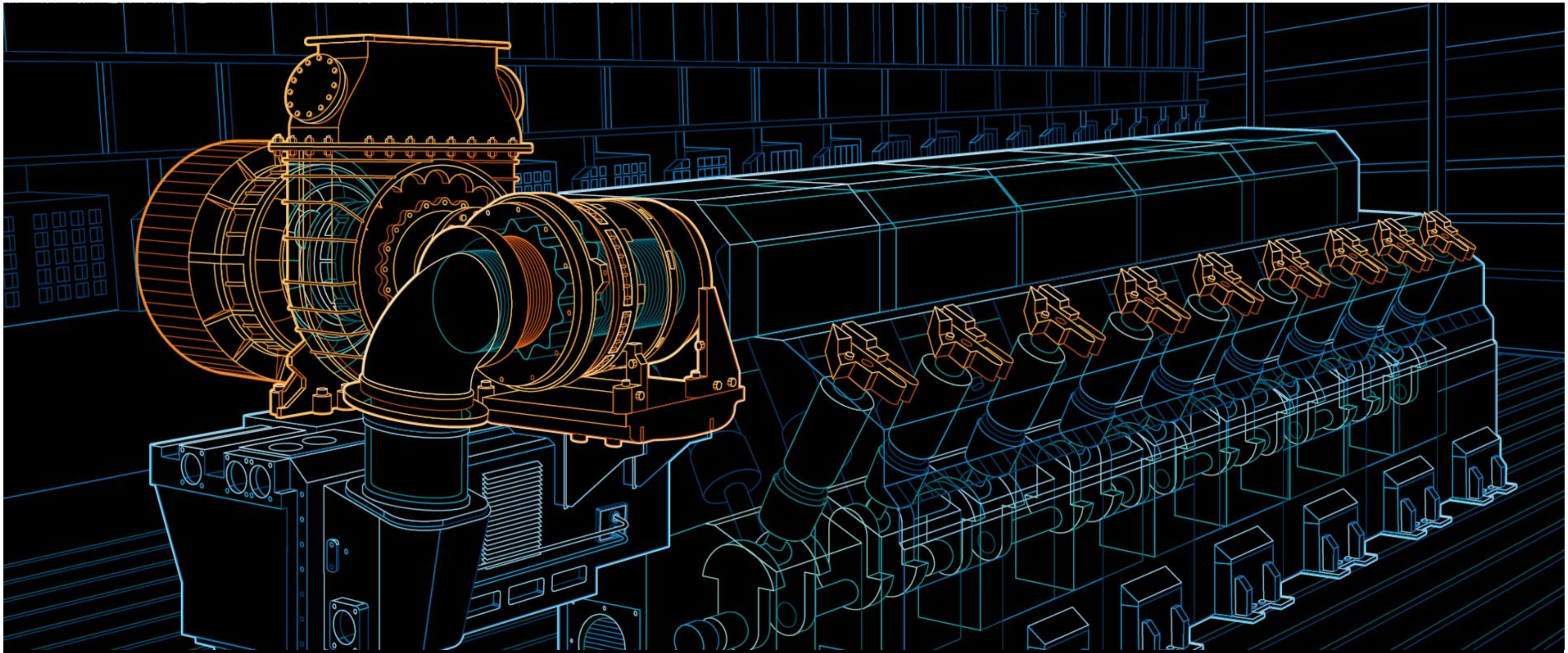


5th CIMAC CASCADES / Jin-woo Seong, 2014-10-23

Flexibility in Turbocharging
Opportunities and Options

Power and productivity
for a better world™

ABB

Flexibility in Turbocharging

Topics

- Introduction
- 2-stage Turbocharging and Variable Valve Timing
- Potential for Otto Gas and DF Engine Applications
  - Stationary EPG
  - Medium Speed Dual Fuel MARINE Propulsion
  - High Speed MARINE Propulsion
- Summary

Flexibility in Turbocharging
Introduction

Opportunities

- Increased engine efficiency
- New applications / extended operation range
- Improved load response
- Standardization
- High altitude capabilities
- New control possibilities

