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Bosch Technologies to achieve Ultra Low Emissions and an Assessment what is feasible in short term.

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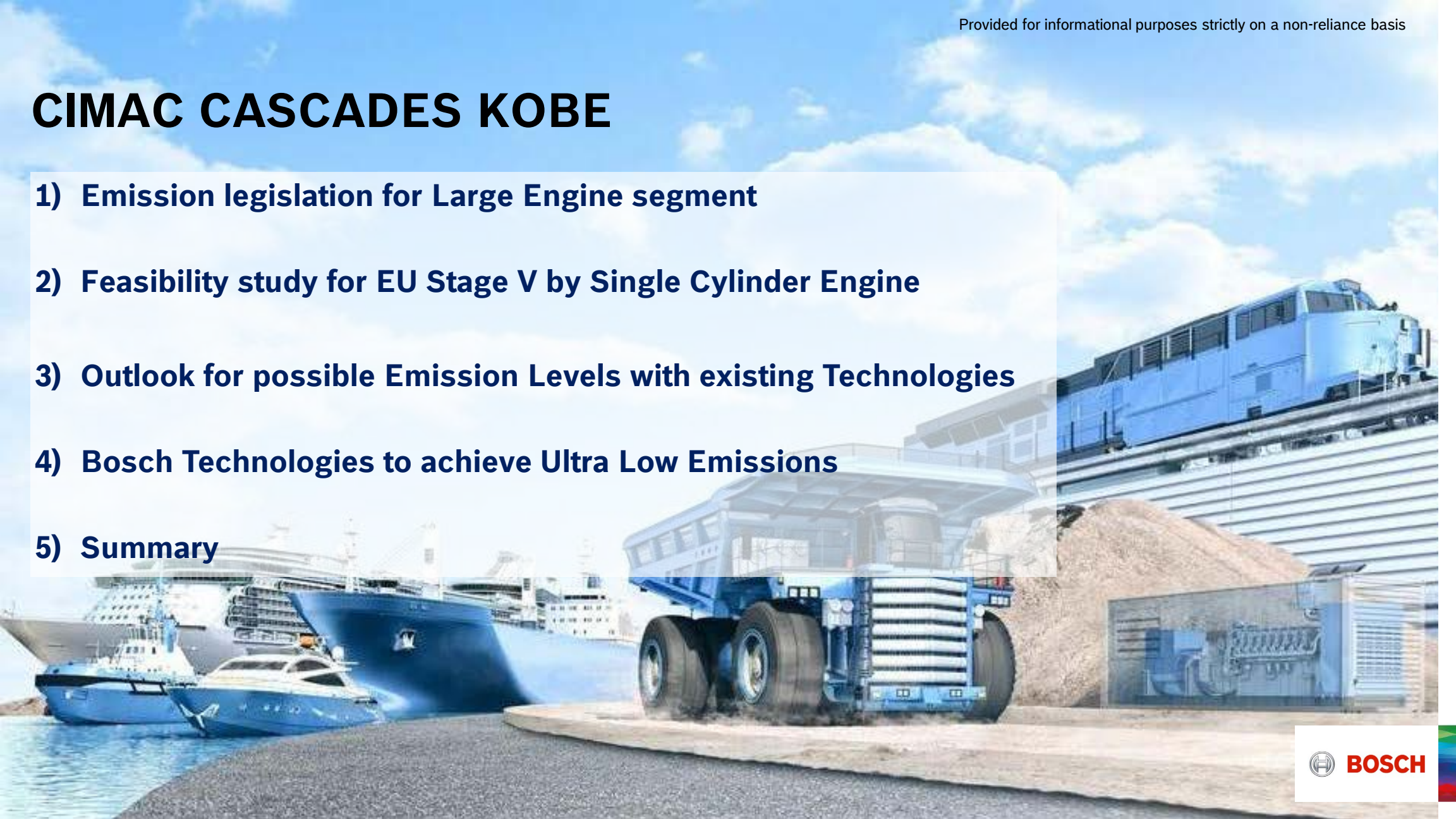
1) Emission legislation for Large Engine segment
2) Feasibility study for EU Stage V by Single Cylinder Engine
3) Outlook for possible Emission Levels with existing Technologies
4) Bosch Technologies to achieve Ultra Low Emissions
5) Summary



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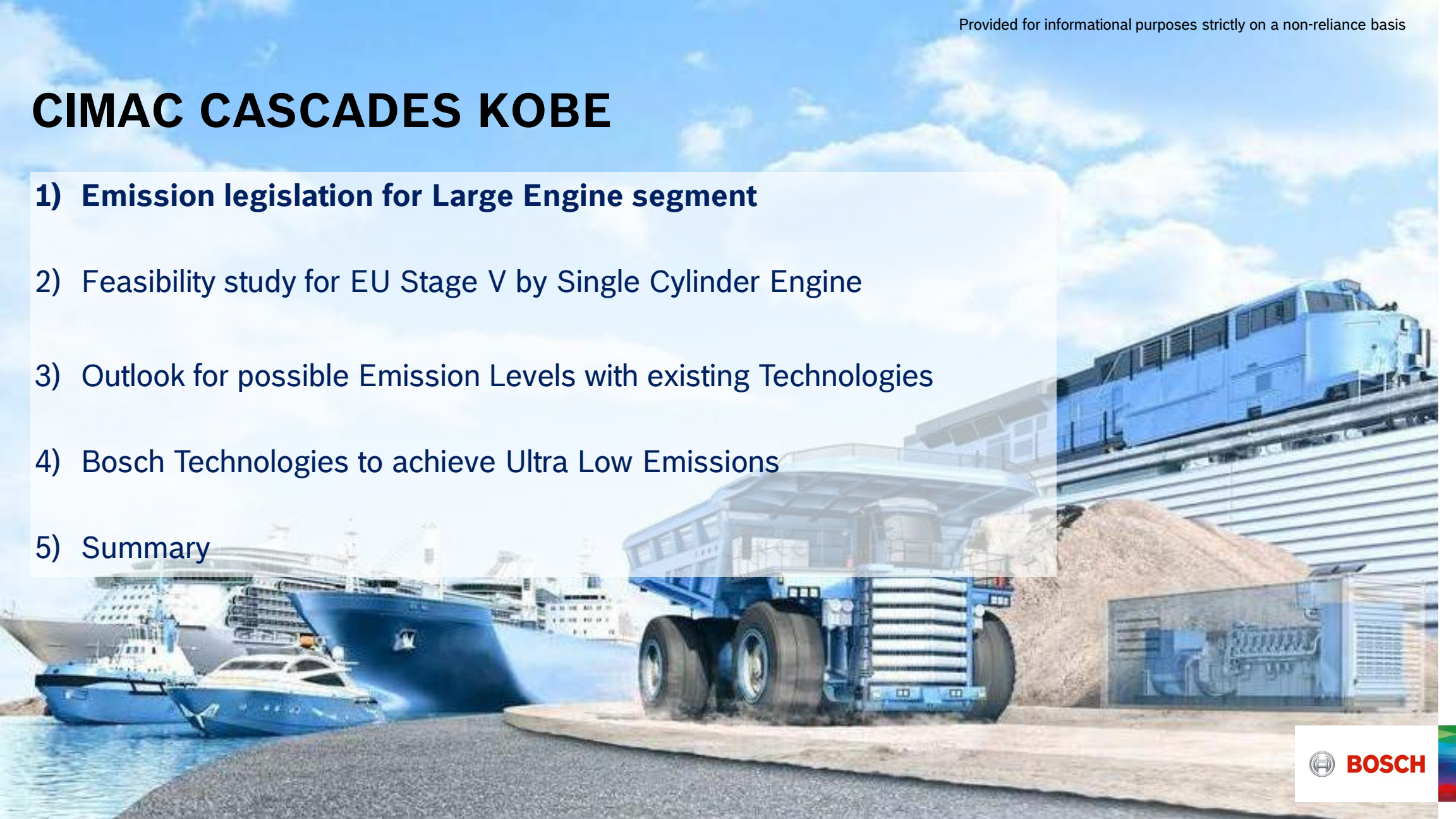

