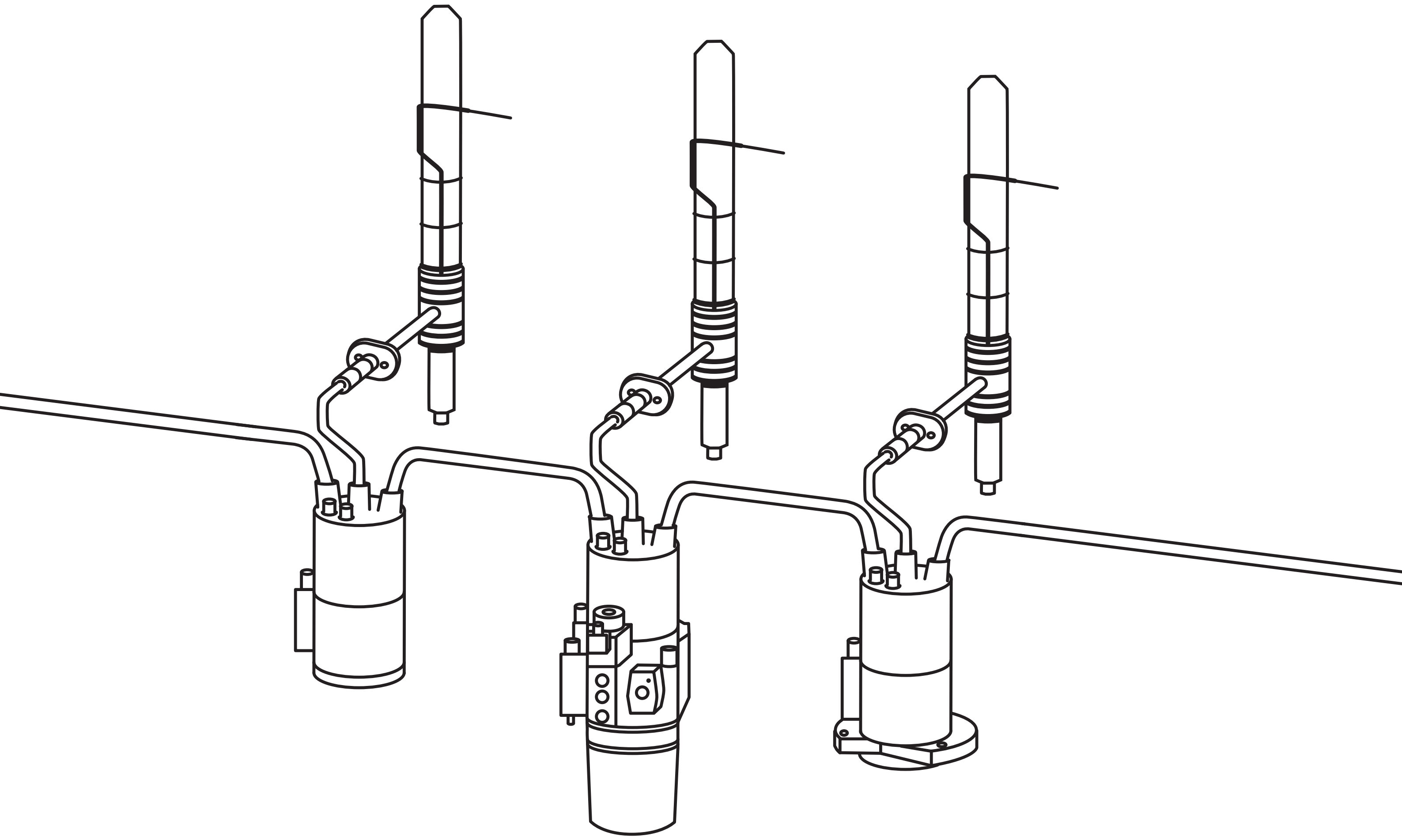
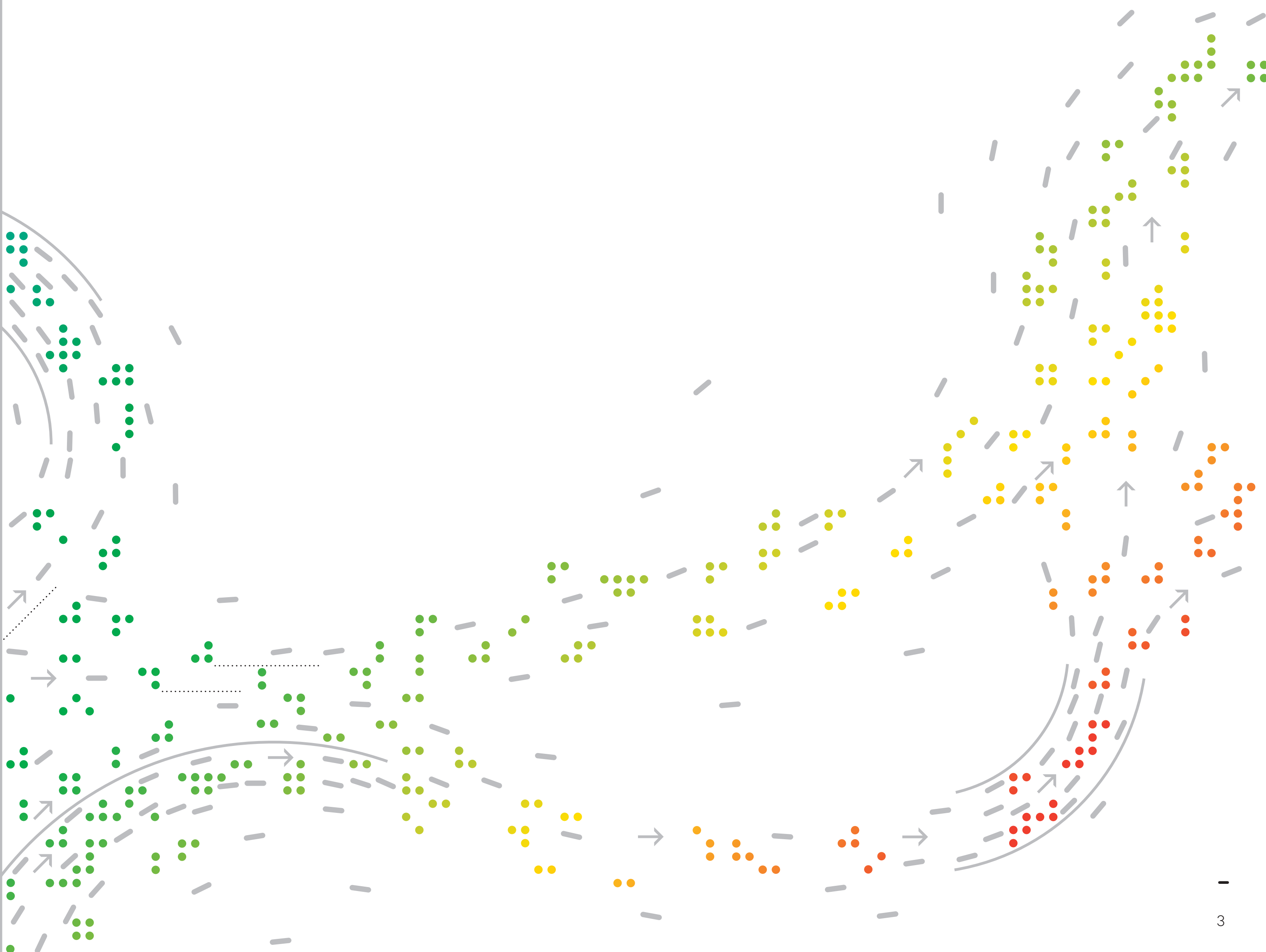