Power2 and VCM
Two-stage turbocharging

Basic potential

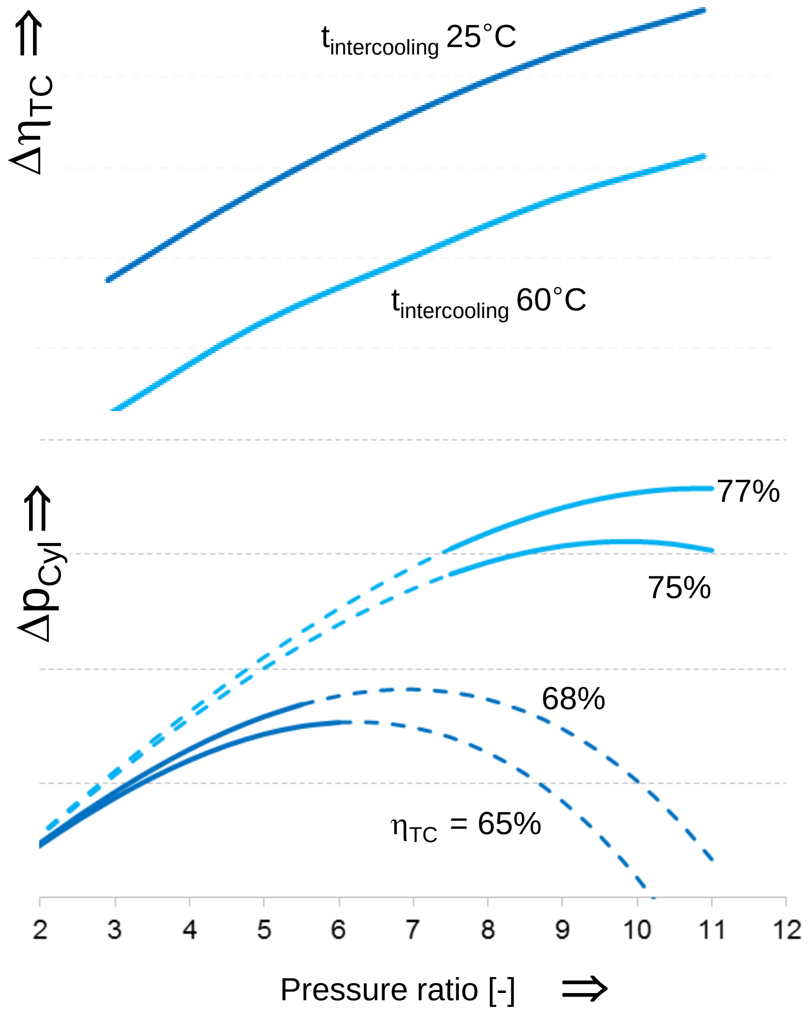
- Pressure ratios of up to 12
- Turbocharging efficiencies above 75%

Power2 and VCM
Two-stage turbocharging

Basic potential

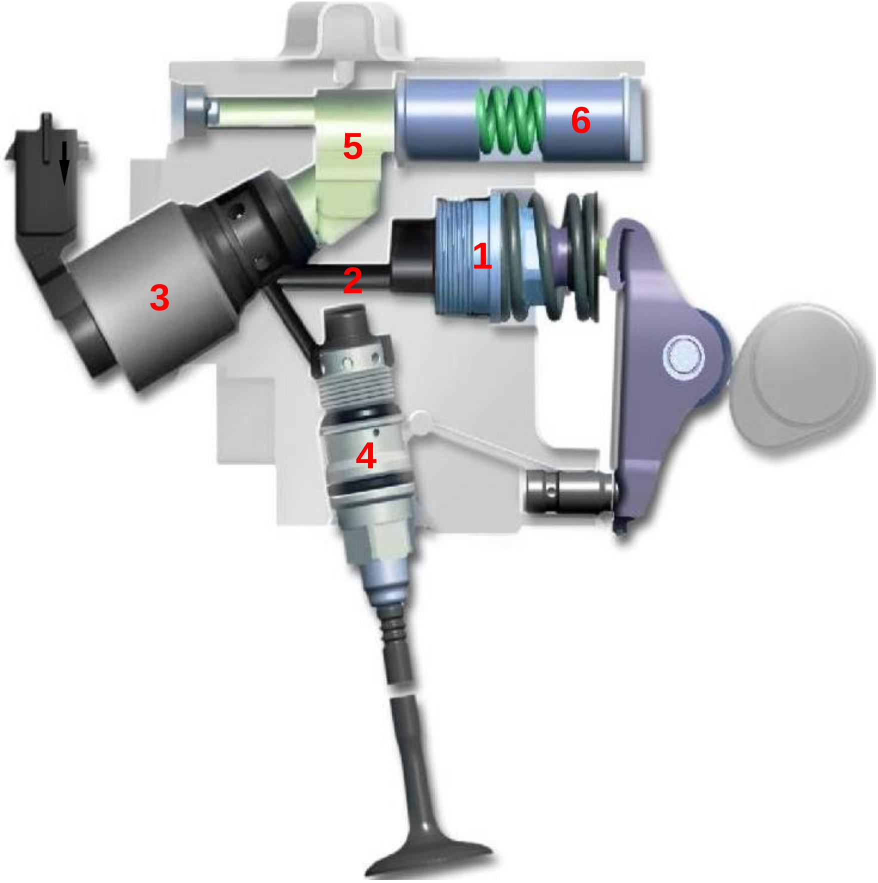
- Pressure ratios of up to 12
- Turbocharging efficiencies above 75%

- With higher pressure ratio …
  - ⇒ … increase in η_{TC}
  - ⇒ … increase in Δp_{Cyl}
  - ⇒ … more compact 2-stage system