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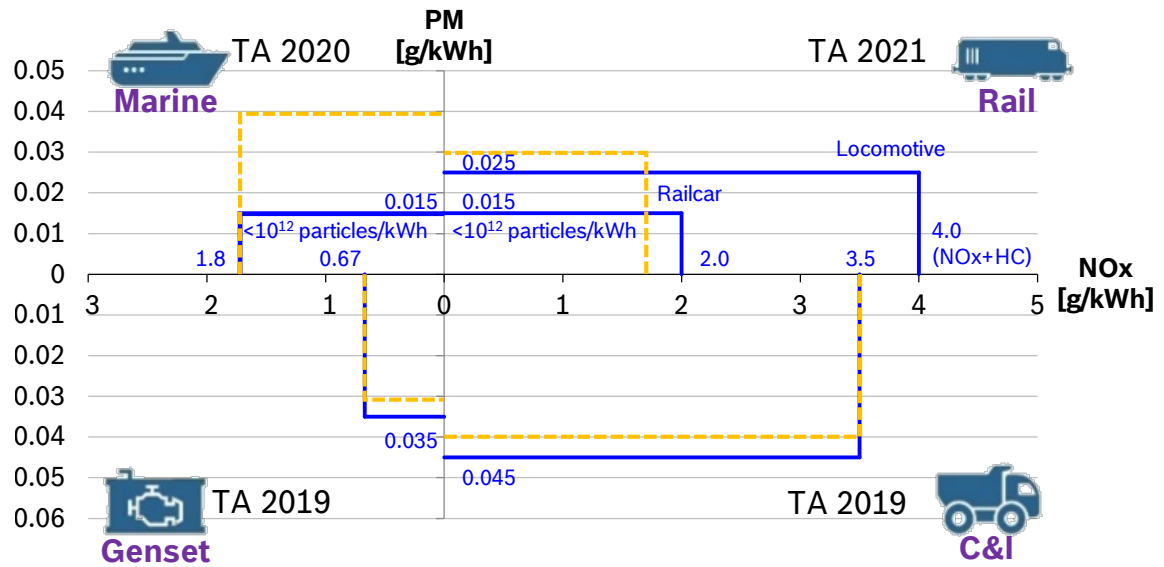
Emission legislation for Large Engine segment
EU Stage V and US EPA Tier 4

- Comparison EU Stage V & EPA Tier 4



*** Current Status :**

European Parliament has adopted on July 5th 2016 the regulatory text with minor changes.

Retrofitting of engines to stage V will be assessed in 2018.

Legislation will come into effect with type approval (TA) of gensets on January 1st 2019.

EU Stage V

- In general, focus on particulates and NO_x emissions

  → DOC/DPF & SCR exhaust gas treatment will be required in some cases

EPA Tier 4

- Already equipped today with either EGR, EGR+DPF or SCR

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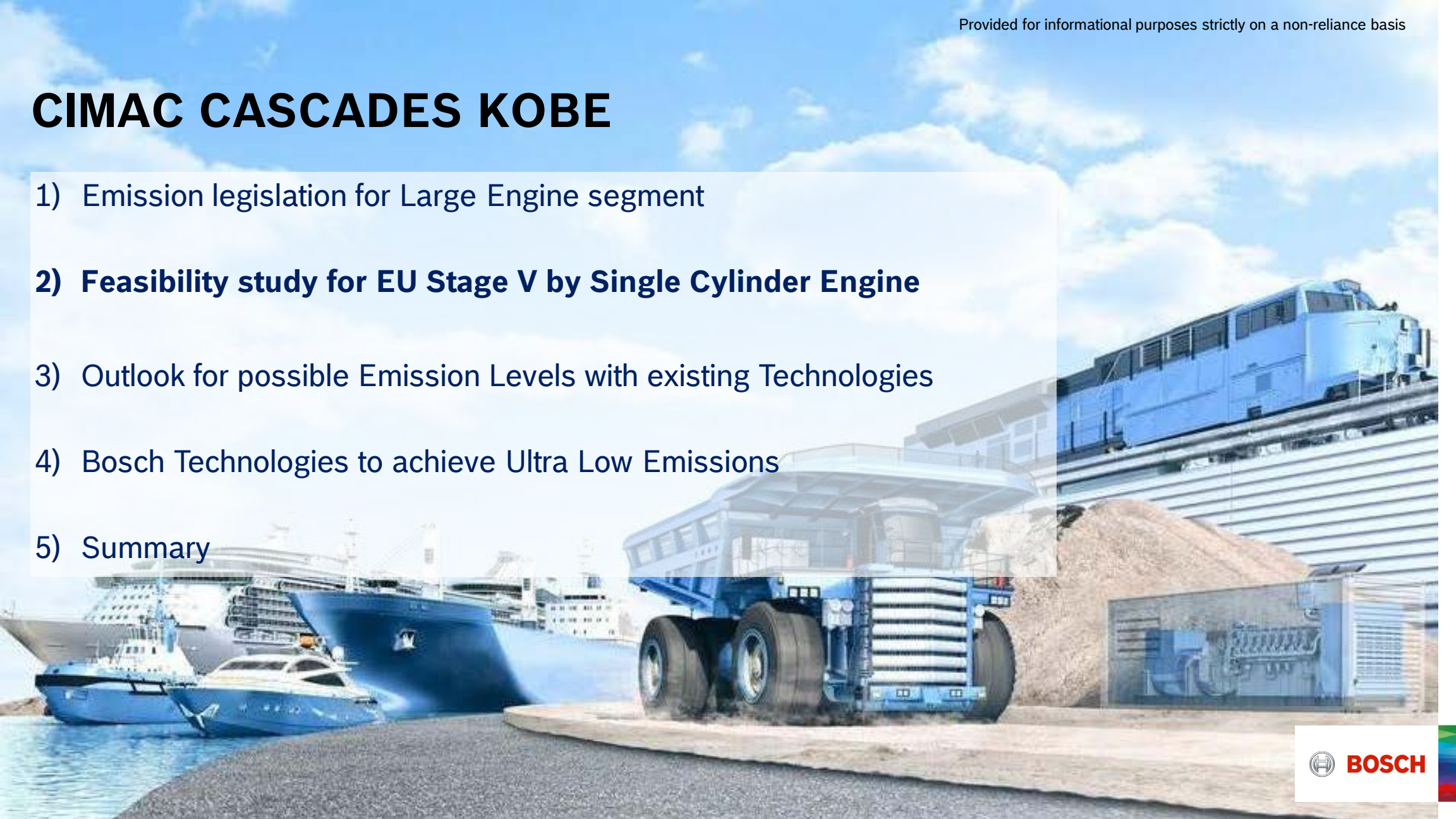
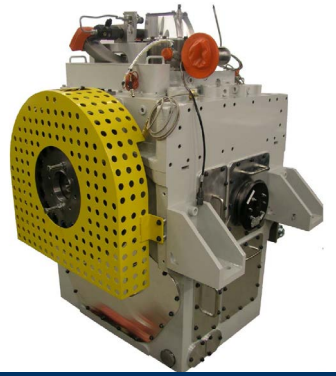


