UCC2
ICE optimization peak thermal efficiency towards 50 %

LONGRUN GA03

26th & 27th of January 2022

Online GoTo meeting

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FEV

The research leading to these results has received funding from the European Union under Grant Agreement no. 874972

Content

- Update Roadmap
- Outcomes/results
- Outlook next 6/12 months

Update Roadmap

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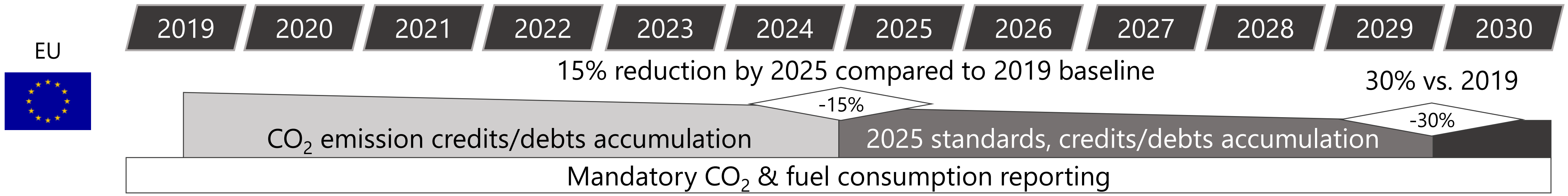
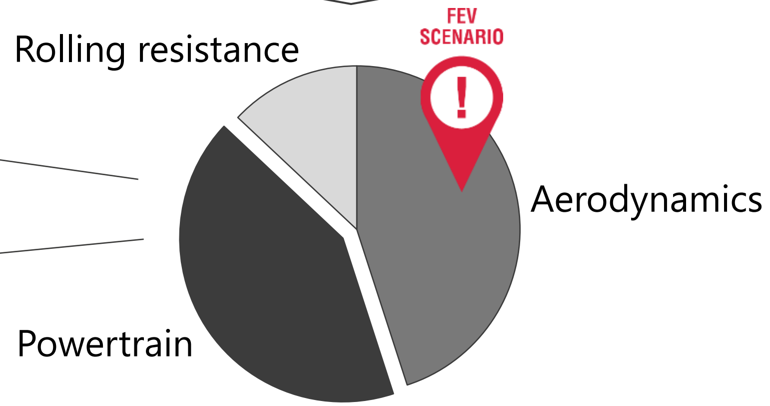
Political impact



Vehicle & powertrain optimizations mandatory

ICE identified as main contributor

- Implementation of new technologies & further engine optimizations required



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Technical impact

- OEMs concentrates on further development of long-haul ICE driven by legislation and costumer TCO