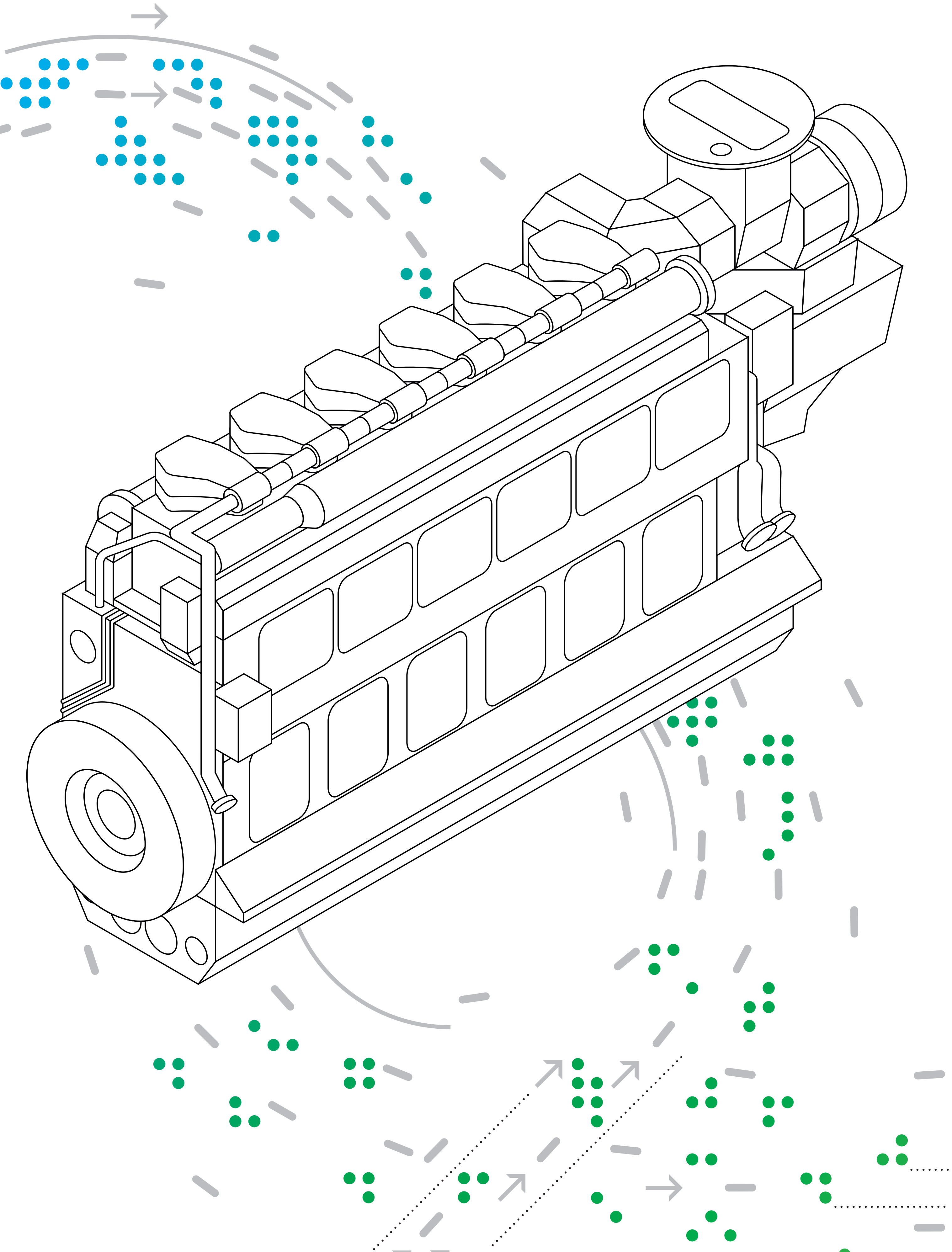
Designed for harsh duty, tuned for efficiency.

