GOVERNMENT OF INDIA
MINISTRY OF RAILWAYS

TECHNICAL SPECIFICATION
FOR
DESIGN & DEVELOPMENT OF NATURAL GAS BASED ALCO ENGINE FOR DIESEL LOCOMOTIVES OF INDIAN RAILWAYS

Specification No. TS/ED/ 2010/47

November 2010

Engine Development Directorate
Research Design and Standard Organization
Manak Nagar, Lucknow- 226011

1.0 Preamble-

One ALCO DLW built 16 – V configuration 3100 HP engine with a Peak Firing Pressure of 1850 psi is to be converted to use Natural Gas as fuel . This engine is the main engine used on diesel locomotives of Indian Railways. The natural gas/ pilot diesel fuel injection system shall be fitted during rebuilding of the ALCO engines at Diesel Modernization Works, Patiala.

The supplied natural gas/ pilot diesel fuel injection system shall be used on locomotives equipped with Microprocessor Control system. Natural gas/ pilot diesel fuel injection system control unit should be capable of communicating with the Microprocessor system of the locomotive.

2.0 General Requirements-

Engine data for 3100HP ALCO engines is given at Annex I and performance data for ALCO engine at full power is given at Annex II. The following general requirements shall be fulfilled by the natural gas/ pilot diesel fuel injection system.

2.1 Rail Traction Characteristics

The natural gas/ pilot diesel fuel injection system shall be suitable for Rail traction service; which is characterized by wide, fluctuating, cyclic load patterns, and extended intervals of operation at idle & full load.

2.2 Operating conditions

It shall be sturdy and reliable in operation and incorporate components that can withstand the hostile environmental conditions in the engine room such as dust, water, fuel/ lubricating oil, vibration, extreme temperatures, Electrostatic / Electromagnetic interference, and an extremely noisy power supply.

2.3 Proven Design

The natural gas/ pilot diesel fuel injection system shall be of a proven design. Customization of an existing design to suit the requirements of Indian Railways (IR) is acceptable.
Tenderer may offer any alternate technical solutions which is capable of meeting late direct high pressure injection of gas with micro-pilot diesel injection so as to meet the thermal efficiency and emission requirements as detailed in these specifications, if available with him with detailed justification. However deliverables as detailed in the tendered specification should be met by the offered technology option.

Tenderer should have at least five years of experience with the activities associated with the design, manufacture and supply of commercially running natural gas/ pilot diesel fuel injection system. Tenderer should also take the responsibility of the overall System Integration, Testing / Optimization & Validation of the natural gas/ pilot diesel fuel injection system on the test engine of ALCO as well as the ALCO locomotive in coordination with Indian Railways.

3.0 Scope of the Project-

It is planned to design and develop gas based ALCO engine for the present fleet of ALCO locomotives. Details of this engine are given in Annexure. Detailed fuel map shall be provided to the successful Tenderer. Fully dimensioned and toleranced CAD models of the engine, cylinder head and piston are available with RDSO. Some of the details are provided in Annexure. More details as needed shall be provided to the successful Tenderer after signing of the Non-disclosure agreement. Details of the present fuel injection system of the engine are as given below.

Parameter	ALCO 16 V fuel injection system
Type	Mechanical, Pump Line Nozzle
Pump plunger diameter	17 mm
Nozzle opening pressure	250 bar
Maximum injection pressure	1100 bar
Nominal output	1333 mm3/stroke max

It is planned to replace the present mechanical fuel injection system of the engines with high pressure late in the cycle gas injection system with provision of injection of pilot diesel fuel to start the ignition. Gas engine development shall consist of [but not limited to] the following activities and may consist of iterations as required.

1. Development of the technical profile of the system/ application (details of power ratings, fuel storage, emissions, operating characteristics etc.) including feasibility study.
2. Conceptual design and architecture of fuel system and other associated components.
3. Concept design review
4. Detailed design
5. Design review
6. Prototype component fabrication and procurement as the case may be
7. Assembly and bench testing of components
8. Prototype engine build and commissioning
9. Combustion, performance, and emission (CPE) development on Dynamometer including systems integration on the engine test bed at RDSO
10. Calibration development for initial prototype vehicle including integration on one diesel locomotive of Indian Railways
11. Fuel storage and High pressure gas supply prototype build and test. **RDSO will provide an existing 3100 hp ALCO locomotive to the successful tenderer on which the scoped schedule of work needs to be executed by the tenderer. This inter-alia shall mean modification of an existing diesel locomotive ALCO engine to meet the requirements of the tendered specification. The modified locomotive shall run on a lead of 400 -500 km approximately. RDSO envisages the tenderer to make arrangement for providing storage facilities initially for the performance tests on**

the engine development test beds and then modify and transfer the same on the locomotive for both types of fuels, along with its associated delivery systems for making the fuel available to the engine and test the locomotive for performance tests. Layout of existing 3100 HP locomotive on which the same is planned is enclosed as Annexure VI. The Engine Development Dte. Test bed and the locomotive has an existing arrangement for storage and supply of High Speed Diesel as the prime fuel which may be utilized as it is or modified to suit the requirements.

12. Prototype vehicle build and test
13. Validation testing
14. Reliability / Durability testing on the field including Reliability Verification Testing.
15. Debugging and development of final technical designs, and drawings.

4.0 Mounting Arrangement-

The complete system including the Engine Management and high pressure gas / pilot diesel fuel injection components, Sensors, Set point Generators, Interfaces, Fuel supply system, electronics and transducers shall be mounted on the engine or in the locomotive cab. For the high-pressure gas / pilot diesel injectors the supplier can offer their best solution for late direct injection of the gaseous fuel into the combustion chamber. During the trial stage on test bed, the system planned to be mounted in the cab can be installed in control room. This is to facilitate the testing of the power pack as one whole unit. Tenderer should specify the requirement in the offer.