2020				2021				2022	
Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2

Weichai/Bosch announcement BTE 50 % engine

Source: Weichai

Daimler presented new DD15 BTE of 48 %

Source: Daimler

Scania presented new Super BTE of 50 %

Source: Scania

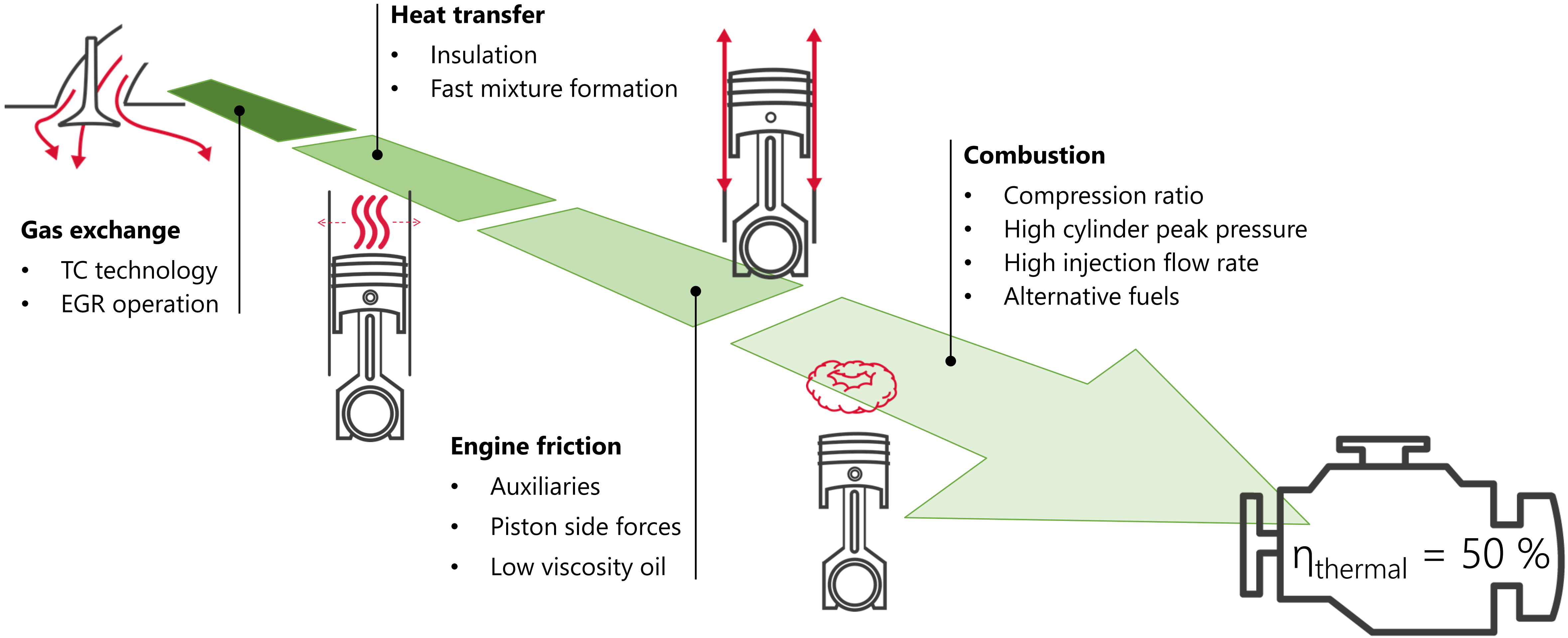
Weichai announcement BTE 51.09 % engine

Source: Weichai

Daimler will present new OM471

Source: Daimler

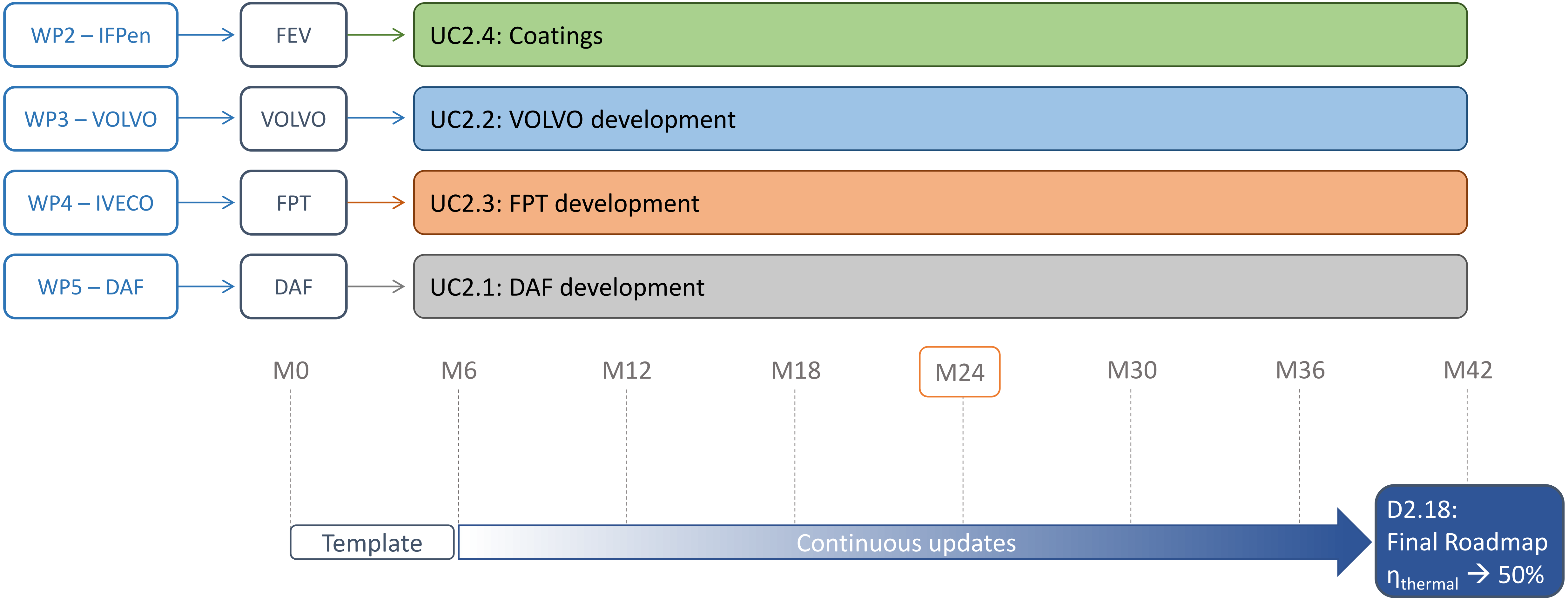
Identified pathways



Objectives

	Engine upgrade	Combustion improvement	Mechanical improvement	Air handling	Heat transfer	BTE Target
DAF development	1.0 %	1.3 %	0.7 %	1.0 %		50.0 %
VOLVO development		1.5 %	1.0 %	2.0 %		50.0 %
FPTi development		3.0 %	1.0 %	3.5 %	0.5 %	45.5 %
Coatings					0.5 %	0.5 %

UCC 2 Roadmap Strategy



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Status of deliverables input

» STATUS M24

CU2.4: Coatings

Del	Deliverable Title	Lead
D2.9	Assessment of thermal insulation	01-FEV

CU2.2: VOLVO development

Del	Deliverable Title	Lead
D3.1	Thermodynamic layout and combustion concept	10-AVL
D3.2	Report on high efficient combustion system	10-AVL
D3.3	Air handling concept, performance and control validation test	11-EATON

