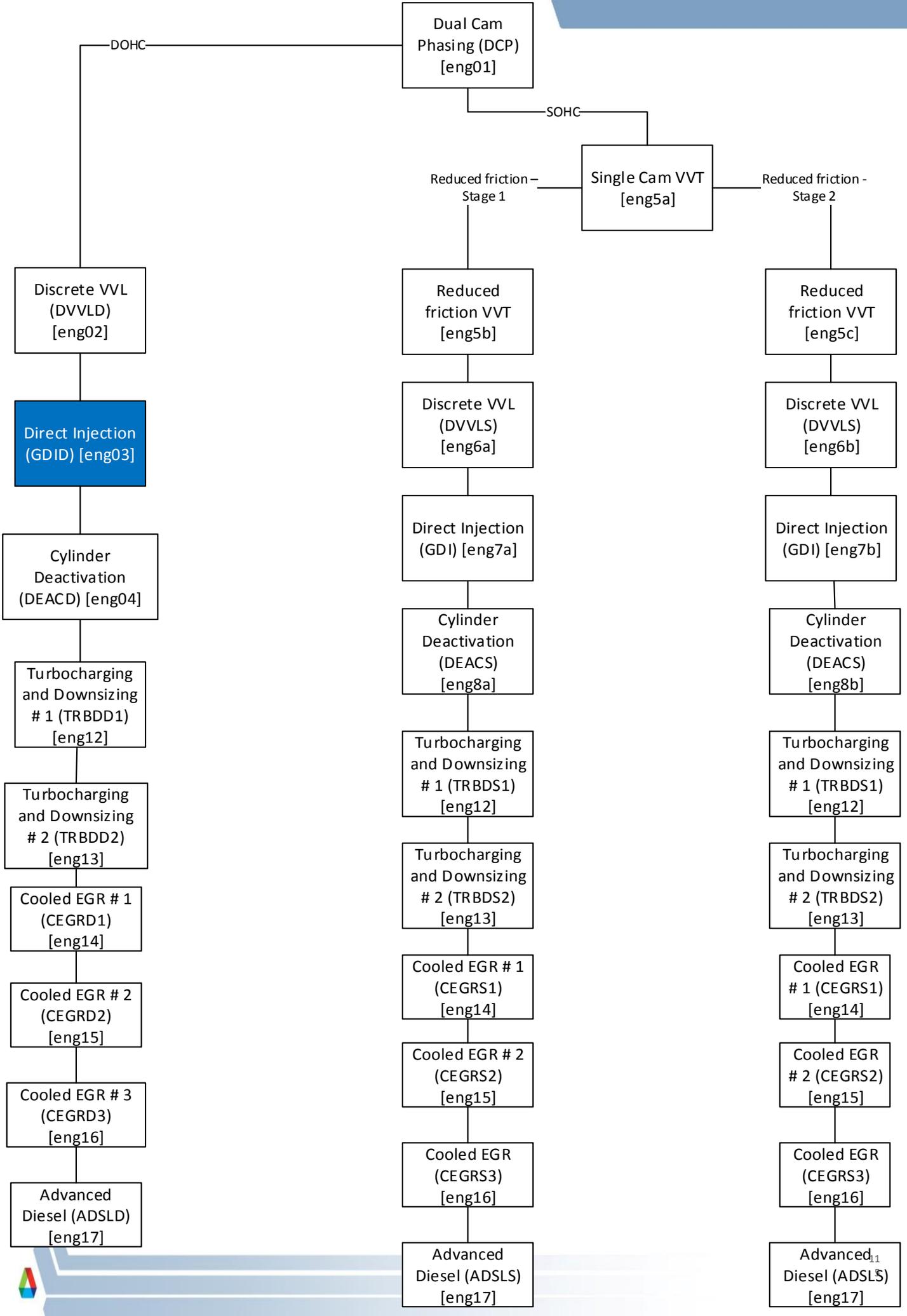


# ENGINE TECHNOLOGIES

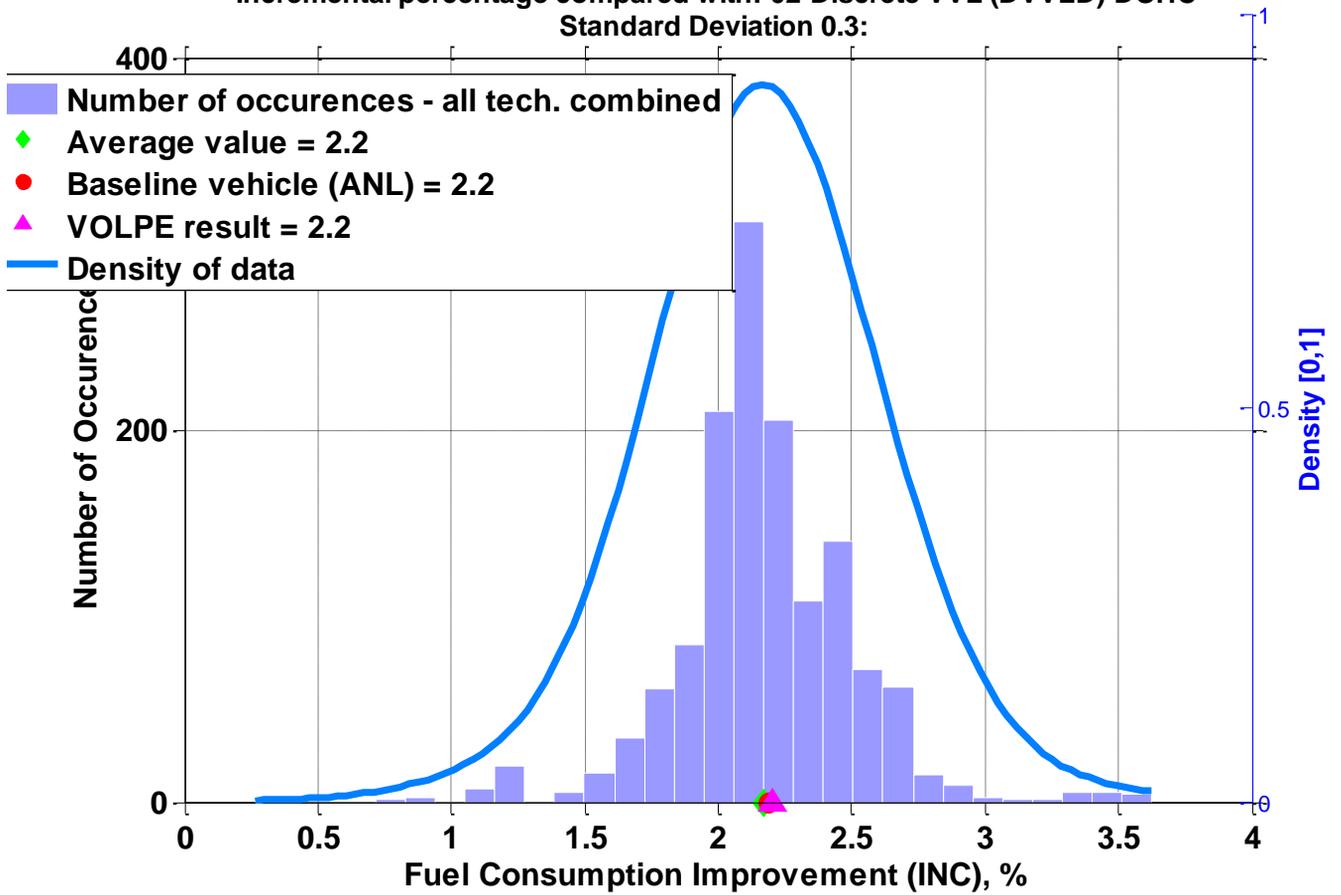


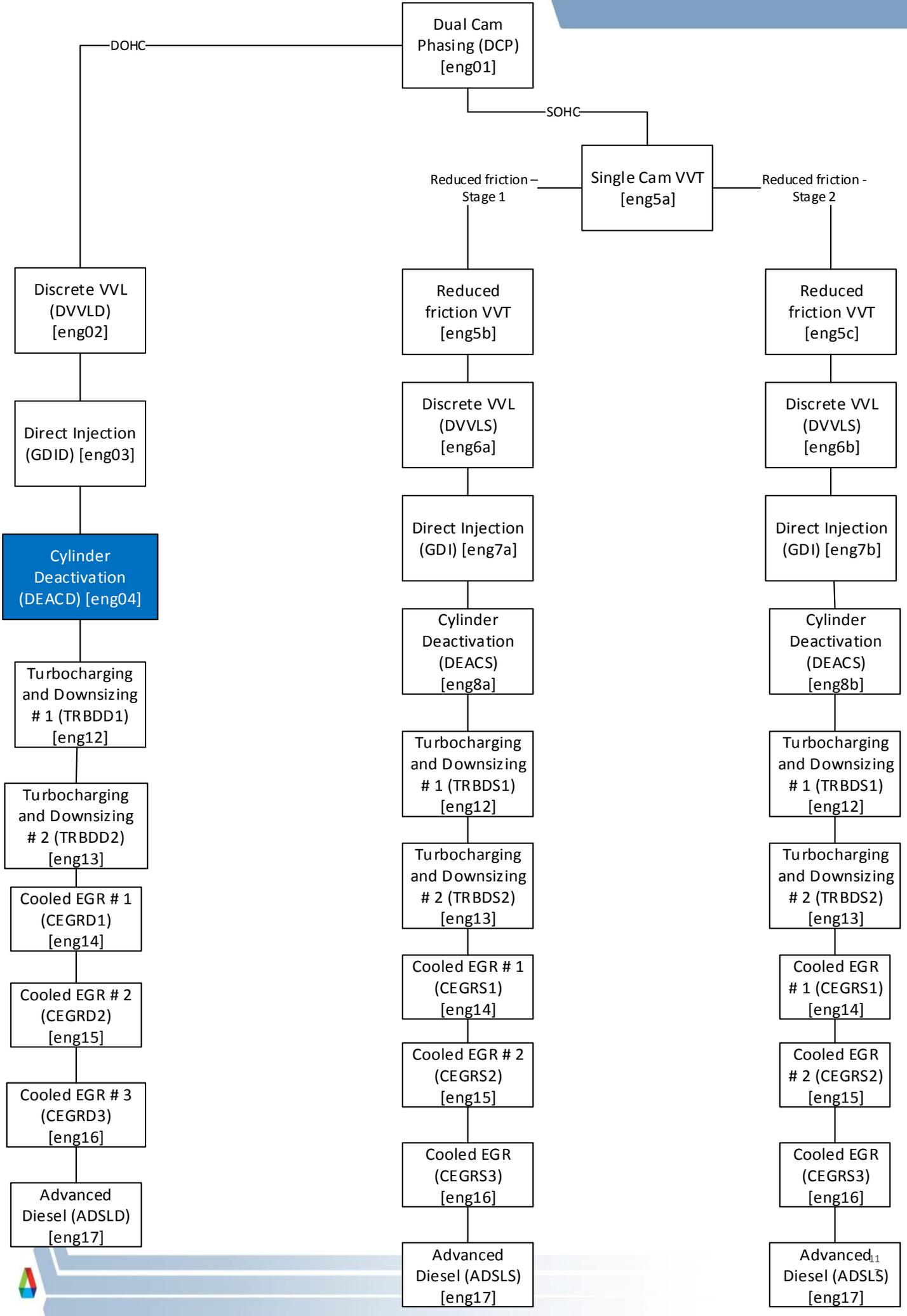
Distribution of Fuel Consumption for Eng02-Discrete VVL (DVVLD)-DOHC  
 Incremental percentage compared with: 01-Dual Cam Phasing(DCP)-DOHC  
 Standard Deviation 0.5:



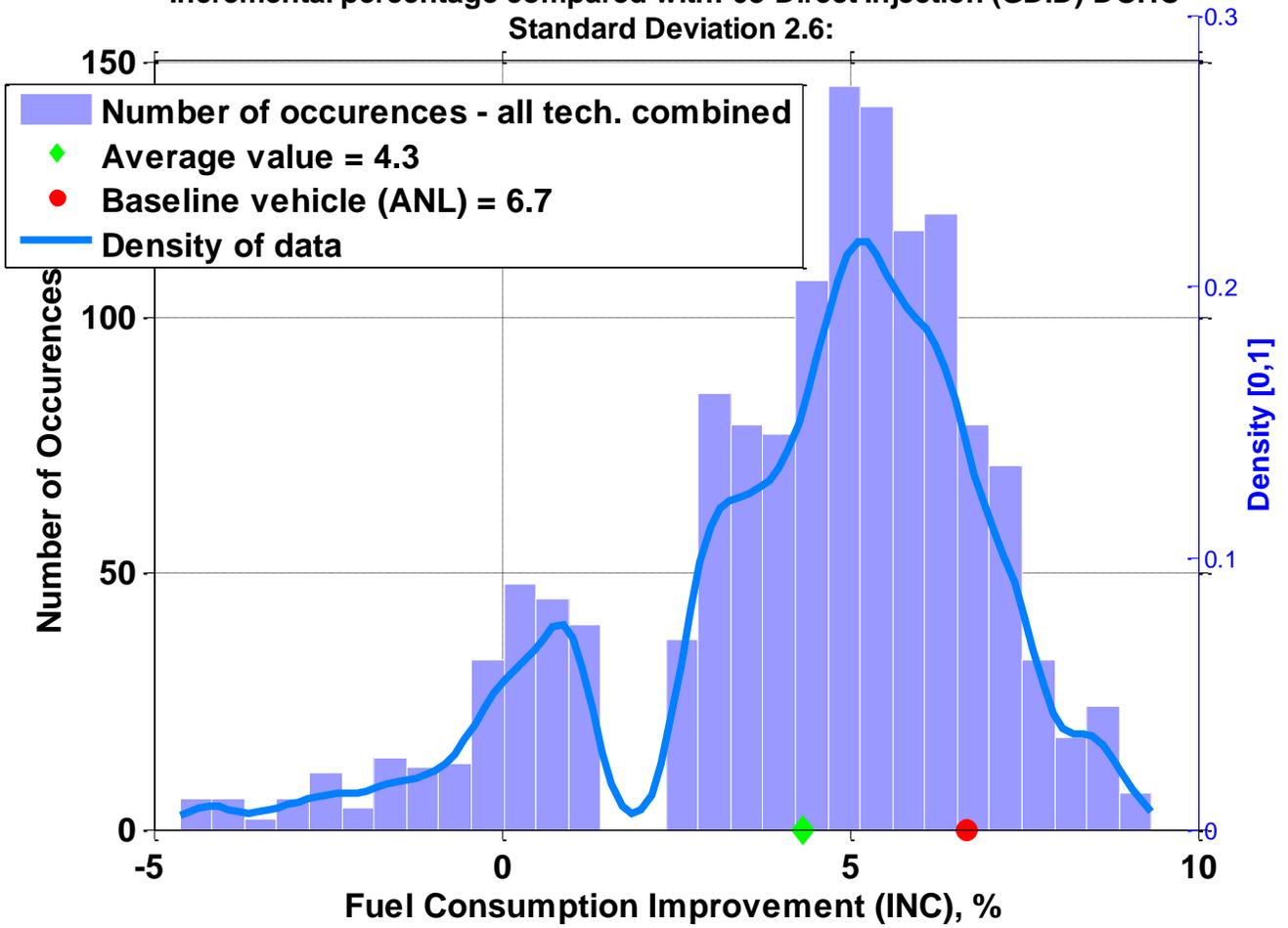


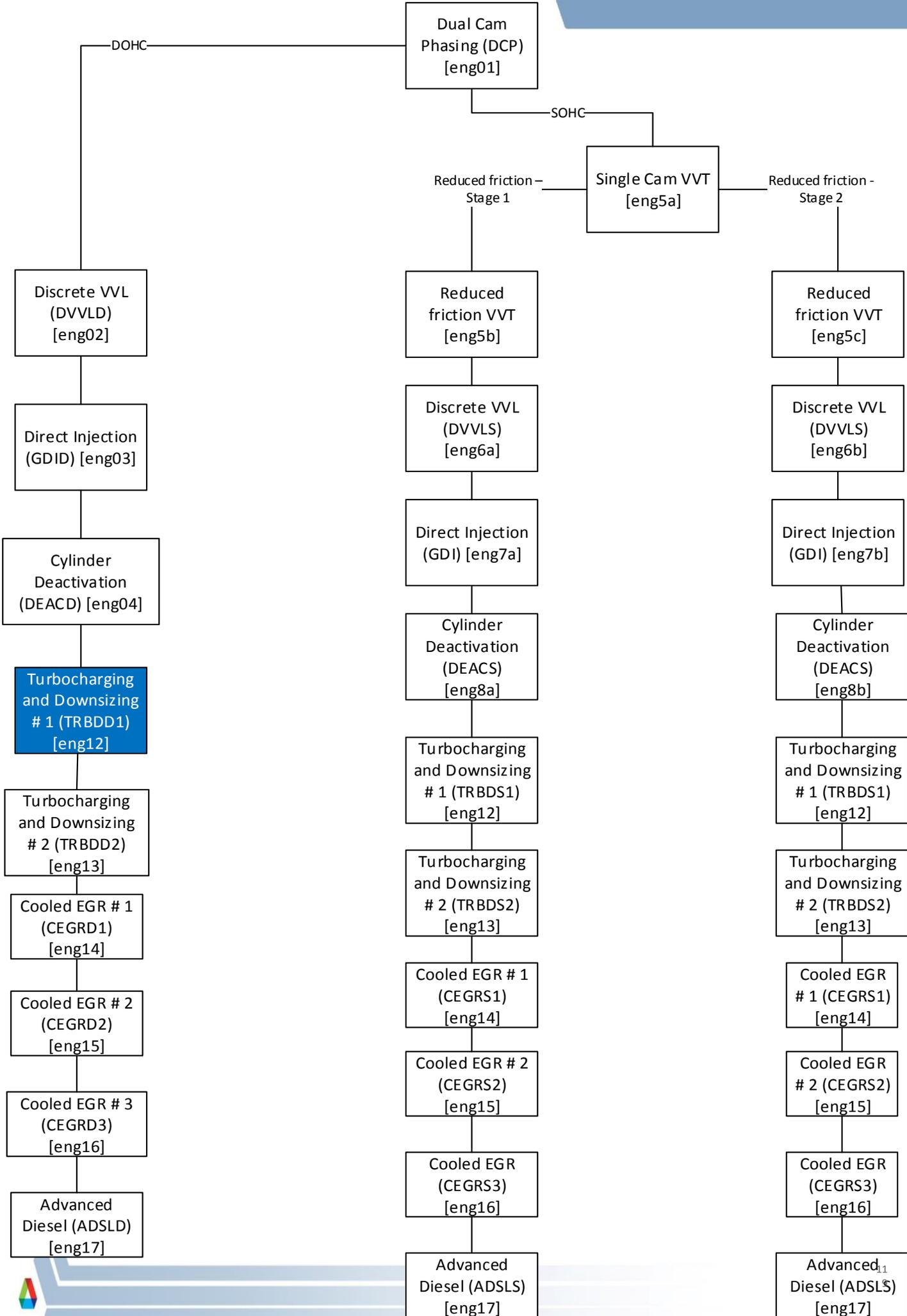
Distribution of Fuel Consumption for Eng03-Direct Injection (GDID)-DOHC  
 Incremental percentage compared with: 02-Discrete VVL (DVVLD)-DOHC  
 Standard Deviation 0.3:



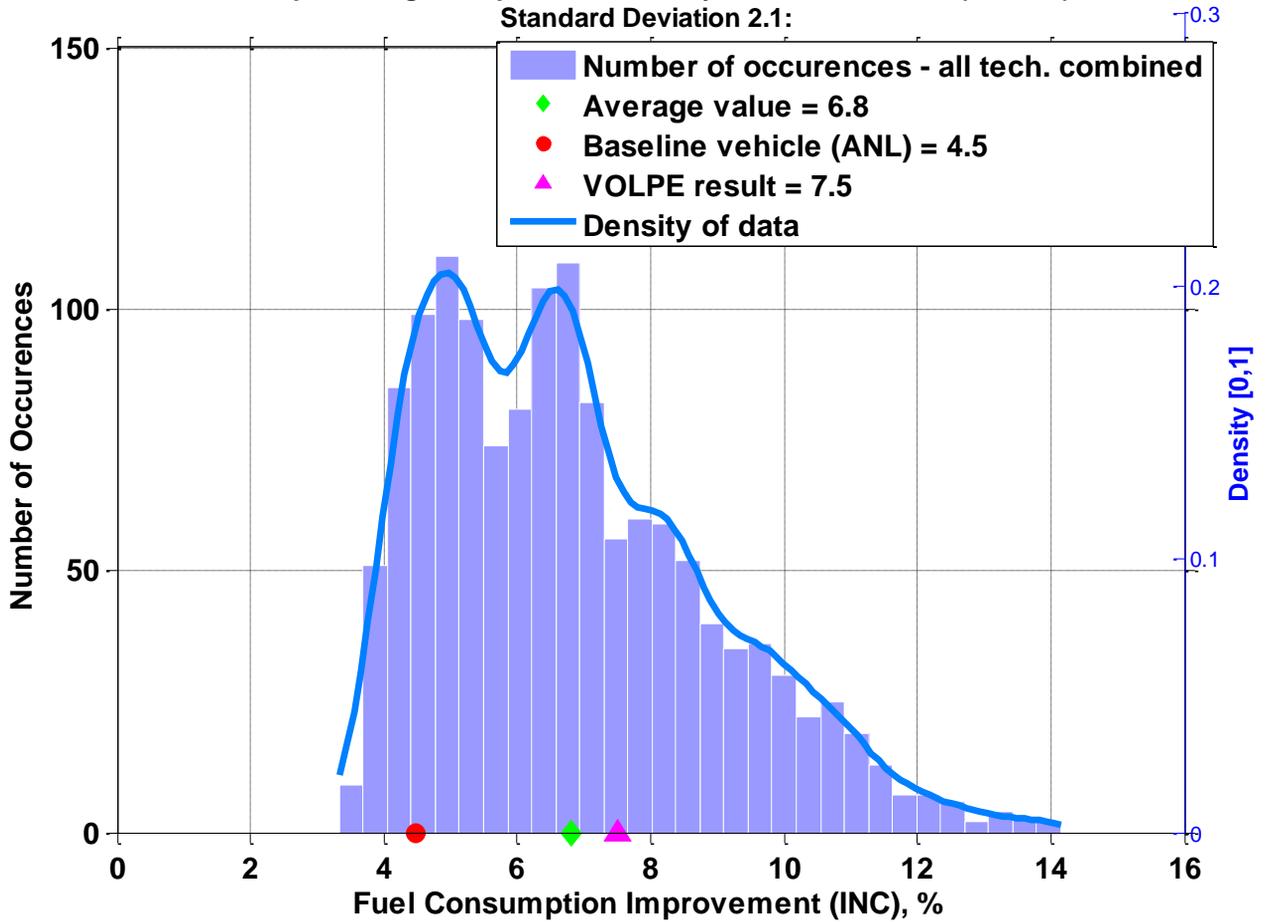


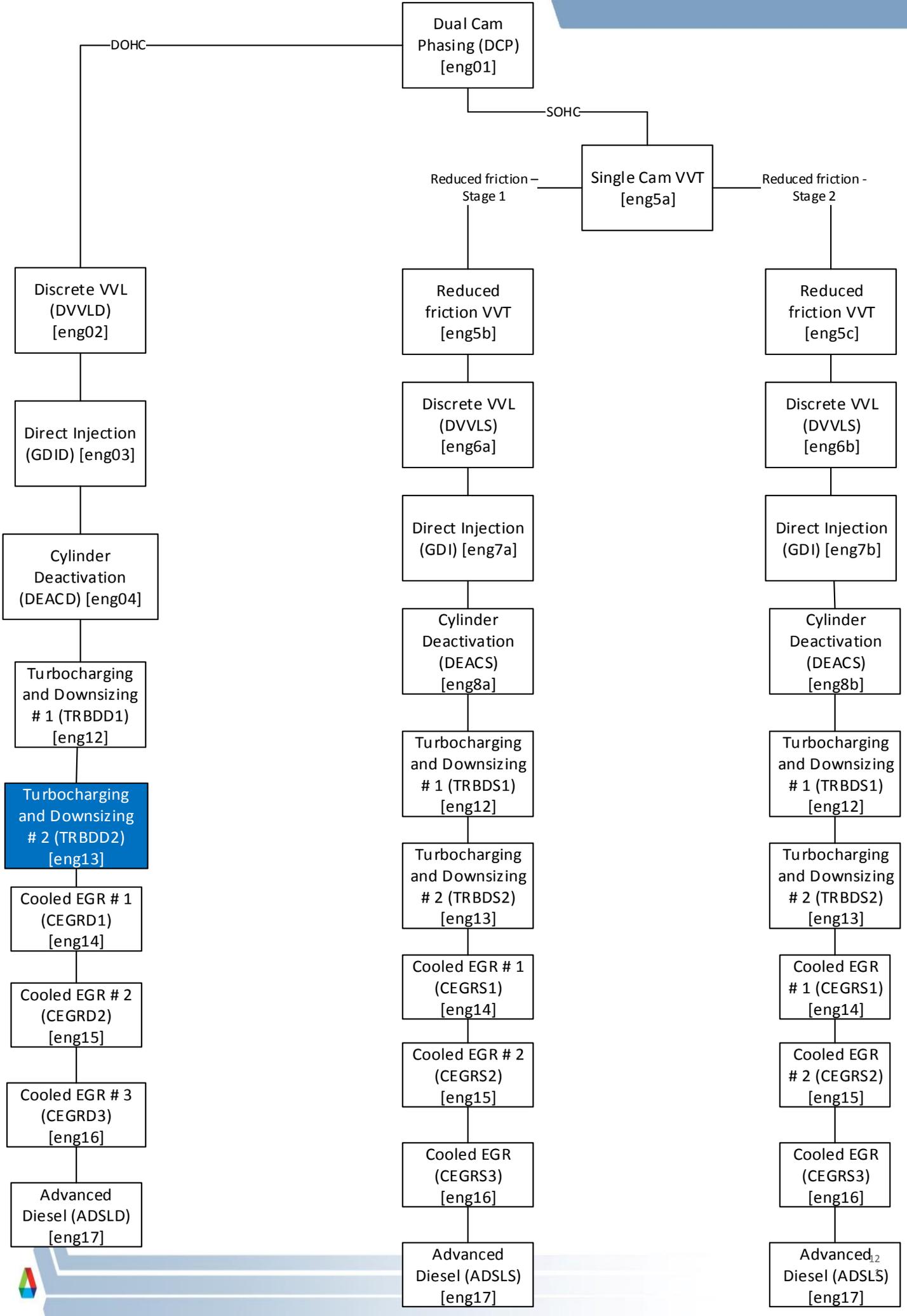
Distribution of Fuel Consumption for Eng04-Cylinder Deactivation (DEACD)-DOHC  
 Incremental percentage compared with: 03-Direct Injection (GDID)-DOHC  
 Standard Deviation 2.6:



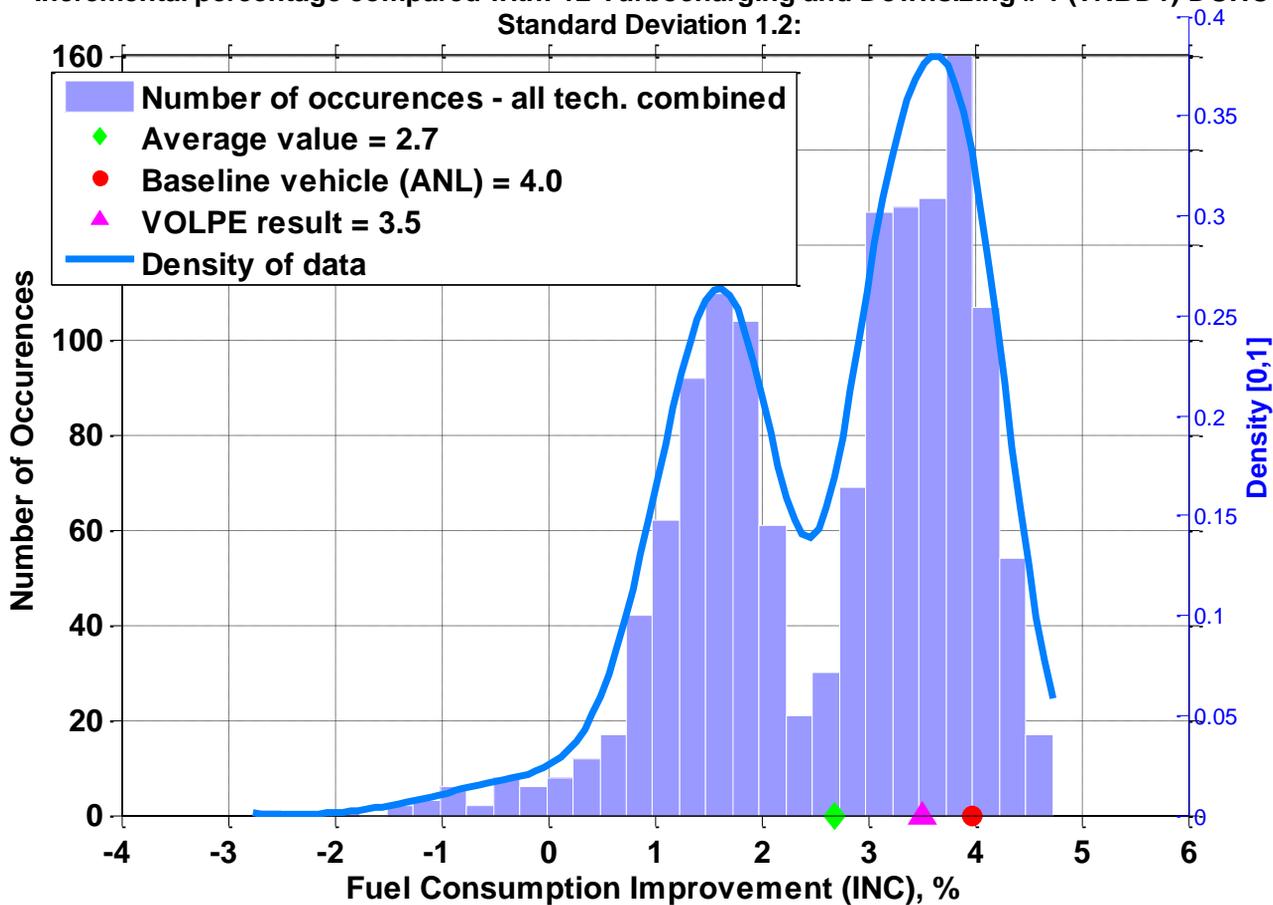


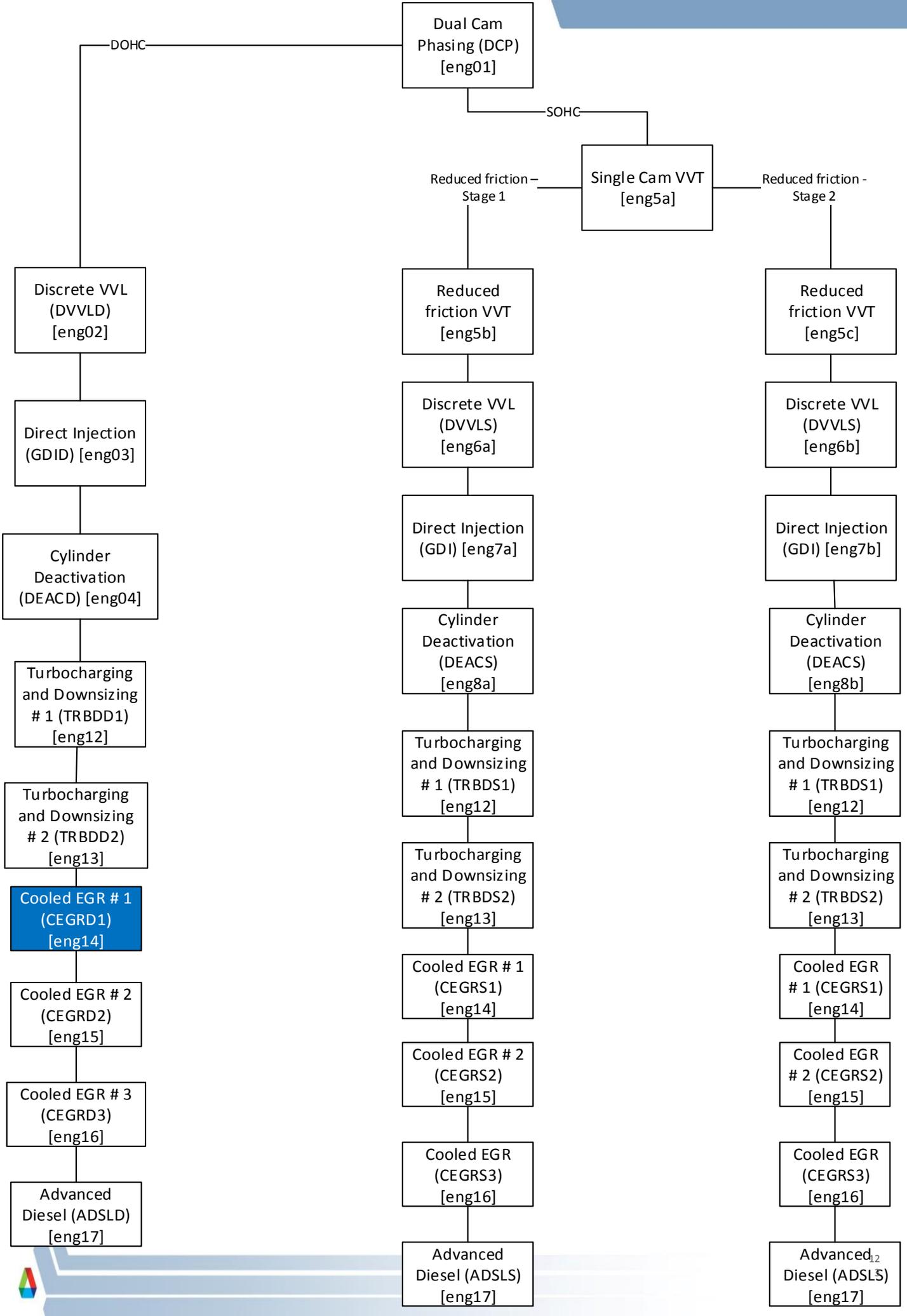
Distribution of Fuel Consumption for Eng12-Turbocharging and Downsizing # 1 (TRBD1)-DOHC  
 Incremental percentage compared with: 04-Cylinder Deactivation (DEACD)-DOHC  
 Standard Deviation 2.1:



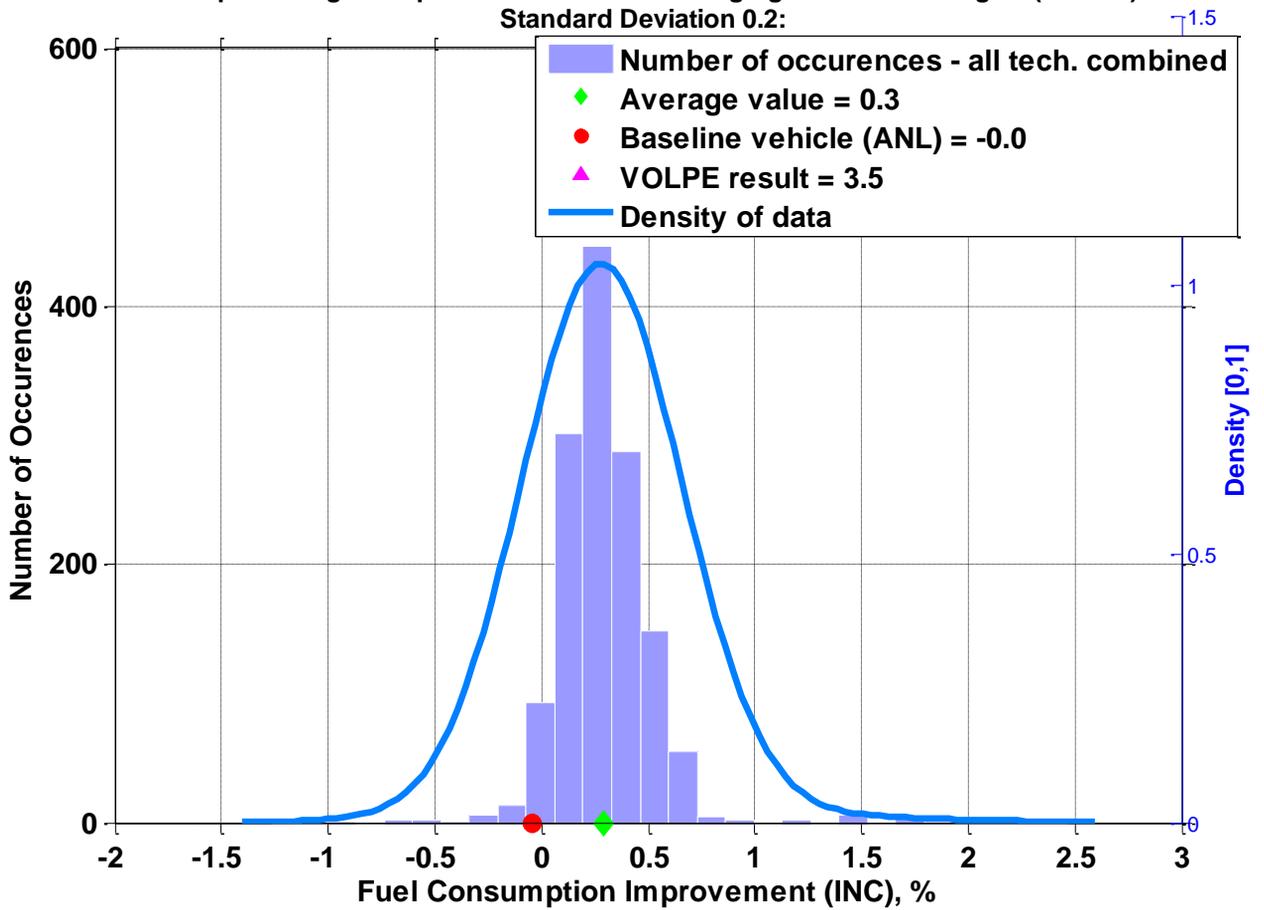


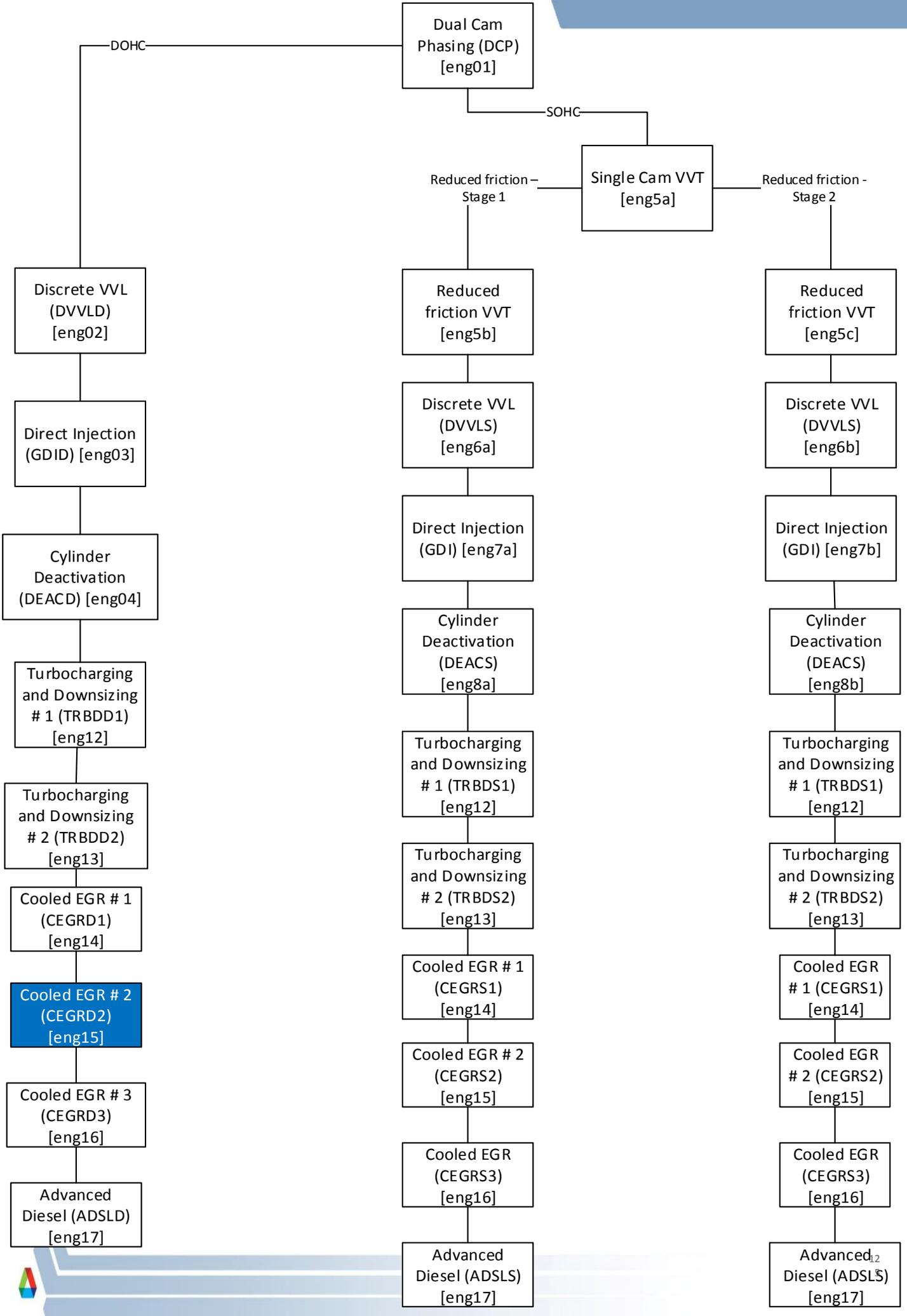
**Distribution of Fuel Consumption for Eng13-Turbocharging and Downsizing #2 (TRBD2)-DOHC  
Incremental percentage compared with: 12-Turbocharging and Downsizing # 1 (TRBD1)-DOHC  
Standard Deviation 1.2:**



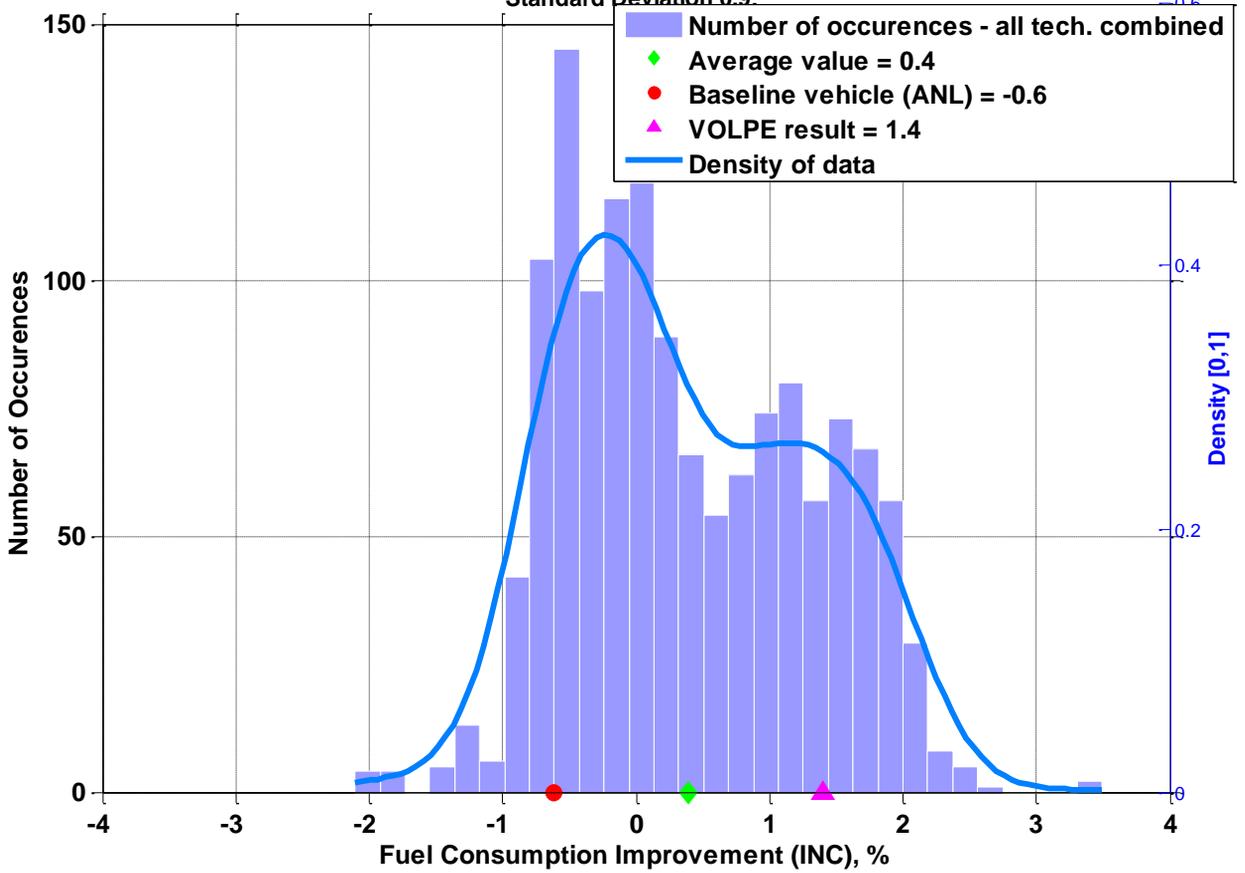


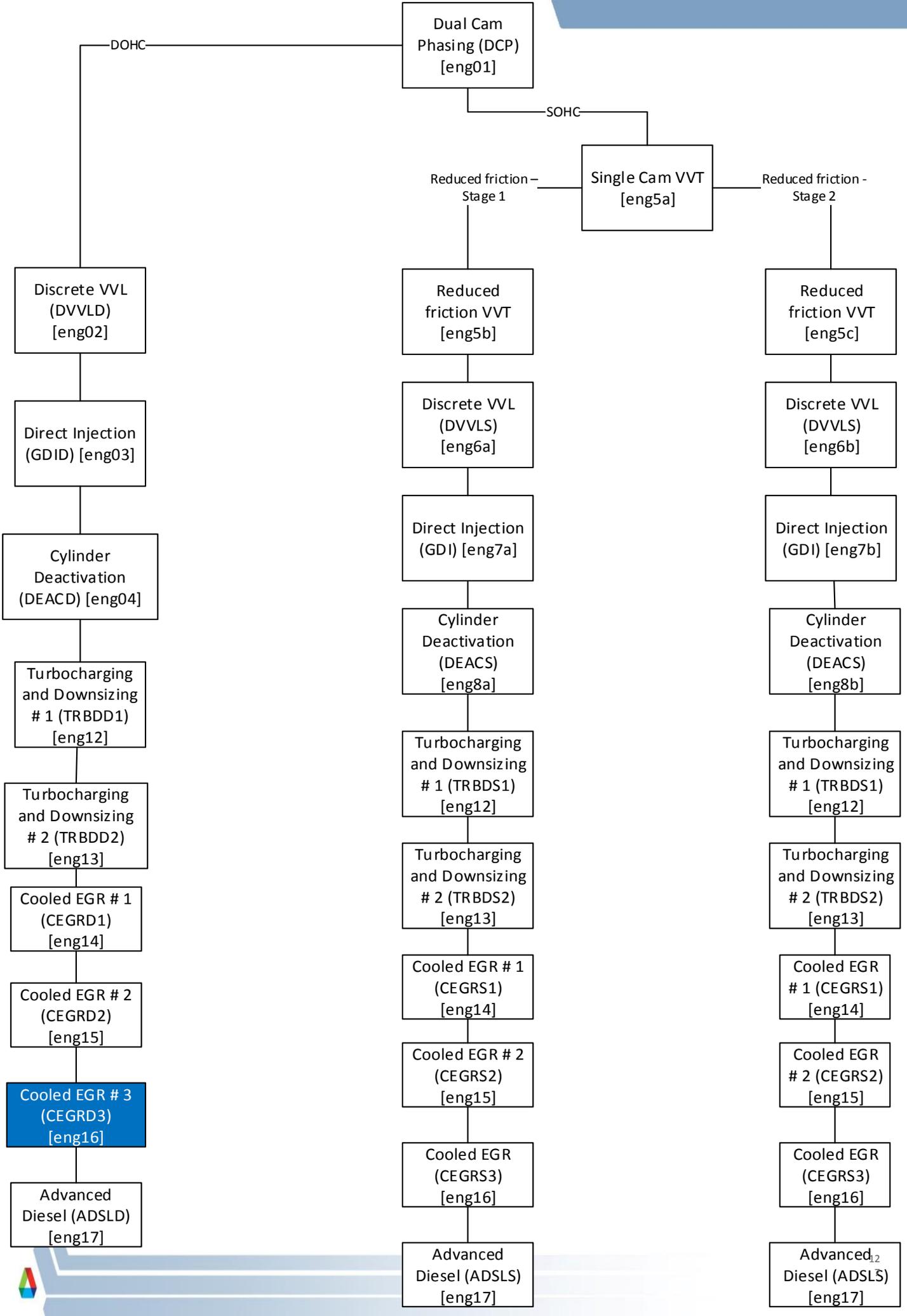
Distribution of Fuel Consumption for Eng14-Cooled EGR#1 (CEGR1)-DOHC  
 Incremental percentage compared with: 13-Turbocharging and Downsizing #2 (TRBD2)-DOHC  
 Standard Deviation 0.2:



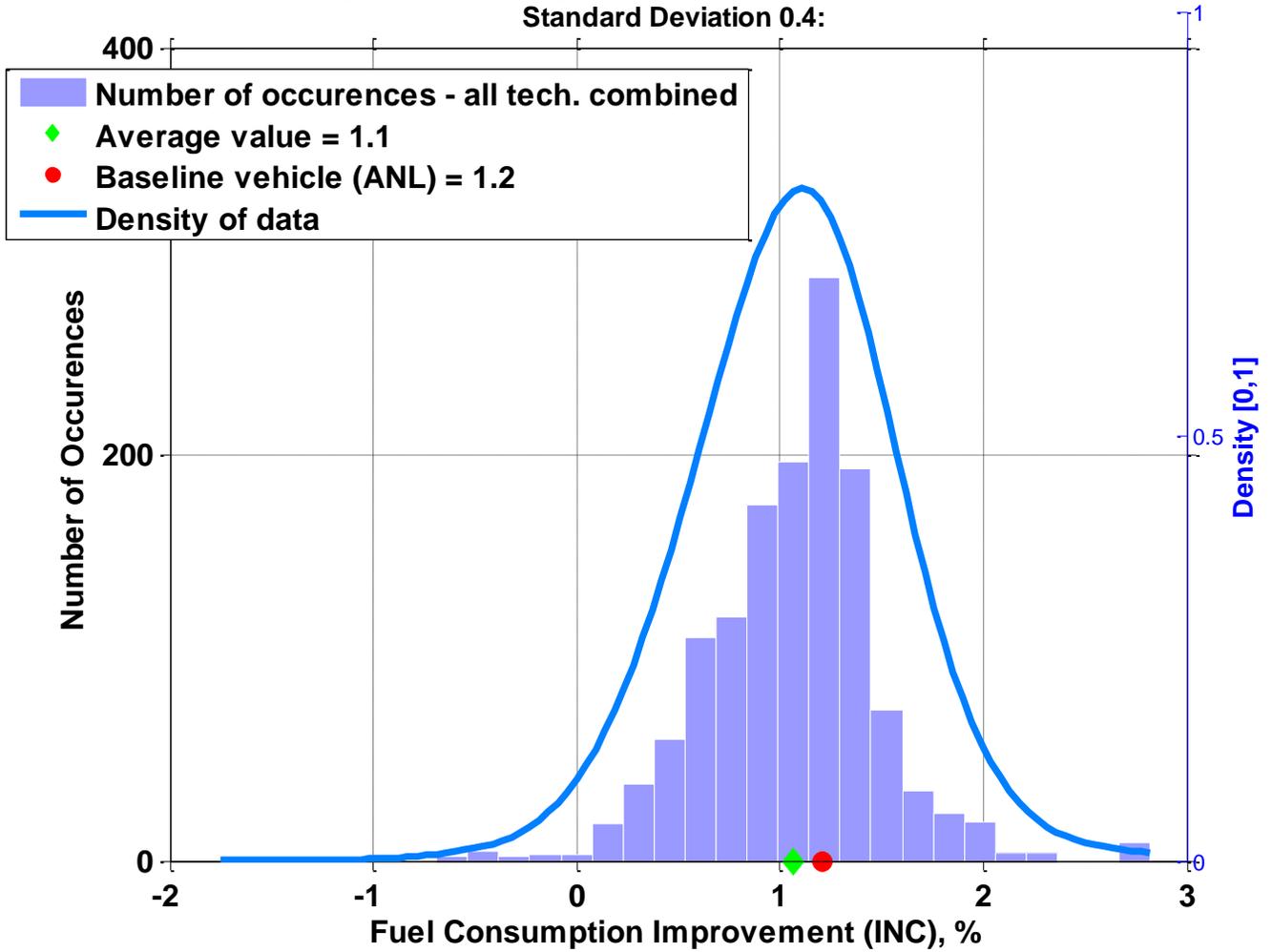


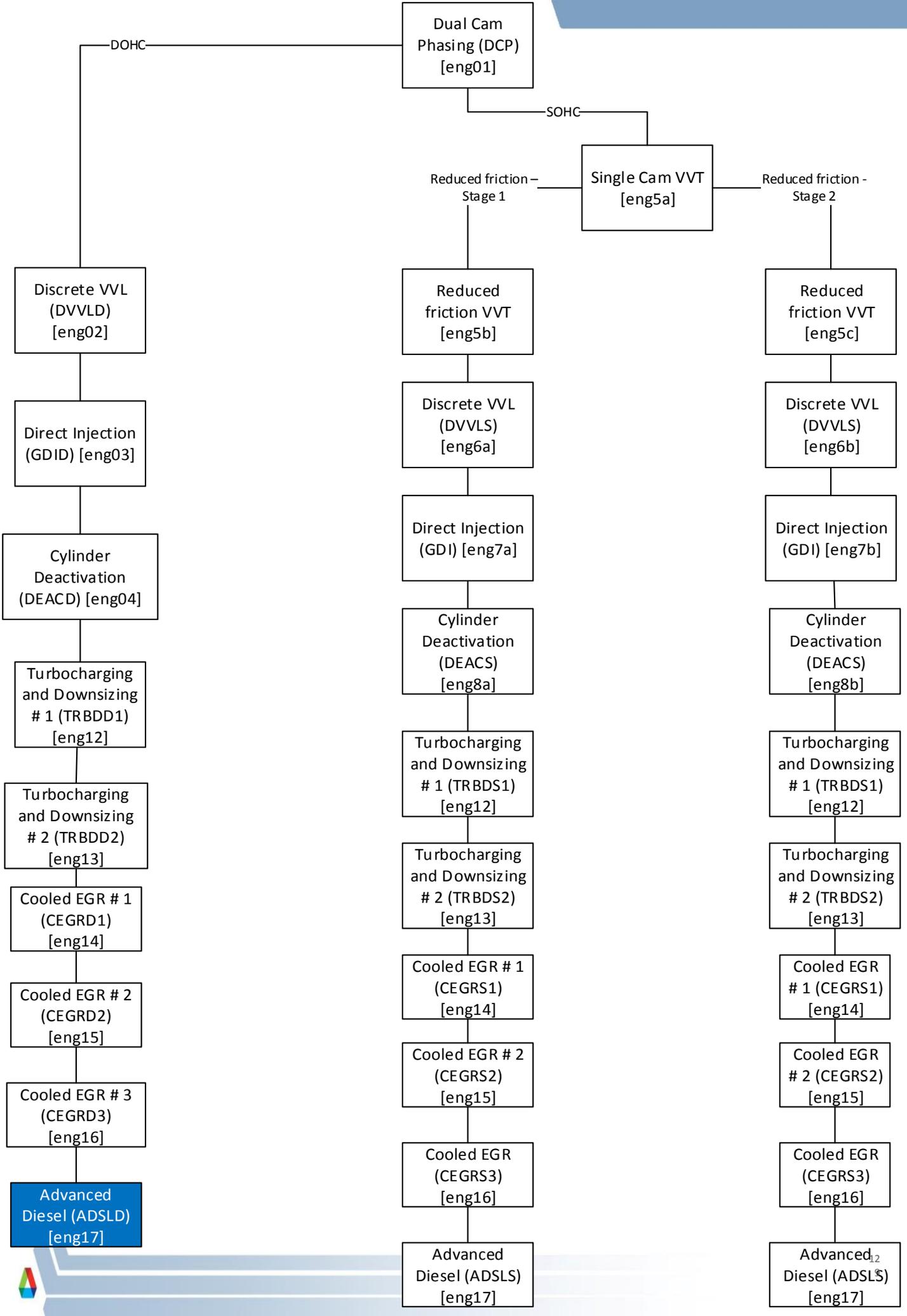
Distribution of Fuel Consumption for Eng15-Cooled EGR#2 (CEGR2)-DOHC  
 Incremental percentage compared with: 14-Cooled EGR#1 (CEGR1)-DOHC  
 Standard Deviation 0.9:



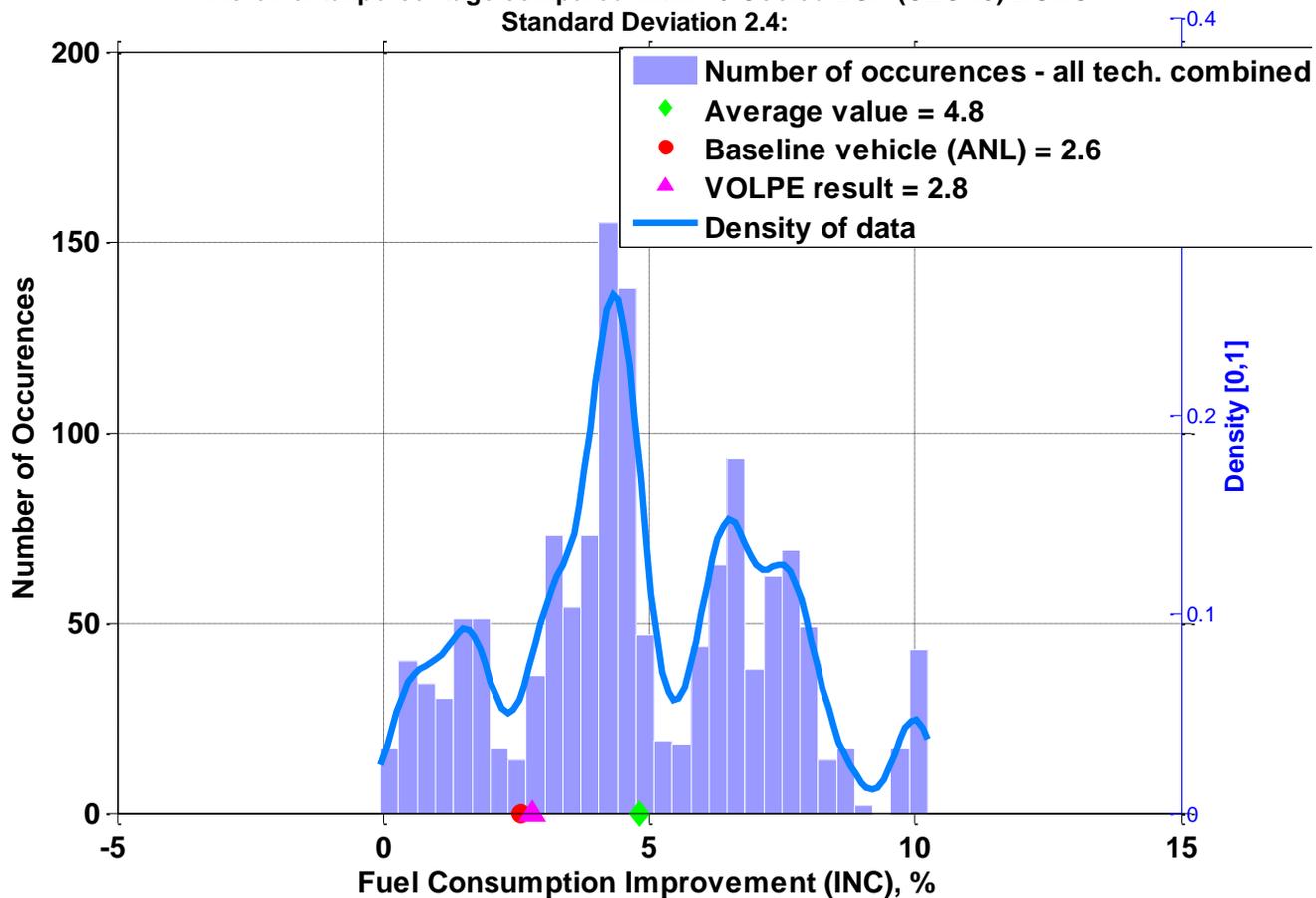


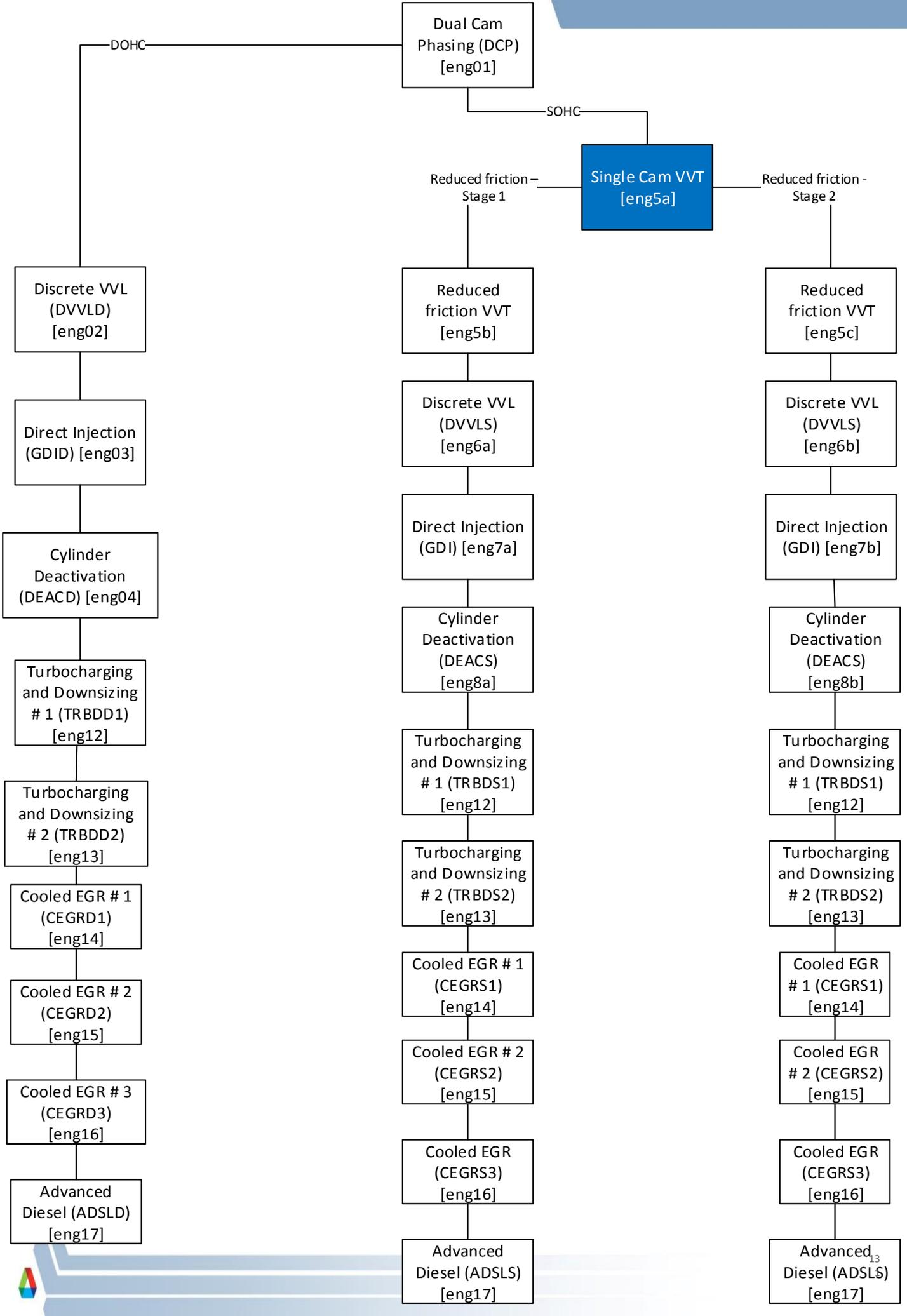
Distribution of Fuel Consumption for Eng16-Cooled EGR (CEGR3)-DOHC  
 Incremental percentage compared with: 15-Cooled EGR#2 (CEGR2)-DOHC  
 Standard Deviation 0.4:



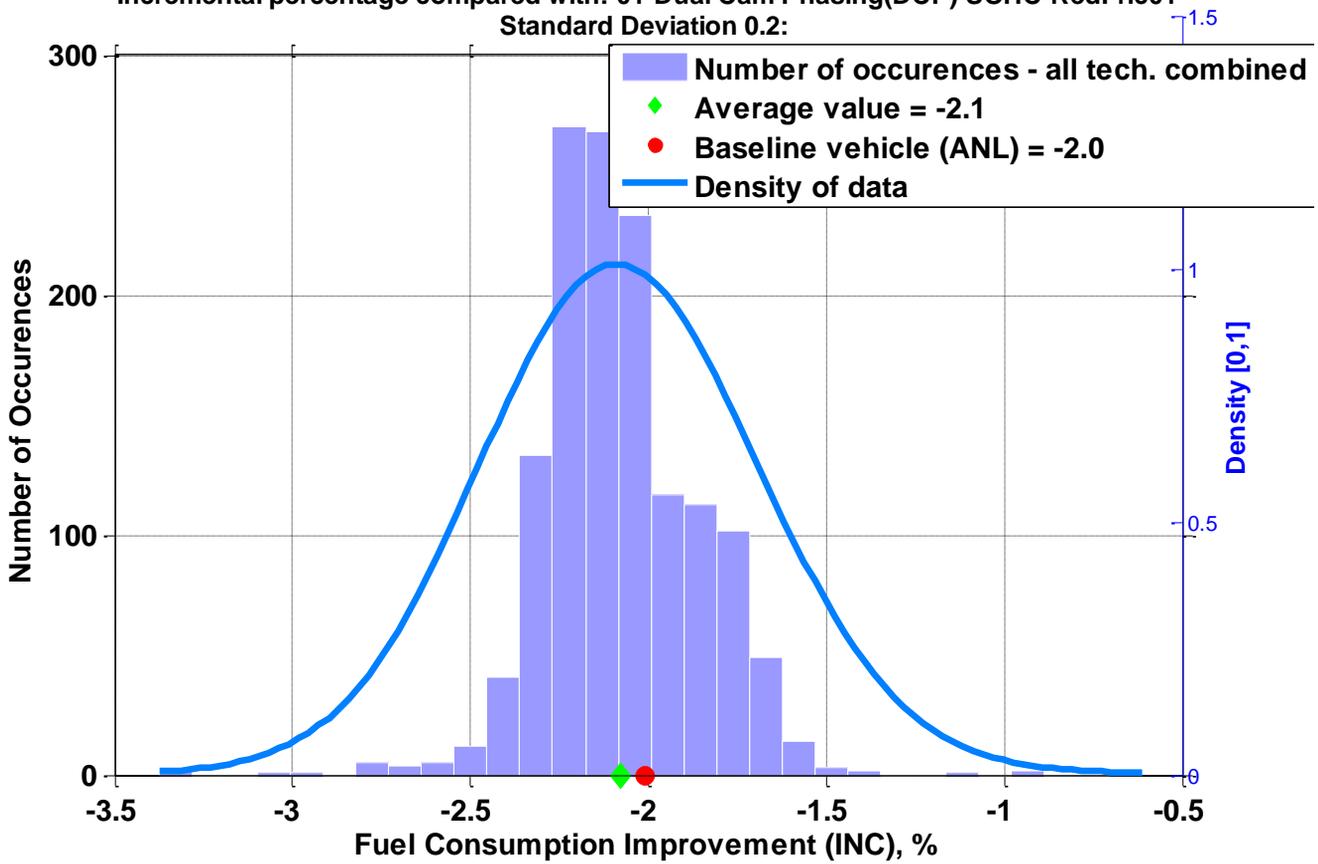


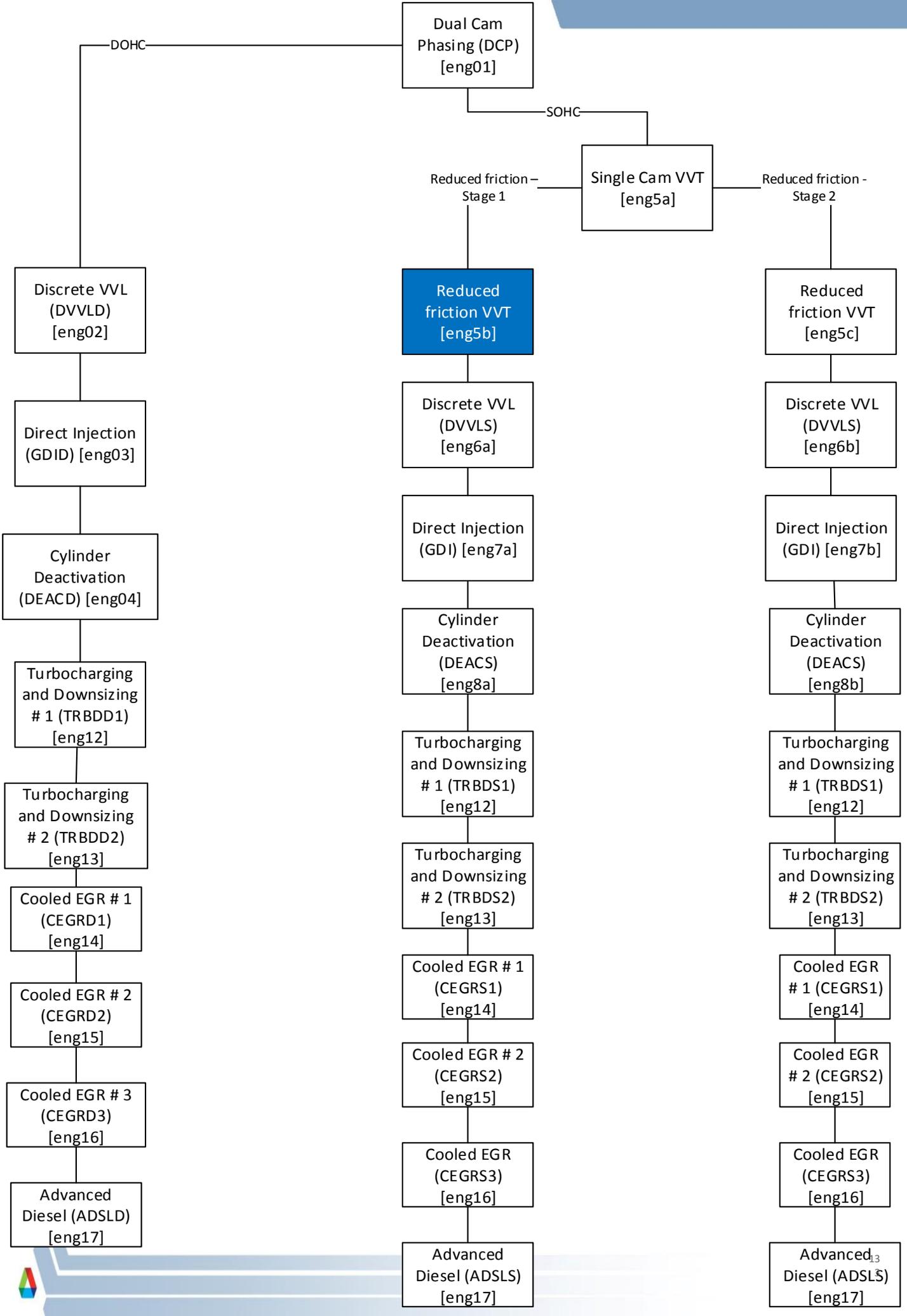
Distribution of Fuel Consumption for Eng17-Advanced Diesel(ADLS)-DOHC  
 Incremental percentage compared with: 16-Cooled EGR (CEGR3)-DOHC  
 Standard Deviation 2.4:



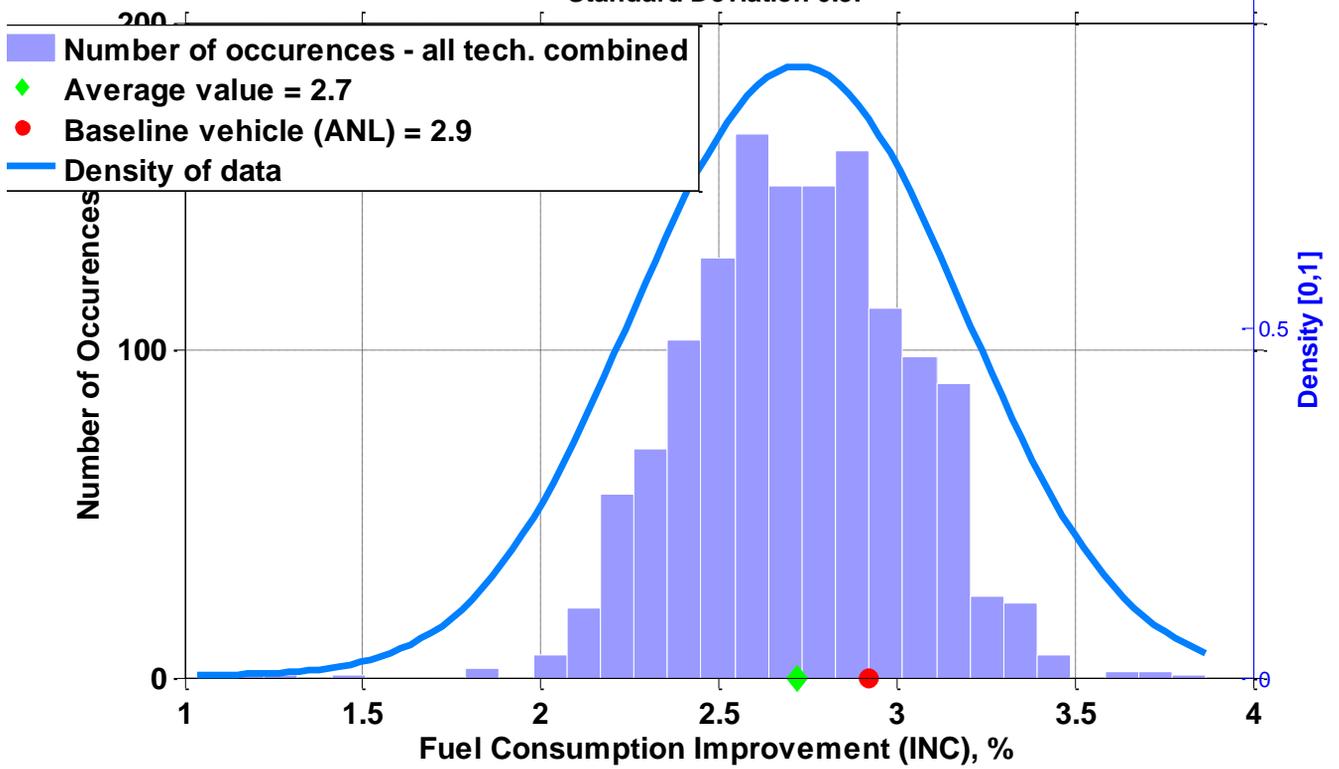


Distribution of Fuel Consumption for Eng05a-Single Cam VVT (SCVVT)-SOHC-RedFric01  
 Incremental percentage compared with: 01-Dual Cam Phasing(DCP)-SOHC-RedFric01  
 Standard Deviation 0.2:



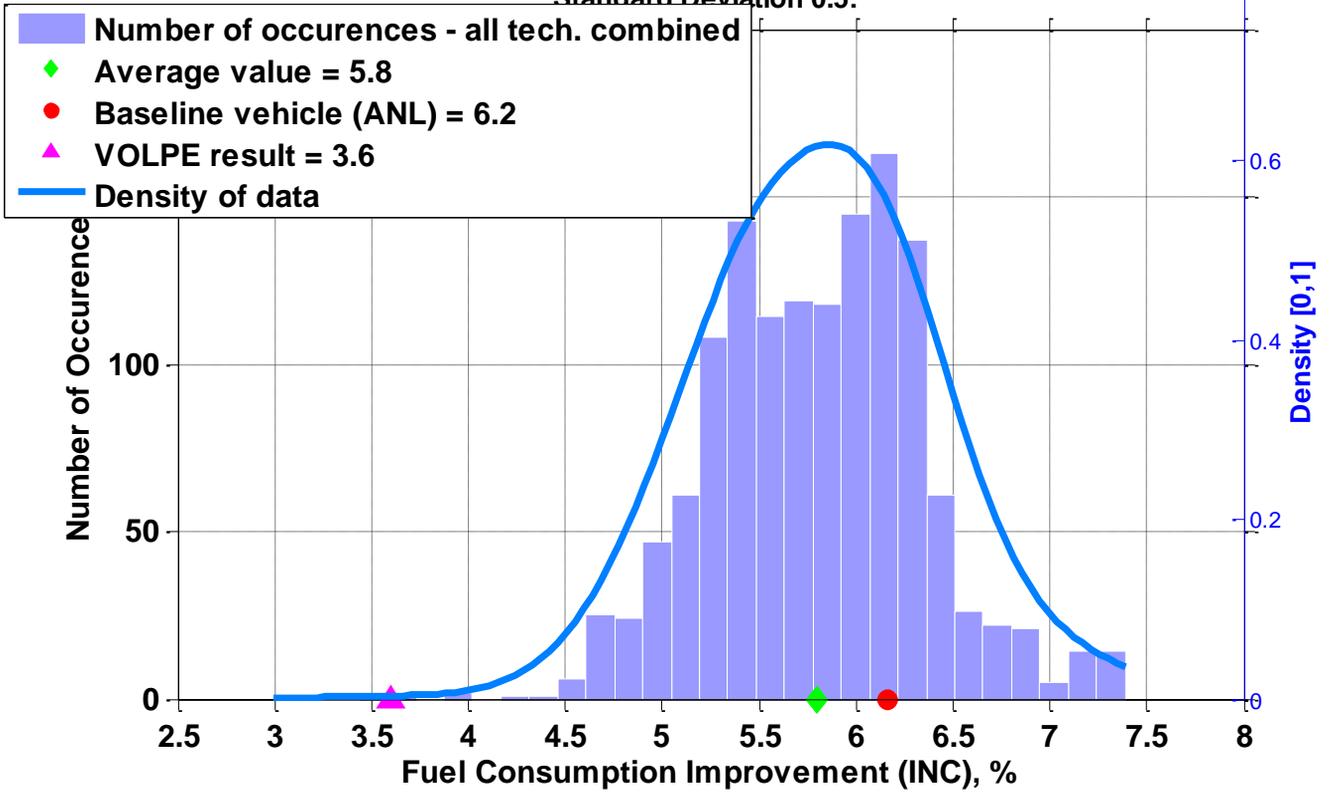


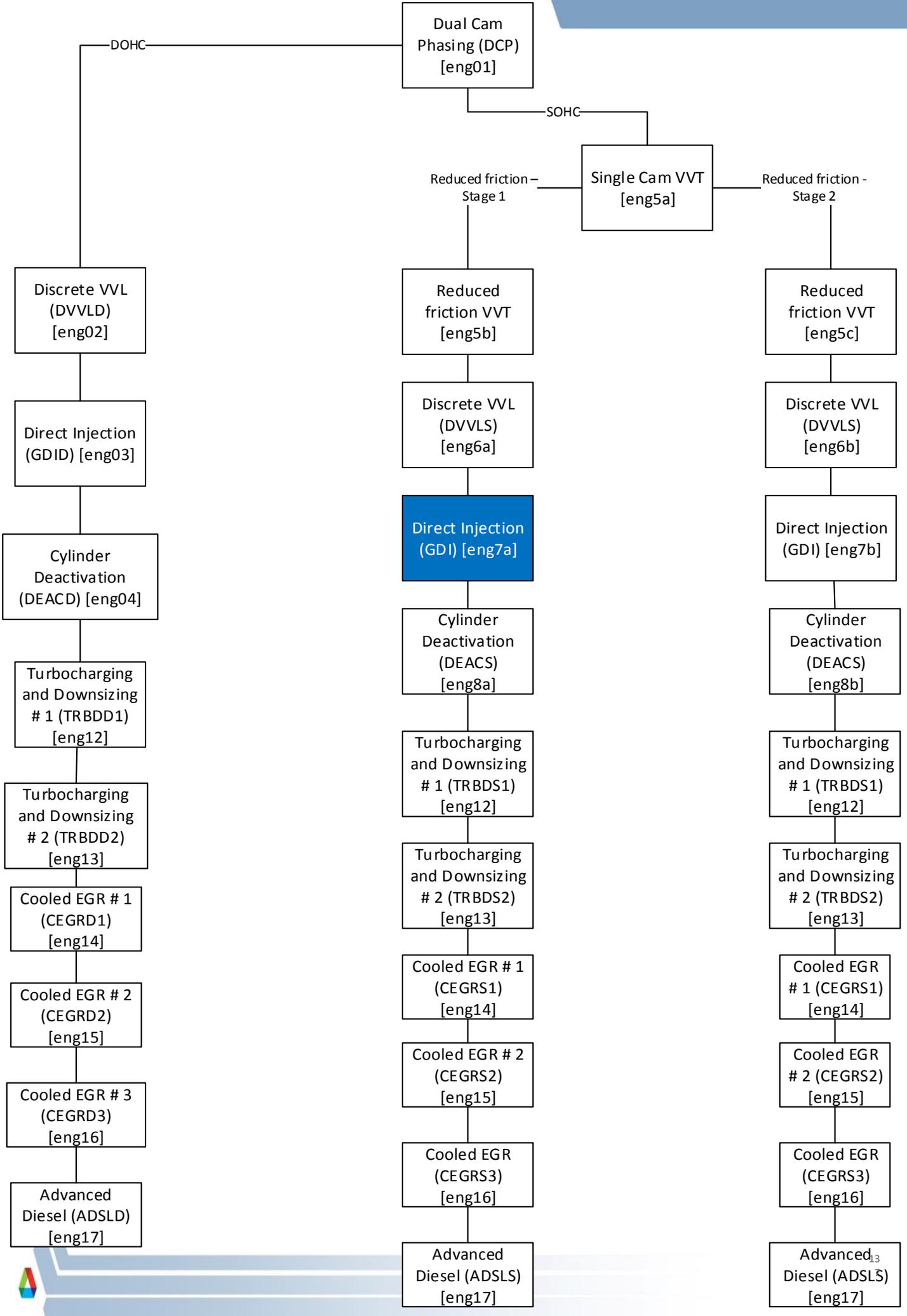
Distribution of Fuel Consumption for Eng05b-Reduced Friction VVT-SOHC-RedFric01  
 Incremental percentage compared with: 05a-Single Cam VVT (SCVVT)-SOHC-RedFric01  
 Standard Deviation 0.3:



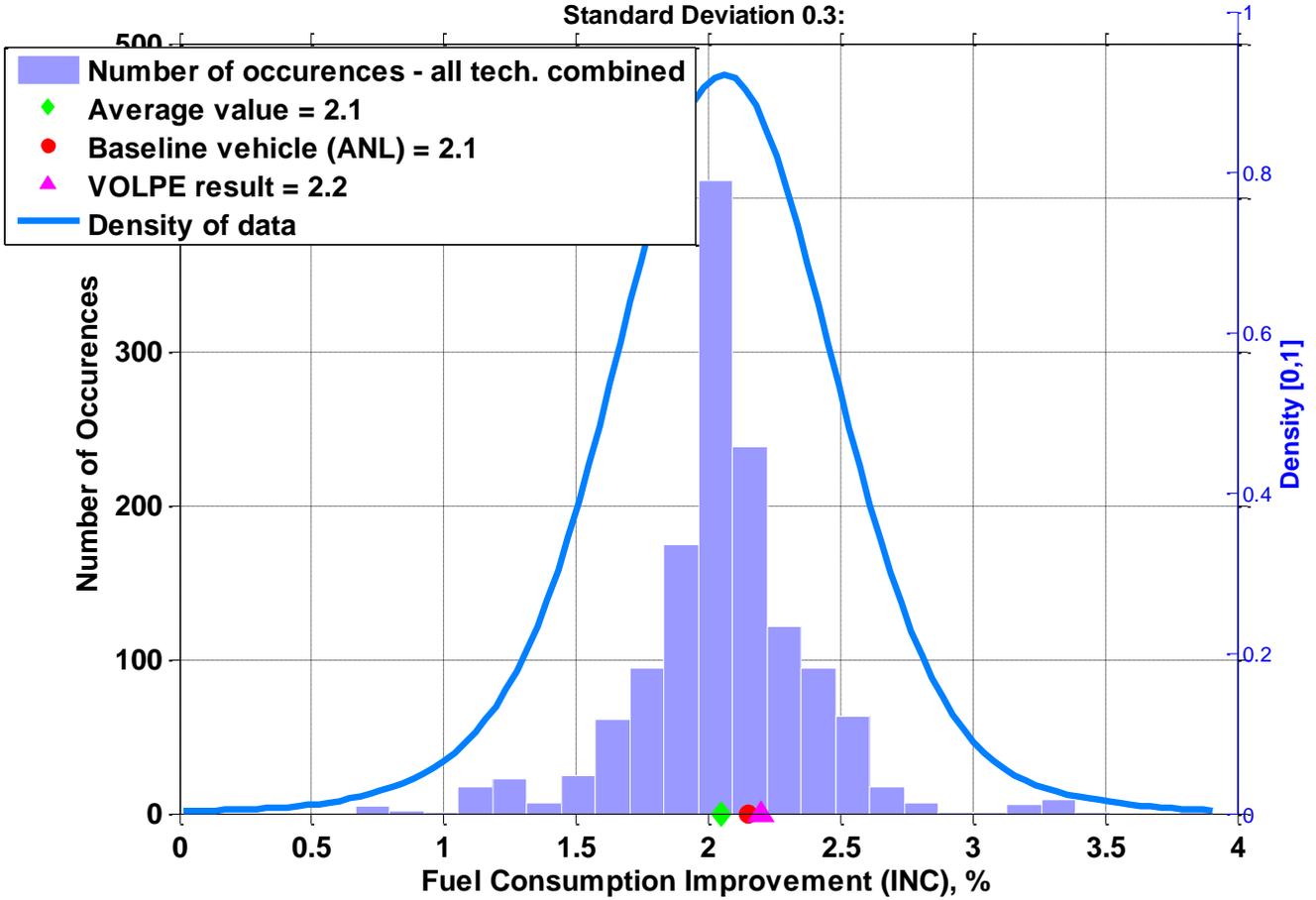


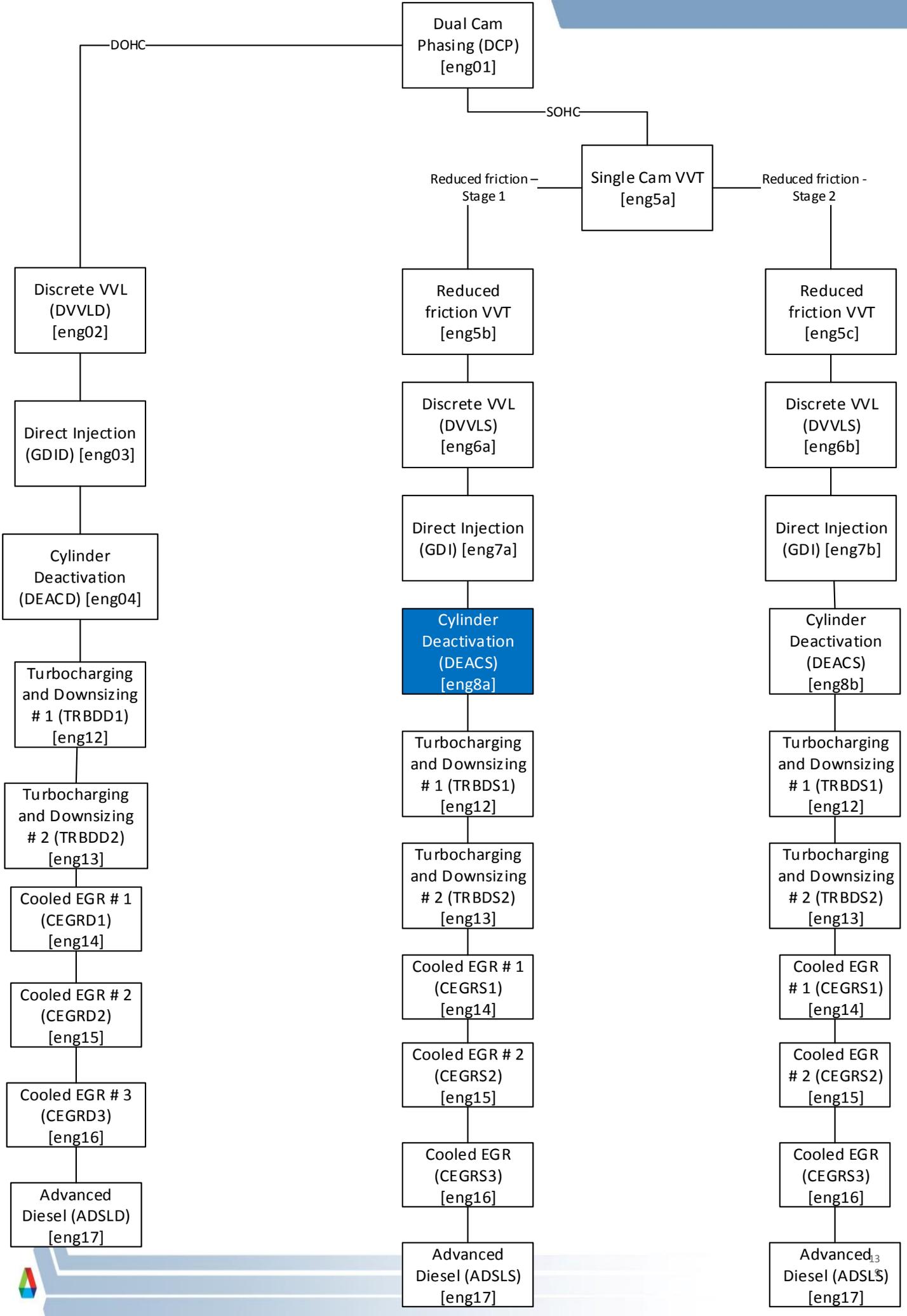
Distribution of Fuel Consumption for Eng06a-Dicrete VVL (DVVLS)-SOHC-RedFric01  
 Incremental percentage compared with: 05b-Reduced Friction VVT-SOHC-RedFric01  
 Standard Deviation 0.5:



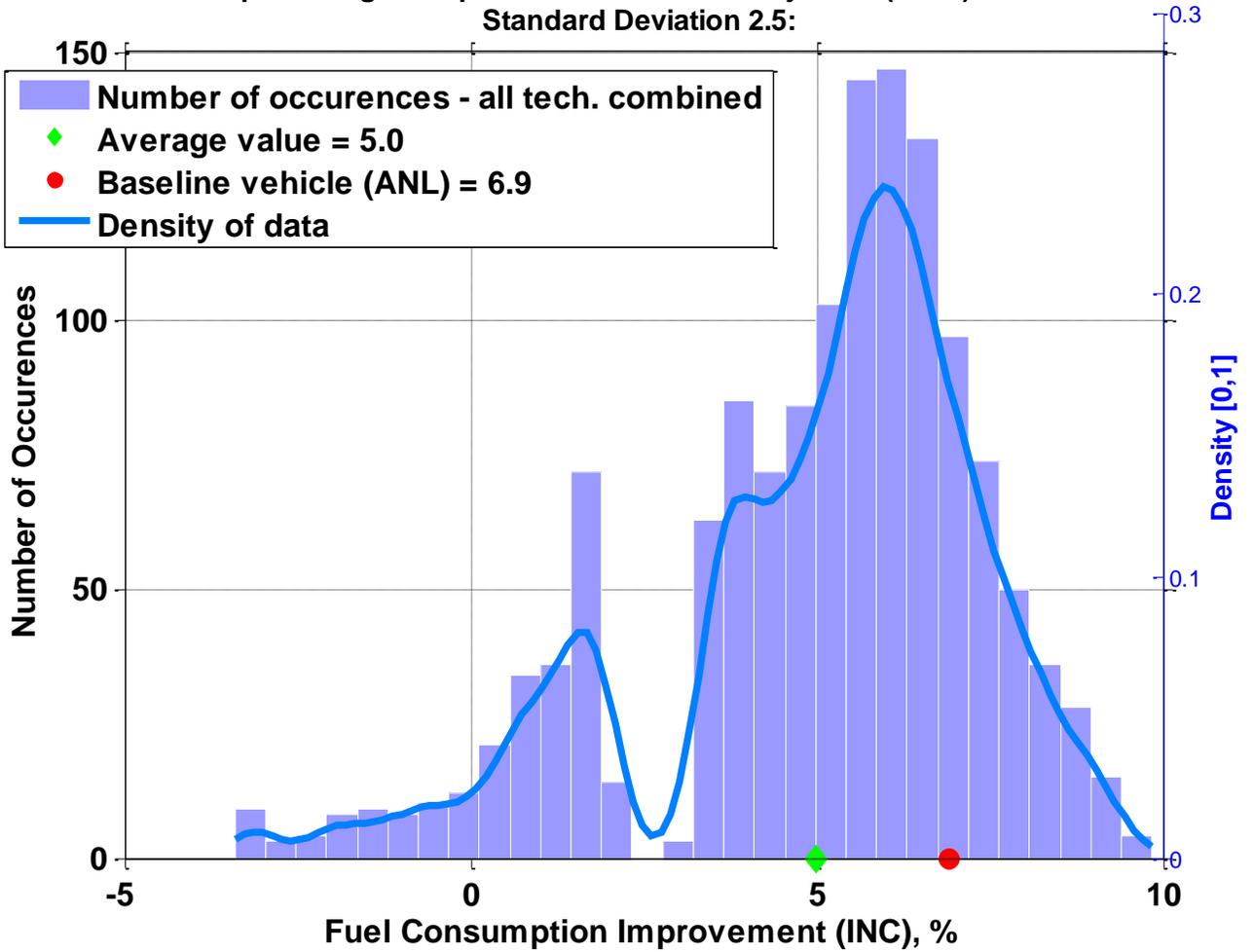


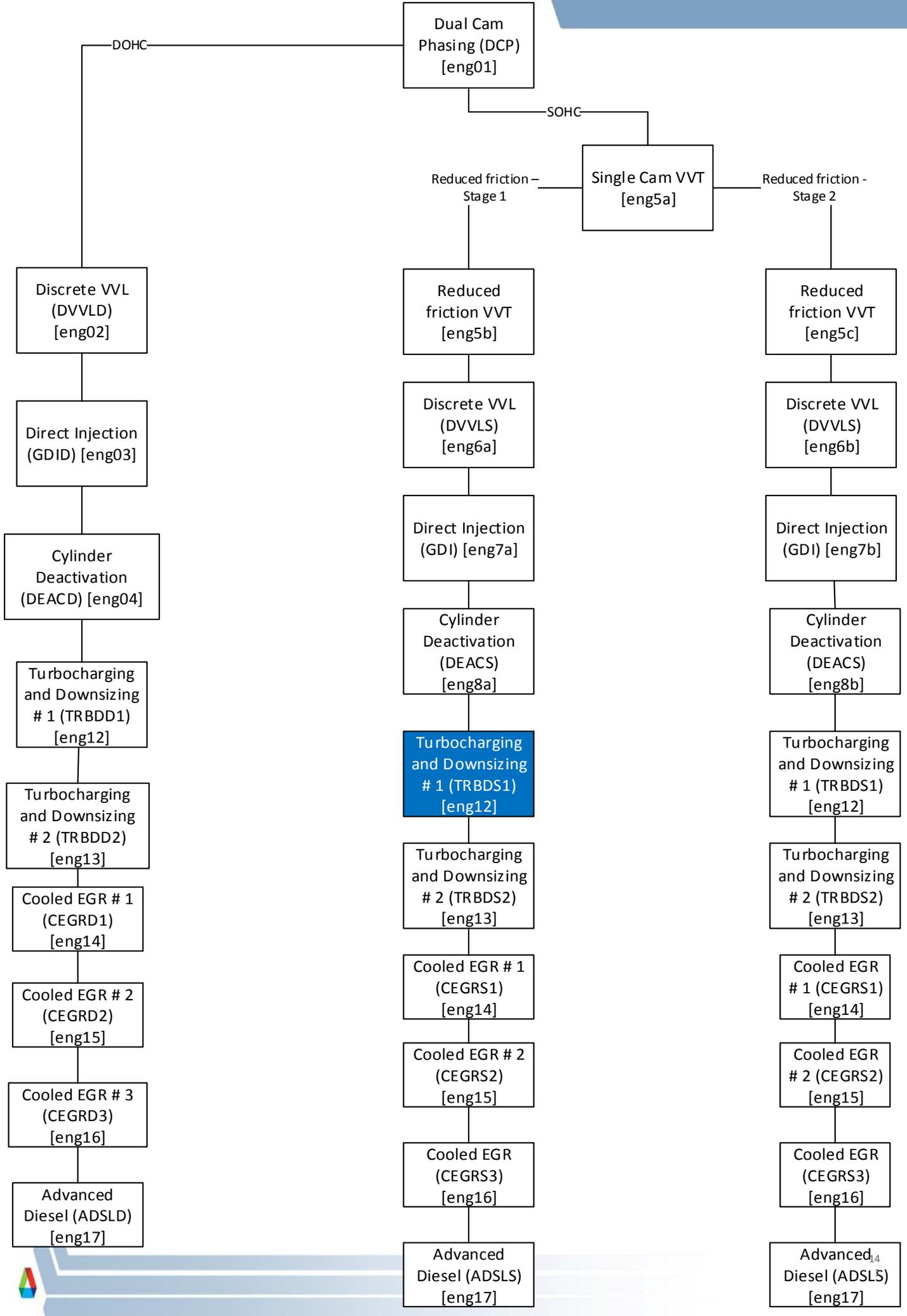
Distribution of Fuel Consumption for Eng07a-Direct Injection (GDIS)-SOHC-RedFric01  
 Incremental percentage compared with: 06a-Dicrete VVL (DVVLS)-SOHC-RedFric01  
 Standard Deviation 0.3:



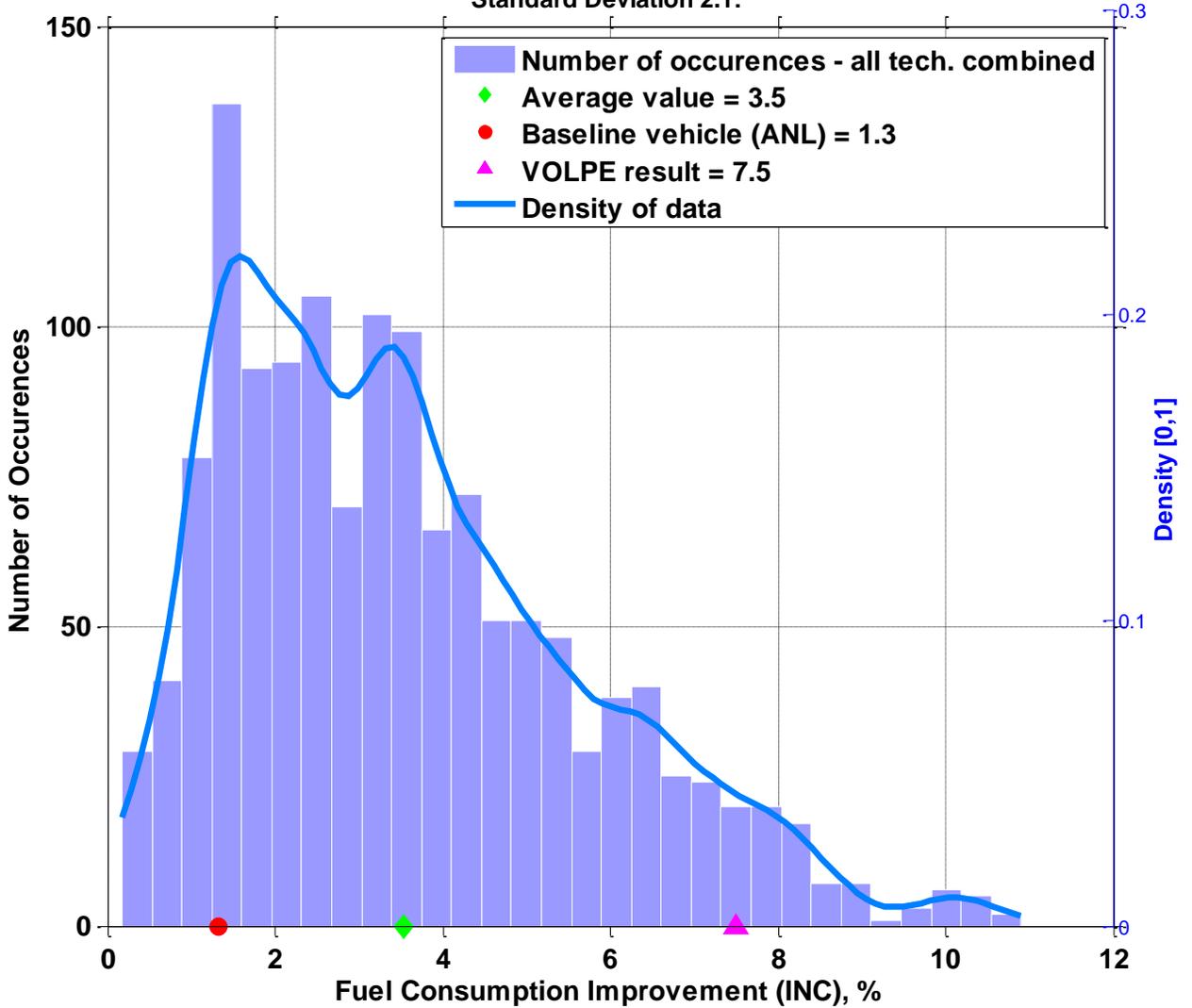


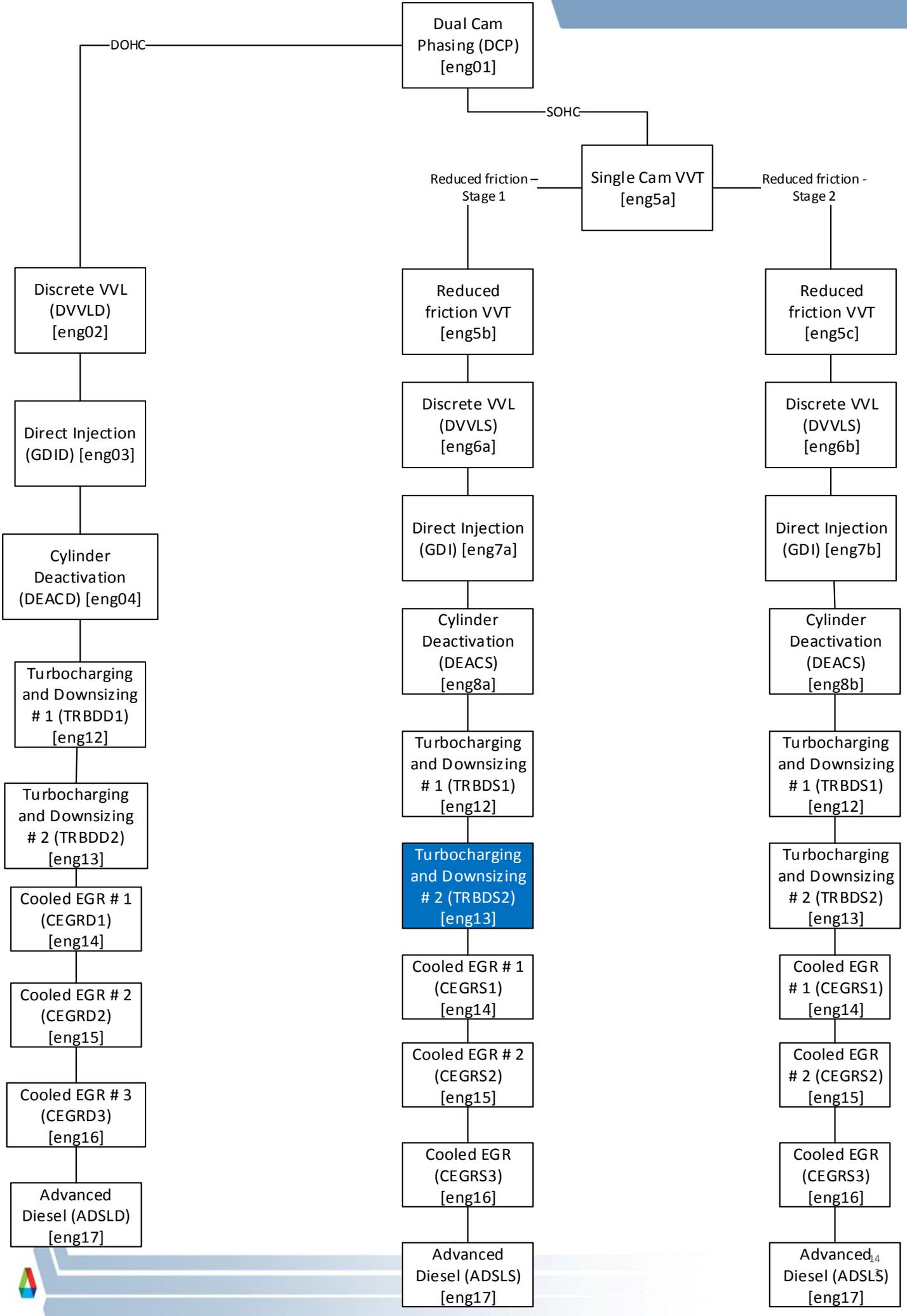
Distribution of Fuel Consumption for Eng08a-Cylinder Deactivation(DEACS)-SOHC-RedFric01  
 Incremental percentage compared with: 07a-Direct Injection (GDIS)-SOHC-RedFric01  
 Standard Deviation 2.5:



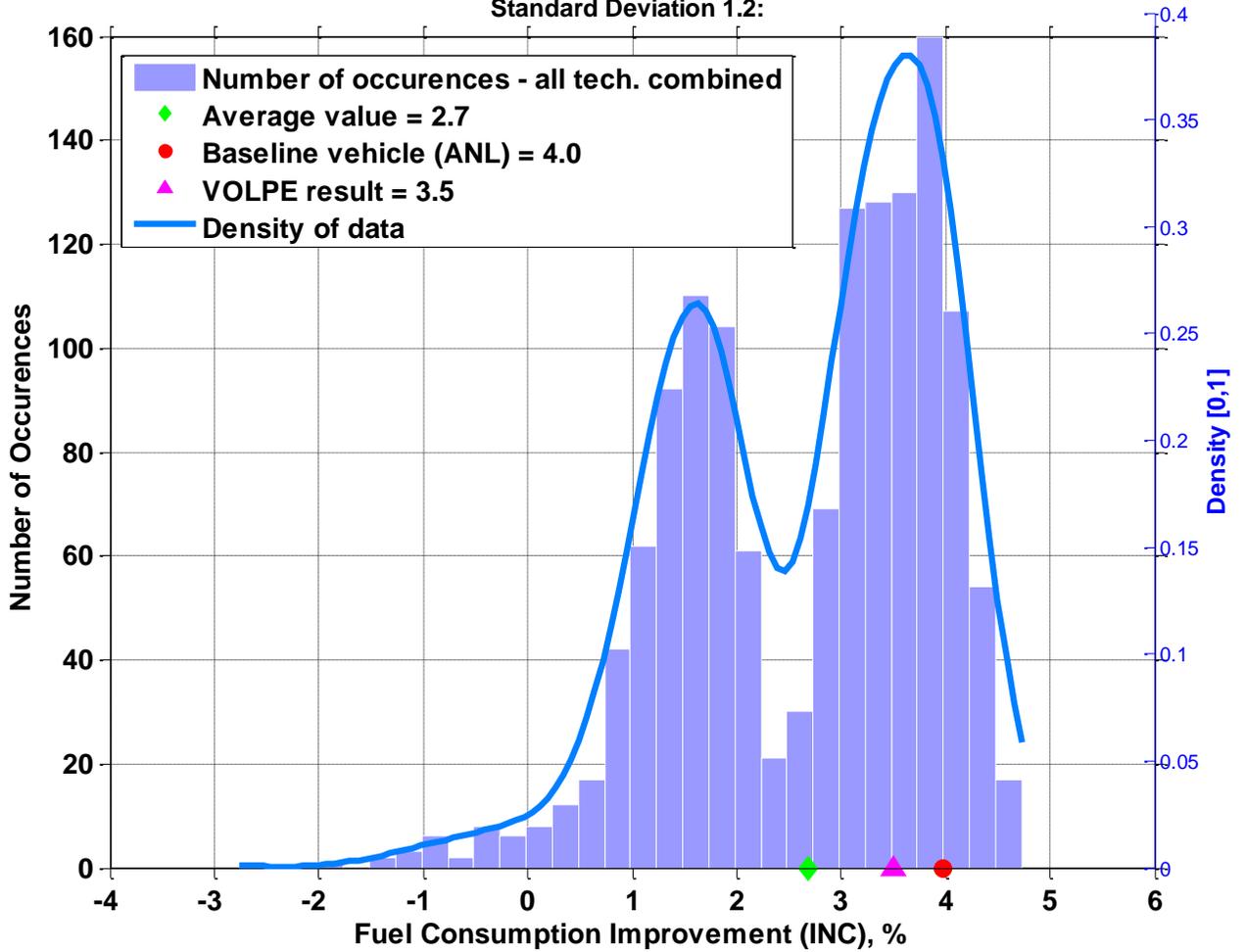


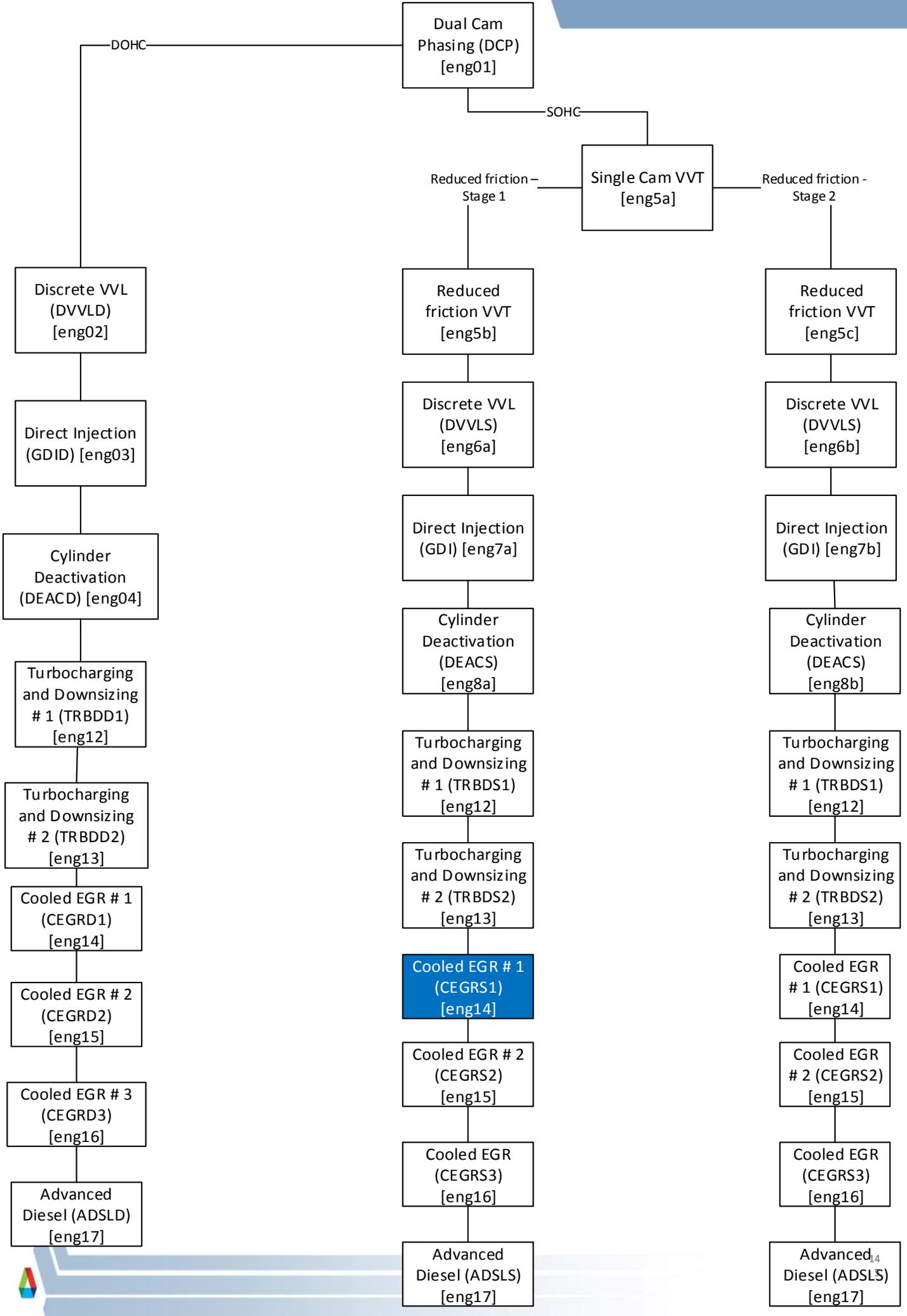
Distribution of Fuel Consumption for Eng12-Turbocharging and Downsizing#1 (TRBD1)-SOHC-RedFric01  
 Incremental percentage compared with: 08a-Cylinder Deactivation(DEACS)-SOHC-RedFric01  
 Standard Deviation 2.1:



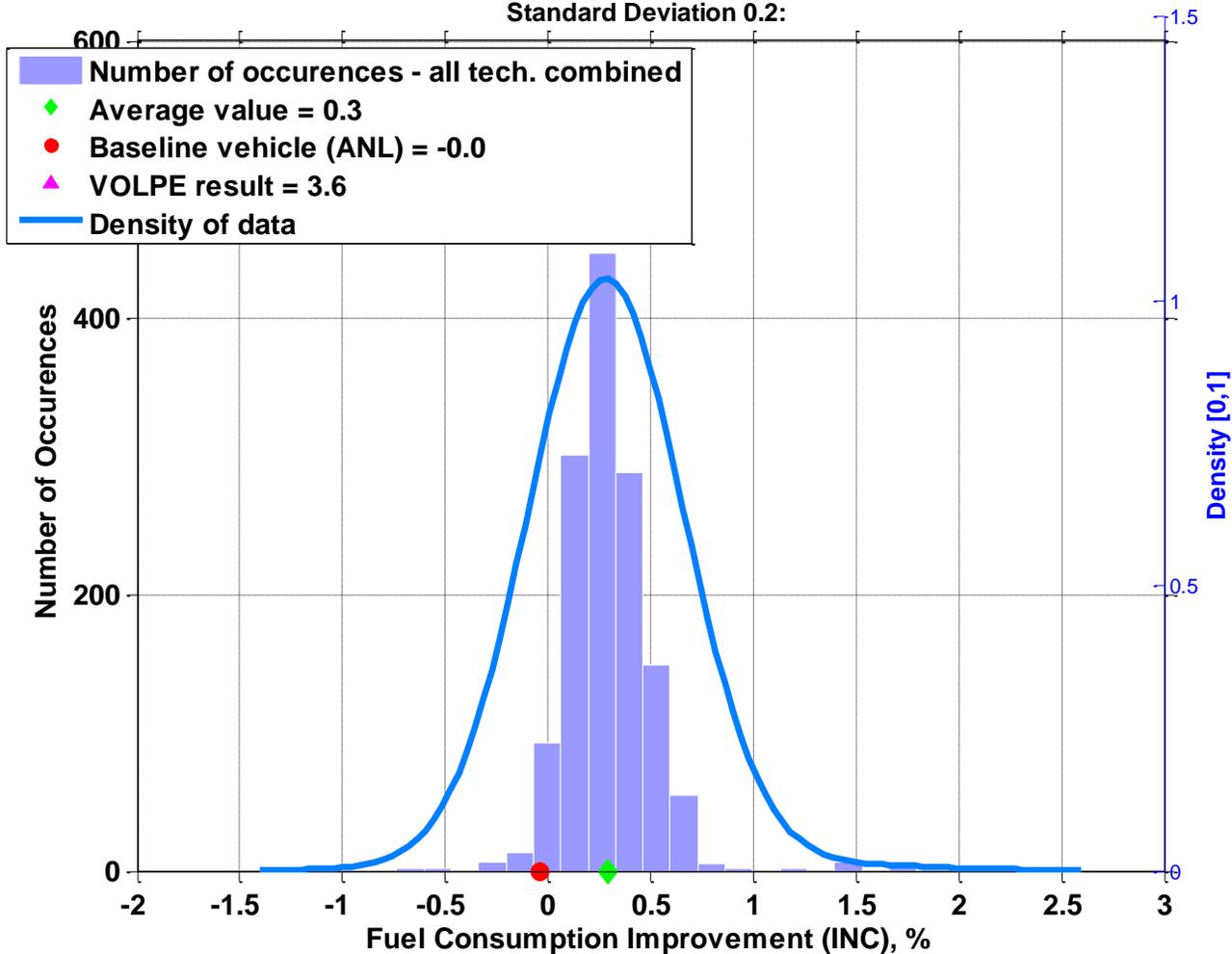


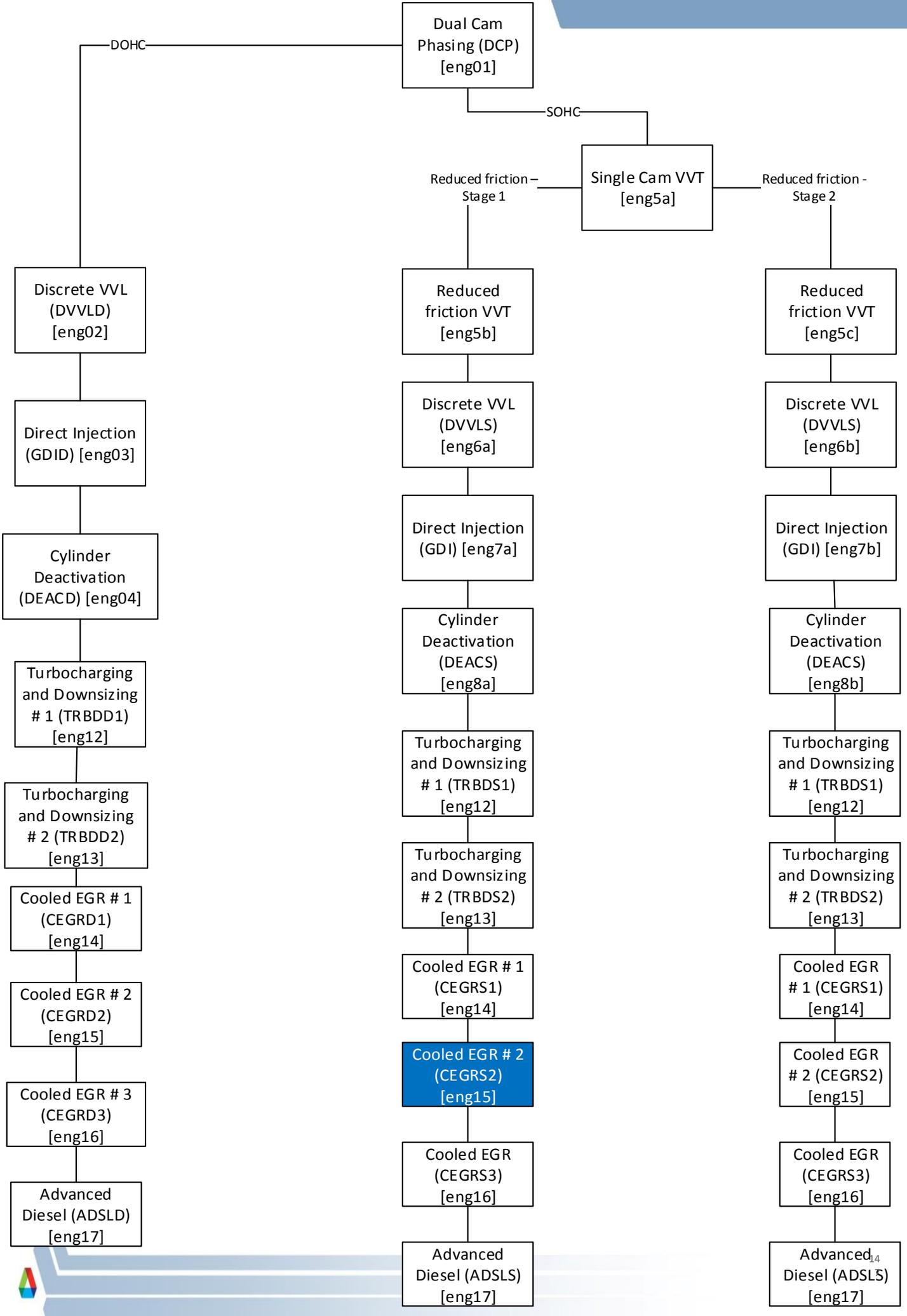
Distribution of Fuel Consumption for Eng13-Turbocharging and Downsizing#2 (TRBD2)-SOHC-RedFric01  
 Incremental percentage compared with: 12-Turbocharging and Downsizing#1 (TRBD1)-SOHC-RedFric01  
 Standard Deviation 1.2:





Distribution of Fuel Consumption for Eng14-Cooled EGR#1 (CEGR1)-SOHC-RedFric01  
 Incremental percentage compared with: 13-Turbocharging and Downsizing#2 (TRBD2)-SOHC-RedFric01  
 Standard Deviation 0.2:

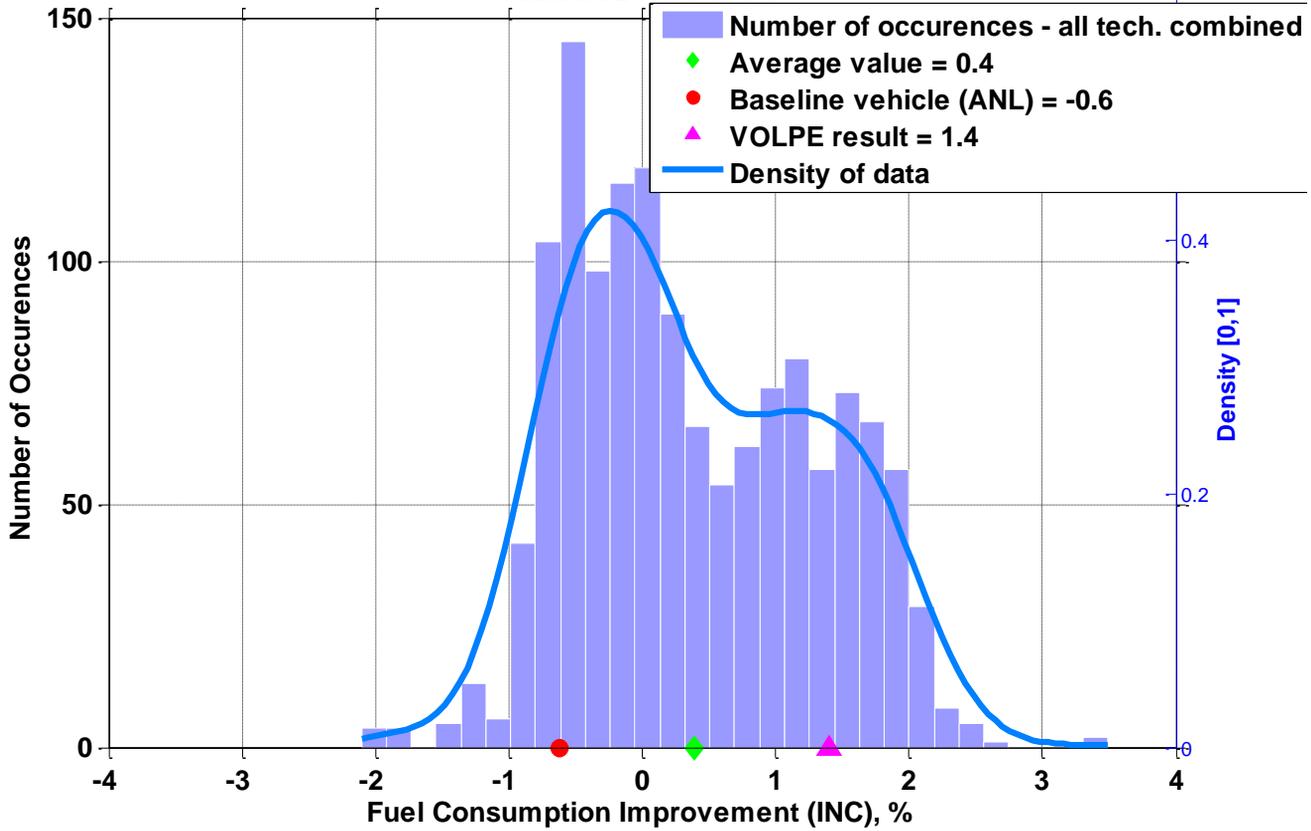


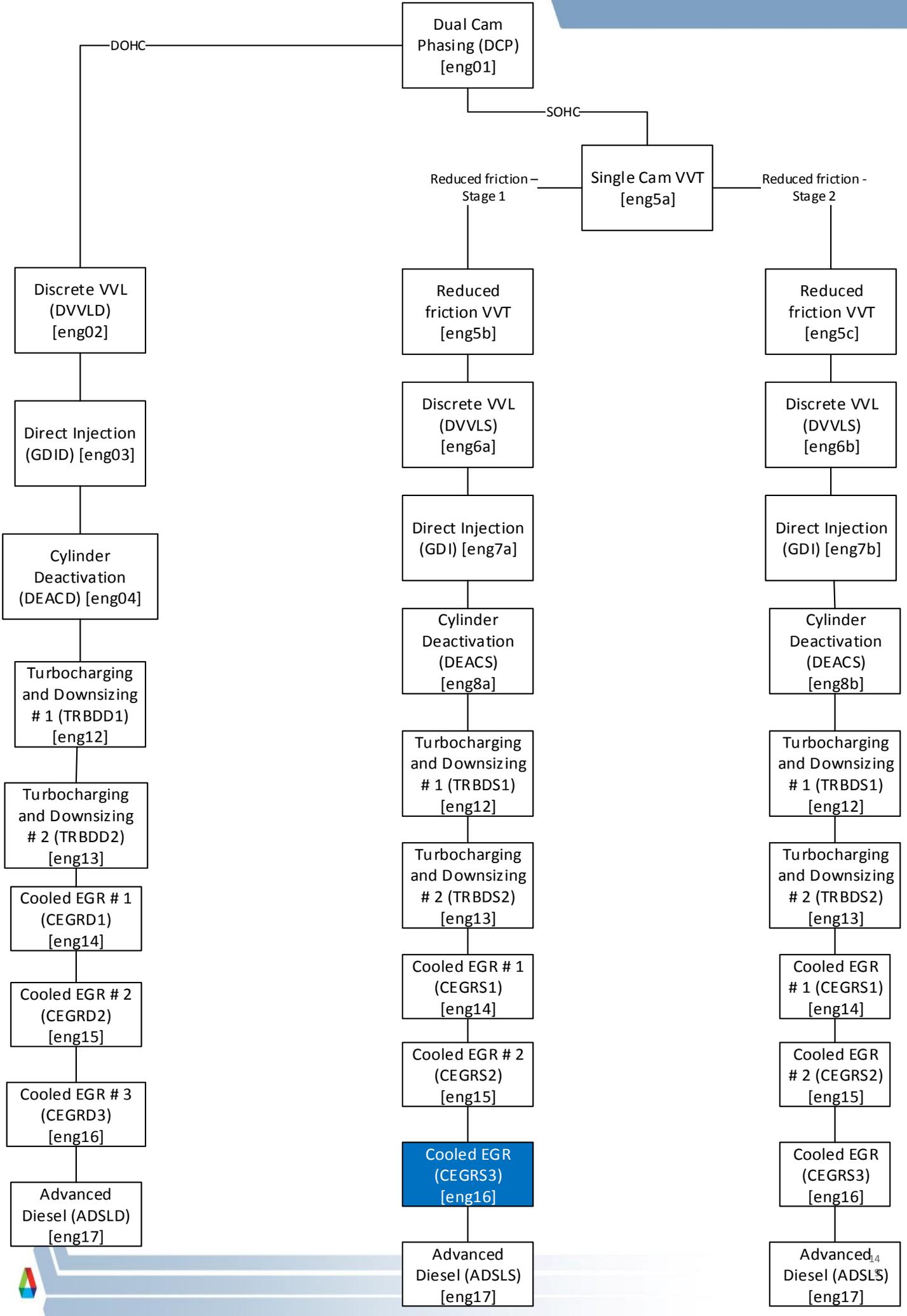


Distribution of Fuel Consumption for Eng15-Cooled EGR#2 (CEGR2)-SOHC-RedFric01  
 Incremental percentage compared with: 14-Cooled EGR#1 (CEGR1)-SOHC-RedFric01

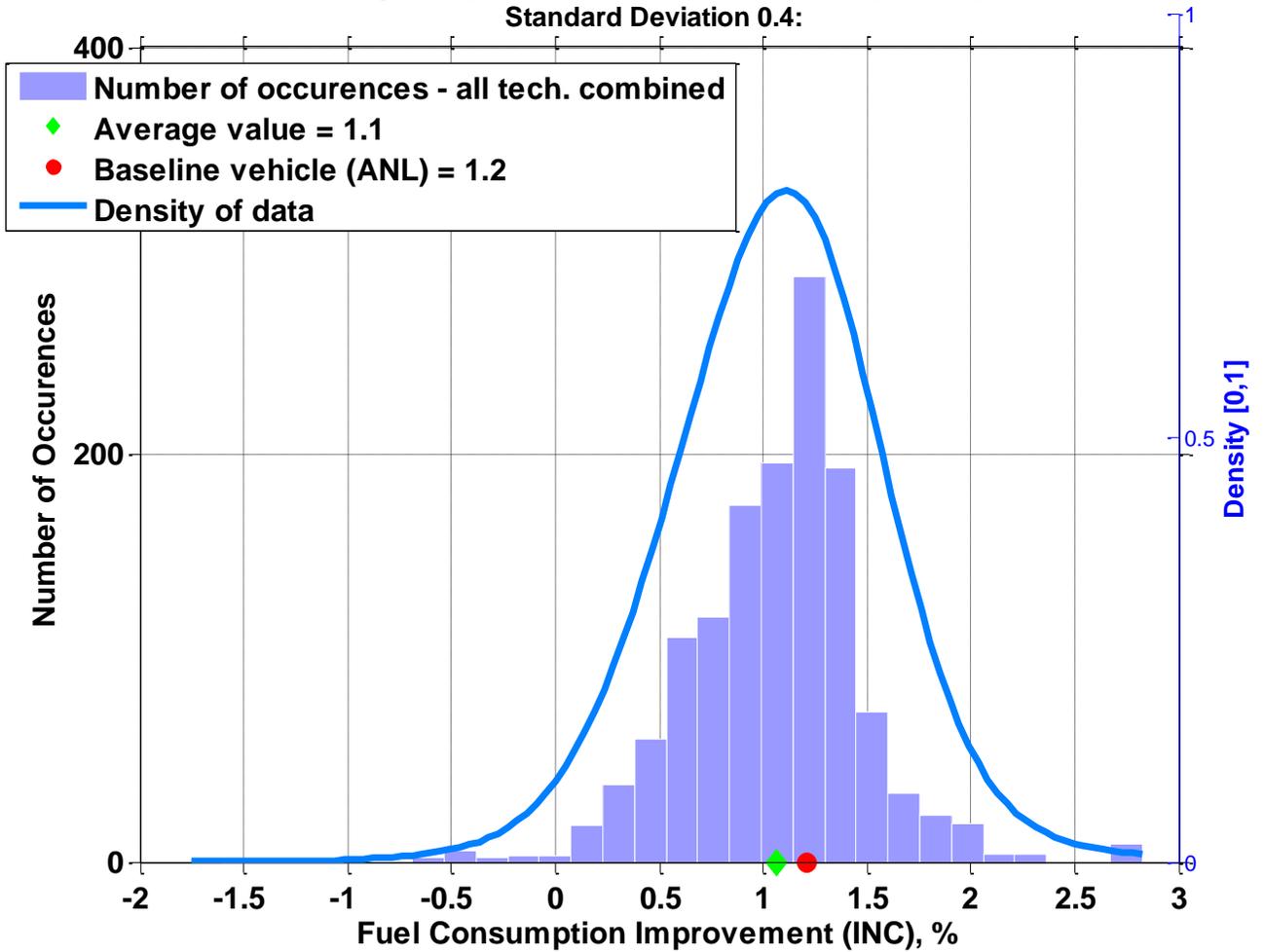
Standard Deviation 0.9:

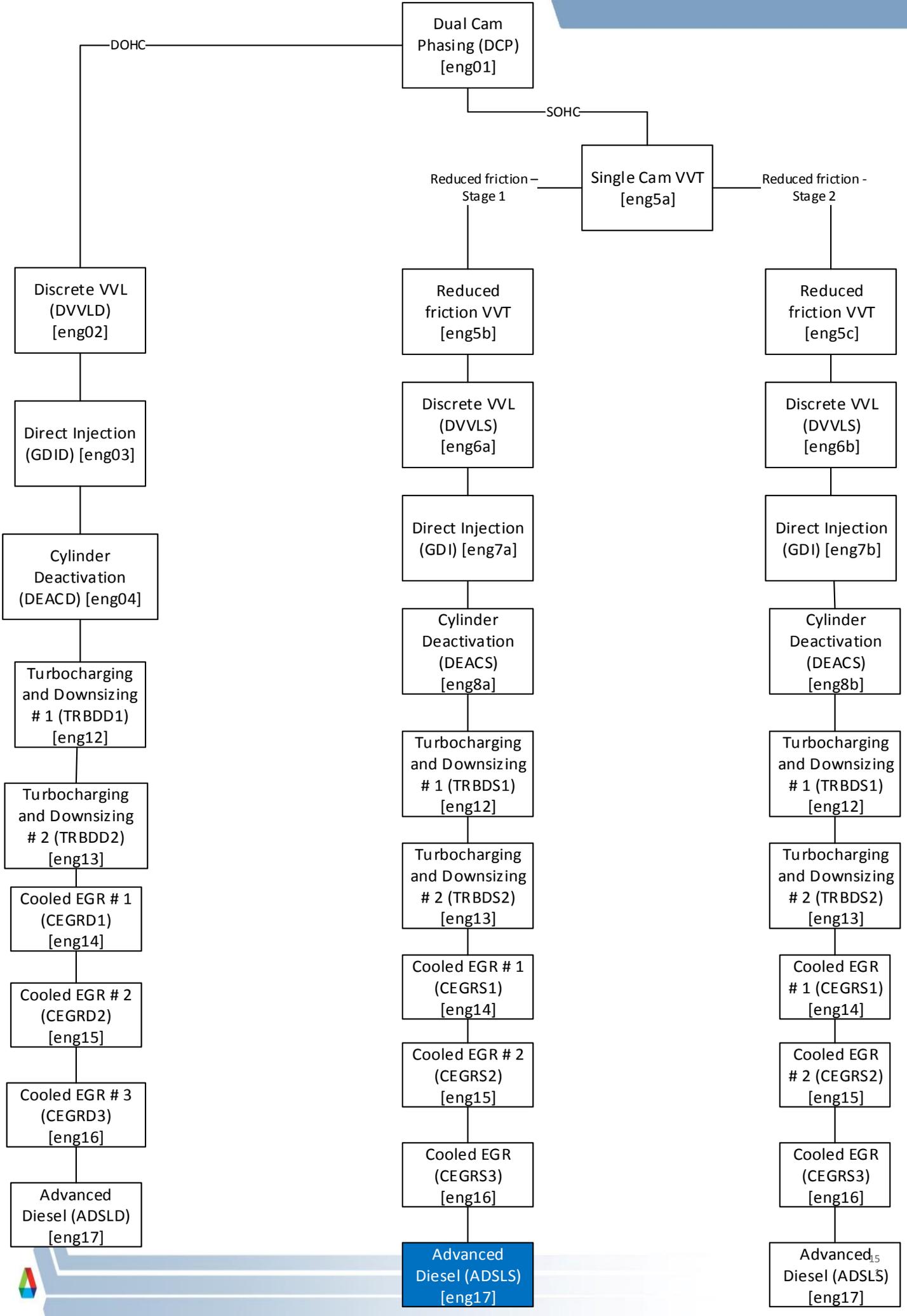
-0.6



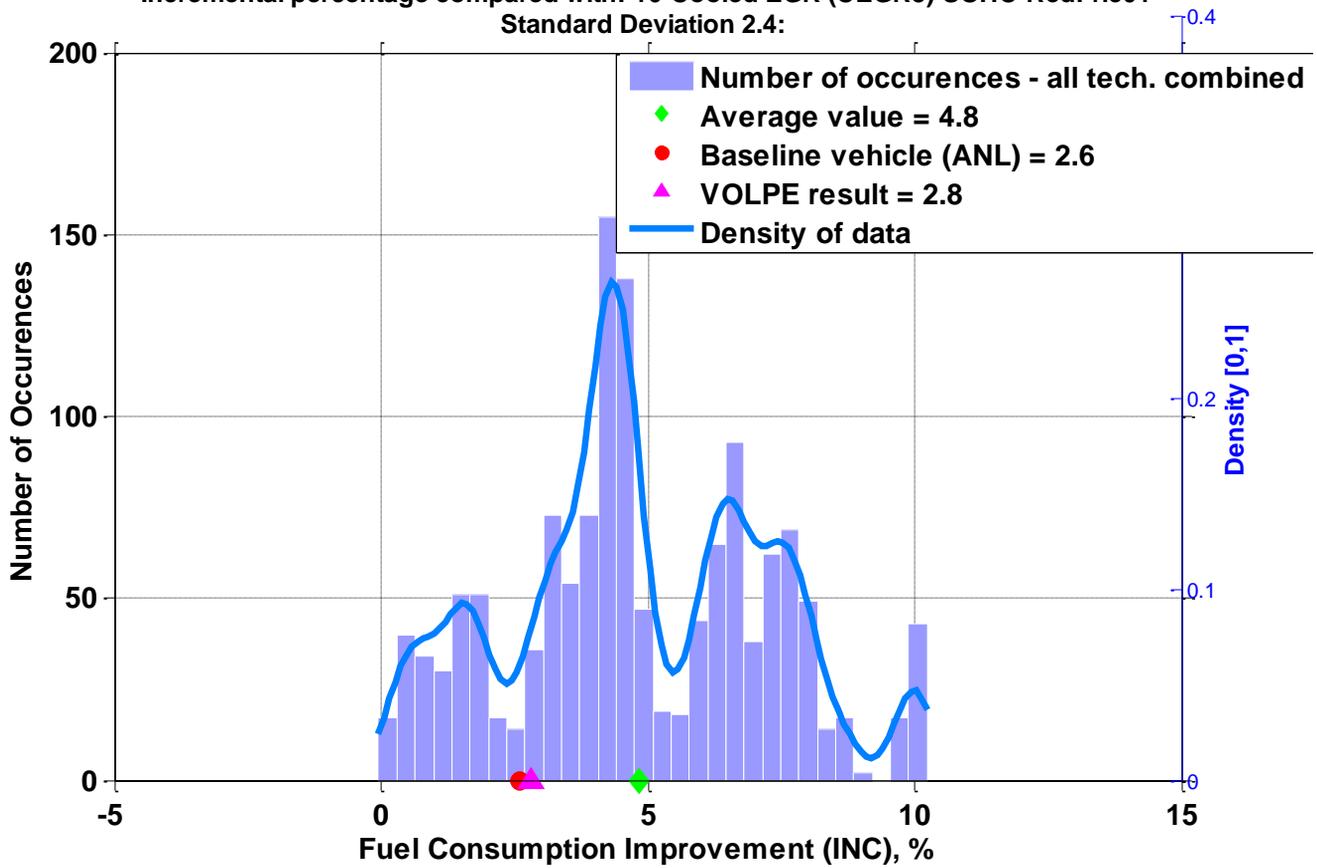


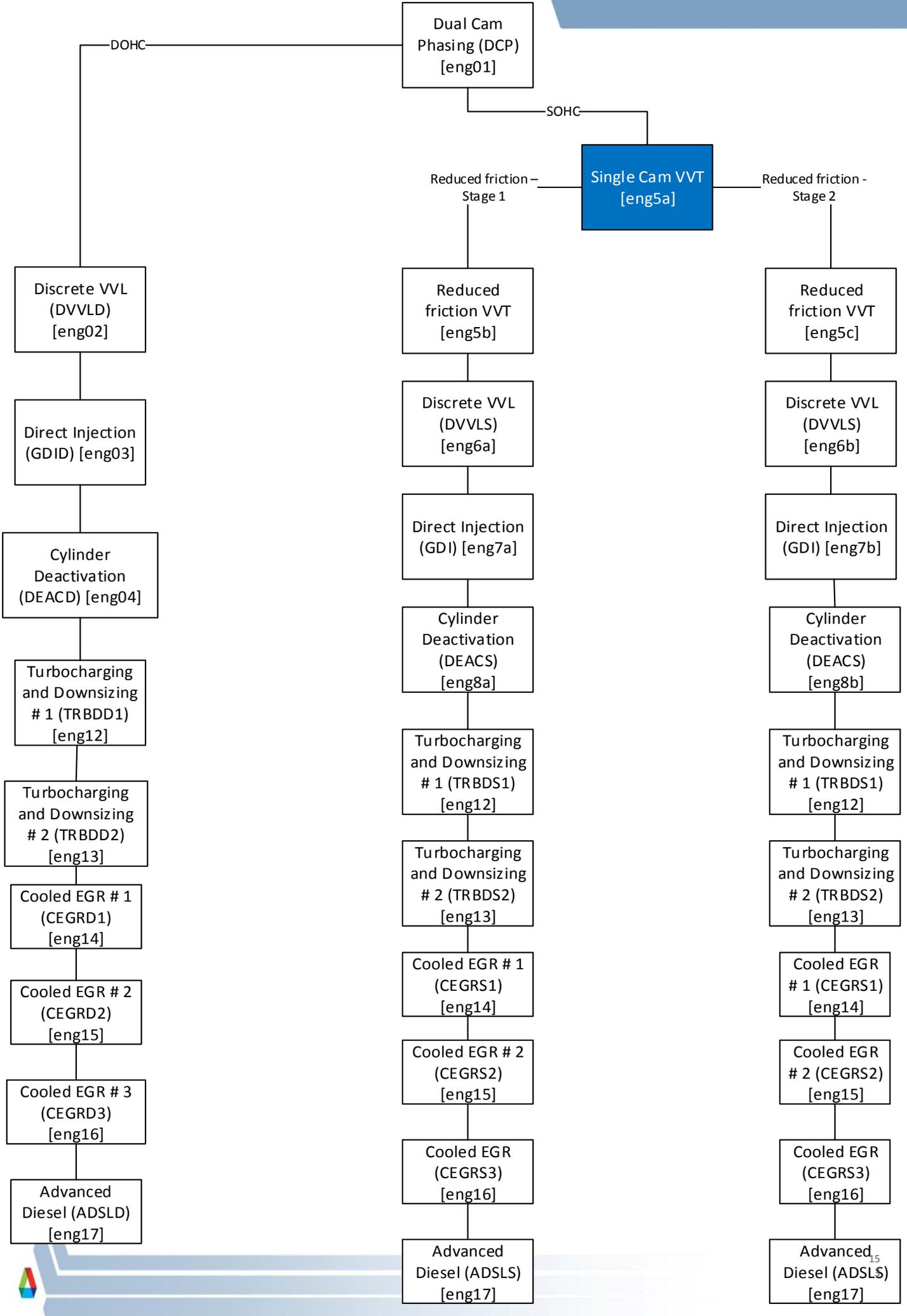
Distribution of Fuel Consumption for Eng16-Cooled EGR (CEGR3)-SOHC-RedFric01  
Incremental percentage compared with: 15-Cooled EGR#2 (CEGR2)-SOHC-RedFric01  
Standard Deviation 0.4:



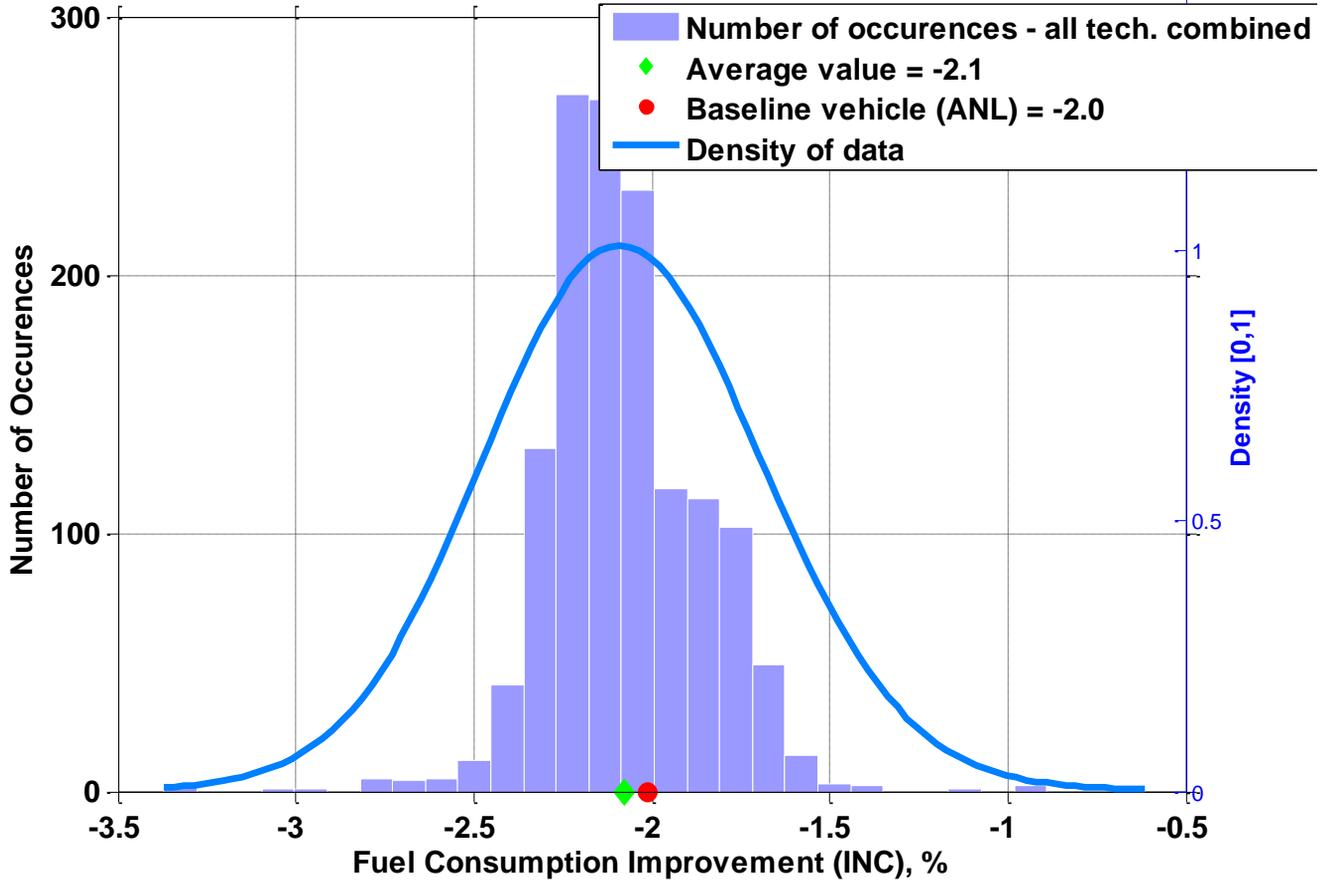


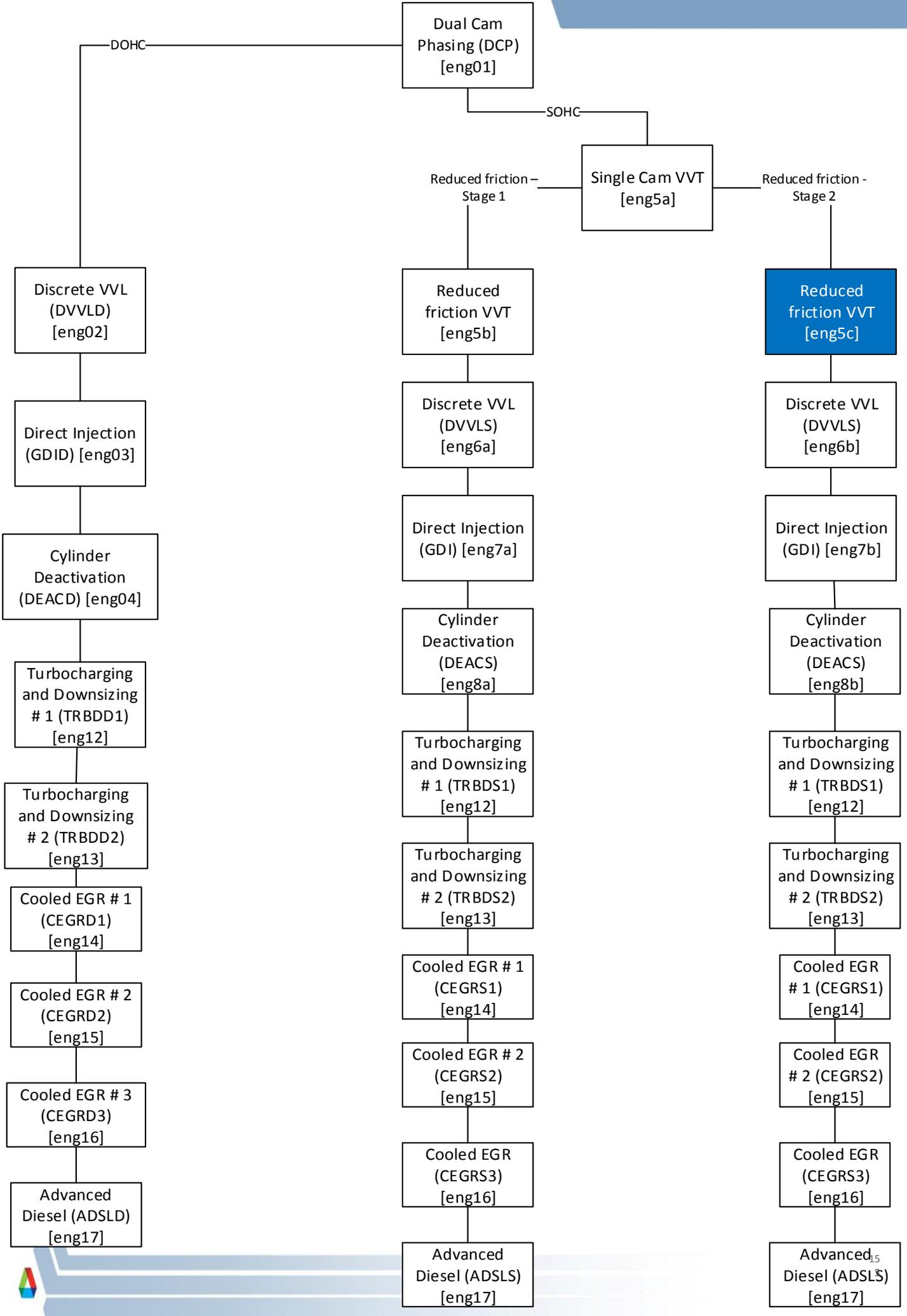
Distribution of Fuel Consumption for Eng17-Advanced Diesel(ADLS)-SOHC-RedFric01  
 Incremental percentage compared with: 16-Cooled EGR (CEGR3)-SOHC-RedFric01  
 Standard Deviation 2.4:



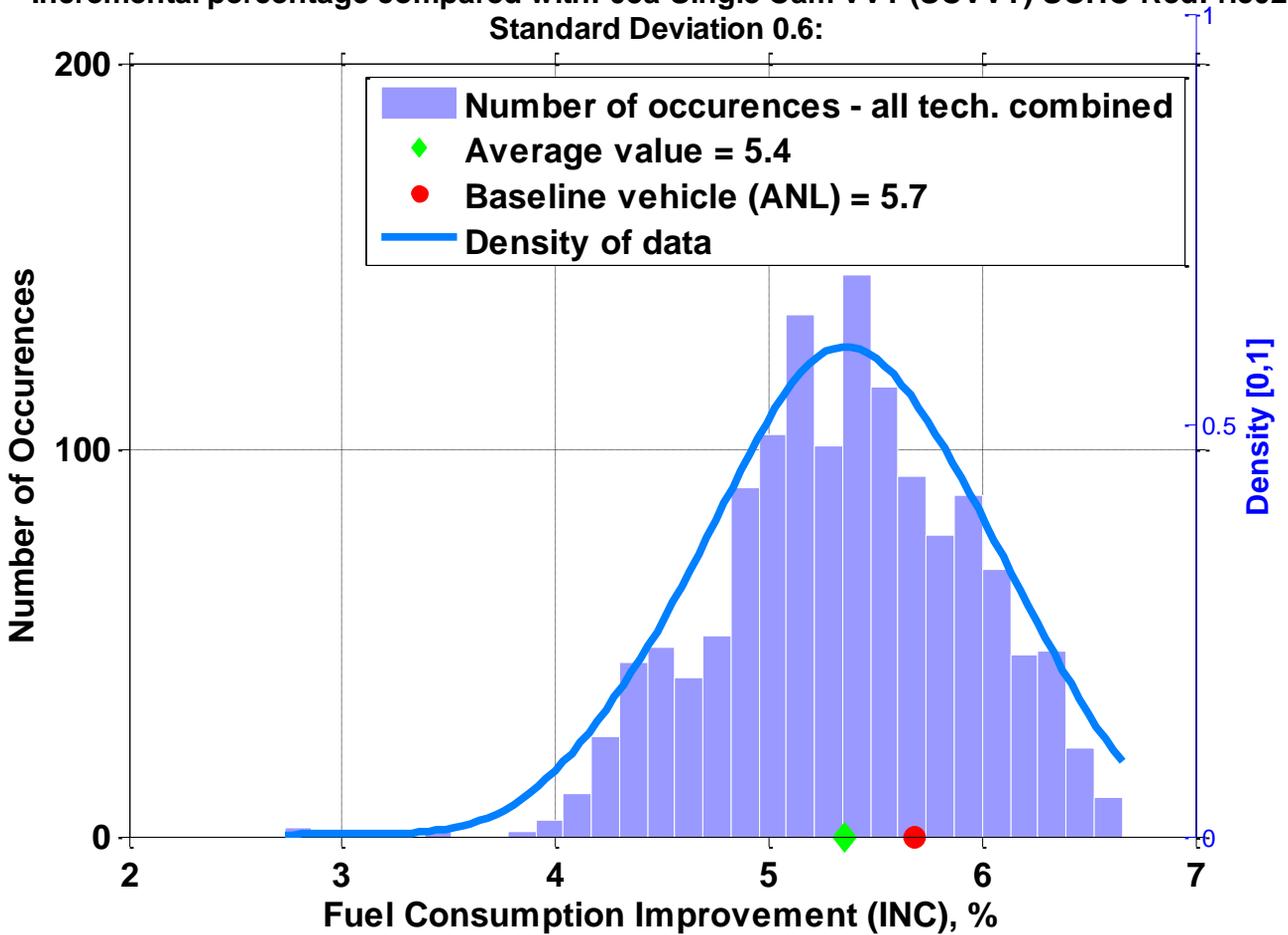


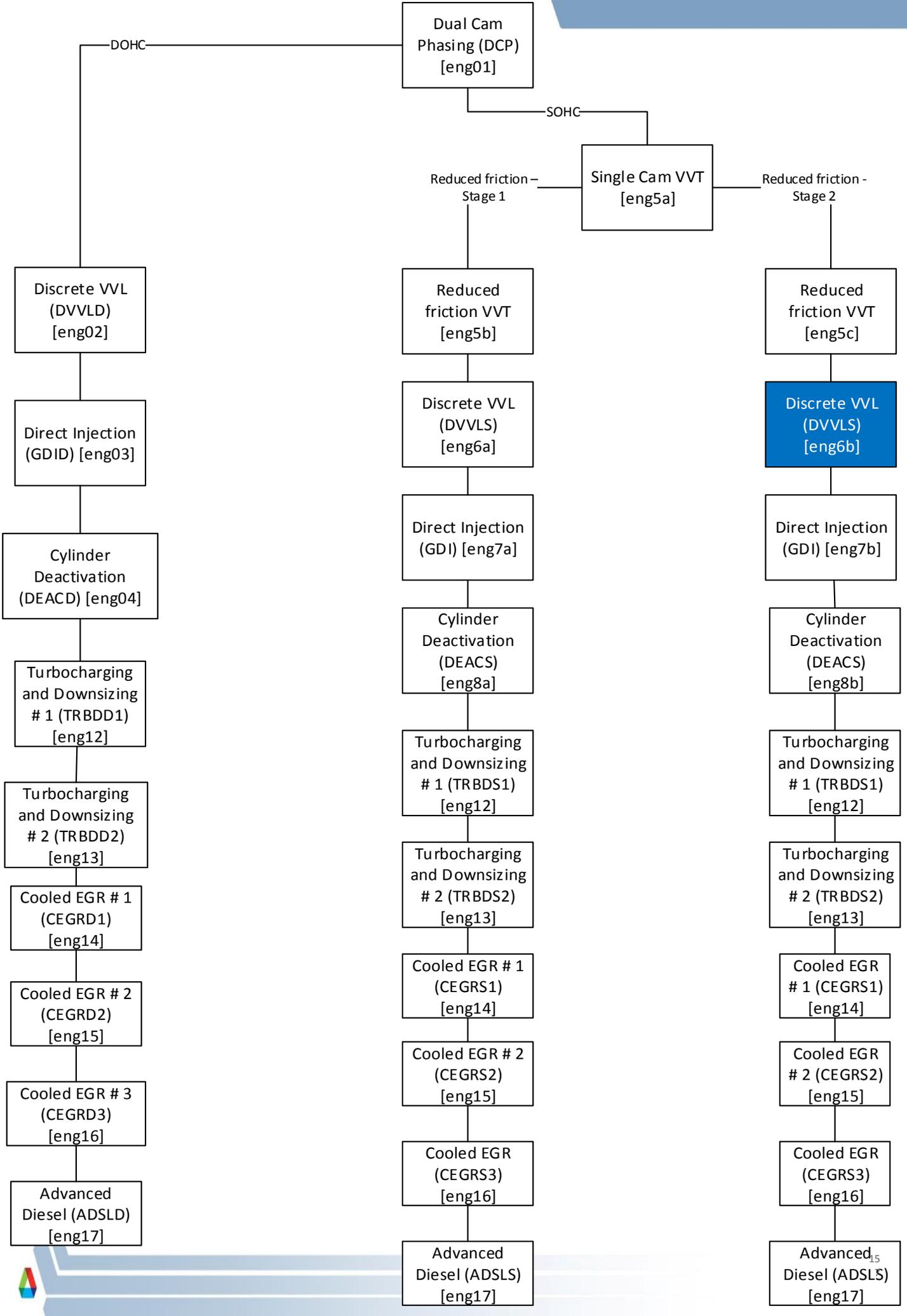
Distribution of Fuel Consumption for Eng05a-Single Cam VVT (SCVVT)-SOHC-RedFric02  
 Incremental percentage compared with: 01-Dual Cam Phasing(DCP)-SOHC-RedFric02  
 Standard Deviation 0.2:



