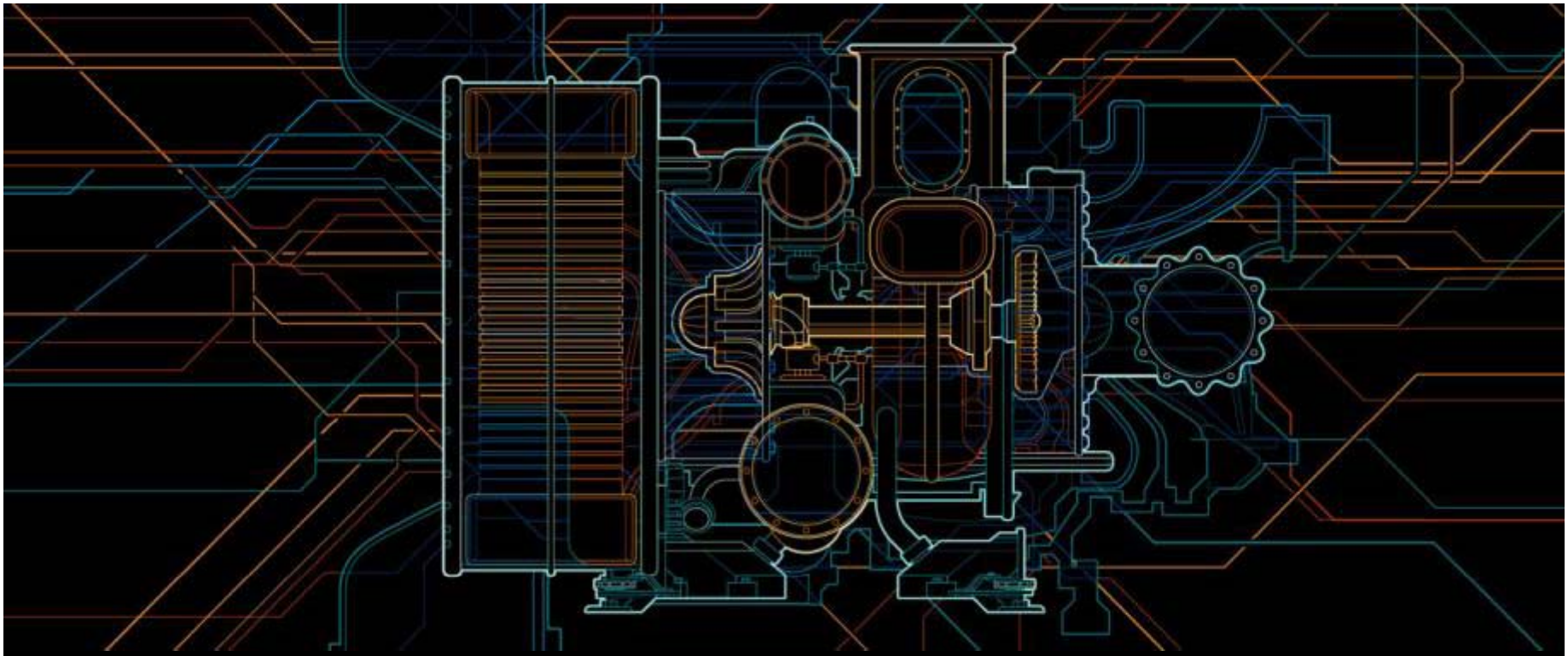

7th CIMAC CASCADES, ABB Jiangjin Turbo Systems, 2105-10-15, Hangzhou

Turbocharging Solutions for Gas and Dual-Fuel Engines

Power and productivity for a better world™

Content

- Basics of gas engine operation
- Turbocharging for gas and DF engine
- 2 stage turbocharging and variable valve timing
- Summary

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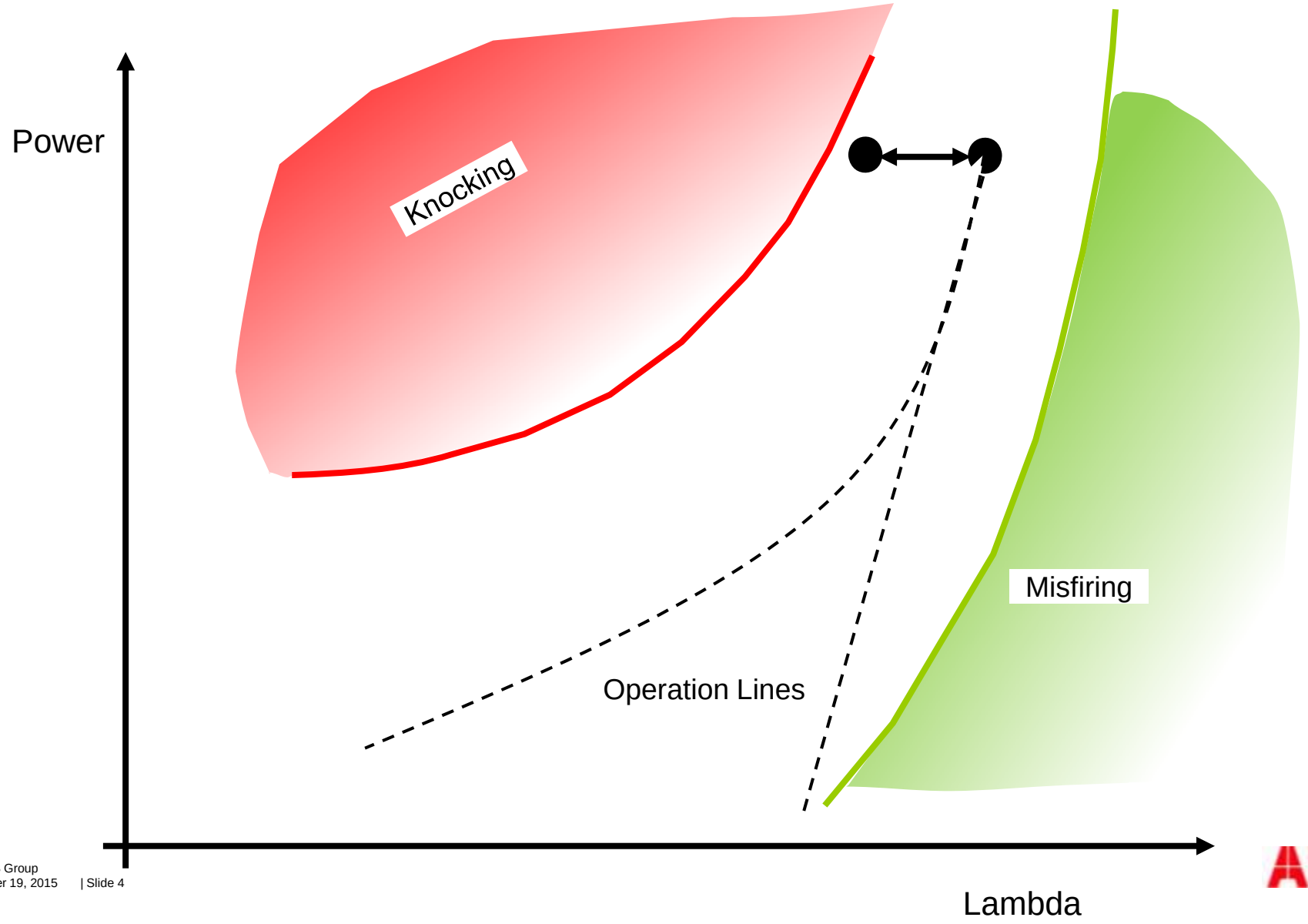
Basics of Gas Engine Operation



