Retrofitting and feasibility (technical and legal considerations) of a LNG-powered port locomotive in Tarragona

Deliverable D3.4

Autoritat Portuària de Tarragona

CORE LNGas hive

Core Network Corridors and Liquefied Natural Gas

2014-EU-TM-0732-S

D3.4– Retrofitting and feasibility (technical and legal considerations) of a LNG-powered port locomotive in Tarragona

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More Information

Public CORE LNGas HIVE reports and additional information related with the project execution and results are available through CORE LNGas Hive public website at **www.corelngashive.eu**

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1. Report summary

Sub-activity number and name:	EV3 – Port locomotive powered by LNG (Tarragona)
Report Author:	Autoritat Portuària de Tarragona
Report date:	December 2017

Table 1 Report summary.

1.1. Objectives from sub-activity and achieved results

The objectives of this sub-activity and the results obtained can be summarized in the following tables:

General objective (as per Grant Agreement)
Retrofitting of the railway manoeuvring services in Tarragona.

Table 2 General objective.

Objective within the CORE LNGas hive Project
Feasibility study to gasify the railway transport services in the Port of Tarragona.

Table 3 Objective within the CORE LNGas hive project.

Specific objectives	Progress towards achieving the objective
The objective of the first part of the study was to evaluate the technical, legal and financial feasibility of the implementation of LNG (Liquefied Natural Gas) in railway traction within the domains of the port (manoeuvring locomotives) to prepare the way towards the introduction of a more sustainable alternative to current	This study is already finished. The main results are shown below: ▪ **Technical** and **legal** barriers have been identified, as well as the solution to overcome them: ▪ *Technical:* Non- standardized availability of LNG engines in the market.

diesel technology, due to increasingly stringent environmental regulations.	▪ *Legal:* A process of accreditation of the rolling stock is needed because LNG is not considered as a fuel in the railway field at present time. ▪ **Economic feasibility** and **Environmental** impact of the railway manoeuvring service gasification of Tarragona's Port: ▪ *Economic:* The profitability has been calculated for the railway operator, for the gas agent and for the whole project. This profitability has been calculated for a baseline scenario and a sensitivity analysis has been carried out according to the key variables identified. Despite not presenting an economic feasibility, the Autoritat Portuària de Tarragona could favour possible scenarios that, in the face of an increase in the cost of diesel (to an approximate value of 0.800€/l), would involve paybacks lower than 13-14 years for the railway operator. ▪ *Environmental*: Accumulated reduction in 30 years of 551.2 tons of CO_2, 14 tons of NOx and 480.0 kg of PM and a saving of 3.451€ from the internalization of CO_2 emissions. ▪ **Recommendations** for the gasification of railway manoeuvring services.
The second part of the study is based on the realization of a transformation study considering all the technical modifications necessary to convert diesel locomotives for manoeuvring to LNG. The results of the feasibility analysis obtained in the first phase will feed this second part of the study, **which will detail all the steps to be carried out for the**	This study is already finished. Below are the main results obtained, grouped according to the three study categories considered: ▪ **Engineering:** the technical requirements and the technical characteristics of the engine and tanks that would be implemented have been defined, as well as their impact on different areas:

transformation of the locomotive with the aim of a possible future implementation of the necessary processes identified in a pilot test.	▪ Weight distribution and gravity centre of the vehicle. ▪ Maintenance plans. ▪ Training plan. ▪ Necessary tests for its start-up. ▪ **Integration:** an analysis has been carried out to define the necessary work to be done by an integrator to replace the diesel-powered system with a new one with LNG in the current locomotive. ▪ **Validation:** In the case of a pilot test, the methodology and data to be recorded during a future monitoring have been defined to evaluate the modified locomotive.

Table 4 Specific objectives and progress towards achieving the target.

1.2. Deviations from work schedule

Cause and description[1]	Corrective action(s)[2]
No deviations observed.	No corrective actions considered.

Table 5 Deviations from work schedule.

[1] List any deviation from plan including a brief description of the reasons
[2] Corrective action undertaken or envisaged by the project to overcome the issue with the impact in terms of delays, quality and quantity of work

1.3. Risks or problems anticipated

Typology[3]	Problem description	Actions foreseen
T	The **LNG engine** for the railway traction is still not normalized in the market (not available in catalogue). Supply time and costs are much higher.	Reach out to engine providers to get to know their interest in the project and to sample their predisposition in order to adapt their products in catalogue to specific requirements.
R	Need for an **accreditation process** (in which an independent certifying body performs an evaluation process and a risk analysis upon the modification) in order to grant the Authorization of Circulation by Adif and AESF (in the event of the railway infrastructure is owned by the administrator). So far LNG is not considered as regular fuel within railway field hence it is necessary to elaborate the documentation with no framework of reference in relation to gas field.	The accreditation cost is significantly high when only converting the first unit. This fact leads to enhance and promote the necessity to elaborate a framework of reference in order to assess the conformity of the LNG security as railway fuel. For this reason, a monitoring process will be carried out on the updates and breakthroughs about the LNG use within rail passenger field project that will contribute to significant progress in this matter.
T	The energy density of the LNG is the 60% of the gasoil's, hence it **will require more quantity of stored liquid fuel to obtain the same amount of energy** and, therefore, to maintain the same range of the original locomotive. The capacity and the	The configuration is selected considering both variables: optimizing the available space and choosing the deposits in the catalogue that maximize the capacity. In case the range is considered as insufficient, it is proposed to complement these

[3] **T** for technical, **C** for Commercial and **R** for Regulatory.

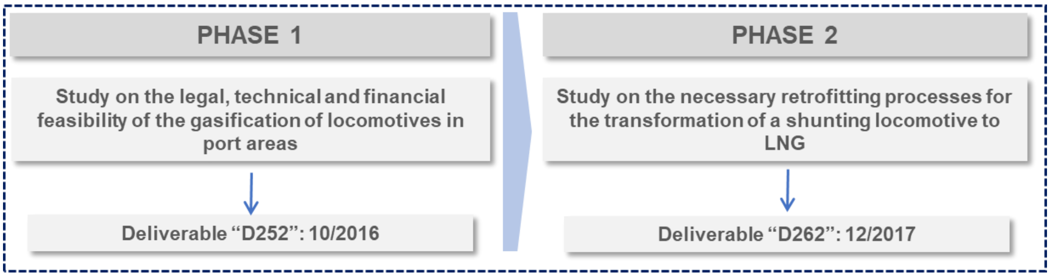
	configuration of the LNG deposits come limited by the manufacturer and the available space to locate the gas tanks into the locomotive. This fact supposes that the range could be affected if the available space is not enough.	tanks with the installation of a set of additional deposits onto the engine cover.

Table 6 Risks or problems anticipated

2. Structure activity EV3

The Port of Tarragona, as a partner of the CORE-LNGas hive project, envisages the possibility to gasify the railway services in the part area. Thus, it is considered as necessary the implementation of the feasibility study describing all the required processes for the integration of technological solutions, with the aim of establishing the basis for its materialization in a forthcoming pilot test.

To achieve this objective, the study has been structured in two phases with the following sub-objectives:



Phase 1 "Study on the legal, technical and financial feasibility of the gasification of locomotives in port areas"

- Characterization of the railway agents, the rolling stock, the rail infrastructure and the railway services in the Port of Tarragona.
- Analysis of the technical, legal and financial feasibility of the transformation, and quantification of the environmental impact.
- Conclusions and recommendations to materialize the gasification of the railway services in the Port of Tarragona.

Phase 2 "Study on the necessary retrofitting processes for the transformation of a shunting locomotive to LNG"

- Detailed analysis of the technological solutions (engine and deposit) planned for the feasibility analysis.
- Engineering study to define the integration process of the new elements (engine, tank, connections of the components, tests).
- Definition of the required aspects related to the technological integration and the monitoring necessities to conduct during the pilot test.

3. Introduction to the study conducted: Phase 1

The aim of this study is to conclude on the technical, legal and economic feasibility of implementing LNG in railway traction (shunting locomotives) within the port domain of Tarragona and to define the steps to be followed in order to carry out the transformation.

The project has been developed in four phases which goals have been set up in order to be fulfilled along the assessment.

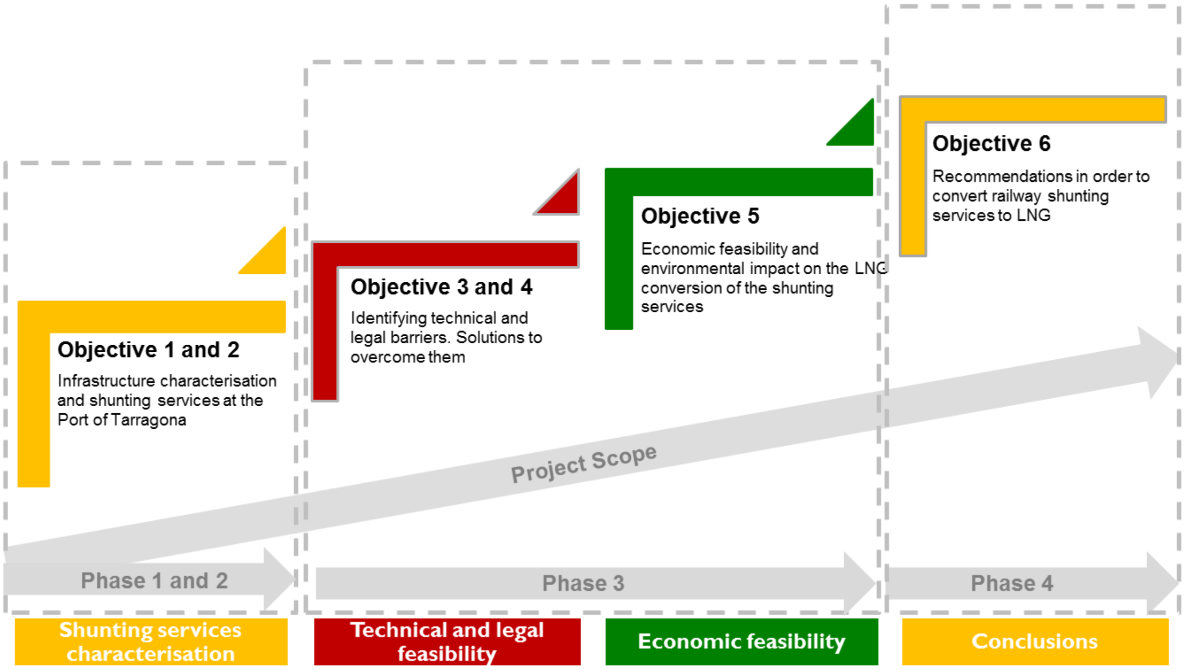


Figure 1. Project development process. Source: Institut Cerdà (2015).

In the figure above is represented the set-up for the assessment. Every stage is described subsequently:

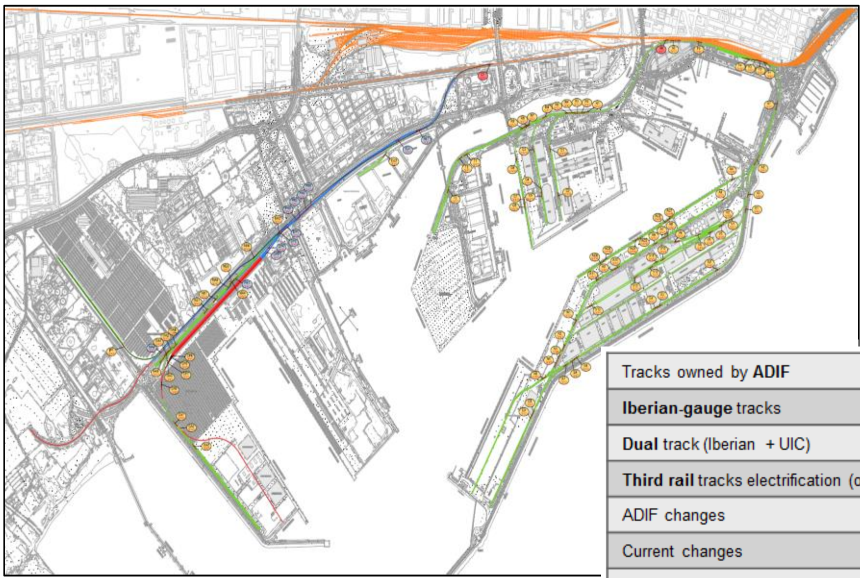
- In the **first phase**, the infrastructure and the current shunting services have been characterised within the Port of Tarragona premises. This enables to profoundly know the state, characteristics and particularities of the infrastructure as well as the shunting services in which the project is carried out.
- In the **second phase**, legal and technical barriers that could affect the project development have been pointed out. Afterwards, a solution for those barriers has been presented in order be able to overcome them.
- In the **third phase** a study of economic feasibility has been carried out considering the agents involved on its exploitation. Moreover, the environmental impact due to gasification of the railway transport services by Liquefied Natural Gas (from now on named as LNG) has been quantified.
- Finally, in the **fourth phase**, the final conclusions on the results obtained throughout the study, as well as the recommendations and the following steps are presented.

4. The shunting railway services at the Port of Tarragona

4.1. Characterisation of the railway network of Port of Tarragona

The railway network in the Port of Tarragona is mostly non-electrified, therefore the operating locomotives use a traction system which is not based on an overhead catenary, leaving **diesel as the sole fuel source** possible. However, part of this network is currently adopting the electrical system in some sections.

The Port of Tarragona – hereinafter PAT- is interested in exploring alternatives which could help to lower the current emissions and to be more environmentally friendly. This alternative is the adoption of LNG as a locomotive fuel.



Tracks owned by **ADIF**	---
Iberian-gauge tracks	39.972 m
Dual track (Iberian + UIC)	4.326 m
Third rail tracks electrification (ongoing)	10.820 m
ADIF changes	3 units
Current changes	95 units
Expected changes	6 units
Track maximum **gradient**	11-12‰ (El Serrallo).
Configuration maximum **load**	1600 Tn
Configuration maximum **length**	750 m

Figure 2. Railfreight network at the Port of Tarragona. Source: Institut Cerdà (2015)

As it is observed in the figure 2, different gauges are present in the Port. Spanish track width coexist with the international track width. Besides, it is showed how the internal railway network of the Port of Tarragona is connected to the Adif railway network through the tracks that are in process of electrification.

4.2. Diesel supply facilities

In the Port of Tarragona there is a sole diesel supply point located in the classification zone. This point consists of a small esplanade where the tank trucks park (since there is a mobile supply point).

Figure 3. Supply point location. Source: Institut Cerdà (2015).

In the picture above, it is shown the esplanade in the classification zone which is located within the Port of Tarragona premises. This area might be the appropriate sector to locate the LNG supply point.

4.3. Current locomotives fleet

The PAT has currently four locomotives that belong to Adif in order to manoeuvre throughout the Port of Tarragona. These locomotives emanate from different series. Three of them originate from 311 series which are simultaneously operating and the other one originates from 310 series which is available in case one of the first mentioned locomotives is in repair and/or maintenance.

311 series:

As it was mentioned before, the PAT has three series of this model. Its technical specifications are shown in the following table:

ENGINE AND PERFORMANCE:	BRAKING SYSTEM:
Engine: 4T Diesel MTU V8 396TC 13 (supercharged) **Nominal power:** 1.065 CV / 785 kW **Maximum velocity:** 92 km/h **High revs range:** 1.800 r.p.m **Low revs range:** 600 r.p.m **Number of traction engines:** 4 electric three-phase motors Siemens (1 per axle)	**- Brake type:** compressed air **- Brake system:** automatic brake pipe pressure **- Brake control:** • Service brake • Direct brake (isolated system) • Electric brake (regulator "F + ") • Distress brake (four-ways valve) • Emergency brake • Parking brake (switch)
DIMENSION AND OTHERS:	**SECURITY SYSTEMS:**
Distance between buffer centrelines: 14.200 mm **Service weight:** 80 t **Track gauge:** 1.668 mm **Shaft arrangements (UIC):** Bo'Bo' **Tank capacity:** 2.200 litres	**Security system:** ASFA and monitoring device (dead man). The ASFA or the monitoring device operation leads to: • Maximum emergency stop in the train and locomotive. • Suppression of the pulling tension. • Suppression of the feeding into the automatic brake pipe.

Table 7 Locomotive specifications 311. Source: Institut Cerdà (2015)

310 series:

There is a single locomotive of this series allocated in the Port of Tarragona facilities. This is used in case of other locomotives are in repair or maintenance. Its specifications are as follows:

ENGINE AND PERFORMANCE:	BRAKING SYSTEM:
Engine: 2T Diesel GM 8-645-E (atmospheric) **Nominal power:** 930 CV / 684 kW. **Maximum velocity:** 114 km/h **High revs range:** 900 r.p.m. **Number of traction engines:** 4 electric motors D29 (1 per axle)	**Brake type:** compressed air **Brake system:** automatic brake pipe **Brake control:** • Service brake TFA (train and locomotive) • Direct brake (independent brake of the locomotive) • Distress brake (four-ways valve) • Emergency brake • Parking brake (chained)
DIMENSION AND OTHERS:	**SECURITY SYSTEM:**
Distance between buffer centrelines: 12.550 mm **Service weight:** 78 t **Track gauge:** 1.668 mm **Shaft arrangements (UIC):** Bo'Bo' **Tank capacity:** 2.770 litres	**Security system:** ASFA and monitoring device (dead man). ASFA or the monitoring device operation leads to: • Maximum emergency stop at the train and locomotive • Suppression of the pulling tension • Suppression of the feeding into the automatic brake pipe.