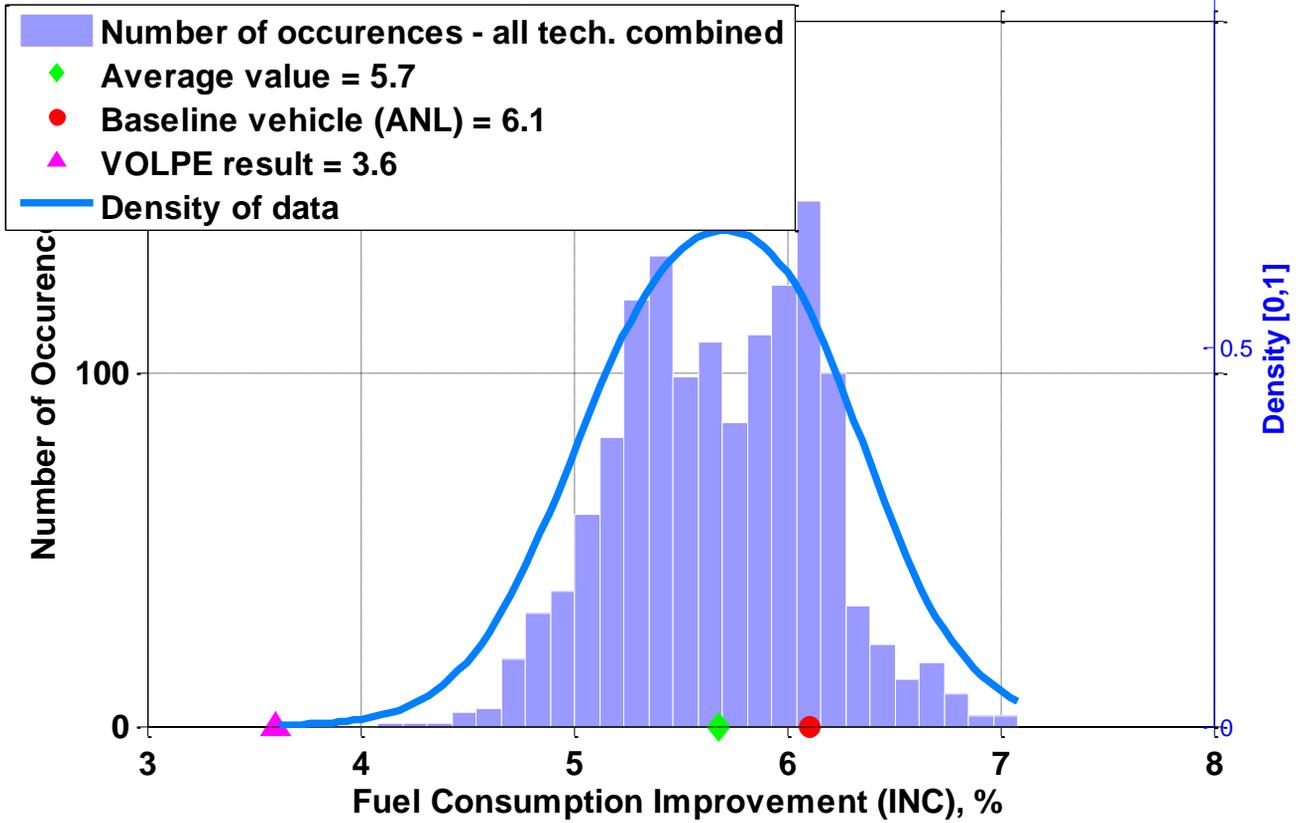


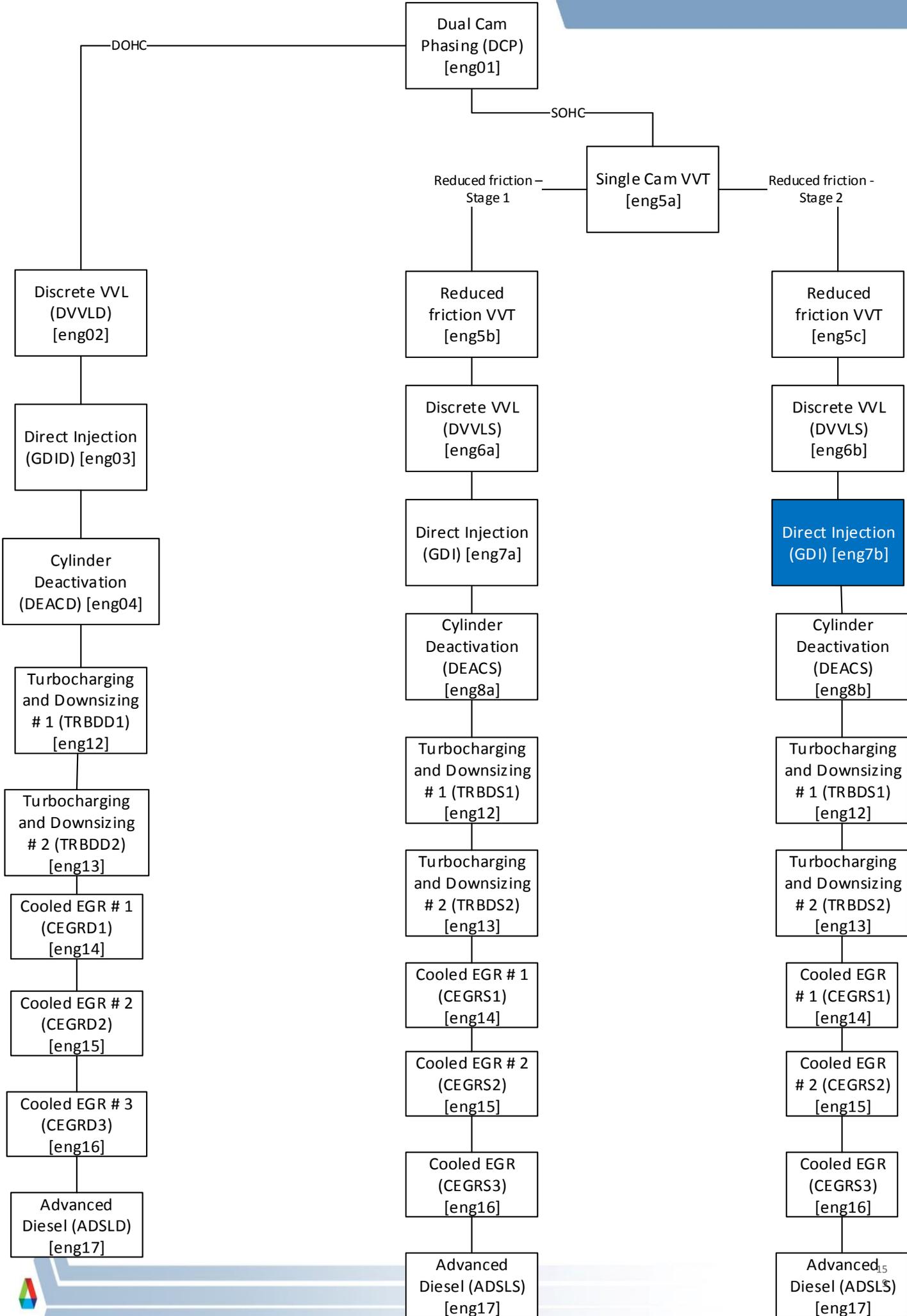
Distribution of Fuel Consumption for Eng05c-Reduced Friction VVT-SOHC-RedFric02  
 Incremental percentage compared with: 05a-Single Cam VVT (SCVVT)-SOHC-RedFric02  
 Standard Deviation 0.6:



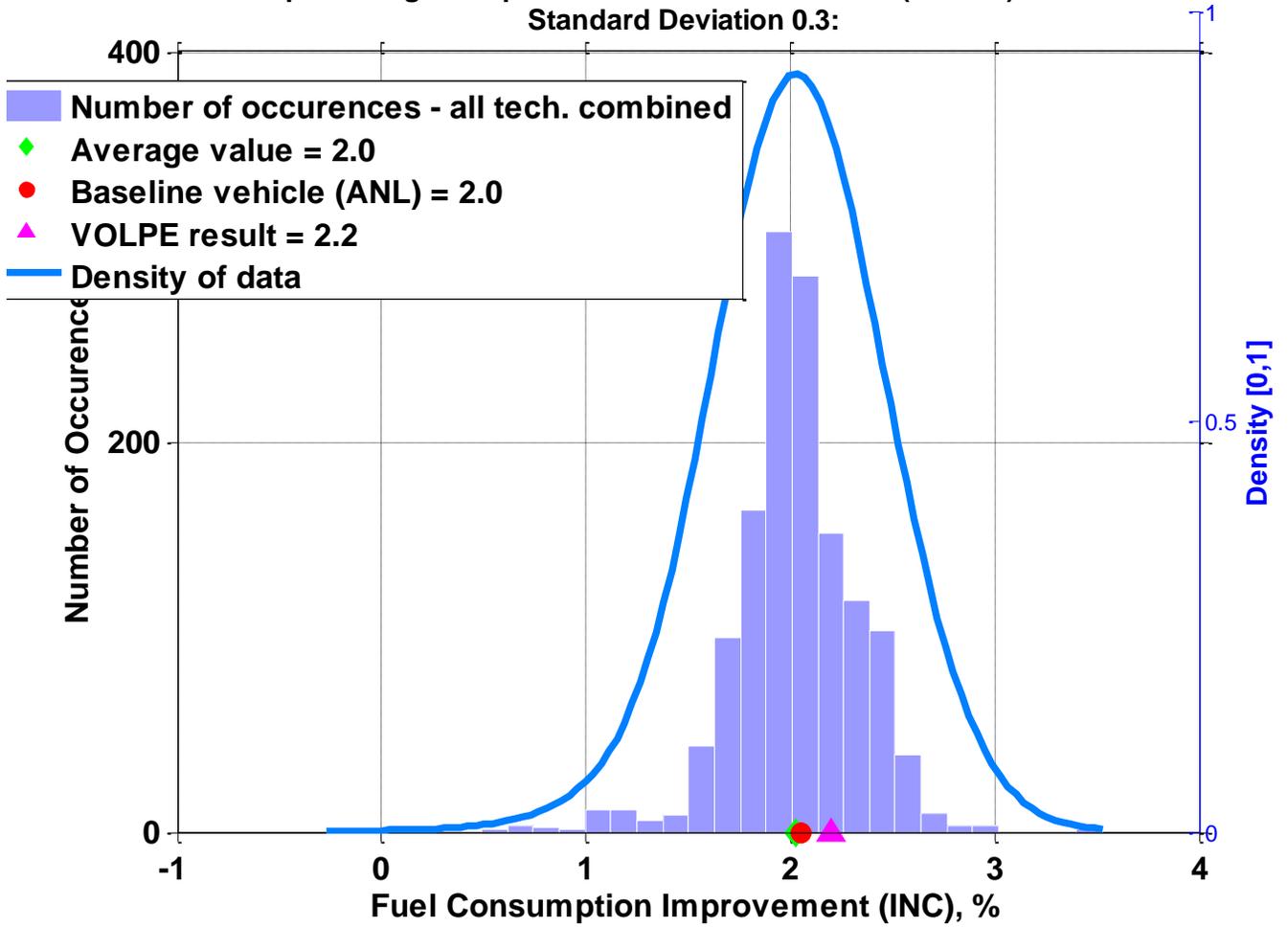


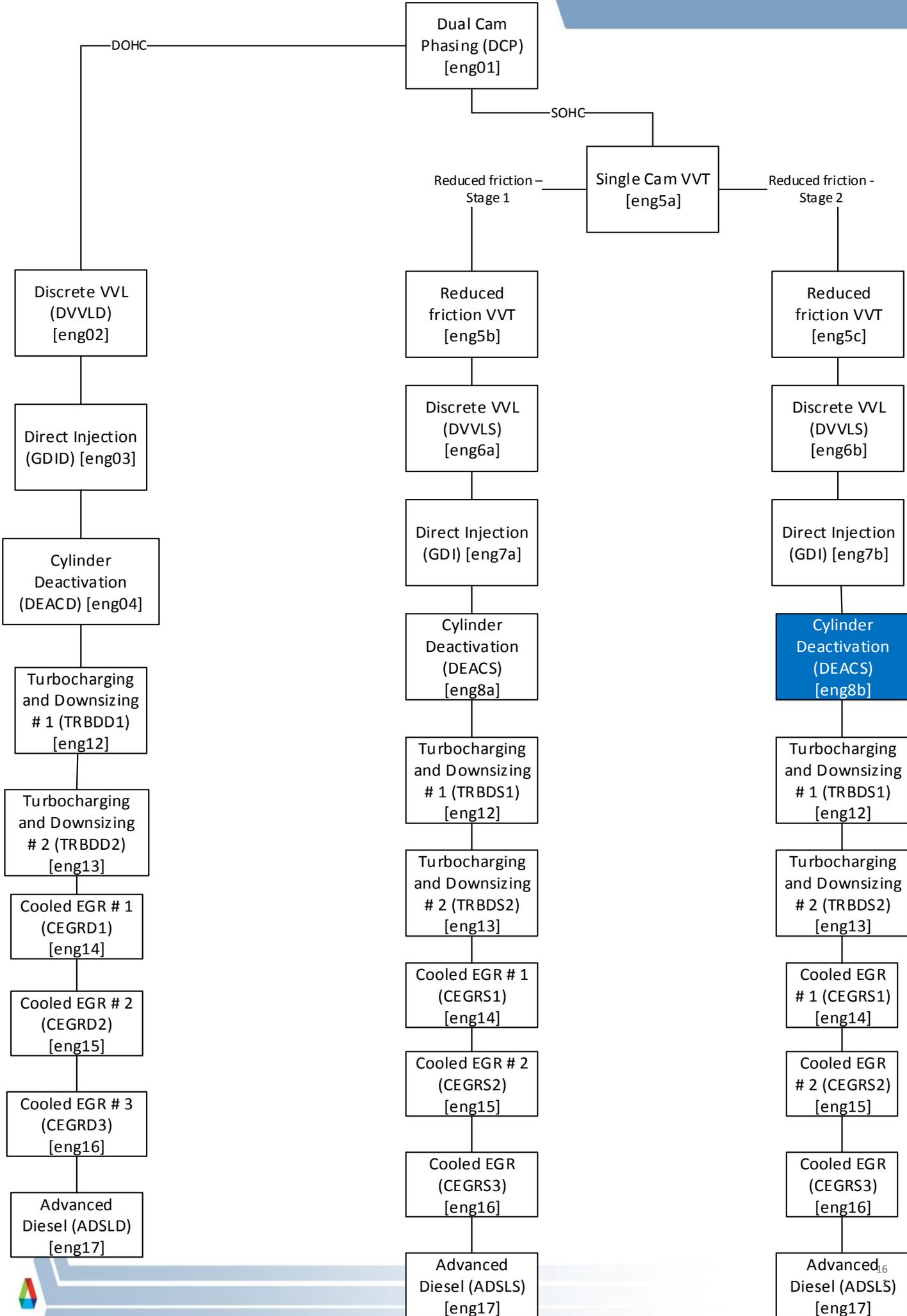
Distribution of Fuel Consumption for Eng06b-Discrete VVL (DVVLS)-SOHC-RedFric02  
 Incremental percentage compared with: 05c-Reduced Friction VVT-SOHC-RedFric02  
 Standard Deviation 0.5:



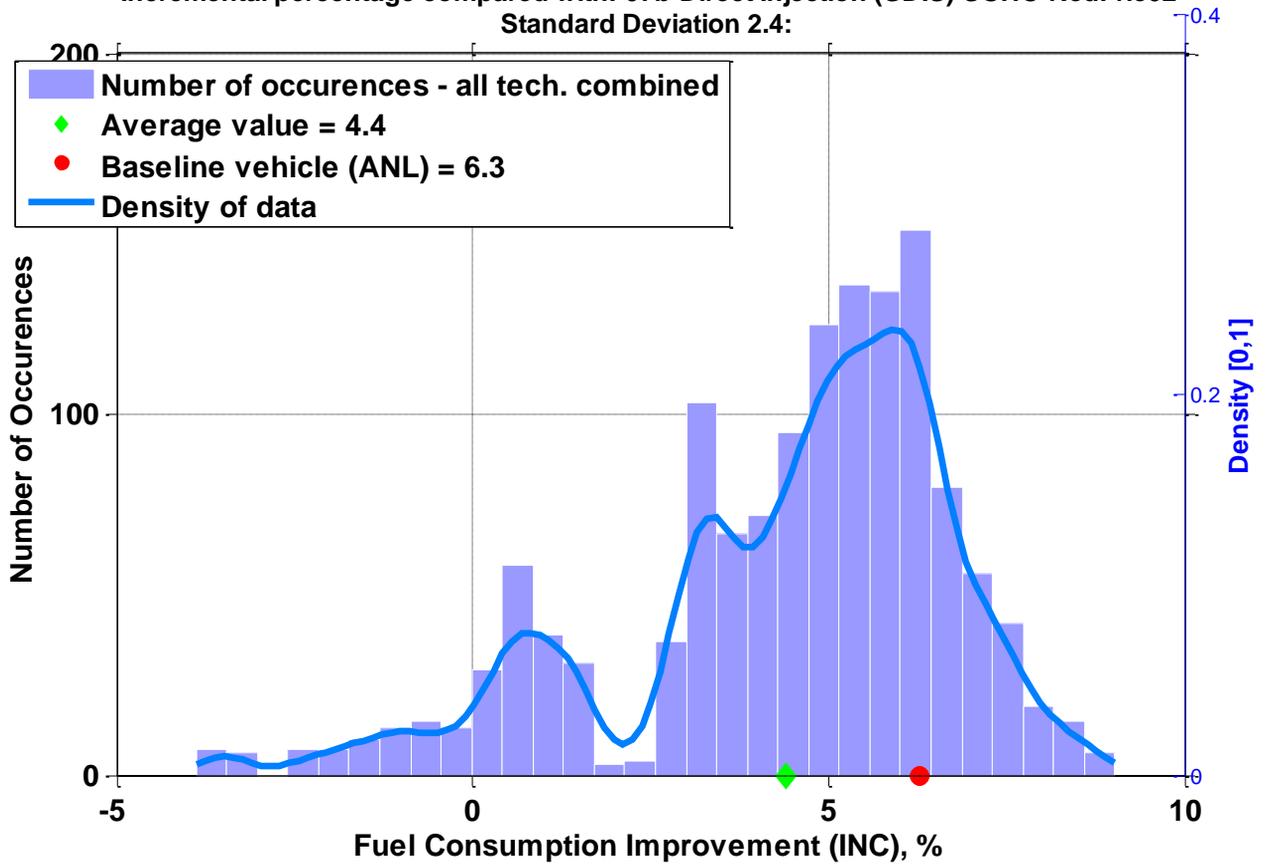


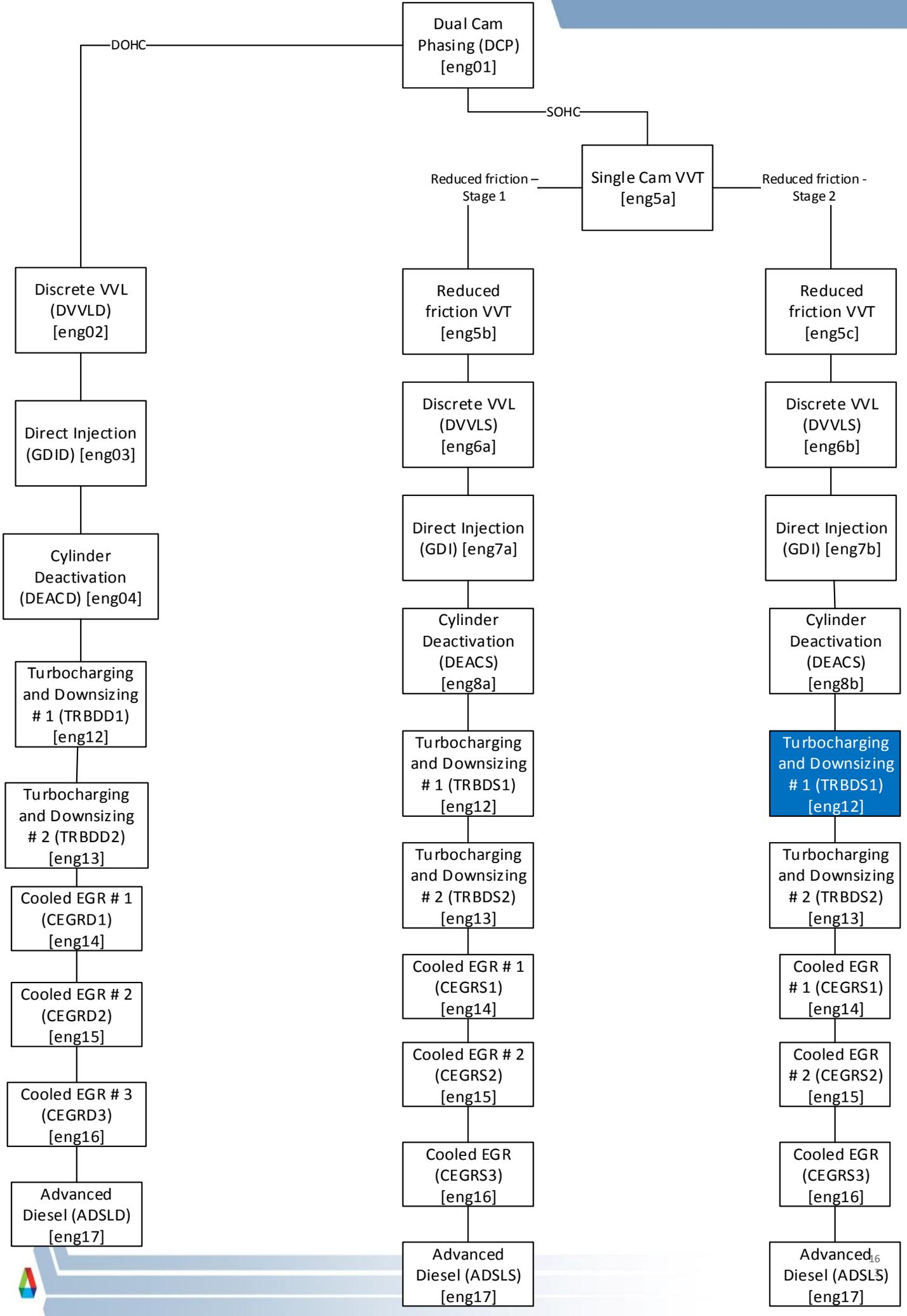
Distribution of Fuel Consumption for Eng07b-Direct Injection (GDIS)-SOHC-RedFric02  
 Incremental percentage compared with: 06b-Discrete VVL (DVVLS)-SOHC-RedFric02  
 Standard Deviation 0.3:



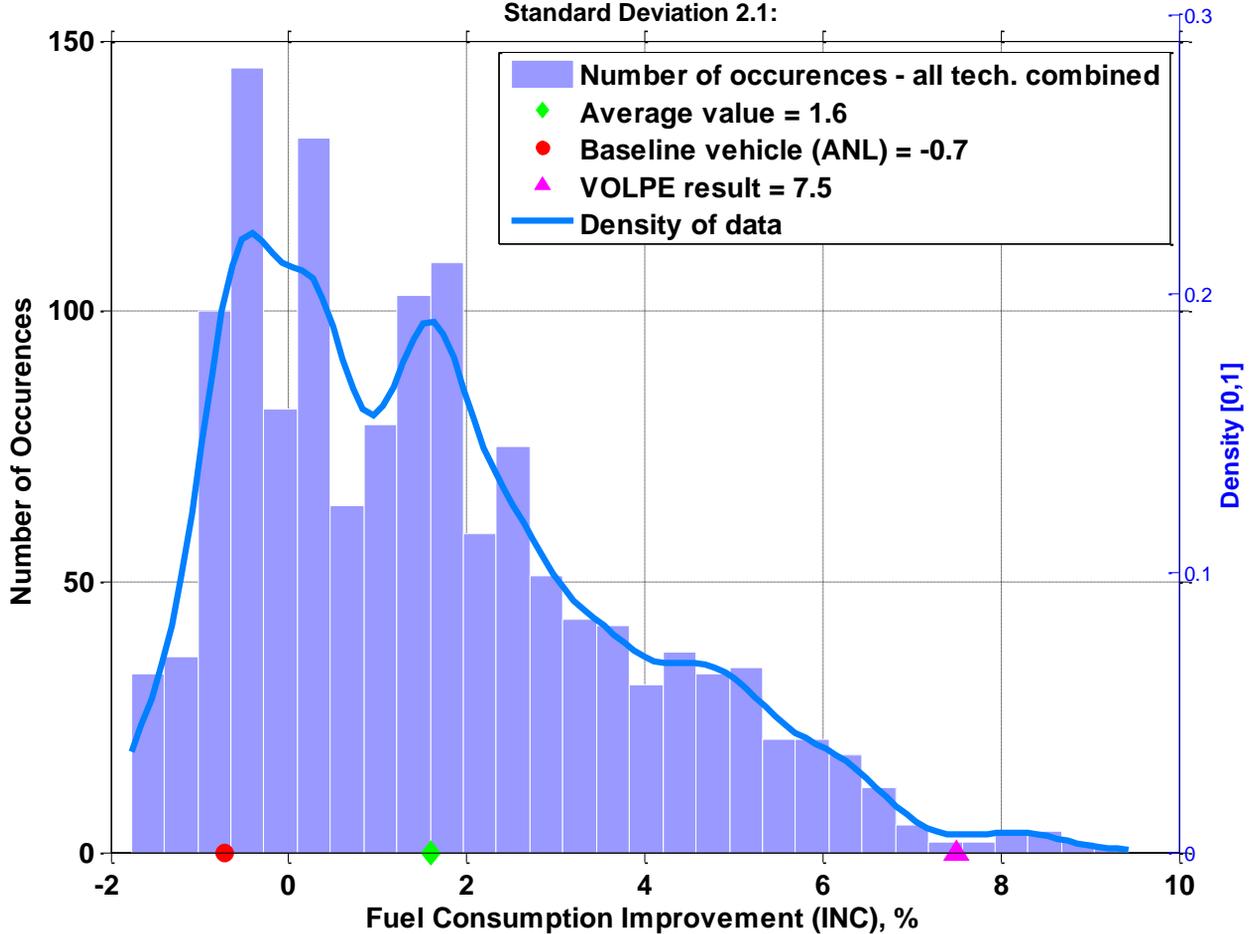


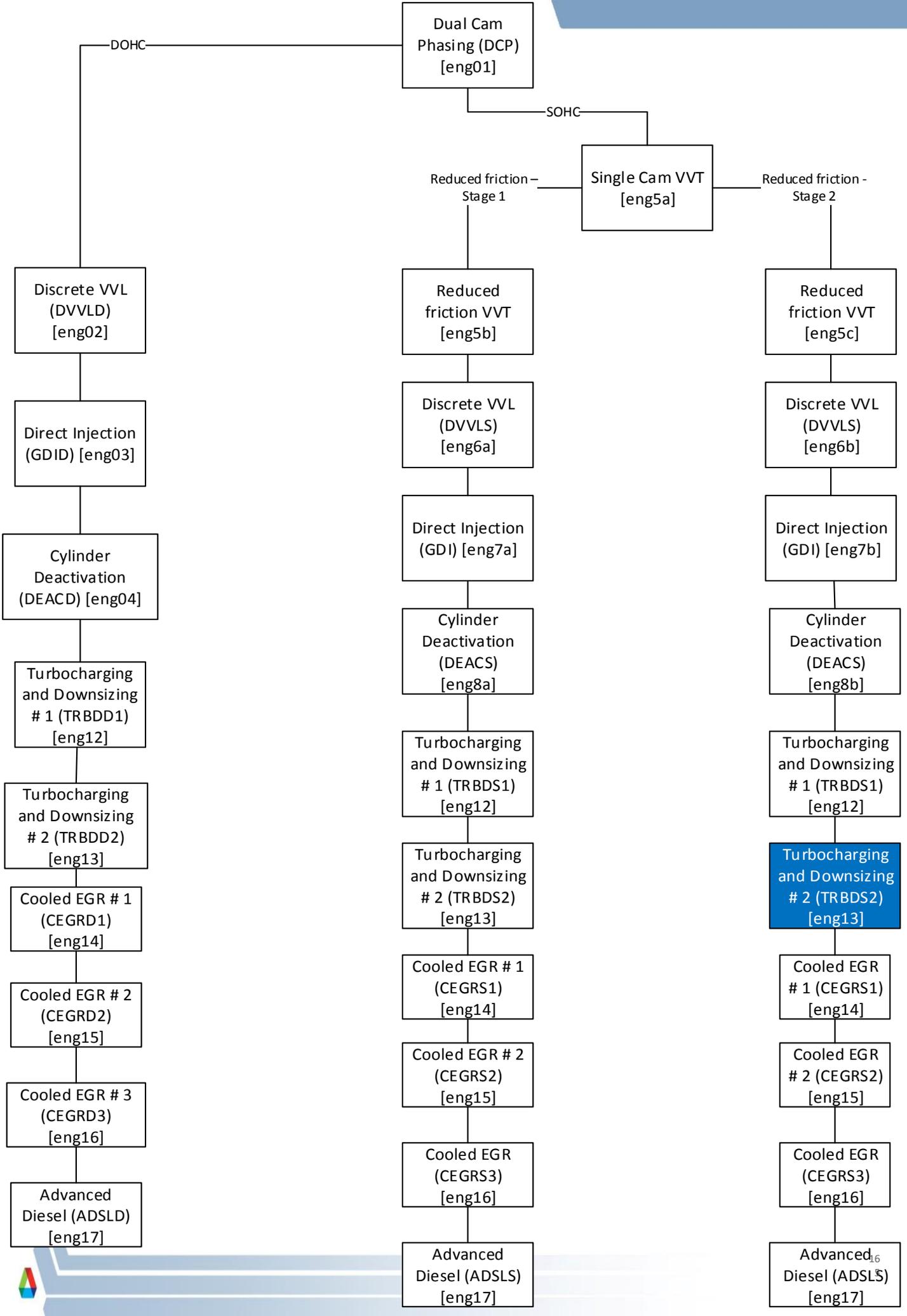
Distribution of Fuel Consumption for Eng08b-Cylinder Deactivation (DEACS)-SOHC-RedFric02  
 Incremental percentage compared with: 07b-Direct Injection (GDIS)-SOHC-RedFric02  
 Standard Deviation 2.4:



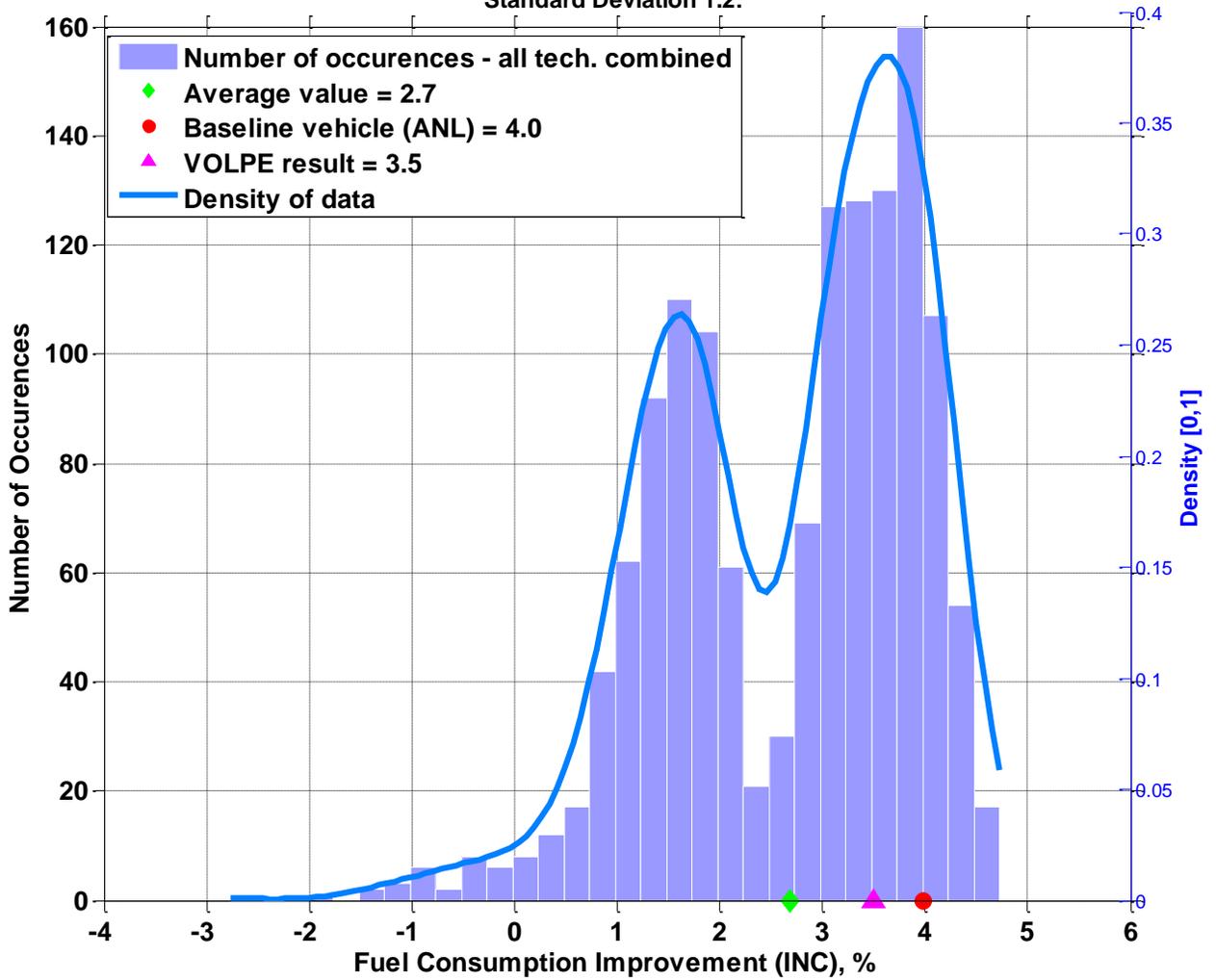


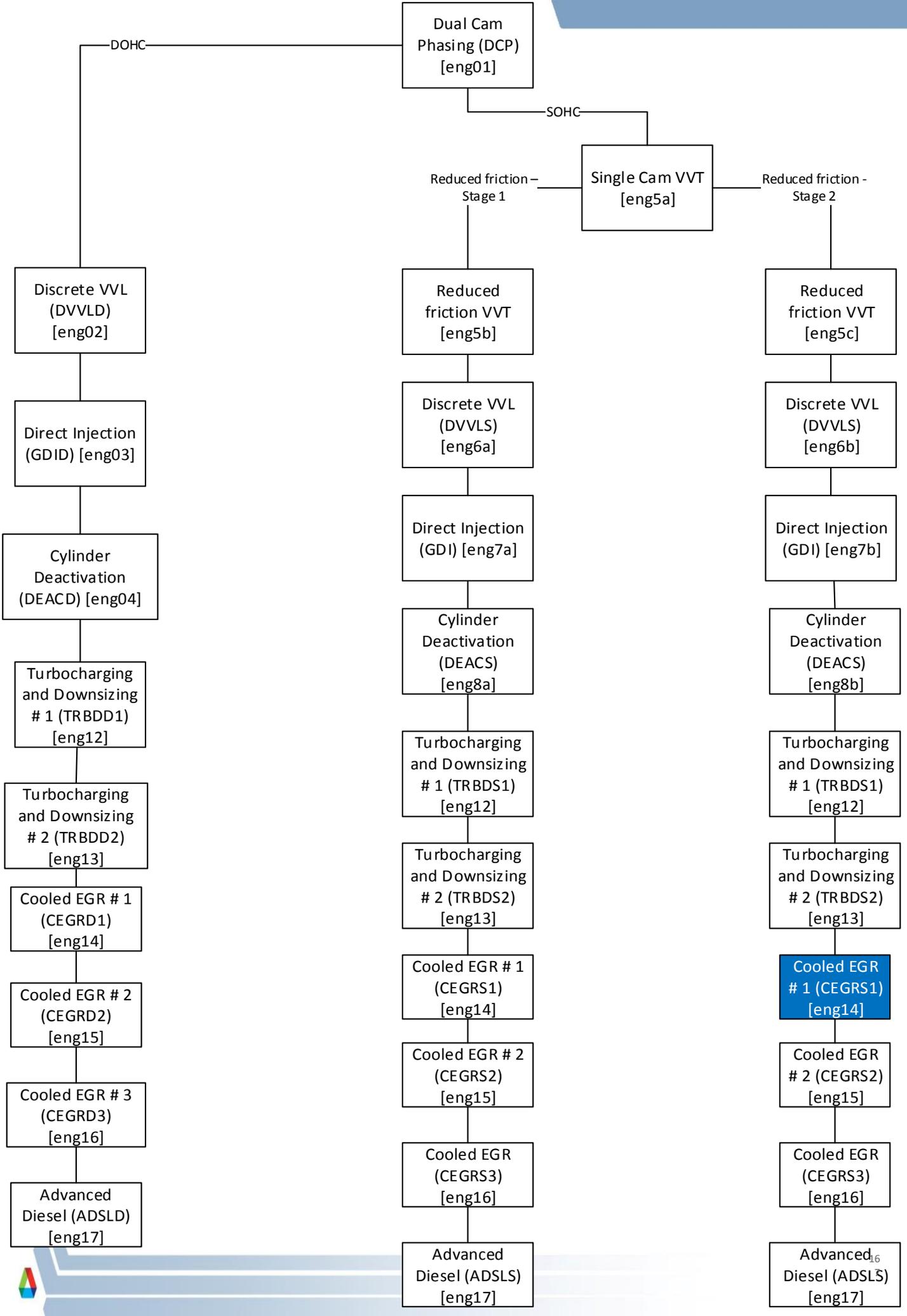
Distribution of Fuel Consumption for Eng12-Turbocharging and Downsizing # 1 (TRBD1)-SOHC-RedFric02  
 Incremental percentage compared with: 08b-Cylinder Deactivation (DEACS)-SOHC-RedFric02  
 Standard Deviation 2.1:



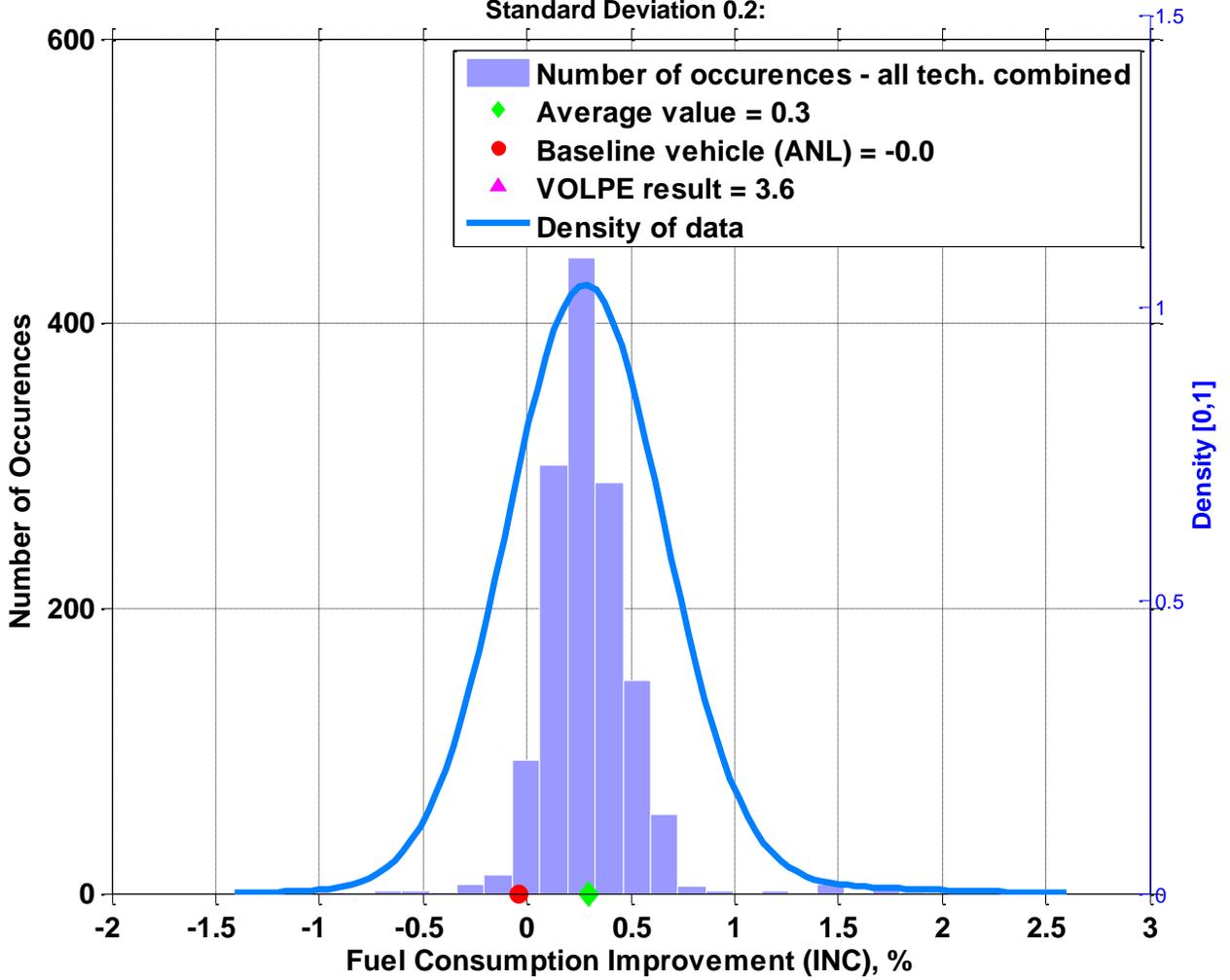


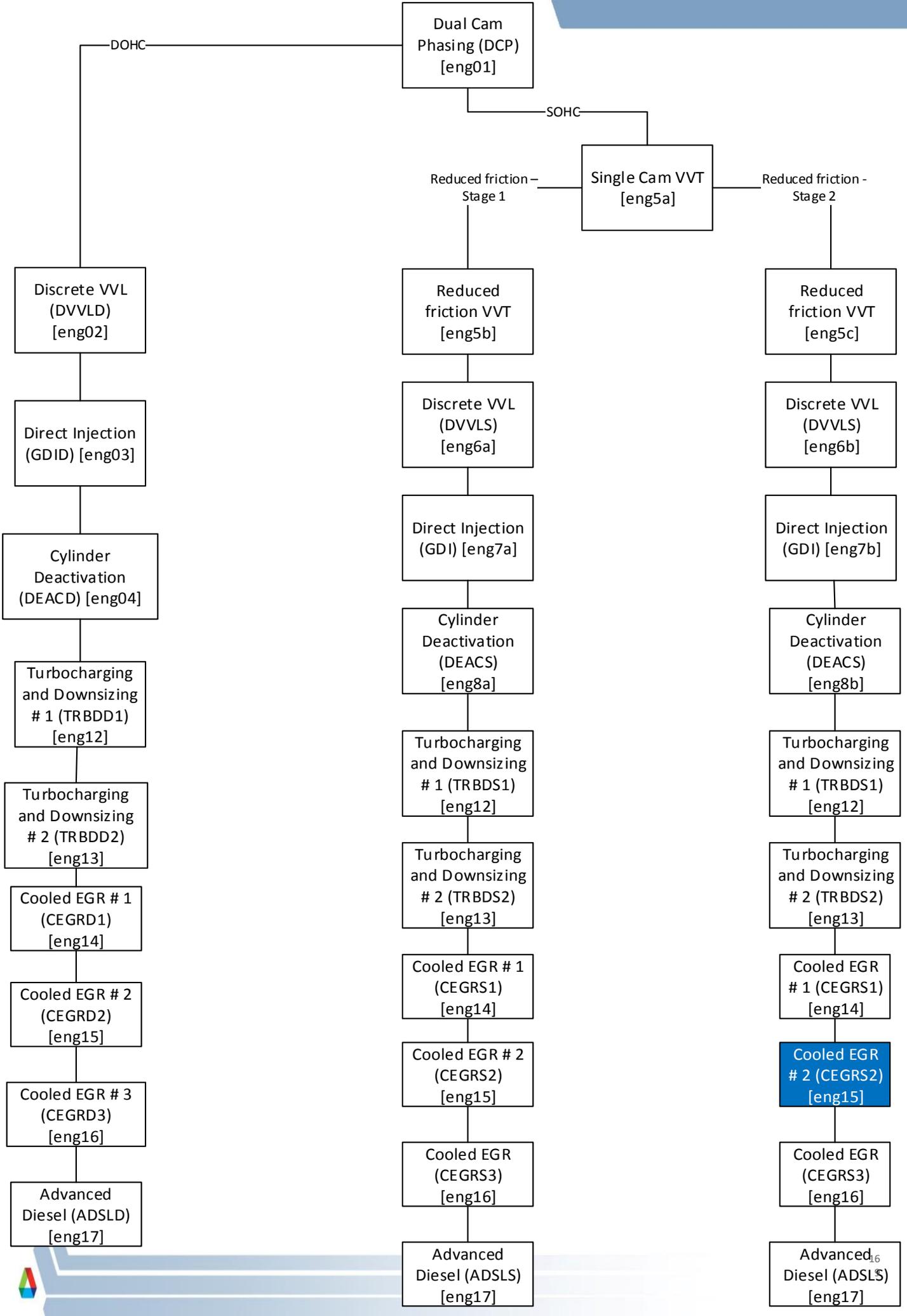
Distribution of Fuel Consumption for Eng13-Turbocharging and Downsizing #2 (TRBD2)-SOHC-RedFric02  
 Incremental percentage compared with: 12-Turbocharging and Downsizing # 1 (TRBD1)-SOHC-RedFric02  
 Standard Deviation 1.2:



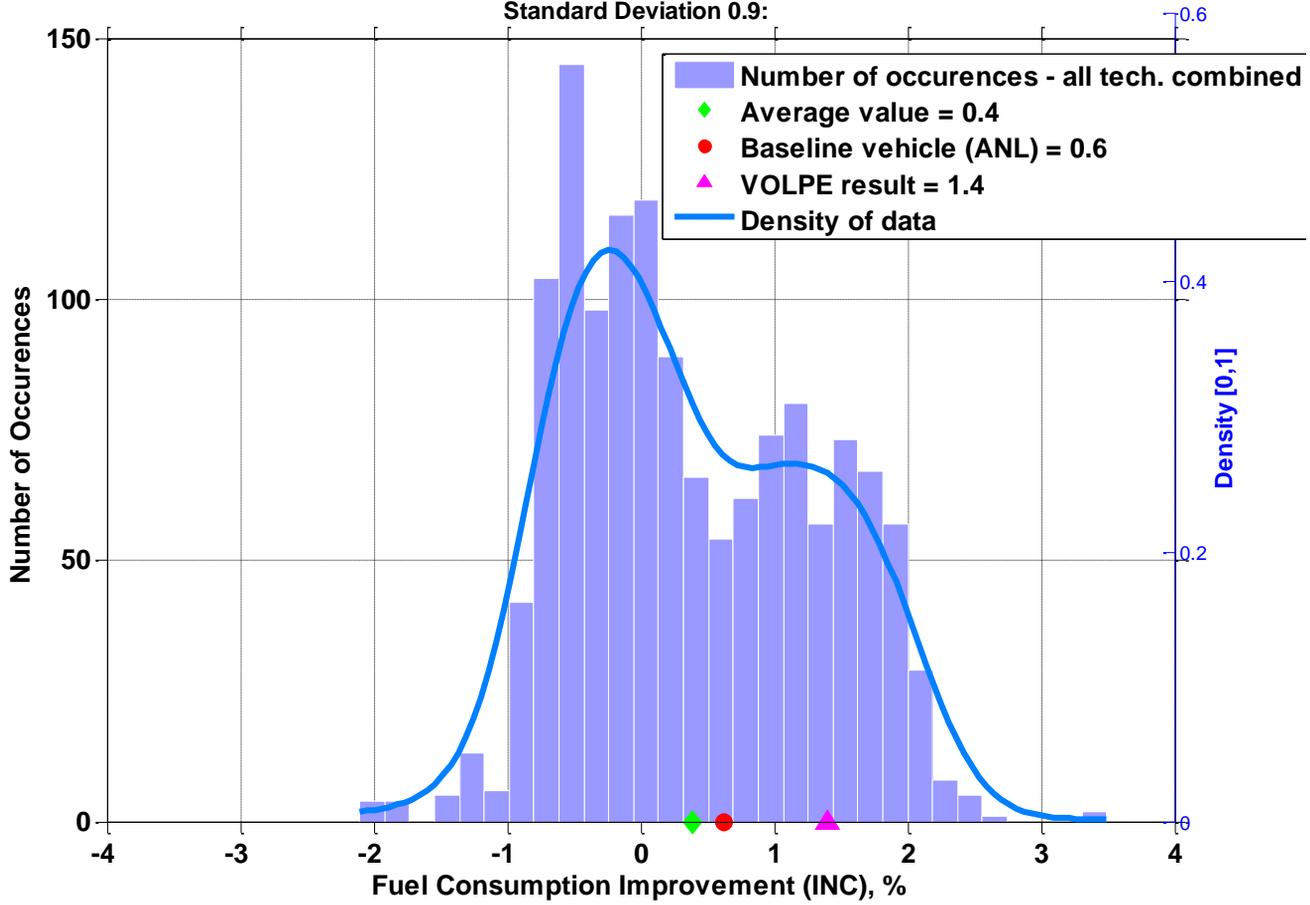


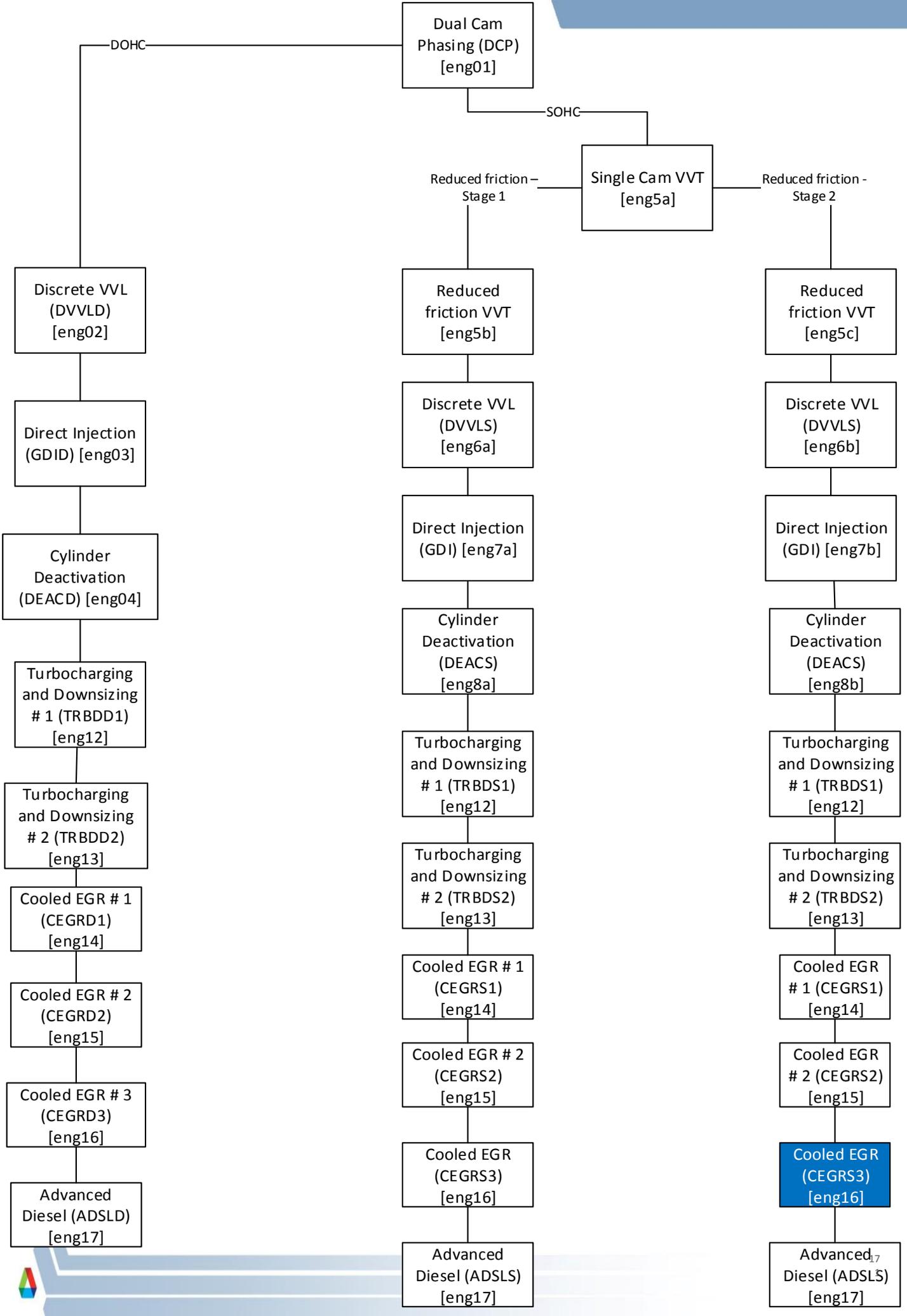
Distribution of Fuel Consumption for Eng14-Cooled EGR#1 (CEGR1)-SOHC-RedFric02  
 Incremental percentage compared with: 13-Turbocharging and Downsizing #2 (TRBD2)-SOHC-RedFric02  
 Standard Deviation 0.2:



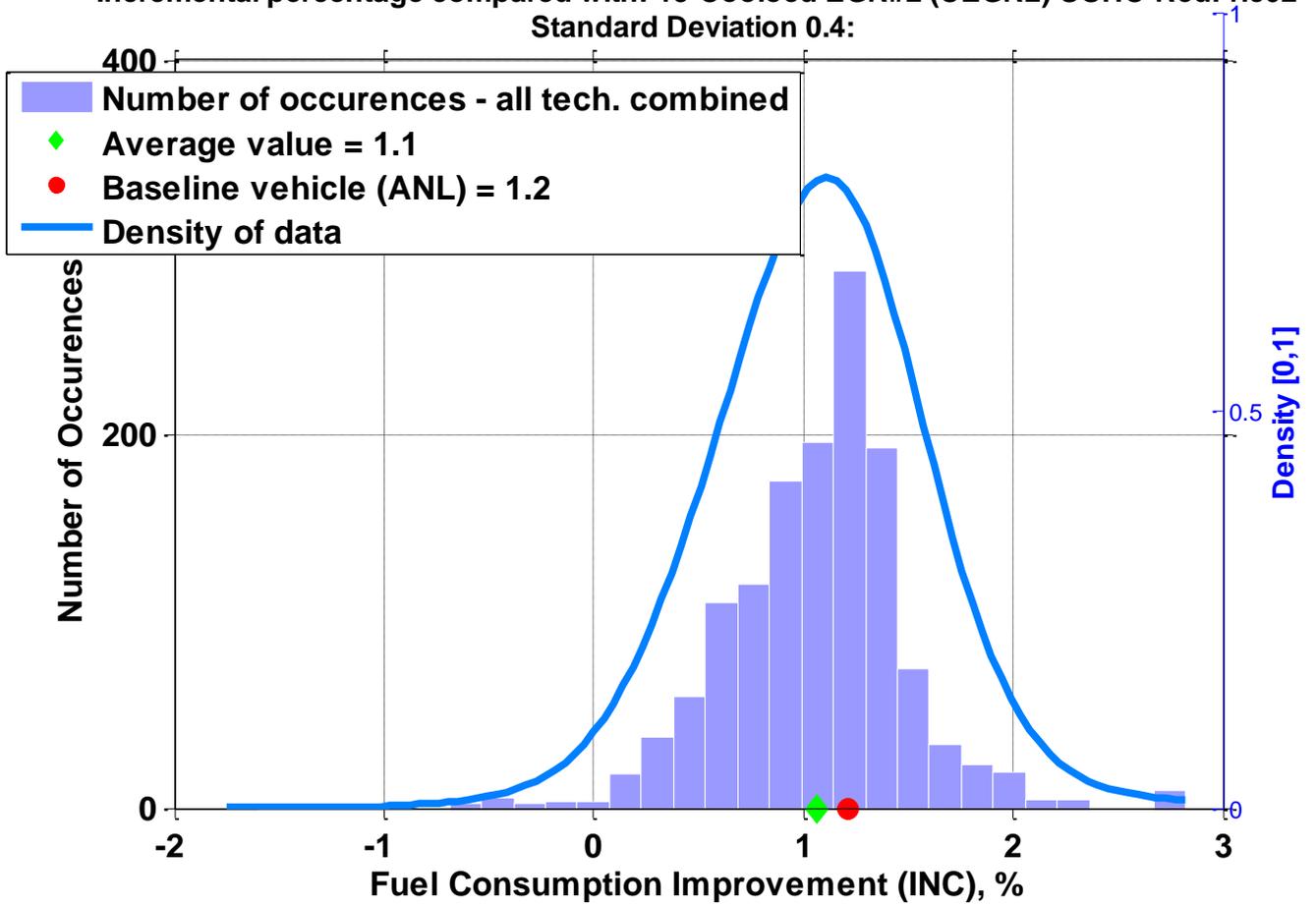


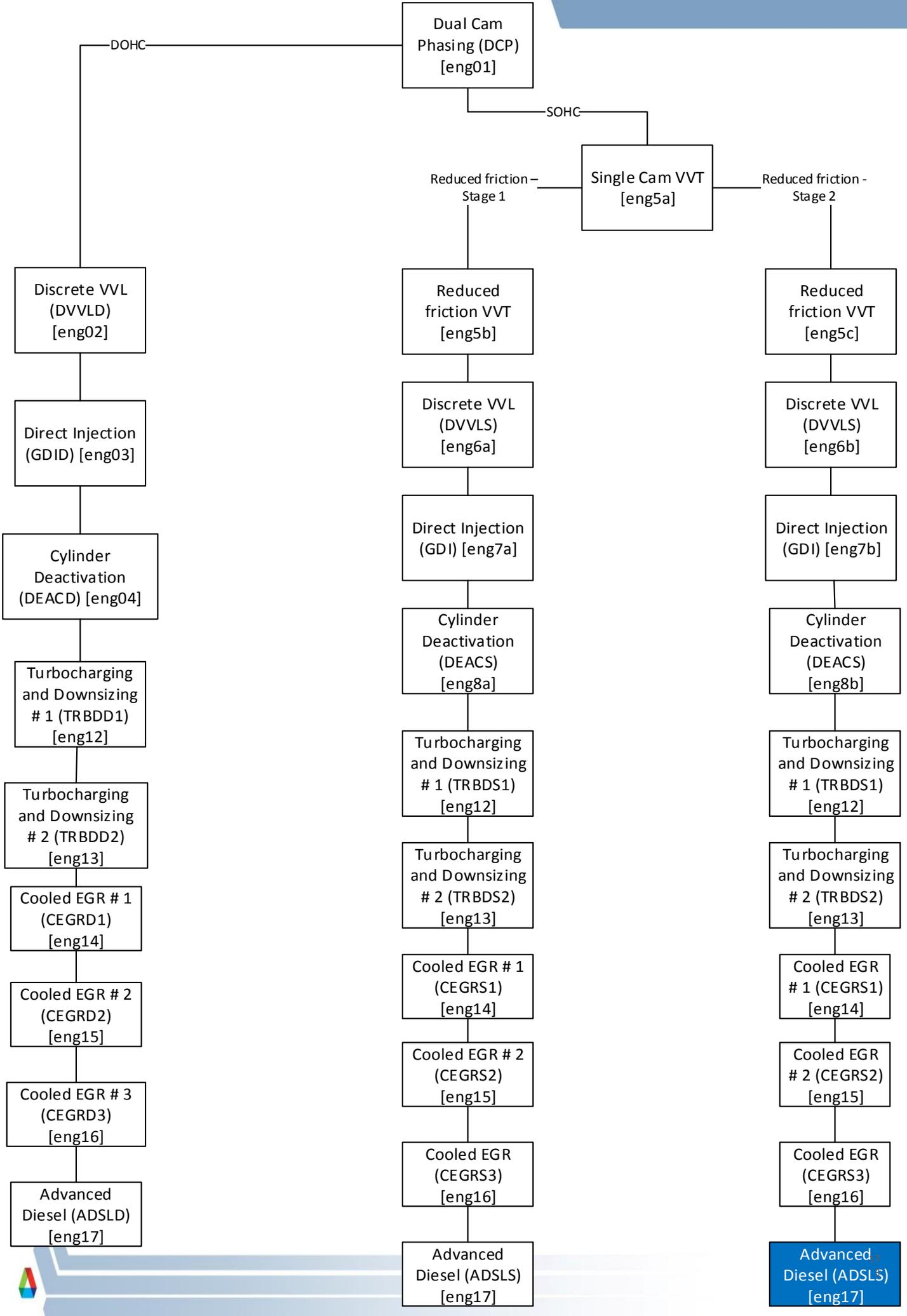
Distribution of Fuel Consumption for Eng15-Cooled EGR#2 (CEGR2)-SOHC-RedFric02  
 Incremental percentage compared with: 14-Cooled EGR#1 (CEGR1)-SOHC-RedFric02  
 Standard Deviation 0.9:



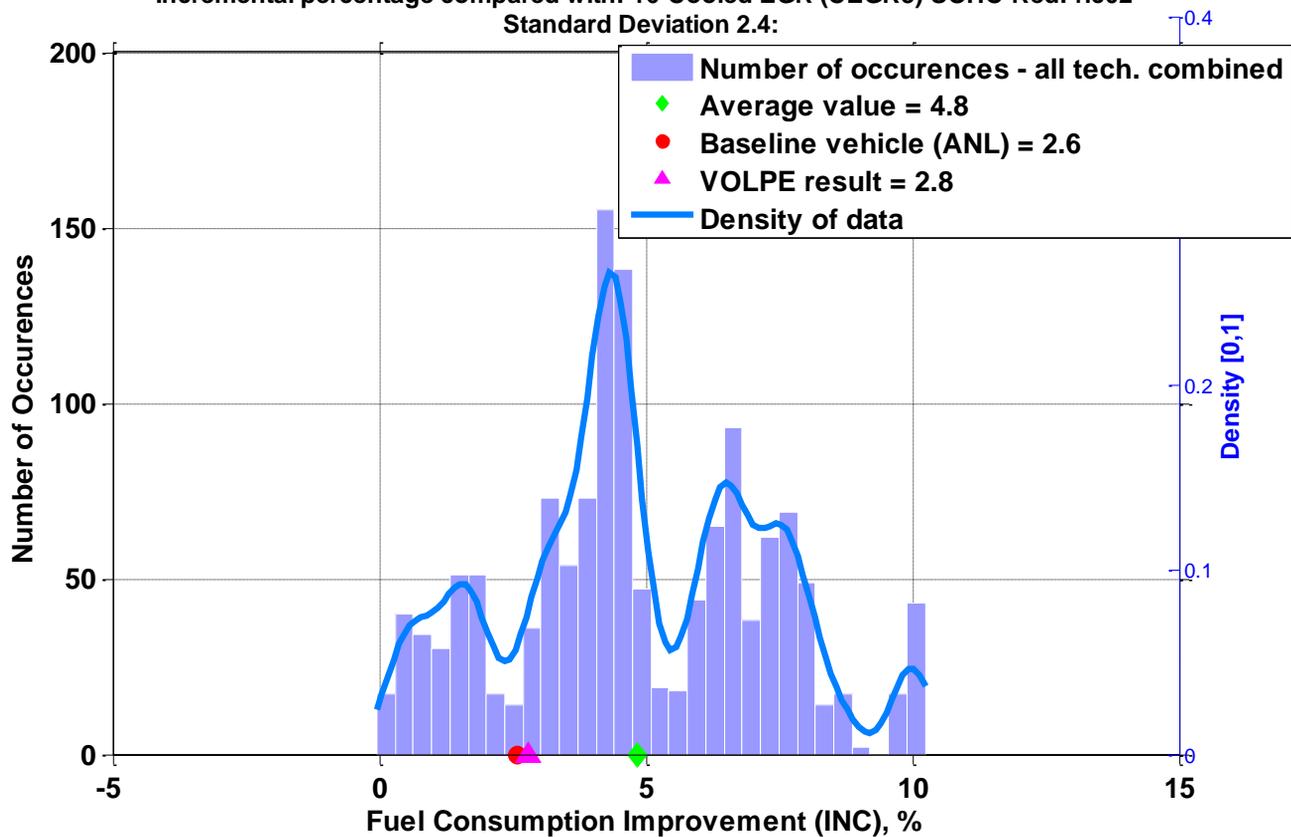


Distribution of Fuel Consumption for Eng16-Cooled EGR (CEGR3)-SOHC-RedFric02  
 Incremental percentage compared with: 15-Cooled EGR#2 (CEGR2)-SOHC-RedFric02  
 Standard Deviation 0.4:





Distribution of Fuel Consumption for Eng17-Advanced Diesel(ADLS)-SOHC-RedFric02  
 Incremental percentage compared with: 16-Cooled EGR (CEGR3)-SOHC-RedFric02  
 Standard Deviation 2.4:



# TRANSMISSION TECHNOLOGY

5-spd Trans (AUTO)

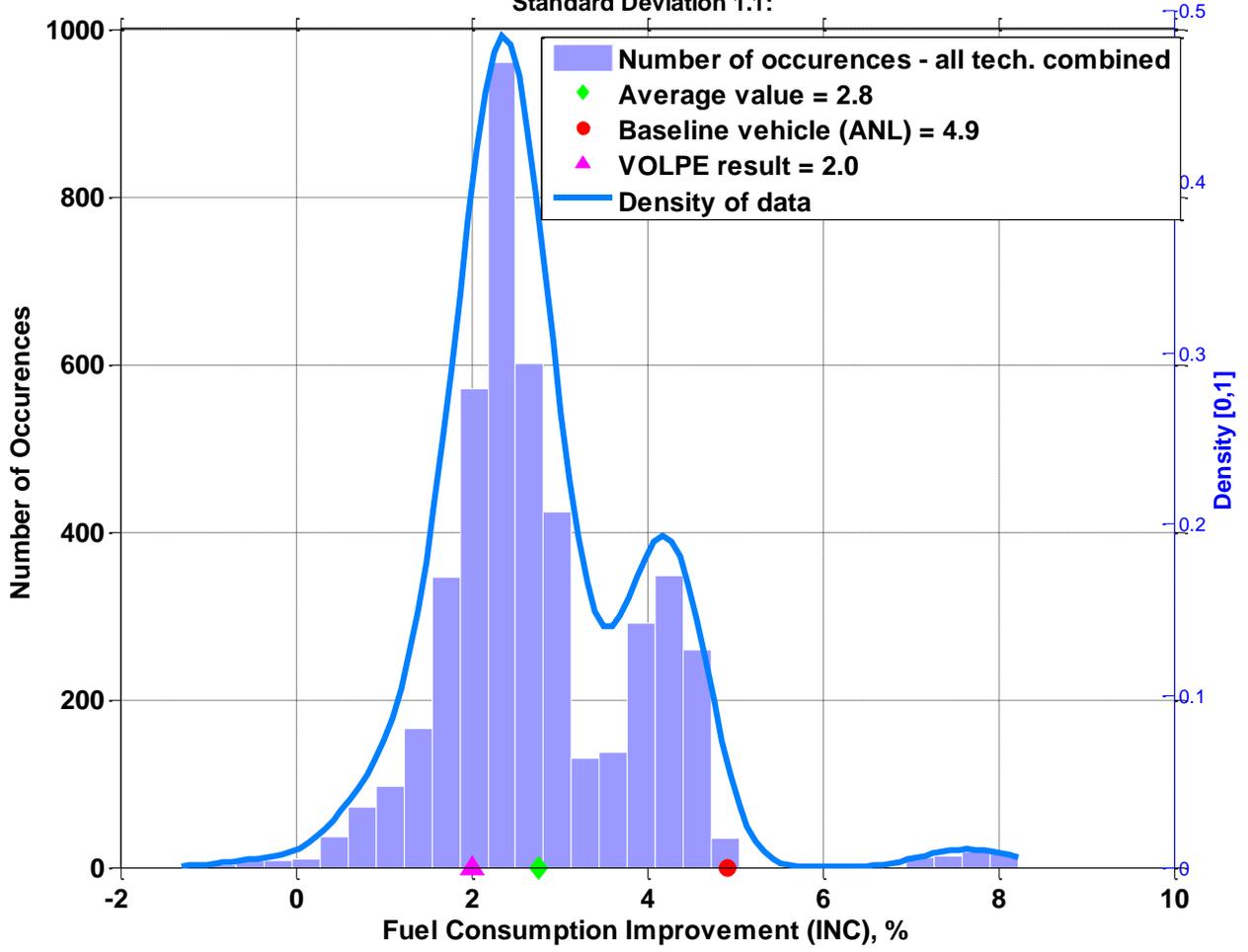


6-spd Trans w/Improved  
Internals (Auto) (NAUTO)



8-spd Trans (AUTO)

Distribution of Fuel Consumption for Transmission-AUTO-6-spd  
 Incremental percentage compared with: 5-spd  
 Standard Deviation 1.1:



5-spd Trans (AUTO)

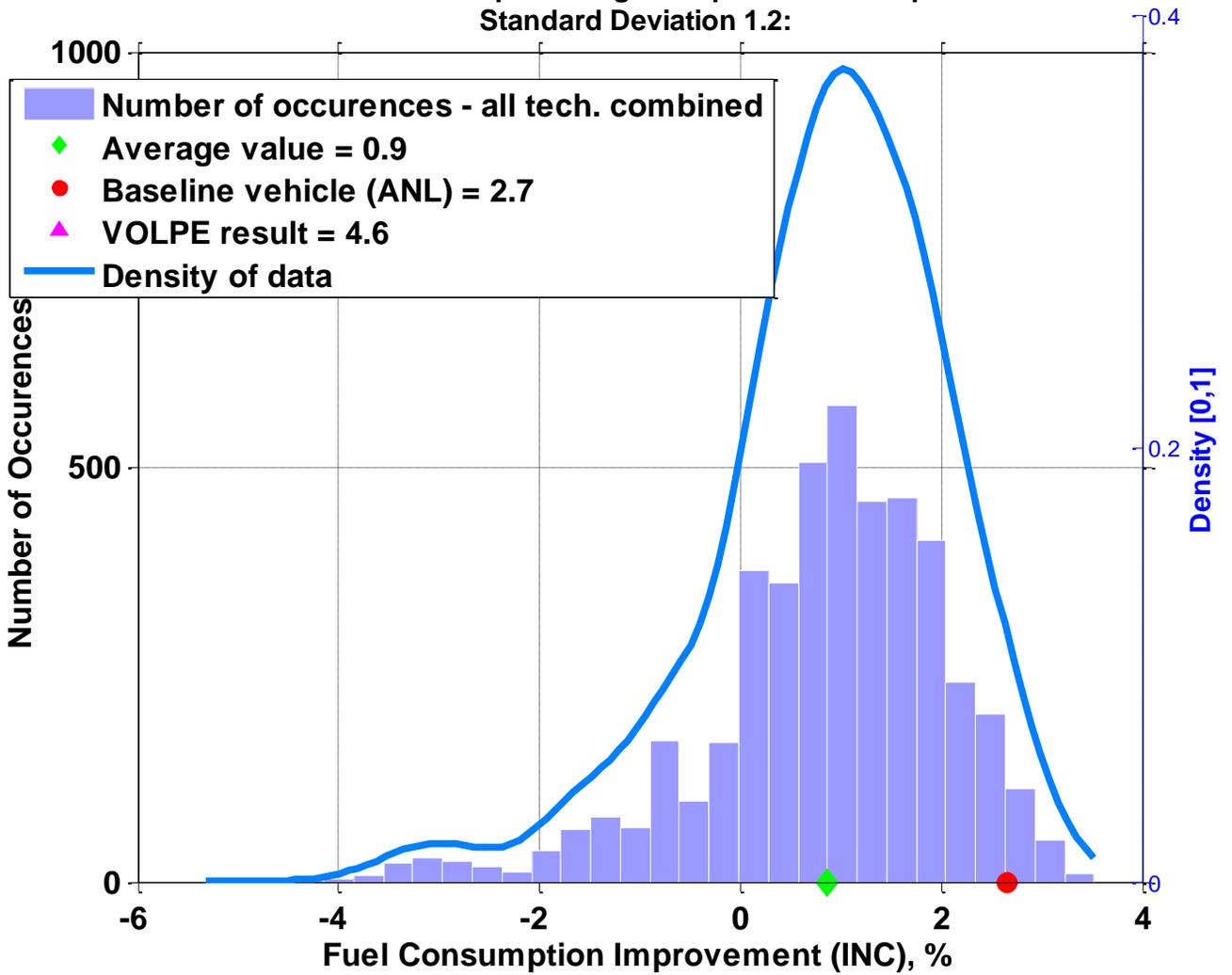


6-spd Trans w/Improved Internals (Auto) (NAUTO)



8-spd Trans (AUTO)

Distribution of Fuel Consumption for Transmission-AUTO-8-spd  
Incremental percentage compared with: 6-spd  
Standard Deviation 1.2:



5-spd Trans (AUTO)



6-spd DCT (DCT)

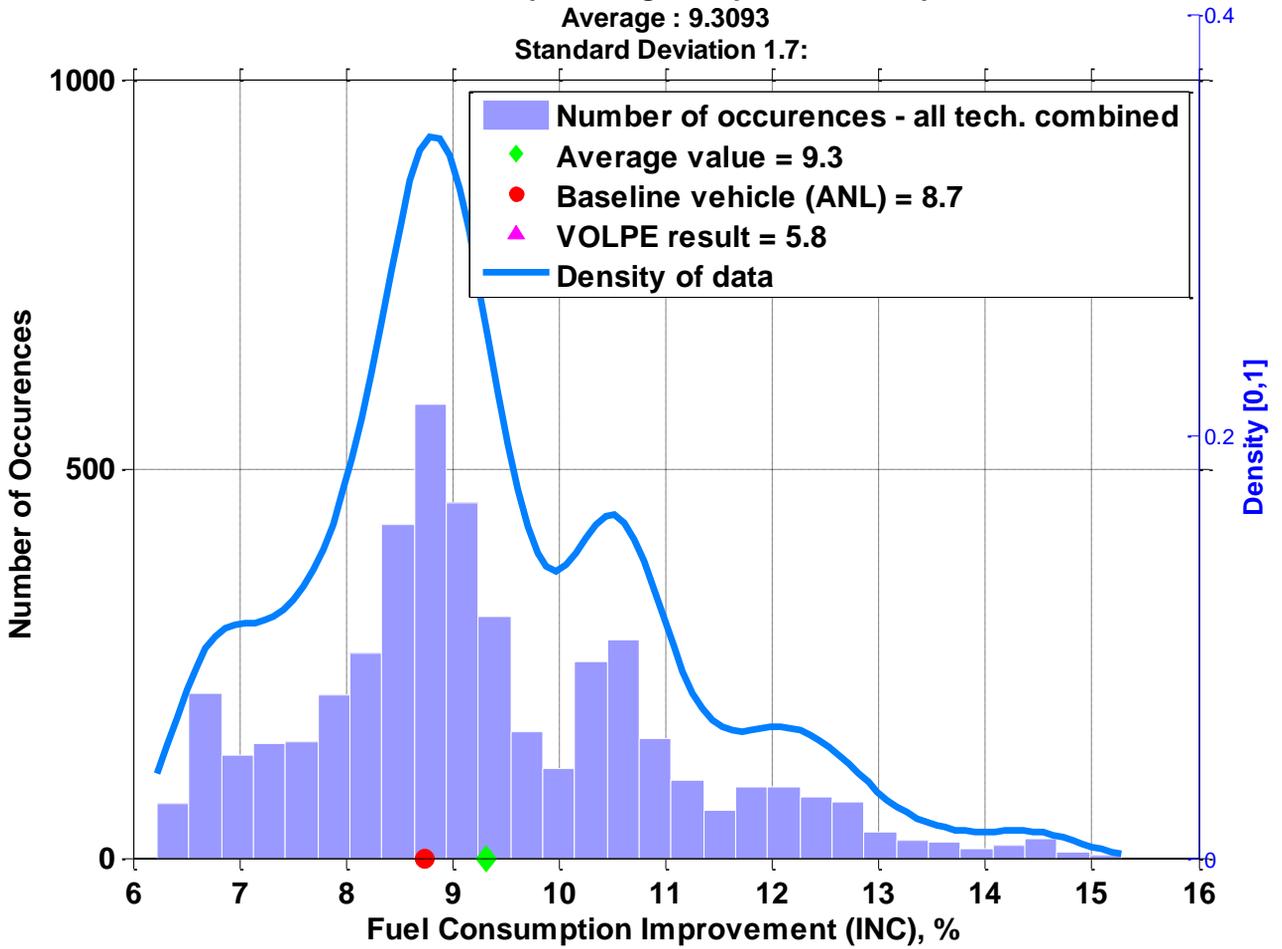


8-spd DCT (DCT)

Distribution of Fuel Consumption for Transmission-DCT-6-spd  
Incremental percentage compared with: 5-spd

Average : 9.3093

Standard Deviation 1.7:



5-spd Trans (AUTO)



6-spd DCT (DCT)

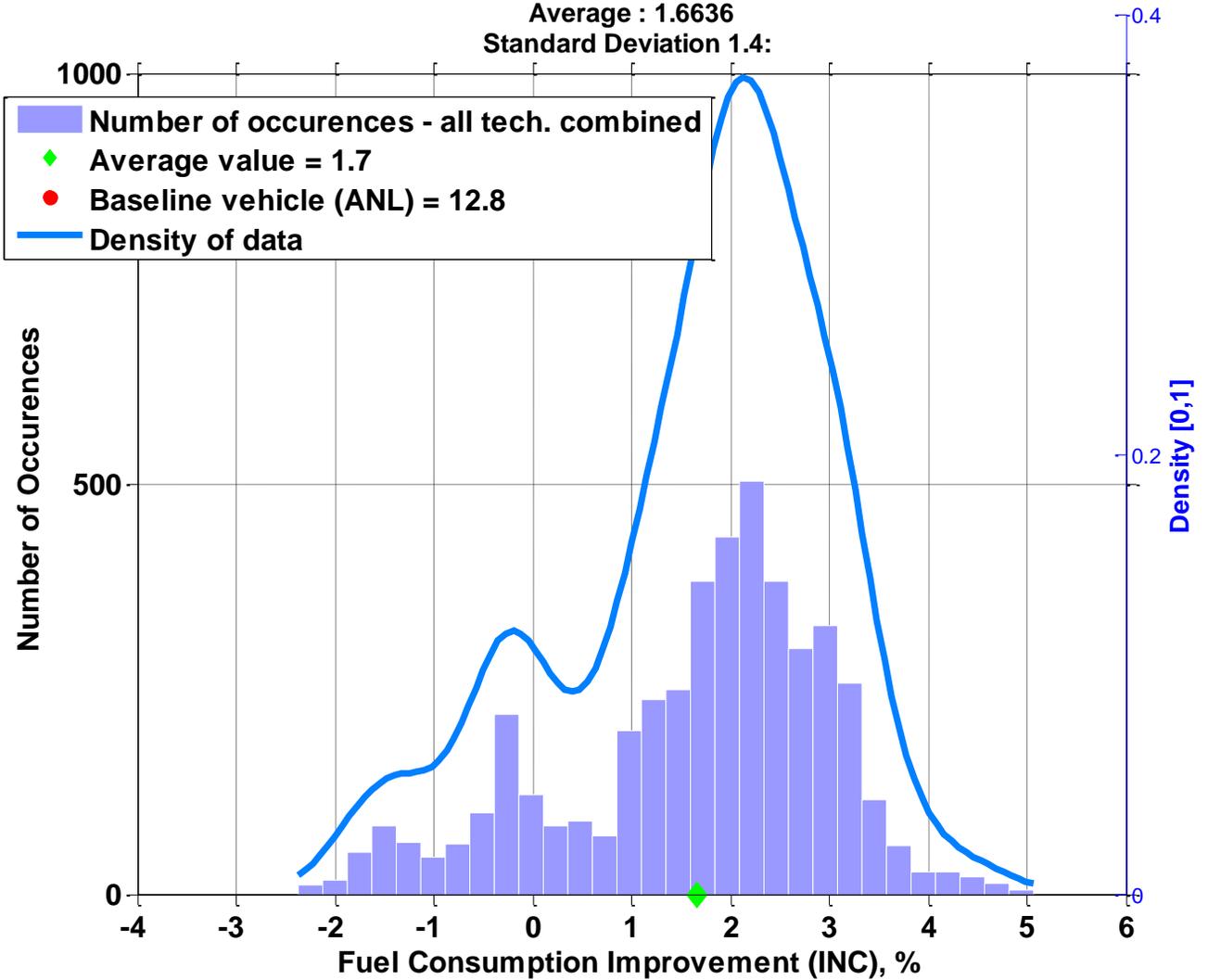


8-spd DCT (DCT)

Distribution of Fuel Consumption for Transmission-DCT-8-spd  
Incremental percentage compared with: 6-spd

Average : 1.6636

Standard Deviation 1.4:



5-spd Manual/Improved  
Internals (5MAN)

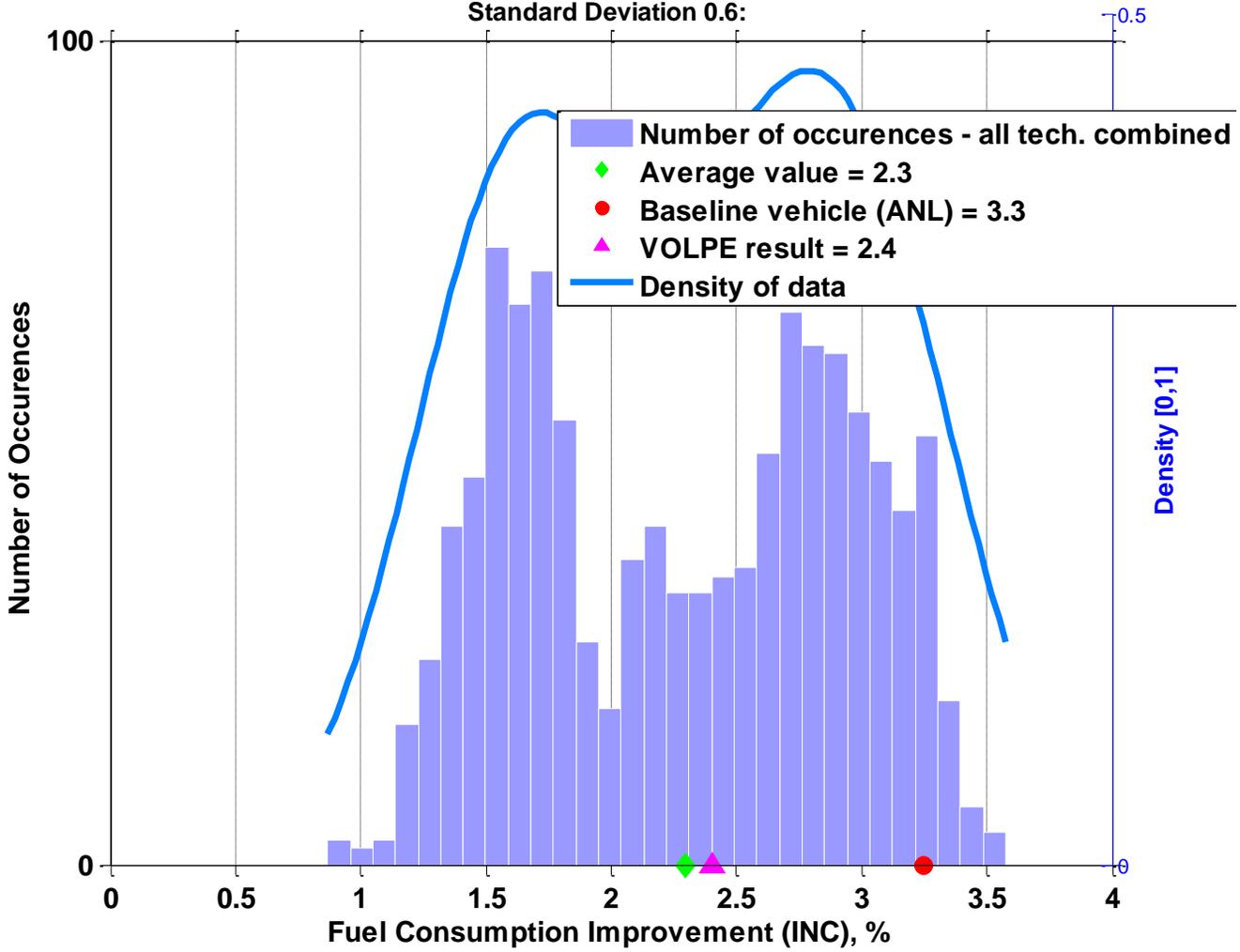


6-spd Manual/Improved  
Internals (6MAN)



8-spd Manual/Improved  
Internals (8MAN)

Distribution of Fuel Consumption for Transmission-DM-6-spd  
 Incremental percentage compared with: 5-spd  
 Standard Deviation 0.6:



5-spd Manual/Improved  
Internals (5MAN)



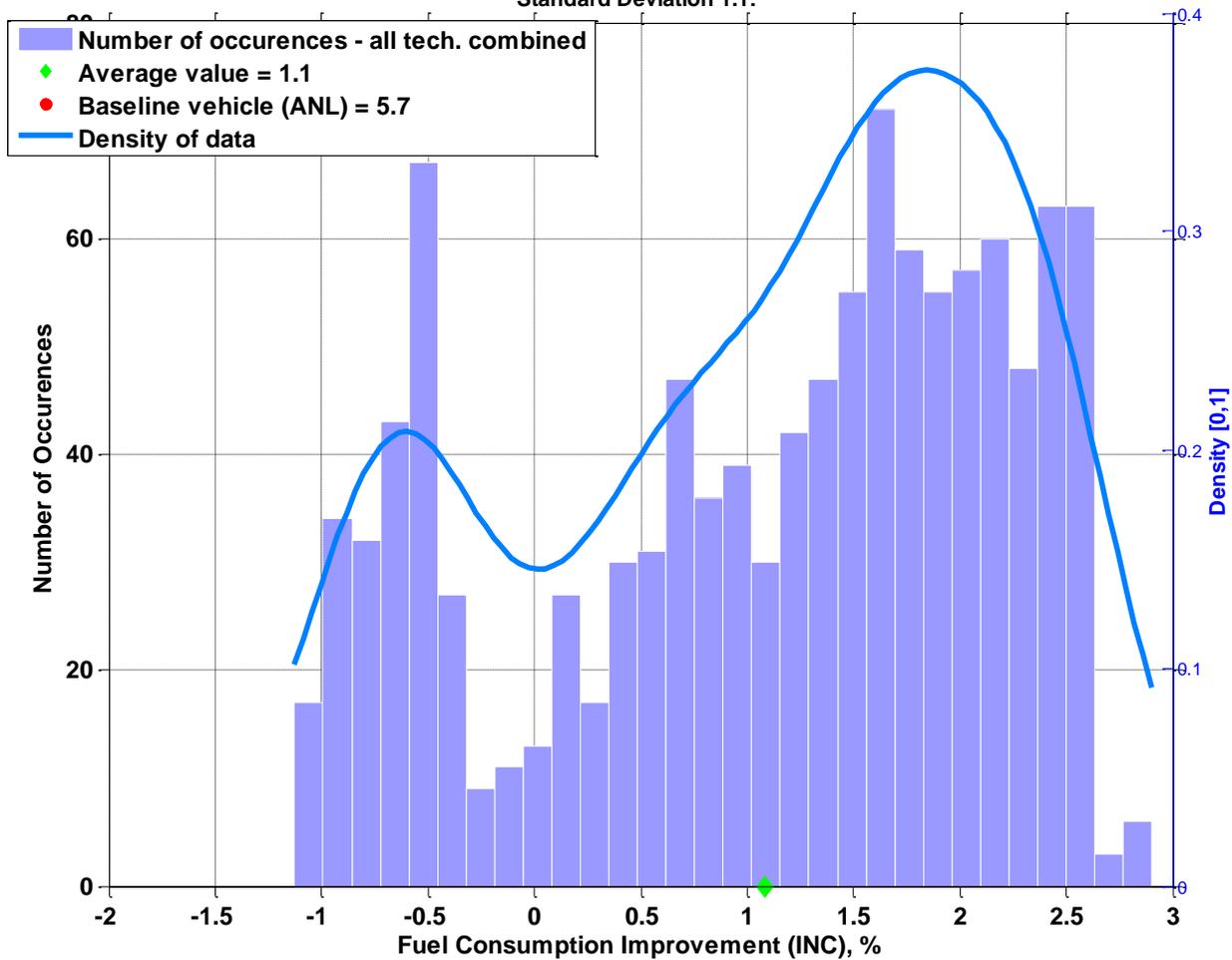
6-spd Manual/Improved  
Internals (6MAN)



8-spd Manual/Improved  
Internals (8MAN)



Distribution of Fuel Consumption for Transmission-DM-8-spd  
 Incremental percentage compared with: 6-spd  
 Standard Deviation 1.1:



5-spd Trans (AUTO)  
(no early lockup)

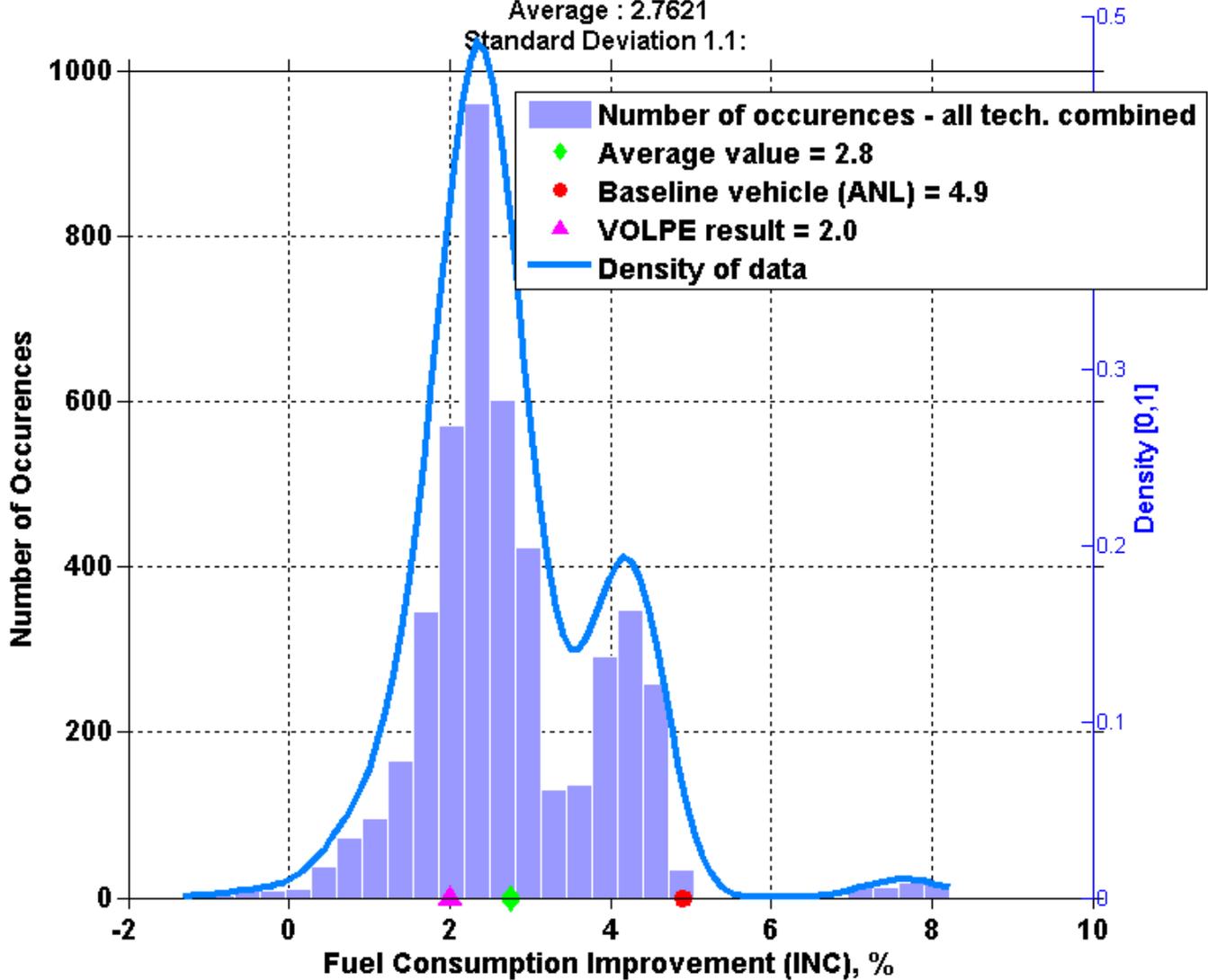
6-spd Trans w/  
Improved Internals  
(Auto) (6AUTO)

CVT Transmission

Distribution of Fuel Consumption for Transmission-6-spd AUTO (early lockup)  
Incremental percentage compared with: 5-spd AUTO (no early lockup)

Average : 2.7621

Standard Deviation 1.1:



5-spd Trans (AUTO)  
(no early lockup)

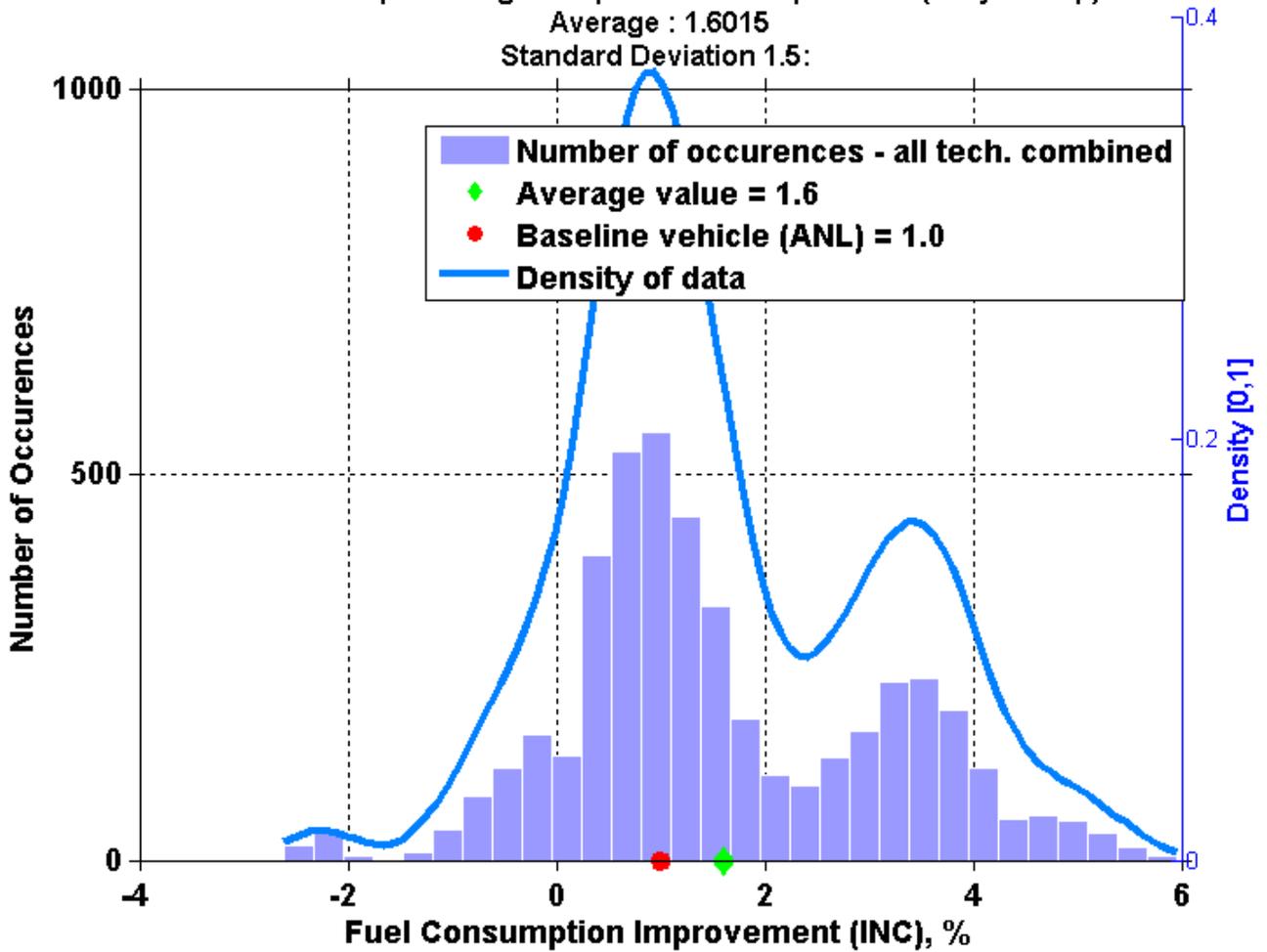
6-spd Trans w/  
Improved Internals  
(Auto) (6AUTO)

CVT Transmission

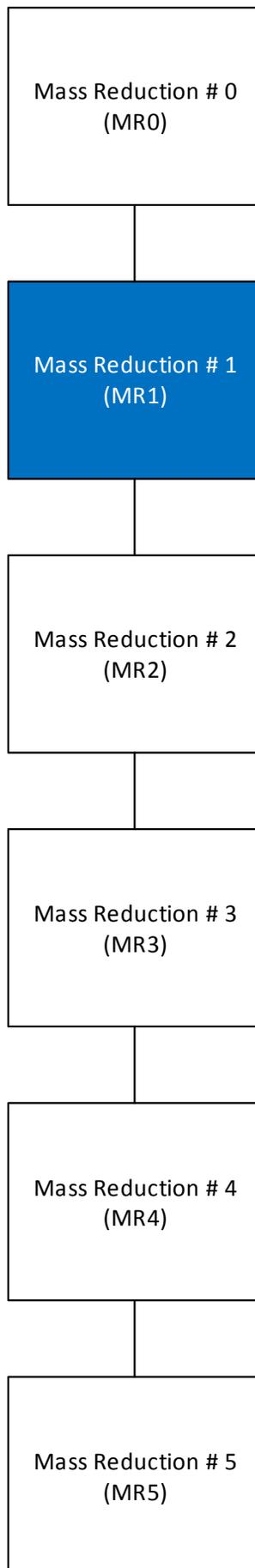
Distribution of Fuel Consumption for Transmission-CVT  
Incremental percentage compared with: 6-spd AUTO (early lockup)

Average : 1.6015

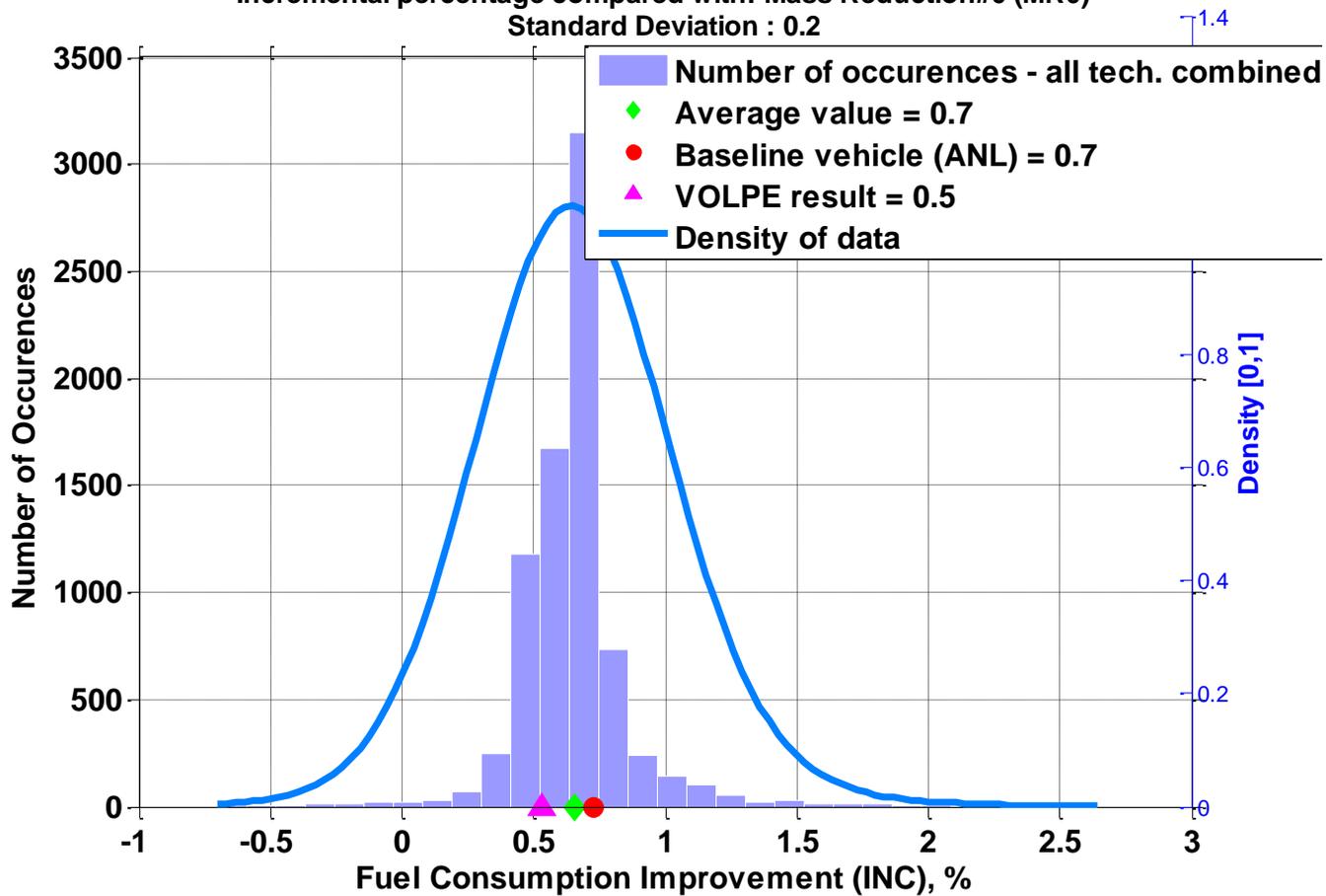
Standard Deviation 1.5:

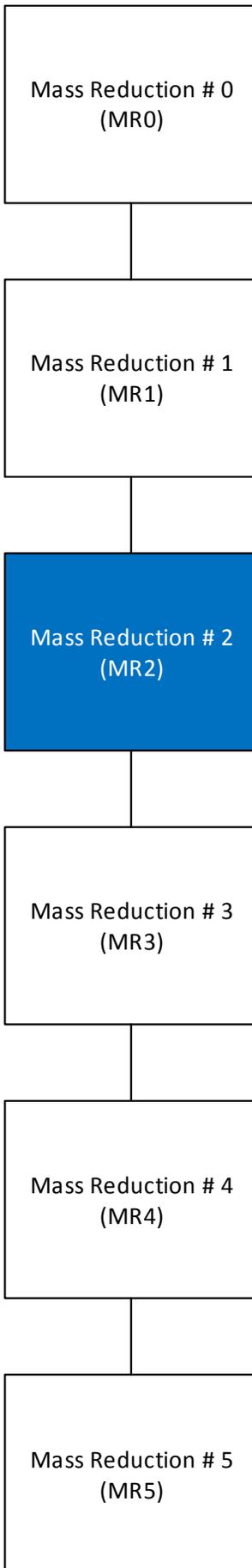


# VEHICLE TECHNOLOGIES

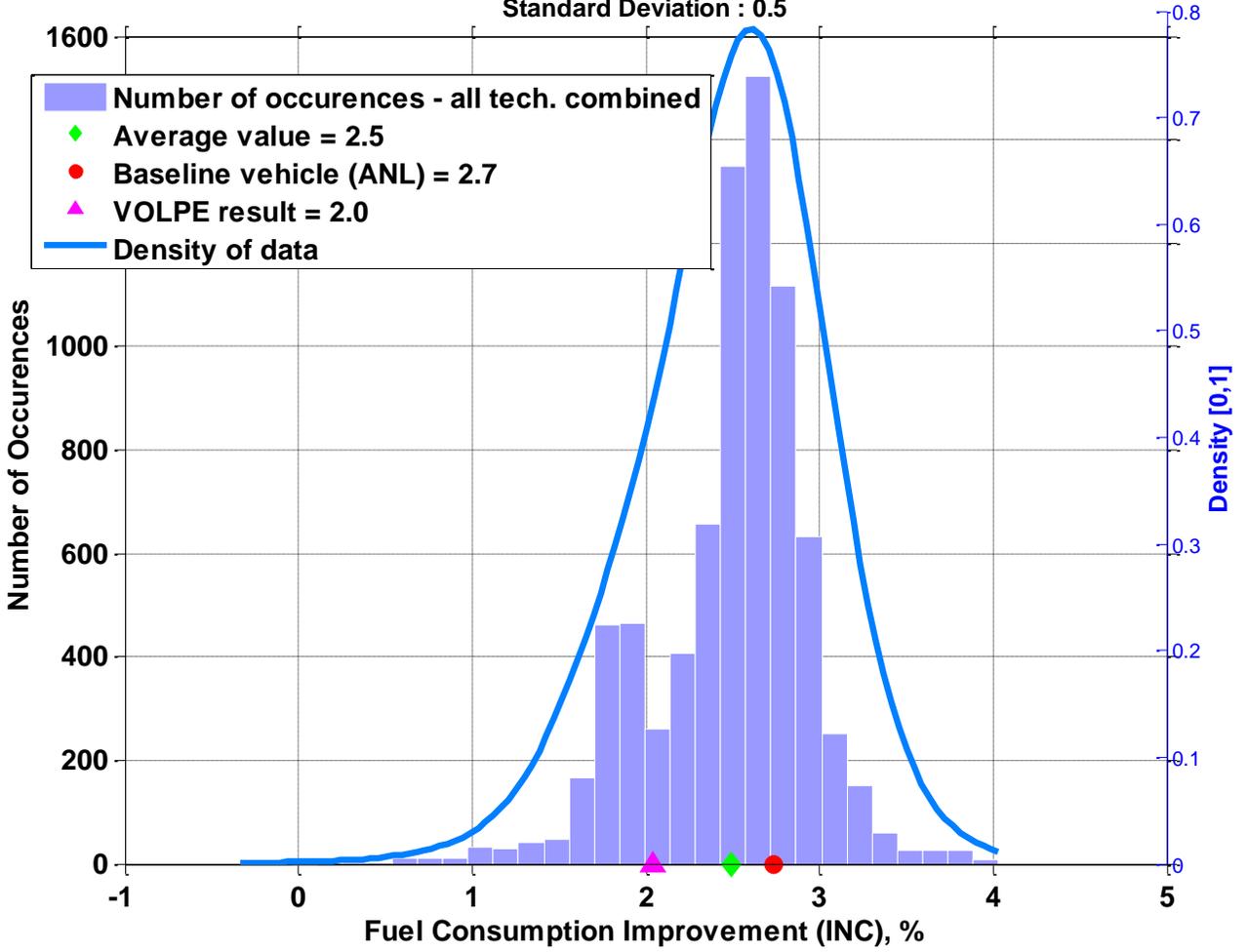


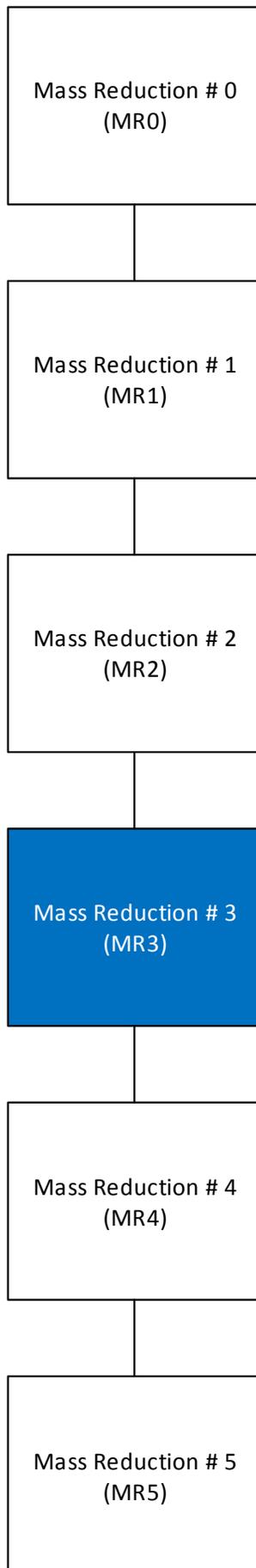
Distribution of Fuel Consumption for Vehicle Technology-Mass Reduction#1 (MR1)  
 Incremental percentage compared with: Mass Reduction#0 (MR0)  
 Standard Deviation : 0.2



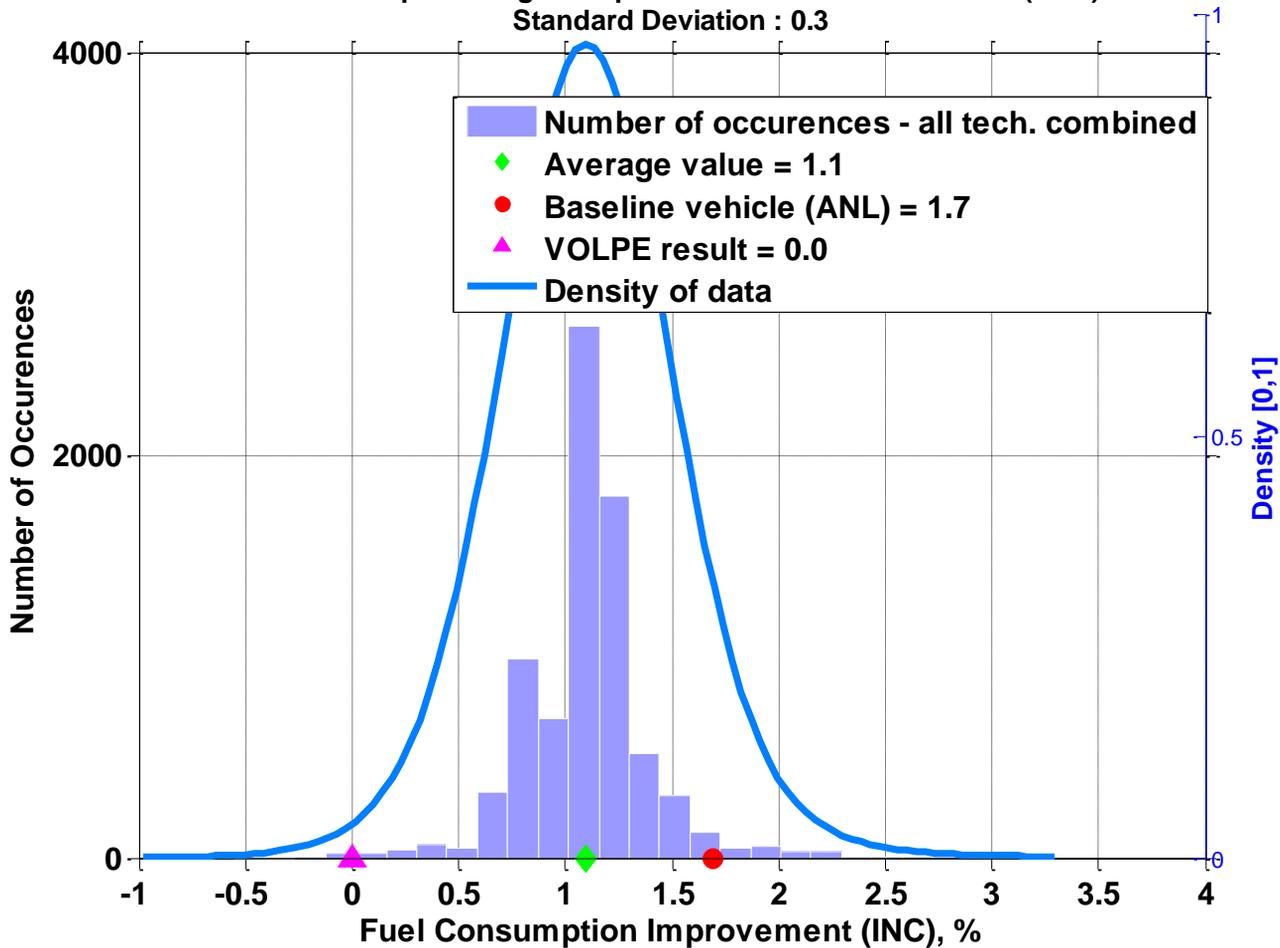


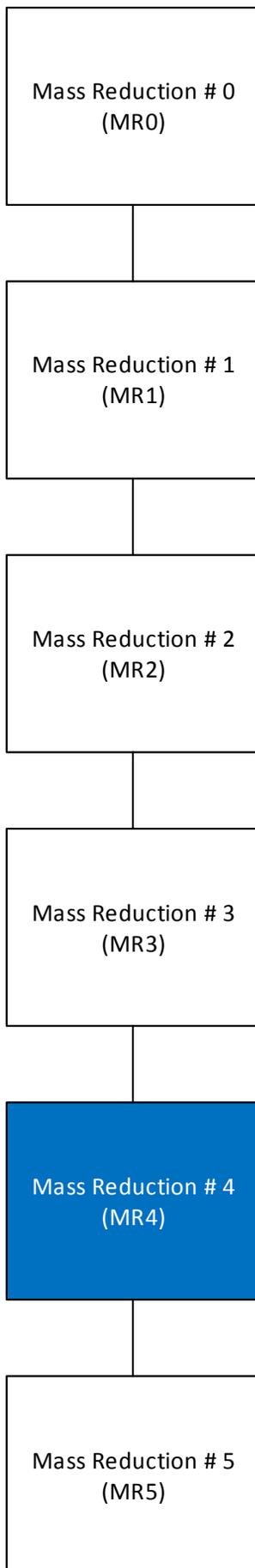
Distribution of Fuel Consumption for Vehicle Technology-Mass Reduction#2 (MR2)  
 Incremental percentage compared with: Mass Reduction#1 (MR1)  
 Standard Deviation : 0.5



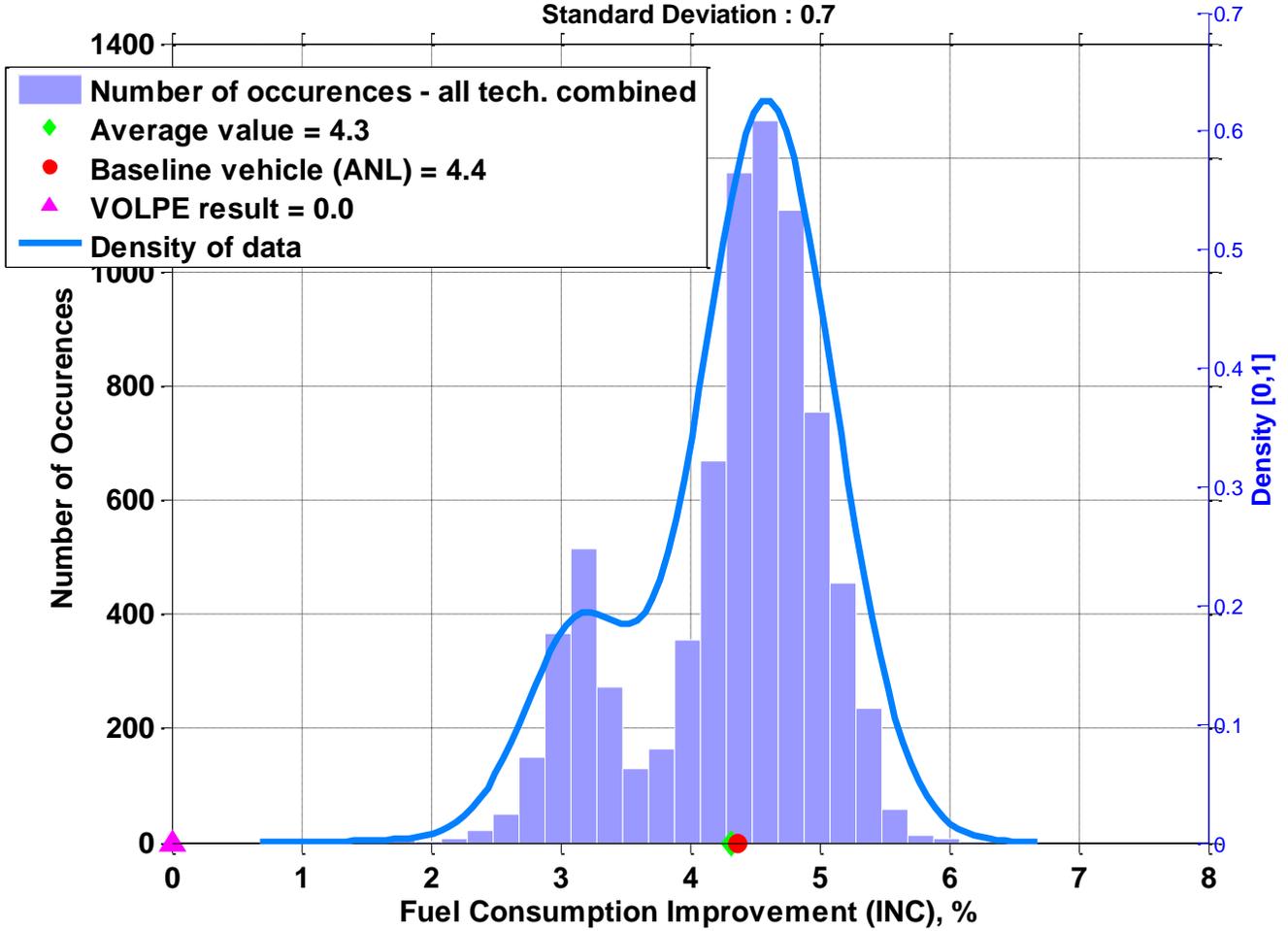


Distribution of Fuel Consumption for Vehicle Technology-Mass Reduction#3 (MR3)  
 Incremental percentage compared with: Mass Reduction#2 (MR2)  
 Standard Deviation : 0.3





Distribution of Fuel Consumption for Vehicle Technology-Mass Reduction#4 (MR4)  
 Incremental percentage compared with: Mass Reduction#3 (MR3)  
 Standard Deviation : 0.7



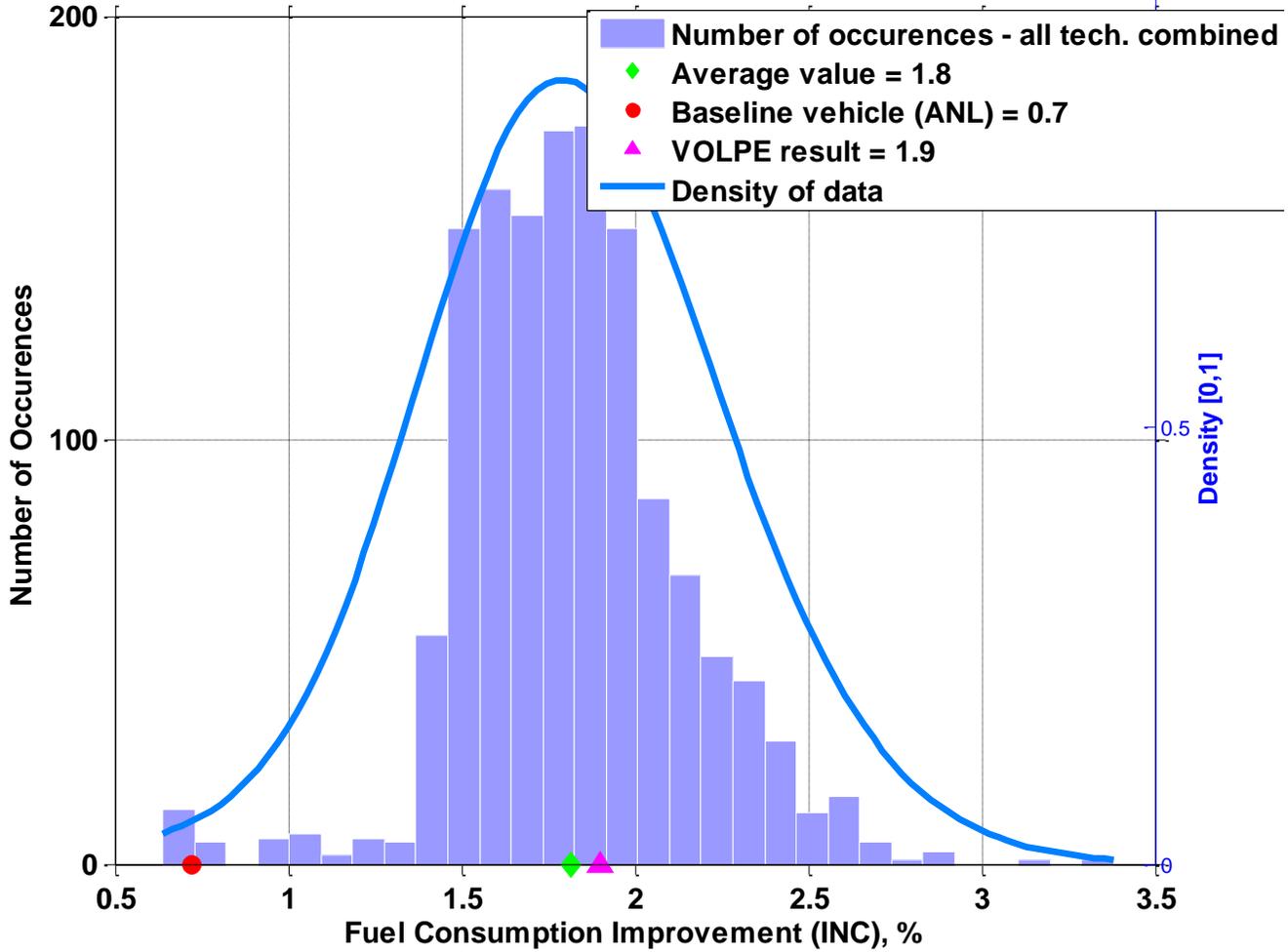
Low Rolling Resistance  
Tires # 0 (ROLL0)

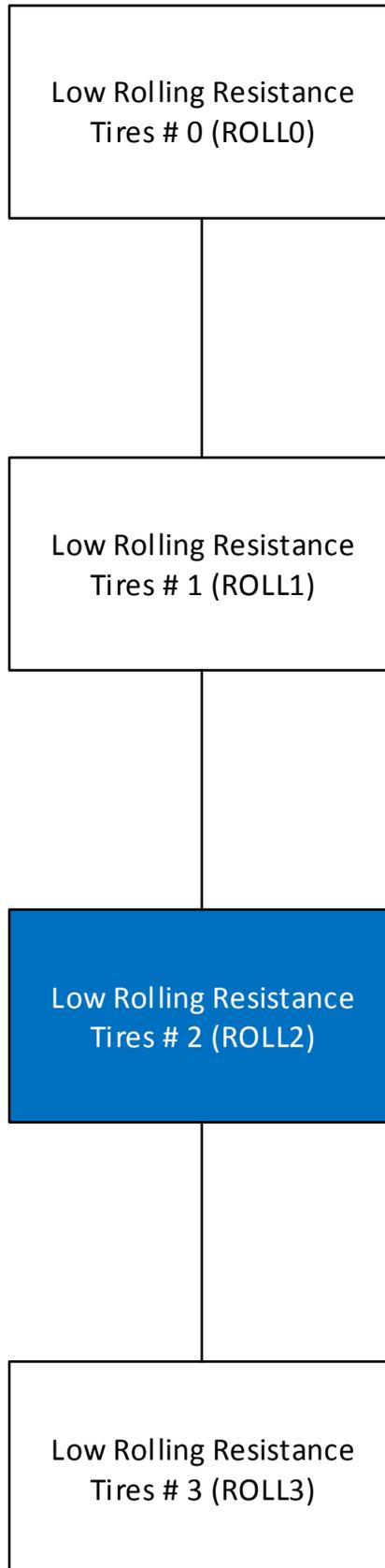
Low Rolling Resistance  
Tires # 1 (ROLL1)

Low Rolling Resistance  
Tires # 2 (ROLL2)

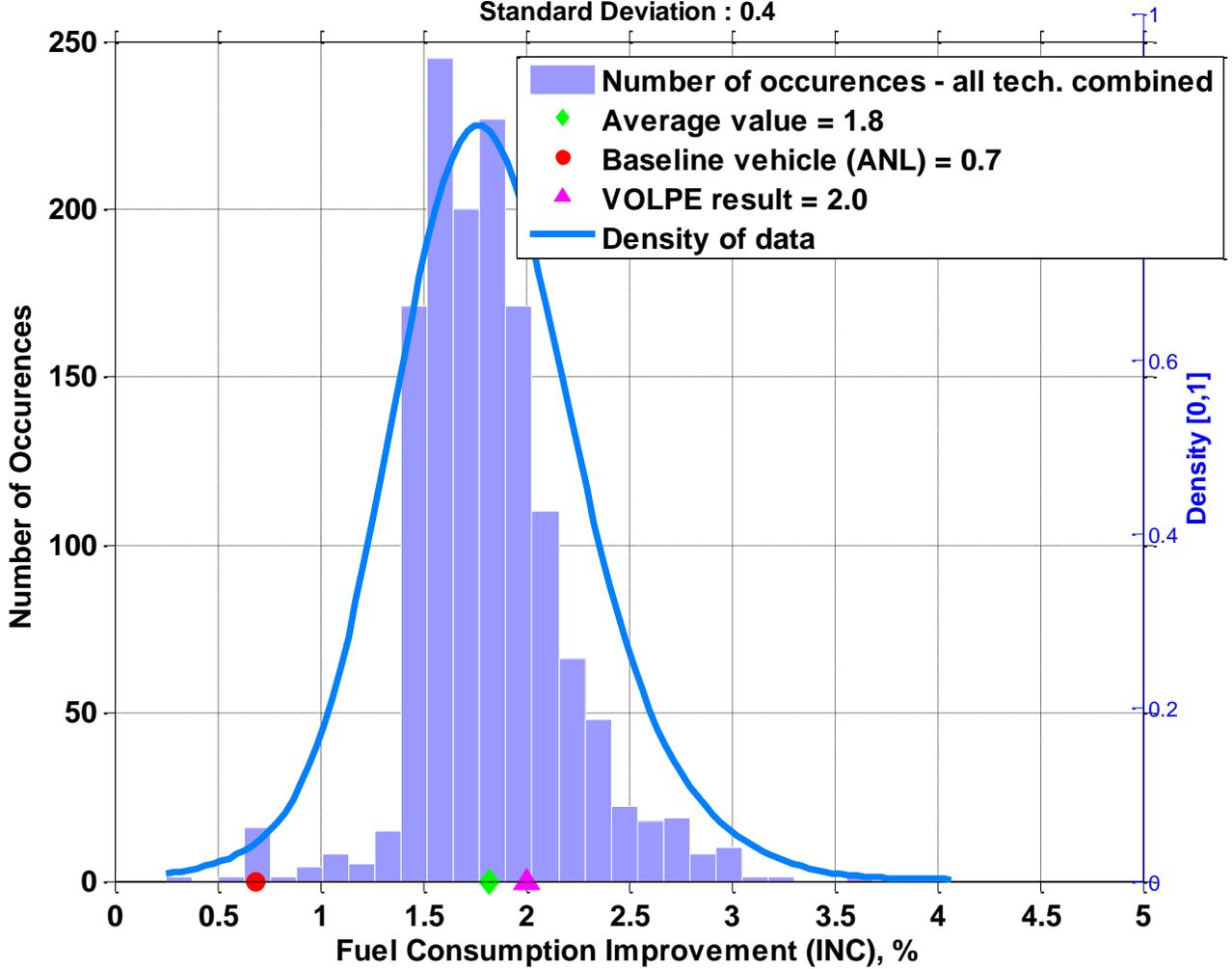
Low Rolling Resistance  
Tires # 3 (ROLL3)

Distribution of Fuel Consumption for Vehicle Technology-Low Rolling Resistance Tires#1(ROLL1)  
 Incremental percentage compared with: Low Rolling Resistance Tires#0(ROLL0)  
 Standard Deviation : 0.3





Distribution of Fuel Consumption for Vehicle Technology-Low Rolling Resistance Tires#2(ROLL2)  
 Incremental percentage compared with: Low Rolling Resistance Tires#1(ROLL1)  
 Standard Deviation : 0.4



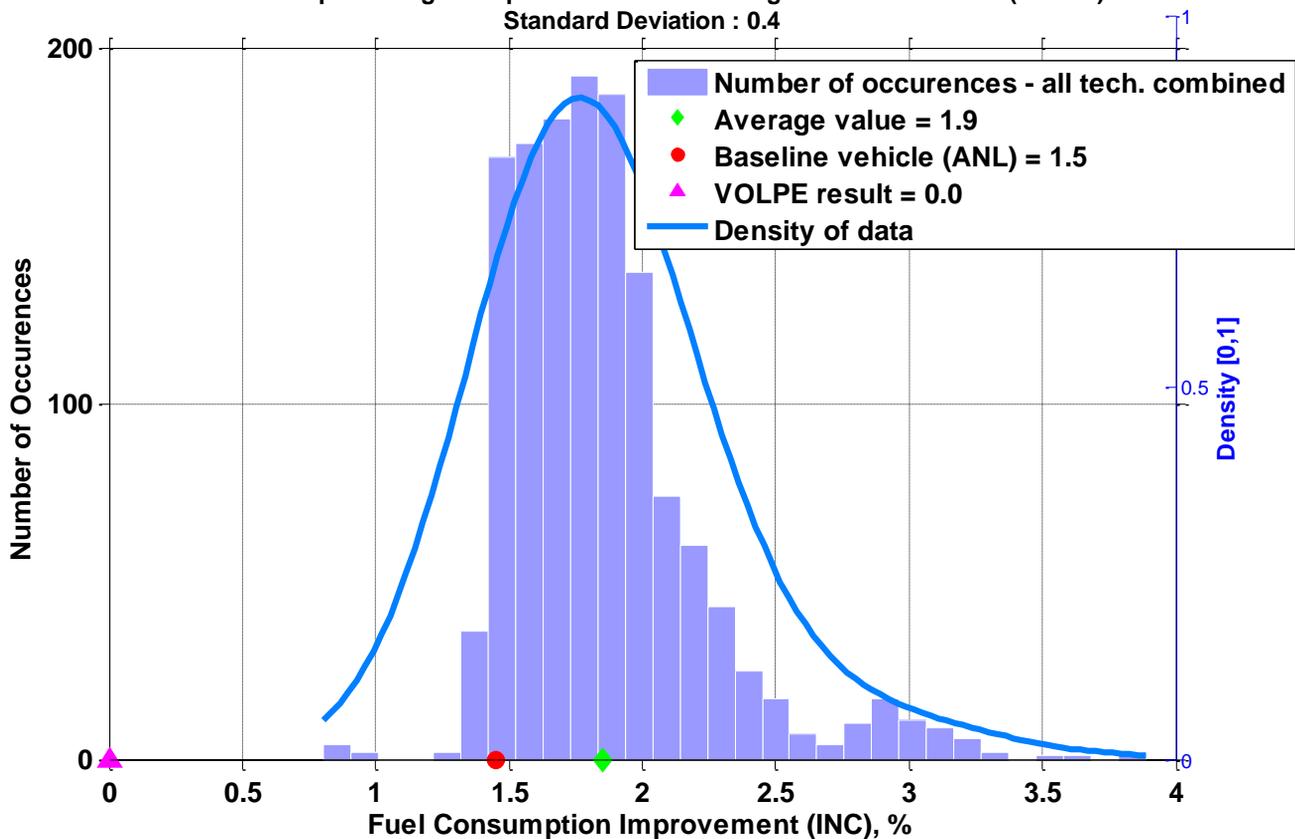
Low Rolling Resistance  
Tires # 0 (ROLL0)

Low Rolling Resistance  
Tires # 1 (ROLL1)

Low Rolling Resistance  
Tires # 2 (ROLL2)

Low Rolling Resistance  
Tires # 3 (ROLL3)

Distribution of Fuel Consumption for Vehicle Technology-Low Rolling Resistance Tires#3(ROLL3)  
 Incremental percentage compared with: Low Rolling Resistance Tires#2(ROLL2)  
 Standard Deviation : 0.4

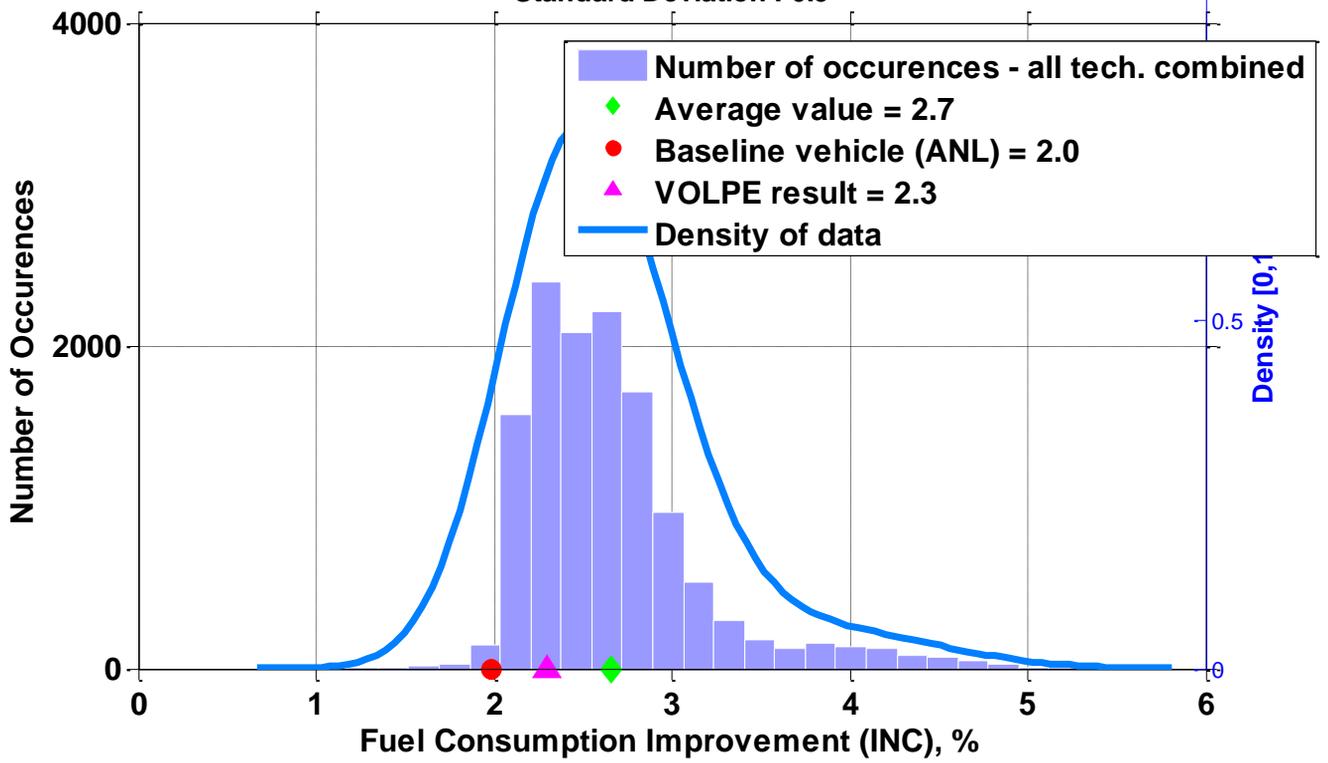


Aerodynamic Drag  
Reduction # 0 (AERO0)

Aerodynamic Drag  
Reduction # 1 (AERO1)

Aerodynamic Drag  
Reduction # 2 (AERO2)

Distribution of Fuel Consumption for Vehicle Technology-Aerodynamic Drag Reduction#1 (AERO1)  
 Incremental percentage compared with: Aerodynamic Drag Reduction#0 (AERO0)  
 Standard Deviation : 0.5

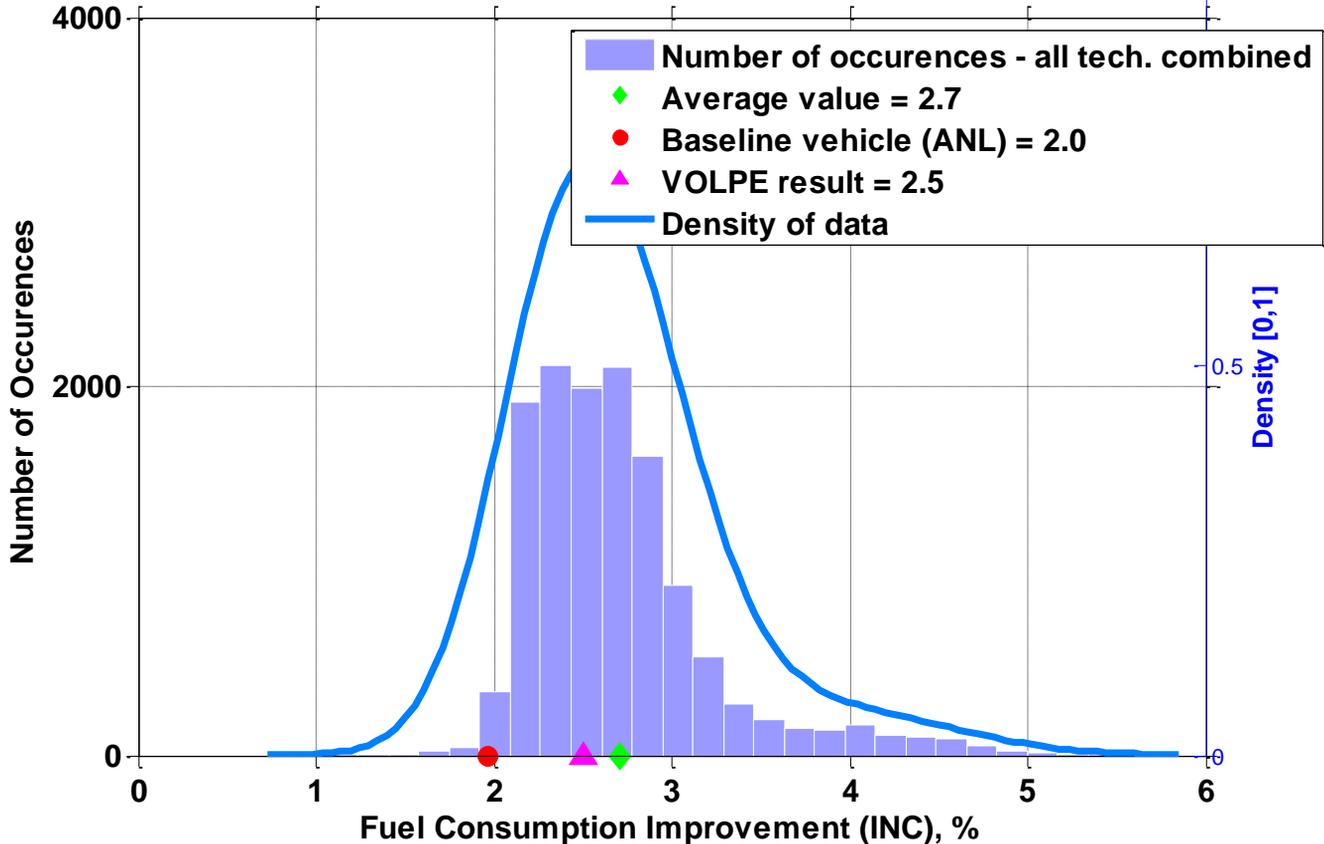


Aerodynamic Drag  
Reduction # 0 (AERO0)

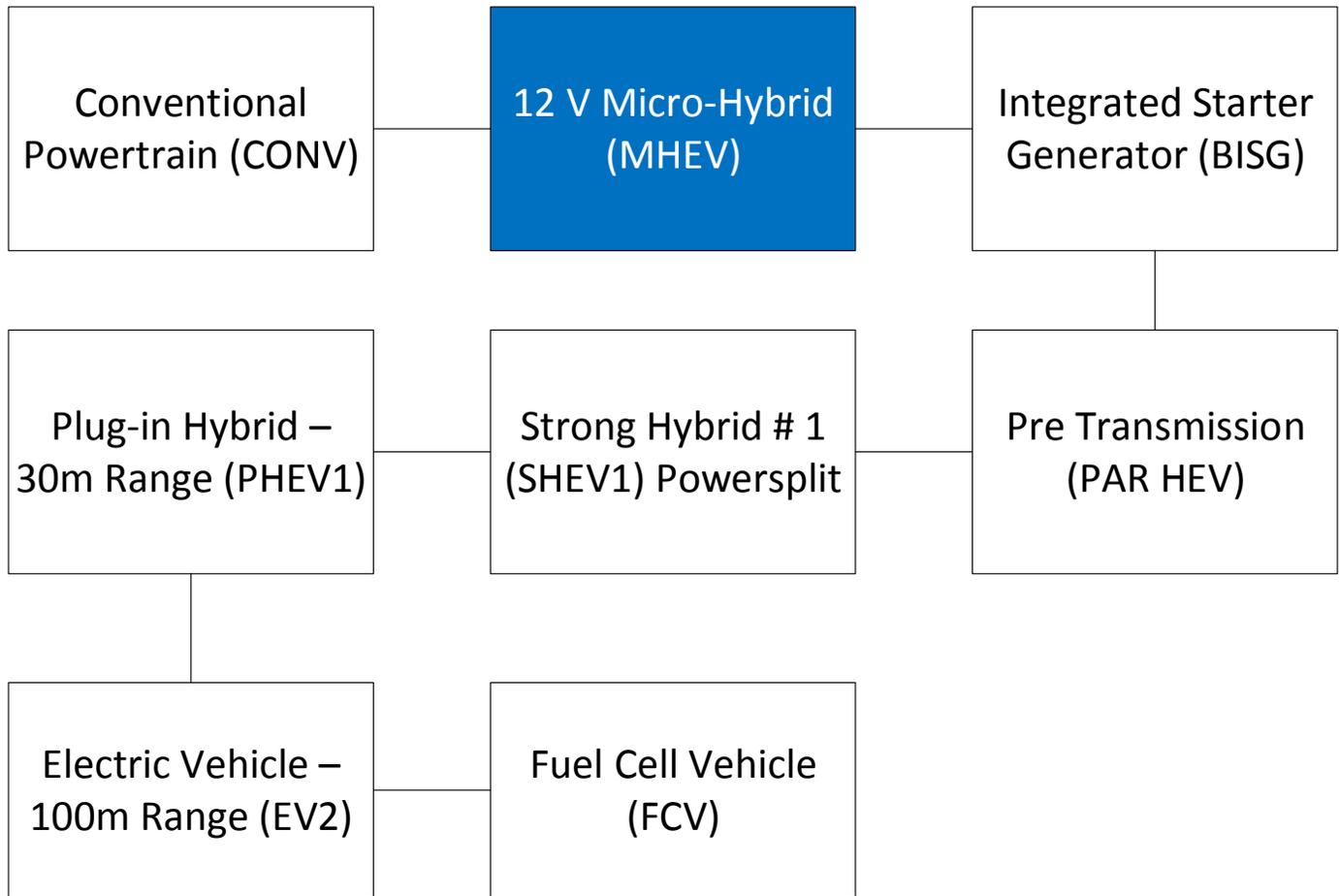
Aerodynamic Drag  
Reduction # 1 (AERO1)

Aerodynamic Drag  
Reduction # 2 (AERO2)

Distribution of Fuel Consumption for Vehicle Technology-Aerodynamic Drag Reduction#2 (AERO2)  
 Incremental percentage compared with: Aerodynamic Drag Reduction#1 (AERO1)  
 Standard Deviation : 0.5



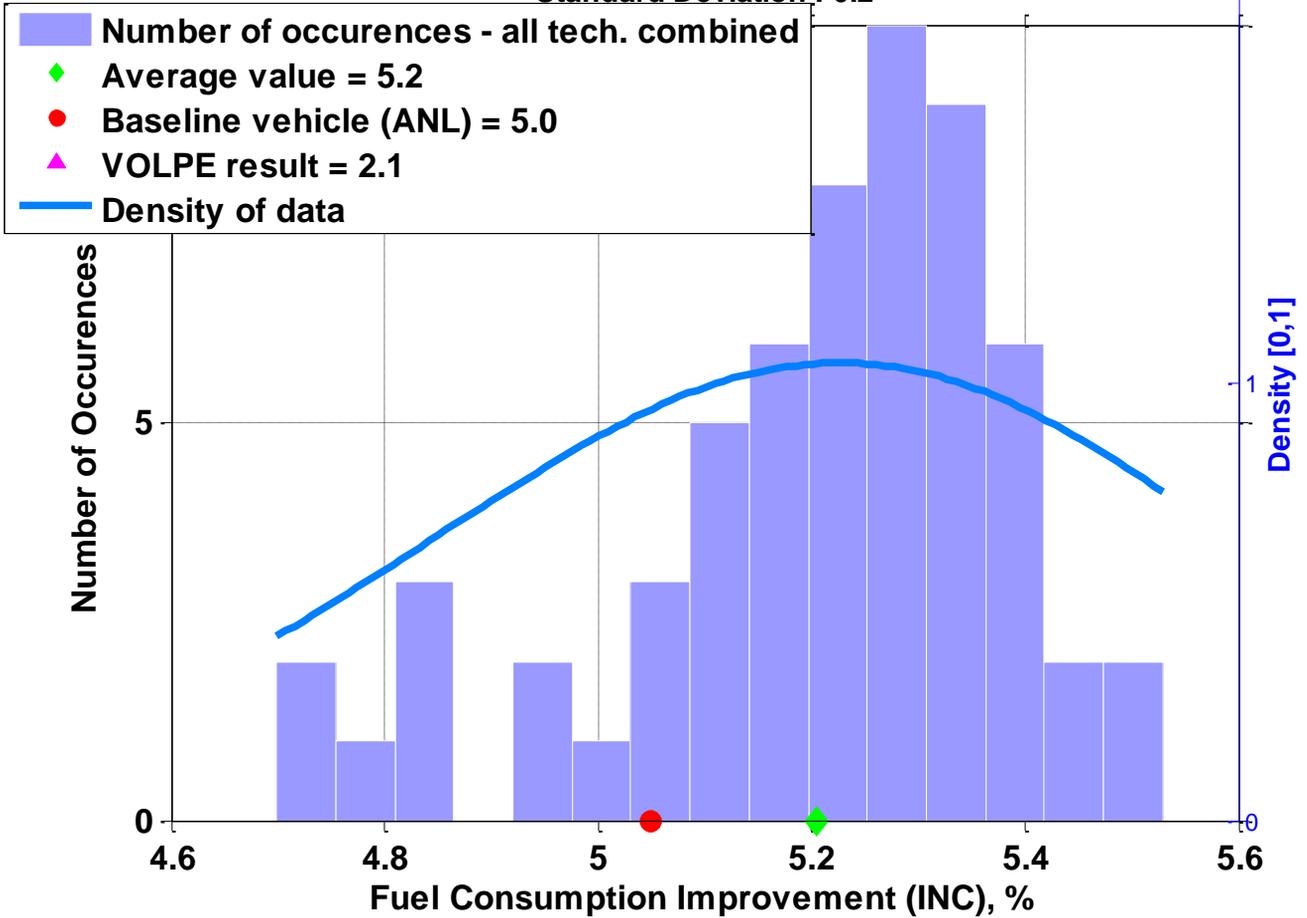
# HYBRIDIZATION TECHNOLOGY

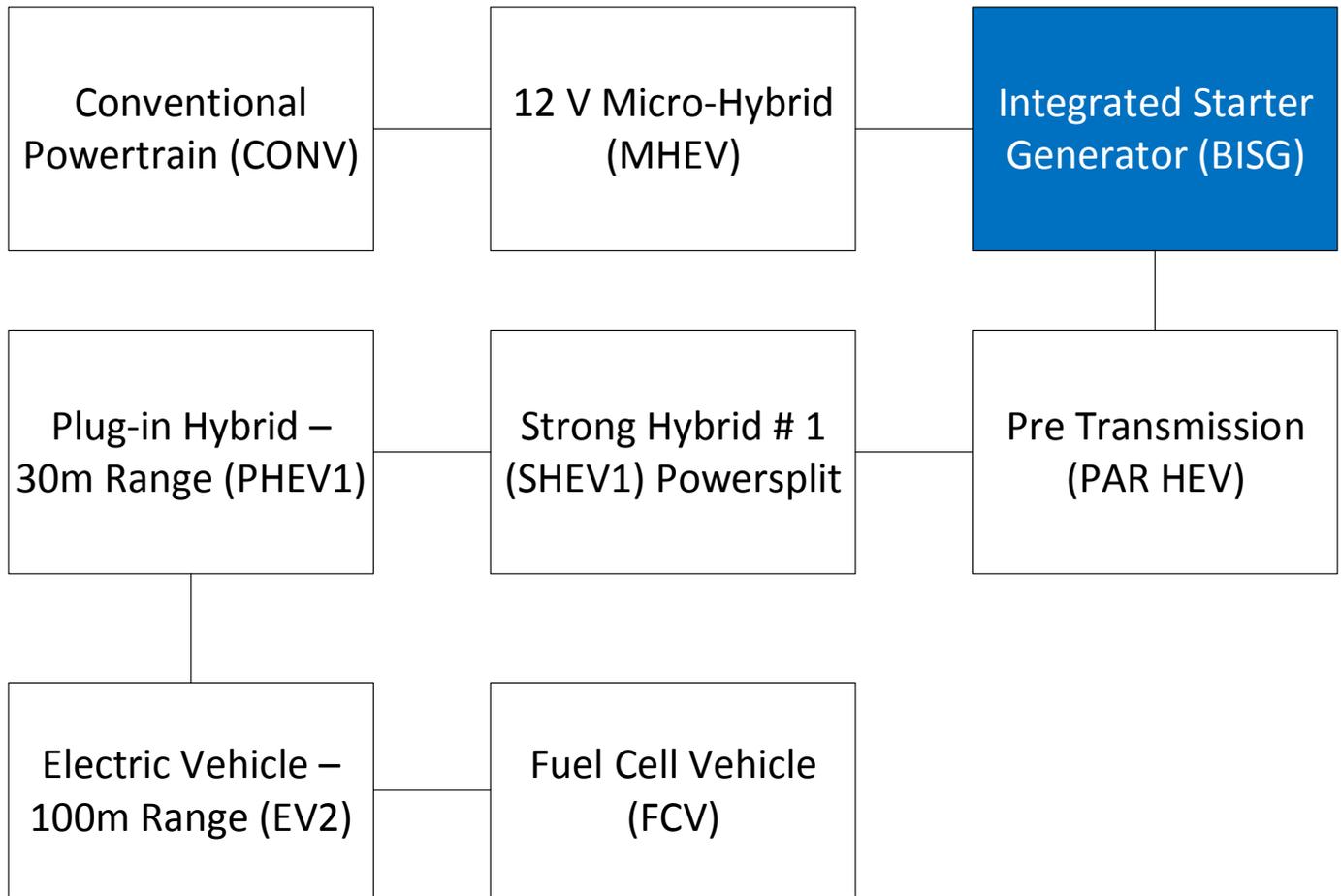


Distribution of Fuel Consumption for Hybrid-12V Micro-Hybrid(MHEV)  
Incremental percentage compared with: Conventional Powertrain

Average : 5.2045

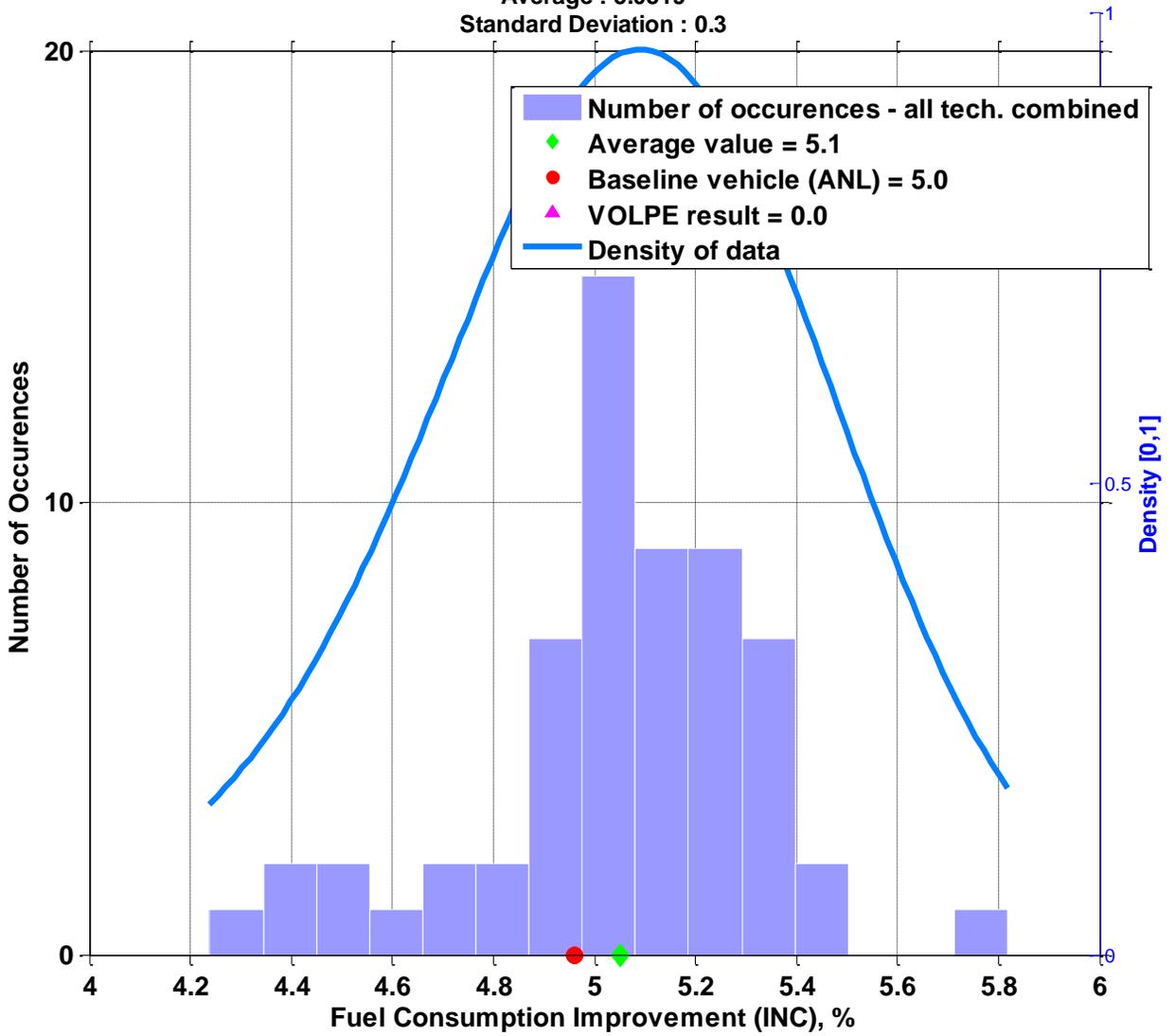
Standard Deviation : 0.2

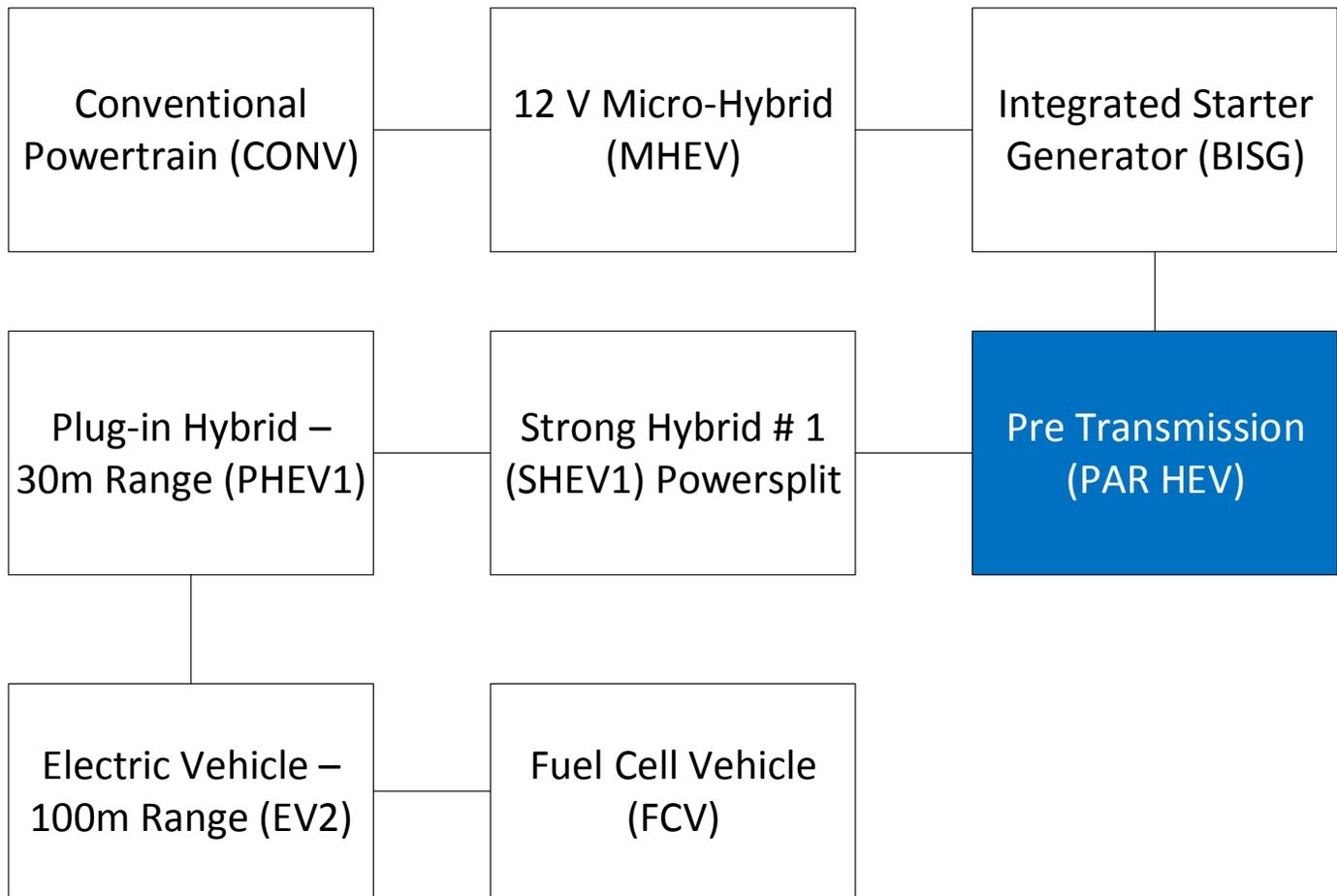




Distribution of Fuel Consumption for Hybrid-Integrated Starter Generator (BISG)  
 Incremental percentage compared with: 12V Micro-Hybrid(MHEV)