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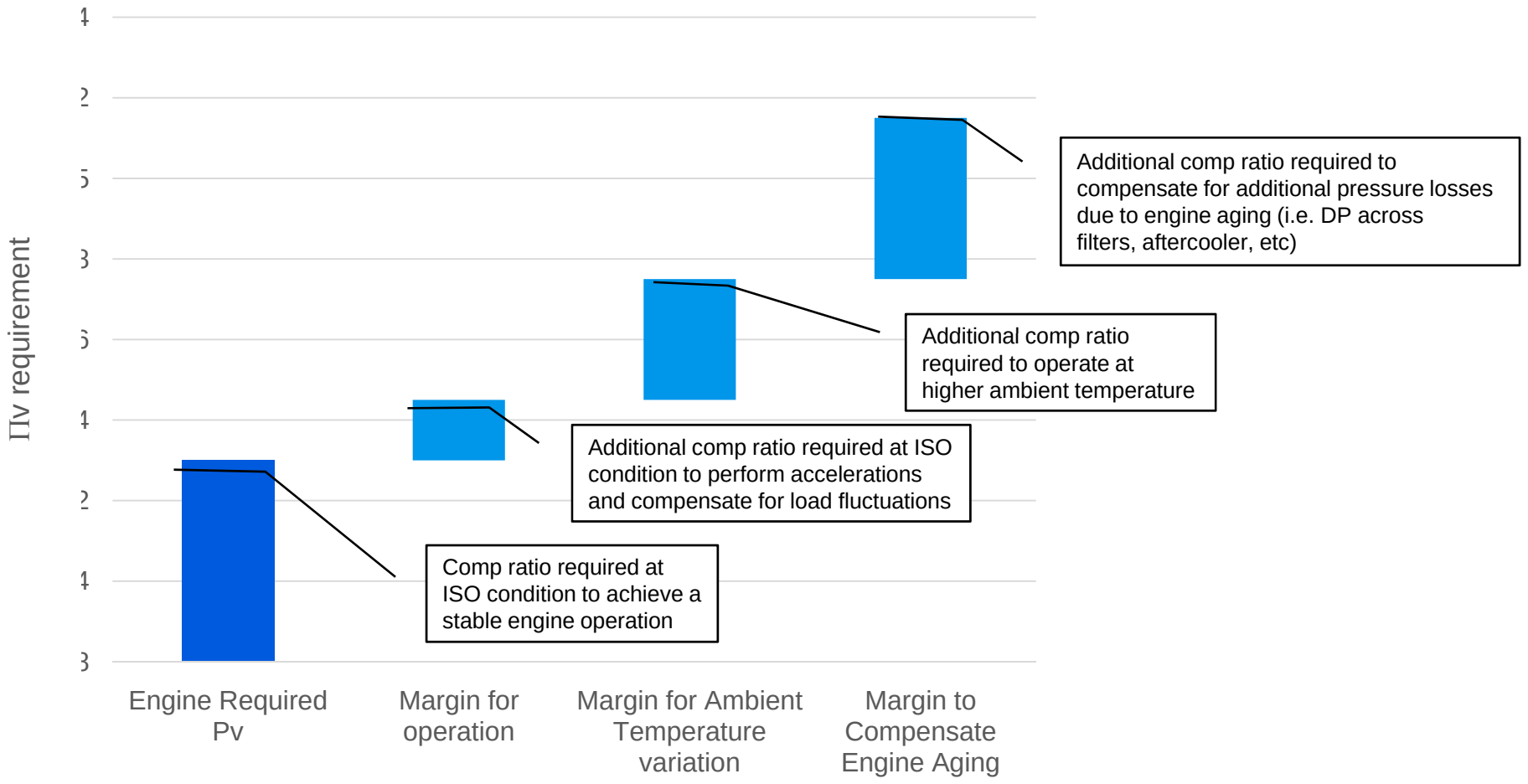
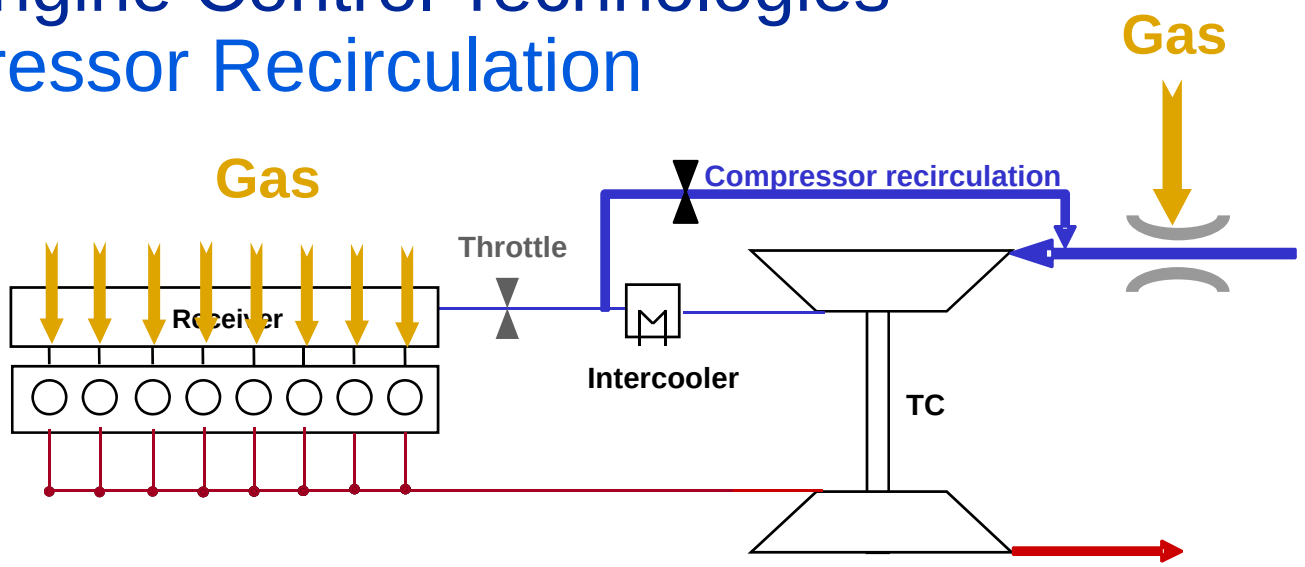
Control Margin Definition



Gas Engine Control Technologies
Compressor Recirculation



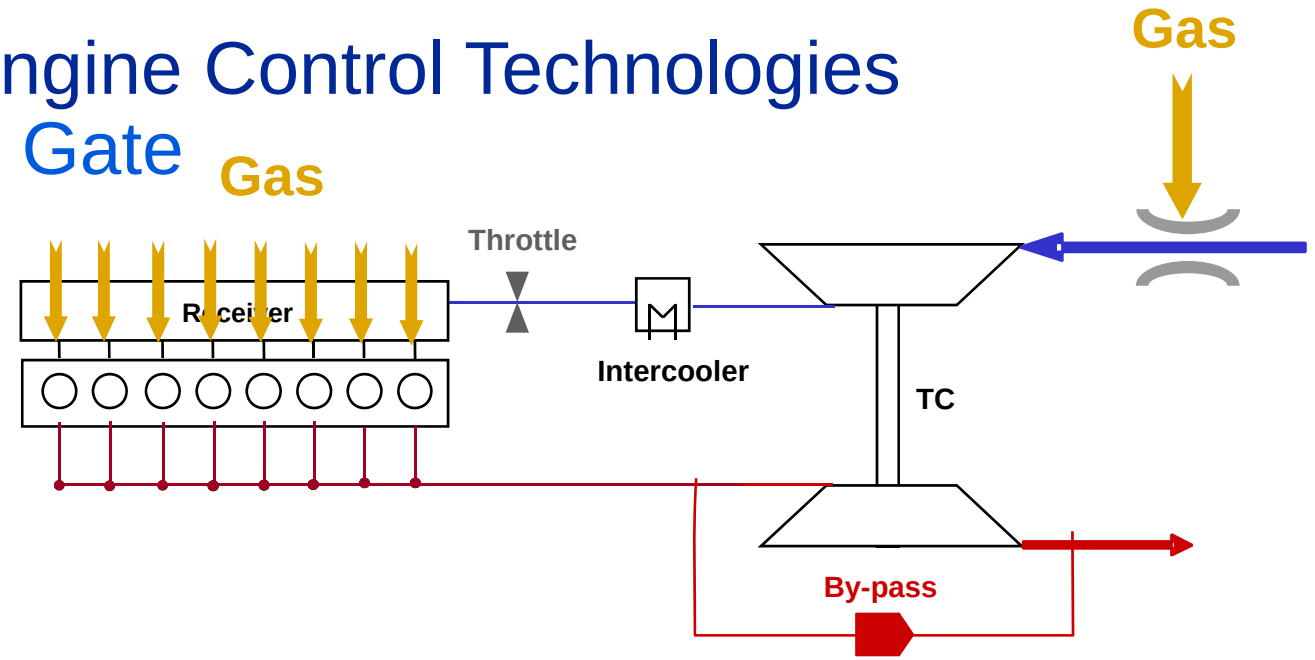
- In case of **Premix**
  - Power is controlled by the compressor recirculation
  - Lambda is controlled by the Mixer
- Acceleration is controlled by the Throttle
- Re-circulation has to be cold (after the intercooler to keep efficiency high)
- At full load re-circulation should be about 0
- In steady state operation DP over the throttle should be 0.1- 0.3 bar (according to the control margin)