Feasibility study for EU Stage V by Single Cylinder Engine

Setup: Engine specification and Engineering target

Specification of Single Cylinder Engine (SCE)	
Displacement	2.54 l
Peak firing pressure	250 bar
Rated Speed	2300 min^{-1}
$NMEP_{max}$	31 bar
Power density	~ 50 kW/l
Injection system	**Common rail**



EU Stage 5 Application	Limit EU Stage V		Engineering Target	
	NOx [g/kWh]	PM [g/kWh]	NOx [g/kWh]	Soot [g/kWh]
Marine (>300 kW)	1.80	0.015	**1.35**	**0.006**
Locomotive	4.00	0.025	**2.94**	**0.010**
Railcar	2.00	0.015	**1.47**	**0.006**
GenSet	0.67	0.035	**0.49**	**0.014**
Construction & Industry	3.50	0.045	**2.57**	**0.019**

Engineering Target

- Margin for NOx and PM considering deterioration over run time
- Ratio of PM and Soot based on experience

Bosch Modular Common rail injection system (MCRS) is used to achieve flexible fuel injection
Engineering target considering deterioration and PM/Soot ratio

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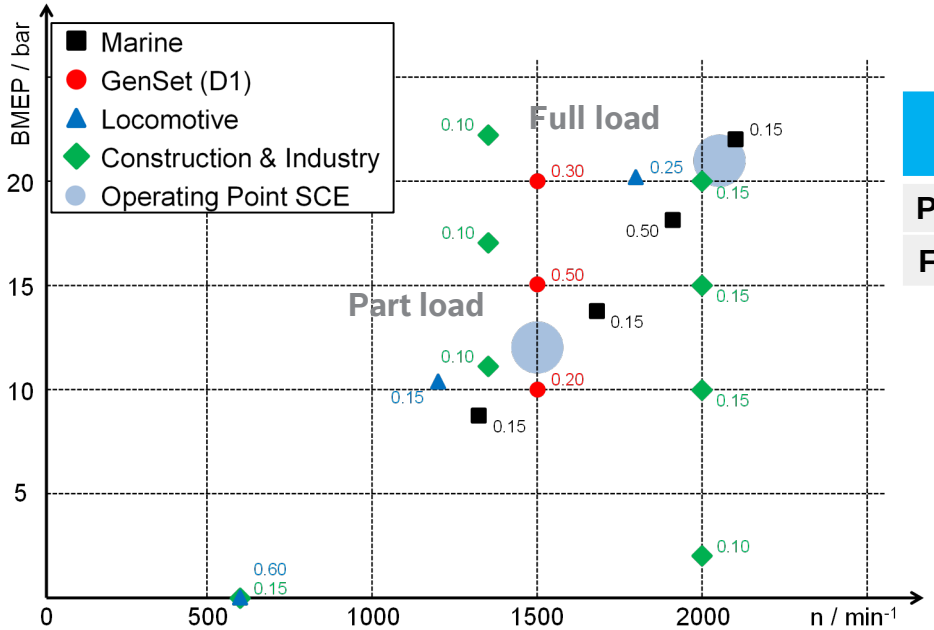
Feasibility study for EU Stage V by Single Cylinder Engine

Setup: Testing points



Load	Speed [min^{-1}]	BMEP [bar]	NMEP [bar]
Part load	1500	12	13
Full load	2050	21	23

Key parameters:

- Boost pressure — simulate single stage, two stage T/C
- EGR — with, without
- Injection pressure & timing

Testing points :

2 testing points are defined based on weighting factors of 4 segments.

2 testing points (Full load and part load) are selected for SCE test

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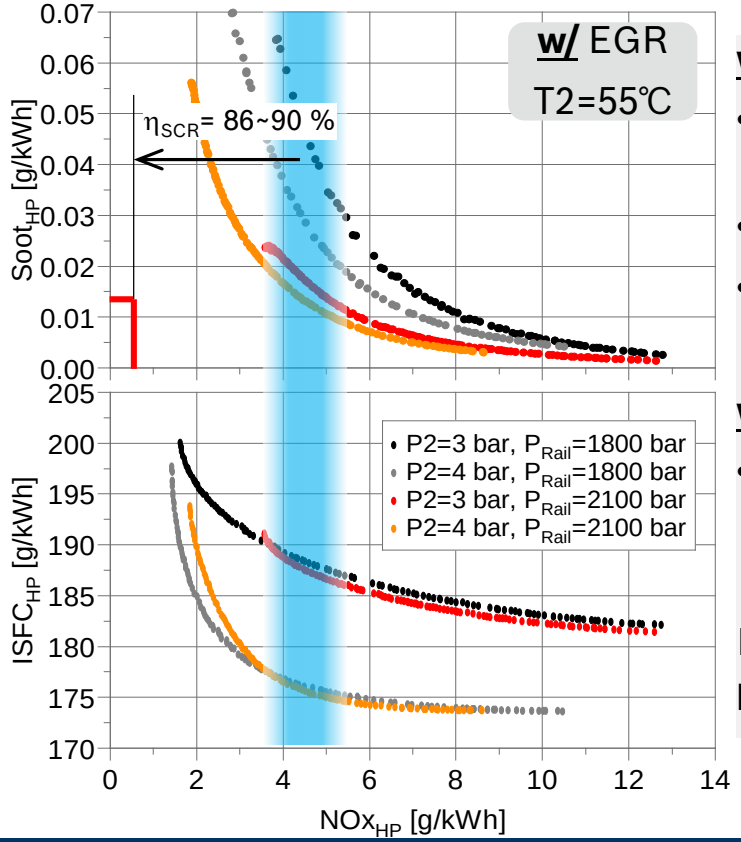
Feasibility study for EU Stage V by Single Cylinder Engine