Average : 5.0519  
 Standard Deviation : 0.3

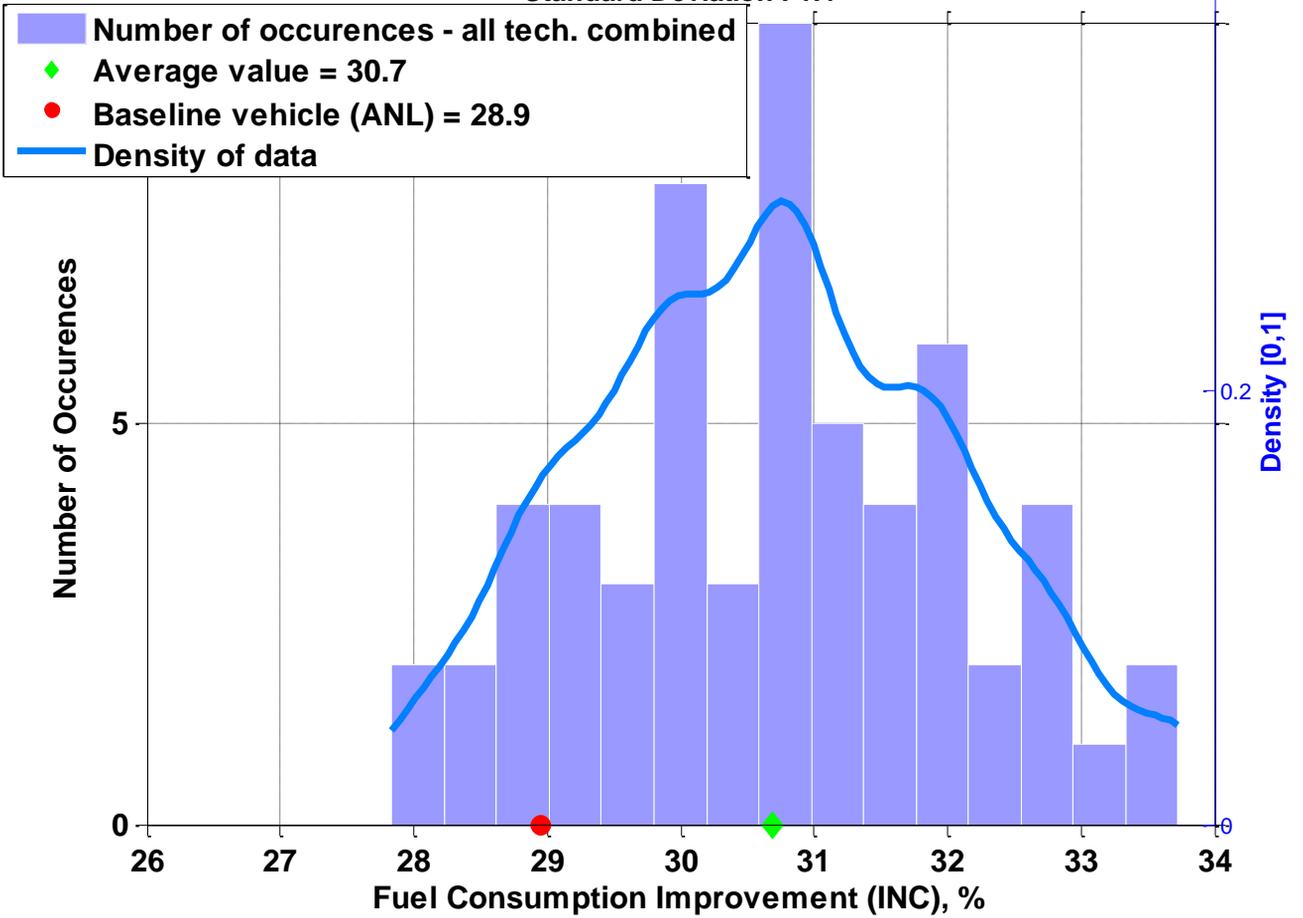


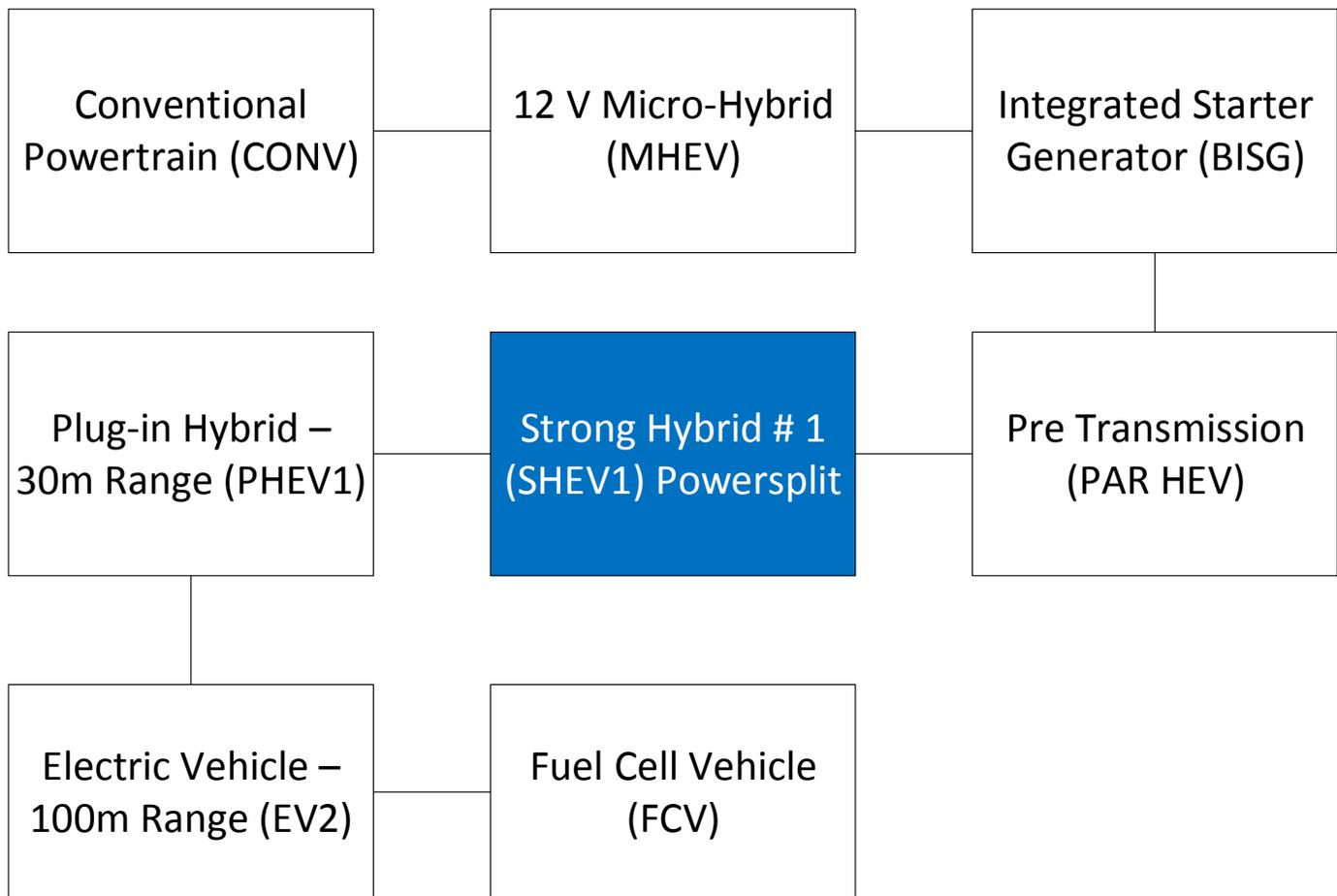


Distribution of Fuel Consumption for Hybrid-Pretransmission Hybrid  
Incremental percentage compared with: Integrated Starter Generator (BISG)

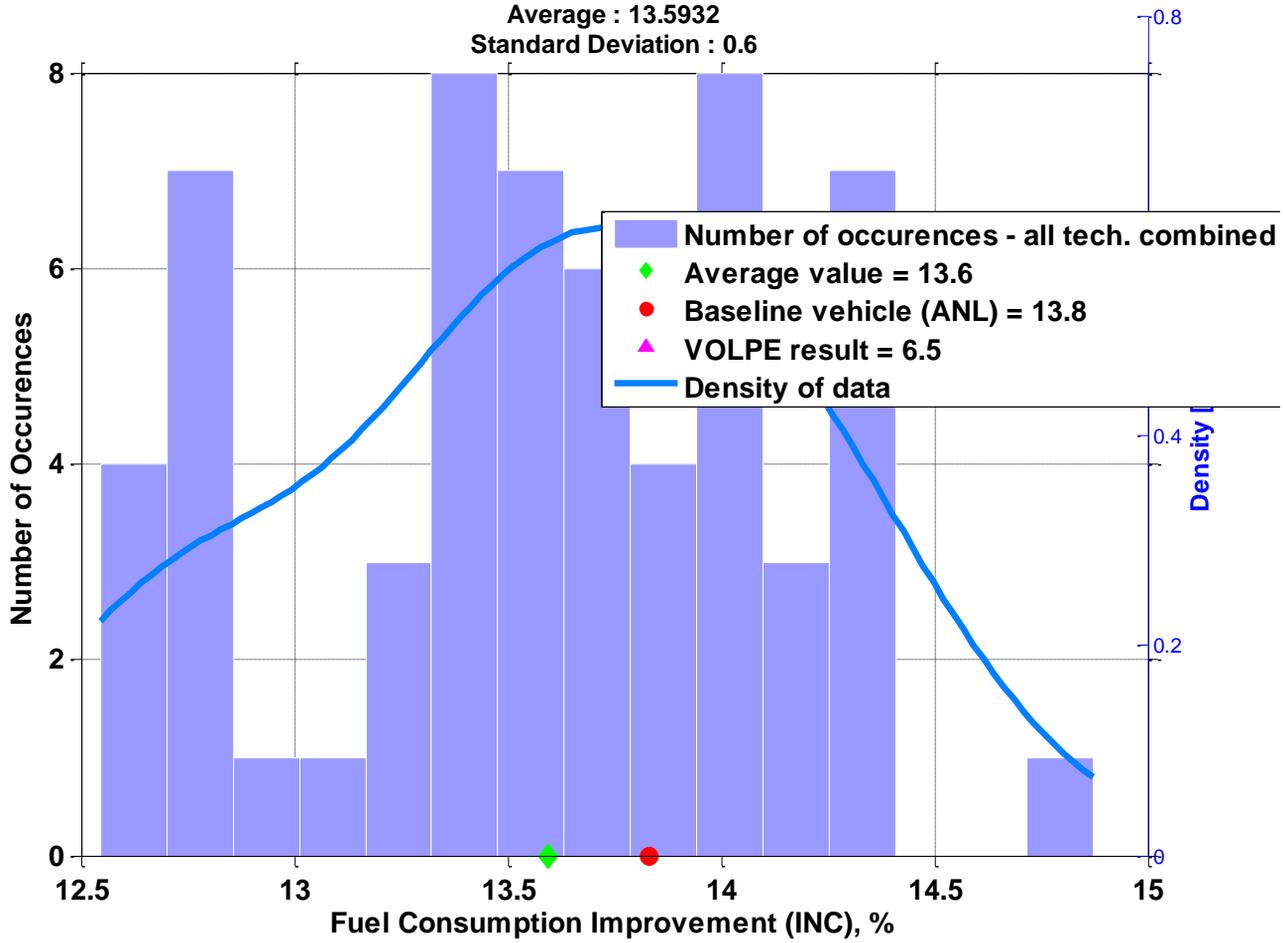
Average : 30.6879

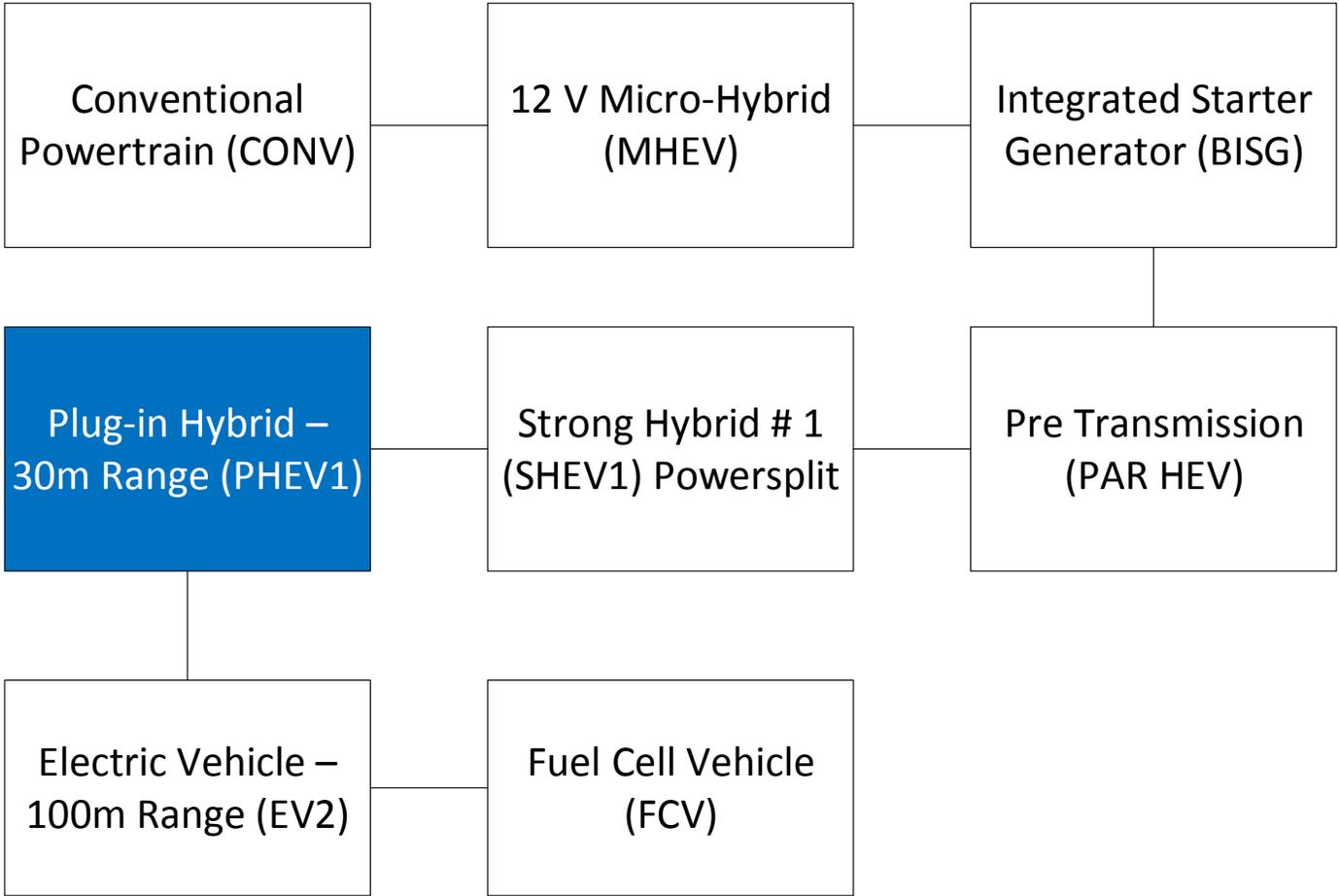
Standard Deviation : 1.4





Distribution of Fuel Consumption for Hybrid-Strong Hybrid#1 (SHEV1)  
 Incremental percentage compared with: Pretransmission Hybrid  
 Average : 13.5932  
 Standard Deviation : 0.6

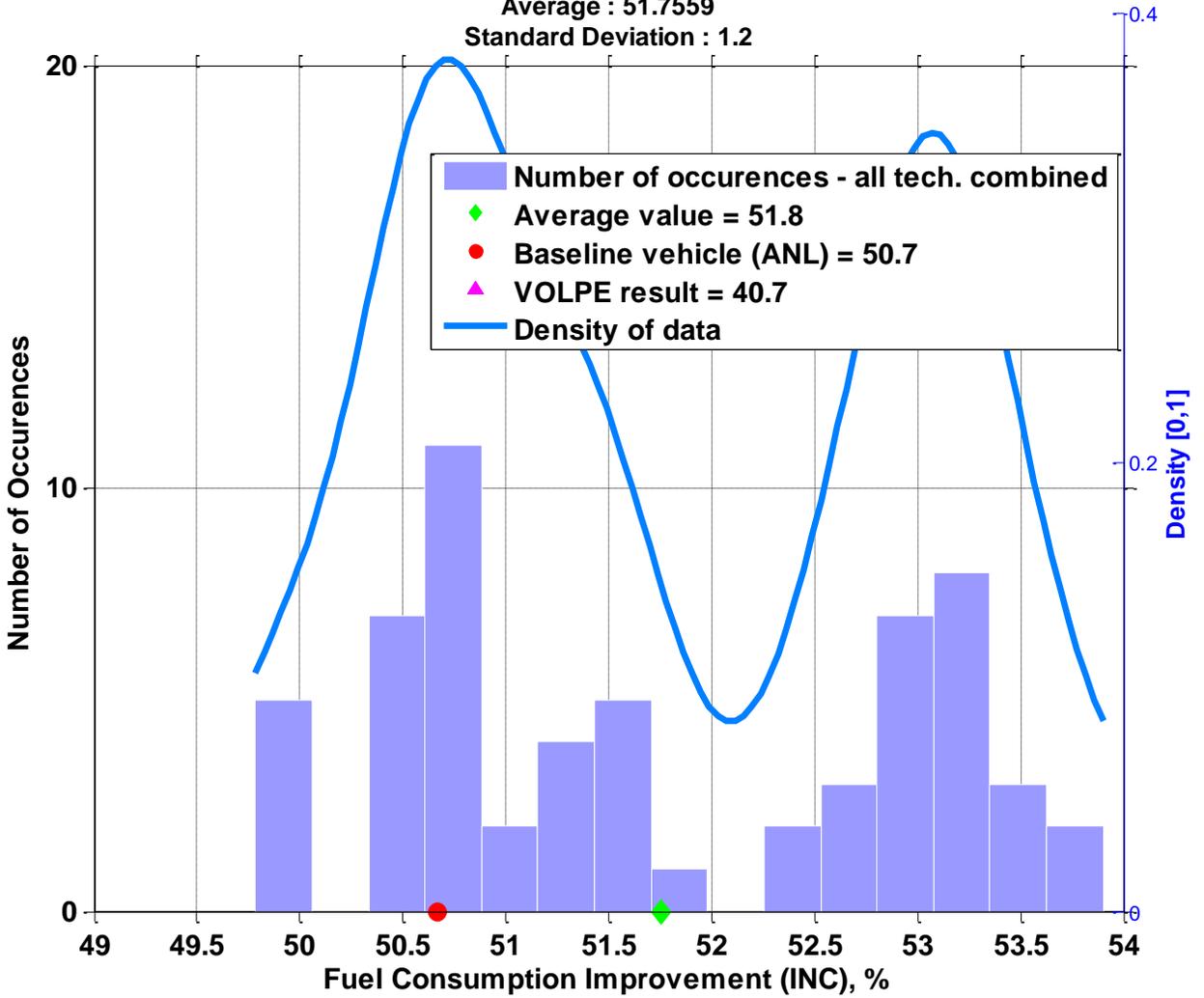


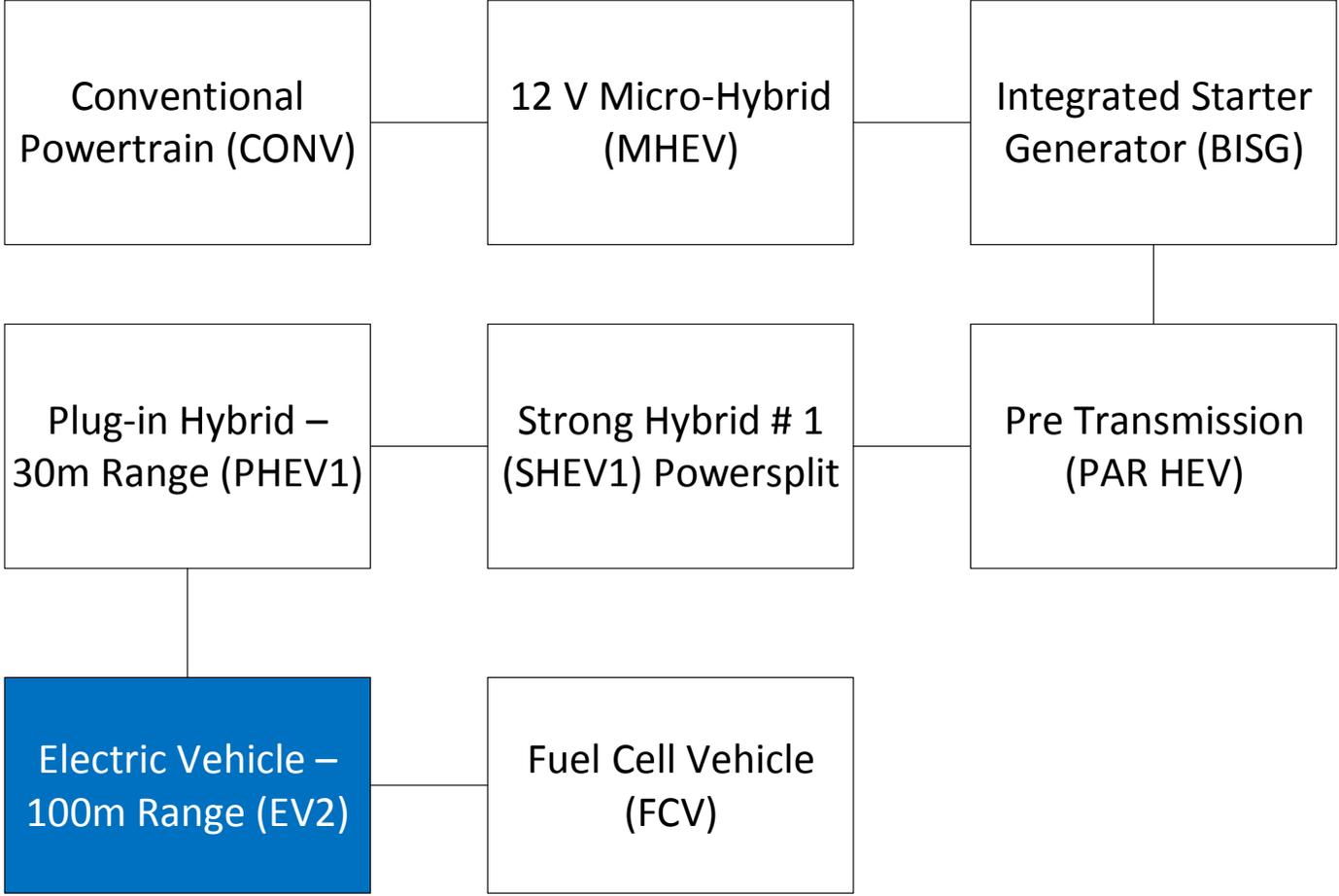


**Distribution of Fuel Consumption for Hybrid-Plug-in Hybrid 30m Range (PHEV1)  
Incremental percentage compared with: Strong Hybrid#1 (SHEV1)**

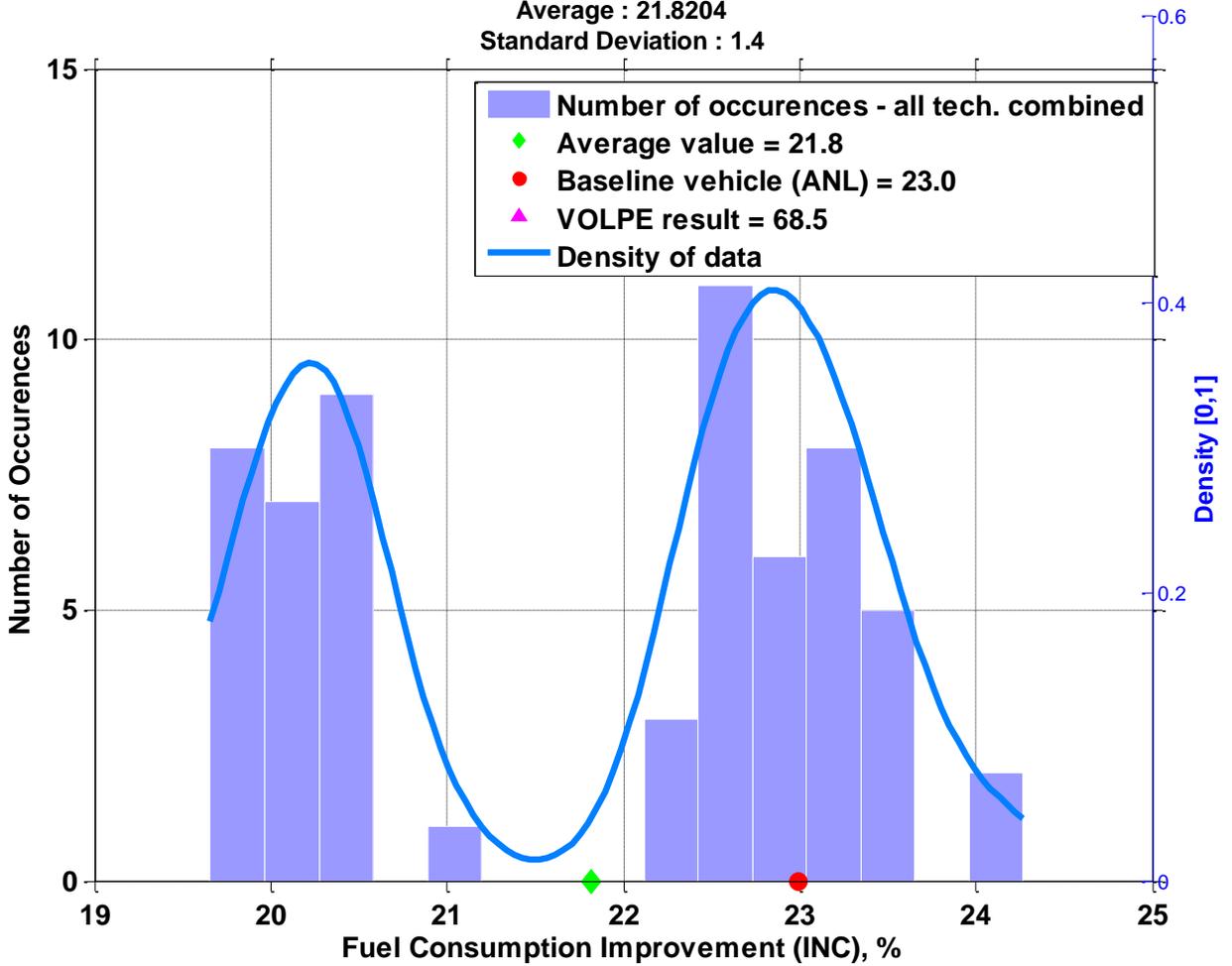
Average : 51.7559

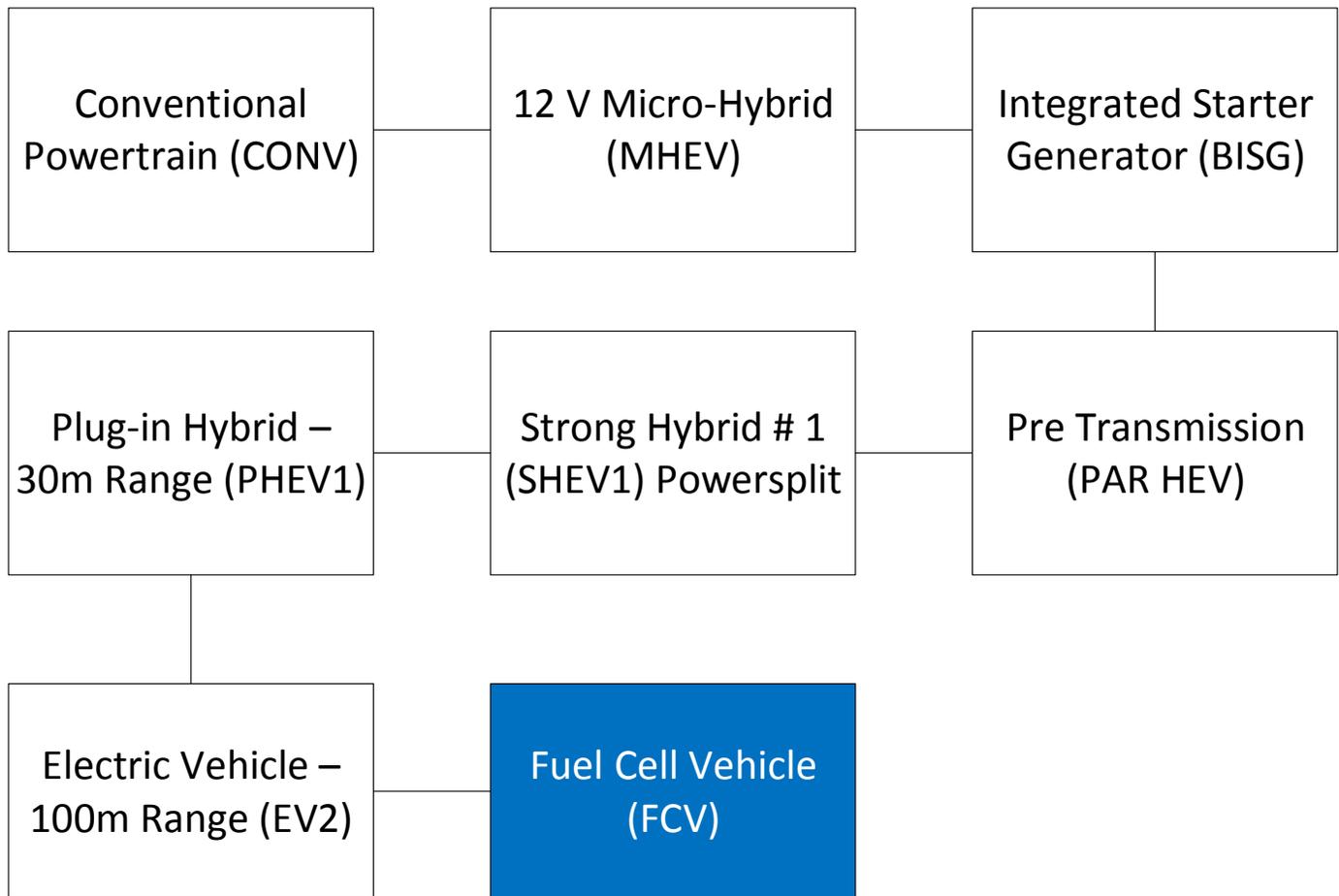
Standard Deviation : 1.2





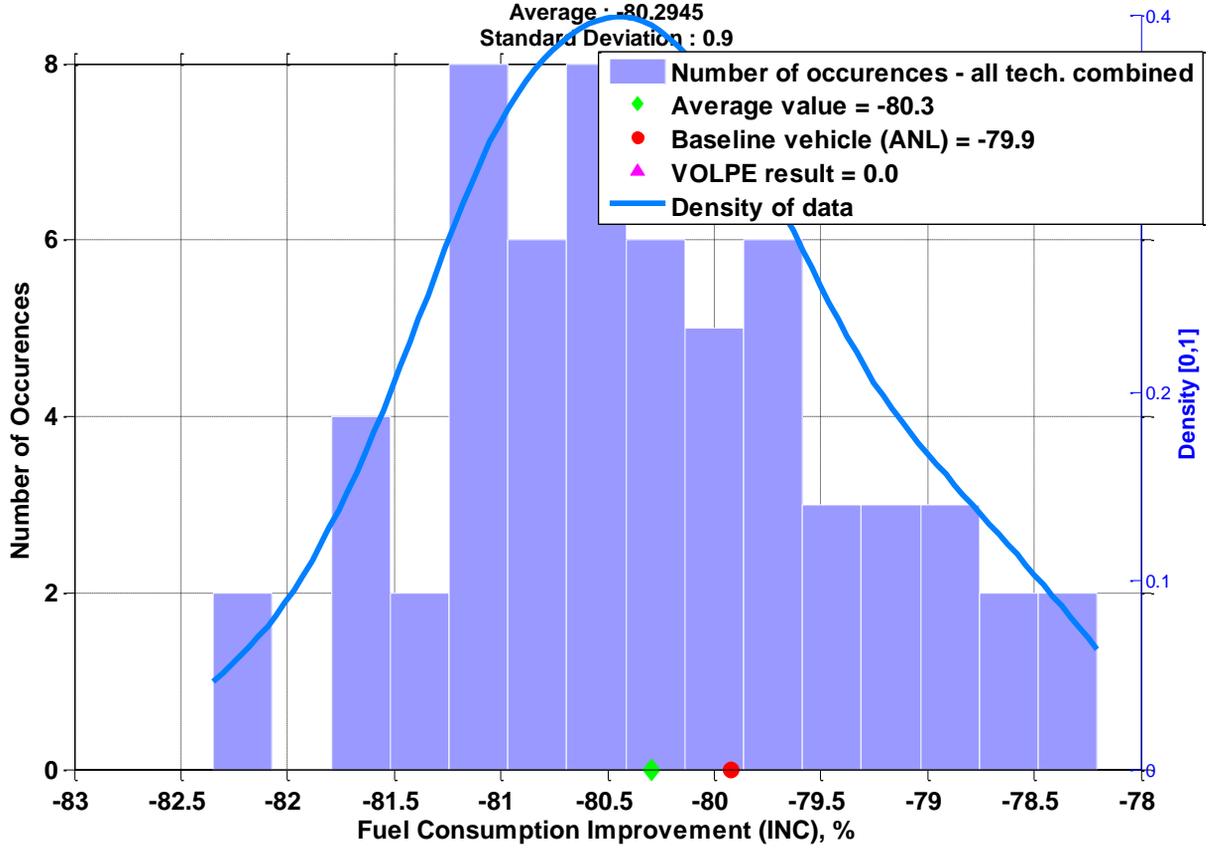
Distribution of Fuel Consumption for Hybrid-Electric Vehicle - 100m Range (EV2)  
 Incremental percentage compared with: Plug-in Hybrid 30m Range (PHEV1)  
 Average : 21.8204  
 Standard Deviation : 1.4





Distribution of Fuel Consumption for Hybrid-Fuel Cell Vehicle (FCV)  
 Incremental percentage compared with: Electric Vehicle - 100m Range (EV2)

Average : -80.2945  
 Standard Deviation : 0.9





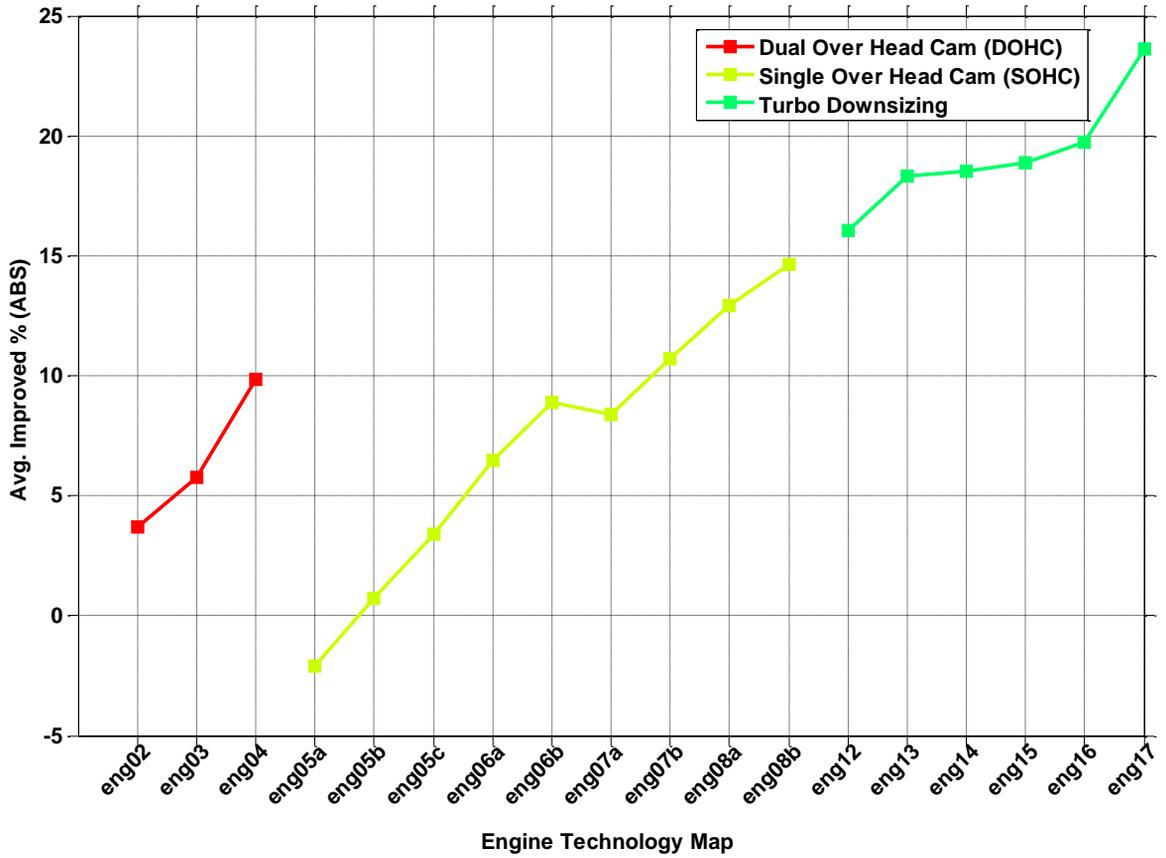
# **SUMMARY OF PLOT RESULTS [Part 3]**



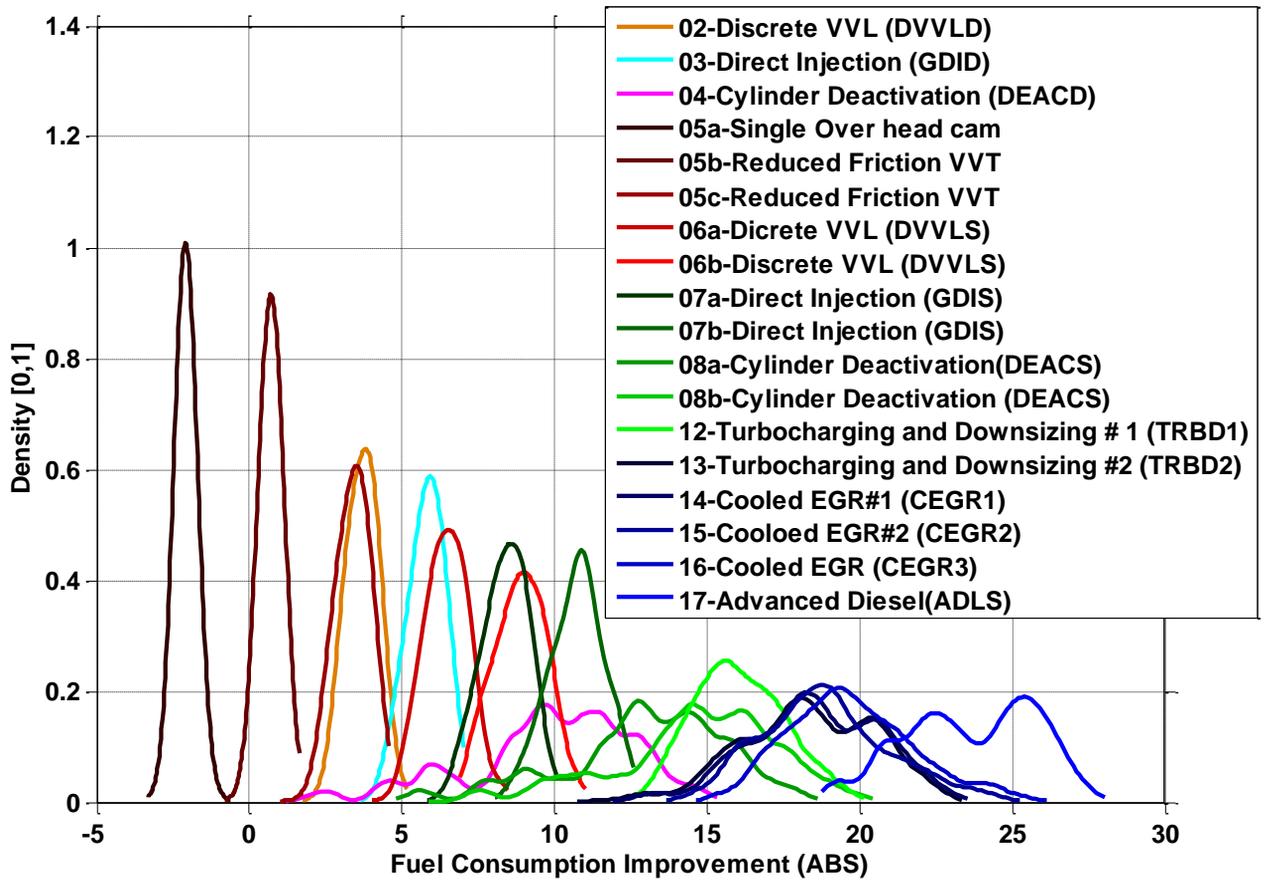
# ENGINE TECHNOLOGY

# **ABSOLUTE IMPROVEMENT RESULTS**

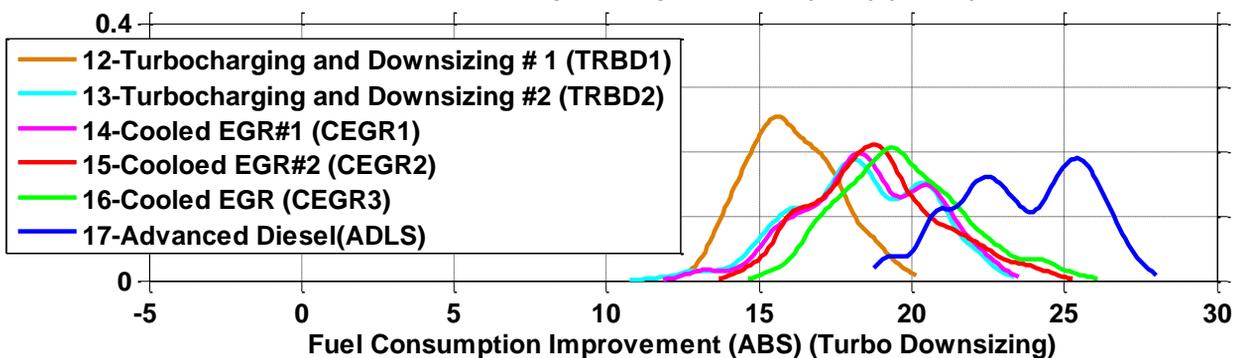
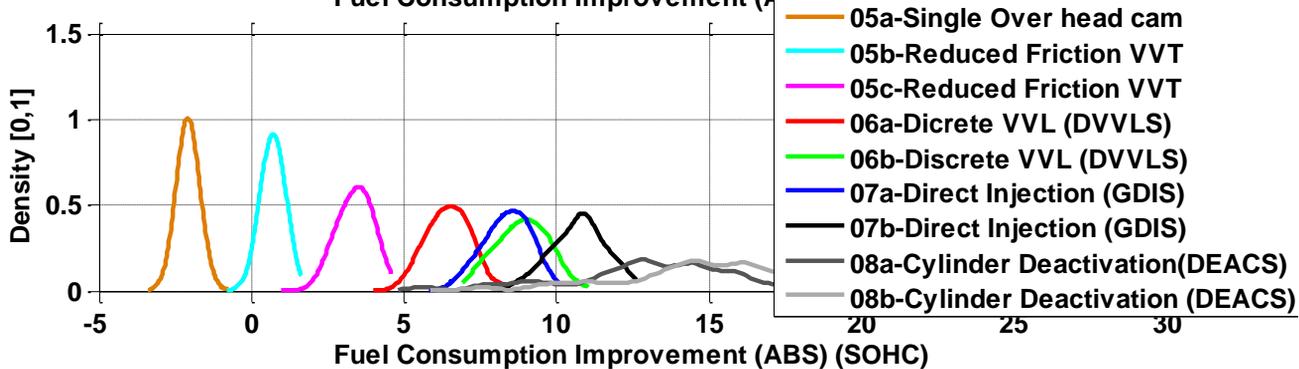
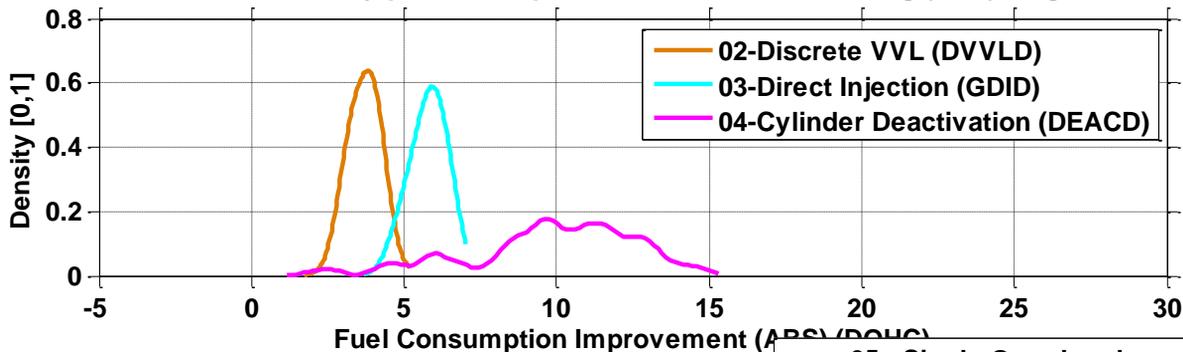
General trendline on engine technologies  
Absolute percentage compared with: Dual Cam Phasing(DCP)[eng01]



Density profile of different engine technologies  
 Absolute density profile compared with: Dual Cam Phasing (DCP) [eng01]

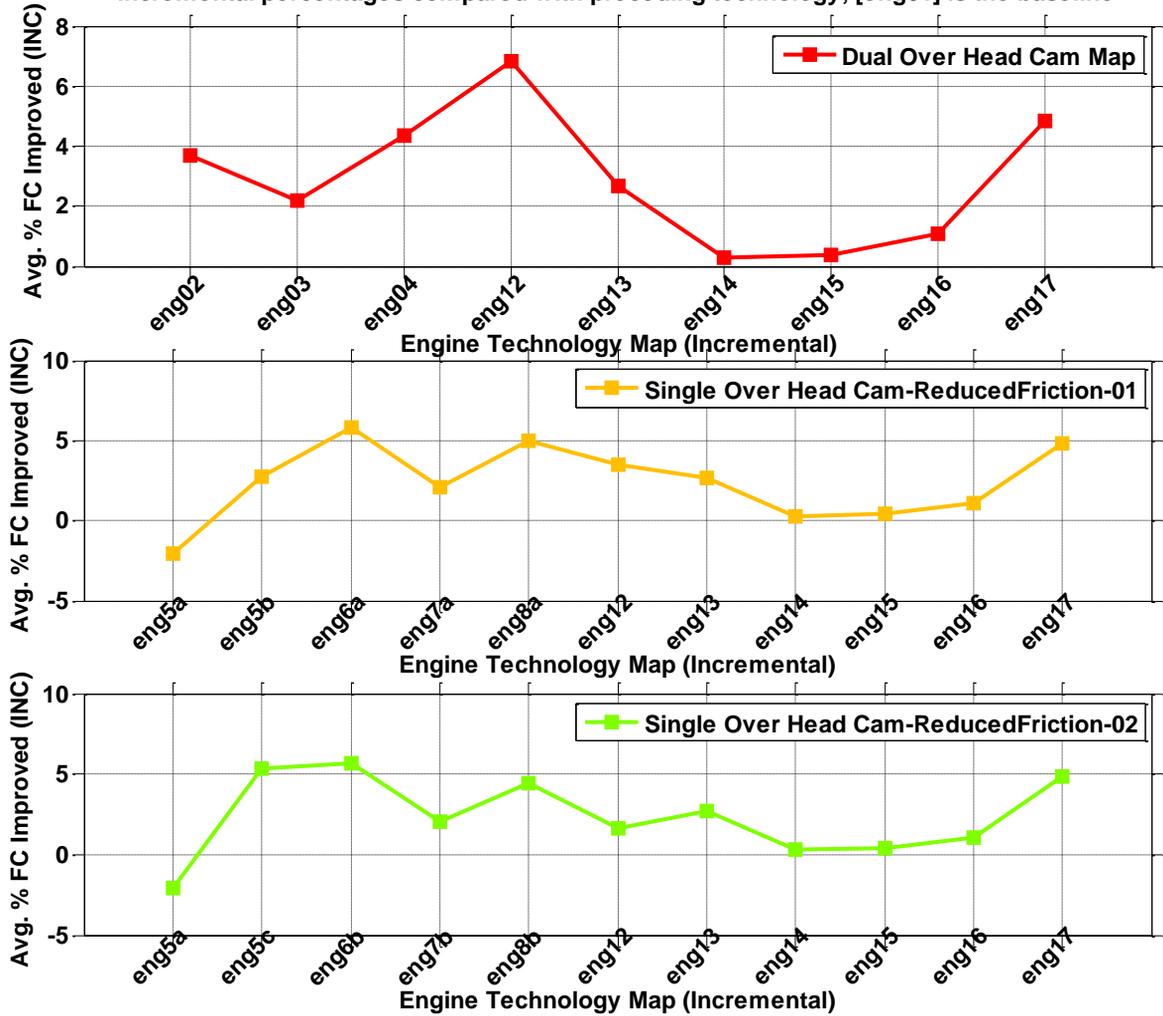


Density profile of different engine technologies  
 Absolute density profile compared with: Dual Cam Phasing (DCP) [eng01]

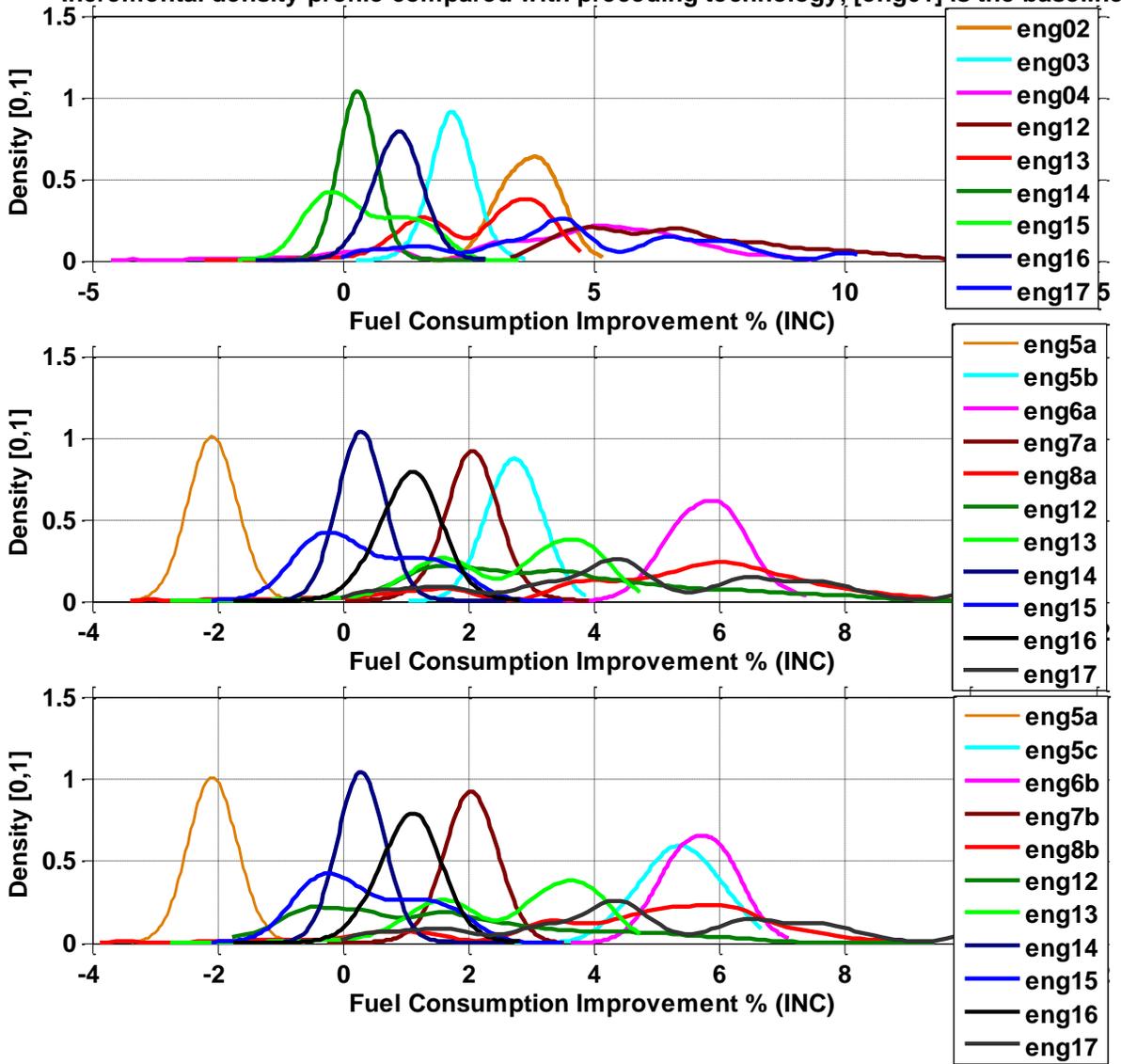


# INCREMENTAL IMPROVEMENT RESULTS

General Incremental trendline on engine technologies  
 Incremental percentages compared with preceding technology, [eng01] is the baseline