Table 8 Locomotive specifications 310. Source: Institut Cerdà (2015)

4.4. Map of actors

Due to the dimension of the project, a massive number of agents and organizations are involved. In order to represent them all and to get to know their influences upon the study, a schematic tree was performed as follows:

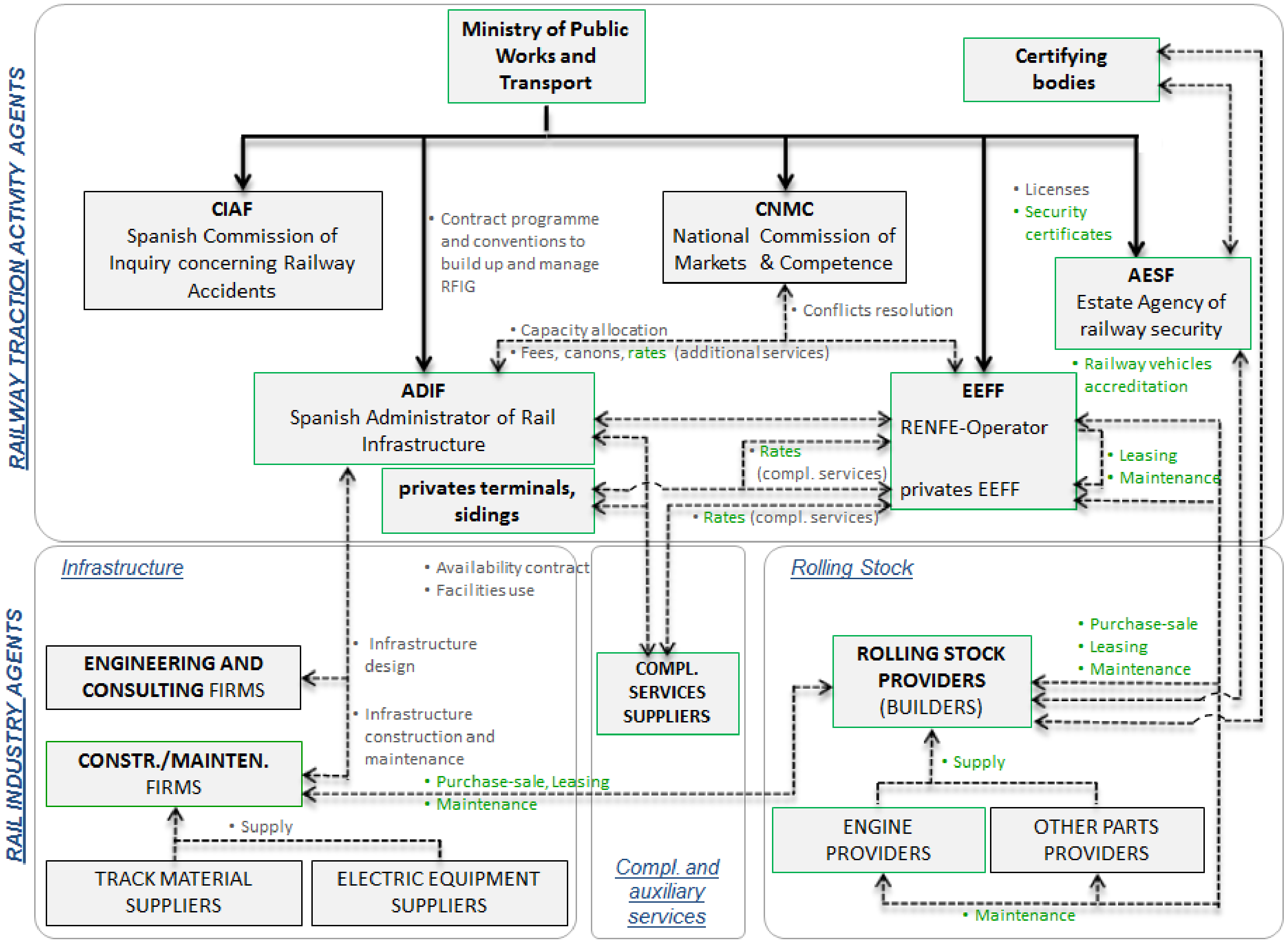


Figure 4. Map of actors. Source: Institut Cerdà (2015)

As it is seen in the above chart, at least 14 types of actors are involved and distinctly related to different sort of aspects. This chart permits to discern between the agents related to the infrastructure and the complementary and auxiliary agents related to the rolling stock, all of them within the railway transport agents.

The **potential drivers concerned by the LNG implementation** to propel the railway transport services are:

- Rolling stock providers/constructors/integrators:
    - **Rolling stock integrators/manufacturers.**
    - **Engine providers.**
    - **Cryogenic tank providers.**
- Rolling stock owners/users:
    - **EEFF: trade services.**
    - **ADIF: Inspection and maintenance tasks.**
    - **Autoritat Portuària de Tarragona.**
- **Companies providing the additional service**: mostly in charge of fuel supply.
- The **Ministry of Public Works and Transport/AESF** (State Agency of Railway Security) which function is to authorize the market entry of the structural sub-systems which form the railway system, as well as proving that all requirements are satisfied.

4.5. Agents characterisation

A general overview of the agents involved and their respective interests are shown in detail hereunder:

4.5.1 Agents

As it was observed, in the former chart multiple sorts of agents take part on the study of LNG commissioning at the Port of Tarragona. Right after a detailed explanation about their individual features and specific role within the project will be presented:

Ministry of Public Works and Transport (AESF):

This institution takes over the authorization in order to place into service the structural sub-systems and proves that all requirements are widely fulfilled. Alternatively, this is in charge of development and supervision of the security normative framework, as well as of developing proposals and technical specifications for further guidance. Finally, the Ministry has competences to deal with the rail dangerous goods transport.

Certification bodies:

In the following group the actors that carry out certification work for the brand new rolling stock are presented. In accordance to their specific features these bodies are displayed hereafter:

- ✓ *Notified Bodies:*
  In charge of the CE verification procedure that are used in order to assess conformity or suitability for use of the interoperability components. In this report, the company named as Cetren was consulted for this matter.

- ✓ *Designated Bodies:*
  These are in charge of the sub-system's verification procedure in terms of national rules. Belgorail, Cetren, ECA Bureau Veritas and Lloyds Register Spain will be the elected organism whose designation scope will be over the rolling stock.

Adif:

This public institution attached to the Ministry of Development through the Secretary General of Infrastructure is charged on the administration, monitoring and inspection of the railway infrastructure, as well as the operation of its assets.

On the other hand, Adif also takes part on the realization and publication of the Network Statement, under the terms provided by LSF and under its developing rules. It is also responsible of issuing the Infrastructure's Capacity to the EEFF and to the other stakeholders. Plus, Adif takes on the role to issue reports before granting by the Ministry of Development of EF licenses and the authorization to serve public interest services.

Finally, Adif is in charge of approving basic projects and construction of railway infrastructures that should constitute the RFIG alongside constructions of railway infrastructures using the resources of the rule of law.

Railway companies:

Railway companies themselves are committed to the railway transport services operations. Nevertheless, an EF valid license and a security certification must be redeemed to enable them to run through the General Interest Rail Network (RFIG).

It should be underlined that only the Renfe-Operator disposes of license for the rail passenger transport. The rest of EEFF possess the EF license to rail freight transport. In the following figure, a catalogue of companies that count with the license mentioned above are presented:

Empresas Ferroviarias con Licencia sin Certificado de Seguridad

- EUSKO TRENBIDEAK FERROCARRILES VASCOS S.A. (Mercancías)
- ARCELORMITTAL SIDERAIL, S.A. (Mercancías)
- FESUR, FERROCARRILES DEL SUROESTE S.A. (Mercancías)
- FGC MOBILITAT S.A. (Mercancías)
- LOGIBÉRICA RAIL, S.A.U. (Mercancías)
- MONBUS RAIL, S.A. (Mercancías)
- ASTURMASA RAIL, S.A.U. (Mercancías)
- ARRAMELE SIGLO XXI, S.A. (Mercancías)
- AVANZA TREN, S.A.U. (Viajeros)
- VECTALIA RAIL, S.A. (Viajeros)
- LA SEPULVEDANA, S.A.U. (Viajeros y Mercancías)
- TRAMESA, TRANSPORTES MIXTOS ESPECIALES S.A. (Mercancías)
- IBERRAIL SPANISH RAILROADS S.A.U (Viajeros)
- EMPRESA DE BLAS Y CIA, S.A.U. (Viajeros)
- MOVENTIS RAIL, S.A.U. (Viajeros)

Empresas Ferroviarias con Licencia y Certificado de Seguridad

- RENFE- VIAJEROS, S.A.U. (Viajeros)
- RENFE- MERCANCÍAS, S.A.U. (Mercancías)
- COMSA RAIL TRANSPORT, S.A. (Viajeros y Mercancías)
- CONTINENTAL RAIL, S.A. (Viajeros y Mercancías)
- ACCIONA RAIL SERVICES, S.A.U. (Viajeros y Mercancías)
- TRANSFESA RAIL, S.A.U. (Mercancías)
- TRACCIÓN RAIL, S.A. (Mercancías)
- LOGITREN FERROVIARIA, S.A. (Mercancías)
- ALSA FERROCARRIL S.A.U. (Viajeros y Mercancías)
- GUINOVART RAIL S.A. (Mercancías)
- FERROVIAL RAILWAY, S.A. (Viajeros y Mercancías)
- TRANSITIA RAIL, S.A. (Viajeros y Mercancías)
- VELOI RAIL, S.A. (Viajeros)
- INTERBUS INTERURBANA DE AUTOBUSES, S.A. (Viajeros y Mercancías)
- ECO RAIL, S.A.U. (Viajeros y Mercancías)
- AISA TREN S.A.U. (Viajeros)

Figure 5. Railway companies licensed. Source: Adif (2015).

Port of Tarragona:

Its role consists on managing the Port of Tarragona. It should be highlighted that the ownership of rail infrastructure within the Port of Tarragona belongs to the Autoritat Portuària de Tarragona (PAT) and that shunting manoeuvres are commissioned by Adif (staff and fleet).

In addition, PAT has competences upon the capacity judgments to and from the Port of Tarragona and alongside Adif is stablished the time-slots of circulation to and from the Port and the Adif classification zone in Tarragona.

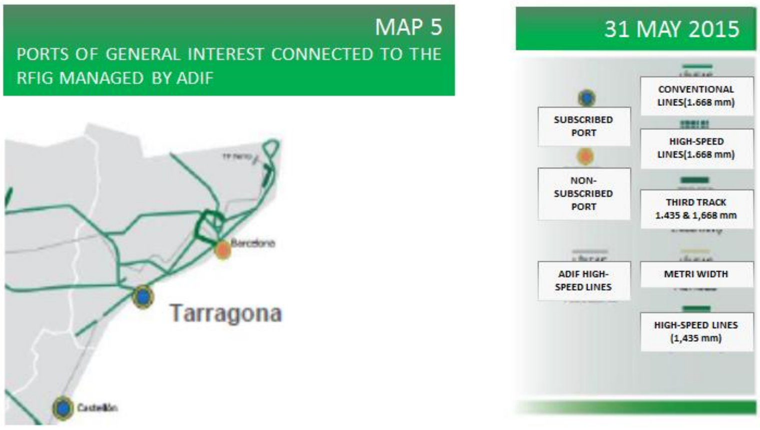


Figure 6. Ports connected to RFIG network managed by Adif. Source: Adif (2015).

Ancillary services companies:

These companies take on for instance fuel supply processes. In the Port of Tarragona, Adif serves the provisioning services by means of an unconditional tender to a specialized company.

Figure 7. Fuel supply point and logistical and technical facilities. Source: Adif (2015).

4.5.2 Agent interests

Once the map of agents has been presented, the wide-range of interests for each of them is listed below. These interests might be gathered according to the **key elements that will determine the technical, economical and legal feasibility of the solution**:

- Owners/users of rolling stock (*Adif, Port of Tarragona*):
    - **Power:** the power should be suffice in order to carry out the rail manoeuvres.
    - **Autonomy:** the new/converted rolling stock and the provisioning logistics should provide enough autonomy.
    - **Cost:** the environmental cost (external costs internalization) and the fuel consumption that should offset the cost of the transformed engine/purchase of a new engine/tank.
- Providers/constructors/integrators of the rolling stock, engines and cryogenic tanks:
    - **Technical feasibility:** the solution should be technically suitable (construction, transformation, integration) with the available locomotives.
    - **Solution expenses versus availability of payment across the clients.**
- Additional companies providing services (provision of LNG):
    - **Return on investment of the LNG supply facilities**.
    - **Viability of upgrading**.
- Ministry of Public Works and Transport:
    - **Security standards**: they should comply with the actual legal framework.

These elements will highlight the competitive values of the LNG and the barriers to changes.

5. Likely technical and legal barriers to gasify the shunting services

There are three phases to adopt LNG as an alternative fuel. These are as follows:

- Phase 1: **Technological adaptation** for the LNG traction.
- Phase 2**: Design and implementation of the supply points** (LNG).
- Phase 3: **Operation and maintenance**.

Certain legal and technical factors that are associated to monetary expenses and time consumption should be taken into account in order to overcome these phases. In the following chapters, likely setbacks that might run into the performance of each phase will be evaluated.

5.1. Phase 1: Technological adaptation

The adjustment to LNG propulsion into railway field implies the engine transformation/acquisition as well as a cryogenic tank, their assembling into the locomotive, commissioning accreditation and authorization of the modified rolling stock as shown in the following figure.

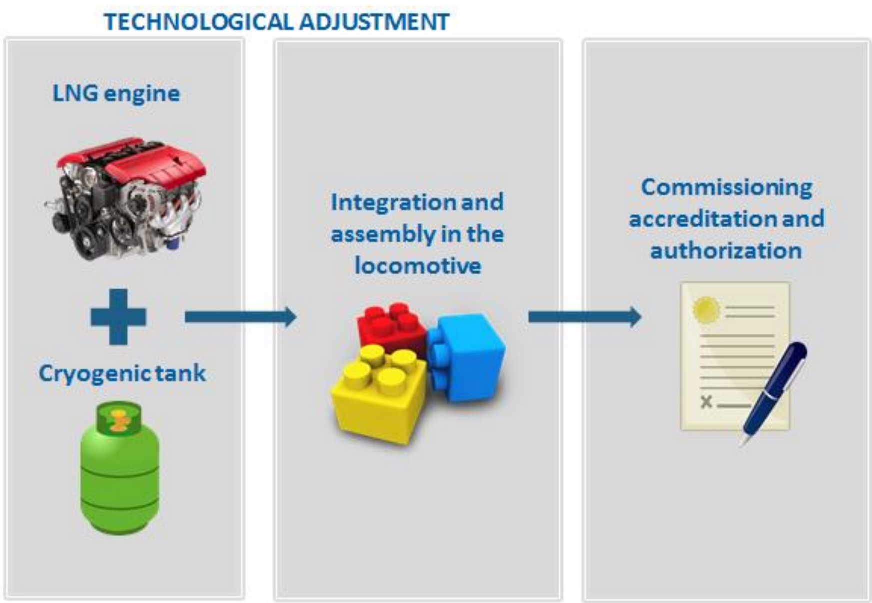


Figure 8. Phase 1: Technological adaptation process. Source: Institut Cerdà (2015).

Once the procedure is defined, the optimal solution for the project regarding cryogenic tanks and LNG engines should be identified. The process followed was the following:

1. Technological requirements identification for the engine and cryogenic tank.

Based on the input information, the engine and tank requirements have been identified The LNG solutions shall comply with these requests is order to adapt to the shunting rail services of the Port of Tarragona.

2. Contact with the main LNG engine and cryogenic tank manufacturers.

Once the requests are acknowledged, the respective contacts are stablished in order to analyse the availability of the offered solutions within the current market.

3. Optimal solutions identification.

Due to the wide range of feasible technical solutions, some of them were selected because of a greater efficiency with respect to the gasification of the shunting railway service by prioritizing price, proximity, production time and transport of the manufacturers. In total, 14 agents were contacted to obtain information about engines and LNG tanks. In particular, 6 agents were related to the engine features and 9 agents owned information about cryogenic tanks.

Thereupon, a list of contacted agents was made alongside a relevance study on how these agents turned out to be valuable regarding engine and cryogenic technical details:

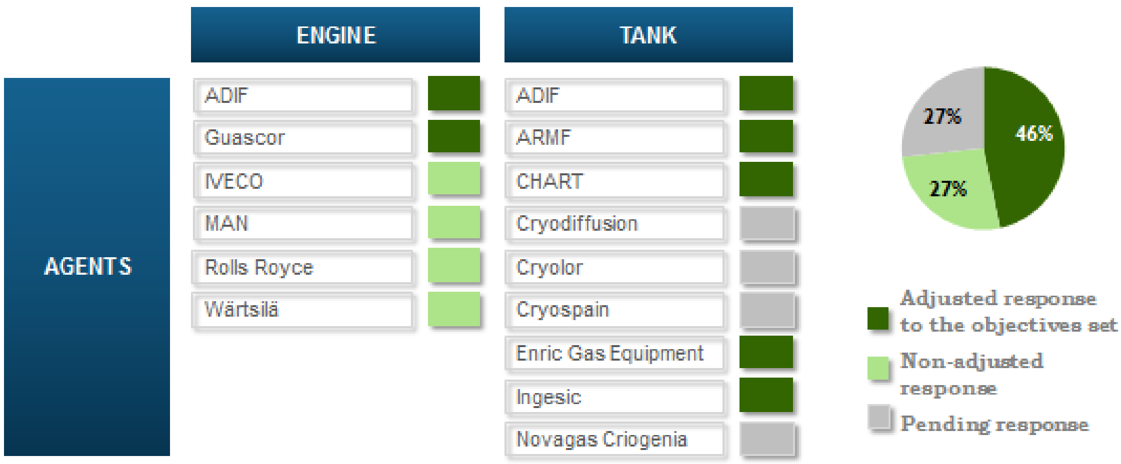


Figure 9. List of agents contacted. Source: Institut Cerdà (2015).

As it is observed, most of the agents provide more information about tanks than the engine itself. Additionally, it should be noted that regarding the information obtained, in the case of engines, only 33% of the answers met the requirements, whereas, in the case of tanks, all answers are adjusted to the requirements.

Below are shown the particularities for each of the elements mentioned before.

The LNG engine:

The engine is one of the crucial technical elements in order to succeed. Therefore the characterization of its features is primordial in order to avert the loss of efficiency in the shunting railway services when the engines are transformed to LNG.

The technical features of diesel engines that currently are running in the 311 and 310 locomotives are displayed in the following table:

Locomotive	Number of engines	Power (kW)	Maximum power revolution (rpm)	Guidance dimensions (mm)
310	1	684	900	
311	1	785	1.800	2.013 x 1.439 x 1.380

Table 9 Technical features of the engine installed in 311/310 locomotive. Source: Institut Cerdà (2015).

It turns out that the available engines are capable of supplying considerable power varying from 700 to 800 kW when they are running between 900 and 1.800 rpm. Moreover it is also observed that every locomotive has one engine that lead to a limitation of available room to implement the future LNG engine.

GUASCOR is the appointed company which adjusts closely to the abovementioned requirements in order to adopt the LNG technology. In the following table is summarized the LNG engine features:

Company	Model	Power (kW)	Maximum power revolution (rpm)	Guidance dimensions (mm)	Production expenses (€)	Productio n time (months)
GUASCOR	SFGLD 360	700	1.800	2.351 x 1.689 x 2.493	235.000 €	4-5

Table 10 LNG engine features from GUASCOR. Source: Institut Cerdà (2015).

From the analysis carried out through the contact with various engine companies, it can be seen that nowadays there are practically no products in catalogue for LNG engines in the railway sector (IVECO, MAN, Rolls Royce, Wärtsilä do not have adjustable products to be delivered for shunting railway services). The considered Guascor's model complies with all the power requirements and the rotational speed of the current diesel locomotives and its supply time is identical to a regular diesel engine (4-8 months). Dual-fuel engines were not taken into consideration since this option reduces the LNG demand.