Get ready for the future with Common Rail 2.2



Contents





A new injection platform for today's liquids – and tomorrow's fuels

PBST is working to prepare four-stroke engines for future fuels such as methanol and ammonia. This calls for fresh thinking in design, materials, and validation. The next generation of fuel-injection systems will build on the technology toolbox created for the second-generation common-rail (CR) platform, briefly called CR2.2.

The CR system delivers state-of-the-art injection performance for today's distillate fuels and for upcoming bio- and synthetic options – serving as an intermediate step on the path to methanol and ammonia. It's the first move to establish the technology in the market, achieving best-in-class fuel consumption on current diesel and dual fuel engines.

CR 2.2 – next-gen common-rail injection

Higher pressure, cleaner layout, future-fuel ready.

Drawing on experience from earlier engine generations, a modular high-pressure system has been designed for medium-speed engines, currently up to 1,300 kW per cylinder. At its core are a solenoid-actuated injector used with an integrated accumulator and a new high-pressure fuel pump.

This chapter outlines the component design and the overall layout of the system. For instance, the concept supports multiple injections per cycle and allows tailored shaping of the injection rate for each engine application. A cam-driven, unified high-pressure pump is employed across several engine types, built for harsh conditions and validated under heavy-duty operation.

The layout described here forms the basis for future injection equipment and paves the way for alternative liquid fuels.

In the early 2010s, the first investigations were started that led to a new common-rail system for medium-speed engines. The decision was to design for 2,200 bar.

The CR 2.2 project was guided by the following goals:

A platform toolkit – not a one-off system

For CR 2.2, the focus was on common, platform-grade components and unified validation efforts. All high-pressure valves are released as platform products.

Multiple injections, precisely shaped

The new injector required a revised hydraulic arrangement. By moving the high-pressure valve into the cylinder head, the hydraulic distance between actuator and needle was shortened. This reduces energizing time, improves rate-shape control, and creates more freedom for defining the injection event, including multiple injections per cycle.

No cut-off leakage – higher hydraulic efficiency

CR 2.2 introduced a different high-pressure valve approach. A single high-pressure fuel valve replaces the earlier combination of two interacting valves. The cut-off valve was eliminated entirely, which markedly improves hydraulic efficiency. No high-pressure fuel is lost at end-of-injection; the residual high-pressure fuel quantity is negligible.

Ready for ISO 8217:2024 fuels, incl. HVO and synthetics

During component validation, a new revision of ISO 8217 – the global marine-fuel standard – was released. To address future needs, tests were completed across a wide spectrum of fuel qualities. The injection components are now released for the full scope of ISO 8217:2024. On request, support can be provided for the application of non-ISO liquid fuels.

Cleaner layout with fewer high-pressure joints

Customer feedback led to a simplified hydraulic layout. With the introduction of an equal accumulator on each cylinder unit, the number of high-pressure pipes was reduced, as were the high-pressure connections and the complexity of the mounting procedure. Assembly checks confirmed improved tightness and higher robustness of the installation. Mounting time is reduced; reliability is increased.

Raised rail pressure – up to 2,200 bar

Since CR 2.2 has been designed as a technology platform with a lifespan of several years, pressure capability was raised to 2,200 bar as a basis for future combustion optimization. The attention given to material selection and part stress ensured sufficient safety margins, enabling performance gains without exceeding material stress limits.

Longer service-life targets for key parts

To equip engines for CR 2.2, their major service intervals had to be aligned. From multiples of 6,000 hours to multiples of 8,000 hours, the target TBO increased by roughly one third despite higher engine loads, making the step particularly demanding. Dedicated injector endurance testing was performed to hit the planned service targets.

