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ECMA

Challenges & solutions of boosting system for H2-ICE in HD applications

AGENDA

MOTIVATION FOR HYDROGEN INTERNAL COMBUSTION ENGINES

KEY CHALLENGES FOR HYDROGEN INTERNAL COMBUSTION ENGINES

SOLUTIONS OF AIRMANAGEMENT SYSTEM FOR HYDROGEN INTERNAL COMBUSTION ENGINES

SUMMARY AND OUTLOOK

Motivation for Zero emission vehicles

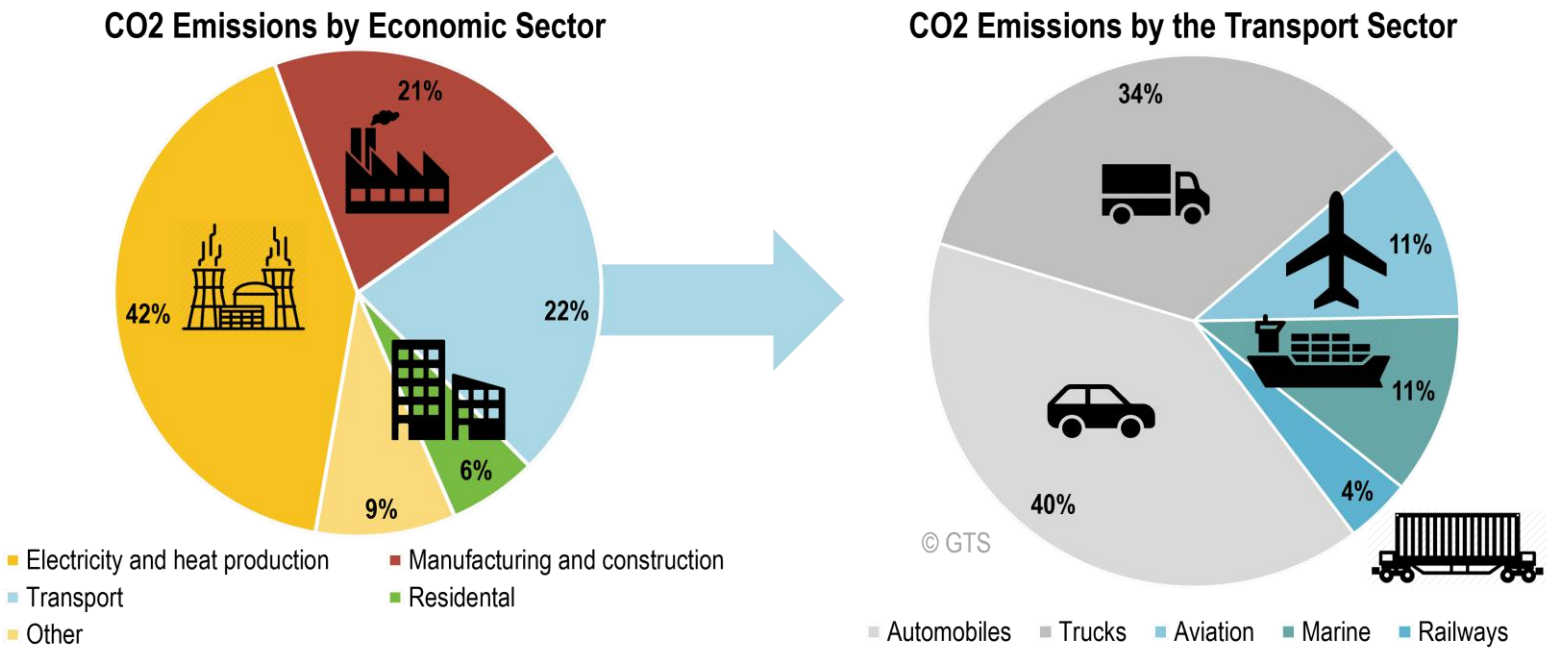
INDIAN CITIES AMONGST THE MOST POLLUTED IN THE WORLD

Source: https://www.hindustantimes.com/cities/delhi-news

REMARKS

- India is host to many of the highest polluted cities in the world
- Vehicular pollution is one of the major contributors
- Zero emission vehicles running with GREEN fuels are needed for bringing real impact on pollution

Transport sector is one of the major contributor of global CO2 emissions



REMARKS

- About 22 % of the global CO2 emissions is related to the transport sector
- Road transport contribute to ~75 % of emissions from transport sector
- Zero-CO2 powertrain solutions are:
  - Pure electric drivetrains
  - Hydrogen (H2) operated powertrains
    - H2-ICE
    - Fuel cell
- There will be challenges in direct electrification of existing ICE fleet of vehicles
  - Infrastructural challenges
  - Development cost and time high
- Upgrading the existing ICE operated fleet to work with H2 fuel can be a cheaper and more robust solution for future

Source: International Energy Association

When compared with other zero emission powertrains, H2-ICE offers many advantages we can make use of in short term