Result@Full load: Genset application (w/o PN limitation)



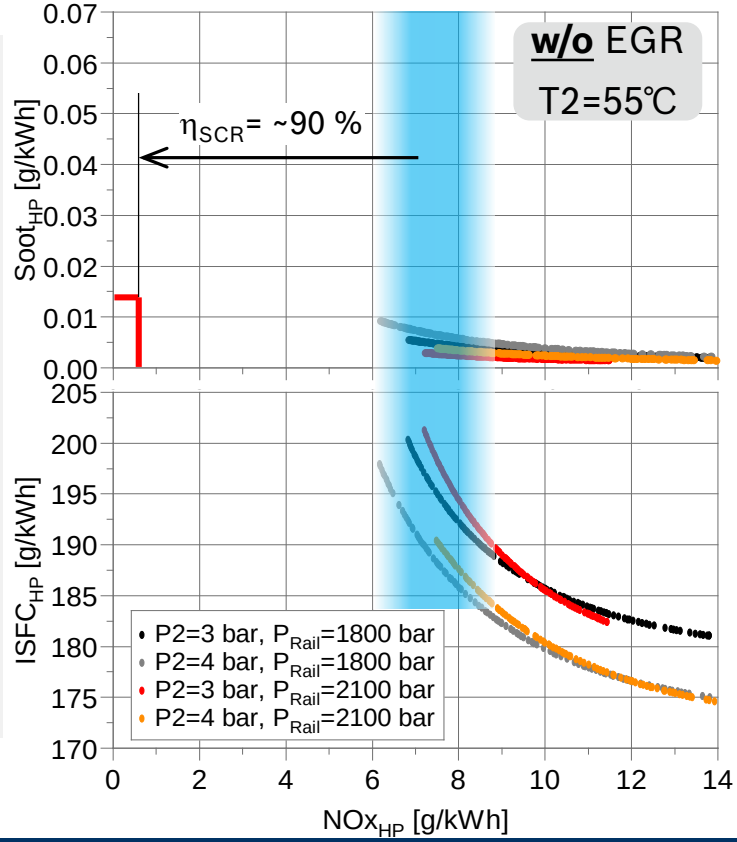
w/ EGR

- Cannot fulfill emission target
  →SCR required (= complex system)
- Higher rail pressure required for PM limit
- 2 stage TC increase emission margin

w/o EGR

- Fulfill emission target with high NOx conversion of SCR

Improvement of ISFC with higher rail pressure is minor



SCR only application can achieve emission targets and will be cost attractive solution

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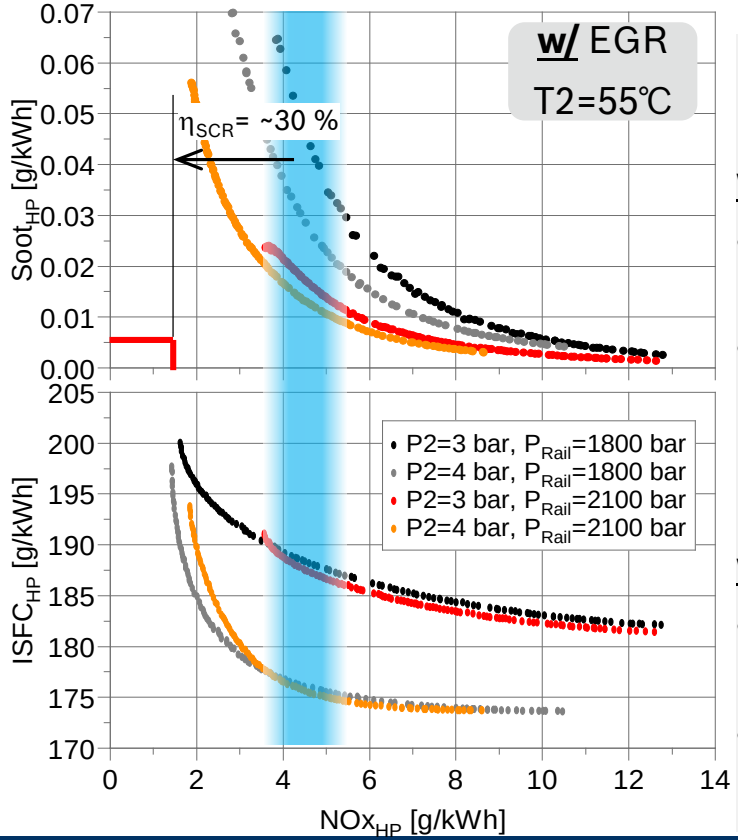
Feasibility study for EU Stage V by Single Cylinder Engine

Result@Full load: Marine application (w/ PN limitation)



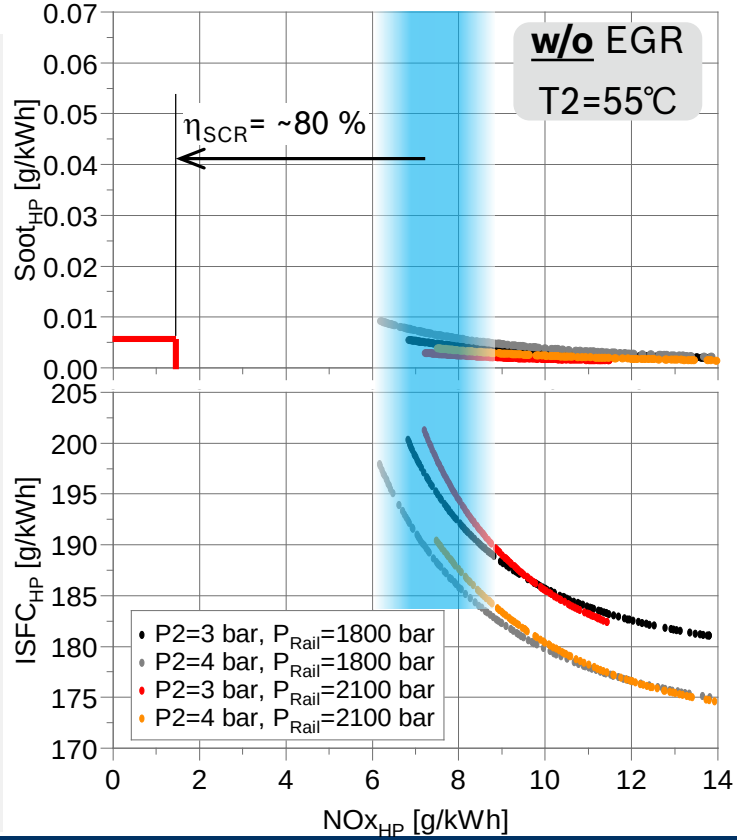
DPF necessary to fulfill PN limitation

w/ EGR

- Hard to fulfill NOx emission target
  →SCR required (= complex system)
- Higher rail pressure and charge pressure recommended to reduce engine out soot
  →reduction of DPF load

w/o EGR

- Lower NOx conversion compare to Genset
- Already low engine out soot at rail pressure <2000bar