5.0 Other Design Requirements -

To ensure easy fitment, the following restrictions in the design shall apply:

5.1 The natural gas/ pilot diesel fuel injection system shall be designed in such a manner, that no major modification to the existing engine shall be required for its fitment. In any case the engine modifications should be minimized. Minor modifications are permitted in the existing Cylinder head .However new design of Cylinder Head would not be preferred.It should not be necessary to have reduced air manifold temperatures.

- The Idle and light loads should not require throttling the air flow.
- **New design of Piston is not preferred**
- The engine should have “limp home capability” of delivering around 7000 Nm torque at 1050 rpm.
- The converted engine should maintain performance and efficiency of the base diesel engine.
- However any modification which the Tenderer feels is for the improvement in performance and reliability of the engine and the locomotive should be offered by the Tenderer preferably with quantification of benefits.

5.2 The external dimensions of the injector shall be identical to the existing ‘BOSCH’ make Injector for ALCO Engine. Injector design offered should not require any major modification in the cylinder head of ALCO engine. **Minor modifications are permitted in the existing Cylinder head .However new design of Cylinder Head would not be preferred.** Dimensioned, tolerance 3-D solid models of cylinder head in UG shall be provided to the

Tenderer after signing of the non-disclosure agreement. This will show the present fuel porting arrangement to the fuel injectors. The offered fuel injector should be integrated to inject diesel pilot fuel and the high pressure gas (late into the cycle) through the same injector (two separate injectors are not allowed as this would call for major modifications to the cylinder head). The injector should be fast response. The way natural gas is injected into the combustion chamber is crucial to meeting the fuel efficiency and emission standards. The injection event needs to be modeled to design the appropriate injector nozzle.

5.3 A systematic analysis of the injector nozzle and its relationship to the combustion chamber geometry shall be conducted. The Tenderer may have to carry out a combustion CFD analysis of the effect of injector holes and orientation on fuel efficiency and emissions using KIVA or other suitable software. The parameters which may need to be optimized are: -

- Injector hole diameter
- Injector hole angle
- Number of injection holes
- Arrangement / location of injector holes
- Injection pressure
- Injection timing
- Injection duration
- Injector tip design

5.4 Durability tests –Durability tests shall be conducted on the injectors on a 16 cylinder converted ALCO engine on the engine test bed at RDSO. This will be followed by the reliability verification testing on a converted field locomotive for a period of 12 months. On the engine test bed, the durability test shall be conducted for **1000** hours with tear down and inspection after every **250** hours. **Tear down shall be done for one injector out of sixteen injectors provided on the engine, which is indicating worst combustion in that power assembly during the test. Complete 16 injectors shall be subjected to tear down inspection only at 500 and 1000 hours.** In the field the injectors shall be run for a period of 12 months to record any abnormal behavior / failures and tear down inspection at the end of the trial period or in case of any out of course repairs**. Life tests shall be conducted as part of the prototype field trials.** The purpose of the durability tests is to identify the failure modes and debug the design, and not for pass and fail of the design.

5.5 Speed governing –

- Speed governing shall be done by modulating gas fuelling parameters.
- Suitable number of ECU(s) should be used for gaseous injection control system and pilot diesel injection control system.

5.6 The engine purely on pilot diesel fuel shall be capable of producing 7000 Nm in limp home mode.

5.7 LNG system – the system should be so designed so as to provide a LNG storage system with capability to increase the pressures of natural gas to required levels with use of hydraulic

pump. The LNG handling system should be capable of providing the low gas pressures and rates (turn-down ratio) required for light load conditions. **This is a tender for 'design and development of Natural Gas based Alco engine for diesel locomotives of Indian Railways'. The natural gas is proposed to be stored and carried in the form of LNG so as to give a higher fuel density per cubic volume. This LNG is supposed to be vaporised and injected in the cylinder head at high pressure at the time of combustion from the storage equipment provided with the system.**

5.8 The Tenderer should endeavor to design and offer a system, which avoids major modifications in the existing locomotive fuel oil circuit. Any special requirements such as additional/ improved filters etc. shall form part of the natural gas/ pilot diesel fuel injection system. The present fuel oil circuit incorporates a primary and a secondary fuel oil filter. The inclusion of any new component shall become part of adaptation kit to be supplied with the system by the Tenderer.

5.9 Tenderer should provide Design support for any design changes needed on the engine parts to use the natural gas/ pilot diesel fuel injection system. Fitment of camshaft/crankshaft speed & position sensors etc. shall not require any major design modifications. Sensors for pressure & temperature measurements shall be mounted on the existing lube oil/ water/ air circuits at suitable locations.

5.10 In case the Tenderer offers a high pressure fuel oil pump (for the common rail diesel fuel injection system) which is to be lubricated by engine lubricating oil, he may specify the filtration requirement and also supply the additional filter for lube oil to be used for filtering the engine lube oil before supply into the high pressure fuel oil pump. The engine lubricating oil pressure varies from 2 to 6 bars in ALCO engine, in case the high pressure fuel pump offered by the Tenderer is designed for higher lubricating oil pressures, the Tenderer should also supply any additional pump required for the purpose. The additional pump should be electrically driven with a fractional horsepower d.c. motor capable of running at 72 V d.c

5.11 The locomotive integration and testing shall be carried on for a period of 12 months including the Reliability Verification Testing

6.0 Safety Requirements-

The natural gas/ pilot diesel fuel injection system both the electronic and the mechanical portions shall be so designed that safety of the locomotive and personnel are not compromised. The following points shall be specifically ensured:

1. There shall be no fire hazard from any type of electrical short circuit.
2. Fuel supply to injectors shall be cut off as soon as the engine stops. This is necessary to prevent fuel oil from dribbling/flowing into the cylinder due to faulty injector operation.