Cryogenic tank:

The tank is the other crucial technical element for the adoption of the LNG traction. As done before, the features of the current tanks installed into the 310/311 locomotive have been studied. Their features are displayed below:

Locomotive	Number of tanks	Capacity (l)	Guidance dimensions
310	1	2.700	n.d.
311	1	2.200	n.d.

Table 11 Current tank features in 311/310 locomotives. Source: Institut Cerdà (2015).

Both locomotives have a single tank whose capacity is 2.700 litres for the 310 and 2.200 litres for the 311. Taking this numbers into account, three out of seven providers have facilitated specific data that is gathered in the next table.

Company	Model	Capacity (l)	Needed tanks for the needed capacity	Production expenses (€/ unit)	Production time (weeks)	Transport expenses (€/ unit)	Transport time (days)
CHART	HLNG 171	582	4	11.800	4-5	150 (sea) 900 (air)	30 (sea) 7-10 (air)
ENRIC GROUP	CDL-2/1.5	2.000	1	20.500	9	800 (sea)	30
INGESIC	2 m^3 17 bar	2.033	1	25.168	10	n.d.	n.d.
INGESIC	3 m^3 17 bar	2.911	1	28.435	10	n.d.	n.d.

Table 12 Available data by 7 tank providers. Source: Institut Cerdà (2015).

These three nominated companies were CHART, ENRIC GROUP and INGESIC. Considering the gathered information, all of them have cryogenic tanks that would be suitable to replace the diesel tank located in the 310/311 locomotives.

The model of ENRIC GROUP and INGESIC comply with all the needed requirements with just a single tank. Additionally, INGESIC is prompted to adapt its offer to the specific necessities of the project.

Engine and tank integration within the 310/311 locomotives:

In order to integrate the LNG engine as well as the cryogenic tank into the locomotive, two options are presented:

- **Modify one Adif's 310/311 locomotive:** approval from the National Rail Administration is needed in order to carry out this option. In this case, a specific integrator should be present (potential options: Adif, Renfe Integra/Maintenance). It is important to highlight that the integrator ARMF has demonstrated its interest in carrying out a modification with this features.
- **Speak to a locomotive provider which may be interested in introducing new locomotives in the market:** Appropriate case if the PAT wants to "internalize the shunting railway services".

Additionally, in order to make possible the integration of the engine and the tank, certain consideration must be performed:

- **LNG engine and the cryogenic tank should not suppose a superior change than +/-10% of the diesel total weight with regard to the diesel engine and tank**, in order not to affect the gravitational centre over the accepted normative.
- **Attempting to assemble the tank at its maximum possible dimensions**, to barely affect the autonomy ($V_{GNL} \approx 1{,}63\ V_{diesel}$ for an uniform amount of energy). Furthermore, the cryogenic tanks cannot be filled to a maximum level in order to be capable of absorbing the boil-off effects and in turn neither can be emptied to the minimum level to avoid the LNG overheating.

- Besides the engine and deposit previously defined, it is identified the necessity of implementing an **evaporation** kit, needed when the boil-off does not suffice and then more LNG requires to be evaporated to increase the pressure in order to power the engine. Additionally, for the integration process, it is necessary the completion of the gas **installation** to lead LNG between the deposit and the engine.

Accreditation process:

In order for the modified rolling stock to be put into service it is essential that it is accredited for the implementation of rail traction with LNG in manoeuvres in the port environment. However, this accreditation is not mandatory when this material is in a testing phase. The **accreditation** aims at **certificating security requirement compliance, technical compatibility, ensuring respect for the environment and finally reliability**. This certification should be done since the engine and the tank are the sub-systems of the mobile material and therefore could affect to the given requirements.

In the event of LNG-traction-locomotive prototype is built up, only a provisional authorization by Adif for the infrastructure under its jurisdiction will be needed to permit test realizations, trails and material transfers.

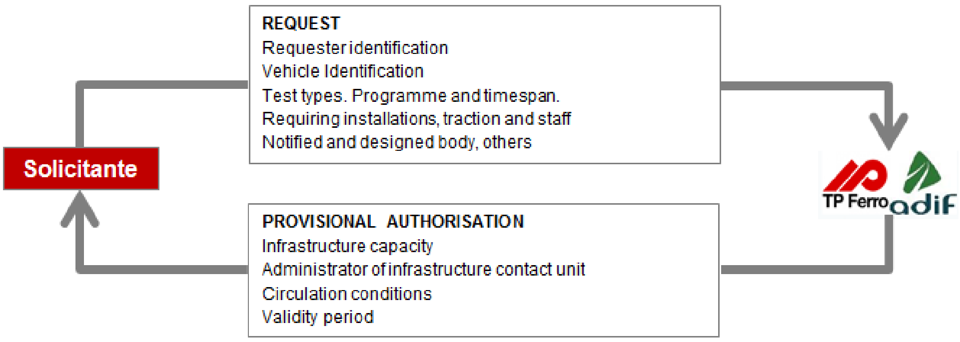


Figure 10. Accreditation process. Request and temporary authorization. Source: Institut Cerdà (2015).

In the event of a **commercial exploitation** after the implementation of the technology, the mobile material should be subjected to other sorts of accreditation. Then, the 2008/57 Regulation (ETI) and the Royal Decree 1434/2010 will be applied.

In the following figure is shown the steps to be followed in order to obtain the commissioning and the circulation authorizations are represented across:

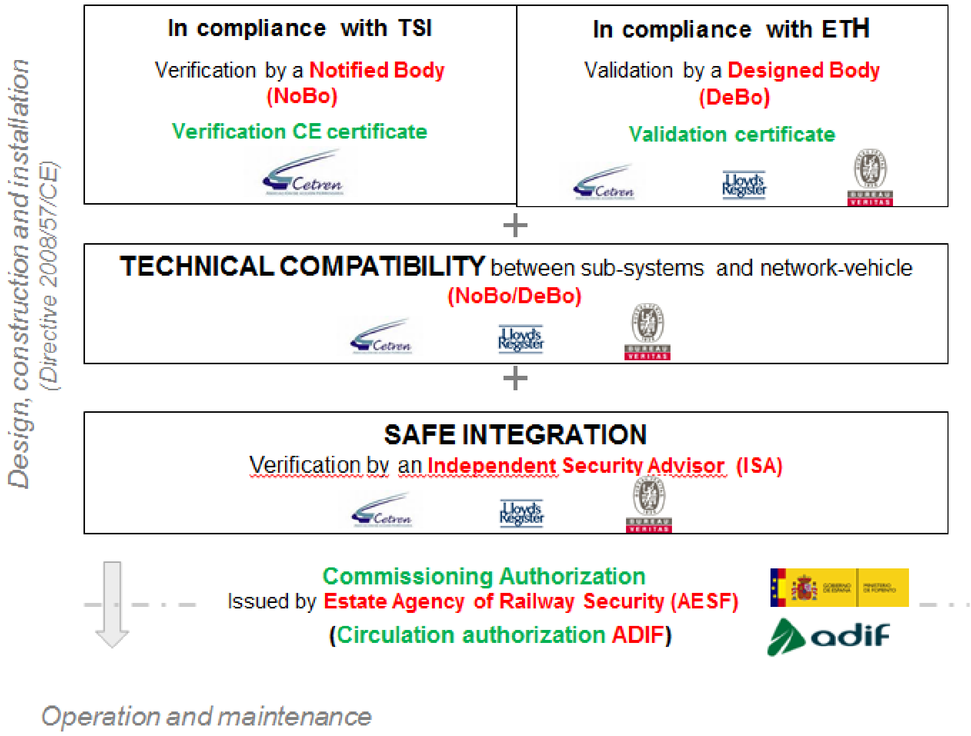


Figure 11. Accreditation process. Certification bodies are highlighted in red and the Documents issued are highlighted in green. Source: Institut Cerdà (2015).

As a first step, the material must comply with the **technical specifications** both at European level (ETI-TSI) and at national level (ETH-TSA). The European technical regulations are the ones that guarantee the interoperability of the railway system at a European level whereas the technical specifications of the type approval at a national level just refer to the mobile material and over time it becomes weaker in favour of the ETI-TSI.

The CE verification (certification ETI-TSI) is carried out against the Technical Specifications of the Interoperability in accordance to the European guidelines which are common for the member states of the EU. Each country may have its own national standards, and when it comes to Spain, must comply with the Technical Specifications of Homologation (ETH-TSA) which, simultaneously, must certify (in the case of metric width) the ETM –Spanish Technical Specification of Metric Width-.

As a whole, in order to obtain the circulation authorisation of a vehicle, the **CE verification** must be provided, as well as the certifications against the national rules (in the case of Spain, certification against ETH-TSA) of the given countries through which the material will circulate. There are certainly a number of exceptions and, additionally, this regulation is being modified at European level to optimize the rolling stock among member states, depending on current authorities of material in other countries.

Furthermore, the **technical compatibility** should be verified for the different sub-systems as well as for the vehicle and the railway network. Finally, the verification of the integration of the subsystems within the machinery is needed so that warrant a proper working of the system.

The process of accreditation of the LNG-traction engine might be simplified if the engine is assembled within a mobile material previously accredited, such as 311/310 locomotives that run throughout the shunting railway services in the Port.

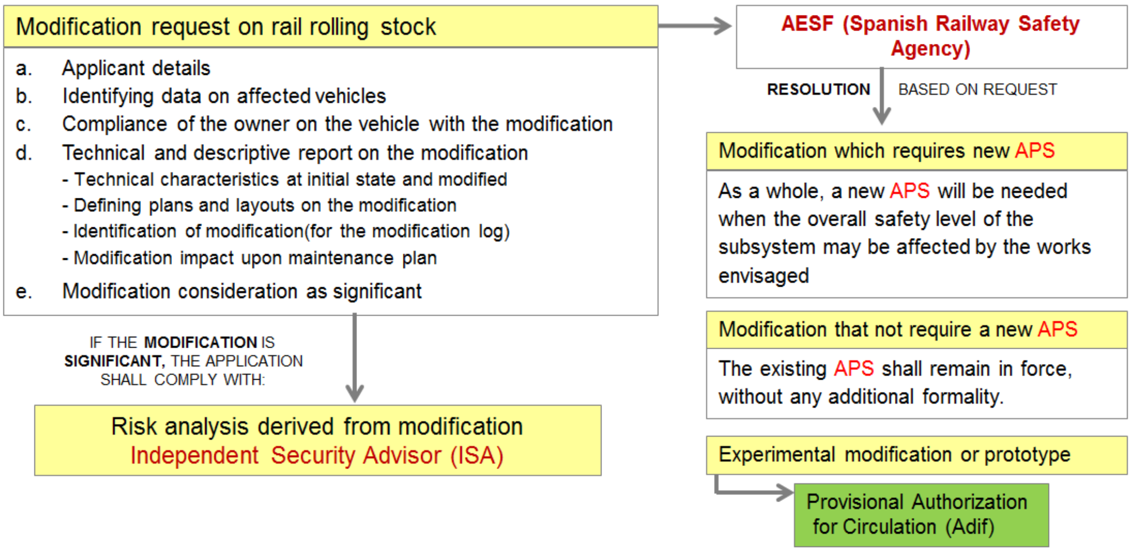


Figure 12. Accreditation process. Application for the modification on the railway rolling stock. Source: Institut Cerdà (2015).

In the event of modifying the already accredited rolling stock (310/311 locomotives), it will be considered as a significant change of the material itself. This modification involves a high technological innovation standard that will lead to the application of the Resolution 1/2011. This Resolution paves the way towards an accreditation of a heavily modified rail material. According to this resolution the following points should be fulfilled:

- Completion of the risk assessment derived to the implementation of the modified scheme.
- Report on the evaluation process and risk analysis by an independent integrator.

As a result of the technological adaptation of the modification, the **main conclusions** are expounded upon the **accreditation process and commissioning** of the modified locomotives:

- As abovementioned, it is evident that the most appropriate way to overcome the barriers derived by the accreditation process and the commissioning of the locomotives operated with LNG is via **the implementation of the LNG unit into 310/311 locomotives already accredited**. This implies tight collaboration alongside **Adif**, as well as its **predisposition**, in order to convert the locomotives or otherwise to share them in order to carry out pilot trial. The major benefits of this collaboration with Adif are the cost in terms of time and money for the accreditation.

- In order to get to know exactly the **cost in terms of time and money** is recommended to become aware of the engine availability (prototype). Moreover, in order to avert an increase of **temporary costs,** it should be assured that an accreditation organism is involved from the beginning of the process. Additionally, the **modification scope** should be evaluated **in accordance to the Resolution 1-2011/Ministerial Order 233 2006**.

- On the other hand, the cost in terms of money rely closely on the number of dossiers to be developed and the number of characteristics (such as security –dangerous goods-, technical compatibility, environment, reliability); therefore the greater is the modification, the more expensive becomes the accreditation.

- Finally, a number of agents that take on different roles of accreditation and integration should be taken into consideration for the practical development of this project. It would be desirable to set the **integrator as the applicant** (ARMF is predisposed to take part as an integrator in case the project comes along). It is certainly advisable that Bureau Veritas plays a role as a designated organism for the **accreditation process** due to its wide expertise in the LNG and railway field.

5.2. Phase 2: Supply infrastructure implementation

Design and implementation of the **LNG supply system** (either fixed or mobile) must permit to provide, at least, an **equal or superior quality of service** than the diesel fuel logistics.

In order to do so, it will be relevant to assure the **autonomy** of the tractor heads to avoid interference to their performance. Therefore, a single provisioning point shall be adopted by means of a mobile plant (tank truck) which would equalize the current number of points and likewise it would equalize the current autonomy (provisioning points offer). The construction of a fixed LNG provisioning point is not envisaged (neither diesel provision) due to low demand.

In turn, the same flexibility should be provided in the times that the fuel stops are conducted. Currently, locomotive tanks are filled once every 4 or 5 days between 13:30 and 14:00. In the same way, the fuel supply services could be subcontracted via a third company in order not to interfere into in the autonomy of the operation.

On the other hand, the key points to provide a proper **design and implementation** of the LNG storage/supply facility are the locations and the capacity. In principle, a location nearby the current one (within the perimeter for railways manoeuvres) is advisable. The security conditions such as the minimum required distances should be analysed in order to specify the exact location. There are no problems detected in the availability of land (the necessary space for the provisioning is minimum).

To determinate the capacity of LNG facilities, a comparison to the existing ones regarding diesel storage and suppling will be carried out. These facilities discharge 3.000 litres and 5.000 litres of diesel every 4 or 5 days, thus this leads to a supply via LNG tank truck of 5 to 8 m^3 which will be enough to equal current diesel logistics.

5.3. Phase 3: Operation and maintenance

In the operation and maintenance phase is crucial to meet the necessary requirements to **provide the offered shunting railway services**.

In this regard, the following points should be fulfilled:

- New engines shall assure **necessary power** to overcome the resistance opposed to the traction. The LNG engine should not entail any reduction in power that prevents the traction resistances (in accordance to: steepness, composition weight –LNG weight that is lower to the diesel weight for equivalent quantities in energetic capacity-, minimum speed).

- **LNG supply system** shall be flexible not only regarding **reaction times** facing refuelling demand but also regarding **schedule**s.

- The rolling stock should be **operational most of the time** and dodge as much as possible the maintenance downtime. The vehicle maintenance needs are reduced by the fact that LNG is cleaner than diesel.

- Legal **requirements** applicable to **air pollution** should be **met**. LNG is a cleaner energy source thus there will not be any problem related to it.

- Alternatively, the train set LNG propelled are to meet the same **security conditions and the riskiness degree** than the diesel propelled. Therefore, the **certificate of accreditation and authorization** of commissioning the unit in service and circulation will be available to guarantee this condition.

5.4. Conclusions on technical and legal barriers

Once the above mentioned three phases identified as necessary to implement LNG traction in the railway sector have been analysed and studied, it is possible to obtain a clear vision about some barriers which could compromise the implementation of the LNG railway traction to railway shunting services at the Port of Tarragona.

From a ***technical feasibility*** perspective, the first uncertainties come out with the engine since there is no LNG engine available on the market yet. Out of 5 manufacturers, only a single one (Guascor) has a catalogue with a LNG engine that meets all the needed requirements in order to be utilized in a 310/311 locomotive. This scarce product offer displayed in catalogue affects directly to prices, fact that could compromise the economic feasibility of the solution in case of limited demand. Hence it is relevant to rouse up the providers' interest to accelerate its availability since it creates a bottle neck when it comes to the implementation process of the LNG railway traction.

The ***legal feasibility*** stands out as the main barrier to overcome in order to implement LNG traction in the accreditation process. There are uncertainties about the treatment of LNG as a fuel (so far, it is considered as a dangerous good). Its authorization as fuel in other modes of transport paves the way to overcome this barrier. Likewise, the first pilot test on rail traction with LNG in the medium-distance passenger segment, to be carried out in Asturias, will pave the way and help in the definition of a voluntary regulatory framework. The outputs of this project are expected by the 2017.

6. Economic and financial feasibility analysis

6.1. Data and hypotheses for the calculation

In order to carry out the economic-financial viability, a series of variables representative of the three different phases in which the project is structured and described in the abovementioned chapter will be chosen.

First of all, in the phase 1 regarding *technological adaptation* will be distinguished the following elements: the **engine**, the **tank**, the **integration** and the **accreditation**. With regard to the engine, the variables that will be used are the number of engines per locomotive, the production time of each of the engines, the investment cost for every LNG engine and the percentage of manoeuvres that will be carried out within the Port premises with traction heads propelled by LNG and diesel. Taking into account the number of **tanks** per locomotive, production time of each tank and the fuel tank capacity are the variables that will be taken into consideration regarding the tank itself. Regarding the **integration** of the system, the variable cost of the engine and tank integration will be used whereas for the **accreditation** the variable cost and time will be used

Secondly, in the phase 2 *supply infrastructure implementation,* the influence of the cost of transporting LNG with a tanker truck as well as the influence regarding the origin of LNG will be both examined.

Finally, in the last phase *operation and maintenance*, nine variables will be considered in the analysis. These refer to the following: average consumption, the shunting railway demand, the evolution, the spread of the demand and the number of transformed locomotives, the speed of transformation, the diesel cost, the LNG cost and the engine maintenance cost.