DPF + SCR only application can achieve emission targets and will be cost attractive solution

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Feasibility study for EU Stage V by Single Cylinder Engine
Summary

Application w/o PN limit:

	w/ EGR	w/o EGR
For all Applications	2200bar: Good Soot-NOx tradeoff Good ISFC-NOx tradeoff	1800bar: Better ISFC-NOx tradeoff
GenSet 	▶ 1 stage TC ▶ SCR ▶ DOC optional	▶ **1 stage TC** ▶ **SCR** ▶ **DOC optional**
Locomotive 	▶ 2 stage TC ▶ Without SCR ▶ DOC ▶ DPF optional	▶ 1 stage TC ▶ SCR ▶ DOC optional
Construction 	▶ 2 stage TC ▶ Without SCR ▶ DOC	▶ **1 stage TC** ▶ **SCR** ▶ **DOC optional**

Application w/ PN limit:

	w/ EGR	w/o EGR
For all Application	1800bar: feasible 2200bar: Better Soot-NOx tradeoff	1800 bar: Better ISFC-NOx tradeoff
Marine 	▶ 2 stage TC ▶ Without SCR	▶ **1 stage TC** ▶ **SCR**
Railcar 	▶ 2 stage TC ▶ Without SCR	▶ **1 stage TC** ▶ **SCR**

DOC and DPF are necessary to fulfill PN limit.

EU stage 5 technologies will be copied:

- GenSet and C&I: from EPA Tier 4 applications
- Locomotive: from EU 3b applications

SCR w/o EGR for best fuel economy and lowest complexity

EGR requires high EGR rates with increased charging pressure and improved EGR cooling to achieve acceptable fuel consumption.

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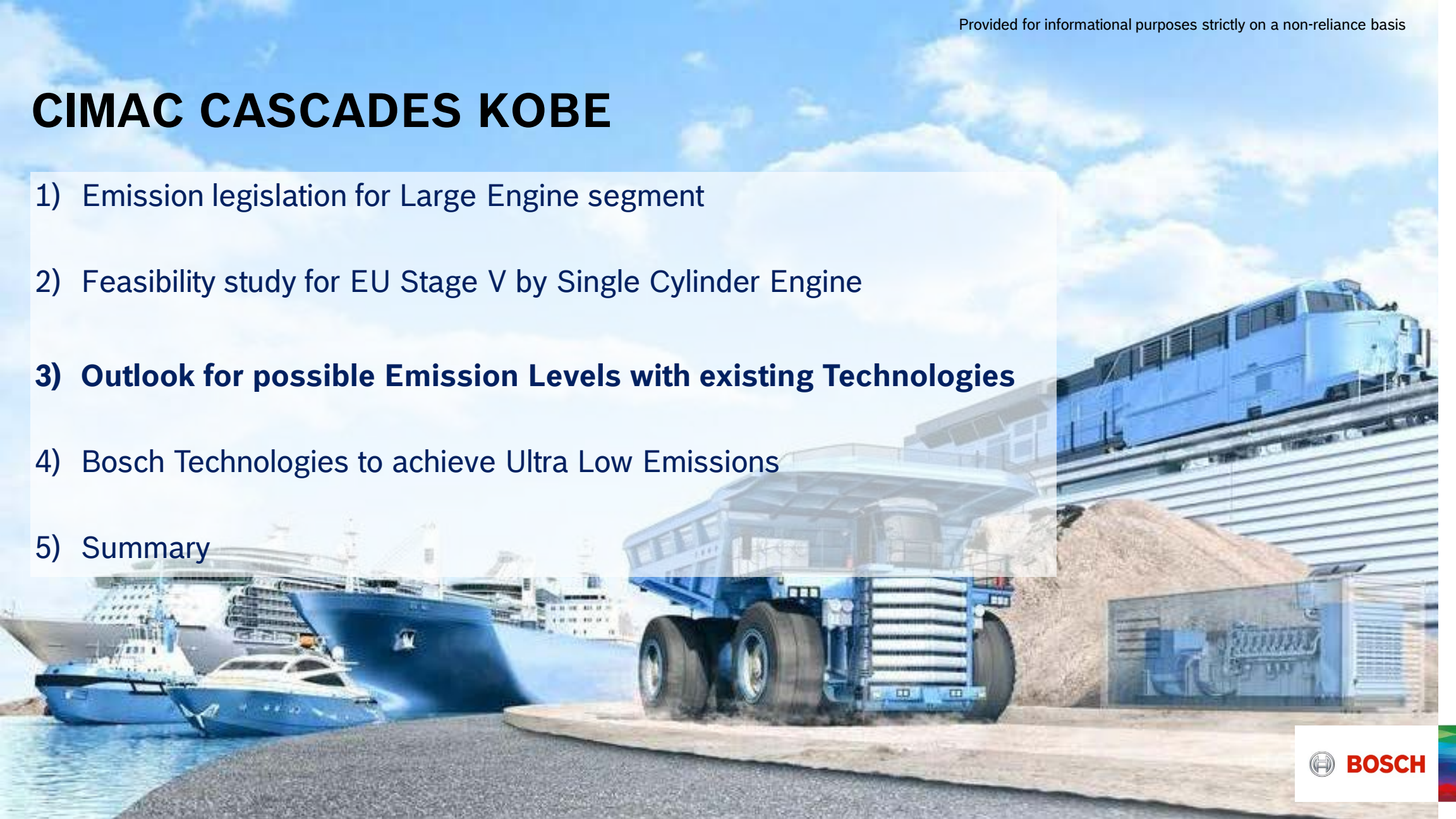
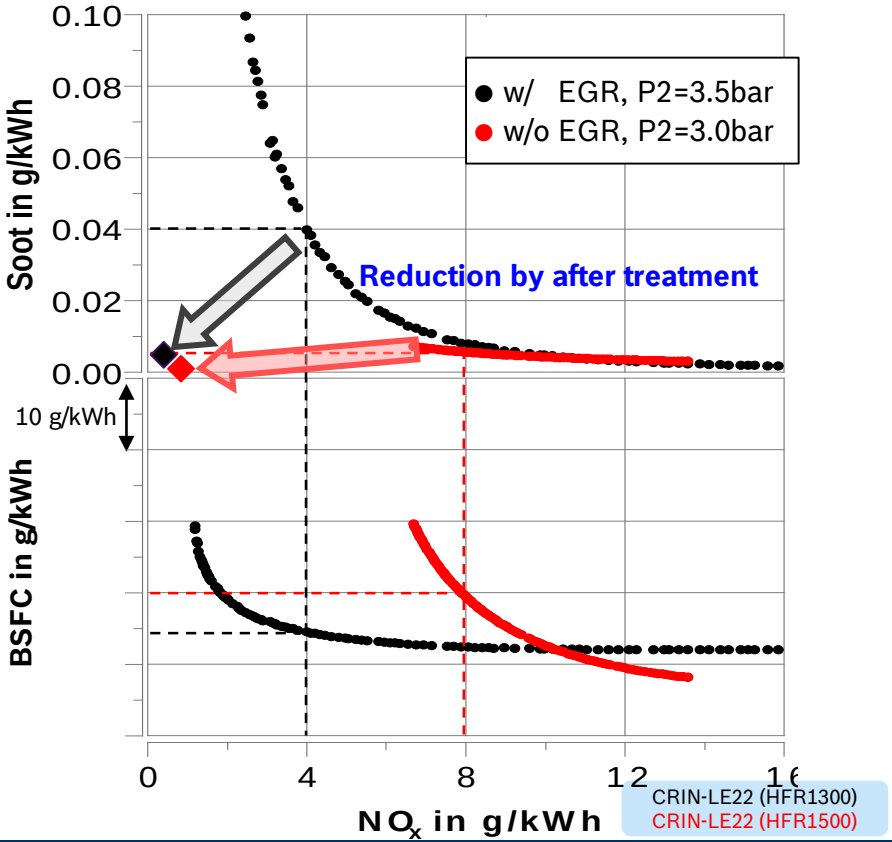
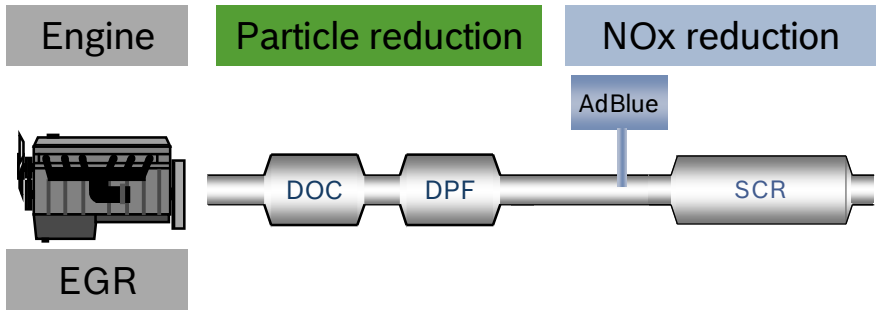