Suitable arrangement in the natural gas/ pilot diesel fuel injection system may be used to ensure this.

7.0 Redundancy-

100% redundancy is desired for the sensors and devices whose failure can lead to unsafe operation of the engine. For those sensors, where 100% redundancy has not been provided, a fail-safe, fall-back strategy shall be adopted for all likely failures. Failure of any single component/ sensor/ sub-system shall not lead to a complete shutdown of the engine. Limp home capability shall be built-in.

8.0 Preventive Maintenance-

No maintenance including inspection of any type shall be required before 120 days. The manufacturer shall specify the preventive maintenance schedule required. Care shall be taken by the manufacturer to ensure that these schedules match the existing locomotive schedules, and the least work content in these schedules shall be preferred.

9.0Technical Data and Drawings-

To support the claims regarding the design, fitment, maintenance, operation, performance, reliability etc. the tenderer is required to submit the following documents along with their offer:-

1. Details of earlier applications of the system on similar engines or engines of similar power output.
2. Details of special tools and rigs required for the maintenance of the natural gas/ pilot diesel fuel injection system for ALCO engine. **The tenderer is supposed to advise the same to RDSO in broad terms along with the offer for RDSO to ascertain whether any major inputs would need to be planned by RDSO for maintenance of the natural gas/pilot diesel fuel injection system for ALCO engine.**

Tenderer should specify the details of the specifications, data and drawings to be provided by RDSO.

After the development of the natural gas/ pilot diesel fuel injection system for the ALCO engine, the supplier shall provide the following technical data and drawings:-

1. Detailed specification of the natural gas/ pilot diesel fuel injection system for ALCO engine including detailed dimensioned drawings of the interfacing dimensions except the proprietary design details.
2. Detailed specifications should include the High pressure pumps, Fuel injectors, pipes/tubes, filters, ECU, sensors etc.

10.0 Main Design Objectives-

It is desired to design & develop a natural gas based ALCO engine for diesel locomotives of Indian Railways with the following broad objectives: -

Environmental Objectives

- Reduced NOx emissions
- Reduced Particulates emissions
- Low emissions of CO and THC
- Reduced Black Smoke emissions
- Reduced noise emissions

Economy Objectives

- Displacement of diesel fuel by natural gas, 80% or more by energy content
- Maintaining or bettering performance and efficiency of base diesel engine
- Reduced Life Cycle costs
- Prolonged Maintenance and Time Between Overhaul intervals
- Prolonged Service life
- Overhaul of main parts (Remanufacturing)

Reliability Objectives

- Improvement in reliability of diesel engine by having restriction on the peak firing pressures and restricting increase in exhaust gas temperatures.

11.0 Functional Requirement of Natural Gas Based ALCO Engine-

The natural gas/ pilot diesel fuel injection system has to take over following existing functions of the engine governor and the over-speed trip mechanism:

1. Isochronous governing of engine speed
2. Engine load shedding as and when required
2. Low Lube oil pressure protection
4. Hot engine protection
5. Engine Over-speed protection.
6. Acceleration control to reduce exhaust smoke
7. Engine Shutdown
8. Limp Home (Get Home) facility

Main functions of the offered natural gas/ pilot diesel fuel injection system for ALCO engine will be as under:

11.1 The basic functions involve the precise control of pilot diesel, Gas-fuel injection timing and fuel quantity at the reference pressure. In this way, the natural gas/ pilot diesel fuel injection system should be able to ensure that the engine has low fuel consumption and smooth running characteristics.

11.2 It will be desirable to have independent forming of opening and closing flank of the fuel injection rate of both fuels – natural gas/ pilot diesel fuel injection system.

11.3 The offered natural gas/ pilot diesel fuel injection system should have the capability for High Injection pressures even at low engine speeds and almost free pressure modulation capability.

11.4 Variable Injection Timing – The offered natural gas/ pilot diesel fuel injection system should have the capability to vary injection pressure and timing over a broad scale.

11.5 The natural gas/ pilot diesel fuel injection system shall be able to map injection timings with respect to load, speed, boost air pressure, boost air temperature & engine jacket temperature to achieve the lowest fuel consumption.

11.6 Automatic Low Idle: The natural gas/ pilot diesel fuel injection system should be able to enter the low idle mode of the engine operation without the driver's intervention. When the driver brings the throttle handle to IDLE, the engine speed shall drop to the specified rpm. After a small time delay, Fuel Injection System shall reduce the engine speed at a predetermined rate. While it is reducing the engine speed, it needs to keep a watch on the engine lube oil pressure and the loco main reservoir pressure. When either of these two pressures reaches a predetermined minimum level, the Fuel Injection System should stop reducing the engine speed further. From this point onwards it should keep adjusting the engine speed in a manner that will ensure that the above-mentioned two pressures never touch their minimum levels. Whenever the driver moves the throttle handle to first notch, the engine speed should be raised to the first notch speed rapidly by the Fuel Injection System.