Hydrogen based vs BEV powertrain



- High energy storage density
- Fast refueling

- Fuel cost (current)
- Maintenance effort

H2-ICE based vs FC/BEV powertrain

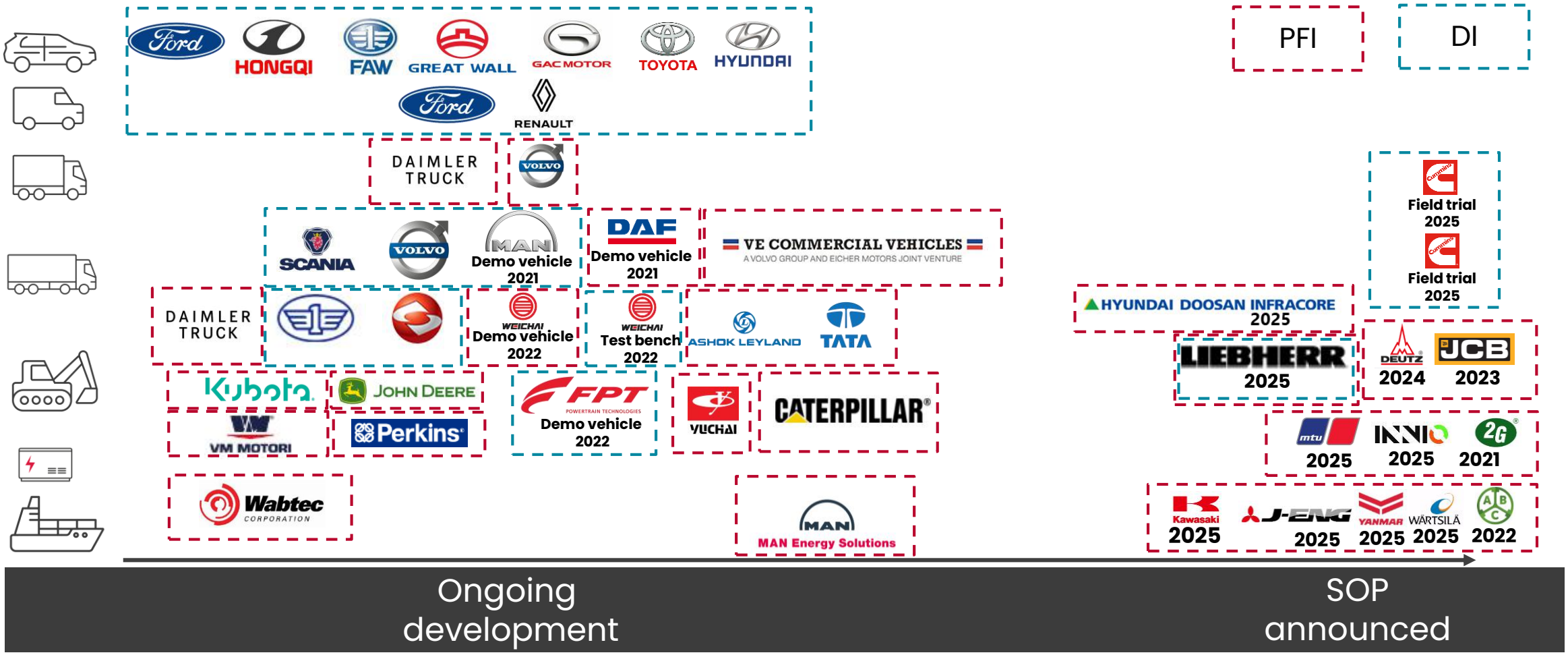


- Lower development and production effort, hence quicker introduction to the market
- Proven powertrain durability and less sensitive to environmental impacts
- Less stringent requirement to hydrogen purity
- Beneficial efficiency in high load operations

- Engine out NO_x emissions require EATS
- Powertrain noise level (still lower than diesel)

Publicly announced interest and investment in H_2-Engine development is now growing strongly amongst on-and off-highway industry players

» INDICATIVE



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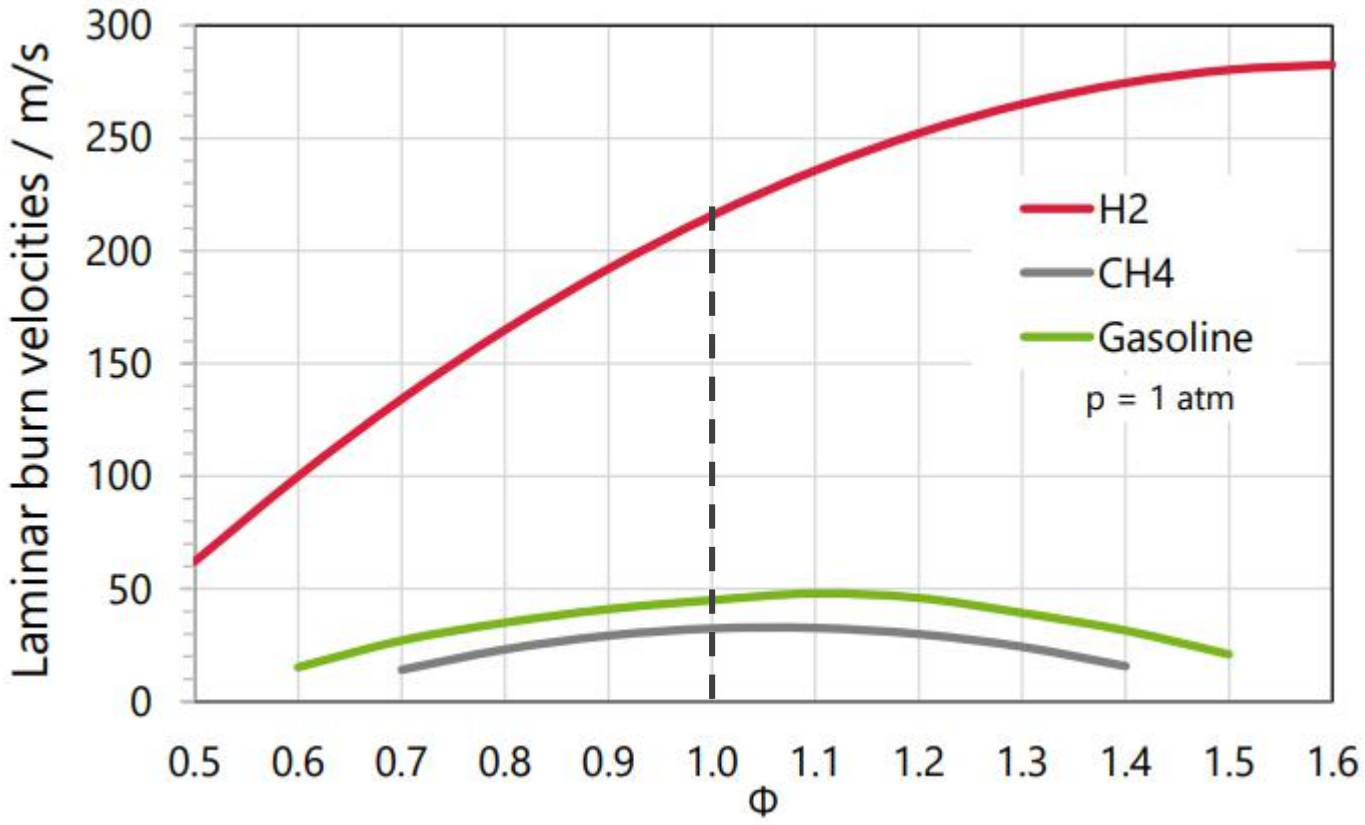
Laminar burning velocity of hydrogen is much higher than other fossil fuels