In summary, the new CR 2.2 is designed to be the future liquid fuel injection system for 4-stroke engines.

+38 %

↗ **max. possible rail pressure**

+33 %

↗ **target TBO interval**

-35 %

↗ **high-pressure connections**

System description and general overview

The system comprises three main component categories: high-pressure pump, injector and high-pressure valves.

Independent of the engine type, the layout is always seen per cylinder unit. In front of each cylinder are repeating bore patterns for the high-pressure pump or accumulator units. This allows standardized machining across different engine types, reducing the cost and complexity of the crank case. All pumps are connected with the same high-pressure pipe to create the common-rail system. From the pumps, the fuel is fed towards the injector via a high-pressure pipe and threaded piece. Each cylinder head houses an injector in the center of the valves. Valve blocks with high-pressure valves complete the system.

The high-pressure pump creates the system pressure independent of engine speed and feeds the injectors between each injection. The injection is freely parameterizable for different engine types, either as pure diesel engine or dual fuel engine. A pressure limiting valve, flow limiters and flushing valve ensure safe engine operation and HFO capability. In terms of low-pressure fuel supply, all the pressure, flow and cleanliness requirements remain, meaning customer acceptance testing is no more demanding and ensuring a high degree of system approval.

The hydraulic path of the fuel flows from the engine inlet through the duplex filter, and runs along the engine to the first high-pressure pump. At each high-pressure pump the fresh fuel flows around the inner pump element for thermal stability and leaves the pump on the opposite side. The fuel flow through the pumps is optimized for balancing the thermal load on these components. This helps keep the fuel temperature from rising excessively as it flows along the engine, consequentially reducing the risk of pump seizures in operation. From the supply, a smaller amount of fuel branches off to the injector for flushing. When running the engine on HFO, it is essential to heat up the fuel system before start-up and maintain the temperature in operation or stand-by. The pneumatic controlled flushing valve allows the fuel to enter the high-pressure system on one side and circulate through, until the other side of the pump deck. This forced fuel flow requires a pressure difference over the engine and is realized with a spring-loaded valve. The required valves are grouped in a valve block at the first cylinder (see Figure 2).

In dual fuel operation with a gaseous fuel as the main energy source, the CR 2.2 injection system is pre-activated. This is achieved by maintaining a residual pressure, significantly lower than the system nominal pressure, in the system to keep the main injectors closed and ready for a quick change over to diesel operation, when needed. To keep the high-pressure pumps in a safe operating range and prevent a lack of lubrication, an additional pressure relief valve is open. This leads to a raised suction throttle position and ensures thermal stability inside the pumps. The released fuel returns to the supply system and will be completely reused.

The CR 2.2 system is equipped with the same sensors as the previous system. Two redundant rail pressure sensors meet maritime class society requirements for the rail pressure control. Solenoid driven control units regulate the fuel brought into the high-pressure system. Special sensors are used to detect break leakages within the double-walled leakage drain. If necessary, it is possible to integrate injector accumulator pressure sensors to determine the injection behavior more precisely in terms of extending the TBO.

Based on full scale engine measurements, the necessary mechanical power needed to drive the injection system could be reduced by 48% compared to the predecessor system.