CU2.3: FPT development

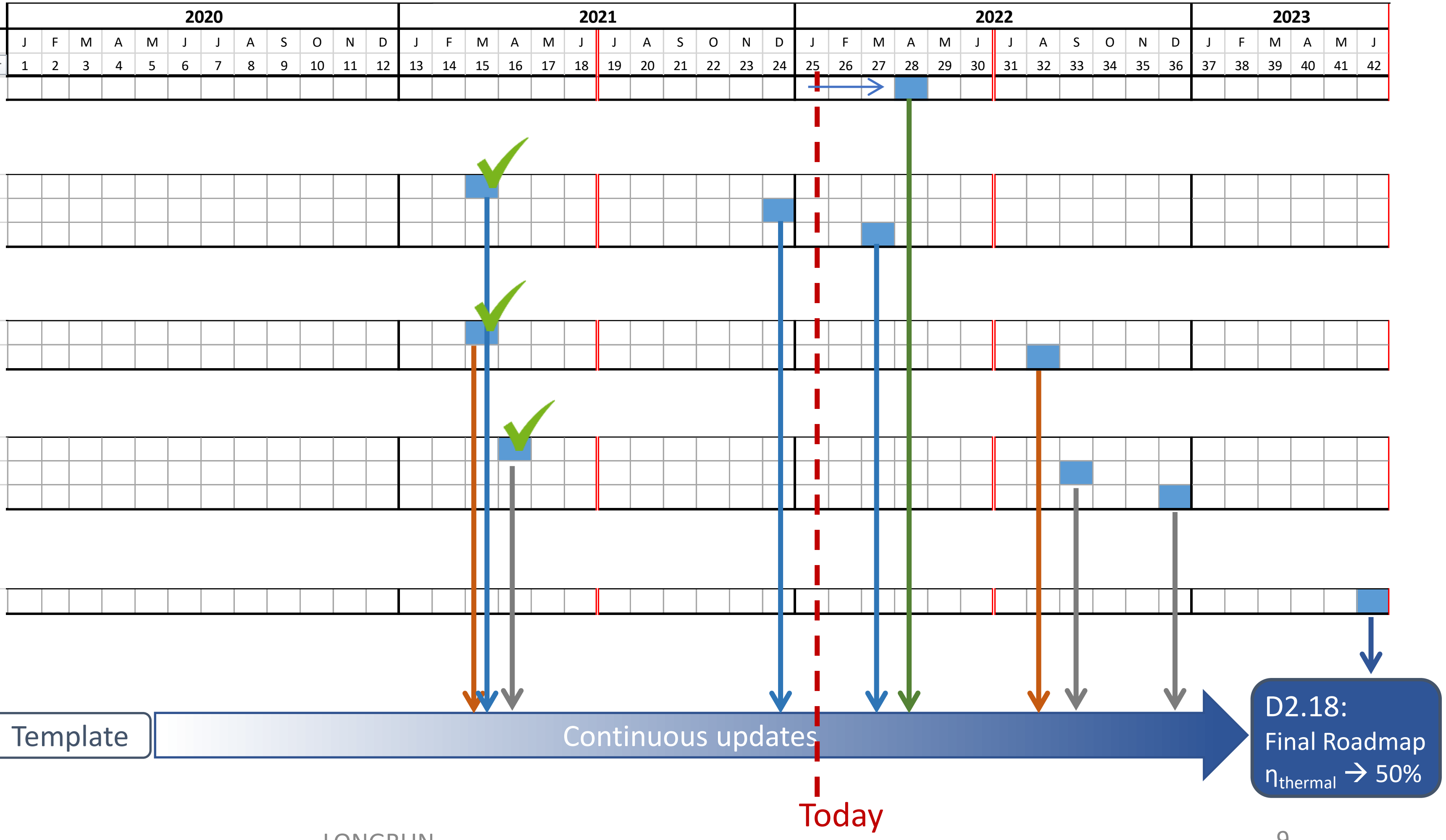
Del	Deliverable Title	Lead
D4.1	Thermodynamic analysis and 1D simulations	10-AVL
D4.2	CFD simulations and single-cylinder test bench activity	14-IFPEN

CU2.1: DAF development

Del	Deliverable Title	Lead
D5.1	SCE adaption to DAF HD application	01-FEV
D5.4	SCE development (thermal efficiency) incl. simulations	01-FEV
D5.6	Simulation total BTE efficiency improvement and emissions	26-RWTH

Final

Del	Deliverable Title	Lead
D2.17	Final roadmap thermal efficiency pathways	01-FEV



Outcomes

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CI diesel ICE improvements Summary