LOWER THERMAL EFFICIENCY



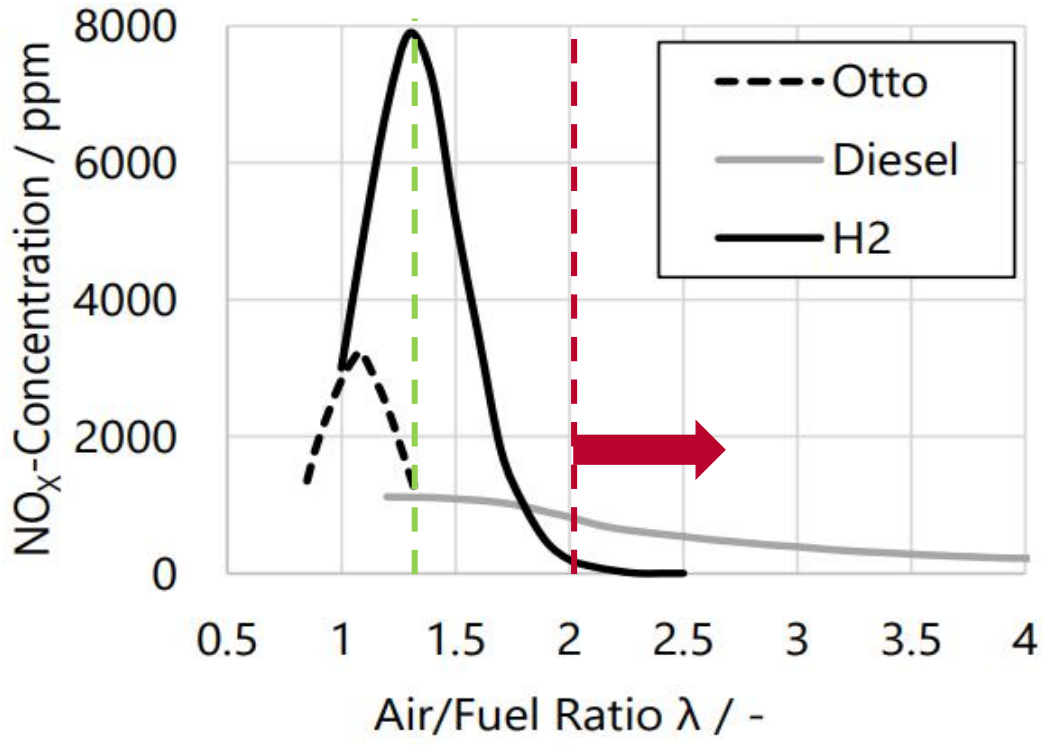
REMARKS

- Laminar burning velocity of H2 is significantly higher compared to other fossil fuels (~4 times at Φ=1 compared to Gasoline)
  - Combustion speed increases resulting in higher pressure rise rates (PRR) in the combustion chamber leading to higher NOX & engine noise
- Flame speed is proportional to the flame thickness & flame quenching distance.
  - the quenching distance of H2 is lower leading to an increased wall heat loss
    - Leads to reduction in thermal effc.

Source: FEV
Note: equivalence ratio Φ is the reciprocal value of the relative air/fuel ratio

NOx is the major emission to be considered from H2-ICE

LEAN COMBUSTION APPROACH REDUCES NOX EMISSIONS AND ALSO REDUCES WALL HEAT LOSSES



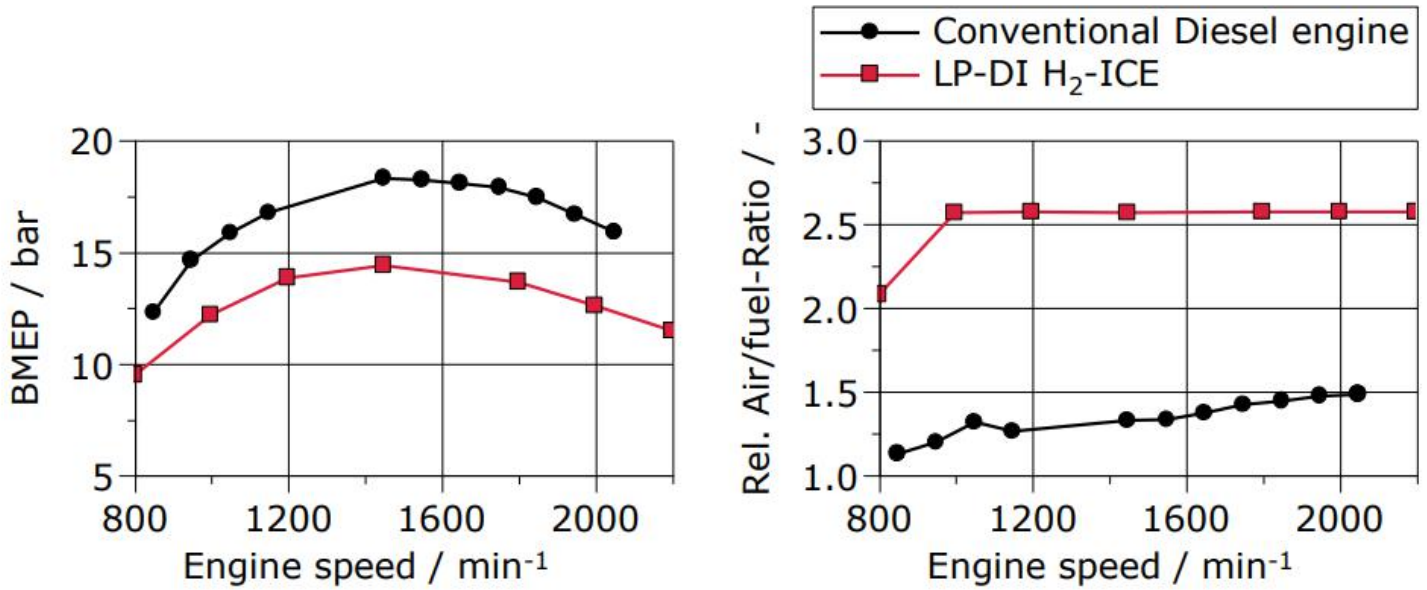
REMARKS

- Major challenges in H2-ICE is the drastic increase in NOx formation.
- Main reason is the fast combustion and the resulting high temperatures in the combustion chamber.
  - NOx maximum with slight excess air as more oxygen is available
  - Increasing $\lambda > 2$ is an effective measure to reduce the NOx raw emissions
    - reduces the combustion speed and wall heat losses leading to an increased engine efficiency.