→ 1 Injector

→ 2 High-pressure pump*

→ 3 Accumulator unit*

→ 4 Flushing valve*

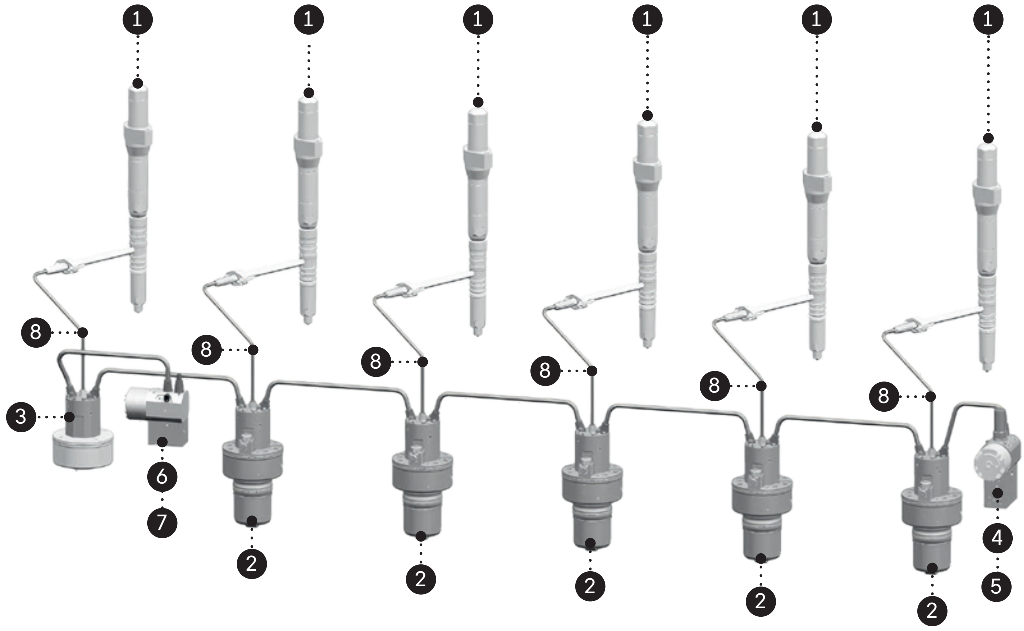
→ 5 Pressure-limiting valve*

→ 6 Pressure reducing valve for DF operation*

→ 7 Non-return valve for flushing

→ 8 High-pressure pipes

↗ ***Cross-platform**



↗ **Figure 1: CR 2.2 injection system from a typical 4X bore DF engine**

→ 1 Injector

→ 2 High-pressure pump

→ 3 Accumulator

→ 4 Valve block

→ 5 Flushing valve

→ 6 Pressure-limiting valve

→ 7 Non-return valve

→ 8 High-pressure pipes

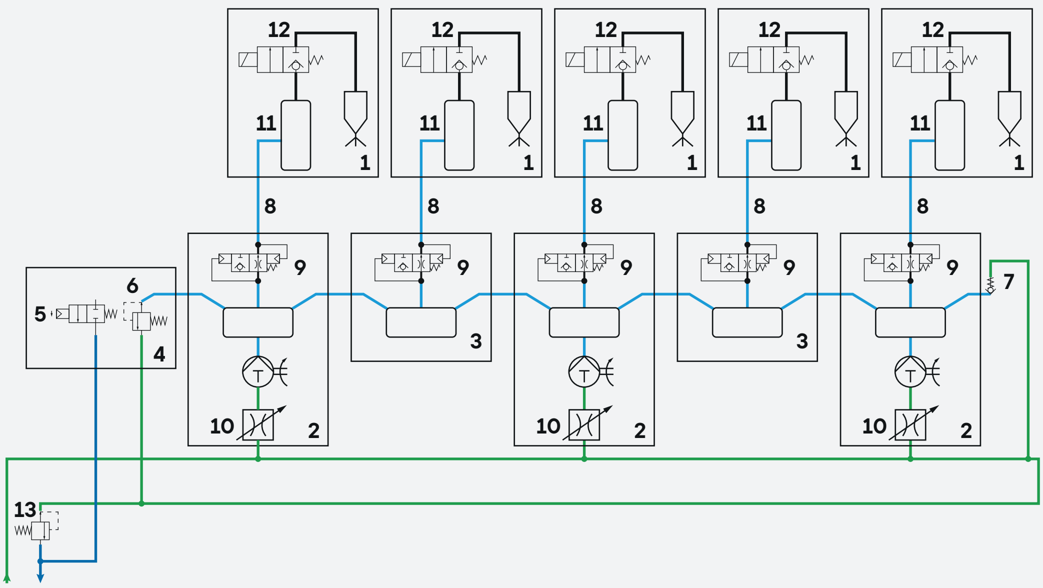
→ 9 Flow limiter

→ 10 Control valve

→ 11 Threaded piece

→ 12 Actuator

→ 13 Pressure relief valve



↗ **Figure 2: Hydraulic layout for common rail engines**

One unified pump for 3X and 4X medium speed engines

The CR 2.2 high-pressure pump was engineered and built in-house. This made it possible to adapt the previous pump architecture to the new requirements. Because the former two-cylinder accumulator units are no longer used in CR 2.2, a pressure reservoir for the fuel had to be mounted directly on the pump. That drove design updates from the pump element up to the high-pressure delivery connection. Several internal routing measures optimize the fuel path through the pump, improving hydraulic efficiency and tightness.

↗ **Figure 3: High-pressure pump CR 2.2**

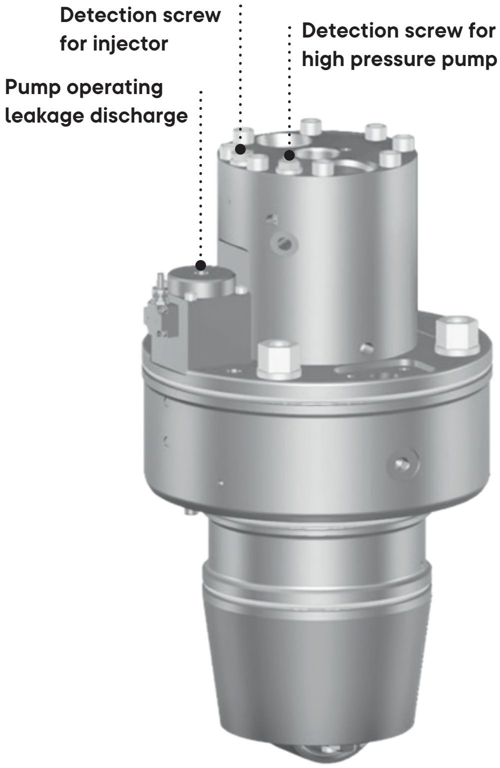
The pumps continue to be cam-driven: a three-lobe cam for 3X engines, and a four-lobe cam for 4X engines. On 4X engines no separate pump drive is needed anymore. Deep integration into the pump deck provides robust mounting without an additional swing arm. Versus former systems, the pump element uses a smaller piston diameter. The piston design has been reworked and, together with optimized features inside the cylinder, greatly reduces internal leakage and lifts efficiency.