- In case of **Port Injection**
  - Power is controlled by gas injection valves
  - Lambda is controlled by the recirculation valve

- Pros
  - High reliability, as the control elements are operating on cold engine side
- Cons
  - Energy dissipation in the recirculation valve and in the throttle

Gas Engine Control Technologies

Waste Gate

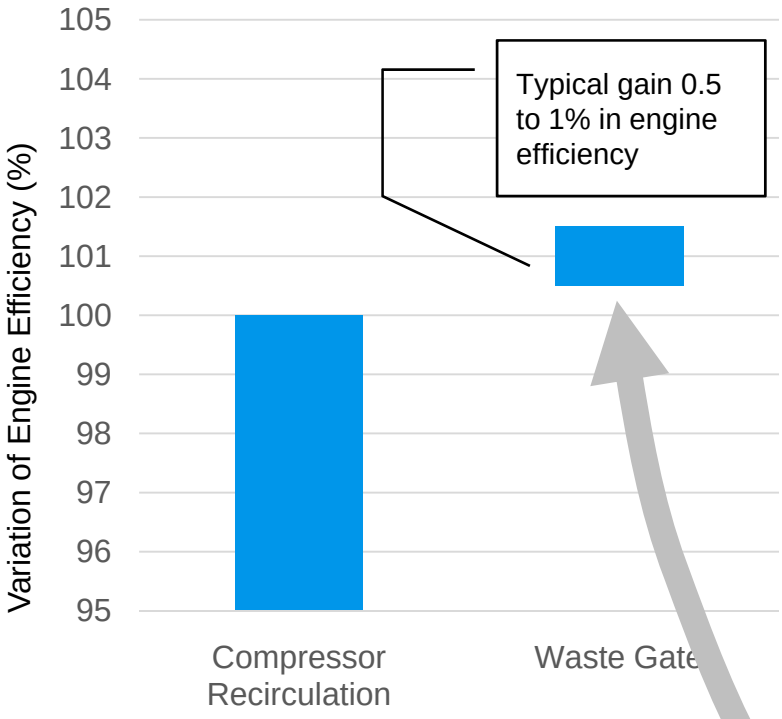


- In case of **Premix**
  - Power is controlled by the turbine waste gate
  - Lambda is controlled by the Mixer
- Acceleration is controlled by the Throttle
- At full load turbine by-pass flow should be about 0
- In steady state operation DP over the throttle should be 0.1- 0.3 bar
- At low loads the engine is controlled only by the Throttle as there is no flow over the WG

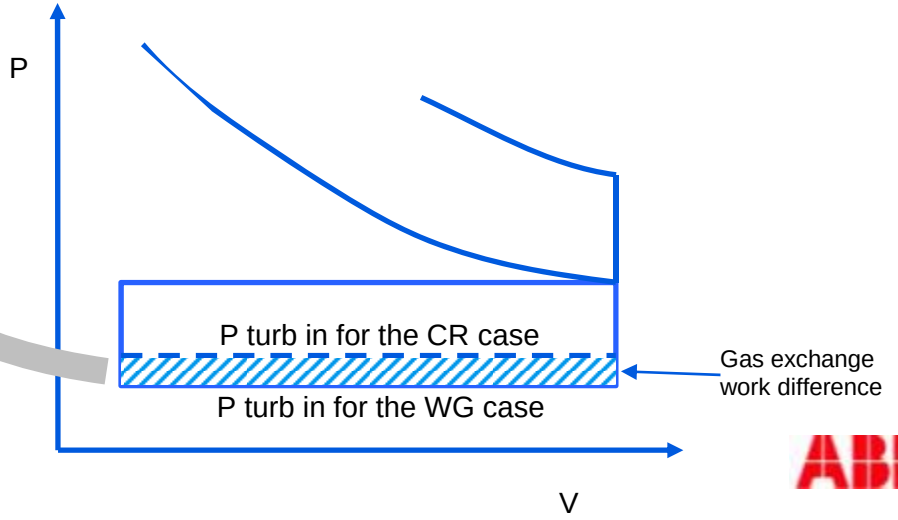
- In case of **Port Injection**
  - Power is controlled by gas injection valves
  - Lambda is controlled by the turbine waste gate

- Pros
  - Higher efficiency than previous,
  - DP across the engine is higher than in previous case
- Cons
  - Losses in the Throttle as previous
  - Reliability of the turbine by-pass

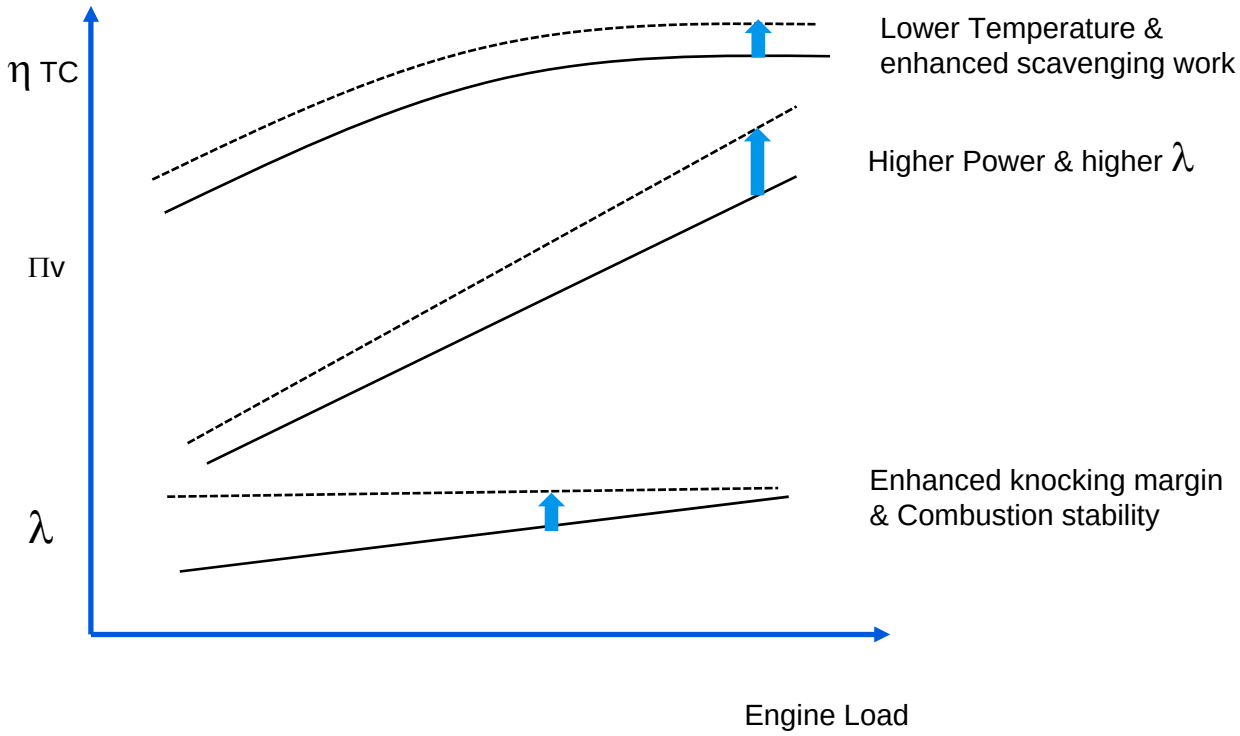
Gas Engine Control Technologies
CR vs WG – Engine Performance Comparison