Source: FEV

H2-ICE w/o modification to boosting system brings major limitation in achieved engine performance

H2-ICE NEEDS UPDATE IN BOOSTING SYSTEM TO ACHIEVE BETTER PERFORMANCE



REMARKS

- Increase of the relative air/fuel ratio to λ > 2-2.8 is needed:
  - gives NOx reduction benefit
  - engine efficiency increases
  - but leads to increased boost pressure demand to meet performance target
    - Needs new boosting system
- Without any boosting system upgrade a significant reduction in engine performance is expected with lean burn approach
- A well matched turbo charging system for H2 operation would be needed

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Advanced boosting system approaches for HD commercial applications

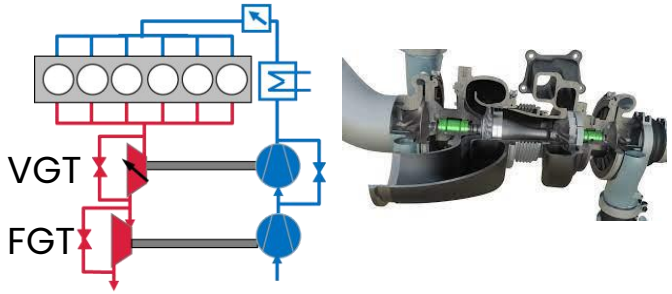
COMMERCIAL APPLICATIONS DEMAND HIGH EFFICIENCY AND DURABILITY

REMARKS

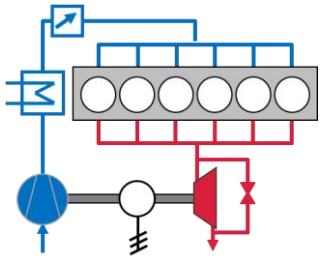
- Replacing the existing Diesel engines with H2-ICE's leads to several challenges
  - H2-ICE operate with low CR → lower efficiency
  - High air/fuel ratio increase ($\lambda > 2.0$) needed to remain within NOx emission limits
- Compensation for reduction in the achievable engine torque
  - Increased engine displacement
  - more complex boosting system
    - electrically supported VGT
    - two-stage charging

Advanced boosting systems for HD commercial applications

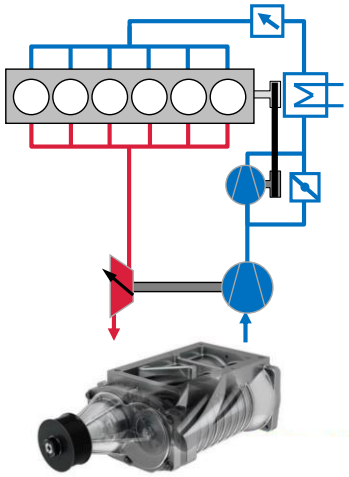
Serial two-stage



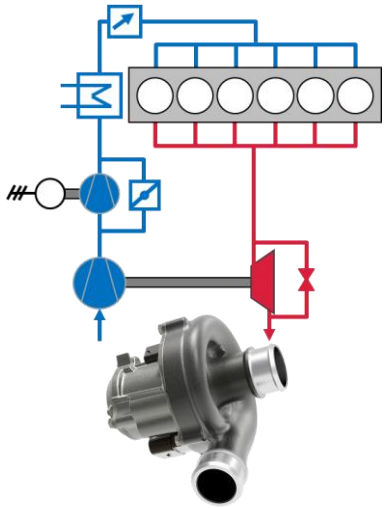
eVGT



VGT + SC



VGT + eC



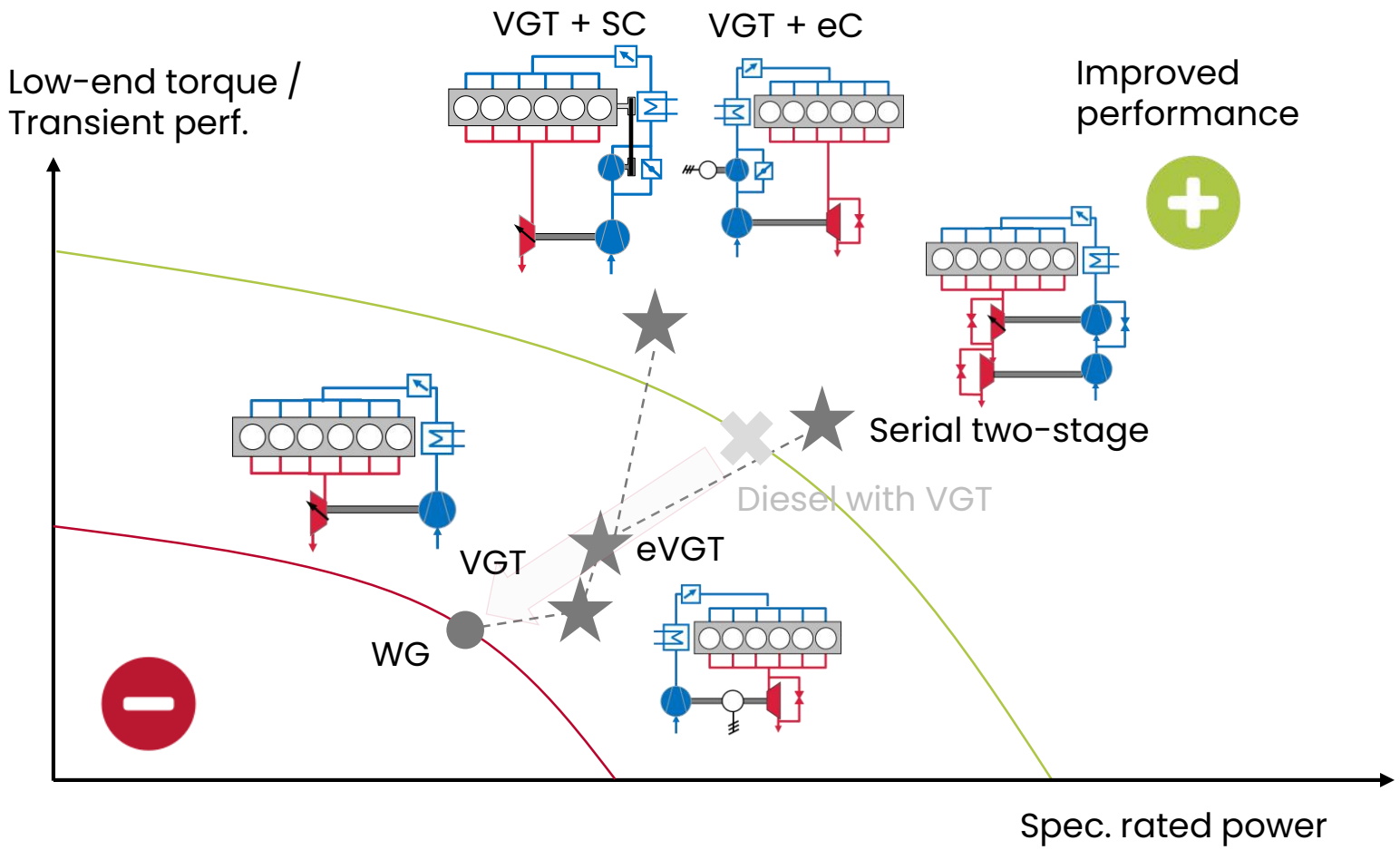
REMARKS

- Two-stage serial boosting system can have packaging limitations
- Electrically supported turbocharger (e-VGT) Improves low engine speed performance & transient performance → need 48 V system
- VGT + eC meets high low end torque and transient performance targets → need high voltage system
- Mechanical supercharger + VGT
  - Improved low end torque & transient performance
  - No additional electric system needed for onboard power supply
  - Cost, weight, and packaging efficient