Rail-pressure sensor feedback controls a solenoid-actuated suction valve that meters the fuel for compression. Above the pump element sits the accumulator, which provides identical high-pressure connections to each cylinder and includes a flow limiter towards the injector.

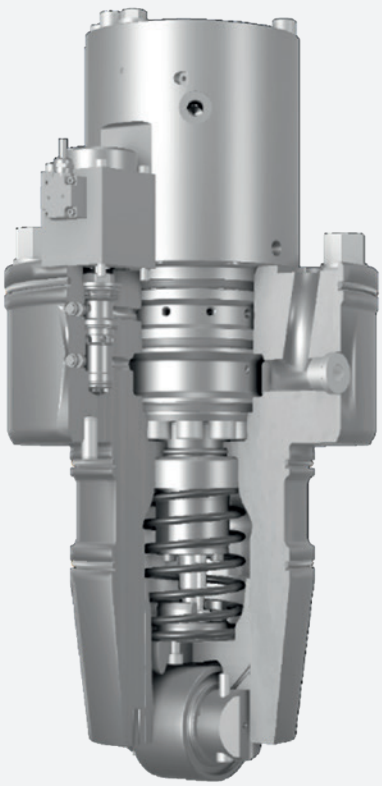
Compared with previous systems the new arrangement of suction and delivery valves and the piston design, yields a 13% gain in hydraulic efficiency at 1,600 bar.

To future-proof the pump, validation covered a wide span of fuels and load cases. Beyond endurance runs, Everllence performed extreme condition tests with sharp load ramps and thermal stress. Even with deliberately reduced inlet pressure or flow—conditions that risk overheating the pump element—the results remained robust. Experience so far supports the decision to use a standardized pump for both frame sizes.

Potential break leakages in the high-pressure circuit are intercepted by double-walled lines and routed to the leakage tank, removing the risk of a developing spray. Two detection screws in the accumulator help pinpoint the leakage location, allowing the affected component to be accessed quickly without dismantling the entire system so the issue can be repaired.leakage to be repaired.



↗ **Figure 4: Leakage detection measures for the high-pressure pump**



↗ **Figure 5: High-pressure pump cross-section**

Integrated accumulator injector

The standout innovation alongside the high-pressure pump is the PBST injector. It is the key element for improved stability, flexibility, and top-tier injection performance. Several functions in previous versions are now combined in one unit (see fig. 7). First, the actuator – a solenoid-operated high-pressure fuel valve – was moved close to the nozzle to shorten response time. Second, an accumulator was mounted directly on the injector to stabilize injection pressure throughout the injection event. These changes remove limits caused by long hydraulics between actuator and nozzle, which had constrained combustion development. With the new injector, the injection profile can be tuned to engine needs, including multiple injections per cycle.

Nozzle with rail-side control

Compared with the long-spring-loaded needle design used in former systems, the nozzle had to be reworked. A major difference is the presence of rail pressure right up to the needle seat. That requires a revised needle concept to let fuel pass. As always, effective flow is ultimately defined by the spray-hole geometry.

Intermediate plate

Between the nozzle and the high-pressure fuel valve, an intermediate plate provides dedicated supply and return throttle ratios. As a separate part, it makes adapting the injection rate to each application easier. By selecting throttle diameters, the start and end of injection can be shaped as required. In most cases a steep end of injection is preferred, which helps to reduce soot formation.

Actuator & high-pressure valve

The valve acts as a high-pressure fuel valve downstream of the control chamber. When energized, the armature lifts and the valve seat opens. Fuel exits the control chamber via the return throttle at the top, changing the hydraulic forces on the needle so it begins to lift. When de-energized, the seat closes; the supply throttle restores full rail pressure to the control chamber and the hydraulic force returns the needle to its seat. The armature area is continually flushed with fuel – firstly for thermal stability and HFO capability, and secondly to route the control quantity back into the fuel supply system.