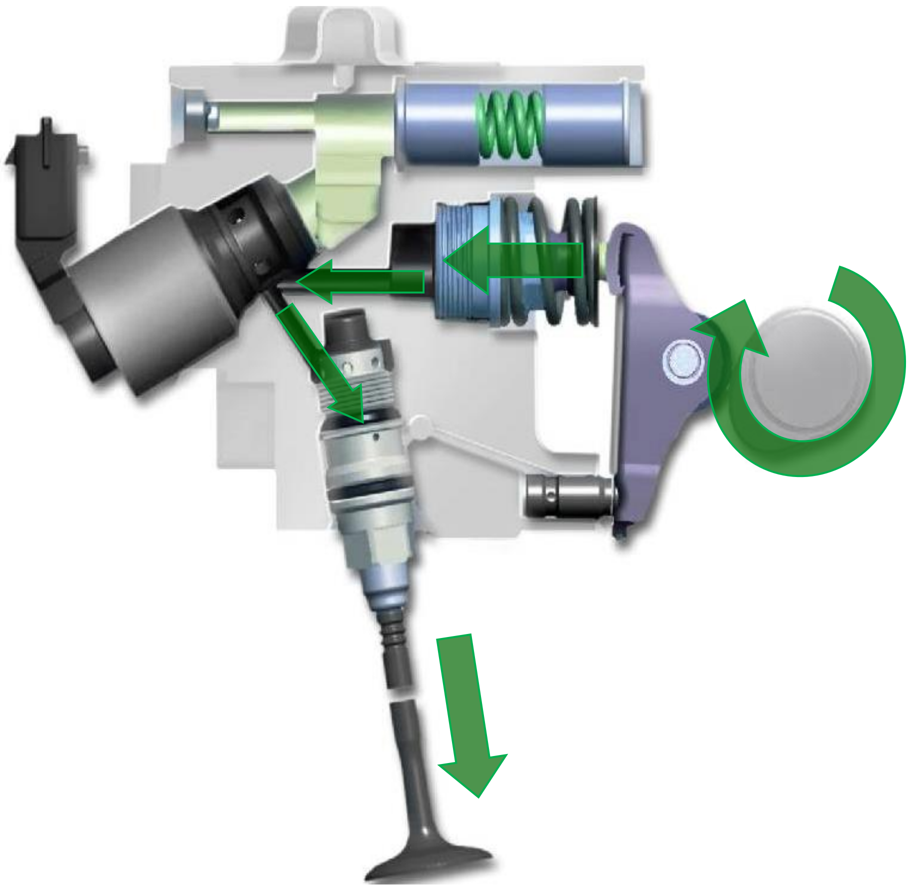
Power2 and VCM
VCM configuration

- VCM is a cam-supported electro-hydraulic valve train
- Components
  1. Pump unit
  2. High-pressure chamber
  3. Solenoid valve
  4. Brake unit
  5. Medium-pressure chamber
  6. Pressure accumulator



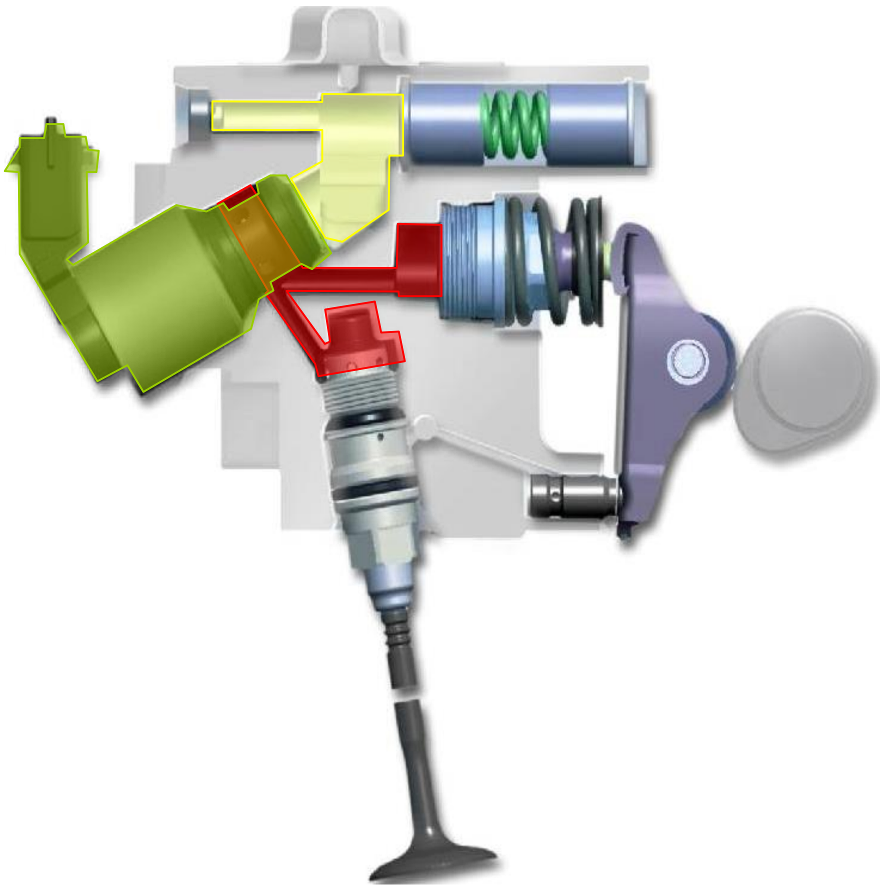
Power2 and VCM
VCM functional principle

- Cam profile transmitted via pump through the high pressure chamber to the engine valve (solenoid valve closed)