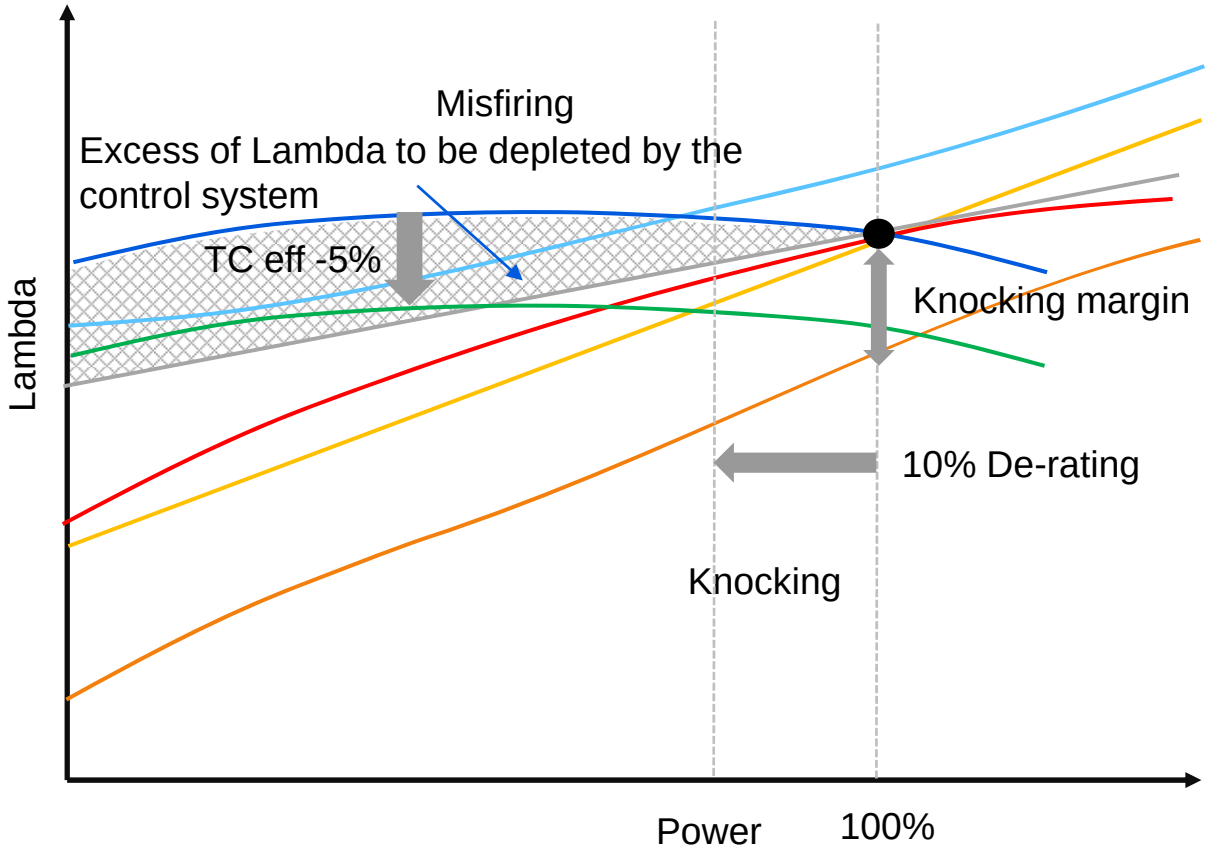
$$(m_{\ air\ to\ engine} + m_{\ recirculating\ air}) * \Delta h_{01} > (m_{\ air\ to\ engine}) * \Delta h_{01}$$

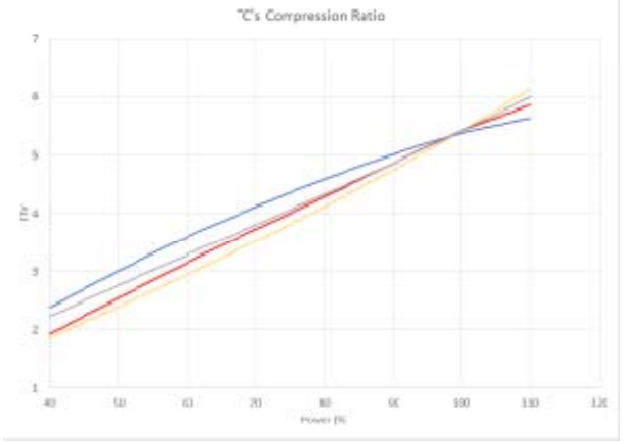


Gas Engine
Turbocharger Requirements

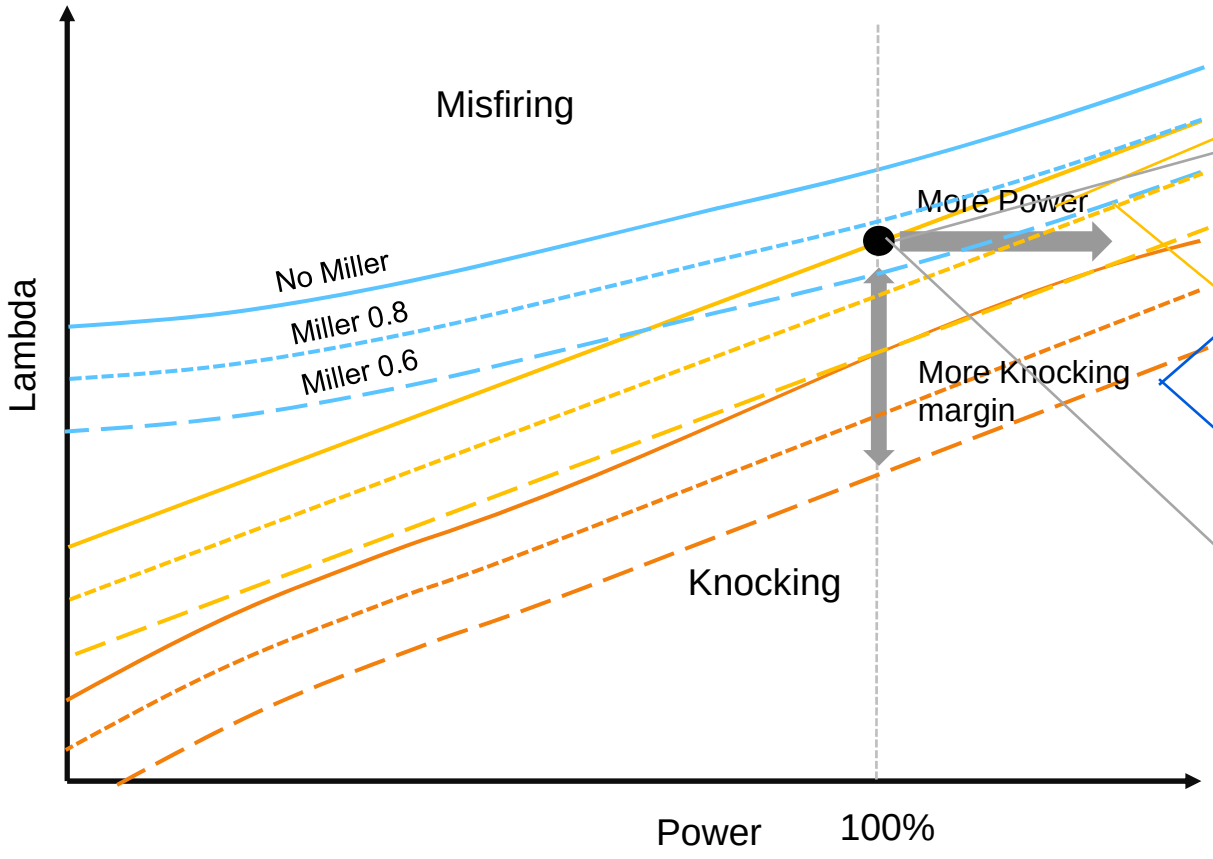


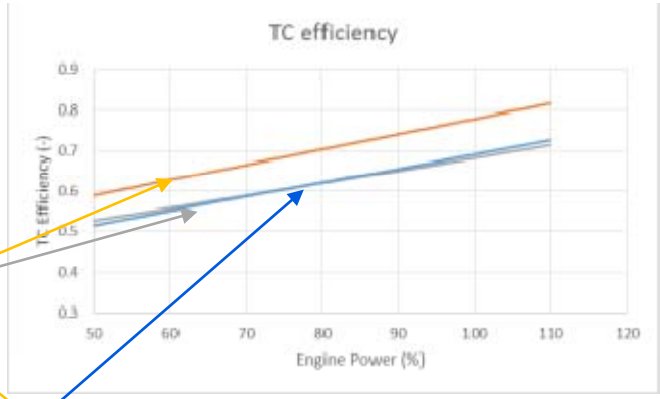
Gas Engine
Turbocharger Requirements

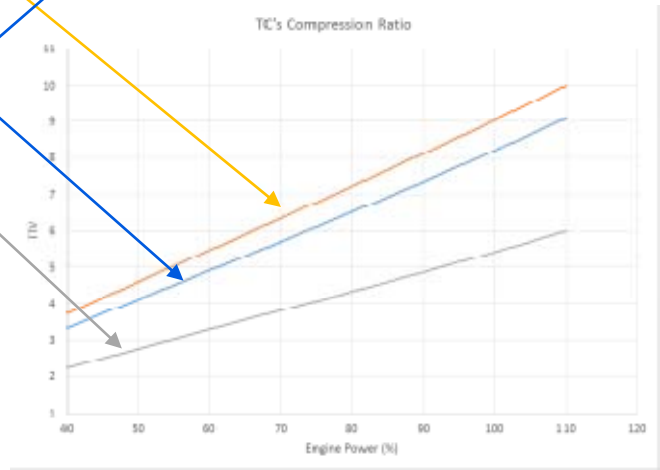




Gas Engine
Turbocharger Requirements







Dual Fuel Engine
Gas vs Diesel Requirements

	Gas	Diesel
Waste Gate	To control lambda (port injected engines)	No need to control
	To compensate ambient variations	No need to control
	Always operated	Always closed as it could be fouled by soot if operated
	To control λ during engine acceleration	No need to control
Engine Compression Ratio	The highest possible without knocking	Highest possible. A minimum value is necessary to ensure stable combustion at all loads
Miller Timing	The most advanced the better. Limits apply to ignitability of pilot fuel	The most advanced the better. Limits apply due to ignitability of fuel