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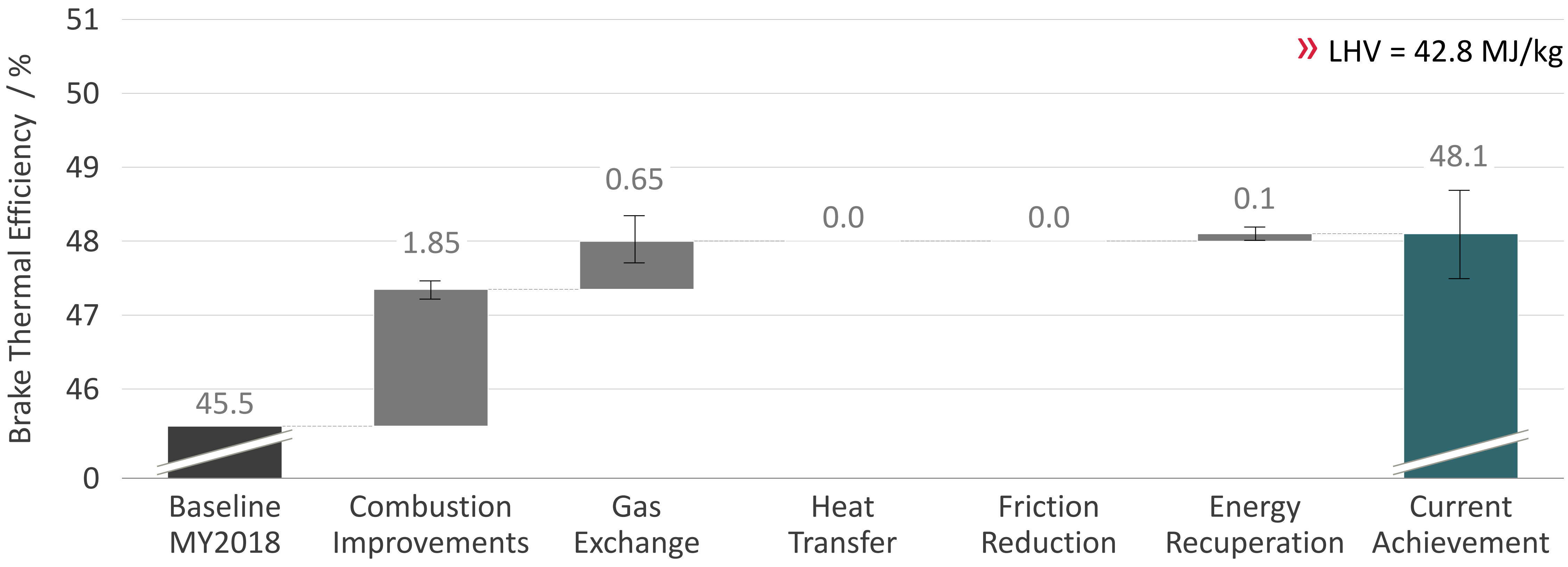
Best efficiency point

n = 1200 min^{-1}, ~75 % of full load, $BSNO_X$ = 8-10 g/kWh



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CI – Combustion improvements Compression ration & peak cyl. pressure

DESCRIPTION

- Increased compression ratio (CR) enhances efficiency of thermodynamic combustion process as long as peak cylinder pressure (PCP) is not limited
- By limited PCP capability the higher peak cylinder pressure must be compensated by retarded beginning of injection
- Increased peak firing pressure helps to avoid fuel consumption penalties

ADVANTAGES

- Increased compression ratio to increase efficiency

RISKS / CHALLENGES

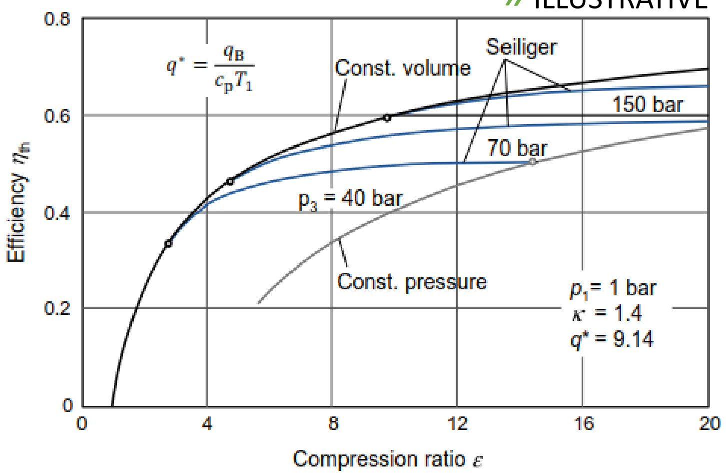
- Higher thermal and mech. stress require more durable engine components
- Smaller piston bowl volume require adaption of injector tech. to keep good mixture formation
- Increased NO_X emissions have to be compensated with improved EATS

ASSESSMENT

BTE impact	● (high)	Around 1.7 %-point BTE improvements
Invest	◐ (medium)	Moderate invest expected
Maturity 2025-2030	◕ (medium/high)	Medium/high maturity level

Impact: low … medium … high

» ILLUSTRATIVE



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CI – Combustion improvements Fuel injection system

DESCRIPTION

- Modern HD diesel engines use common rail systems, systems with up to 2,700 bar pressure are state-of-the-art, whereas 3,000 bar is under development
- “Leakage free” injectors increase injection pressure with affecting fuel consumption positive
- Higher pressure breaks the trade-off between good air utilization at low engine speeds and high engine output power
- Strong benefits by high pressure only in combination with EGR

ADVANTAGES

- Reduced PM emission
- Enables further optimization of PM/NO_X trade off (only with applied EGR concept)
- Enables good mixture formation for high CR concepts

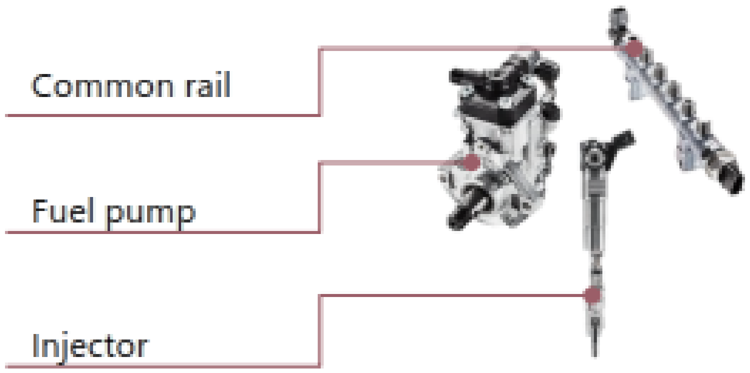
RISKS / CHALLENGES

- Lower reliability due to the increased stress caused by high pressure
- Increase of frictional losses
- Higher costs (improved injectors / components required)