Source: Garrett, Eaton , BorgWarner, VGT: Variable Geometry Turbine, SC: super charger, eC: Electric Compressor

Selection of a suitable boosting system is done based on performance targets and application requirements

TO ACHIEVE DIESEL LIKE PERFORMANCE H2-ICE NEED ADVANCED BOOSTING APPROACH



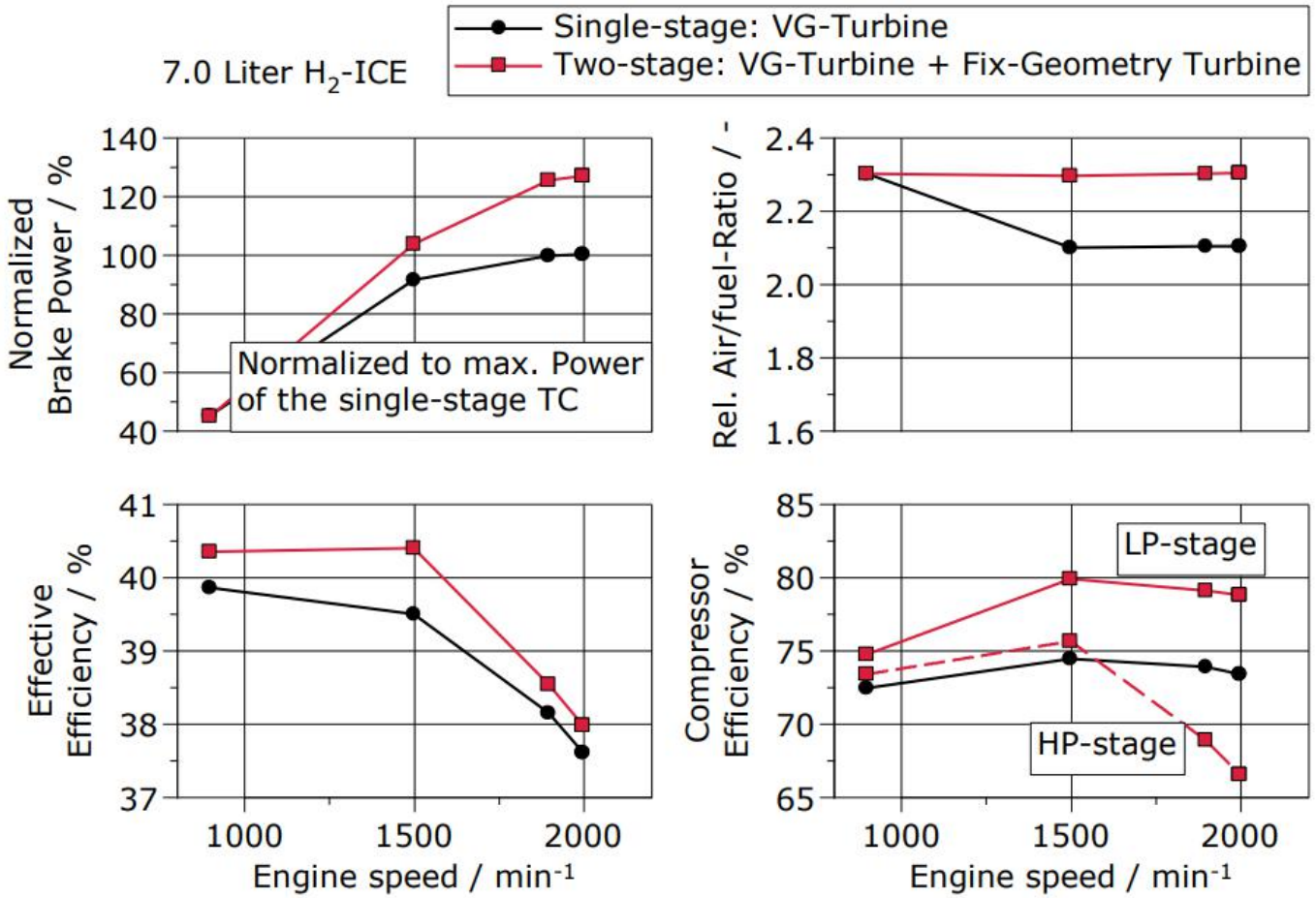
Source: FEV
VGT: Variable geometry turbocharger, e-VGT: electrically assisted VGT, SC: Super charger, eC: elctric compressor

REMARKS

- The wastegate (WG) turbocharger → low cost approach but highly limited performance
- Clear trend for VGT turbos
  - Due to low exhaust enthalpy → boost pressure / enleanment is limited.
  - The electrically supported VGT (eVGT) can partially compensate
- Two-stage system needed to meet Diesel like performance
  - Serial two-stage system, with a small high-pressure stage and a larger low-pressure turbocharger leads to an improved performance and enleanment potential
- High low-end torque performance and transient responsiveness by
  - VGT + eC
  - VGT + SC

Serial two-stage boosting compensates for reduced performance from single stage boosting