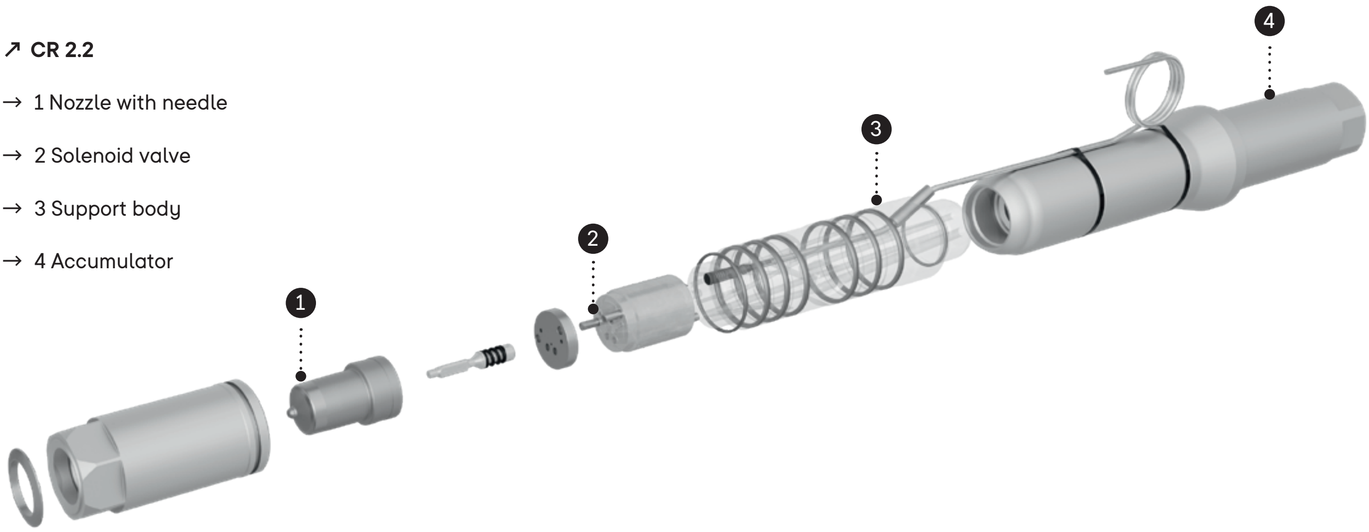
↗ **CR 2.2**

→ 1 Nozzle with needle

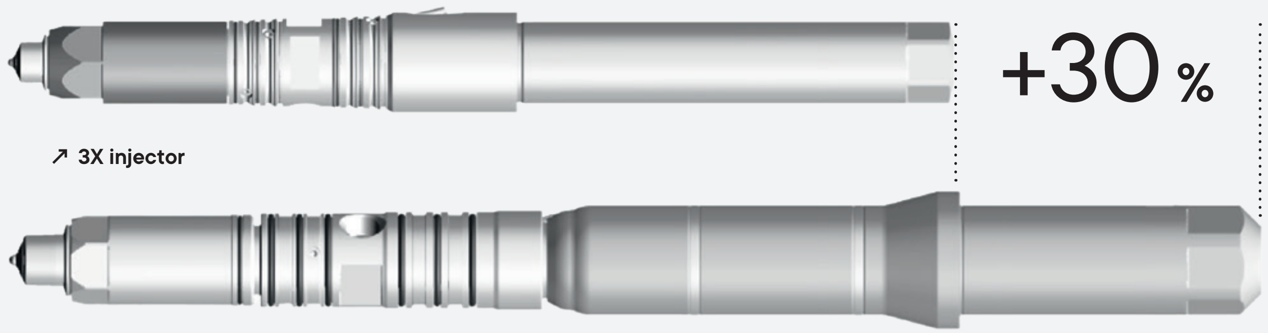
→ 2 Solenoid valve

→ 3 Support body

→ 4 Accumulator



↗ **Figure 7: Layout of CR 2.2 main components**



↗ **Figure 8: Size comparison of 3X- and 4X bore.**

Safety functions of our high-pressure valves

Reliable operation and full compliance with regulations require purpose-built high-pressure safety devices. The concept has been adapted for the higher pressure level, with extra features where appropriate.

The pressure-limiting valve and flushing valve are grouped in a dedicated valve block. Mounted via a high-pressure line on a low-pressure connection block, this arrangement lets technicians check or replace high-pressure parts without disturbing the low-pressure side. The same principle applies across all CR 2.2 engines.

Pressure limiting valve (PLV)

A spring-loaded safety valve by design, the PLV uses factory shims to set the opening pressure precisely. For stability, the needle seat includes a leakage discharge path so small leaks don't shift the setpoint. The valve head is arranged so the spring chamber is flushed during opening, and released fuel is routed back into the valve block rather than vented locally.