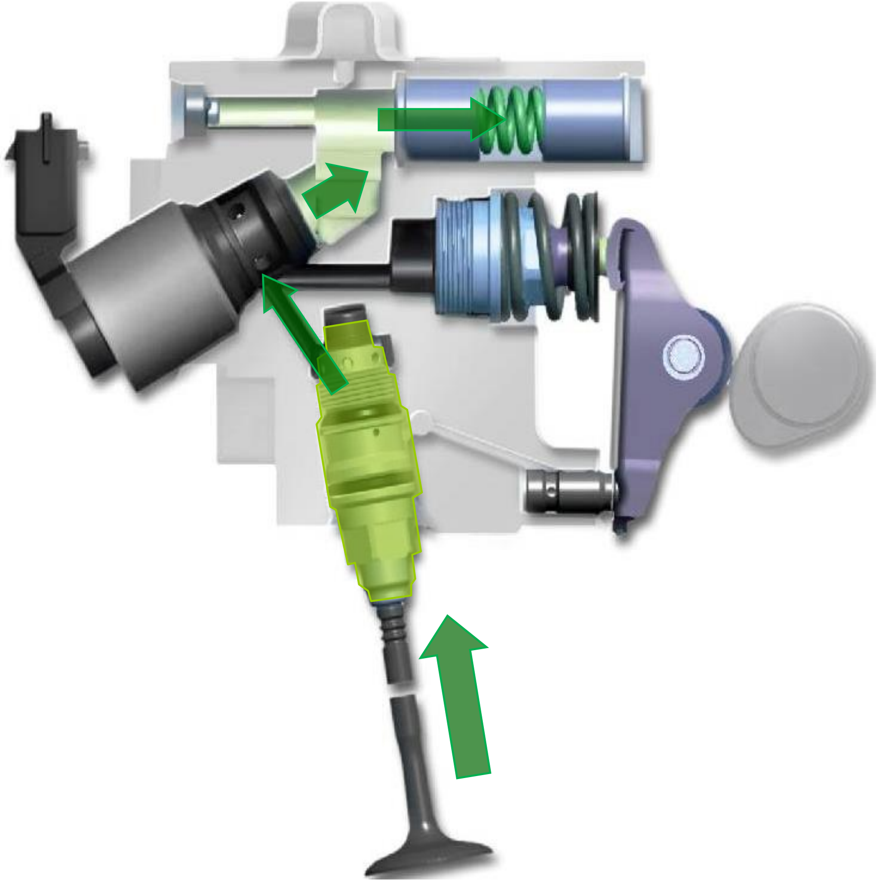
Power2 and VCM
VCM functional principle

- Cam profile transmitted via pump through the high pressure chamber to the engine valve (solenoid valve closed)
- High-pressure area closed and opened towards middle pressure area by fast switching solenoid valve (SV)



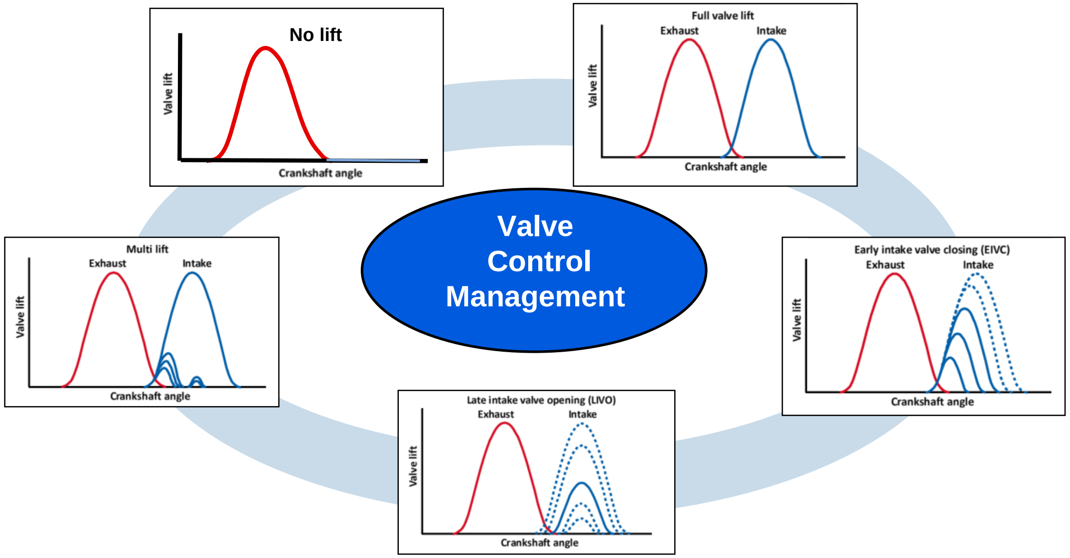
Power2 and VCM
VCM functional principle

- Cam profile transmitted via pump through the high pressure chamber to the engine valve (solenoid valve closed)
- High-pressure area closed and opened towards middle pressure area by fast switching solenoid valve (SV)
- Engine valve closing not cam controlled (ballistic phase); seating velocity controlled by hydraulic brake