TWO-STAGE BOOSTING IMPROVES OVERALL ENGINE PERFORMANCE



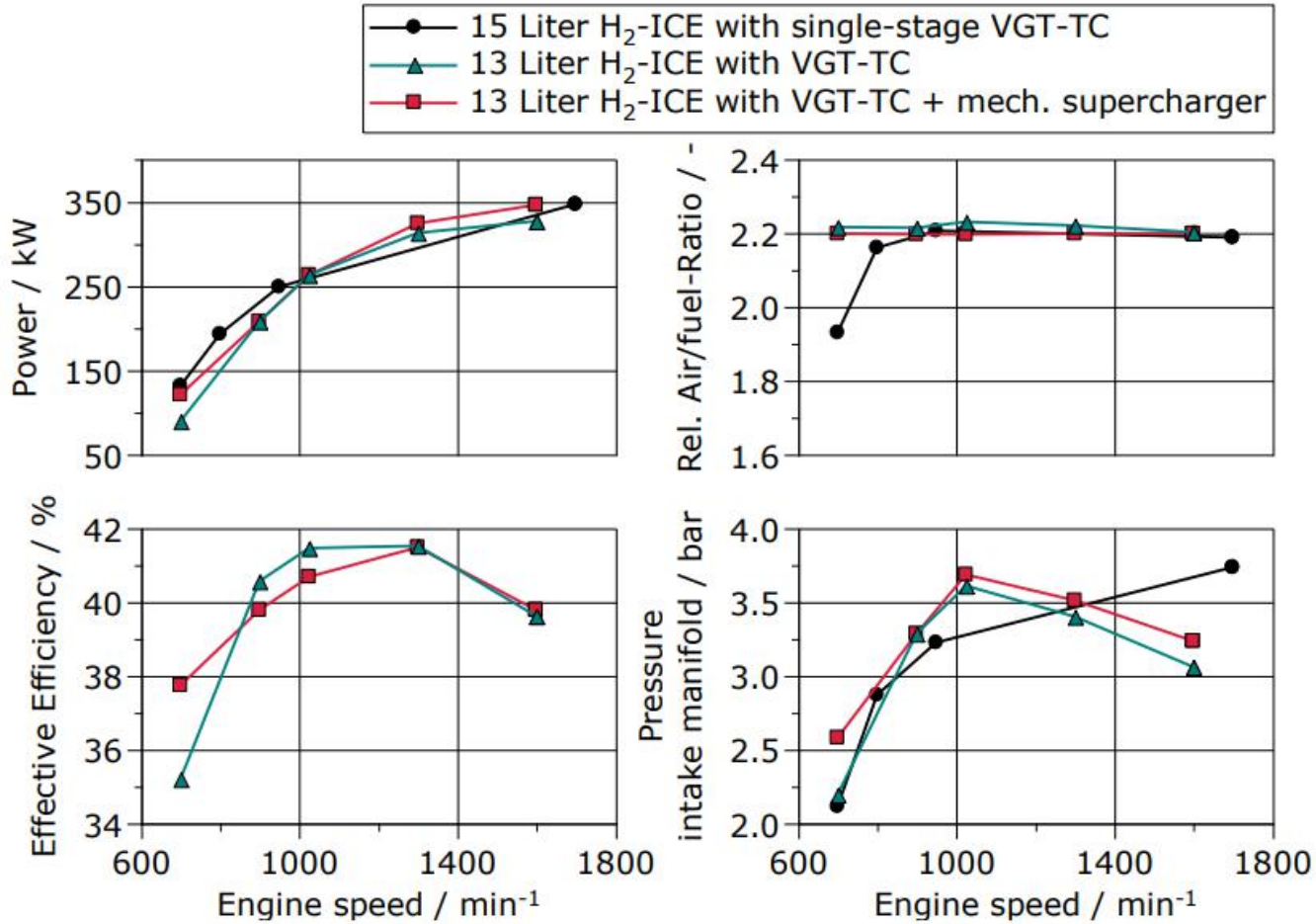
REMARKS

- Base engine with single-stage VGT-TC system
  - At low engine speeds the available exhaust enthalpy is limited → low perf.
  - For high engine speeds the maximum pressure ratio and turbocharger speed are limiting factors.
- Two-stage serial boosting system:
  - VGT (HP)+ Fixed Geometry TC (LP)
  - Brake power increased by ~30 %.
  - Increased air/fuel ratio
    - NOx emissions are reduced.
- In Two-stage system the operation of each turbocharger at lower pressure ratios
  - Higher operating effeciencies

Source: FEV

Increased engine displacement with single stage VGT can also improve engine performance