Outlook for possible Emission Levels with existing Technologies

Combination of existing technologies (Full load)





For EU Stage V…

NOx : SCR w/o EGR is sufficient

Soot: DOC/DPF is option in case no PN limitation

For Ultra Low emission…

NOx : **EGR** for low engine out emission + **SCR** for further reduction at tailpipe

Soot: With **DOC/DPF**, tailpipe emission can be reduced

Combination of EGR and after treatment (SCR+DPF) enable ultra low Emissions

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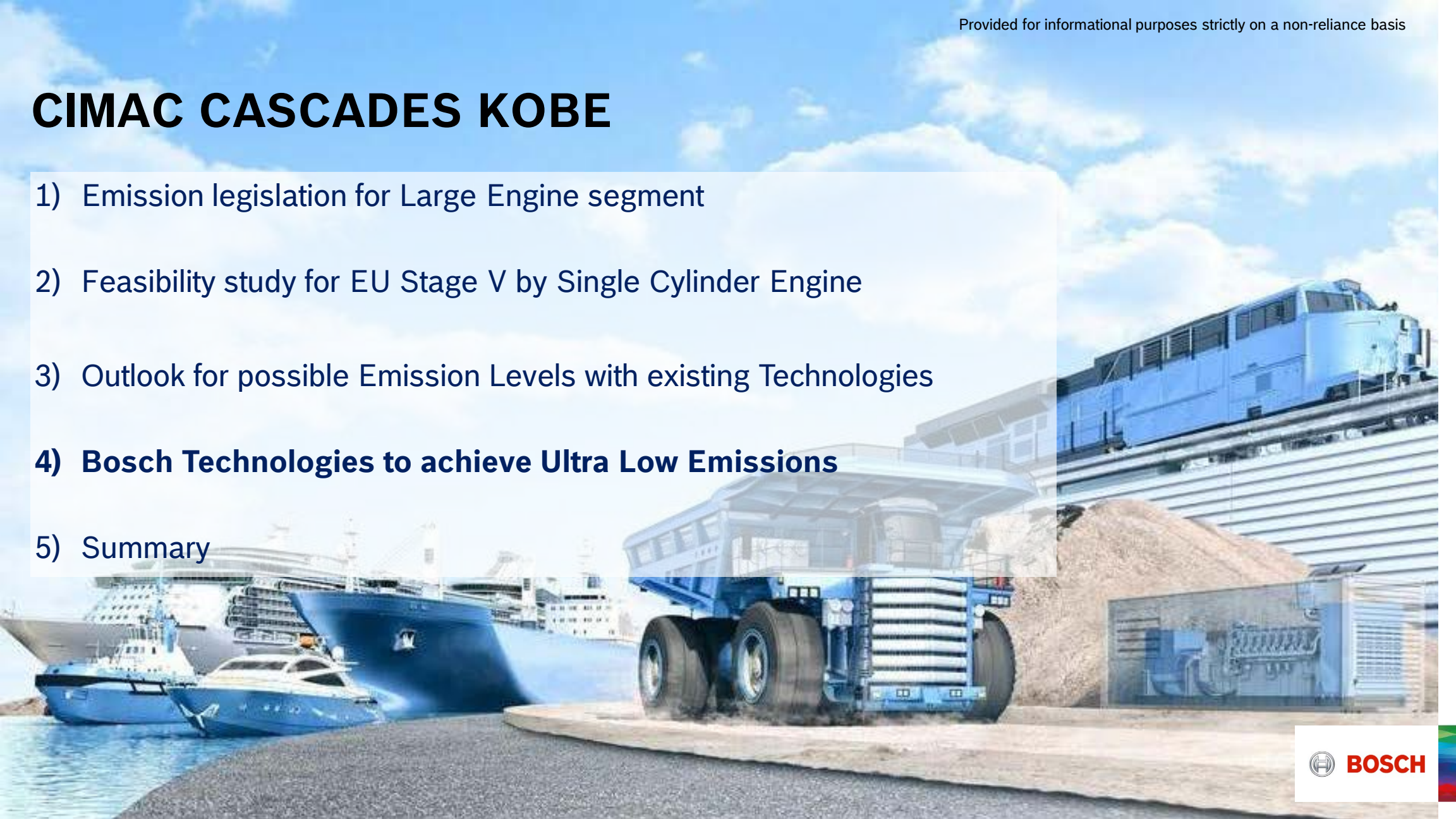

Bosch Technologies to achieve Ultra Low Emissions

Product Portfolio

Economical. Powerful. Reliable.