The variables are summarized in the table below:

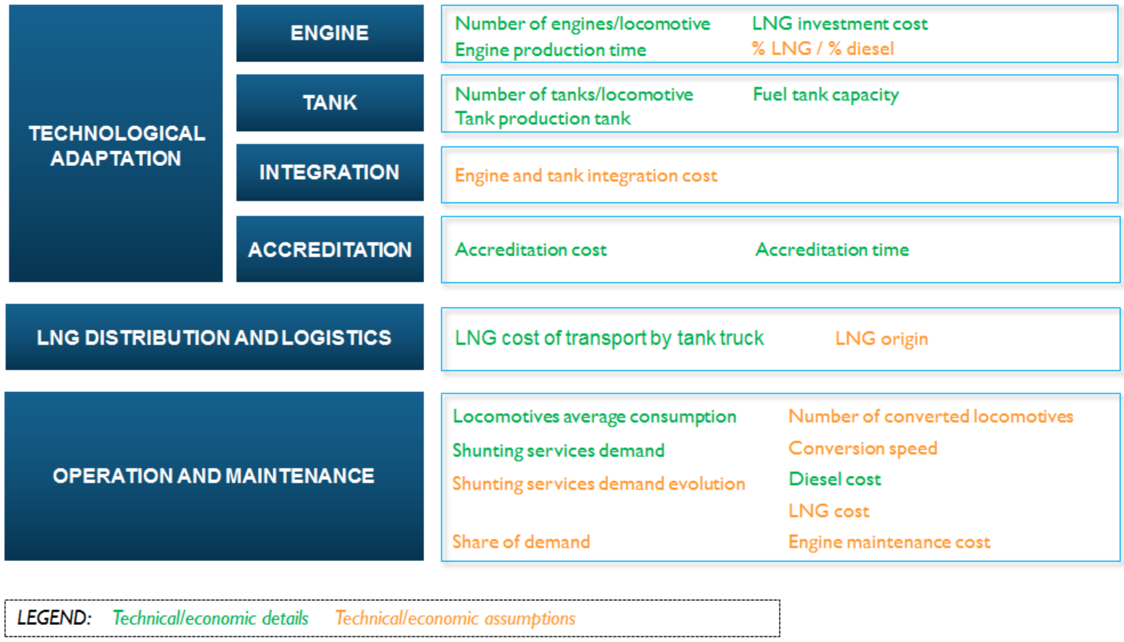


Figure 13. Variables for the economic-financial feasibility analysis. Source: Institut Cerdà (2015).

6.1.1 Variables description

From now on and for each phase, a variety of variables will be described in detail to justify, in the necessary cases, the assumptions made. In the first instance, a distinction will be made between the technical data and the technical assumptions and secondly between the economic assumptions and the regular data.

<u>Phase 1: Technological adaptation:</u>

Technical data in the technological adaptation phase is as follows:

- **Number of engines per locomotive.**
  - A single engine per locomotive is considered, since the existing diesel engine is replaced by a LNG engine with similar characteristics.
- **Number of tanks per locomotive/ cryogenic tank capacity.**
  - A single tank per locomotive is considered, since the existing diesel tank is replaced by a cryogenic tank with similar capacity (Enric Group, Ingesic, 2015). This will decrease the current autonomy; however the operating feasibility is not affected.
- **Engine and tank production time.**
  - Approximate production time required for the engine accounts for 4-5 months (Guascor, 2015).

    - Approximate production time required for the tank accounts for 2-3 months (Chart, 2015; Enric Group, 2015).
- **Accreditation time** (Spanish Railway Safety Agency, AESF).
    - The AESF has a 4 month period, once the required certificates are presented and the Commissioning Authorization is requested (AESF, 2015).

Technical assumptions are as follows:

- **LNG dedication percentage in the engine combustion.**
    - At first, due to low consumption rates derived from the shunting railway services, the option of a 100% LNG engine is envisaged in order to make the most of the LNG advantages. This option is envisaged since LNG cost is inferior regarding diesel for the same consumption. Additionally, as shown in the following chapter, the possibility of a dual fuel engine is presented. This engine is capable of shifting its own functioning between both fuels (diesel and LNG).

In relation to the **economic data** considered have been the following points:

- The **LNG engine cost.**
    - There are different orders of magnitude according to the provider:
        - Guascor (2015): 235.000 € (approximate cost).
        - Pasch (2013) and GRI (1993): The price will rely on the installed power. The cost key figures will be used in accordance to the installed power (115 €/kW), with an enlargement factor of 20%. In this case, the cost of the engine would be: 700 kW x 115 €/kW x 1,20 = 96.600 €.
    - The definition of a baseline scenario will be conducted according to an **average cost** between both solutions. Therefore, the cost considered is **170.000 €.**
- The **LNG tank cost.**
    - The cost of the LNG tank considered for the available capacity is **20.500 €,** with a transport cost of 800 € (Enric Group, 2015).
- The **accreditation cost** is described as follows:

Validation and certification cost (€ / vehicle)		Commissioning authorisation (€ / vehicle)	
1st unit	*From the 2nd unit*	*1st unit*	*From the 2nd unit.*
300.000	30.000	3.000	300

Table 13 Accreditation cost description. Source: Institut Cerdà (2015) of data coming from Bureau Veritas & AESF (2015).

The meaningful difference on the certification and commissioning cost (depending on whether it is the first unit or from the second unit) is because the certification for the first unit is taken as a pattern for the consecutive units resulting in lower costs.

Economic assumptions are as follows:

- **Engine and tank integration cost**.
  - It is assumed a tank/engine integration cost in the order of **21.000 €** (ARMF, 2015).

Phase 2: Supply infrastructure deployment:

The **technical assumptions** encountered in this phase are as follows:

- **LNG provenance.**
  - The tank truck will convey the LNG directly from the plant of Barcelona to the Port of Tarragona (nearest regasification plant). The distance between the plan and the supply area is 98.3 km.
- The **tank truck's unloading time**.
  - It is considered to be less than 2 hours.
- **Fuel unloading rate**.
  - It is considered to be 80 l/min.
- **Tank truck capacity**.
  - It is considered that 5 m^3 is enough (equivalent to the diesel logistics).

- **Tax system**.
  - The LNG conveyed in the tank truck shall have a unique tax system. This does not allow spare LNG to be used for other purposes.

The **economic data** utilized are as follows:

- The **LNG transport cost** (ESK, 2015).
  - As a first approach was considered the following costs.
    - Transport cost of the LNG tank: 1.2 €/km.
    - Unloading cost (immobilization of the vehicle): 35.5 €/h, assuming that the first 2 hours involves no cost.

It is noteworthy that in near future horizon the Port of Tarragona will have LNG storage for vessels bunkering supplying, hence this cost associated to transport could be negligible.

<u>Phase 3: Operation and maintenance</u>:

The **technical data** in this phase is as follows:

- **Average locomotive consumption** (Adif, 2015).
  - 311 series: 3.49 l diesel/km equivalent to 5.69 l LNG/km.
- **Demand on shunting railway operations** (Adif, 2015).

Historical data of the shunting railway operations served by the 311 locomotives in the Autoritat Portuària de Tarragona and the Tarragona station (Tarragona classification):

Year	Total Diesel Litters	Total Hours	Total Km
2007	270.730	14.904	73.983
2008	239.344	13.200	73.838
2009	140.378	7.711	45.919
2010	147.638	8.465	43.506
2011	198.021	9.923	54.713
2012	185.252	9.029	50.541
2013	161.733	8.555	44.466
2014	173.181	9.582	47.870

Table 14 Historical data for the shunting railway operations served by the 311 locomotive. Source: Adif (2015).

The **technical assumptions** are as follows:

- **The expected evolution of the shunting railway services**.
  - Three different scenarios are defined in terms of demand evolution (year 2014).

- **Pessimistic scenario**: Maintaining values associated to the year 2014.
- **Realistic scenario**: Rise in demand similar to the Spanish GDP growth (FMI, 2015).
- **Optimistic scenario**: Rise in demand similar to the double Spanish GDP growth (FMI, 2015).

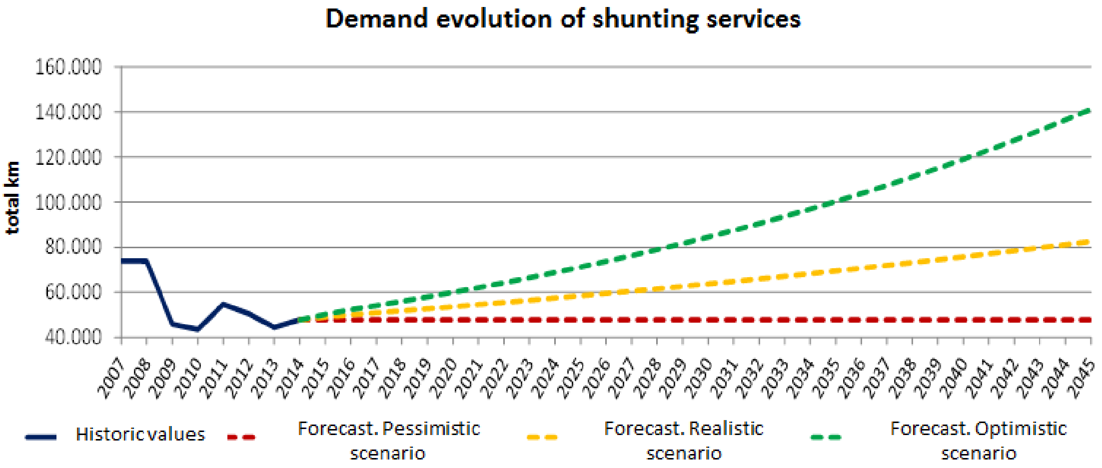
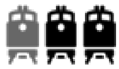
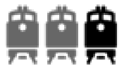


Figure 14. Evolution of the shunting railway operations demand. Source: Institut Cerdà (2015) coming from FMI (2015).

- **Spread of the railway demand between available locomotives**.
  - Two different scenarios are assumed, taken into account that the total number of the locomotives in service are 3:
    - **Equitable schedule lines between the available locomotives** (**baseline scenario**): Distribution evenly divided (1/3, 1/3, 1/3) of total kilometres travelled by the 3 available locomotives, regardless of the propelling fuel.
    - **Favourable schedule lines to LNG propelled locomotive** (sensitivity analysis scenario): Distribution which maximizes the km travelled by each LNG propelling locomotives, in accordance to the transformed locomotives. In general, the LNG usage distribution utilized is as indicated in the following figure:

1 locomotives converted 

LNG	**50%**	**of the total trains-km**
Diesel	25%	of the total trains-km
Diesel	25%	of the total trains-km

2 locomotives converted 

LNG	**45%**	**of the total trains-km**
LNG	**45%**	**of the total trains-km**
Diesel	10%	of the total trains-km

Figure 15. Schedule lines on fuel uses. Source: Institut Cerdà (2015).

- **Locomotives to transform.**
  - Since the 310 locomotives have a residual demand on the shunting railway services at the Port of Tarragona, then uniquely the transformation of the 311 locomotives is analysed.

- **Number of transformed locomotives.**
  - Three different scenarios are presented:
    - Transformation of the 3 locomotives with diesel traction into LNG (baseline scenario).
    - Transformation of a single locomotive with diesel traction into LNG (sensitivity analysis scenario).
    - Transformation of two locomotives with diesel traction into LNG (sensitivity analysis scenario).

- **Conversion velocity rate of locomotives.**
  - In scenarios that the transformations are conducted by more than 1 locomotive, it is considered that the majority of them will be converted within the 2 first years of the project (one for the first year, and the rest in the second year).

The **economic data** is as follows:

- **Fuel cost:**

In the price is included the source of energy cost with the margin, the transport cost plus the management and supply cost according to Adif.

- **Diesel cost** (energy cost + margin + transport cost). Thereon the diesel cost is presented:
  - 2013 values: **0,763 €/l** (Enagás, 2013).
  - 2014 values: **0,576 €/l** (Adif, 2015).
  - 2015 values: **0,450 €/l** (Adif, 2015).
- **Management cost by Adif:**
  - 0,021 €/l (Adif, 2012).
- **Supply cost by Adif:**
  - 0,020 €/l (Adif, 2012).

The **economic assumptions** are:

- **LNG selling price**. Considering a minimum price for LNG (without margin for the gas company):
  - **LNG cost** (energy cost).
    - 31,31 €/MWh = **0,199 €/l** (Gas Natural Fenosa, 2015).
  - **LNG transport cost.**
    - **0,015 €/l** (ESK, 2015).
  - **Management cost by Adif.**
    - **0,021 €/l** (Adif, 2012).
  - **Supply cost by Adif.**
    - **0,021 €/l** (Adif, 2012).
- **LNG taxation system:**
  - Tax free scheme is considered (comparable to the current railway scenario). In case of applying taxes, it would add up an extra cost of 0,026 €/litter (law 38/1992, December 28th, Special taxes).
- **Maintenance cost of one LNG engine**:
  - The increase of the maintenance cost of a LNG vehicle with respect to a diesel vehicle is negligible, since the renovation frequency of the engine valves are increased. The possible differential aspects do not suppose any critical nor significant aspect that would increase the maintenance cost.

6.2. Baseline scenario

The following table shows all the input variables used in the base scenario as well as values or the value fork they have adopted:

BASELINE SCENARIO	TECHNOLOGICAL ADAPTATION	ENGINE COST	170.000 €
		TANK COST	21.300 €
		INTEGRATION COST	21.000 €
		Nº LOCOM. CONVERTED	3
		GASIFICATION SPEED	3 every 2 years
	ACCREDITATION & VALIDATION	1st UNIT	300.000 € + 3.000 €
		FROM THE 2nd UNIT	30.000 € + 300 €
	FUEL SUPPLY	DIESEL PRICE	0,600 €/litre
		LNG PRICE	Varying 0,250-0,350
		FUEL TAXES	NO
	DEMAND SCENARIOS	CIRCULATION EVOLUTION	Evol. sce. realistic demand
		LNG LOCOMOTIVES USAGE	EQUITABLE
	FINANCIAL VARIABLES	REINVERSEMENT RATE	8%
		FINANCING RATE	5%

Figure 16. Baseline scenario overview. Source: Institut Cerdà (2015).

6.2.1 Baseline scenario profitability

The profitability analysis is based on the computation of the Net Present Value (NPV) and the payback of the project. The NPV corresponds to a financial indicator that gauges future revenues of the project once the initial investment is accounted. Hence, in the event of a positive output, the project is bound to be feasible. Regarding payback, it should be mentioned that it is an indicator that corresponds to a static evaluation method for the investment and, as a result, determines the right time when the initial disbursement is paid off.

After the profitability analysis was performed on the **baseline scenario**, it was found that the project is not profitable for the operator of shunting railway services at the Port of Tarragona when a realistic demand is considered. The evolution of both NPV and payback will be assessed in the following charts to prove the project's non-profitability as above-mentioned.

In order to proceed with the NPV calculation, project's cash flows are determined. Cash flows correspond to the sum of benefits minus the expenses which might be translated to the inflow cash obtained by the economic benefits that entails the LNG shifting minus the outflow cash related to the costs.
For the calculation of the cash flows, the following points have been considered:

- The **cost difference of fuel supply**: calculated as the difference between the costs associated to the consumption of the current diesel scenario with respect to the costs associated to the consumption of either the evaluated scenario of the conversion to a 100% LNG consumption or a dual engine (LNG and diesel).
- **Environmental benefits:** corresponding to a monetisation derived by the reduction of CO_2 emissions due to the shift to LNG fuel scenarios.
- **Maintenance cost:** this cost is considered negligible since the possible differences in the maintenance are not significant, hence it is concluded that the difference between the current scenario with diesel fuel and the scenarios analysed thereupon (LNG dedicated and dual –LNG and diesel-) are negligible.

Next, the calculation methodology of the previous points is presented here below.

Firstly, for the fuel supply cost, the following variables are considered:

- Total number of kilometres for each locomotive per year.
- The corresponding fuel consumption: based on the current scenario with diesel, either on the evaluated scenarios of transformation to 100% LNG or on the dual engine (LNG and diesel).
- LNG and diesel cost for the operator, depending on the evaluated scenario.

Current scenario (diesel locomotive)

$$C_{supply}^{diesel} = total\ km\ [Km] * diesel\ consumption\left[\frac{l}{km}\right] * diesel\ cost\ for\ the\ operator\left[\frac{€}{l}\right]$$

Dedicated engine scenario(locomotive 100% LNG)

$$C_{supply}^{LNG} = total\ km\ [Km] * LNG\ consumption\left[\frac{l}{km}\right] * LNG\ cost\ for\ the\ operator\left[\frac{€}{l}\right]$$

Dual engine scenario (locomotive % LNG and % diesel)

$$\begin{aligned} C_{supply}^{d+LNG} = {} & total\ km\ [Km] \\ & * \left[\left(\%\ LNG\ consumption\left[\frac{l}{km}\right] * LNG\ cost\ fot\ the\ operator\left[\frac{€}{l}\right]\right)\right. \\ & \left. + \left(\%\ diesel\ consumption\left[\frac{l}{km}\right] * diesel\ cost\ for\ the\ operator\left[\frac{€}{l}\right]\right)\right] \end{aligned}$$

COST DIFFERENCE OF FUEL SUPPLY (SAVING)

Dedicated engine scenario:

$$Dif_{supply} = C_{supply}^{diesel} - C_{supply}^{LNG}$$

Dual engine scenario:

$$Dif_{supply} = C_{supply}^{diesel} - C_{supply}^{d+LNG}$$

Figure 17. Calculation for the cost difference of fuel supply. Source: Institut Cerdà.

In the case of the **environment benefits**, the calculation is based on the following variables:

- CO_2 emissions for every scenario (current 100% diesel and the scenarios assessed for the transformation scenarios: 100% LNG and dual engine).
- Emission factor with the goal of monetize the CO_2 tons.

The difference between an specific scenario of conversion (100% LNG or dual) in relation to the current scheme of diesel locomotives, provide a reduction on the resulting emissions that, once multiplied by the emission factor which outline the price per CO_2 ton, results in the monetary value saved because of LNG transformation.

Current scenario (diesel locomotive)

$$Emissions\ _{CO2}^{diesel} = total\ km\ [Km] * diesel\ locomotive's\ emission\ factor \left[\frac{\mathrm{Kg}}{km}\right]$$

Dedicated engine scenario(locomotive 100% LNG)

$$Emissions\ _{CO2}^{LNG} = total\ km\ [Km] * LNG\ locomotive's\ emission\ factor \left[\frac{\mathrm{Kg}}{km}\right]$$

Dual engine scenario(locomotive % LNG y % diesel)

$$Emissions\ _{CO2}^{d+LNG} = \left(total\ km\ LNG[Km] * LNG\ locomotive's\ emission\ factor \left[\frac{Kg}{km}\right]\right) + \left(total\ km\ diesel\ [Km] * diesel\ locomotive's\ emission\ factor \left[\frac{Kg}{km}\right]\right)$$

REDUCTION OF CO_2 EMISSIONS (BENEFIT)

Dedicated engine scenario:

$$Dif_{emissions} = \left(Emissions\ _{CO2}^{diesel} - Emissions\ _{CO2}^{LNG}\right) * Cost \left[\frac{€}{tCO2}\right]$$

Dual engine scenario:

$$Dif_{emissions} = \left(Emissions\ _{CO2}^{diesel} - Emissions\ _{CO2}^{d+LNG}\right) * Cost \left[\frac{€}{tCO2}\right]$$

Figure 18. Calculation for the reduction of CO_2 emissions. Source: Institut Cerdà.