Power2 and VCM
VCM capabilities

- Individual valve control
  - Lift height
  - Opening time
  - Closing time
- Steep closing flanks
- No increase of mechanical load
- Variation from cycle-to-cycle



Power2 and VCM
Status product development

Power2

- Testing on ten different engine platforms completed, ongoing or under preparation
- Two systems of first generation released, serial deliveries for over 120 engines
- Second generation prototype testing on engine ongoing

VCM

- Over 5,000 rhs with two prototypes operated on mechanical test beds, single and multi cylinder engines
- Highly integrated design for first customer application realized
- Thermodynamic potential exceeding expectations

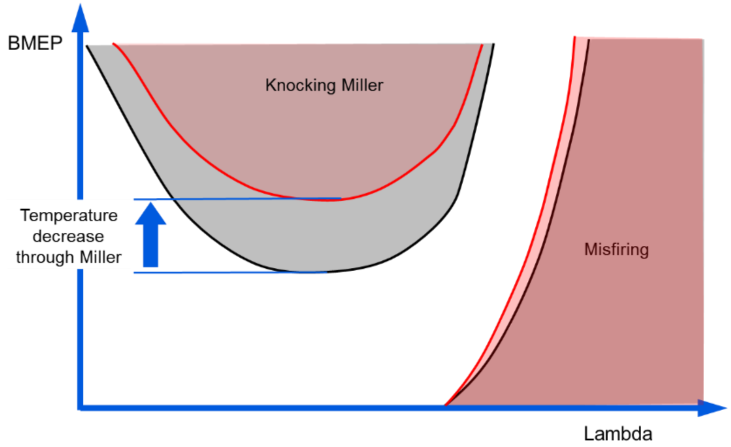
Potential for Gas Engine Applications
Stationary EPG
(baseload, industrial, back-up, …)

Development drivers

- Engine efficiency ⇒ 1%pt = ~15 €/kW savings p.a.[1)]
- Power Density ⇒ lower 1st cost/kW, smaller engine footprint
- Robustness ⇒ lower MN, altitude, ambient temperature