Fuel

Natural Gas | **Diesel**

Dual Fuel | Dual Fuel

FIE

Large Engine Gas Valves

LEGV50 LEGV400

CRSN
Common Rail System
up to 2500 bar

MCRS
Modular Common Rail System
1600 / 2200 bar

Pump Injector Pump Injector

UI/UPS
Unit Injector/
Unit Pump System

Electronic Unit Injector Unit Pump (& NHA)

Conventional
Mechanical systems

Nozzle Holder Assembly (NHA) PF-Pump or Inline pump

ECU

Engine control unit

ECU

LE-ECU-MD1CE200-LE *
Engine Control Unit for Large Engines,
also available w/ marine certification

Sensors

Powertrain sensors e.g. Speed sensor Temp. Sensor Knocking sensor and further sensors.

EGT

SCR: DNOX-LE based on DNOX2.2
Supply module, 2x dosing modules,
dosing control unit, backflow valve

Services

Marine Certification
ABS, BV, CCS, DNV GL, Lloyd's Register
Korean Register; ClassNK, RINA, RS

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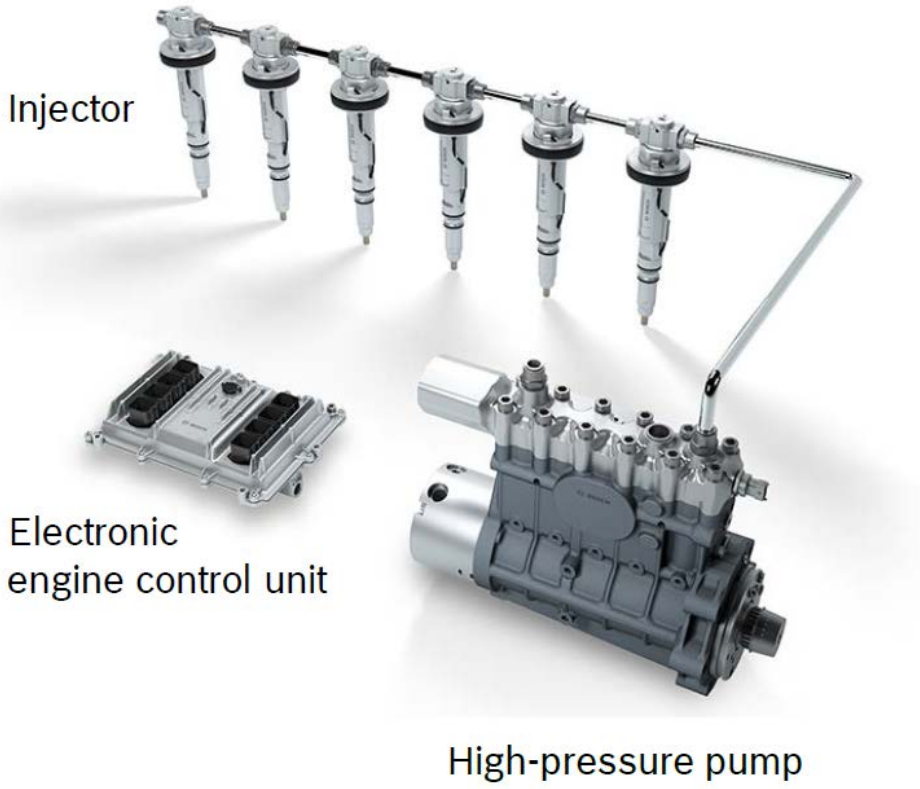
Bosch Technologies to achieve Ultra Low Emissions

MCRS-22 for best Mixture Preparation

- The MCRS is a Modular Common-Rail System with injectors, high-pressure pump, and an ECU tailored for large engines.
- System pressure levels: 1600 / 2200 bar
- Power range: 500 kW to 5000 kW

Injector: Multi injection up to 5 inj./cycle
Pump: 2-5 plunger types available
ECU: Large engine specific

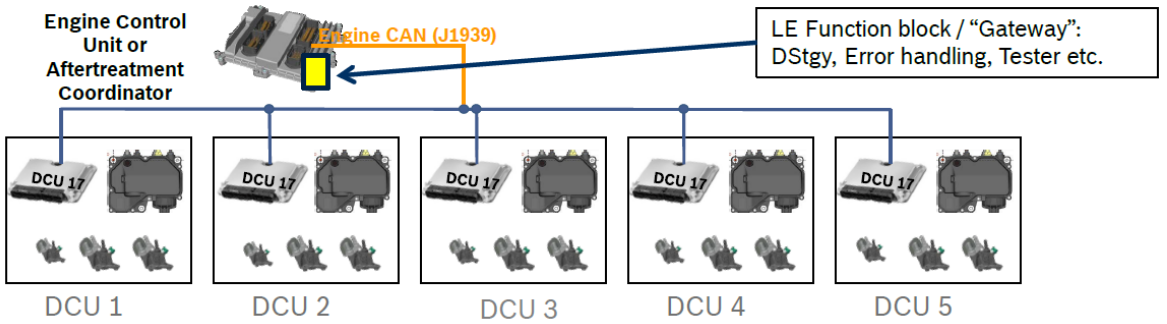
- MCRS provides flexibility to improve combustion strategy

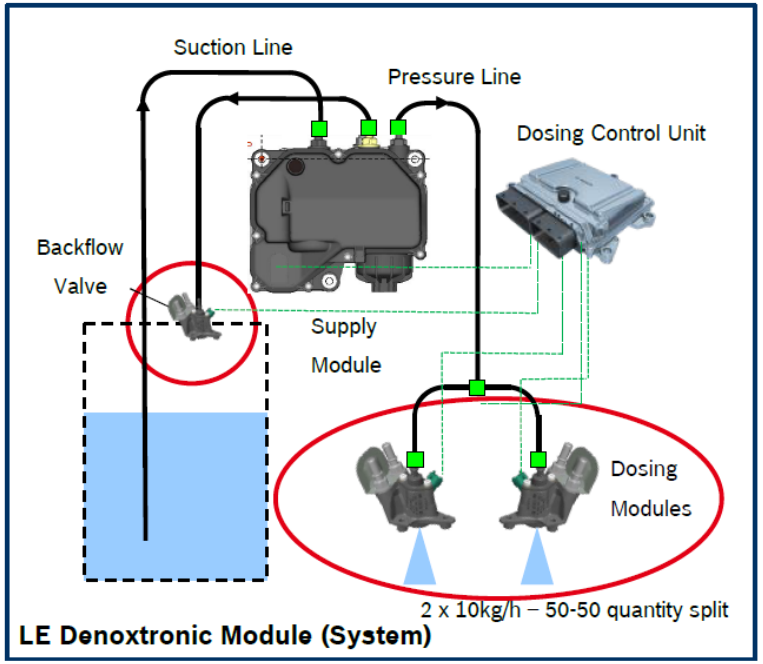


Modular Common Rail System (high pressure pump, injector and ECU) enables very low tailpipe emissions.