Finally, the value of the **initial investment** corresponds to expenses on the conversion of the current scheme (diesel 100%) to LNG (100% dedicated or dual engine). The factors included on the conversion are as follows:

- Engine cost
- Cryogenic deposit cost for LNG scheme
- Integration cost
- Validation and certification cost
- Commissioning cost

Additionally, a discount rate (*r*) of 8 % is considered. As well as the value of (*n*), which it accounts for the calculated period of time which extends from 2016 to 2045 being equal to 31.

From now on, the employed formulas are expounded below as follows:

$$VAN = \sum_{t=1}^{n} \frac{Q_t}{(1+r)^t} - I_0 \qquad (1)$$

Where:

- r , is the assumed discount rate of the project
- Q_t , cash flow for every period
- I_0 ; initial investment
- n , number of periods considered

Then, the payback period is calculated by subtracting the initial investment of the cash flows for every period up to a given period when the investment is recouped.

$$Payback = a + \frac{I_0 - b}{F_t} \tag{2}$$

Where:

- a , accounts for the previous period number in which the initial investment is recovered
- I_0 ; initial investment
- b , the sum of cash flows until the end of period "a"
- F_t , cash flow value of the recovery period

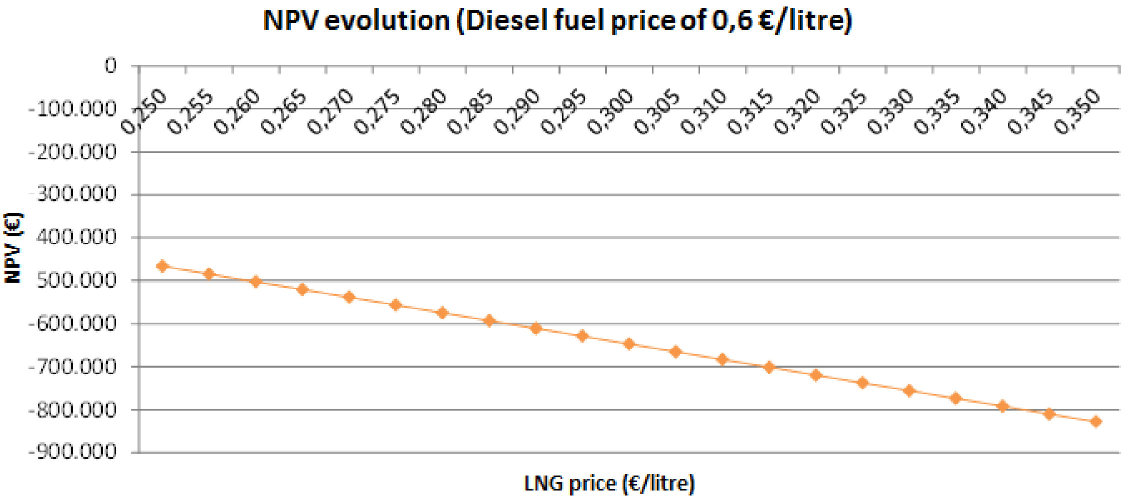


Figure 19. NPV evolution chart of the baseline scenario. Source: Institut Cerdà (2015).

As it is observed, the VAN value is not positive for any sales price value of the LNG. Then it turns out that the value is always below 400.000 euros leading to a justification as to why this project is non-profitable in this scenario.

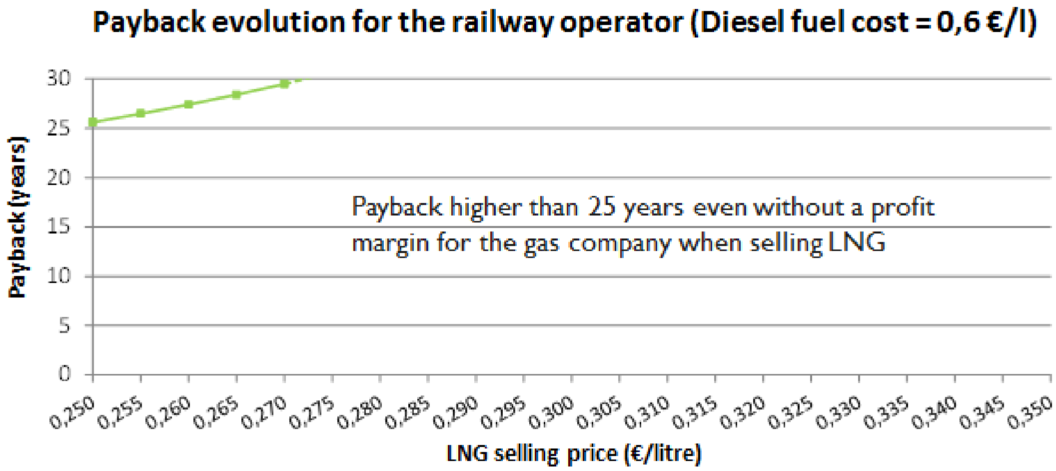


Figure 20. Payback evolution chart upon the baseline scenario. Source: Institut Cerdà (2015).

As for payback for the railway operator, it is visualized that it is higher than 25 years even on the scenario in which the gas agent has no benefits. Hence, it is considered that this scenario is not feasible to operate the railway machinery at the Port of Tarragona.

6.3. Sensitivity analysis

As a consequence of the negative result on the project's profitability for the baseline scenario, a sensitivity analysis has been carried out in order to explore distinct scenarios and its associated profitability.

In order to perform the sensitivity analysis, a variety of **key variables** have been taken into consideration to build up **profitable schemes** for the railway operator. Those scenarios were also analysed from the gas company's point of view. Thereof, the actions to be undertaken were analysed in such a way to guarantee the project's economic feasibility.

Therefore, building a feasible scenario for the **railway operator** entails the following steps:

1. **Identifying determining drivers for the project's feasibility** (according to the operator's perspective).
2. **Building the optimal scenario up** (most favourable) from the railway operator's perspective.

3. Formulate **possibilist scenarios for the Autoritat Portuària de Tarragona**.

Additionally, it has also been evaluated the feasibility for the gas company as well as for the whole project (railway operator and gas agent).

6.3.1 Key variable identification for the railway operator

In the first stage of the sensitivity analysis, the impact of each of the variables on the payback of the railway operator has been analysed, in order to identify and prioritize the key variables that affect this profitability.

The **variables** considered for the sensitivity analysis are as follows (parameters highlighted in violet):

TECHNOLOGICAL ADAPTATION	TYPOLOGY & ENGINE COST	Dedicated (96.600 – 235.000 €) / Dual (44.170 €)
	TANK COST	21.300 €
	INTEGRATION COST	21.000 €
	No. LOCOM. CONVERTED	1 – 2 – 3 locomotives
	GASIFICATION SPEED	2 – 5 – 10 years
ACCREDITATION & VALIDATION	1st UNIT	100.000 – 300.000 € + 3.000 €
	FROM THE 2nd UNIT	10.000 – 30.000 € + 300 €
FUEL SUPPLY	DIESEL COST	0,400 – 0,900 €/litre
	LNG COST	Variable between 0,250 & 0,350
	FUEL TAXES	NO
DEMAND SCENARIOS	CIRCULATION EVOLUTION	Pessimistic-Realistic-Optimistic
	LNG LOC. USAGE SHARING	Diesel-LNG Equitable / LNG Favourable
FINANCIAL VARIABLES	REINVESTMENT RATE	8%
	FINANCING RATE	5%
ENVIRONMENTAL IMPACT	EMISSIONS INTERNALISATION	Yes / No

Figure 21. Railway operator drivers. Source: Institut Cerdà (2015).

Based on the previous variables, from now on the results from the sensitivity analysis will be presented by concluding which variables have the greatest impact on the transformation of diesel traction to LNG traction.

1. **Engine cost and typology**

The first element to be evaluated is the engine's typology. As it is mentioned on the *5.1.1 Variables description*, even though the baseline scenario is based on an exclusive LNG engine, the possibility of a dual LNG-diesel engine is considered. This dual engine enables its functioning alternatively fuelled either by liquefied natural gas or diesel, permitting combustion by employing both combustibles in an automatic manner. These differences between engine's typologies are represented by applying an utilisation rate for each fuel (diesel or LNG) in the context of a dual engine and 100% LNG in the context of a dedicated engine.

In order to contemplate how the variation affects the whole project, sensitivity analysis was carried out by modifying the "engine cost and typology" variable with respect to the baseline scenario (it is noted that the variable studied and modified is highlighted in yellow).

Variable	Value
Typology and engine cost	Dedicated (96.600 € / 170.000 € / 235.000 €) LNG dual 90% (44.170 €) LNG dual 80% (44.170 €)
Tank cost	21.300 €
Integration cost	21.000 €
No. loc. converted	3
Transformation speed	2 years
Accreditation cost 1st unit	300.000 € + 30.000 €
Accreditation cost from the 2nd unit	3.000 € + 300 €
Diesel cost	0,600 €/litre
LNG cost	0,250 - 0,350
Fuel taxes	No
Demand evolution	Realistic
LNG usage sharing	Equitable
Reinvestment rate	8%
Financing rate	5%

Modified values concerning the baseline scenario

Figure 22. Engine cost and typology as an adjustable variable. Source: Institut Cerdà (2015).

The results obtained for the payback are represented in the following graphic:

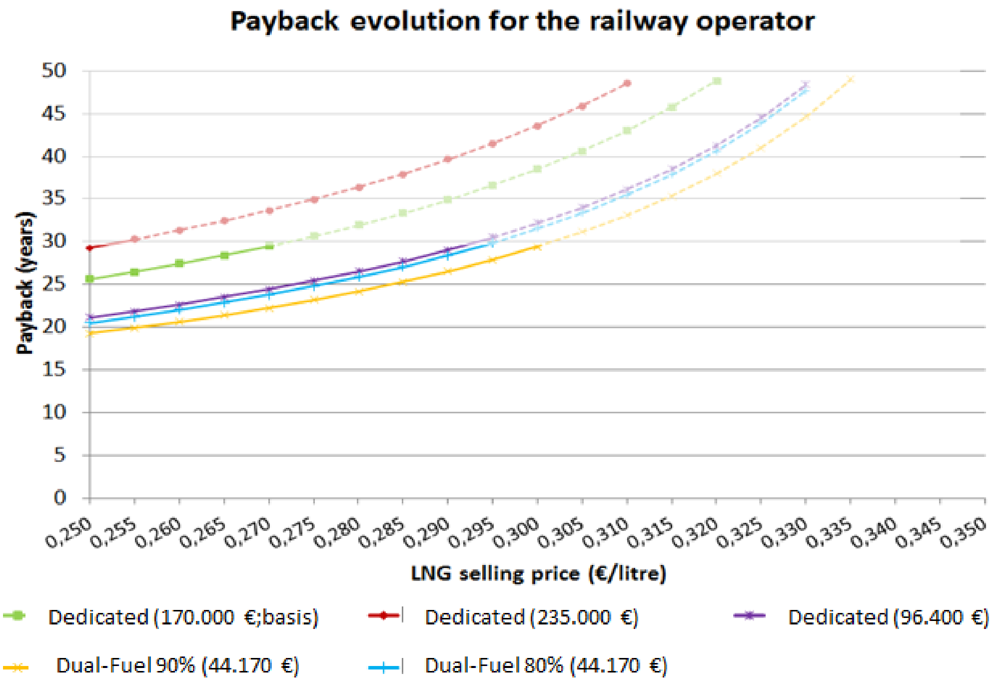


Figure 23. Payback evolution upon the baseline scenario with an adjustable variable on the engine cost and typology. Source: Institut Cerdà (2015).

It is noted that, for every calculation of the payback period the abovementioned formulas are used in accordance to the chapter 5.2.1.

As it is observed in the scenarios evaluated, the engine cost affects significantly on the payback variability. Thus, the reduction of 75.000 € on the engine cost leads to a reduction of the payback in the order of 5 years. Since the dual engine is noticeably cheaper than a dedicated LNG engine (44.000 € vs 170.000 €, approx.), the typology of the engine also represents a driving factor with a high impact in the project profitability.

The greater payback observed stands for a dual fuel engine with a high percentage of LNG in the fuel mix in order to minimise operating costs.

2. Number of locomotives converted

Similarly, to the previous one, a sensitivity analysis has been carried out in which it is determined in this case which is the ideal number of locomotives to transform to ensure the highest profitability.

In this case, the variables that will be modified are the number of transformed locomotives and the speed at which they are transformed. The scenario for this sensitivity analysis is as shown in the following table:

Variable	Value
Typology and engine cost	Dedicated: 170.000 €
Tank cost	21.300 €
Integration cost	21.000 €
No. loc. converted	1 / 2 / 3
Transformation speed	1 / 2 / 2 years
Accreditation cost 1st unit	300.000 € + 30.000 €
Accreditation cost from the 2nd unit	3.000 € + 300 €
Diesel cost	0,600 €/litre
LNG cost	0,250 - 0,350
Fuel taxes	No
Demand evolution	Pessimistic / Optimistic
LNG usage sharing	Equitable
Reinvestment rate	8%
Financing rate	5%

Modified values concerning the baseline scenario

Figure 24. Number of locomotives and conversion speed as an adjustable variable. Source: Institut Cerdà (2015).

The outputs obtained on the payback of the project for the railway operator are represented in the following chart:

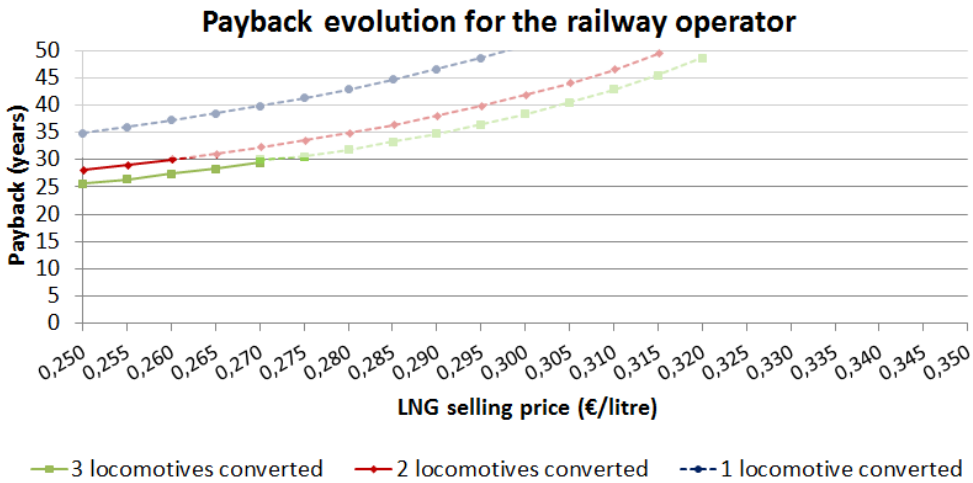


Figure 25. Payback evolution on the baseline scenario with an adjustable variable on number of locomotives and conversion speed. Source: Institut Cerdà (2015).

Due to the **distinction** of the accreditation costs between the **first unit** and the **successive** units, an increase of the payback is obtained in the one-single-transformed-locomotive scenario (minimum of 35 years to convert one locomotive vs. minimum 25 years to convert 3 locomotives).

The **total fleet transformation** (3 locomotives) represents the **most favourable scenario** for the railway operator.

3. Conversion speed of shunting locomotives fleet

For this variable it has been studied the influence on the payback for the railway operator according to the speed of transformation of the locomotives, considering a range of values between 2 and 10 years. The variables considered in the analysis are summarized in the following table.

Variable	Value
Typology and engine cost	Dedicated: 170.000 €
Tank cost	21.300 €
Integration cost	21.000 €
No. loc. converted	3
Transformation speed	2 / 5 / 10 years
Accreditation cost 1st unit	300.000 € + 30.000 €
Accreditation cost from the 2nd unit	3.000 € + 300 €
Diesel cost	0,600 €/litre
LNG cost	0,250 - 0,350
Fuel taxes	No
Demand evolution	Pessimistic / Optimistic
LNG usage sharing	Equitable
Reinvestment rate	8%
Financing rate	5%

Modified values concerning the baseline scenario

Figure 26. Transformation speed as an adjustable variable. Source: Institut Cerdà (2015).

Like former cases, payback variations are presented for the railway operator in the following graphic.

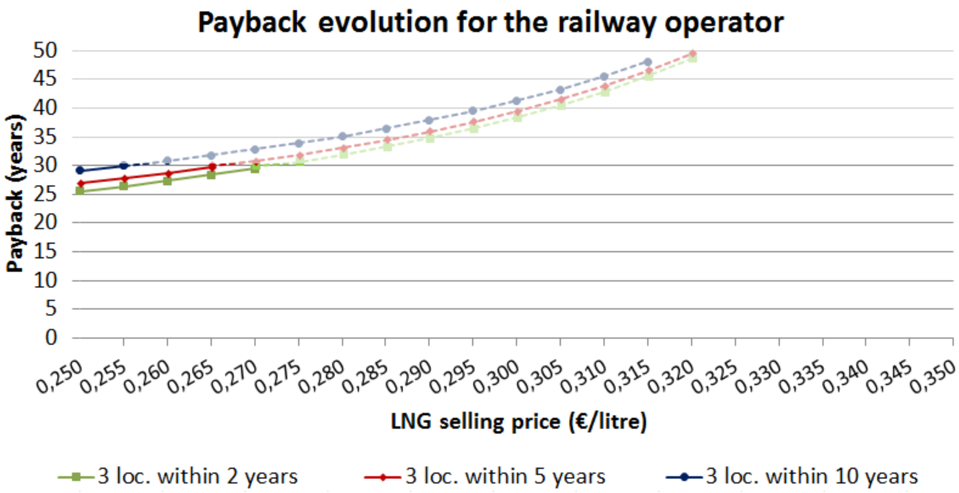


Figure 27. Payback evolution on the baseline scenario with the transformation speed as an adjustable variable. Source: Institut Cerdà (2015).

Fleet conversion within **2 years** reduces nearly **5 years** the payback with respect to the **10 years** transformation scenario. Then, it is **recommended to convert as fast as possible the whole fleet**, with the goal of accomplishing positive results at the earliest possible scenario.

4. Accreditation cost

The accreditation cost is another determining variable on the project profitability. The influence of the variability of the accreditation cost (between 300.000 euros (first unit) and 100.000 euros (from the second unit)) must be analysed in detail. In In the following table, the variables considered for the analysis are presented:

Variable	Value
Typology and engine cost	Dedicated: 170.000 €
Tank cost	21.300 €
Integration cost	21.000 €
No. loc. converted	3
Transformation speed	2 years
Accreditation cost 1st unit	300.000 € / 200.000 € / 100.000 € + 30.000 €
Accreditation cost from the 2nd unit	10.000/20.000/ 30.000 € + 300 €
Diesel cost	0,600 €/litre
LNG cost	0,250 - 0,350
Fuel taxes	No
Demand evolution	Realistic
LNG usage sharing	Equitable
Reinvestment rate	8%
Financing rate	5%

Modified values concerning the baseline scenario

Figure 28. Accreditation cost on the first and second units as an adjustable variable. Source: Institut Cerdà (2015).