11.7 Closed Loop Hot Engine Load Shedding: During the summer months the Diesel Locomotives are subjected to high ambient temperatures, which bring down the efficiency and heat dissipating capacity of the radiator panels and a hot engine alarm results. The natural gas/ pilot diesel fuel injection system should monitor the engine water temperature and whenever it starts approaching the upper limit it should gradually reduce the power output of the engine without reducing the engine speed. This will result in decreased heat production by the engine. On the other hand the cooling capacity of the radiator shall remain at its maximum, as the radiator fan and the water pump (which are engine driven) shall continue to run at their max. rated speed. The engine water temperature shall not be allowed to exceed its maximum limit. The power from the engine shall be restored back to its normal value gradually, as it cools down

11.8 Improved Engine Control: The natural gas/ pilot diesel fuel injection system shall have superior engine speed control capability. It shall be able to hold the engine speed with +/- 5 rpm (or less) of the required speed at all speeds and loads under steady state conditions. Under a step input, this control shall be achieved without any signs of hunting or overshooting.

11.9 Limp Home Capability: The system shall be designed in such a way that if there is failure of any component or subsystem of the natural gas/ pilot diesel fuel injection system or due to depletion of the LNG, it shall be possible to run the locomotive at a reduced level of efficiency or power or functional capability as per the torque limit defined above.

11.10 Design Flexibility: The system will allow full flexibility for development and tuning in a test cell under the direction of trend development engineers. Development will allow the same calibration to be applied to multiple engines fitted with similar natural gas/ pilot diesel fuel injection system. Operation of natural gas/ pilot diesel fuel injection system engine will be the same as for diesel engine (i.e. same flexibility) other than fuelling. This design is being developed for 3100 hp rated ALCO 16 V cylinder engine.

11.11 Diagnostics: The natural gas/ pilot diesel fuel injection system shall have built-in diagnostics. It shall run a full self-diagnostic on every power-on. In addition, it shall also run diagnostics at regular intervals, even while the engine is in operation. This operation shall be transparent, and should not affect the normal working of the system. All faults shall be logged for later downloading to a PC by the maintenance staff. Major fault conditions shall be indicated by a suitable indicator mounted on the controller itself. This is to help the driver in the field where a PC is not available.

11.12 The Electronic Fuel (s) Control offered along with the natural gas/ pilot diesel fuel injection system should have the capability for integration with the overall locomotive propulsion control system and shall be tenderer's responsibility. **The existing diesel locomotives of IR are fitted with microprocessor for traction control which monitors the state of the engine and the locomotive for various parameters. This needs to be interfaced to the Fuel systems (FS) controller. This project hence would not require development of a totally separate engine controller. Engine controls need to be so designed by the tenderer to meet the requirements as per tendered specifications.**

11.13 Depending on the output stages of the engine control unit, adequate number of engine control units may be planned in the design. These can be coupled within the "master/slave" network via an internal, high speed interface. This should lead to a higher microcontroller processing capacity available. Some functions can be permanently allocated to a specific control unit (e.g. fuel balancing control). Others can be dynamically allocated to one or other of the control units as situations demand. (e.g. to detect sensor signals)

12.0 Design-

The natural gas/ pilot diesel fuel injection system shall consist of the following main component groups, but not limited to: -

- LNG Tank.
- Diesel Hydraulic Tank.
- LNG pump.
- Hydraulic pump.

- CNG accumulator.
- High pressure common rail diesel fuel pump.
- Fuel conditioning module.
- Duel fuel injectors.
- Fuel delivery controller and injector driver modules.
- Any additional filtration components.
- The low pressure stage, comprising the fuel supply system components.
- The high-pressure system, comprising components such as the high-pressure pump, fuel rail, injectors and high pressure fuel lines.
- Sensors, the Electronic Control Unit and Actuators, Wire harness etc.

12.1 Injector- Required Injector characteristics are as given below-

- Integrated dual fuel injector with concentric needle type and having the same envelope as the existing stock injector.
- Both natural gas and diesel fuel to be supplied to the injector at suitable pressures via suitable pipelines.
- Diesel and natural gas pressures should be balanced using suitable regulators with the diesel pressure higher than gas pressure to prevent any leakage of natural gas into diesel fuel.
- Injector process which occurs near the end of compressor stroke (late cycle) should be controlled by solenoid valves.
- Diesel and natural gas injection timings are independently controlled using an electronic control unit that actuates the solenoid drivers.
- Hydraulically operated with abort spring.
- Minimal hydraulic seal oil leakage into the cylinder.
- Zero fuel gas leakage into cylinder, crankcase and hydraulic oil.
- No fuel flow upon loss of hydraulic oil.

Tenderer is free to offer the state-of-the-art Injector technology which would meet or exceed the design goals. The Injector should be capable of achieving rapid switching times by suitable control of Voltage and Currents at the highest operating efficiencies. The Injector should be capable of operating at the design fuel injection pressures with adequate tolerance for peaks.

12.2 High Pressure pump for common rail fuel injection system-

The high-pressure pump is the interface between the low-pressure and high-pressure stages. Its function is to make sure there is always sufficient fuel under pressure available in all engine operating conditions. The product specification should match the Industry Standard and/ or the best-in-class. This includes providing a fuel reserve that is required for quick engine starting and rapid pressure rise in the fuel rail/accumulator(s). The high pressure pump generates a constant system pressure for the high pressure accumulator/fuel rails independent of the fuel injection.

Present Fuel Injection Pumps of the ALCO DLW 16 V engine is a Mechanical Pump-High pressure line-Mechanical Injector (PLN) system. With the introduction of the natural gas/ pilot diesel fuel injection system on the ALCO, these PLN items would not be required. High pressure pump offered should be able to supply the required high pressure fuel to the accumulators/ rails of the natural gas/ pilot diesel fuel injection system and should be reliable and sturdy in operation and able to give repeatable results. The drive for the high pressure pump shall be offered by the Tenderer, however RDSO will be required to be involved during the design, fitment and testing of the natural gas/ pilot diesel fuel injection system. Tenderer should familiarize himself with the capabilities of RDSO for this purpose. Involvement of the supplier will include providing design inputs, expected outputs, sharing of their experience, providing comments, suggestions, modifications to the offered system so that the performance and reliability goals of the natural gas/ pilot diesel fuel injection system are met.