MECHANICAL SUPERCHARGER BETTER ON LOW END TORQUE



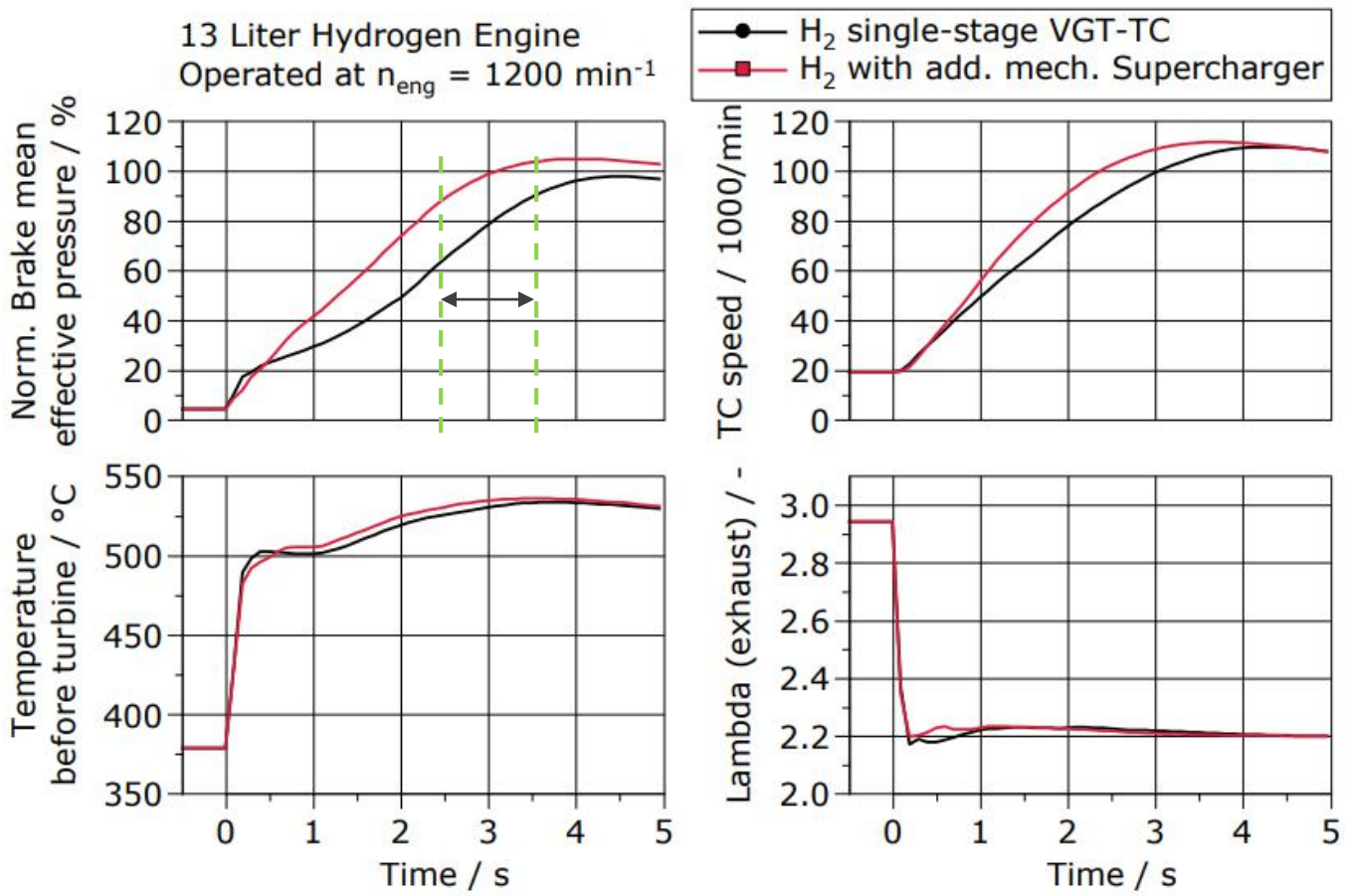
REMARKS

- Increasing the engine displacement can be considered to compensate the reduced performance of the H2-ICE.
  - Need new engine development
  - Packaging challenges in existing vehicles
- With base engine displacement mechanical supercharger can compensate the required boost pressure to achieve the target torque of an equivalent Diesel engine variant.
  - The benefit is achieved by increasing the exhaust turbocharger size for an improved rated power
  - Low end improved with mechanical supercharger

Source: FEV

Addition of supercharger capable to achieve diesel like transient response

TTT-90% TEST



REMARKS

- Supported by mechanical supercharger
  - transient performance can be improved
  - the time to achieve 90 % of the full load torque (TTT-90%) can be reduced by more than 1 s
    - no additional electrical components required
- During part load conditions with SC
  - Efficiency improvement and lower NOx emissions are achieved from a higher air/fuel ratio of approximately λ = 2.8…3.5.
- Increased system cost and the additional packaging requirement for the supercharger must be considered

Source: FEV

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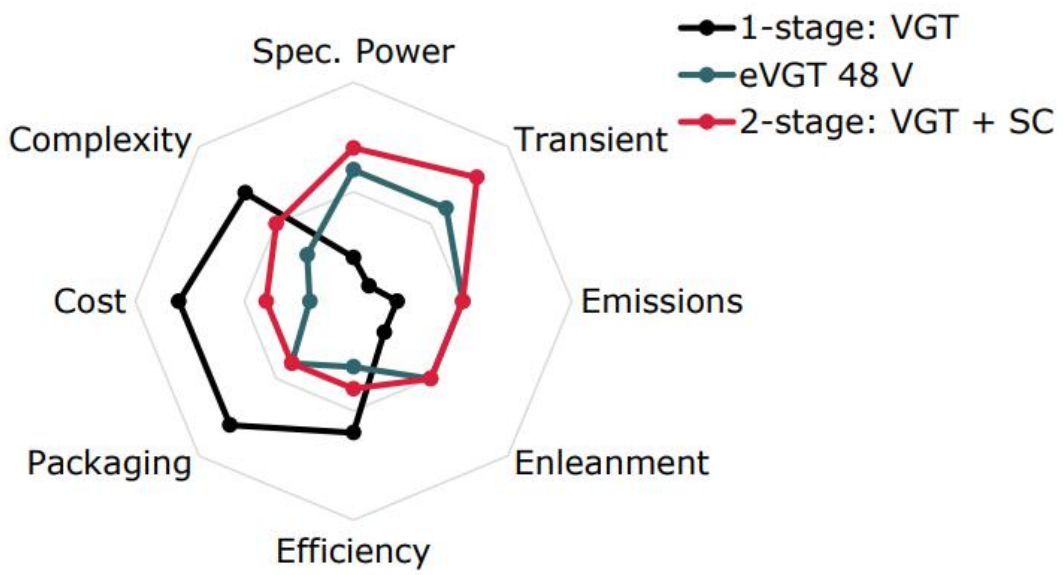
SUMMARY AND OUTLOOK

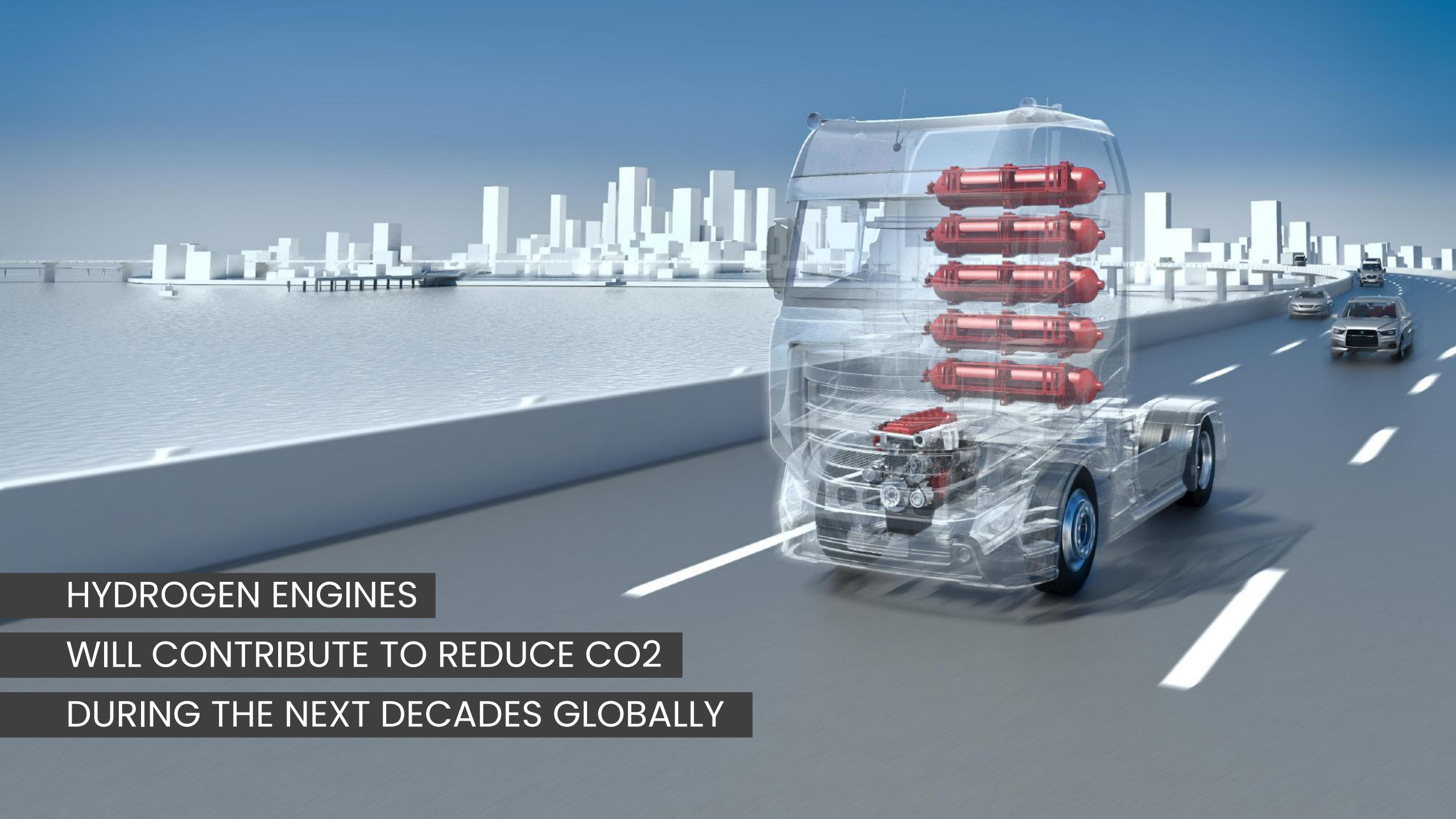
Summary : assessment of boosting concept for HD applications