Dual Fuel Engine
Performance Requirements

Engine data	Diesel fixcam	Diesel VVT	Gas fixcam	Gas VVT
P max [bar]	Fixed for all cases			
Lambda at full load	2.40	2.20	2.20	2.20
Engine Compression ratio	CR	CR+1.5	CR	CR+1.5
Valve timing	EVO/EVC/IVO/IVC			
	EVO/EVC/IVO/IVC	IVC-30	IVC	IVC-30
Waste gate position gas mode	always close	none	open all loads	open all loads
Engine control tool in gas mode	N/A	N/A	Waste gate	Waste gate
Pscav (bar)	5.20	5.20	4.70	5.00
TTI (°C)	517	538	545	523
TC efficiency	65.7%	66.9%	68.0%	67.5%
Eng.efficiency	43.8%	44.9%	46.2%	47.6%

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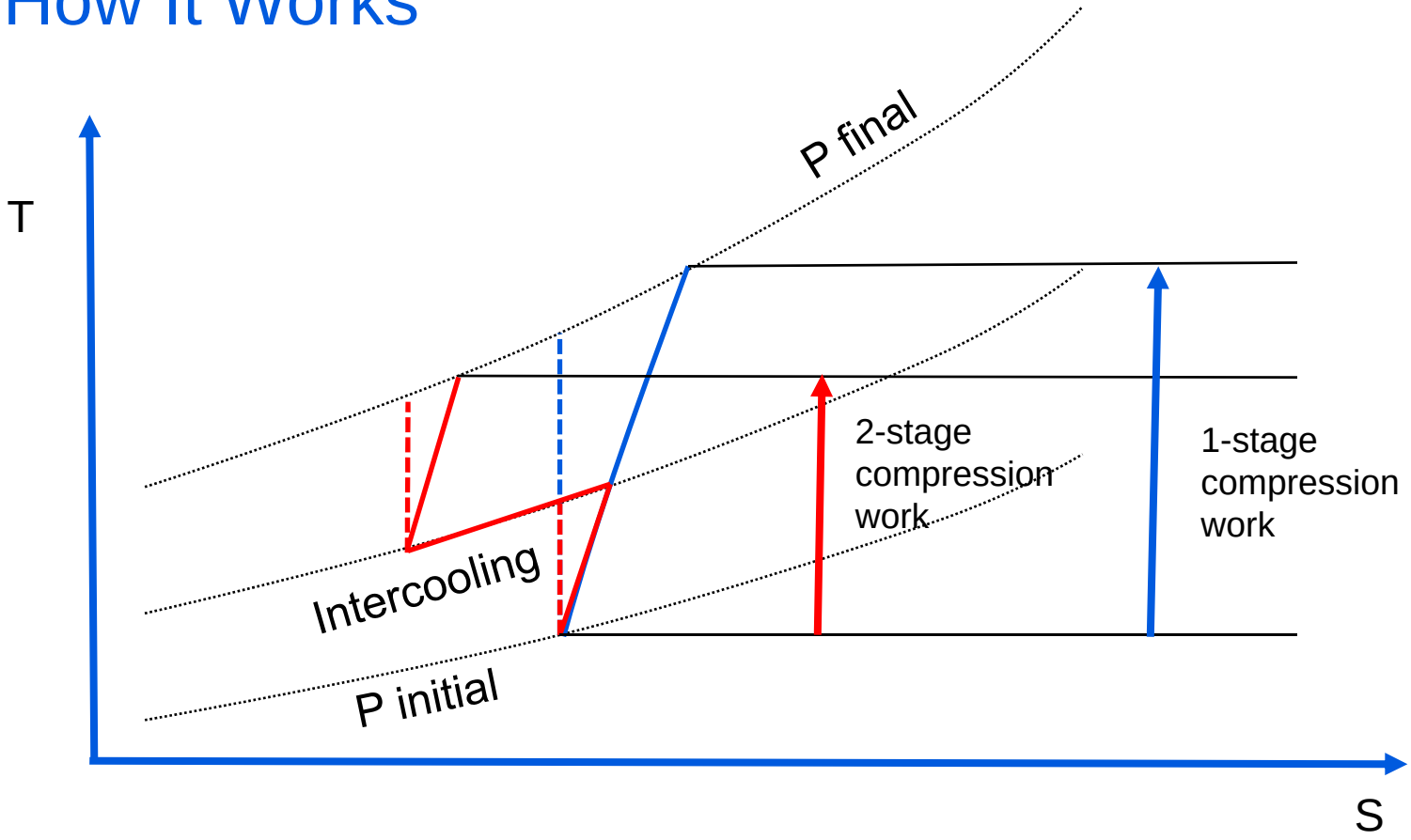
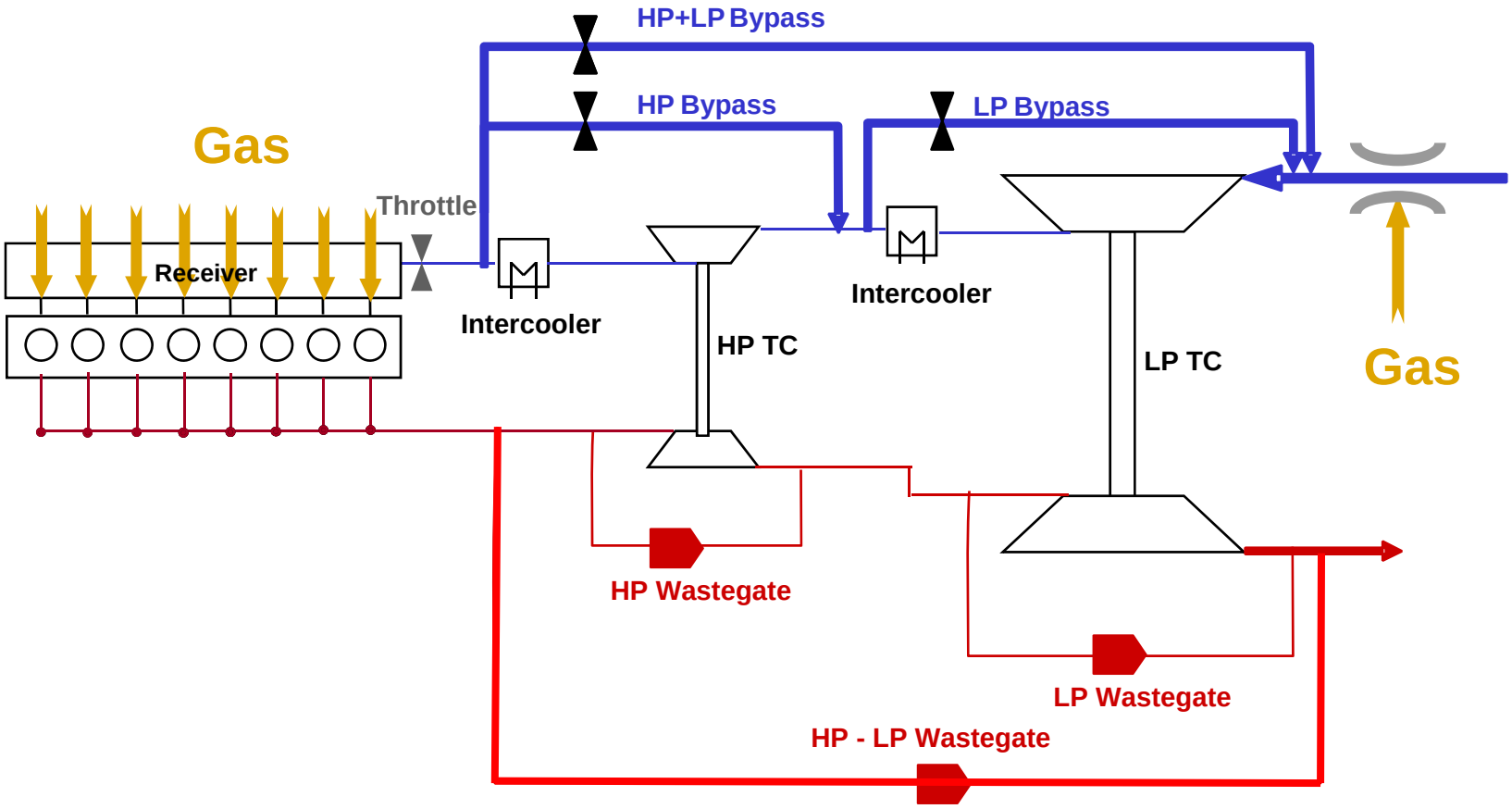
Two-stage Turbocharging
How It Works