12.3 Accumulators / Common Rails -

Tenderer should offer a suitable accumulator system for the high pressure fuel. This can be Common Rails with suitable considerations for the Wave Dynamics and pressure oscillations or individual accumulator type Injectors with thin high pressure lines connecting the Injectors. Sufficient safety should be provided in the high pressure pipes, tubes etc. so that the system is able to withstand the harsh operating conditions of the rail traction as given above.

12.4 Engine Control Unit (ECU)-

The Engine Control Unit shall control the entire natural gas/ pilot diesel fuel injection system. The interface and integration of this ECU with the locomotive microprocessor control system [which is procured by IR to specification no MP-0.17.00.01 (Rev.02 or Latest)] shall be the responsibility of the supplier. Access to the microprocessor specification will be made available to the Tenderer after signing of the non-disclosure agreement. The supplier may at his discretion source the ECU and associated hardware i.e. wire harness, sensors and pickups, engine Crank angle and TDC pickup, cabling etc. as required and ECU development from a third party having familiarity with locomotive traction control systems in order to reduce the development times and costs and to develop superior interfacing systems to the Locomotive traction control system. However the responsibility for proper functioning and reliability of the supplied system shall rest with the supplier.

13.0 Proto Type Development-

The tenderer is required to have the suitable CAD software, CFD software, suitable Hydraulic simulation software like AMESim for fuel system simulation, high pressure hydraulic pump test bench, and injector test bench etc. The tenderer is expected to follow the following path for prototype design and development-

- Feasibility study and concept formulation.
- Detailed design of all system components. Including simulation work.
- Ordering of parts for prototype.
- Design changes based on in-house testing and ordering of parts for the complete engine (for 18 cylinders keeping two extra).
- Fitment of the system on the ALCO engine on the Test Bed at RDSO.
- Completion of Engine Performance tests at RDSO.
- Revision of designs if any based on the above.
- Changes to the proto engine parts for fitment on the locomotive.
- Fitment on locomotive.
- Field trials for one year.

13.1 Supply to RDSO of the following Assembly drawings and documentation prior to beginning of Hardware manufacturing or prior to beginning of natural gas/ pilot diesel fuel injection system assembly for Engine Test Bed testing.

13.1.1 Dimensional outline drawing of Injector.
13.1.2 Dimensional outline drawing of the LNG tank, hydraulic pump, hydraulic tank.
13.1.3 Dimensional outline drawing of diesel high pressure pump.
13.1.4 Dimensional natural gas/ pilot diesel fuel injection system installation drawing.
13.1.5 Technical specifications needed for assembly of the natural gas/ pilot diesel fuel injection system on the RDSO engine test bed.

14.0 Description and Scope of Supply-

The requirement envisages inclusion in the offers, separately, of the following major components along with associated safety devices [but not limited to]:

14.1 LNG Tank along with all safety accessories.
14.2 Gas train.
14.3 Hydraulic Tank.
14.4 Hydraulic high pressure pump.
14.5 Fuel conditioning modules.
14.6 50 complete dual fuel injectors.
14.7 50 individual injector micron filters.
14.8 50 spare nozzle blanks, hardened and ready for hole configuration matching (to be used for alternative spray configurations). Hole drilling on these blank nozzle shall also be the responsibility of the supplier.
14.9 2 complete high pressure pumps along with all lubrication piping, tubing, valves and other accessories.
14.10 CNG accumulator including pressure sensor.
14.11 Pressure relief valves.
14.12 1 complete set of piping's and tubing's along with flow limiters.

14.13 Cabling harness required to connect ECU, Injectors, dual fuel injectors, pumps, pump delivery control, pressure sensor, Engine Crank angle and TDC pickups.

14.14 Engine Control Unit with necessary hardware and software.

14.15 Adaptation requirements on Engine Test Bed at EDD.

14.16 Adaptation requirements on the trial locomotive.

14.17 CCOE, Nagpur clearance for all pressure vessels (including LNG & Accumulator tanks) as required shall have to be obtained by the tenderer.

14.18 Any other component may be offered to complete the system.

Note: - This conversion kit shall first be used for test and trial purpose on EDD test bed and then has to be fitted and adapted on the locomotive for field trial by the supplier.

14.19 Instrumentation - One complete set of sensors consisting of but not limited to -

(i) High pressure diesel fuel oil pressure sensors (01 no.).
(ii) Natural gas pressure sensor.
(iii) Hydraulic oil pressure sensor.
(iv) Engine Oil pressure sensor (01 no.) or alternatively the firm should be able to use the output from the existing oil pressure sensor on the Microprocessor based ALCO locomotive.
(v) Boost air pressure sensor (01 no.) or alternatively the firm should be able to use the output from the existing boost pressure sensor on the Microprocessor based ALCO locomotive.
(vi) Engine Coolant Water temperature sensor (01 No.) or alternatively the firm should be able to use the output from the existing coolant water temperature sensor on the Microprocessor based ALCO locomotive.
(vii) Engine Speed sensor (01 no.).
(viii) Phasing sensor/cam index sensor (01 no.).