TWO STAGE BOOSTING SYSTEMS CAN MEET DIESEL LIKE PERFORMANCE

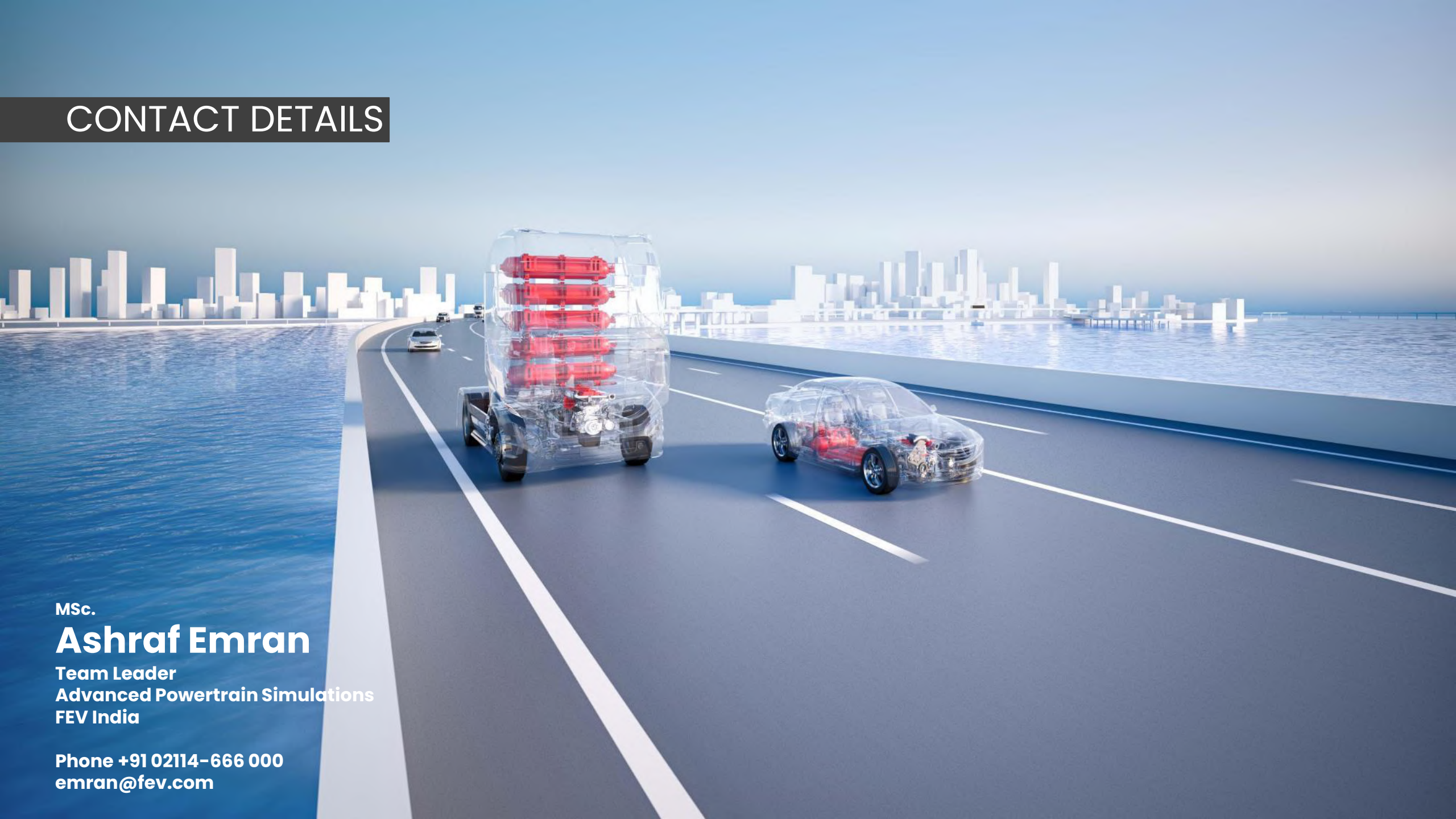


- HD diesel applications currently have single-stage boosting system
  - offers a cost and packaging efficient concept.
- The conversion of existing Diesel engines to a lean hydrogen combustion engine leads to reduced performance
- Lost performance can be compensated
  - increasing the engine displacement → new engine development needed / packaging challenges
  - 48 V e-VGT boosting concepts need additional power supply and have packaging and cost limitations.
- Two stage boosting system achieve Diesel like performance → can have packaging challenge
- VGT + SC solution offers an alternative concept to increase the performance even with a similar engine displacement.
  - As no additional electric components are required, cost and packaging demands are lower compared to e.g., eVGT or e-compressors (eC)

Source: FEV


HYDROGEN ENGINES
WILL CONTRIBUTE TO REDUCE CO2
DURING THE NEXT DECADES GLOBALLY

CONTACT DETAILS



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