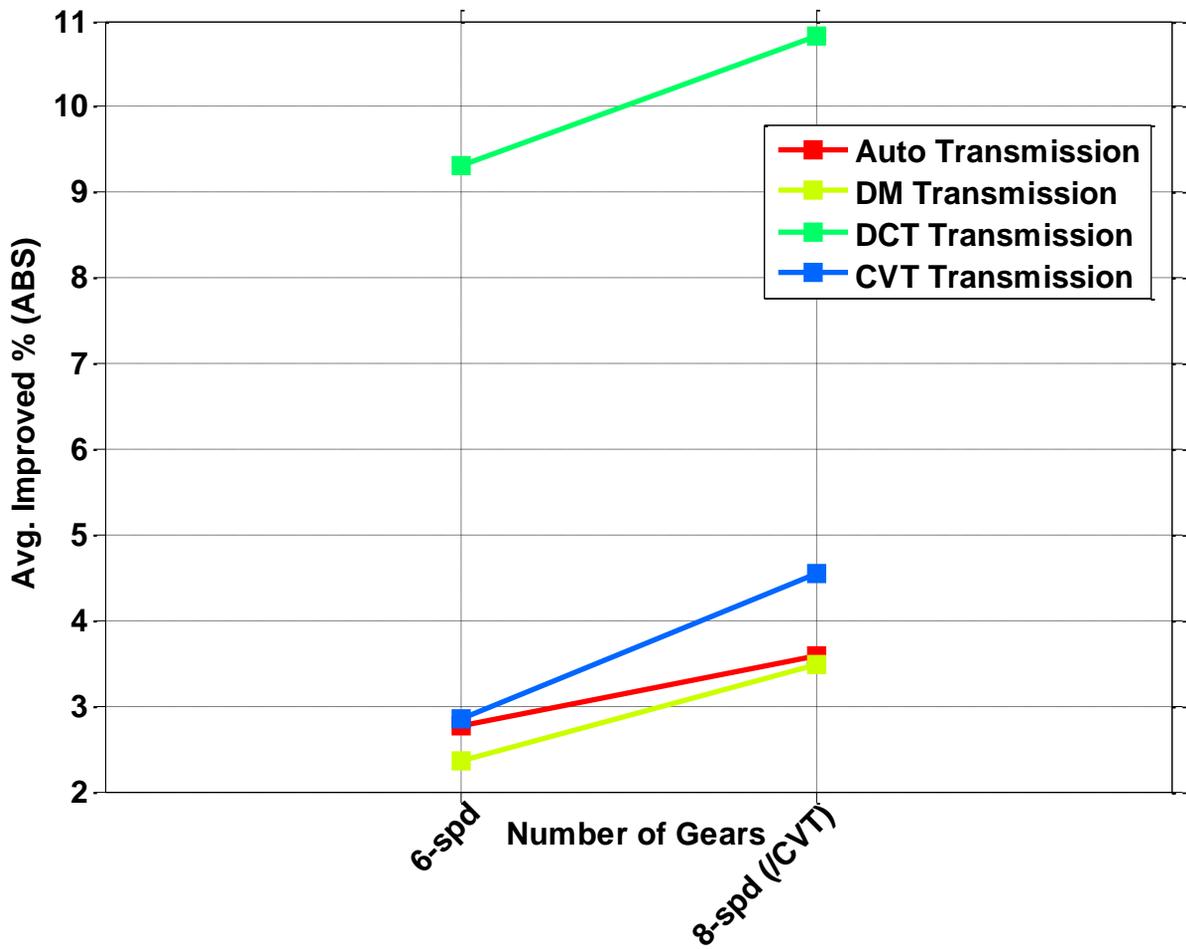
Density profile of different engine technologies  
 Incremental density profile compared with preceding technology, [eng01] is the baseline



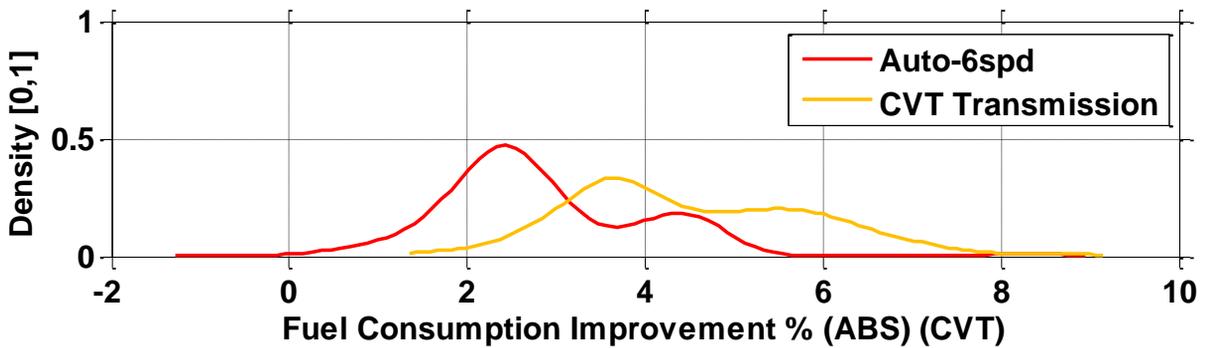
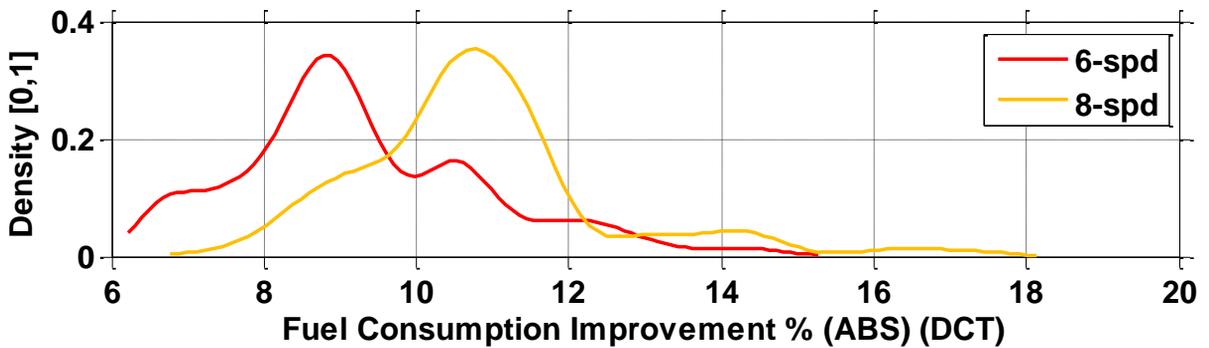
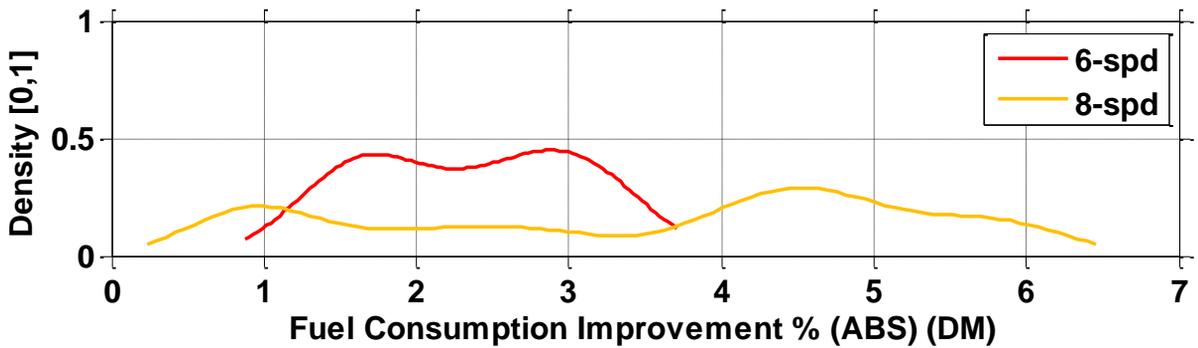
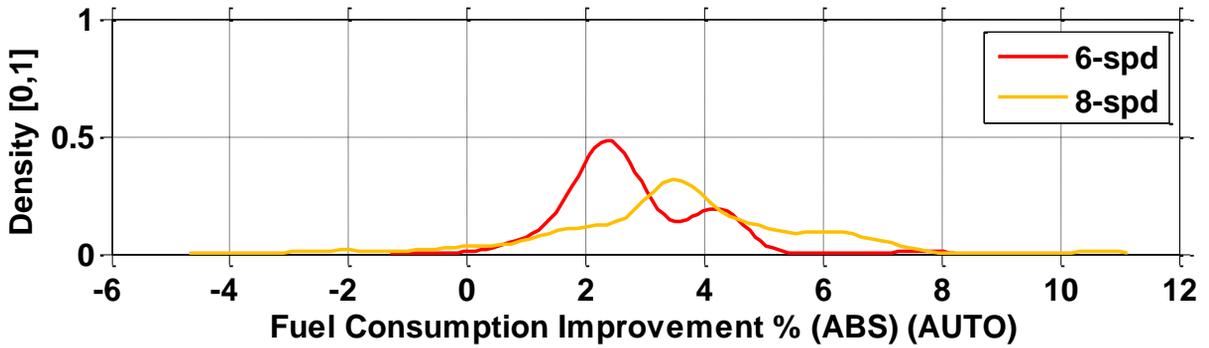
# TRANSMISSION TECHNOLOGY

# **ABSOLUTE IMPROVEMENT RESULTS**

**General trendline on transmission technologies**  
**Absolute percentages compared with: 5-spd transmission**

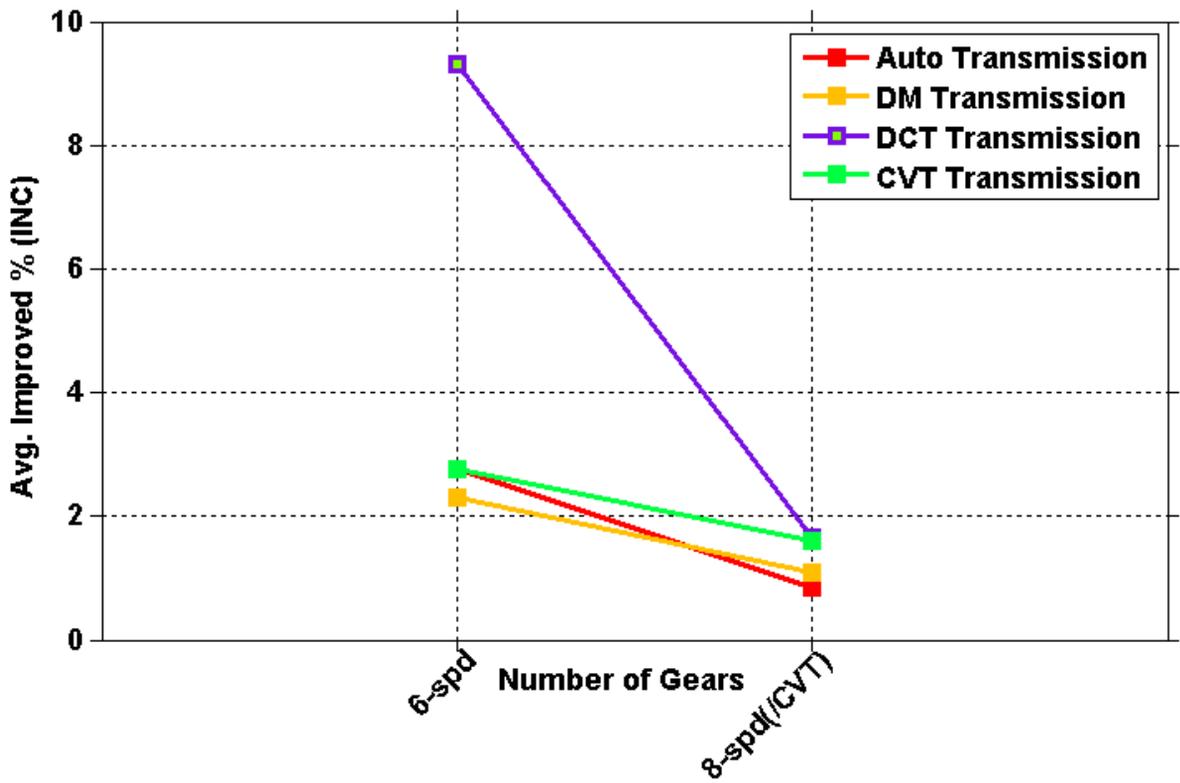


**Density profile of transmission technologies**  
**Absolute density profile compared with: 5-spd transmission**

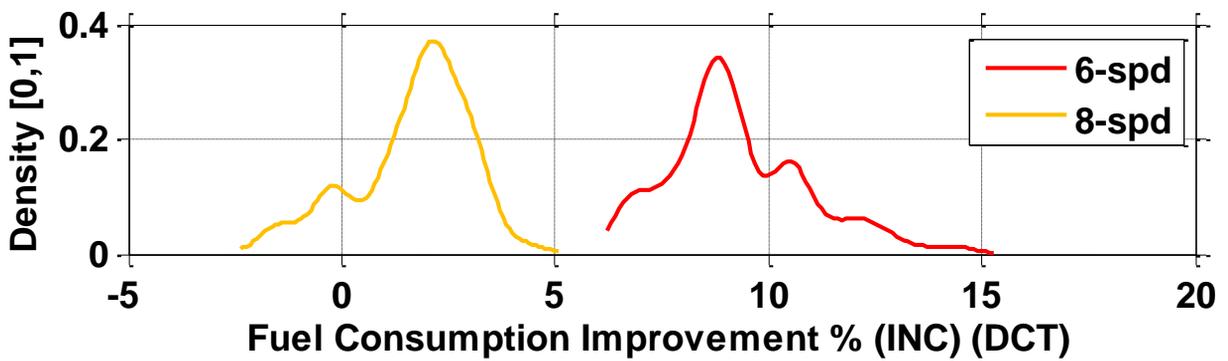
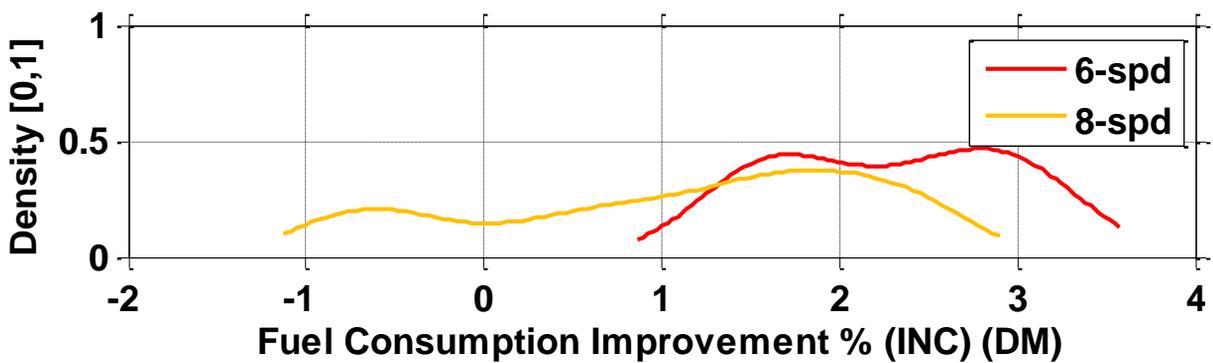
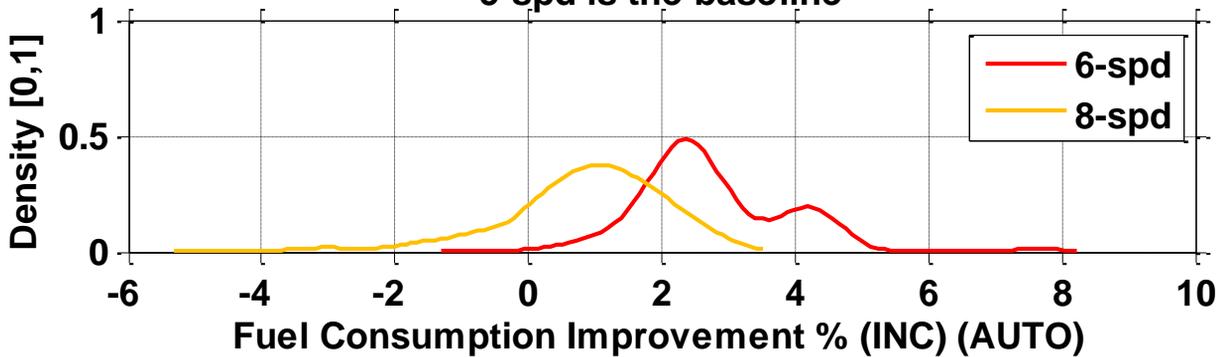


# INCREMENTAL IMPROVEMENT RESULTS

**General trendline on transmission technologies**  
Incremental percentages compared with preceding technology,  
[5-spd] is the baseline



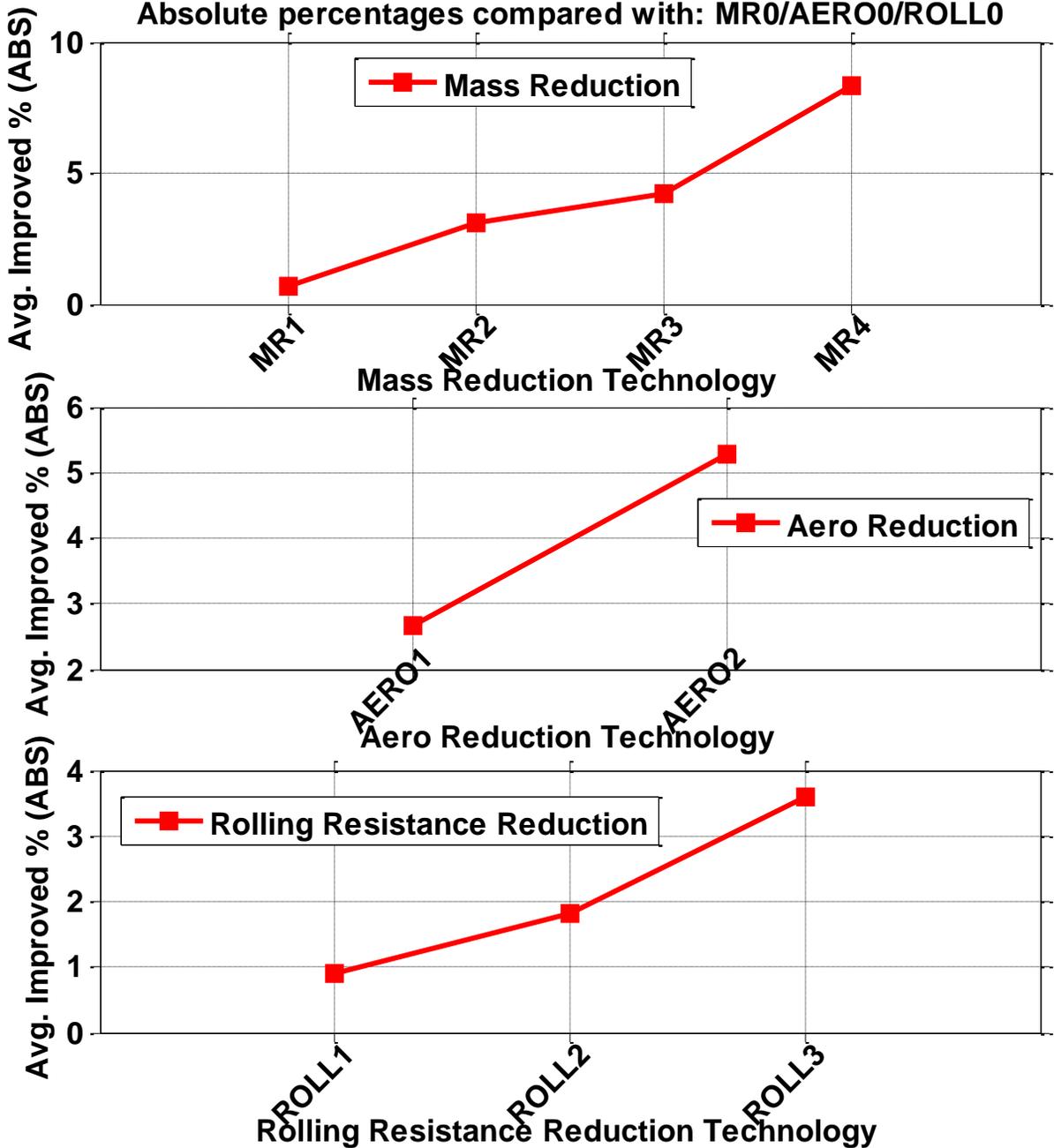
**Density profile of transmission technologies**  
**Incremental density profile compared with preceding technology,**  
**5-spnd is the baseline**



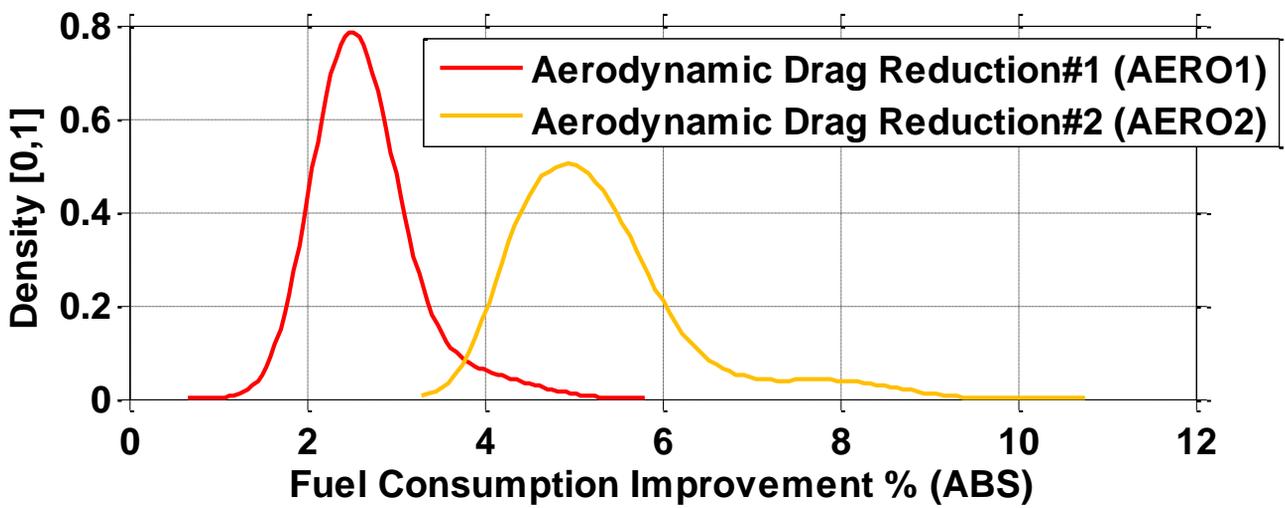
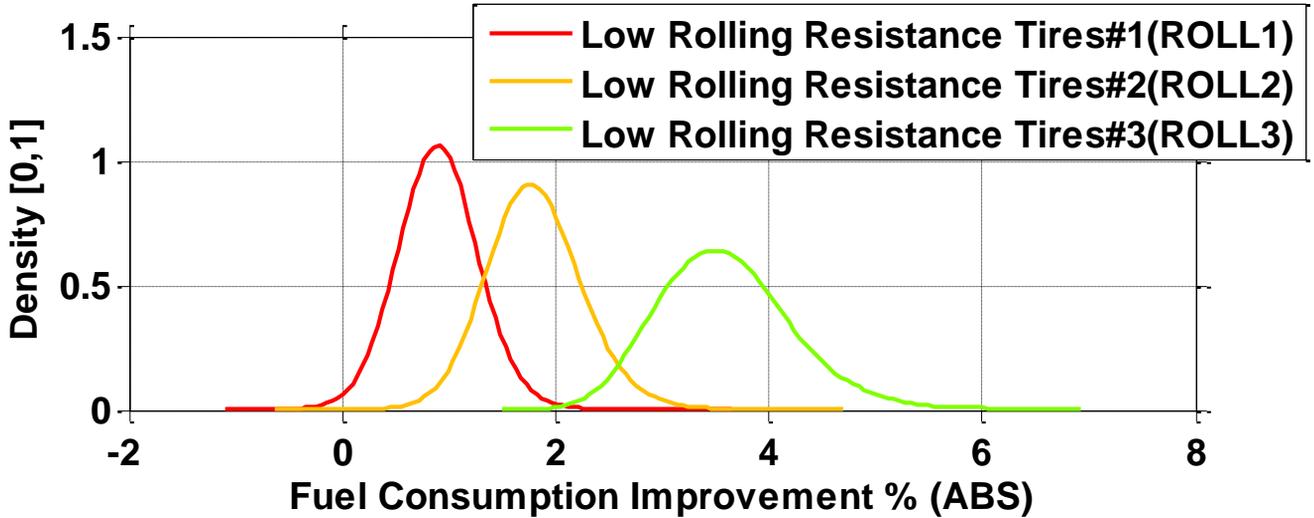
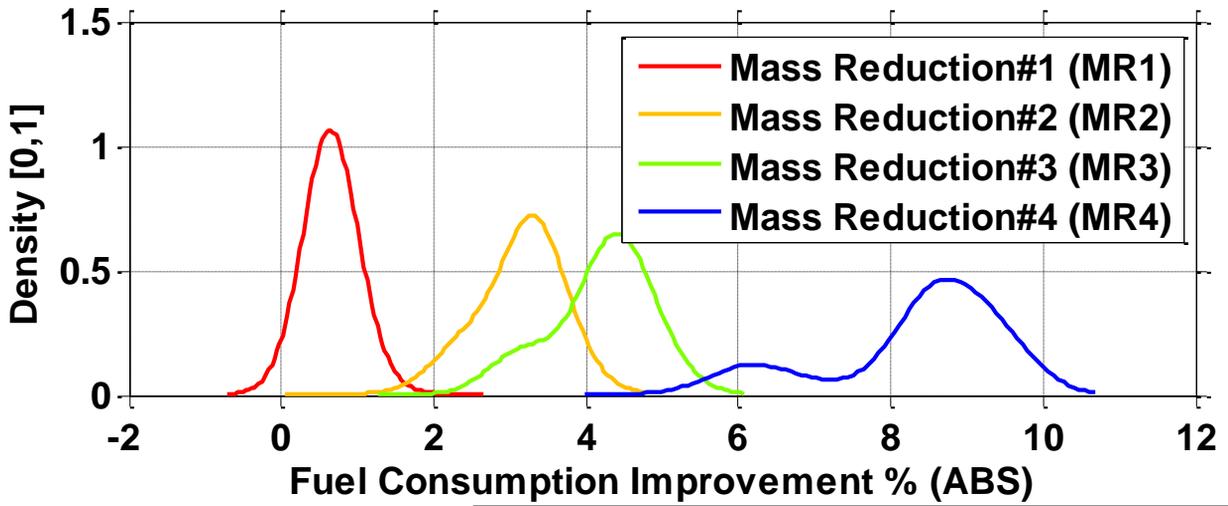
# VEHICLE TECHNOLOGY

# **ABSOLUTE IMPROVEMENT RESULTS**

General trendline on different vehicle technologies  
 Absolute percentages compared with: MR0/AERO0/ROLL0

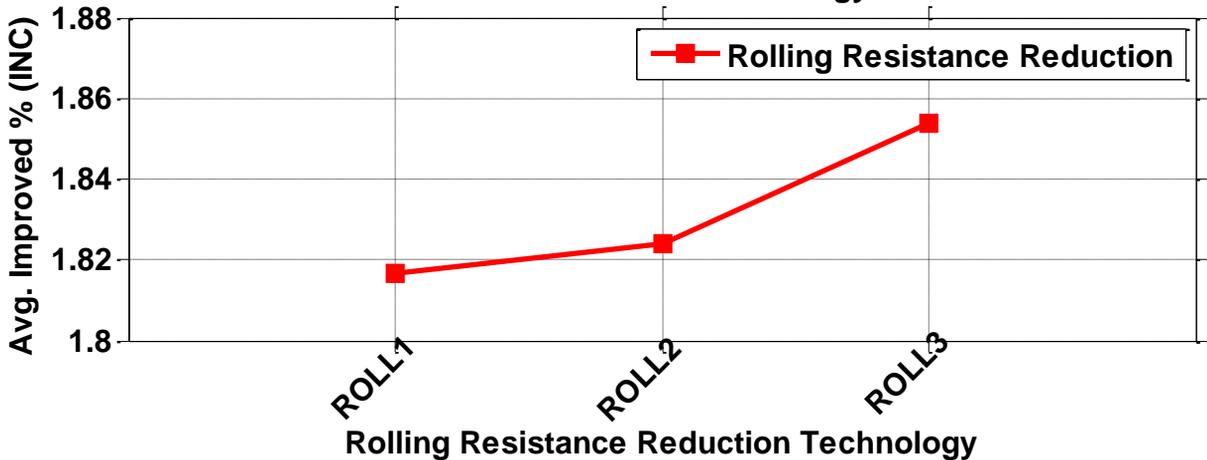
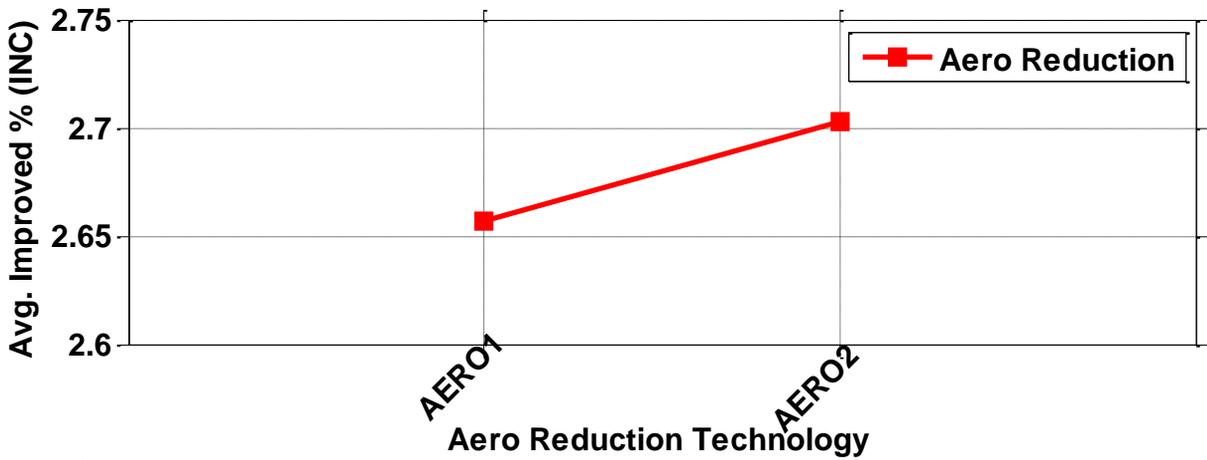
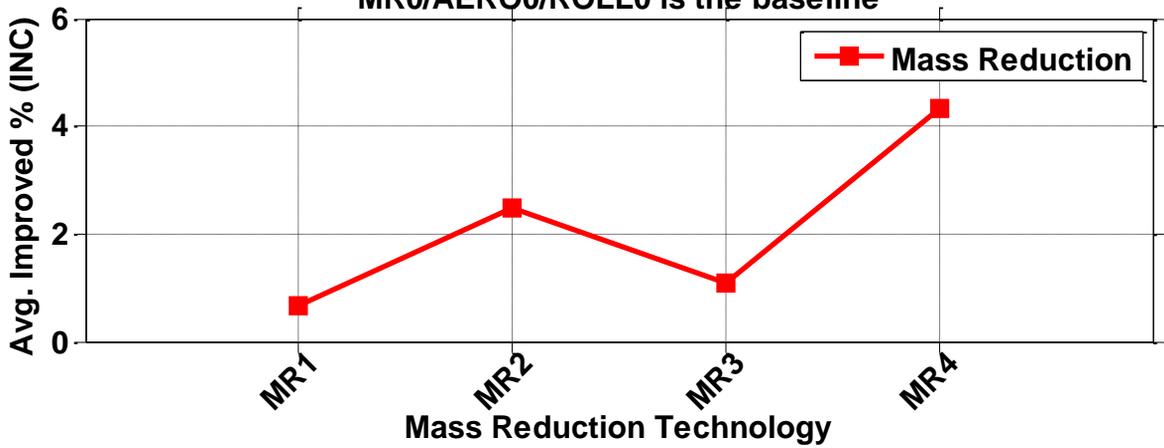


**Density profile of vehicle technologies**  
**Absolute density profile compared with: MR0/AERO0/ROLL0**

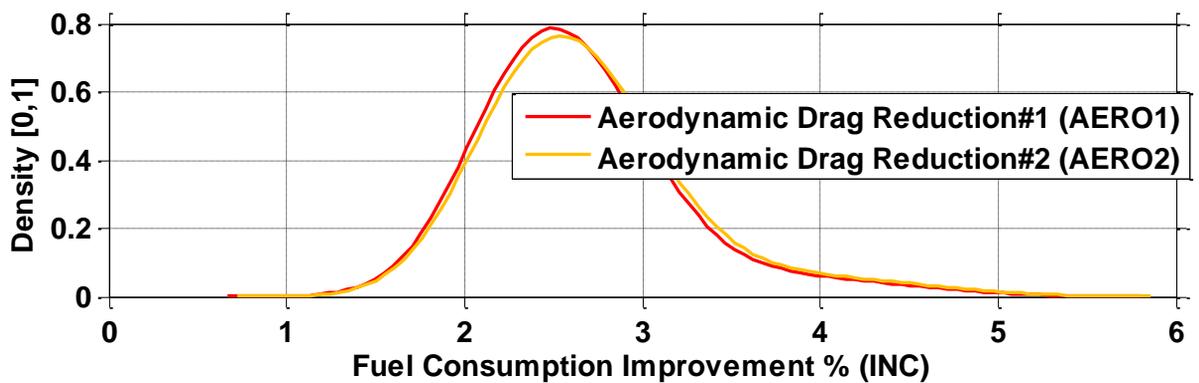
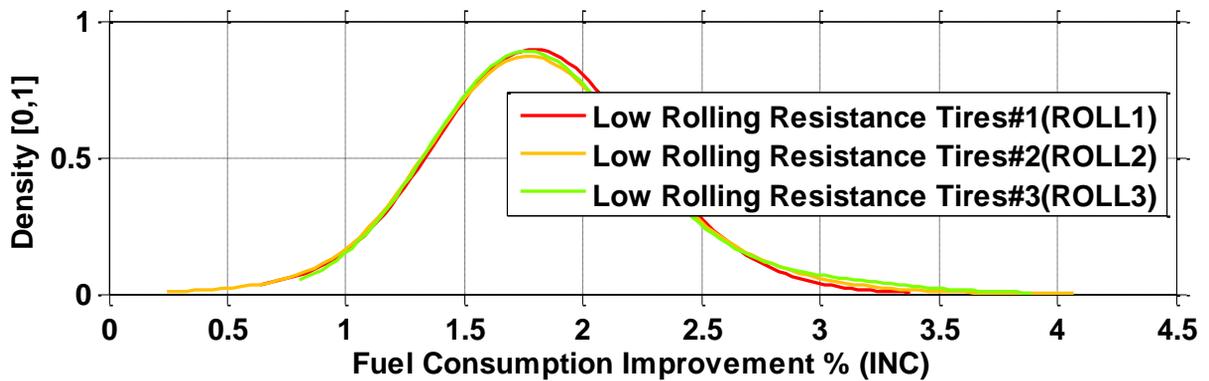
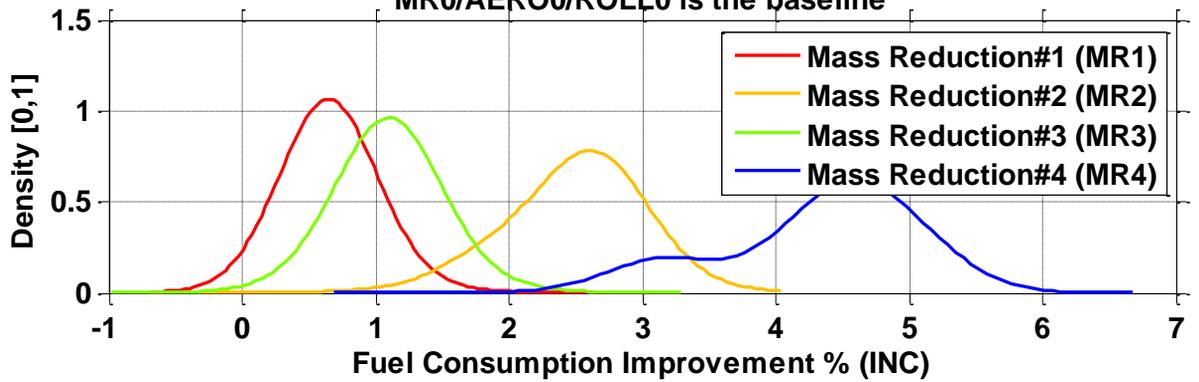


# INCREMENTAL IMPROVEMENT RESULTS

General trendline on different vehicle technologies  
 Incremental percentages compared with preceding technology,  
 MR0/AERO0/ROLL0 is the baseline



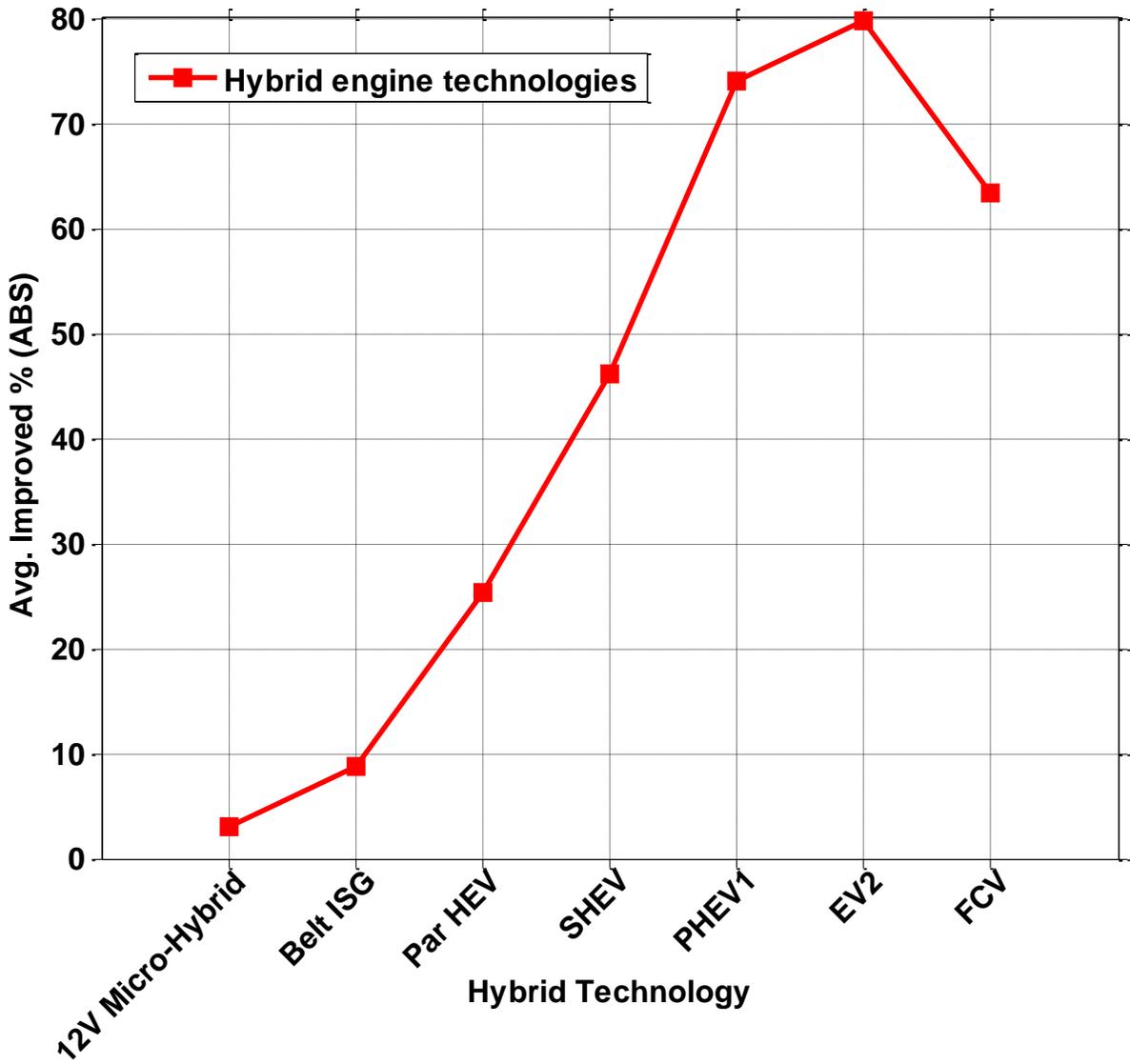
Density profile of vehicle technologies  
 Incremental density profile compared with preceding technology,  
 MR0/AERO0/ROLL0 is the baseline



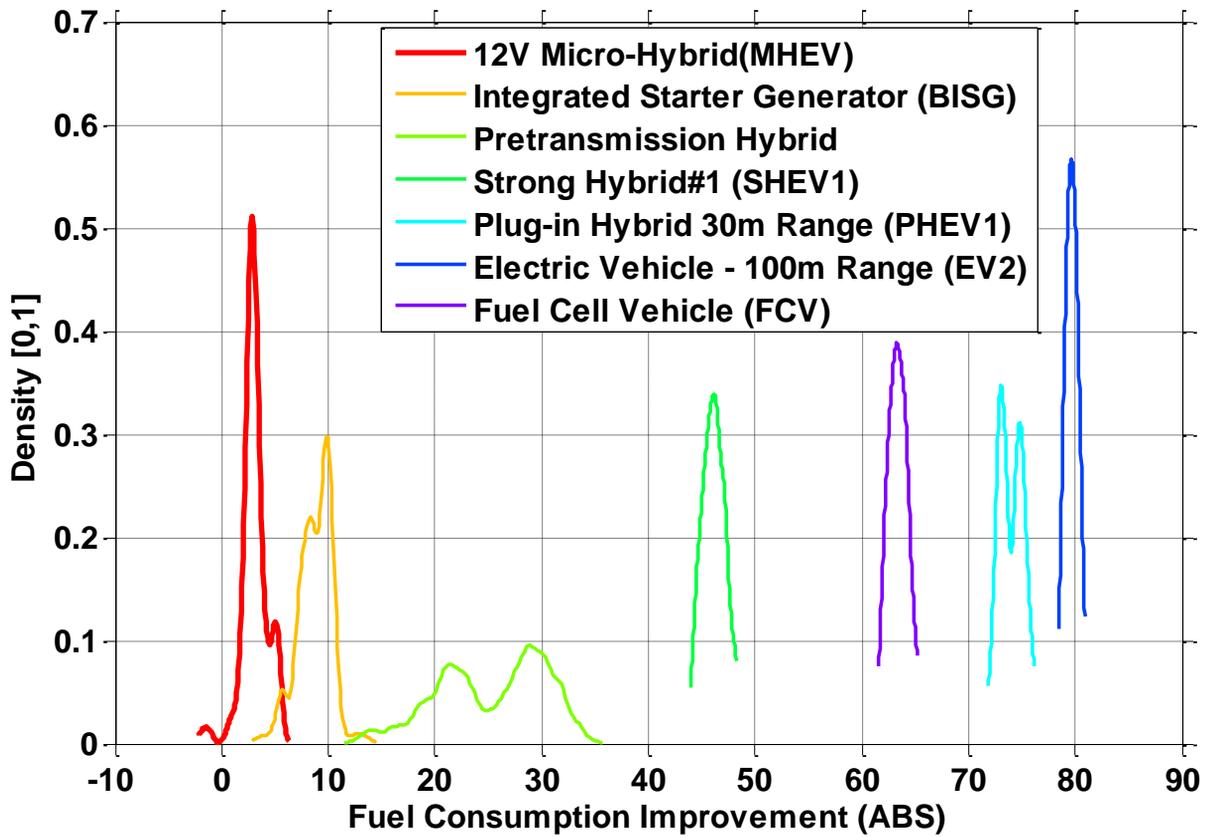
# HYBRIDIZATION TECHNOLOGY

# **ABSOLUTE IMPROVEMENT RESULTS**

**General trendline on hybridization technologies**  
**Absolute percentage compared with: Conventional Powertrain (CONV)**

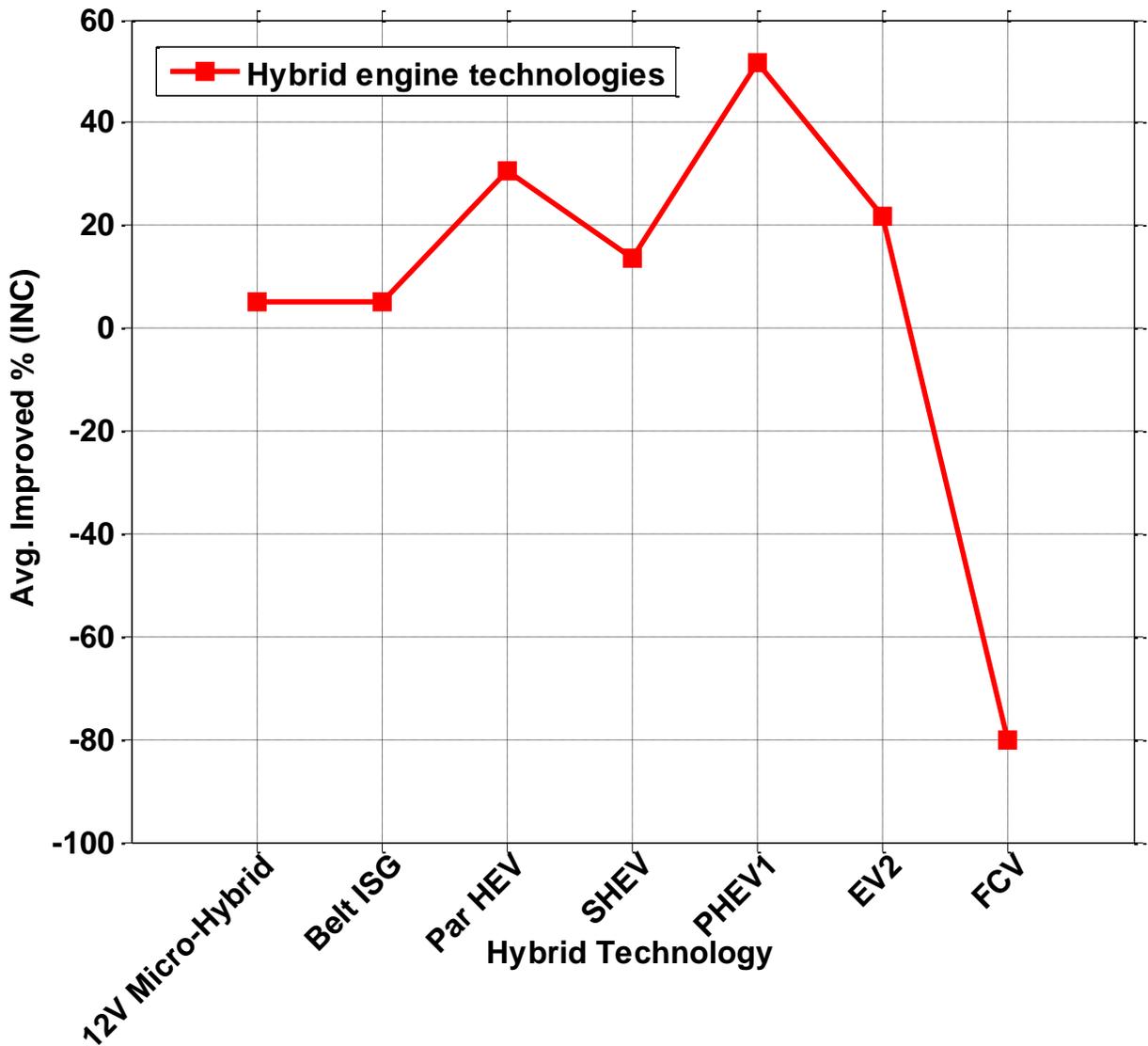


### Density profile of different hybrid technologies Absolute density profile compared with: Conventional Powertrain (CONV)

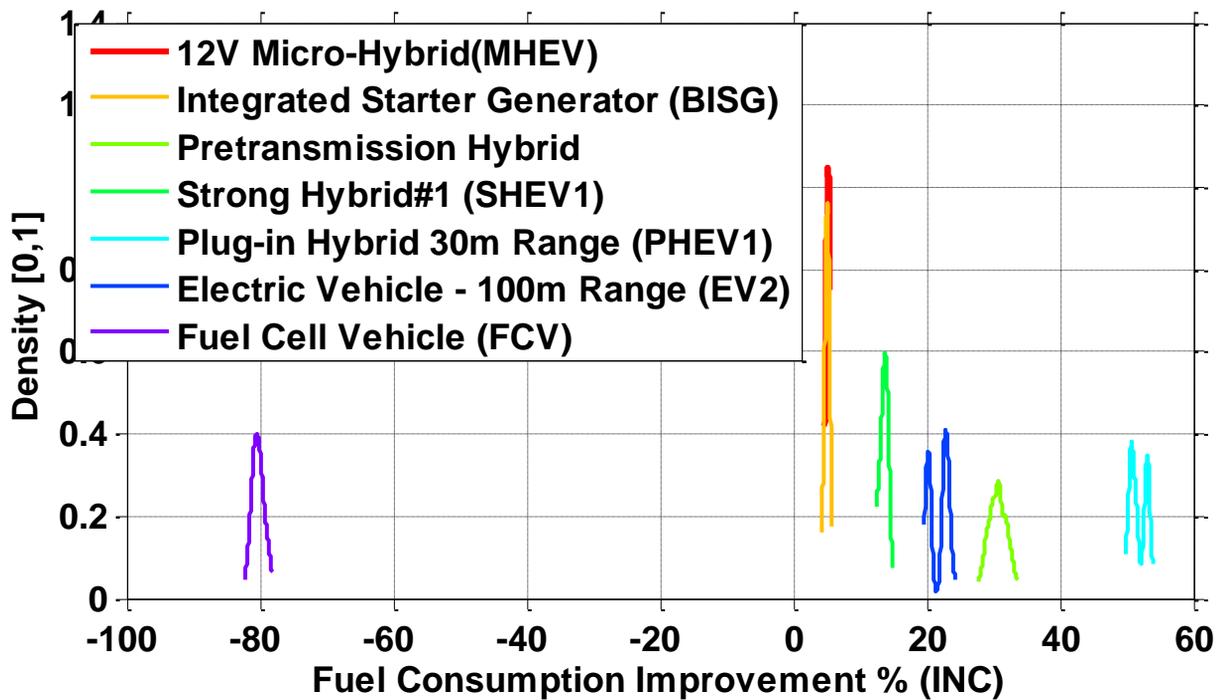


# INCREMENTAL IMPROVEMENT RESULTS

**General trendline on hybridization technologies**  
Incremental percentages compared with preceding technology,  
Conventional Powertrain (CONV) is the baseline



**Density profile of different hybrid technologies**  
**Incremental density profile compared with preceding technology,**  
**Conventional Powertrain (CONV) is the baseline**



**THANK YOU**