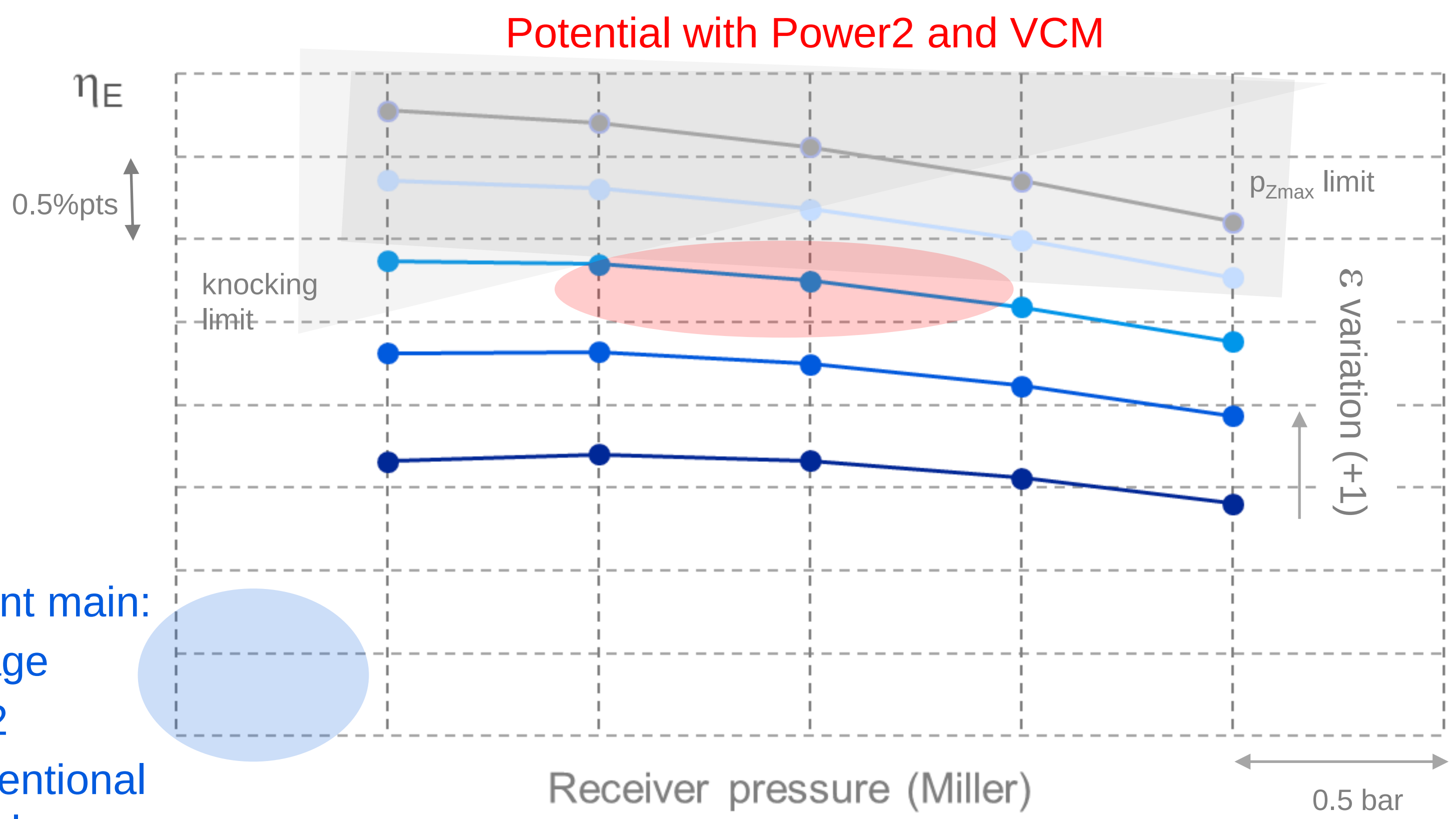
Possibilities with Power2 and VCM

- λ control via IVC variation replacing conventional control elements
- increase Miller timing, keeping high valve lift
- use lower temperature at start of compression:
  - ⇒ higher compression ratio ε
  - ⇒ increased engine bmep / p_{Zmax}
- utilize high turbocharging efficiency @ high pressure ratio



1) 8’000 rhs/a @ 100% load, natural gas price 0.04 €/kWh

Potential for Gas Engine Applications
Stationary EPG
(baseload, industrial, back-up, …)



Current main:
- 1-stage
- ε ~12
- conventional control

Potential for Gas Engine Application
MARINE Propulsion – Diesel Electric
(Cruise & Ferries, LNG carriers, RO-RO/PAX, …)

Development drivers

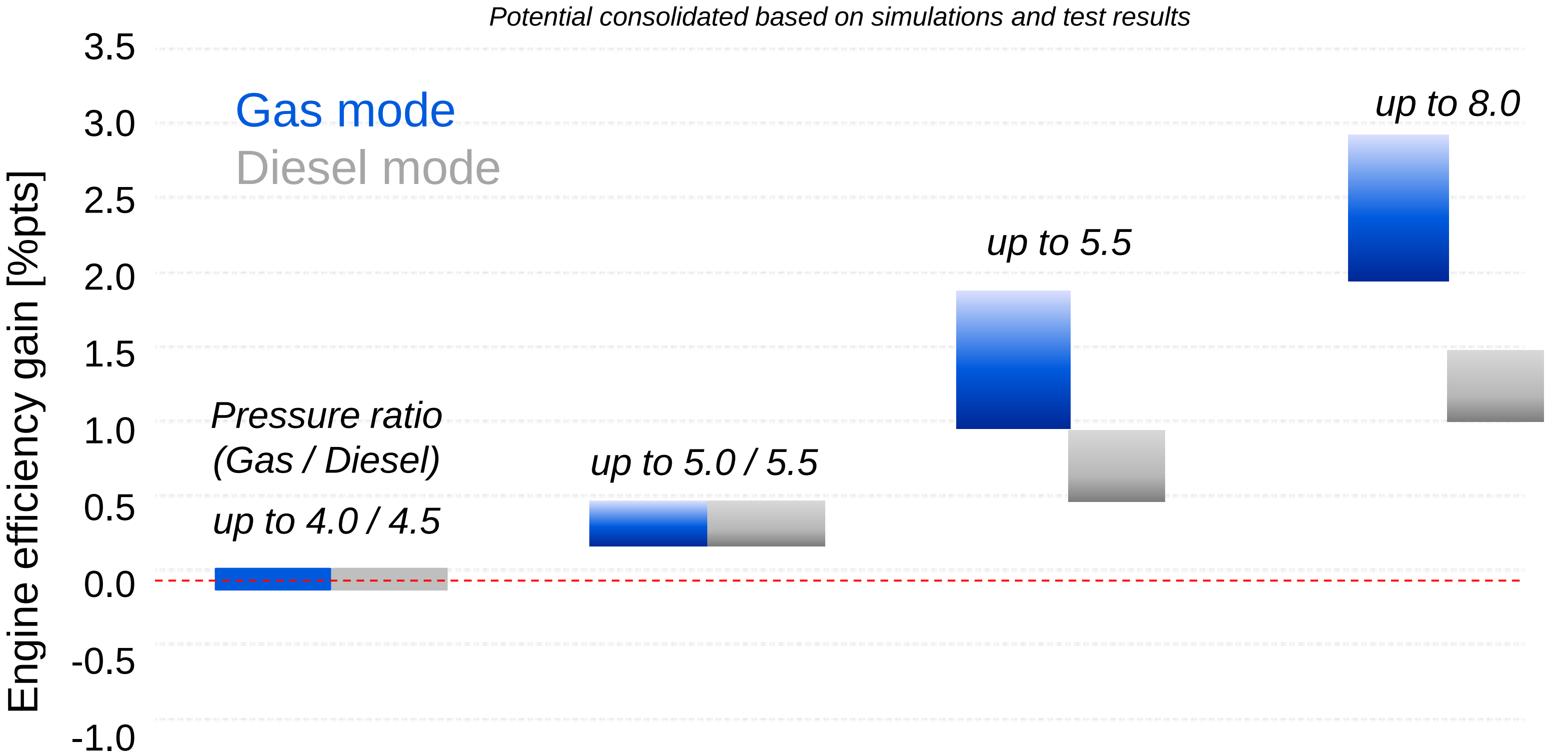
- Engine efficiency $\Rightarrow$ optimize gas mode, minimize compromise in Diesel mode
- Power Density $\Rightarrow$ lower 1st cost/kW, less cylinders, smaller engine footprint
- Emissions $\Rightarrow$ IMO III compliance in Gas mode, no related aftertreatment