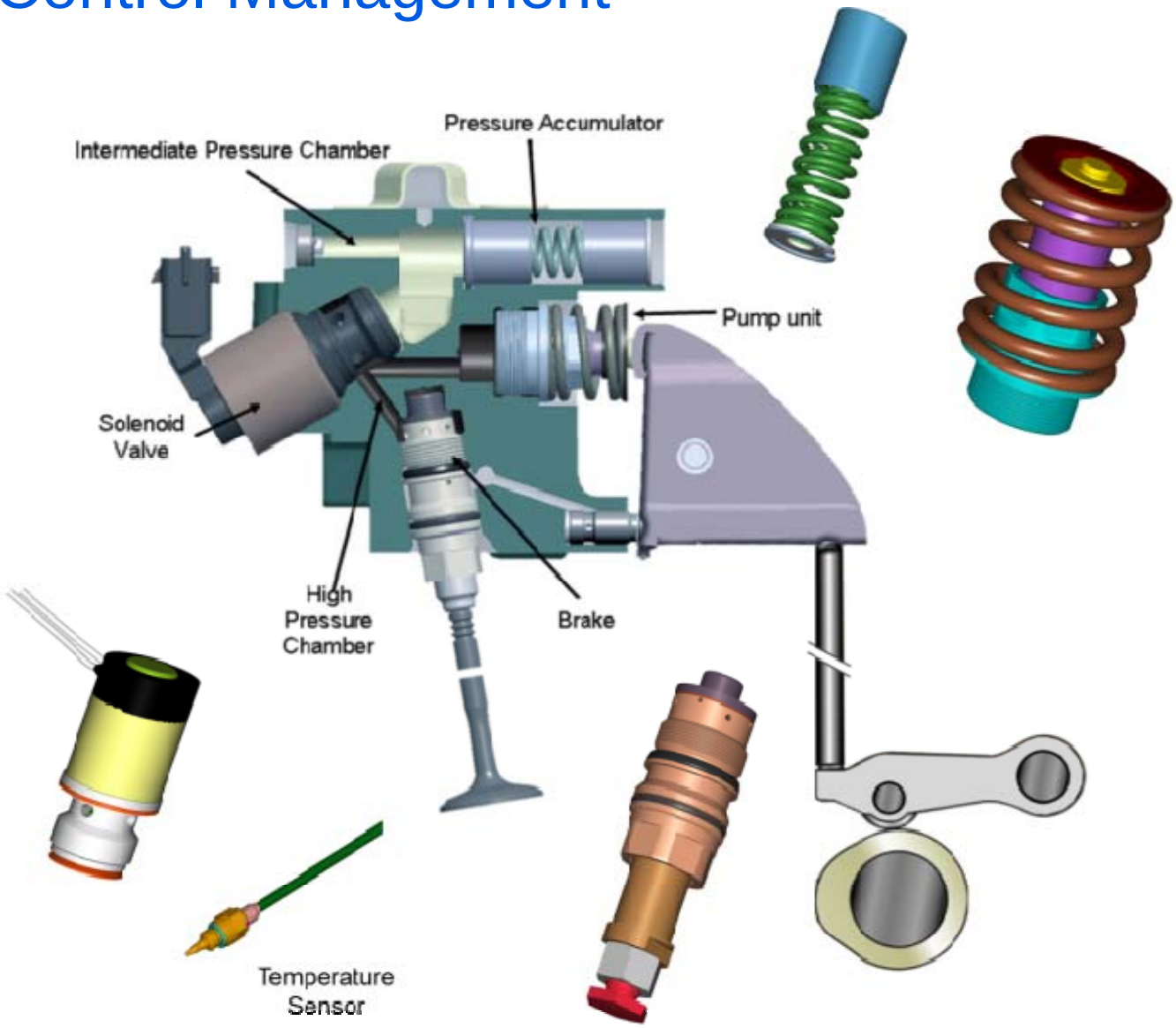
- Intercooling is the key factor to make two-stage more efficient than single stage
- The higher the intercooling the higher the Turbocharging efficiency, but there are limits …

2-stage Turbocharging
Control Possibility

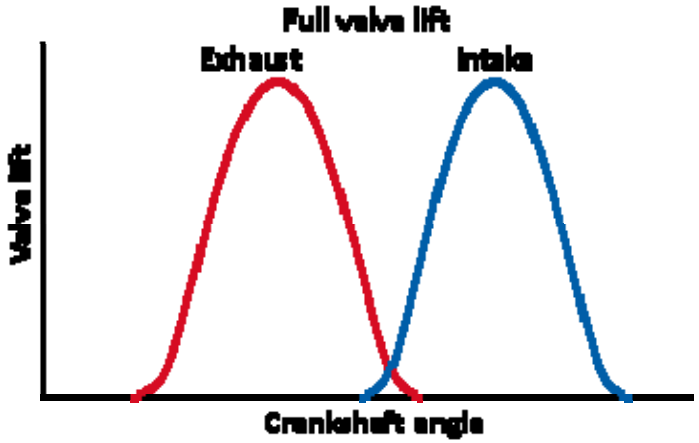


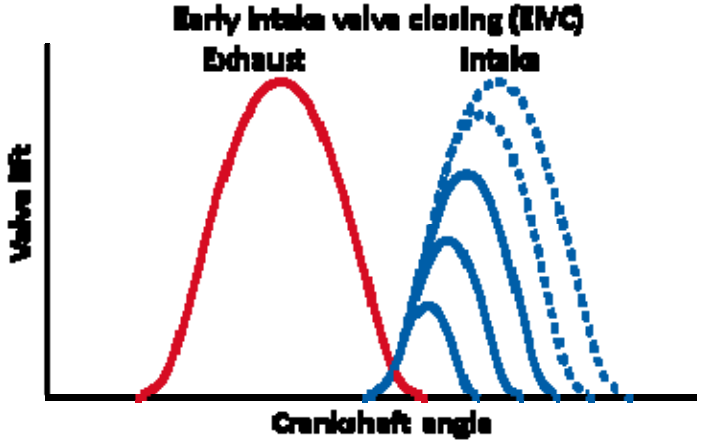
Most popular solution

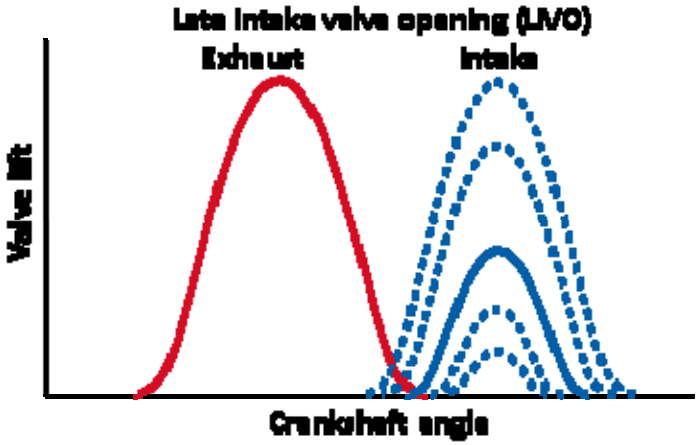
Variable Valve Timing
Valve Control Management