14.20 Software- All required software including any diagnostics software.

14.21 Documentation- After the design of the prototype system and before fitment on the engine on the Engine Test Bed at RDSO, the supplier shall need to provide the following documentation to RDSO:-

i. Dimensional outline drawing of Injector.
ii. Dimensional natural gas/ pilot diesel fuel injection system installation drawing .
iii. Technical specifications needed for assembly of the natural gas/ pilot diesel fuel injection system on the RDSO engine test bed.
iv. Literature, Maintenance and operating instructions, spare part catalogues (including drawing's reference parts) and tools catalogues appropriate for a prototype system.

14.22 Service-

(i) Assistance during Test bed trials at RDSO
(ii) Assistance during Locomotive fitment and field trials
(iii) After sales service for two years

(iv) For the entire major bought out items / components, the essential detail should be given in the offer. In addition, the Tenderer must give parawise remarks to all the clause of specification. Without these, the offer is likely to be rejected.

14.23 In case the Tenderer offers a high pressure fuel oil pump which is to be lubricated by engine lubricating oil, he may specify the filtration requirement and also supply the additional filter for lube oil to be used for filtering the engine lube oil before supply into the high pressure fuel oil pump. The engine lubricating oil pressure varies from 2 to 6 bars in ALCO, in case the high pressure fuel pump offered by the Tenderer is designed for higher lubricating oil pressures, the Tenderer should also supply any additional pump required for the purpose. The additional pump should be electrically driven with a fractional horsepower d.c. motor capable of running at 72 V d.c.

14.24 The Tenderer can offer other features that may be useful to the Indian Railways. The technical aspects and price impact of these additional features should be clearly brought out in the offer.

15.0 Performance Tests on RDSO Engine Test Bed-

15.1 The performance of the natural gas/ pilot diesel fuel injection system in respect of fuel displacement, brake specific energy consumption, smoke, Noise and Emission shall be shown. An 80% displacement of diesel (energy content) by natural gas is desired along with limp home capability. The instrumentation required to be provided by RDSO on the test bed engine (at RDSO) if any for measurement should be detailed in the offer. The detailed requirements of Test Bed upgradation will be provided by the successful tenderer and the upgradation of RDSO Test cell will be carried by RDSO itself in association of the firm. The Tenderer may like to visit the RDSO test bed to assess the facilities available with RDSO and its capabilities.

15.2 The specified performance shall be validated on the test bed of ALCO engine at Engine Development Directorate, Research Designs & Standards Organization (RDSO), Lucknow, India by first generating baseline data with the existing FIE and then with the fitment of the natural gas/ pilot diesel fuel injection system equipment and its accessories. All other engine components shall be kept identical. The ALCO engine will be run at the predetermined speed and load points during the test as per Annexure-IV. The optimization will be done under the identical conditions and combination of components. The engine will be loaded by hydraulic dynamometer controlled by AVL test commander. For calculation of corrected horsepower and brake specific fuel consumption, ALCO formula will be used. The performance parameters will be recorded in direction of descending order of load and speed.

15.3 The Tenderer in consultation with RDSO shall draw up the optimization programme.The detail of data acquisition system of the test bed is at Annexure-V.

15.4 Performance Tests on RDSO Engine Test Beds shall be carried out for a period of two months **(tentative)** after complete assembly. **The costs of use of RDSO facility for the tests would be overall charged to the internal project costs of RDSO. However use of RDSO test facility would be available free of cost to the successful tenderer after placement of**

purchase order for carrying out the required tests at Engine Development Directorate. Cost of fuel during in-house testing is to be borne by RDSO for self projects including the present case.

16.0 Performance Tests on Locomotive-

16.1 After the validation of the system performance on ALCO engine test bed at Engine Development Directorate, RDSO, the system would be fitted on ALCO-DLW diesel locomotive by the supplier.

16.2 After proving out the functional requirement on the locomotive, its performance regarding maintainability and reliability under field conditions would be jointly monitored by RDSO and the manufacturer for one year. All problems noticed during this period be logged and a satisfactory solution found.

17.0 Confidentiality of Test Results-

All data that is generated as a result of testing of the natural gas/ pilot diesel fuel injection system on the engine and/or the test rigs by Indian Railways shall automatically become the sole property of RDSO. No part of such information shall be disclosed to any third party without prior written consent of RDSO, Ministry of Railways.

18.0 Training and Inspection-

18.1 The Tenderer shall be willing to train IR personnel for short and long trainings in the new technology at his premises without any additional cost for 750 mandays. **(One person for eight hours per day working is one man day. These 750mandays shall be calculated based on calculation between number of men and number of days being trained).** The training schedule of the IR officials will be advised to the Tenderer. Expenses for travel to the Tenderers premises, boarding and lodging of the IR personnel shall be borne by IR**.**

18.2 The tenderer shall indicate for each equipment the relevant specification to which the equipment shall be type tested. If the tenderer is not prepared to conduct any type test of particular equipment for any reason, it shall be clearly brought out.

18.3 The test programme shall be drawn up by the Tenderer in consultation with RDSO. Type tests of all equipment shall be carried out by the manufacturer at his own responsibility and cost, and in his premises, in the presence of a representative of EDD/RDSO. Such tests may include laboratory/ bench tests for the validation of design of major components.

18.4 The Tenderer shall formulate and submit an inspection and routine/ acceptance test protocol for the approval of RDSO before undertaking manufacture.

19.0 Warranty-

The supplier shall guarantee that the supplied system will be free from all defects in material, workmanship, and manufacture. The supplier shall, at his expense, replace any part of the system

failing or proving unsatisfactory in service, due to any reason whatsoever, within a period of 24 months from the date of it's commissioning into service in the locomotive.