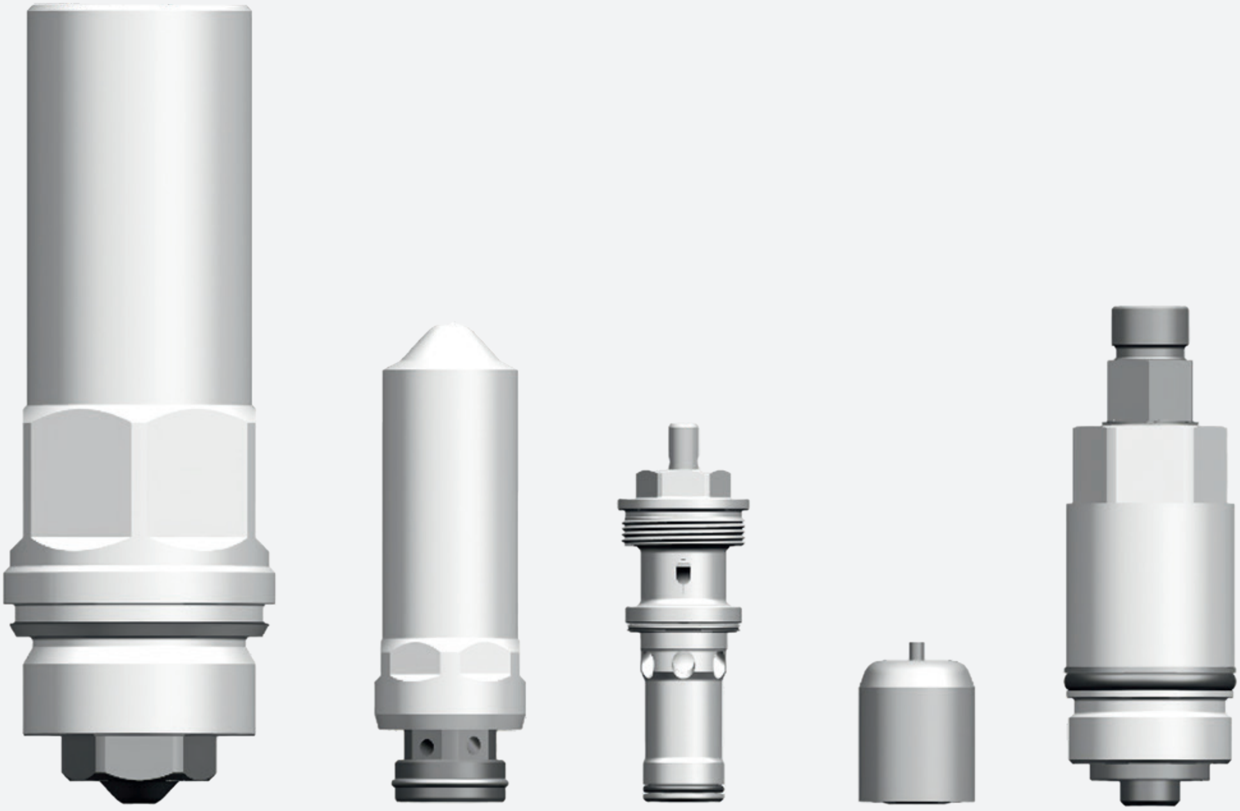
Flow limiting valve (FLV)

Positioned in the accumulator on the high-pressure pump or unit, the FLV follows a pressure-balanced layout in the flow path to the injector. Because rail pressure reaches the injector needle seat, additional safeguards were implemented to ensure that even with a leaking needle, fuel cannot enter the combustion chamber unnoticed.

Flushing valve (FV), pneumatic cylinder and non-return valve

During HFO standby or after cold conditions, the high-pressure system is force-flushed to preheat or hold temperature. Three parts act together: the FV isolates the high- and low-pressure sides and is actuated by a double-acting pneumatic cylinder to guarantee opening force even with aging or low air pressure; when opened, it vents system pressure to the low-pressure outlet. At the opposite end, a non-return valve connects to the higher-pressure supply and opens when supply pressure rises, routing fuel through the pump-deck components.

For the cylinder head, an additional flushing path feeds the injector. Fuel is brought along the engine through the head's central bore, distributed via ring grooves, and guided through the solenoid area to keep a uniform temperature field—supporting stable spray behavior and reduced wear.



↗ **Figure 9: CR 2.2 high-pressure valves, from left to right pressure limiting valve, flow limiter, control valve, flushing valve and non-return valve**

Closed break leakage circuit

In marine service, safety is paramount. All components tie into a closed, monitored break-leakage system so maintenance can be performed without hazard. Every high-pressure connection has a channel to the leakage circuit; pipes are double-walled, and the interspace diameter matches or exceeds the feed diameter. If tightness is lost, pressure cannot build and spills are avoided. Each cylinder bank has a monitored collection point, and sensors raise alarms in the engine control system. Together with the cylinder-level detection screws, leaks can be located quickly. Experience from numerous commissions shows the simplified layout provides reliable detection; the multi-level detection screws used on former systems are no longer necessary. After the level switch, break-leakage merges with operational leakage and returns via one common line, enabling fuel reuse and a single engine-supply connection.

The pump deck is included as well: sensors watch for any external fluids – cooling water, lube oil, or fuel. Such external leakage is excluded from reuse.

Operational changes and service model

PBST is launching a dedicated service concept for the injector and pump element. We will run a closed-loop exchange of worn components through a network of global service hubs. Due to design and tolerances, an injector cannot be overhauled with standard hand tools.

For operators, this means less work in onboard workshops. A plug-and-play replacement of the injector cuts engine downtime, and on many engines the maintenance schedule for the injection system demands fewer people and less time.

At an authorized service hub, the injector is disassembled, cleaned, and inspected for reuse. Trained technicians reassemble the unit with approved parts at a state-of-the-art assembly station – ensuring correct injection behavior and production conformity.

CR 2.2 – liquid injection, ready for tomorrow

Across medium-speed engines, fuel portfolios are shifting fast. With no clear winner for the next 10–20 years, multiple injection concepts may be needed to satisfy evolving combustion requirements.

With CR 2.2 in place, liquid-fuel injection remains state of the art. The platform supplies core building blocks like advanced nozzle concepts and solenoid actuation, ready to transfer to methanol- or ammonia-capable injectors. Materials and manufacturing routes are pre-defined, and the accumulated validation know-how carries over so the same verification strategy can be applied.

From proven ground into new fuel territory – CR 2.2 is the enabler for the next generation of liquid injection equipment.

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