ASSESSMENT

BTE impact	Around 0.5 %-point BTE improvements by better air utilization
Invest	Moderate invest expected
Maturity 2025-2030	Medium/high maturity level, ready for series production

Impact: low medium high



Source: Denso

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CI – Combustion improvements Alternative fuels – HVO

DESCRIPTION

- Hydrotreated Vegetable Oil (HVO) is a transparent paraffinic and a most-promising alternative to diesel fuel
- Feedstock and industrial processes availability
- Increased low heating value and more reactive ignitability enables > 2 % fuel economy benefit compared to diesel
- HVO is a drop-in capable fuel
  - Fulfills EN 15940 regulation and calibration changes not required

ADVANTAGES

- Drop-in capability
- Significant lower PM emission due to absent of aromatics
- Excellent ignitability also at cold start due to high Cetane number
- > 90 % WtW CO_2 reduction

RISKS / CHALLENGES

- Phase out of HVO made from high indirect land use change from 2022 due to EU RED II

ASSESSMENT

BTE impact	(low–medium)	Max. 0.3 %-point BTE improvements by better combustion behavior
Invest	(low)	Low invest
Maturity 2025-2030	(high)	Already released for series application

Impact: low … medium … high

Source: Neste

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CI – Gas Exchange Intake Miller

DESCRIPTION

- Miller cycle increases ratio between expansion and compression
- An increased geometric CR is compensated by reducing the effective CR at high load through early/late intake valve closing; a valve train with variable intake valve timing is required
- Potential power losses in part load can be balanced with increased boosting pressures

ADVANTAGES

- Potential to increase the compression ratio without increasing the peak firing pressure

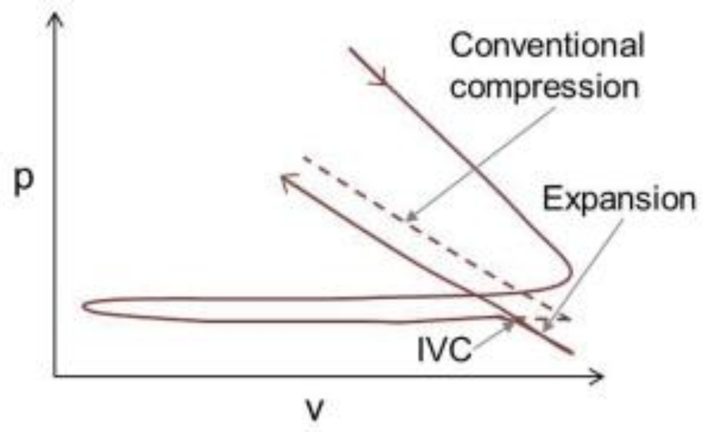
RISKS / CHALLENGES

- High degree of boosting required to compensate for less cylinder filling
- Lower NO_x reduction efficiency compared to EGR

ASSESSMENT

BTE impact	Around 0.3 %-point
Invest	Moderate invest expected
Maturity 2025-2030	High maturity level, series production

Impact: low – medium – high



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CI – Gas Exchange Turbocharger efficiency

DESCRIPTION

- More efficient turbocharger enables lower engine back pressure and reduces work of gas exchange
- Reduced temperature downstream compressor for a given boost pressure level
- Less delta pressure over EGR route needs to be considered and requires recalibration

ADVANTAGES

- Lower gas exchange losses increase engine efficiency and with better fuel economy
- Enables reduced PM tendency
- Potential to increase altitude margin

RISKS / CHALLENGES

- Reduced engine back pressure limits EGR availability
- If required, new manufacturing methods have to be established

ASSESSMENT

BTE impact	Around 1.0 %-point BTE Improvement by reduction gas exchange and increased cylinder filling
Invest	Moderate to medium invest expected
Maturity 2025-2030	High maturity level

Impact: low – medium – high

Source: Daimler

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CI – Energy recuperation Turbocompound

DESCRIPTION

- Additional turbine downstream of the turbocharger
- The recovered waste heat energy gets reintroduced into the system via mechanical connection of turbine to the crankshaft
- Turbocompound can support downspeeding and/or downsizing by supplying additional mechanical power to the crankshaft
- In order to leverage full turbocompound potential an (more expensive) axial flow turbine is required

ADVANTAGES

- Lower fuel consumption and therefore less CO_2 emissions
- Proven technology for CO_2 reduction (commercial vehicle applications)
- Increased back pressure can be used for higher EGR rates

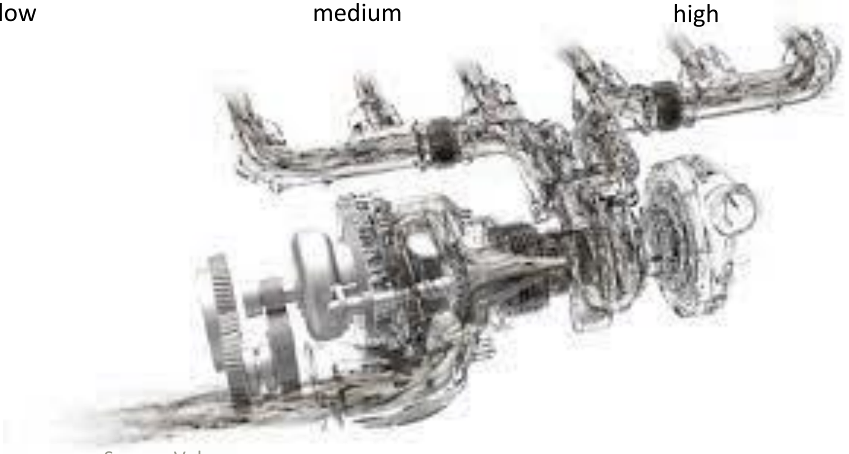
RISKS / CHALLENGES

- Complex gear drive to adjust turbine to engine speed
- Potential fuel saving towards higher loads & higher back pressure
- Usage of waste-heat from EGR not possible