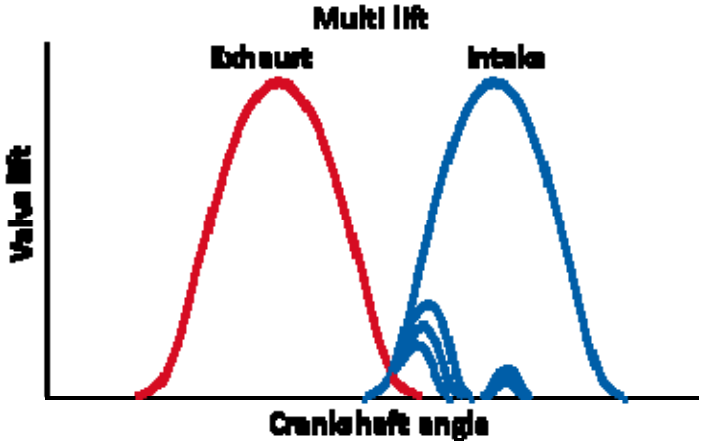


Valve Management Control
Valve Lift Profile Capabilities







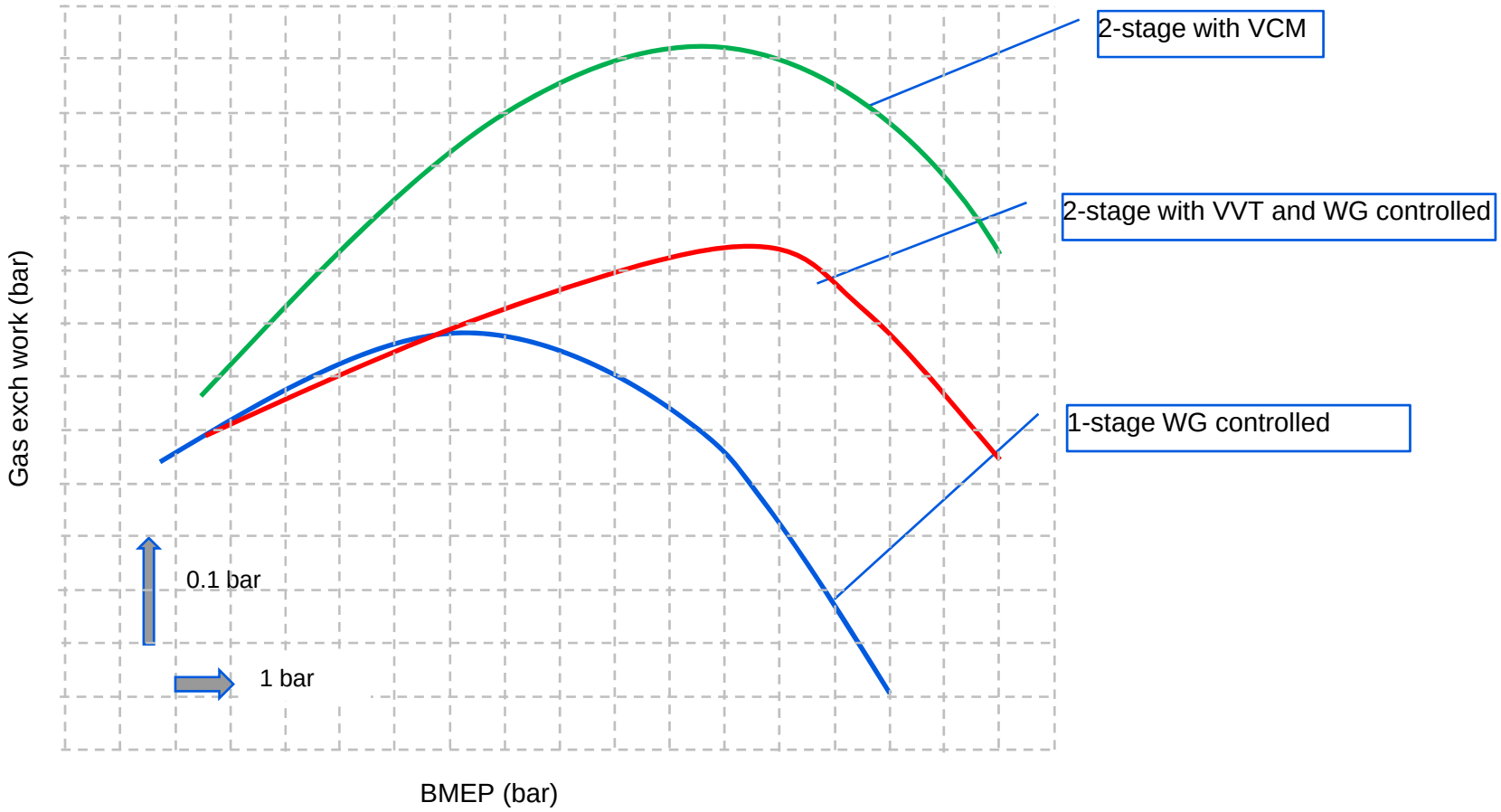


Advanced Miller Cycle – Power2 & VCM – Gas Engine
Performance comparison 1

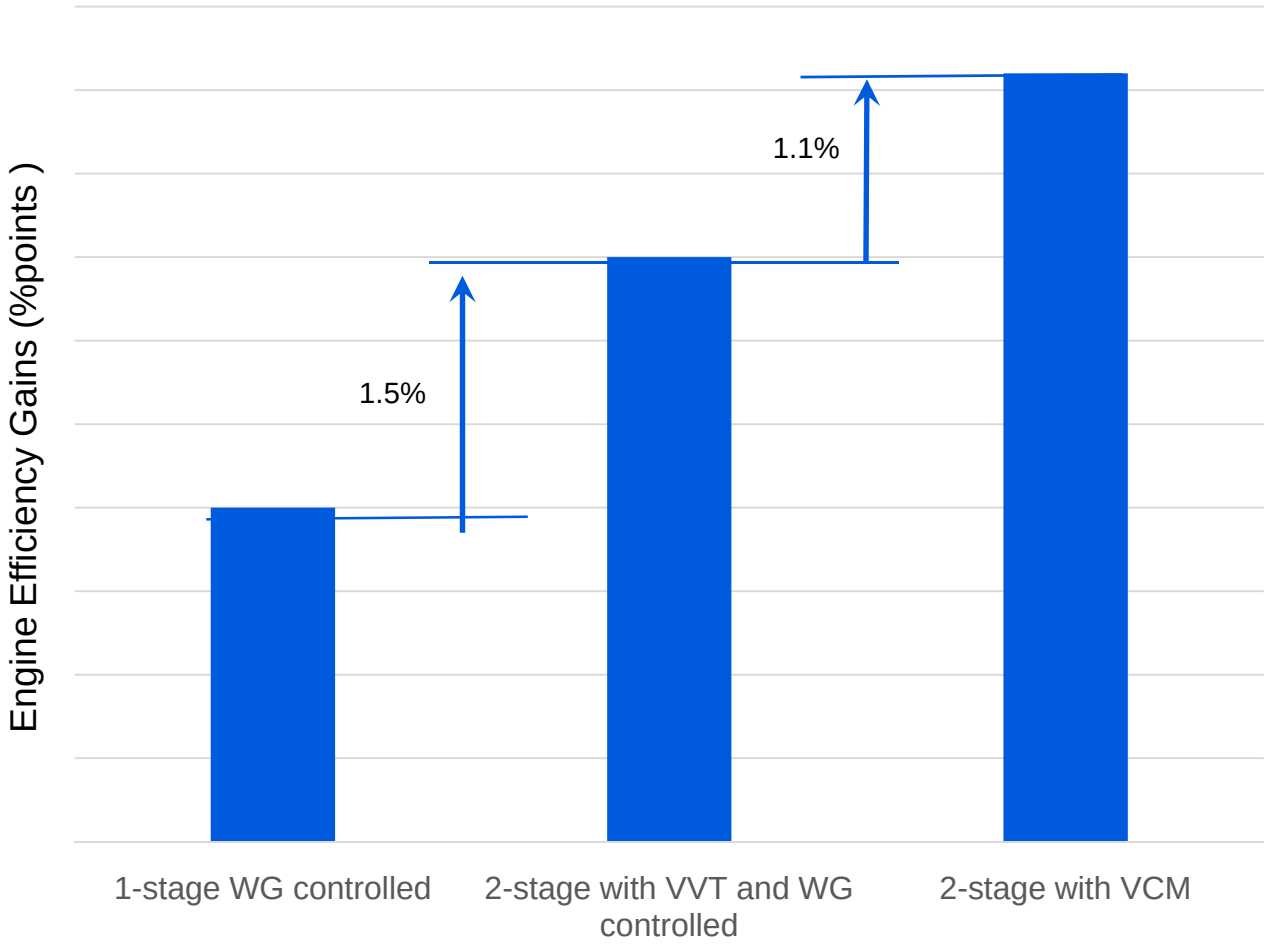
- **1-stage with WG + TV** 22 bar bmep
- 1-stage with VTG + TV 22 bar bmep
- 2-stage with hpt WG + TV 22 bar bmep
- 2-stage with hpt WG + TV 24 bar bmep
- 2-stage with hpt WG + TV + VVT for 2-stage 24 bar bmep
- 2-stage with hpt WG + VVT for 2-stage layout point 50% load 24 bar bmep
- **2-stage with hpt WG + VVT for 2-stage layout point 25% load** 24 bar bmep
- **2-stage VCM**