The results of the sensitivity analysis are presented in the following chart.

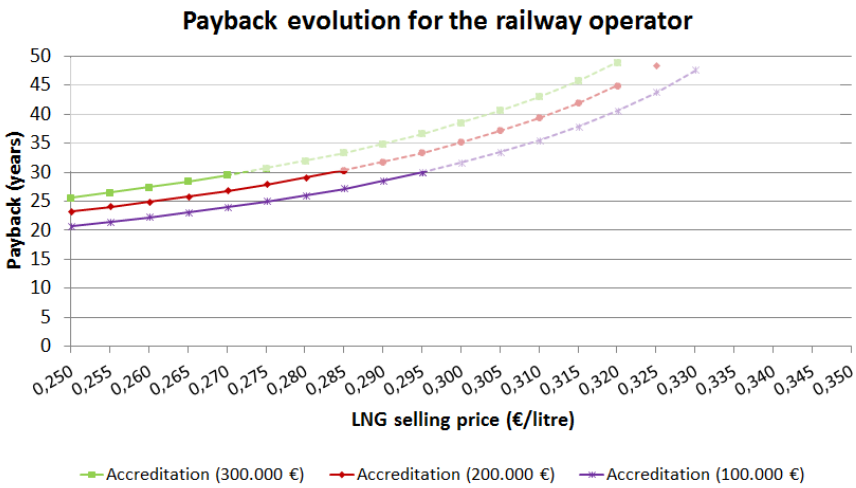


Figure 29. Payback evolution on the baseline scenario with the first and second unit accreditation as an adjustable variable. Source: Institut Cerdà (2015).

The **accreditation cost** on the first transformed unit turns out to be of **massive impact** on the **payback** of the railway operator, since its cost becomes 10 times higher than the successive units. As the accreditation of one unit presents an economy of scale, **converting 3 locomotives is way more feasible than converting a single one.**

And, last but not least, **saving 100.000 €** in relation to the accreditation might contribute to **reduce payback** over **2 years.**

5. Cost of one litre of diesel

The price of one litre of diesel has taken changing values in recent years. That is why a consideration should be made in relation to its boom and bust cycles. In this project the price of one litre of diesel might reach values between 0,5 €/l to 0,9 €/l. In order to examine the profitability variation in terms of diesel cost, a sensitivity analysis will be conducted like the former ones. The variables considered in this analysis are presented down as follows:

Variable	Value
Typology and engine cost	Dedicated: 170.000 €
Tank cost	21.300 €
Integration cost	21.000 €
No. loc. converted	3
Transformation speed	2 years
Accreditation cost 1st unit	300.000 € + 30.000 €
Accreditation cost from the 2nd unit	3.000 € + 300 €
Diesel cost	0,5-0,9 €/litre
LNG cost	0,250 - 0,350
Fuel taxes	No
Demand evolution	Realistic
LNG usage sharing	Equitable
Reinvestment rate	8%
Financing rate	5%

Modified values concerning the baseline scenario

Figure 30. Diesel cost as an adjustable variable. Source: Institut Cerdà (2015).

The results of this sensitivity analysis are displayed in the following chart:

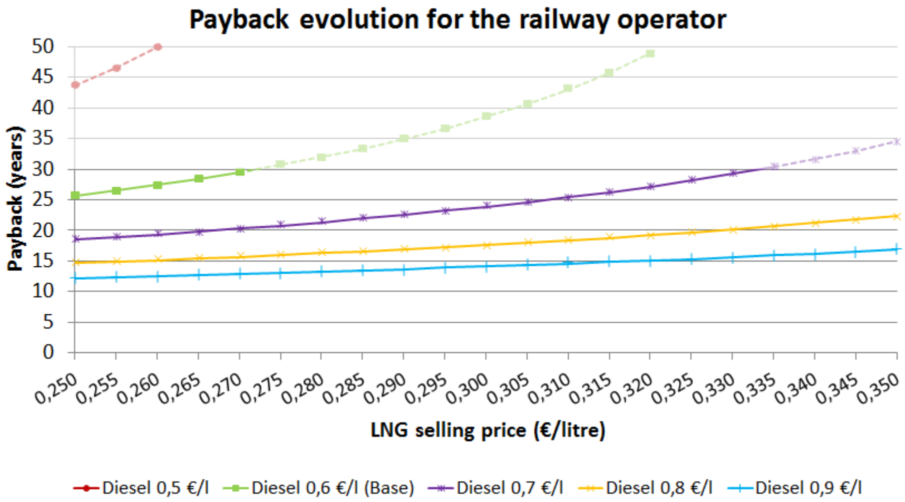


Figure 31. Payback evolution on the baseline scenario with diesel cost as an adjustable variable. Source: Institut Cerdà (2015).

The cost of one litre of diesel is the **driving factor with a greater influence** on the project profitability from the railway operator's point of view.

Therefore, increasing the fuel cost margin (the difference between LNG and diesel cost, which is 0,1 €/l) result in obtaining a significant **reduction** of the project's payback of up to **18 years**.

Focusing on the fuel cost margin, that is to say, the difference between the cost of diesel and the sale price of LNG, we obtain the results presented in the following graph.

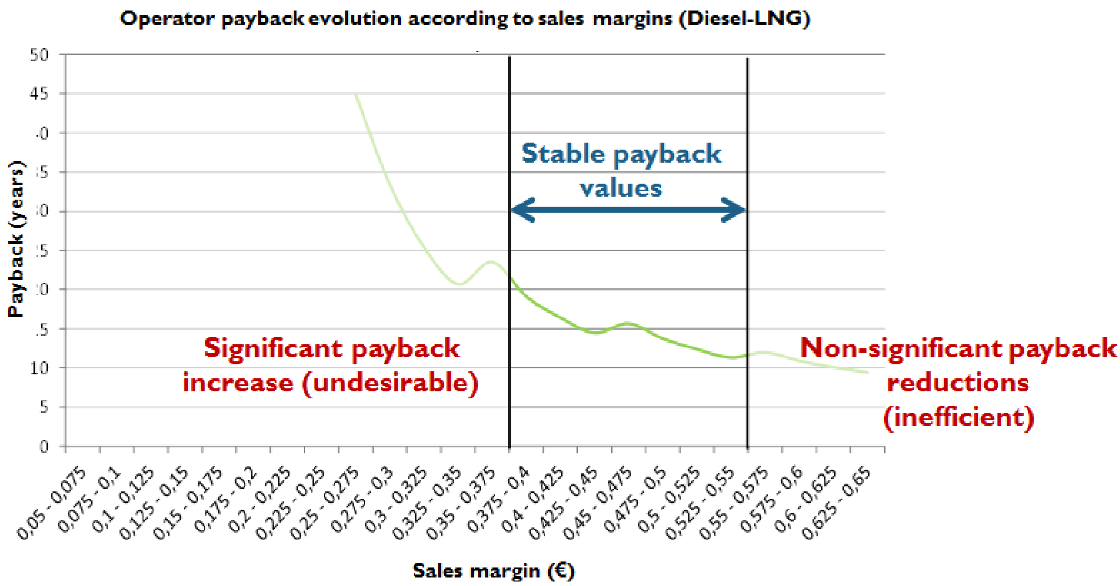


Figure 32. Payback evolution on the baseline scenario with diesel cost as an adjustable variable. Source: Institut Cerdà (2015).

The chart has been obtained by calculating the average value of every payback for the range of price of LNG. The optimal fuel cost margin interval in order to get values of payback less sensitive to fuel cost margin variations is situated between **0,375 and 0,550 €/l**. **Lower margins** lead to **notable increases** of payback, whereas **upper margins** end up with **no reductions** of payback.

6. Demand Evolution

The volume of fuel consumption will depend on the demand as well as the suitability whether to perform or not the transformation investment of the locomotives. Therefore a sensitivity analysis concerning how much influence this evolution has on the payback of the railway operator has been conducted. Three scenarios are considered for the demand that will correspond to realistic, pessimistic and optimistic scenarios. The data considered in this analysis is presented in the following table.

Variable	Value
Typology and engine cost	Dedicated: 170.000 €
Tank cost	21.300 €
Integration cost	21.000 €
No. loc. converted	3
Transformation speed	2 years
Accreditation cost 1st unit	300.000 € + 30.000 €
Accreditation cost from the 2nd unit	3.000 € + 300 €
Diesel cost	0,600 €/litre
LNG cost	0,250 - 0,350
Fuel taxes	No
Demand evolution	Realistic / Pessimistic / Optimistic
LNG usage sharing	Equitable
Reinvestment rate	8%
Financing rate	5%

Modified values concerning the baseline scenario

Figure 33. Demand evolution as an adjustable variable. Source: Institut Cerdà (2015).

The results achieved for these scenarios assessed are presented down on this chart:

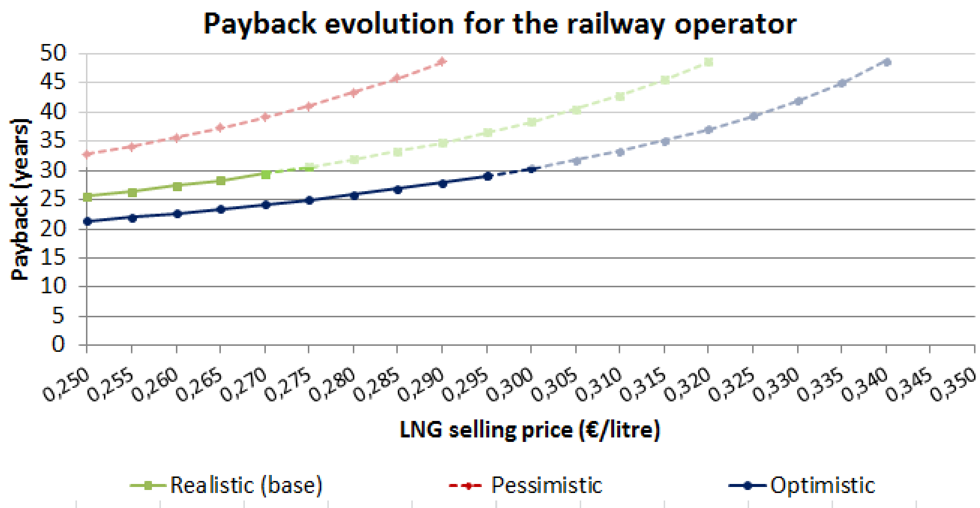


Figure 34. Payback evolution on the baseline scenario with a demand evolution as an adjustable variable. Source: Institut Cerdà (2015).

It is noticeable a **payback variability** over at least **5 years** difference in distinct demand evolution scenarios (**realistic, pessimistic and optimistic**), being the most favourable registered on the optimistic demand evolution scenario.

Hence, **demand evolution** plays a **key** role on the project profitability.

7. Distribution of use of LNG

In this case the variables that will be modified with respect to the base scenario will be the number of locomotives transformed as well as the distribution of the use of LNG that may be either equitable between diesel and LNG or favourable to LNG. The data considered in this analysis are as follows.

Variable	Value
Typology and engine cost	Dedicated: 170.000 €
Tank cost	21.300 €
Integration cost	21.000 €
No. loc. converted	2 / 3
Transformation speed	2 years
Accreditation cost 1st unit	300.000 € + 30.000 €
Accreditation cost from the 2nd unit	3.000 € + 300 €
Diesel cost	0,600 €/litre
LNG cost	0,250 - 0,350
Fuel taxes	No
Demand evolution	Pessimistic / Optimistic
LNG usage sharing	Equitable / LNG Favourable
Reinvestment rate	8%
Financing rate	5%

Modified values concerning the baseline scenario

Figure 35. Number of locomotives converted and LNG usage as some adjustable variables. Source: Institut Cerdà (2015).

The resulting paybacks are presented down into the following graph:

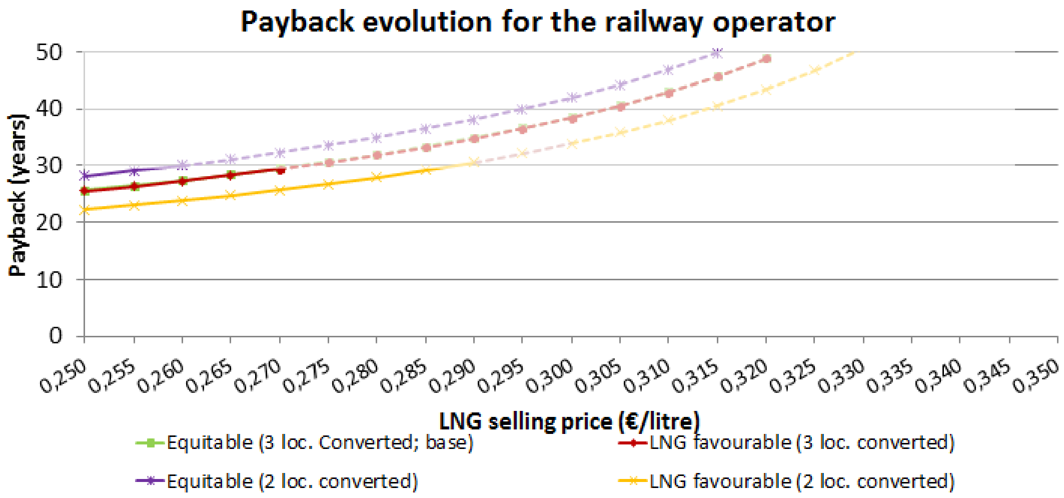


Figure 36. Payback evolution on the baseline scenario with number of locomotives converted and LNG usage as some adjustable variable. Source: Institut Cerdà (2015).

As a result, **the distribution of use of LNG** is relevant in the case of **two locomotives** are converted (6 years difference between paybacks) and nearly negligible with three locomotives (less than 0.2 years difference between paybacks).

Then, when **two locomotives** have an **equitable LNG usage** turns out to be the most **unfavourable scenario**. On the contrary, if an **intensive LNG use** is performed then the two-locomotive scenario ends up being the **most favourable** scenario for the railway operator.

8. Emissions impact

The internalization of the emissions has not been taken into account in the analysis of profitability of the base scenario. Nevertheless, it has been considered to analyse its impact on the profitability of the project by comparing the scenario without considering the internalization of the emissions (base scenario) and considering this internalization.

Variable	Value
Typology and engine cost	Dedicated: 170.000 €
Tank cost	21.300 €
Integration cost	21.000 €
No. loc. converted	3
Transformation speed	2 years
Accreditation cost 1st unit	300.000 € + 30.000 €
Accreditation cost from the 2nd unit	3.000 € + 300 €
Diesel cost	0,600 €/litre
LNG cost	0,250 - 0,350
Fuel taxes	No
Demand evolution	Realistic
LNG usage sharing	Equitable
Reinvestment rate	8%
Financing rate	5%

Modified values concerning the baseline scenario

Figure 37. Emissions internalisation as an adjustable variable. Source: Institut Cerdà (2015).

Once again, the results will be displayed in the following chart.

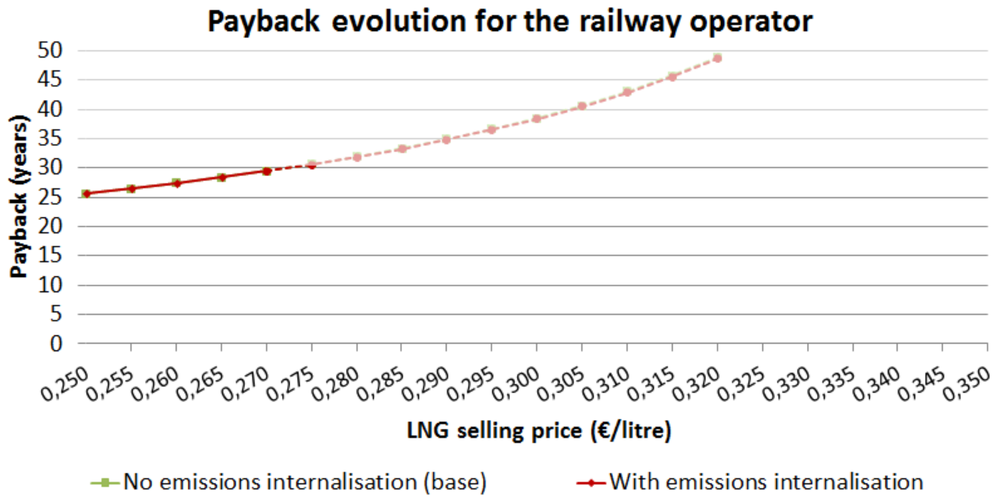


Figure 38. Payback evolution on the baseline scenario with the internalisation of the emissions as an adjustable variable. Source: Institut Cerdà (2015).

At merely economic level, the **internalisation** of the **emissions** (monetization of the reduction of CO_2 emissions) **has a negligible impact on the payback value** (difference between payback less than 0,1 years).

To conclude, it is important to mention that, as it is presented in the following chapter of this report dedicated to the environmental impact, the **saving of emissions** counted in mass of pollutants emitted to the atmosphere is **significant**.

6.3.2 Identification of the most influential variables

The sensitivity analysis carried out affirms that the following variables: diesel cost as well as the number of locomotives converted, demand evolution and typology and cost engine, constitute the most influential variables on the profitability of the diesel traction conversion to LNG.

The following table summarizes all the variables analysed as well as the main results obtained in the analysis of sensitivity in relation to the payback for the railway operator. They have been ranked according to the degree of greatest to least influence.

Key variable	Options assessed	Payback variation range	Impact
Litre of diesel cost	*0,400 – 0,900 €/ litre*	*31 years*	***Very High***
Demand evolution	*Pessimistic-Realistic-Optimistic*	*11 years*	***High***
No. locomotives converted	*1 – 2 – 3 locomotives*	*10 years*	**High**
Typology and engine cost	*Dedicated (96.600 – 235.000 €) / Dual (44.170 €)*	*10 years*	**High**
LNG usage sharing	*Equitable Diesel-LNG / LNG Favourable)*	*6 years (2 loc. trans.) 0,2 years (3 loc. trans.)*	***Medium***
Accreditation cost	*100.000 – 300.000€ + 3.000€ / 10.000 – 30.000€ + 300€*	*5 years*	**Medium**
Transformation speed	*2 – 5 – 10 years*	*4 years*	***Low***
Emissions internalisation	*Yes / No*	*0,1 years*	***Very Low***

Figure 39. Most influential variables. Source: Institut Cerdà (2015).

6.3.3 Sensitivity analysis on the most favourable scenario

Once variables are identified, the most favourable values have been combined in order to get optimal boundary conditions that assure the greatest profitability of the converted locomotives to LNG (minimum payback for the railway operator).