Bosch Technologies to achieve Ultra Low Emissions
DENOX-LE System

- Automotive base SCR system
- One module (system) is consist of 2x Dosing Modules, 1x supply module 1x ETI (Backflow valve) and Dosing control unit.
- One module can support engines up to 1 MW
- Modular expandable 1..5 DENOX-LE system via CAN-Bus (20kg/h…100kg/h).
  Equals need for 1MW…5MW- engines.





Automotive base DENOX-LE system is reliable SCR system covering 1MW…5MW engines.

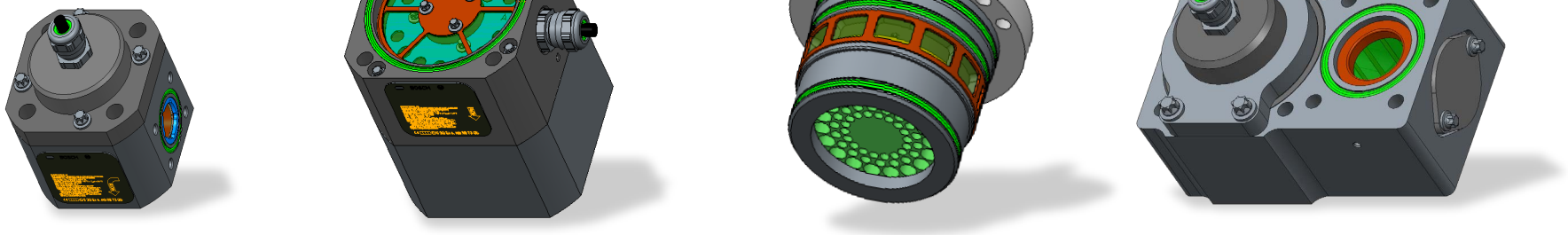
Bosch Technologies to achieve Ultra Low Emissions
LEGV

Gas engine has a potential to achieve very low emissions

- LEGV (Large Engine Gas Valve) is Cylinder-individual gas admission valve for SI & DF engines

Features of Bosch LEGV

- **High lifetime of up to 720 mill. load-cycles**, which corresponds to approx. 16,000 h @ 1500rpm
  →Reduce TCO (Total Cost Ownership)
- Support the optimization of HC slip and transient response time of engine
- Modular gas valve design allows adaptation to engine specific flow rates and housing incl. Marine
  →Customer specific design



Reduce TCO by high lifetime and flexible design by modular concept

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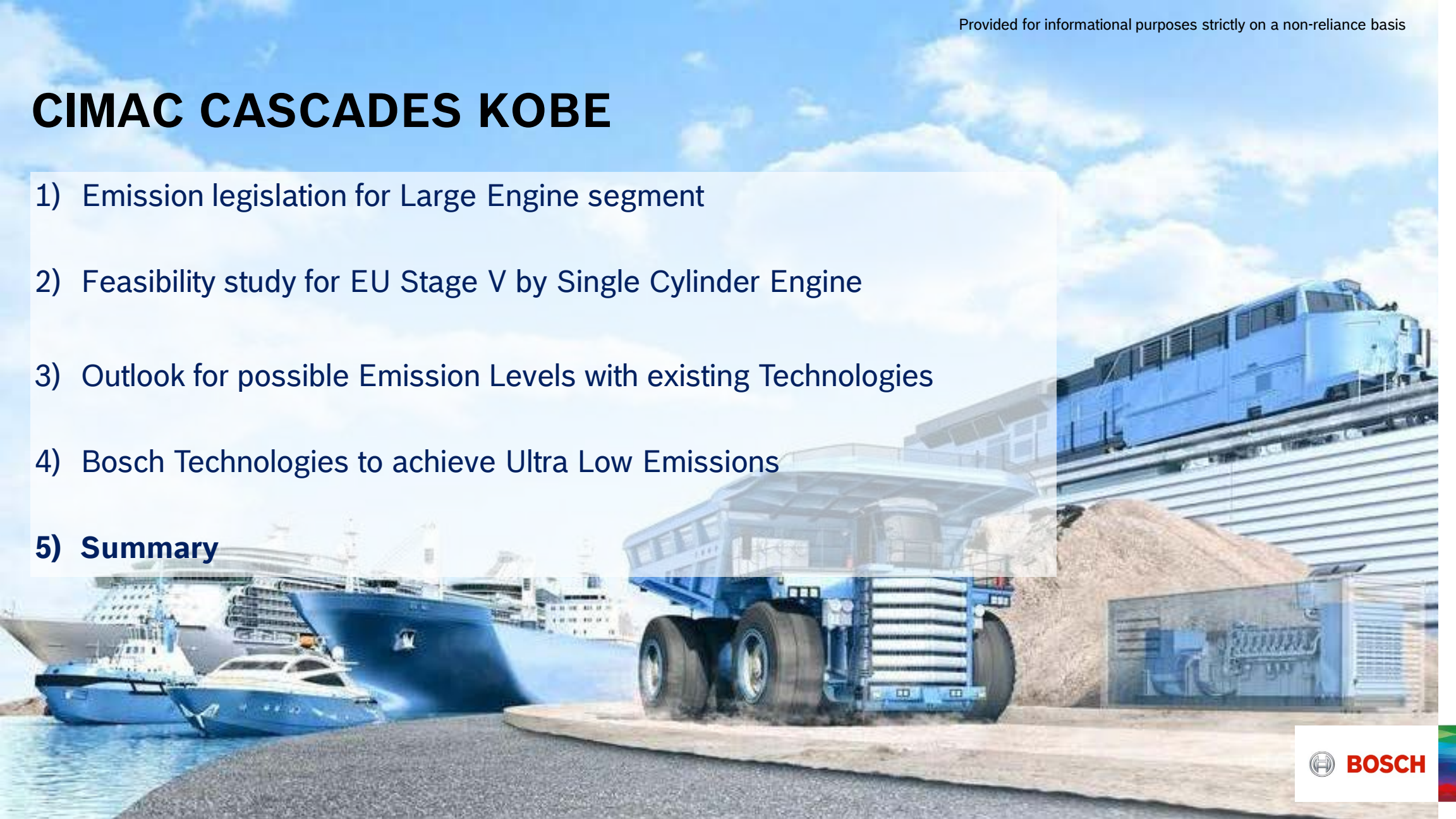

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Bosch Technologies to achieve Ultra Low Emissions and an Assessment what is feasible in short term

Summary

1. Meeting today's most stringent emission regulations EU Stage V and EPA Tier 4 is feasible with state-of-the-art system configurations including Common Rail, SCR and DPF
2. The combination of EGR plus SCR and DPF allows OEMs to target ultra low emissions beyond today's requirements

Bosch contributes with technical solutions to allow engine OEMs achieving ultra low emissions using

- MCRS-22 Injection system
- Engine Control Unit MD1CE200
- DENOX-LE system
- Gas Admission Valve LEGV

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Thank you very much for your attention