WG = wastegate; TV = throttle valve; VVT = variable valve timing

Advanced Miller Cycle – Power2 & VCM – Gas Engine
Performance comparison 2 –Gas Exchange Work

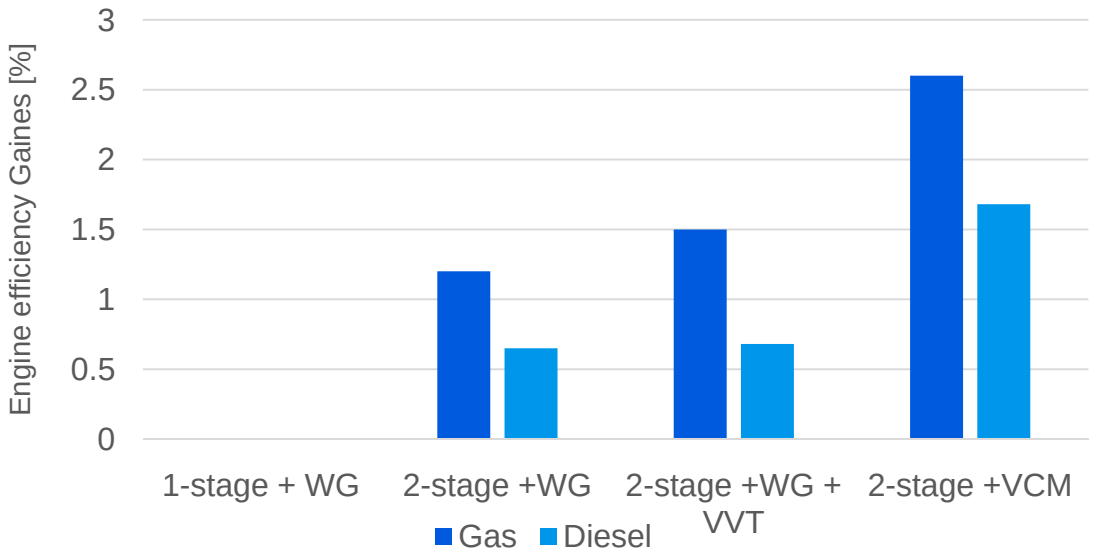


Advanced Miller Cycle – Power2 & VCM – Gas Engine
Performance comparison 3 – Engine efficiency gain



Advanced Miller Cycle – Power2 & VCM – DF Engine
Performance comparison

Engine data	1-stage	Power2+EWG	Power2 + EWG+VVT	Power2+ VCM
Valve timing	Miller	Miller	Moderate Miller with 2 positions VVT	Advanced Miller VCM controlled
Valve timing	EVO/EVC/IVO/IVC			
	IVC	IVC-2	IVC-25 / IVC-10	Gas: IVC-38 / IVC-30 Diesel: IVC-40 / IVC
Waste gate position gas mode	open all loads			none
Waste gate position diesel mode	open full load / close elsewhere			none
Engine control tool	Exhaust gas waste gate	HP Turbine by-pass		VCM



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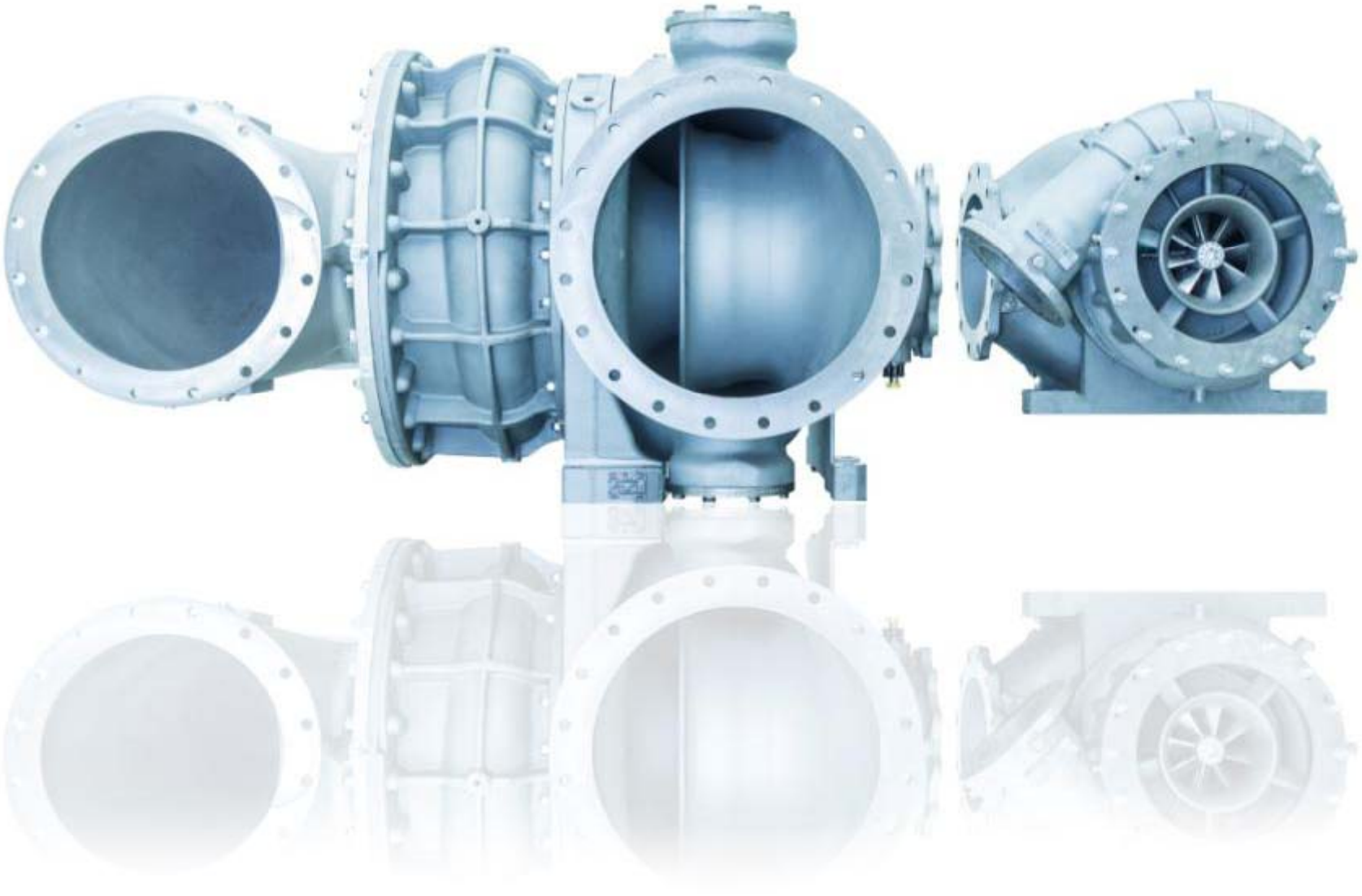
Conclusions

- Gas engines require an higher control level than their correspondent diesel versions
- Dual-fuel engines need to overcome the design compromise in order to operate with comparable efficiency in both modes.
- Proper engine operation requires a degree of turbocharging flexibility in order to cope with different requirements.
- High performance engines require advanced turbocharging solutions like:
  - High compression ratios
  - High efficiency
  - Variable valve timing
- ABB can provide all the required solutions:
  - 1-stage: A100
  - 2-stage: Power2 (comp. ratio up to 12 and TC efficiency beyond 75%)
  - Variable valve timing: VCM

The Power of Power2 …



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