As regards Warranty during the durability tests to identify the failure modes and debugging of the design warranty shall not be applicable for various iterations.

The supplier must effect the replacement under the warranty within 90 days of the failure and the warranty shall stand extended, by the period that is taken to effect replacement.

20.0 Credentials of the Firm's Desirous of Participating in the Tender-

Following are the expected credentials of the firms desirous of participating in the tender

20.1 The firm and/or its partners should be in the line of design, development and manufacture of the direct gas/ pilot diesel fuel systems for at least past five years. The firm itself must possess this qualification. Representation on behalf of a reputed manufacturer or designer/consultant will not be sufficient. This inter-alia means the interested firm should have the requisite expertise in the design and development of the offered fuel injection systems or its manufacturing or both. It can tie-up with complimentary firm(s) to offer the design, development, manufacturing, proto-testing, field proving and freezing of specification as turn-key solution.

20.2 The firm should have necessary expertise in the following areas : -

a) Design of the various elements of the gas/ pilot diesel fuel system as given in the Scope of the project above.
b) Have sufficient manufacturing, programming, integration and troubleshooting capabilities for hardware and software production
c) Should have designed and developed similar fuel system for large diesel engines of similar or higher per cylinder horsepower rating.
d) Should be willing to support the IR program for the development of the gas & pilot diesel fuel systems for the ALCO engine through all steps as mentioned above.
e) The firm should not have been indicted by any court of law or any regulatory body or any state/central government agency in India or abroad.
f) Should be of sound financial standing.

------x-----

Annexure-I

ENGINE DATA – 16 CYLINDERS DLW built 251-B ALCO engine

1.	Application	Rail traction diesel (Indian Railways, Broad gauge) 3100 HP
2.	Engine type	DLW built 251-B engine
3.	No. of cylinders	16
4.	Configuration	'V'
5.	Cycle	4 stroke
6.	Bore	9"(228.6 mm)
7.	Stroke	10.5"(266.7mm)
8.	Compression ratio	11.75:1
9.	Ratio of con rod length to crank radius	4
10.	Fuel injection (at full load)	
	Spill port closing	22.0 degree CA BTDC
	Duration of injection	Approx.34 degree CA
	Pumps	17 mm plunger dia, 20mm stroke
	Nozzles	0.35 mm dia. 9 holes, 157-degree spray angle, 90-degree tip angle.
11.	Firing order	1R 1L, 4R 4L, 7R 7L ,6R 6L, 8R 8L, 5R 5L, 2R 2L, 3R 3L
12.	Valves (4 valve head) Air inlet open	80.1 degrees CA before TDC
	Air inlet close	35.4 degrees CA after BDC
	Exhaust open	57.7 degrees CA before BDC
	Exhaust close	57.7 degrees CA after TDC
	Valve dia	7.62 cm
	Max. valve lift	2.04 cm
	Port diameter	7.40 cm
13.	Turbocharger	One per engine
14.	After cooler	Single, water-cooled.

Annexure-II

ENGINE PERFORMANCE DATA AT FULL LOAD- 16 CYLINDERS DLW built 251-B engine

1.	Brake horse Power	3100HP
2.	Engine speed	1050 rpm
3.	BMEP	14.25 bar approx.
4.	BSFC (Corrected 60ºF/15.55ºC)	154 gm/BHP hr
5.	Turbo inlet temperature	485ºC (approx.)
6.	Average cylinder head exhaust temperature	350ºC (approx.)
7.	Max. Ambient temp. Expected	55ºc
8.	Specific air consumption	4.5 kg/sec.approx
9.	Compressor outlet pressor	1.60 bar-g approx
10	Pressure drop across after cooler	0.1 bar approx.
11	Inlet manifold pressure (engine air gallery)	1.55 bar approx.
12	Exhaust pressure before turbine	1000 mm of Hg approx
13	Turbine outlet pressure (Exhaust)	440 mm H2O g approx. on engine test bed
14	Maximum cylinder pressure	1800 psi.

NOTE: These figures are indicative and can be used only for approximate guidance

Annexure-III

TYPICAL INDIAN RAILWAY OPERATING DUTY CYCLE FOR DIESEL LOCOMOTIVES

NOTCH	FREIGHT SERVICE %	PASSENGER SERVICE %
Idle	60	49
1st	3	6
2nd	5	7
3rd	3	5
4th	4	4
5th	4	7
6th	5	5
7th	6	5
8th	10	12

Extracted from RDSO report no.-MP-Misc. – 204, Feb. - 2008

Annexure-IV

OPERATING POINT AT VARIOUS NOTCHES FOR ALCO 251B ENGINE

NOTCH		3100 HP	
	RPM	LOAD (N)	POWER (HP)
8 th	1050±3	21600±50	3100
7th	950±3	19082±50	2500
6th	850±3	16018±50	1870
5th	750±3	13826±50	1430
4th	650±3	10616±50	950
3rd	550±3	8138±50	615
2nd	450±3	5471±50	330
1st	350±3	2984±50	145
Idle	350±3	2131±50	105