ASSESSMENT

BTE impact	Around 0.1 %-point BTE improvement by waste energy utilization
Invest	Medium invest expected
Maturity 2025-2030	High maturity level, series production

Impact: low – medium – high



Source: Volvo

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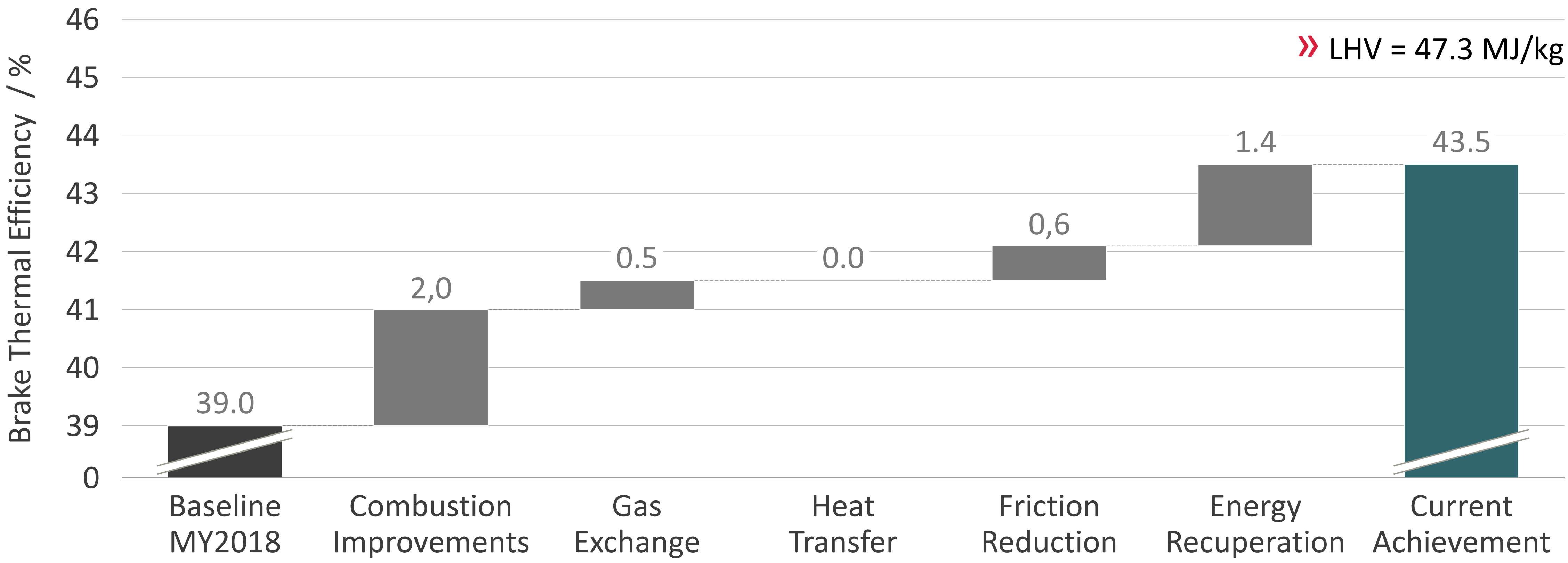
SI natural gas ICE improvements Summary

» STATUS M24

Full load efficiency @ n = 1100 min^{-1}



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SI – Combustion improvements Application of high CR & EGR

DESCRIPTION

- Increased compression ratio enhances efficiency of thermodynamic combustion process as long as knock tendency is not present
- Application of EGR suppresses knock tendency without retarding spark timing at high engine loads
- In part load operation, EGR allows to de-throttle the engine operation

ADVANTAGES

- Increased compression ratio to increase efficiency
- Fuel consumption benefits due to de-throttling of the engine

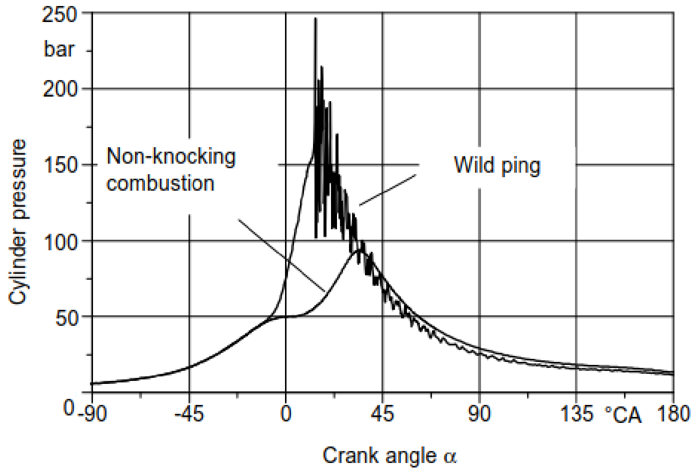
RISKS / CHALLENGES

- Increased combustion temperatures enhance knock tendency
- Components of EGR path have to be durable for high exhaust temperatures at full load
- Implementation of swirl charge motion