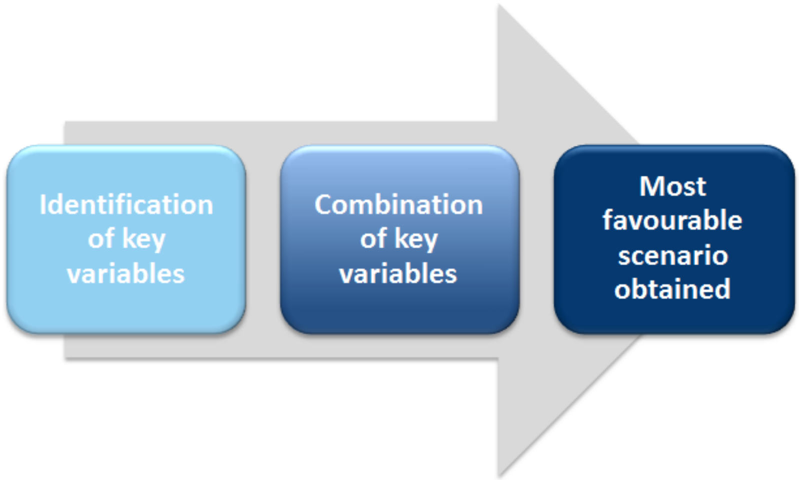


Figure 40. Process of the sensitivity analysis to the most favourable scenario. Source: Institut Cerdà (2015).

Combination of the most favourable values along with the key driving factors leads to paybacks between 5 and 10 years for the railway operator.

The optimal values concluded in the different sensitivity analyses are shown below for all the studied variables.

Variable	Value
Typology and engine cost	Dual 90% LNG (44.170 €)
Tank cost	21.300 €
Integration cost	21.000 €
No. loc. converted	2
Transformation speed	1 year
Accreditation cost 1st unit	100.000 € + 3.000 €
Accreditation cost from the 2nd unit	10.000 € + 300 €
Diesel cost	0,600-0,800 €/litre
LNG cost	0,250 - 0,350
Fuel taxes	No
Demand evolution	Optimistic
LNG usage sharing	LNG Favourable
Reinvestment rate	8%
Financing rate	5%

Modified values concerning the baseline scenario

Figure 41. Variables modified regarding a baseline scenario to result in the most favourable scenario. Source: Institut Cerdà (2015).

The obtained results in such conditions are presented as follows:

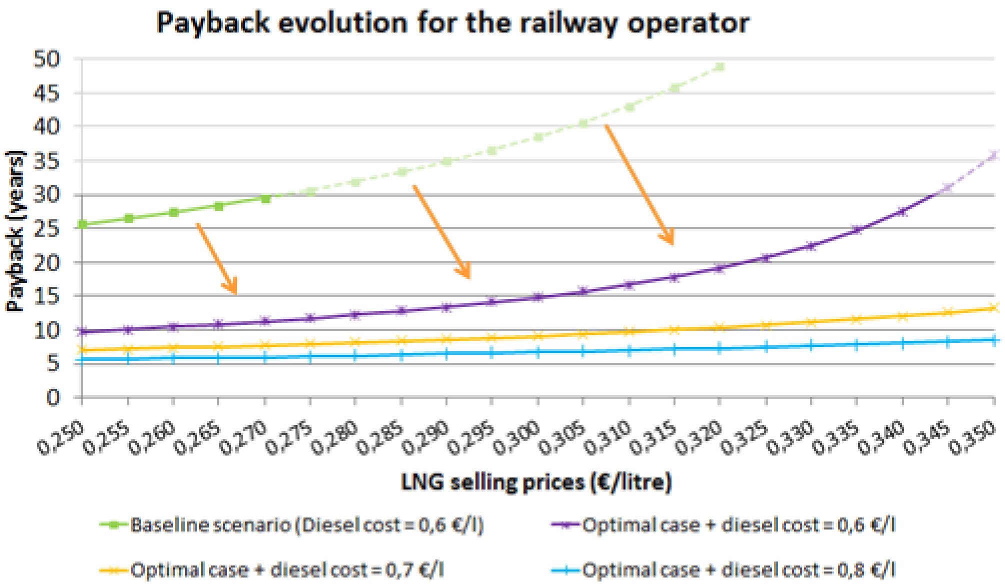


Figure 42. Payback evolution on the most favourable scenarios. Source: Institut Cerdà (2015).

The **optimal scenario** for the project profitability is achieved by means of a **combination** of the most favourable values of each given variable. With these **ideal conditions**, payback values in the order of **5-10** years are obtained considering the cost of diesel around 0,700-0,800 €/litre and a LNG sales price of 0,300 €/litre.

6.3.4 Sensitivity analysis on the possible scenarios

The most influential variables regarding the profitability of the project have been assessed for the purpose of achieving **possible scenarios** with an **intermediate profitability** between the **baseline** scenario (payback > 25 years) and the **optimal** scenario (payback ~ 5-10 years). These variables at the same time are the ones that depend the most on the Autoritat Portuària de Tarragona. This ensures that the result obtained in this analysis is as realistic as possible by having control over the variables.

These variables are accounted to be three: number of converted locomotives, engine cost and typology and finally the distribution of LNG use. In the following table the variables and its respective values are gathered and presented.

Key variables	Options assessed	Payback variation range	Impact	Influential capacity/ PAT dependency
Litre of diesel cost	*0,400 – 0,900 €/litre*	*31 years*	*Very High*	*Low*
Demand evolution	*Pessimistic-Realistic-Optimistic*	*11 years*	*High*	*Medium*
No. locomotives converted	***1 – 2 – 3 locomotives***	*10 years*	***High***	***High***
Typology & engine cost	***Dedicated (96.600 – 235.000 €) / Dual (44.170 €)***	*10 years*	***High***	***High***
Distribution of LNG usage	***Equitable Diesel-LNG / LNG favourable***	*6 years (2 loc. trans.) 0,2 years (3 loc. trans.)*	***Medium***	***High***
Accreditation cost	*100.000 – 300.000€ + 3.000€ / 10.000 – 30.000€ + 300€*	*5 years*	*Medium*	*Low*
Transformation speed	*2 – 5 – 10 years*	*4 years*	*Low*	*High*
Emission internalisations	*Yes / No*	*0,1 years*	*Very Low*	*Low*

Variables assessed to build possibilistic scenarios up

Figure 43. Most influential variables on the possibilistic scenarios. Source: Institut Cerdà (2015).

In order to construct the possible scenarios, four cases have been defined by the variation of the three variables identified above: type and cost of the engine, number of locomotives transformed and distribution of the use of LNG.

Variable	Baseline Scenario	Possibilistic scenario A (Dual fuel / 2 loc. / 0,600 €/l)	Possibilistic scenario B (Dual fuel / 3 loc. / 0,600 €/l)	Possibilistic scenario C (Dedicated / 2 loc. / 0,600 €/l)	Possibilistic scenario D (Dedicated / 3 loc. / 0,600 €/l)	Optimal scenario
Typology & engine cost	Dedicated: 170.000 €	Dual 90% LNG (44.170 €)	Dual 90% LNG (44.170 €)	Dedicated (96.600 €)	Dedicated (96.600 €)	Dual 90% LNG (44.170 €)
Tank cost	21.300 €	21.300 €	21.300 €	21.300 €	21.300 €	21.300 €
Integration cost	21.000 €	21.000 €	21.000 €	21.000 €	21.000 €	21.000 €
No. loc. transformed	3	2	3	2	3	2
Transformation speed	2 years	2 years	2 years	2 years	2 years	1 years
Accreditation cost 1st unit	300.000 € + 3.000 €	300.000 € + 3.000 €	300.000 € + 3.000 €	300.000 € + 3.000 €	300.000 € + 3.000 €	100.000 € + 3.000 €
Accreditation cost from the 2nd unit	30.000 € + 300 €	30.000 € + 300 €	30.000 € + 300 €	30.000 € + 300 €	30.000 € + 300 €	10.000 € + 300 €
Diesel cost	0,600 €/litre	0,600 €/litre	0,600 €/litre	0,600 €/litre	0,600 €/litre	0,800 €/litre
LNG cost	0,250 - 0,350	0,250 - 0,350	0,250 - 0,350	0,250 - 0,350	0,250 - 0,350	0,250 - 0,350
Fuel taxes	No	No	No	No	No	No
Demand evolution	Realistic	Realistic	Realistic	Realistic	Realistic	Optimistic
Distribution of use of LNG	Equitable	Favourable GNL	Equitable	Favourable GNL	Equitable	Favourable GNL
Investment rate	8%	8%	8%	8%	8%	8%
Financing rate	5%	5%	5%	5%	5%	5%

Variables modified with regard to baseline scenario

Figure 44. Most influential variables on the possibilistic scenarios ABCD. Source: Institut Cerdà (2015).

The obtained results are presented on the following chart.

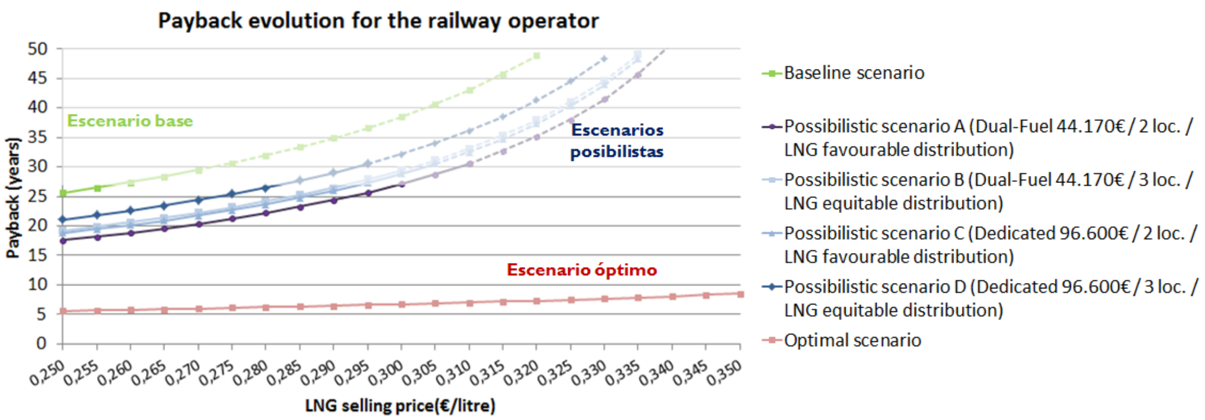


Figure 45. Payback evolution on the most influential variables of the possibilistic scenarios ABCD. Source: Institut Cerdà (2015).

The four possible scenarios presented **paybacks above 17 years**. These values do not represent a sufficiently attractive profitability for the railway operator. However, given the likely increases in diesel cost, this profitability could increase significantly, leading to attractive paybacks.

Based on the above situation and to reflect the most likely increase in diesel prices, it has been decided to study four new possible scenarios. These additional 4 scenarios (E, F, G, H) simulate an increment of diesel cost of 0,600 €/l and 0,800 €/l.

Variable	Base	Possibilistic scenario A (Dual fuel / 2 loc. / 0,600 €/l)	Possibilistic scenario B (Dual fuel / 3 loc. / 0,600 €/l)	Possibilistic scenario C (Dedicated / 2 loc. / 0,600 €/l)	Possibilistic scenario D (Dedicated / 3 loc. / 0,600 €/l)	Possibilistic scenario E (Dual fuel / 2 loc. / 0,800 €/l)	Possibilistic scenario F (Dual fuel / 3 loc. / 0,800 €/l)	Possibilistic scenario G (Dedicated / 2 loc. / 0,800 €/l)	Possibilistic scenario H (Dedicated / 3 loc. / 0,800 €/l)	Optimal
Typology and engine cost	Dedicated 170.000 €	Dual 90% LNG 44.170 €	Dual 90% LNG 44.170 €	Dedicated 96.600 €	Dedicated 96.600 €	Dual 90% LNG 44.170 €	Dual 90% LNG 44.170 €	Dedicated 96.600 €	Dedicated 96.600 €	Dual 90% LNG 44.170 €
Tank cost	21.300 €	21.300 €	21.300 €	21.300 €	21.300 €	21.300 €	21.300 €	21.300 €	21.300 €	21.300 €
Integration cost	21.000 €	21.000 €	21.000 €	21.000 €	21.000 €	21.000 €	21.000 €	21.000 €	21.000 €	21.000 €
No. loc. converted	3	2	3	2	3	2	3	2	3	2
Transformation speed	2 years	2 years	2 years	2 years	2 years	2 years	2 years	2 years	2 years	1 year
Accreditation cost 1st unit	300.000 € + 3.000 €	300.000 € + 3.000 €	300.000 € + 3.000 €	300.000 € + 3.000 €	300.000 € + 3.000 €	300.000 € + 3.000 €	300.000 € + 3.000 €	300.000 € + 3.000 €	300.000 € + 3.000 €	100.000 € + 3.000 €
Accreditation cost from the 2nd unit	30.000 € + 300 €	30.000 € + 300 €	30.000 € + 300 €	30.000 € + 300 €	30.000 € + 300 €	30.000 € + 300 €	30.000 € + 300 €	30.000 € + 300 €	30.000 € + 300 €	10.000 € + 300 €
Diesel cost	0,600 €/litre	0,600 €/litre	0,600 €/litre	0,600 €/litre	0,600 €/litre	0,800 €/litre	0,800 €/litre	0,800 €/litre	0,800 €/litre	0,800 €/litre
LNG cost	0,250 - 0,350	0,250 - 0,350	0,250 - 0,350	0,250 - 0,350	0,250 - 0,350	0,250 - 0,350	0,250 - 0,350	0,250 - 0,350	0,250 - 0,350	0,250 - 0,350
Fuel taxes	No	No	No	No	No	No	No	No	No	No
Demand evolution	Realistic	Realistic	Realistic	Realistic	Realistic	Realistic	Realistic	Realistic	Realistic	Realistic
Distribution of use of LNG	Equitable	LNG favourable	Equitable	LNG favourable	Equitable	LNG favourable	Equitable	LNG favourable	Equitable	LNG favourable
Reinvestment rate	8%	8%	8%	8%	8%	8%	8%	8%	8%	8%
Financing rate	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%

Variables modified with respect to baseline scenario

Values modified with respect to ABCD scenarios

Figure 46. The most influential variables on the possibilistic scenarios EFGH. Source: Institut Cerdà (2015).

The obtained results for the new scenarios are displayed below:

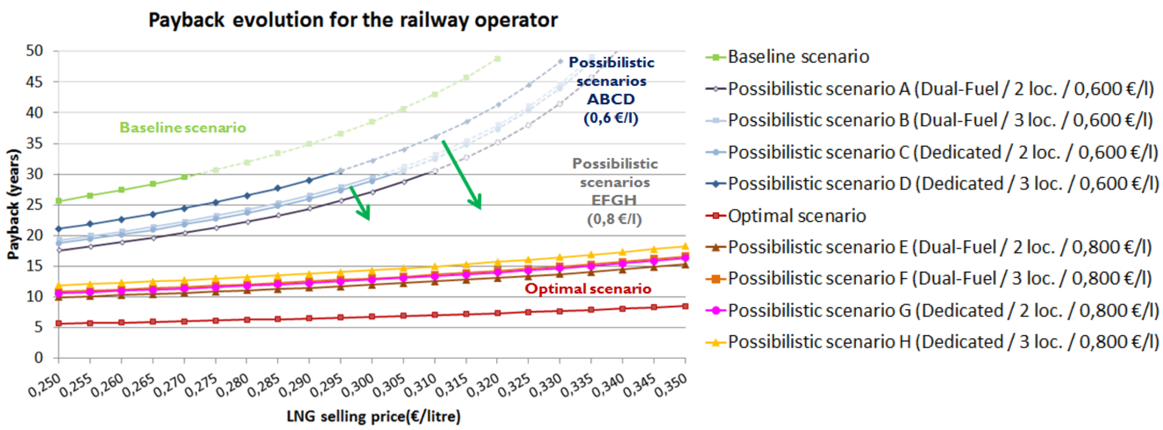


Figure 47. Payback evolution of the most influential variables on the possibilistic scenarios EFGH. Source: Institut Cerdà (2015).

The assumption for the diesel cost of **0,800 €/l** permits to reduce **payback** to **10-15 years** for the railway operator for the possible scenarios A,B,C and D (diesel price 0,600 €/l).

6.3.5 Sensitivity analysis for the gas operator

The profitability analysis for the gas agent was carried out for the identical scenarios defined previously: Baseline, A-H and Optimal. A part from the variables that have been taken into account in the previous cases, the following variables are added: type of refuelling, the loss of capacity by the shape of the tank, the minimum tank volume, the distance between the regasification plant and the port of Tarragona, The cost of LNG and the refuelling flow. The following table shows all the variables that will be used for the sensitivity analysis.

Variable	Base	Possibilistic scenario A (Dual fuel / 2 loc. / 0,600 €/l)	Possibilistic scenario B (Dual fuel / 3 loc. / 0,600 €/l)	Possibilistic scenario C (Dedicated / 2 loc. / 0,600 €/l)	Possibilistic scenario D (Dedicated / 3 loc. / 0,600 €/l)	Possibilistic scenario E (Dual fuel / 2 loc. / 0,800 €/l)	Possibilistic scenario F (Dual fuel / 3 loc. / 0,800 €/l)	Possibilistic scenario G (Dedicated / 2 loc. / 0,800 €/l)	Possibilistic scenario H (Dedicated / 3 loc. / 0,800 €/l)	Optimal
Engine typology	Dedicated	LNG Dual 90%	LNG Dual 90%	Dedicated	Dedicated	LNG Dual 90%	LNG Dual 90%	Dedicated	Dedicated	LNG Dual 90%
No. locomotives converted	3	2	3	2	3	2	3	2	3	2
Transformation speed	2 years	2 years	2 years	2 years	2 years	2 years	2 years	2 years	2 years	2 years
LNG cost	0,250 - 0,350	0,250 - 0,350	0,250 - 0,350	0,250 - 0,350	0,250 - 0,350	0,250 - 0,350	0,250 - 0,350	0,250 - 0,350	0,250 - 0,350	0,250 - 0,350
Refuelling type	Mobile (tank)	Mobile (tank)	Mobile (tank)	Mobile (tank)	Mobile (tank)	Mobile (tank)	Mobile (tank)	Mobile (tank)	Mobile (tank)	Mobile (tank)
Assuming prismatic tank capacity -> cylindric	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Tank truck capacity (litres)	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000
Distance to LNG distribution point	98,3 (Port of Barcelona)	98,3 (Port of Barcelona)	98,3 (Port of Barcelona)	98,3 (Port of Barcelona)	98,3 (Port of Barcelona)	98,3 (Port of Barcelona)	98,3 (Port of Barcelona)	98,3 (Port of Barcelona)	98,3 (Port of Barcelona)	98,3 (Port of Barcelona)
LNG cost (€/l)	0,250 - 0,350	0,250 - 0,350	0,250 - 0,350	0,250 - 0,350	0,250 - 0,350	0,250 - 0,350	0,250 - 0,350	0,250 - 0,350	0,250 - 0,350	0,250 - 0,350
Refuelling flow (l/min)	80	80	80	80	80	80	80	80	80	80
Demand evolution	Realistic	Realistic	Realistic	Realistic	Realistic	Realistic	Realistic	Realistic	Realistic	Optimistic
LNG usage distribution	Equitable	LNG Favourable	Equitable	LNG Favourable	Equitable	LNG Favourable	Equitable	LNG Favourable	Equitable	LNG Favourable
Reinvestment rate	8%	8%	8%	8%	8%	8%	8%	8%	8%	8%
Financing rate	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%

Variables modified with respect to baseline scenario

Influential parameters for gas company

Figure 48. Influential variables for the gas operator. Source: Institut Cerdà (2015).