Current challenges

- Low ε in gas mode leads to poor performance in Diesel mode
- Operation in Diesel mode leads to significant higher TC pressure ratio needs (closed WG)
  - limitations by TC speed
  - further reduced Diesel performance due to too high λ_V

Potential for Gas Engine Application
MARINE Propulsion – Diesel Electric

(Cruise & Ferries, LNG carriers, RO-RO/PAX, …)



Single-stage TCing		→ Enhanced Miller		→ Strong Miller		**Power2**
Moderate Miller	➔	Bmep ~22 bar	➔	→	➔	Extreme Miller
bmep ~20 bar		→ Simple VVT, WG		→ **VCM**		bmep ~24 ÷ 26 bar
ε ~12						ε ~ 14 ÷ 16
WG						**VCM**

ABB

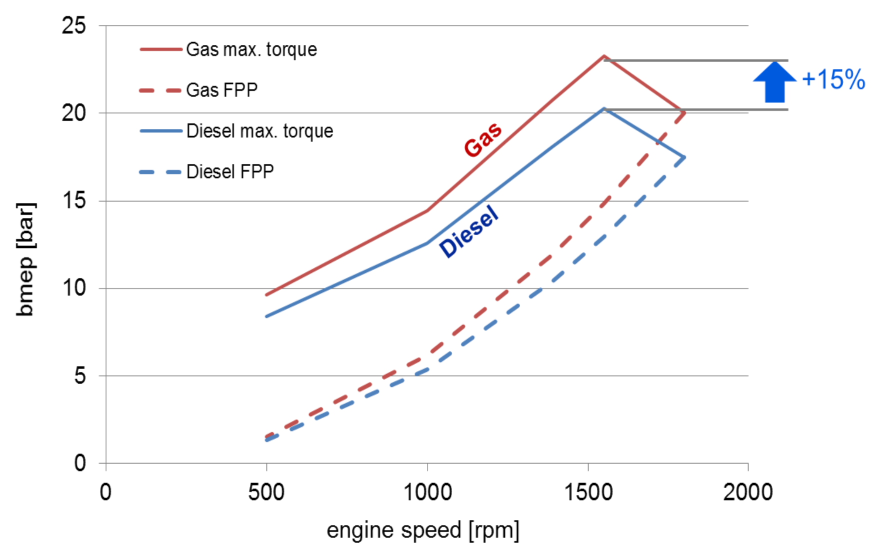
Potential for Gas Engine Applications
MARINE Propulsion – Direct Drive
(Tug & Salvage, Inland Waterways, Pleasure Crafts, …)

Development drivers

- Operational cost ⇒ gas price lower than MDO, engine efficiency
- Emissions legislation ⇒ no NOx aftertreatment, no particulates
- Wide operating range ⇒ FPP, high torque, load response, maneuverability

Simulation example:

- Diesel reference:
  - 17.5 bar bmep @ 1’800 rpm
  - FPP, torque rise to 20 bar bmep
  - Sequential turbocharging
- Gas:
  - Lean burn, port injection
  - 15% increase bmep
  - 1-stage turbocharging