ASSESSMENT

BTE impact	Around 2.0 %-point BTE improvements
Invest	Moderate invest expected
Maturity 2025-2030	Medium/high maturity level

Impact: low — medium — high



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SI – Gas Exchange Intake Miller

DESCRIPTION

- Miller cycle increases ratio between expansion and compression
- Miller reduced combustion knock tendency due to reduced temperature at the end of compression and of combustion process
- Late IVC supports swirl formation for EGR compatibility
- Potential cylinder filling losses in part load can be balanced with increased boosting pressures

ADVANTAGES

- Potential to increase the compression ratio without increasing combustion process temperature that lowers knock tendencies
- Increased EGR compatibility

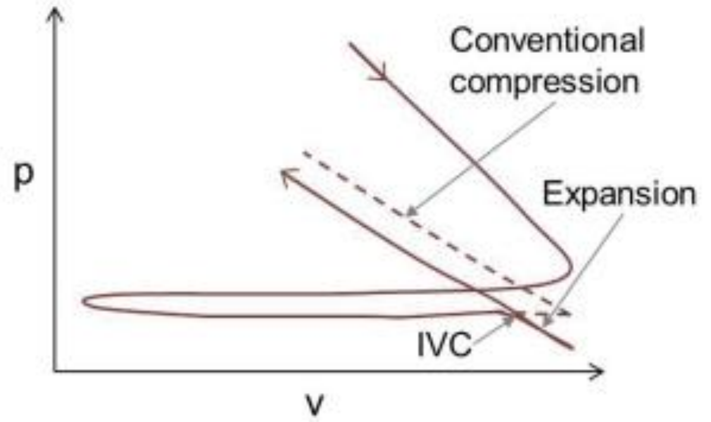
RISKS / CHALLENGES

- High degree of boosting required to compensate for less cylinder filling
- Lower NO_X reduction efficiency compared to EGR

ASSESSMENT

BTE impact	Around 0.2 %-point
Invest	Moderate invest expected
Maturity 2025-2030	High maturity level, series production

Impact: low – medium – high



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SI – Gas Exchange Turbocharger efficiency

DESCRIPTION

- More efficient turbocharger enables lower engine back pressure and reduces work of gas exchange
- Reduced temperature downstream compressor for a given boost pressure level
- Less delta pressure over EGR route needs to be considered and requires recalibration

ADVANTAGES

- Lower gas exchange losses increase engine efficiency and with better fuel economy
- Potential to increase altitude margin

RISKS / CHALLENGES

- Reduced engine back pressure limits EGR availability
- If required, new manufacturing methods have to be established

ASSESSMENT

BTE impact	Around 0.3 %-point BTE Improvement by reduction gas exchange
Invest	Moderate to medium invest expected
Maturity 2025-2030	High maturity level,

Impact: low – medium – high

Source: Daimler

UCC 2 | SI – Energy recuperation Turbocompound

DESCRIPTION

- Additional turbine downstream of the turbocharger
- The recovered waste heat energy gets reintroduced into the system via mechanical connection of turbine to the crankshaft
- Turbocompound can support downspeeding and/or downsizing by supplying additional mechanical power to the crankshaft
- In order to leverage full turbocompound potential an (more expensive) axial flow turbine is required

ASSESSMENT

BTE impact	Around 0.4 %-point BTE improvement by waste energy utilization
Invest	Medium invest expected
Maturity 2025-2030	High maturity level, series production

Impact: low – medium – high

ADVANTAGES

- Lower fuel consumption and therefore less CO_2 emissions
- Proven technology for CO_2 reduction (commercial vehicle applications)
- Increased back pressure can be used for higher EGR rates

RISKS / CHALLENGES

- Complex gear drive to adjust turbine to engine speed
- Potential fuel saving towards higher loads & higher back pressure
- Usage of waste-heat from EGR not possible

Source: Volvo

UCC 2

SI – Energy recuperation Waste heat recovery

DESCRIPTION

- Approx. 50 % of the energy in an internal combustion engine is lost as waste heat
- Thermal energy of the exhaust gas can be used and transferred into electric energy in an expander coupled to a generator (especially at high temperature level, e.g. in the HP-EGR path)
  - Mechanical coupling to crankshaft or 48 V generator
- Different operation fluids (water, ethanol) as well as expanders (piston expander, turbine, etc.) under consideration

ADVANTAGES

- Add. power by using exhaust energy
- Less FC & less CO_2 emission (depending on application)
- Usage of waste-heat from exhaust gas or EGR possible
- ORC independent from the rest of the engine system

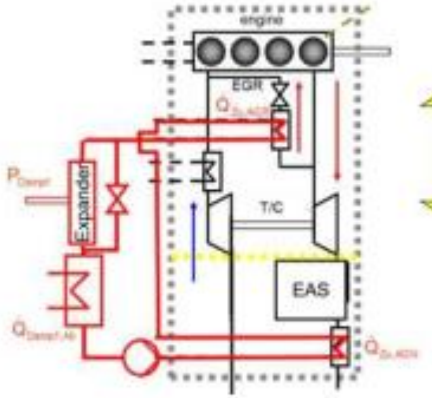
RISKS / CHALLENGES

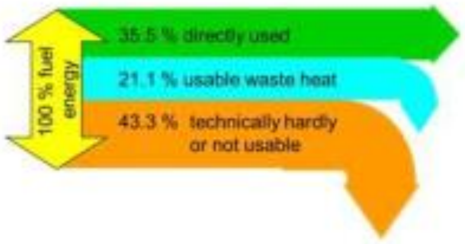
- Cooling capacity, weight, costs and package demands
- Slightly higher back pressure due to the heat exchanger
- Control system (very dynamic exhaust gas heat flow)
- Trade-off between EATS and ORC