Annexure-V

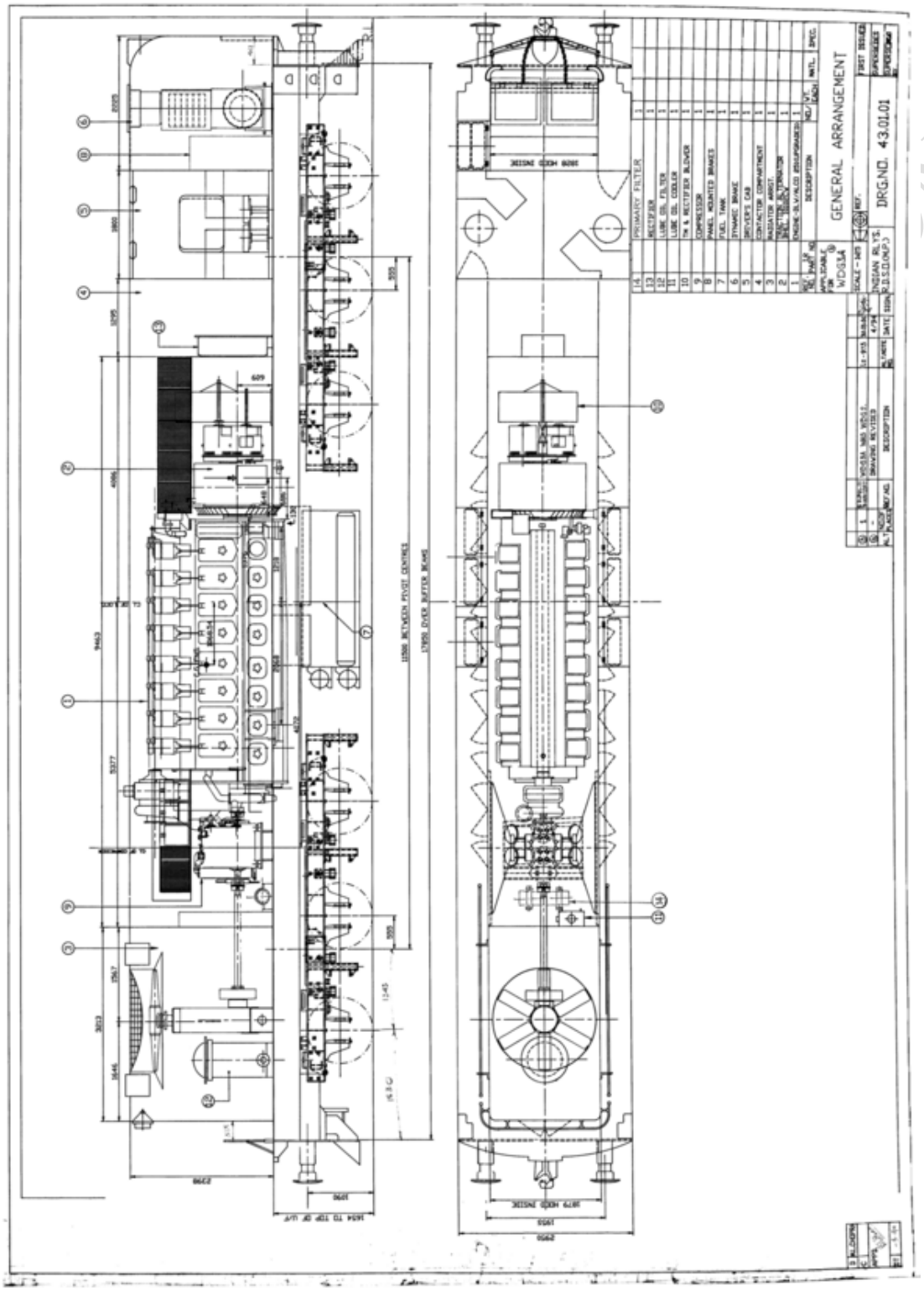
DATA ACQUISITION SYSTEM OF TEST BED

(a) AVL test commander, capable of real time measurements on 176 channels, controls the engine. The test commander controls the dynamometer coupled to the diesel engine. Different parameters like speed, load, torque, power, temperature and pressure at various critical location of engine are measured and recorded. The test commander operates on "Window NT" operating system with "PUMA 5" engine monitoring and testing software.

(b) The high-speed data acquisition system (HSDA) of M/s AVL is used to measure online high-speed parameters of engine such as Cylinder pressure, Fuel line pressure, Injector needle lift etc.

(c) AVL frequency based fuel balance measures the online Brake Specific Fuel Consumption and rate of fuel flow. Fuel leak-off is measured separately. The rate of leak off amount is subtracted from the rate of fuel flow to get the exact consumption of fuel.

Annexure-VI



Annexure-VII

RESPONSIBILITY, APPROVAL, SUPPORT, INFORM, CONSULT (RASIC) MATRIX

1. Successful Tenderer
    - Engine Design activities as required
    - Combustion Research and system development as required
    - Injector design and optimisation & Final design of Injectors and the systems
    - Single cylinder research or in-house testing
    - Control system design, development and optimisation (in conjunction with control systems supplier) This should include but not limited to the design and development of the diesel ECU, the gas ECU and the communication between the two ECUs. The interfacing of the gas and the diesel ECUs to the Engine Test Commander and to the Locomotive traction control computer shall also be responsibility of the successful tenderer.
    - Support RDSO in full engine research and test bed trials at RDSO
    - Support RDSO in the locomotive fitment program and to fit it on a diesel locomotive and demonstrate the performance, and reliability
    - Complete systems engineering
    - Supply, installation and commissioning and prove-out of the scoped supply on the engine development test bed and on the diesel locomotive of Indian Railways
    - Overall responsibility for the deliverables
    - Any other activity or material considered essential for the completeness of the project
2. RDSO
    - Providing support to the successful tenderer for providing engine and locomotive information including drawings, specifications etc. on signing of a non-disclosure agreement subsequent to Purchase Order placement..
    - Upgradation of the Test Bed in respect of the infrastructure facilities as may be required.
    - Full test bed trials
    - Complete optimisation with guidance and support from the tenderer
    - Fitment on locomotive and proving out [All of the above with the support of the successful tenderer]