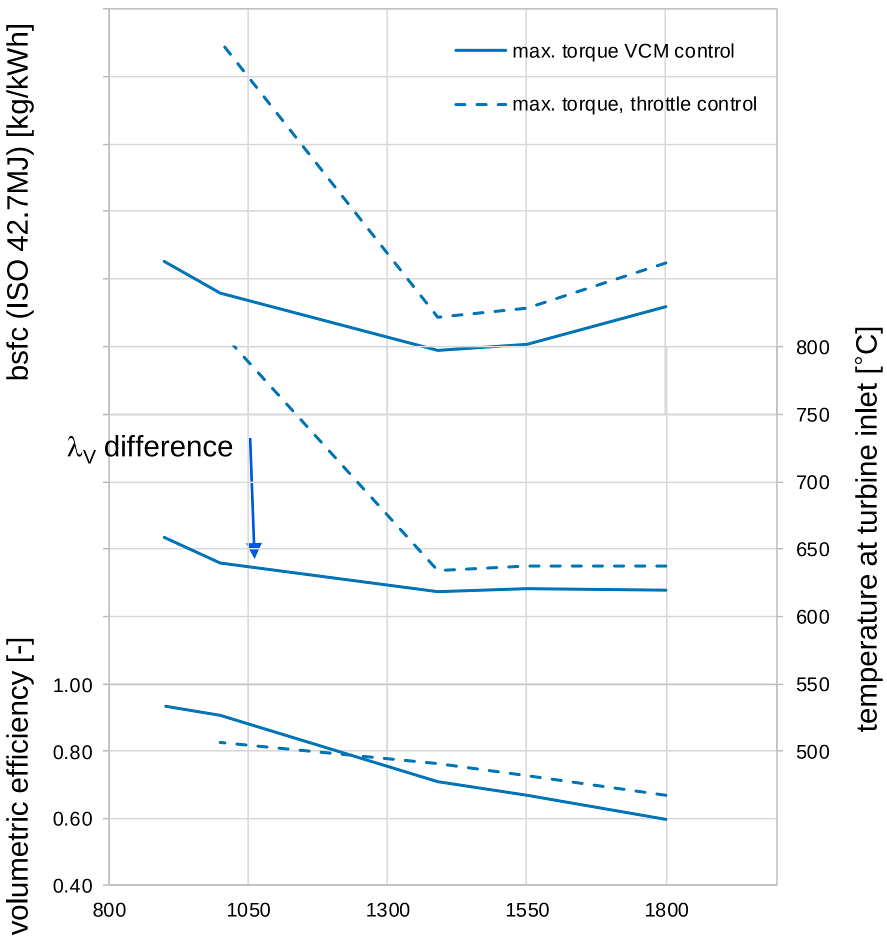
Potential for Gas Engine Applications
MARINE Propulsion – Direct Drive
(Tug & Salvage, Inland Waterways, Pleasure Crafts, …)

Approach steady–state operation

- High pressure 1-stage turbocharging and strong Miller timing
- Load- and λ_V-control through VCM and gas admission valve

⇒ max. torque well covered with high pressure 1-stage turbo-charging and VCM

⇒ good bsfc characteristic and low exhaust gas temperatures over entire operating range



Potential for Gas Engine Applications
MARINE Propulsion – Direct Drive

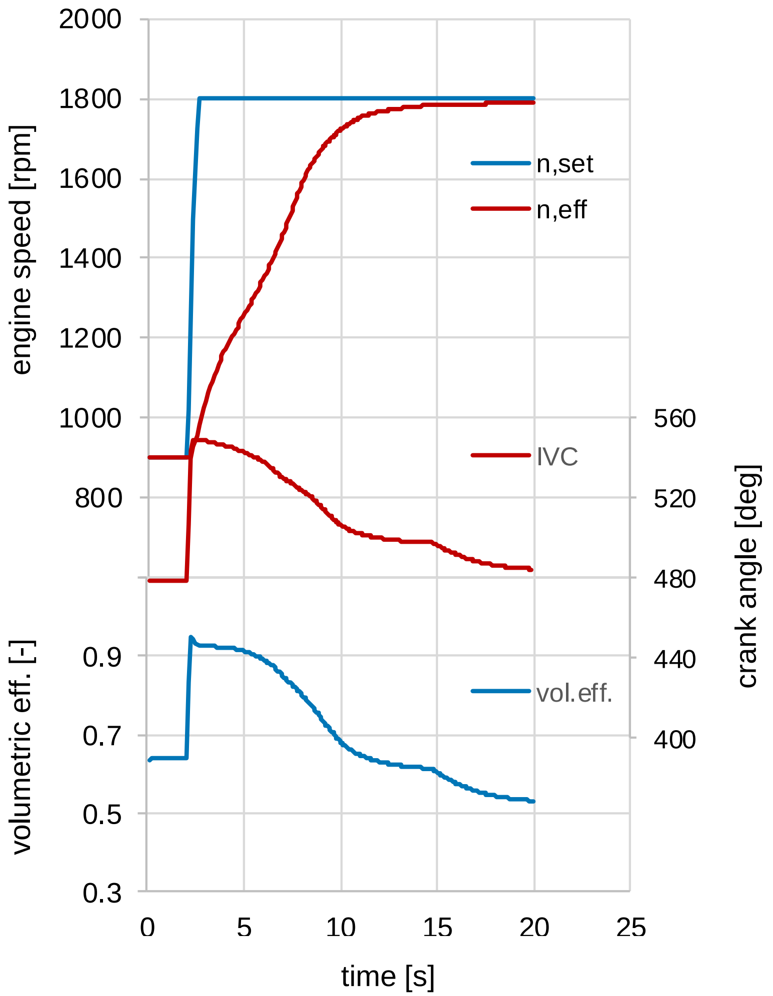
(Tug & Salvage, Inland Waterways, Pleasure Crafts, …)

Approach transient operation

- Max. cylinder filling through optimized IVC timing
- Max. gas injection without falling below min. λ_V
- Acceleration from 900-1800rpm

⇒ fast and «step-less» load response based on simulations

⇒ equal or even better than current diesel feasible



Power2 and VCM
Summary

- High pressure turbocharging and VCM enable high bmep gas engines for demanding applications:
  - Engine efficiency gains of min 2%pts for stationary EPG applications (first test results)
  - Dual Fuel capabilities with optimized gas operation without compromising the Diesel performance (high ε)
  - Unrestricted operational flexibility including traditional high speed diesel applications

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for a better world™