ASSESSMENT

BTE impact	Around 1.0 %-point BTE improvement by waste energy utilization
Invest	High invest expected
Maturity 2025-2030	Moderate maturity level, no series production

Impact: low – medium – high





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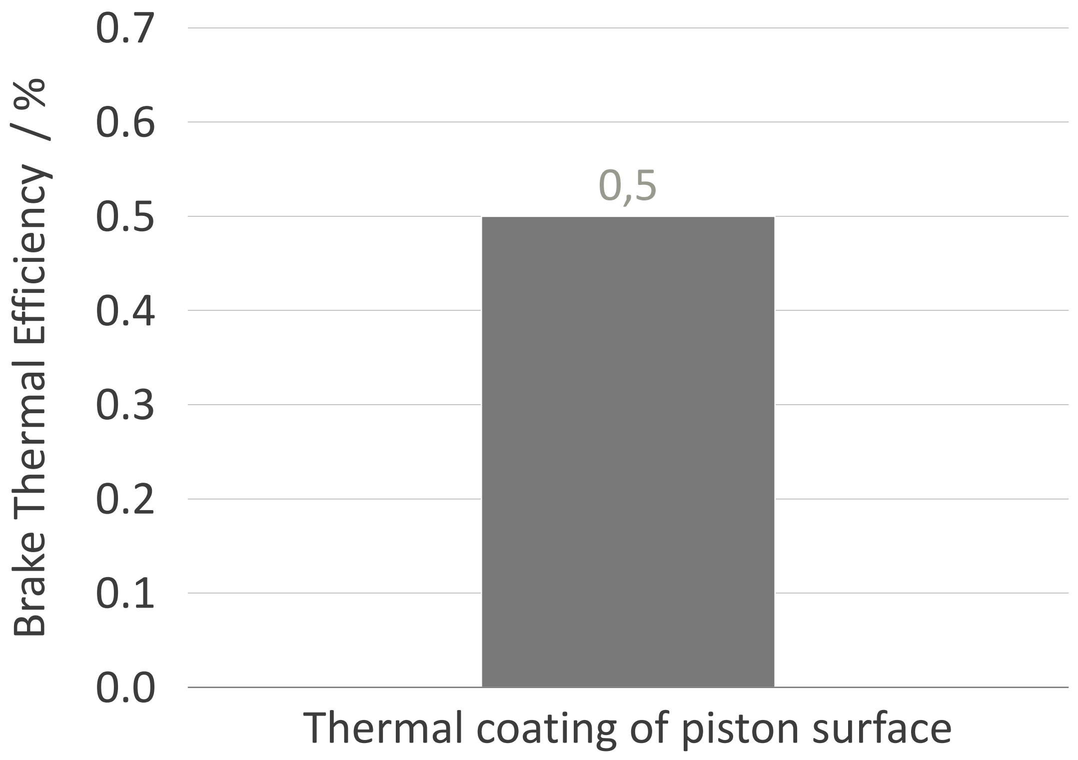
ICE improvements by coatings Summary

» STATUS M24

Best efficiency point

n = 1200 min^{-1}, ~75 % of full load, $BSNO_X$ = 8-10 g/kWh



» LHV = 42.8 MJ/kg

Coatings

DESCRIPTION

- Coating of advanced materials on metallic surfaces to insulate components from large and prolonged heat loads
- Can be applied to e.g. combustion chamber, turbocharger and exhaust system
- A typical material used in automotive applications are plasma-applied ceramic coatings

ADVANTAGES

- Reduced thermal strain on components
- Higher thermal efficiencies due to reduced heat loss
- Less add-on parts due to reduced heat shielding need
- Use of lightweight materials close to heat sources possible

RISKS / CHALLENGES

- Increased costs
- Preparation of internal surfaces prior to coating
- Durability of coatings
- Higher temperatures in turbocharger cooling requirements for e.g. TC shaft bearings

ASSESSMENT

BTE impact	Around 0.5 %-point Improved thermal efficiency by reduction of wall heat transfer
Invest	Medium invest expected
Maturity 2025-2030	Medium maturity level expected

Impact: low … medium … high

UCC2 Outlook

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Outlook – Next 6 months

1 DAF development

- Single cylinder engine
  - Multi pulse injection
  - Intake Miller timings
  - Exhaust port insulations
  - HVO
- Multi cylinder engine
  - High efficiency eTurbo

2 VOLVO development

- Validation of high efficiency combustion on single cylinder engine
- Initial multi cylinder engine investigations

3 FPTi development

- Validation of Swumble™ combustion concept on single cylinder engine
- Initial analysis of SI pre-chamber technology on thermal efficiency
- Initial analysis of energy recovery system e.g. eTurbo, WHR

4 Coatings

- Further investigation of combustion chamber insulations on single cylinder engine
  - Thermal piston coating
  - Thermal flame deck coating

Thank you

The research leading to these results has received funding from the European Union under Grant Agreement no. 874972