Once analysed every type of scenarios the outputs obtained are presented below:

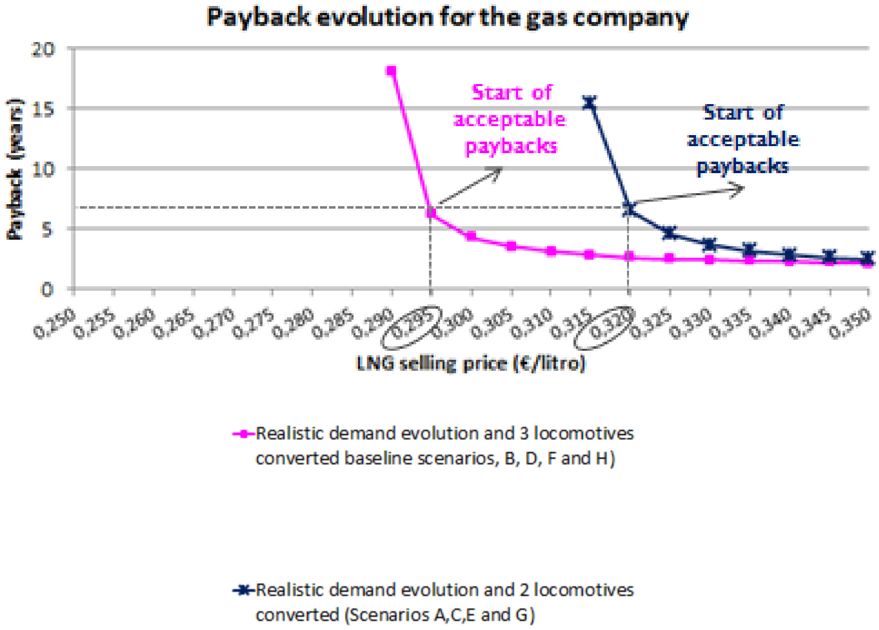


Figure 49. Payback evolution for the gas operator. Source: Institut Cerdà (2015).

The profitability for the gas agent on the analysed scenarios depends on **the number of the converted locomotives** (parameter which determines the LNG consumption). The **minimum sales** prices of LNG to ensure the profitability of the gas operator on the scenarios analysed are **0,295 €/l** (in the case of 3 converted locomotives) and **0.320 €/l** (in the case of 2 converted locomotives).

These sales prices of LNG guarantee **paybacks less than or equal to 6 years** and an IRR (internal rate pf return) higher than 12 % for the gas agent.

6.3.6 Global sensitivity analysis

In order to guarantee the transformation viability of the traction head by LNG, it is suitable to meet the following conditions simultaneously:

- LNG is tax-free the same way it is for diesel.
- The LNG price should not be inferior to **0,295 €/l** if 3 locomotives are converted or inferior to **0,320 €/l** if 2 locomotives are converted.
- The railway operator shall accept paybacks of **12-14 years** (only possible in conditions of high diesel price -0,800 €/l diesel-) or even in the order of **27-35 years** if the sales diesel price remains at a current level (0,600 €/l).

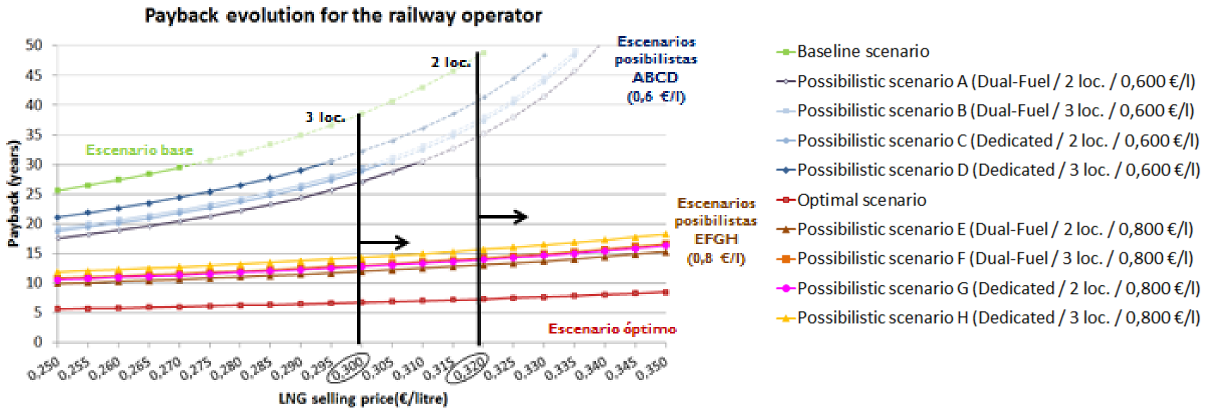


Figure 50. Payback evolution for the railway operator. Source: Institut Cerdà (2015).

Scenario	Base	A	B	C	D
No. locomotives converted	3	2	3	2	3
Minimum LNG selling price(€/l)	0,295	0,320	0,295	0,320	0,295
Payback railway operator (years)	**36,6**	**35,2**	**27,9**	**37,3**	**30,5**
Payback gas company (years)	6,2	6,6	6,3	6,6	6,2

E	F	G	H	Optimal
2	3	2	3	2
0,320	0,295	0,320	0,295	0,320
13,1	**12,9**	**14**	**14,2**	**7,3**
6,6	6,3	6,6	6,2	*

Remarks:
Cash flows of the gas company are positive over its useful life in accordance to the optimal scenario

Table 15 Overview table for the obtained results on the diverse evaluated scenarios. Source: Institut Cerdà (2015).

As an observation of the above table, it should be noted that in the optimum scenario for the rail operator, the economic flows for the gas agent are positive throughout the project lifetime.

6.4. Profitability conclusions

Even though results are not economically feasible on the baseline scenario, the Autoritat Portuària de Tarragona is capable of encouraging possibilistic scenarios that in light of an increase on diesel price (approximated value of 0,800 €/l) are bound to achieve paybacks lesser than 13-14 years for the railway operator.

Hence the conversion to a LNG traction head should be feasible both for the railway operator and the gas company in order to make this transformation viable. Right after the main conclusions drawn derived from the profitability analysis are presented:

Gas company profitability:

- The transformation **viability** of the diesel traction head to LNG for the gas company is driven by the **minimum LNG sales price**. Those must be **higher than or equal to 0,295 €/l** if 3 locomotives are converted or, similarly, higher than or equal to **0,320 €/l** if 2 locomotives are converted. By assuming these minimum prices, most of the analysed scenarios present **paybacks less than 7 years** and IRR superior to 12% for the gas company.

Railway operator profitability:

- The profitability analysis of the **baseline scenario** (dedicated engine - 170.000€, 3 converted locomotives within 2 years, accreditation cost of 300.000€ + 3.000€ for the first unit and of 30.000€ + 300€ for further conversions, diesel cost of 0,600 €/l, realistic scenario for demand evolution, equitable usage of LNG) does not show a feasible picture for the railway operator (**payback of 36 years**).
- The **Autoritat Portuària de Tarragona** may accomplish scenarios with more attractive paybacks by modifying those **variables** upon which it has a **relatively influence** (engine typology, number of converted locomotives and LNG usage in the LNG locomotives within the available fleet).
- **Diesel cost** is shifting in term of project profitability with a **vast influence** on the railway operator.
- By combining an **engine** with a **reduced cost** (inferior to 100.000€), the **intensive** usage of the converted fleet with **LNG** (prioritizing the LNG locomotives use before diesel ones) and with a **diesel price** scenario equal to or higher than **0,800 €/l**, the railway operator **payback** will be decreased to **13-14 years**.

- **The railway demand evolution** and **accreditation** cost also have a **meaningful impact** on the project profitability, although in this case the Autoritat Portuària de Tarragona has a minor influence to change them.
- As long as the **election** of the type of **engine**, number of the converted **locomotives** and **LNG** locomotive usage **distributions** within the available fleet (variables upon which the PAT possess a vast influence) are **added** along with the **diesel cost** drivers **higher than or equal to 0,800 €/l** and most **favourable** conditions for railway **demand** and **accreditation costs** (variables upon which the PAT do not possess any influence), the **payback** for the railway operator might reach **7,3 years** on the optimal scenario, but by no means being reduced less than 7 years.

7. Environment impact quantification

7.1. Environment benefits

The studies performed to date show relevant environmental benefits of LNG versus diesel. Some points considered to be relevant are presented thereupon:

- **Environmental benefits of natural gas:**
  - Reduction of the **acoustic contamination**.
  - Reduction of **gas contaminants** emissions and **greenhouse effect**.
    - NO_x emissions, particles, monoxide and carbon dioxide are minimized.
    - Sulphur dioxide is barely emitted, since natural gas does contain neither lead nor traces of heavy metals.

  In accordance to various executed studies on distinct transport sectors, the ensuing advantages are as follows:

  - In the road transport sector, where the use of natural gas has been around several years before the rail transport sector, the analysed studies show successful results on emissions reductions.

Emissions	CO_2	CO	SO_2	NO_x	Particles	Volatile organic compounds
Reduction in LNG with respect to Diesel	20-30%	70-90%	99%	75-95%	90%	89%

Table 16 Reduction in pollutants for road transport. Source: Institut Cerdà (2015).

  - In rail-mobility recent studies about the LNG usage as combustible have estimated the following reduction of emissions with respect to diesel:
    - Reduction of the environmental contamination **(NO_x, particles, CO) superior to 70%.**
    - Reduction of greenhouse gases in the order of **20-30%.**

7.2. Environmental impact expected

With the goal of computing the environmental impact associated to the gasification of shunting locomotives at the Port of Tarragona several data and assumptions have been considered as follows:

- **Economic data:**
  - Quotation of CO_2 emissions.
    - 6,26 € / tons of CO_2 (SENDECO, 2015).
- **Technical hypothesis:**
  - Diesel locomotives: Emission factors of gas and particles (EMIMOB, 2015)
    - 742 grams CO_2 / km
    - 9,46 grams NO_X / km
    - 0,32 grams PM / km
  - LNG locomotives: Emission factors of gases and particles
    - -20% grams CO_2 / km with respect to the CO2 emissions of diesel locomotives.
    - -70% grams NO_X / km with respect to the NOX of diesel locomotives.
    - -70% grams PM / km with respect to the PM emissions of diesel locomotives.

As a result, it turns out that the gasification of shunting railway services at the Port of Tarragona is driven to **reduce** to **551,2 tons of CO_2**, **14 tons of NO_x** and **480,0 kg of PM**, as well as **saving 3.451 €** coming from the internalisation of the CO_2 emissions within 30 years.

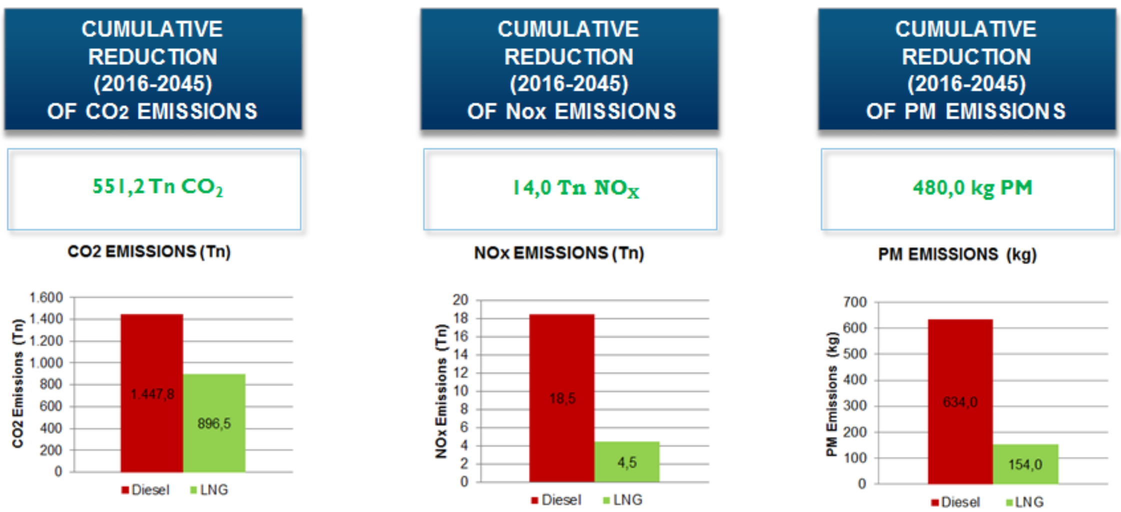


Figure 51. Emission savings. Source: Institut Cerdà (2015).

8. Conclusions and considerations of Phase 1

As seen from the section "*5. Likely technical and legal barriers to gasify the shunting services*", there are several barriers to gasify the shunting services at the Port of Tarragona, although all of them might be overcome by increasing time and cost.

8.1. Conclusions

From now on, main conclusions are presented down below derived from the feasibility study in accordance to its nature.

Technical feasibility:

- **LNG engine** for the railway traction is not yet within a standardised market (listed in a catalogue). Only one out of five providers (Guascor) has a LNG engine available in a catalogue which might be used for the shunting railway services at Port of Tarragona since it **meets the requirement requested**. Therefore, this might increase cost and supply time.
- In principle, the acquisition of a **LNG tank** for the rail traction does not entail **any** major **problem**: few of them are shown in catalogue (3 out of 7 providers contacted –Chart, Enric Group and Ingesic- have them listed in catalogue).
- **LNG engine** and **cryogenic tank** shall not imply a **modification higher than +/- 10%** than the weight with respect to the engine and diesel tank, in order to barely shift the gravitational centre over the accepted normative standards.

Legal feasibility:

- The **accreditation process** involves the main legal barrier (since LNG is not considered as fuel for the locomotive sector to date). However, the LNG railway project coordinated by Institut Cerdà will achieve a substantial progress to this matter.
- If the modification approach on the already accredited rolling stock (310/311 locomotive) is chosen, Adif shall approve it as the locomotives' owner.
- The necessity of developing **documentation with no framework of reference** in terms of gas. In the case of considering a prototype of locomotive with LNG traction, **a Provisional Authorization for its Circulation** will be required. On the other hand, if the technology is intended to be implemented for its commercial exploitation, then it will be requested to follow the following steps:

- **Risk assessment** arising from the implementation of the proposed amendment.
- An **independent assessor**'s report about evaluation process and risk analysis.

<u>Economic feasibility:</u>

In order for **rail traction with LNG** to be **viable** it must be profitable for the railway operator and for the gas agent.

Profitability for the gas company:

- The viability of the transformation for the gas agent is **conditioned** to the LNG minimum prices. Those should be higher than or equal to **0,295 €/l** by the time 3 locomotives are converted, when only 2 locomotives are transformed the prices should be higher than or equal to **0,320 €/l**. By assuming these minimum prices, all scenarios evaluated present a **lower payback of 7 years** and IRR superior to 12% for the gas company.

Profitability of the railway operator:

- The profitability analysis of the **baseline scenario** (dedicated engine - 170.000€, 3 locomotives transformed along 2 years, accreditation cost of 300.000 € for the first unit and of 30.000 + 300 € for the successive schemes, diesel cost of 0,600 €/l, realistic scenario for the demand evolution, LNG equitable usage) **does not appear to be a profitable approach** for the railway operator (payback of 36 years).
- The Autoritat Portuària de Tarragona may, by means of the modification of variables with which has a vast influence (engine typology, number of converted locomotives and LNG usage for the available fleet), accomplish scenarios with a more attractive paybacks.
- **Diesel cost** is the **most influential variable** to affect the project profitability for the railway operator.
- Combining an **engine** with a reduced cost (lower than 100.000 €), the **intensive use** of the LNG fleet (prioritizing the use of LNG locomotives as compared with diesel) and with a **diesel price scenario** higher than or equal to **0,800 €/l** leads to a decrease on the railway operator **payback** to **13-14 years.**

As long as the election of the type of engine, number of the converted locomotives and LNG locomotive equitable usages on the available fleet (variables upon which the Autoritat Portuària de Tarragona possess a vast influence) are added up alongside diesel cost higher than or equal to 0,800 €/l and most favourable conditions for **railway demand** and **accreditation** costs (variables on which the PAT do not possess any influence), the payback for the railway operator might reach 7,3 years on the **optimal scenario**, although by no means being reduced less than 7 years.

Environmental impact:

The transformation of the existing locomotives to LNG traction heads will provide a **cumulative reduction** of 551.2 tons of **CO_2** within 30 years, 14 tons of **NO_x** and 480,0 kg of **PM**, as well as saving up to **3.451 €** that comes from the internalisation of the CO_2 emissions.

8.2. Observations

Based on the conclusions presented above, it is clear that for the base scenario studied, the project in the Port of Tarragona does not present a viable scenario due to the high payback values obtained. In addition to the sensitivity analysis, considering the values of the variables that make up an optimal scenario, it is not possible to obtain payback values of less than 7 years.

Although due to the current conditions, the implementation of the LNG in the shunting services of the Port of Tarragona is not foreseen viable, next are listed some identified considerations to take into account, derived from the analysis realized throughout the study, and that frame important aspects to consider in the implementation of LNG in the railway sector.

8.2.1 Technical feasibility considerations

Fleet to be converted:

To choose the type of fleet transformation (existing/new) to be made:

- An existing locomotive for its modification requires (in the context of the Port Authority of Tarragona: 310/311 from Adif):
  - Reaching out to Adif in order to obtain the approval for the transformation.
  - Reaching out to the integrator. In this respect and for this project, ARMF set outs its predisposition towards operating as an integrator.
- New fleet acquisition: In the context of Port Authority of Tarragona, due to its willingness of internalizing the railway shunting services, it is essential to get in touch to a locomotive provider that might be interested on launching new shunting locomotives in the market, fuelled by LNG fuel.

LNG components:

- Gaining insight on the availability of technical solutions adjusted to the project necessities.
- Reaching out the engine (e.g. Guascor) and the cryogenic tank providers (e.g. Chart, Enric Group and Ingesic) in order to sample its interest on the project, as well as its predisposition to adjust its products listed in catalogue to the specific necessities.

8.2.2 Legal feasibility considerations

Project scope:

- **Limited option**: Testing process on the prototype locomotives.
  It is only required to obtain a Provisional Authorization for Circulation. This should be issued by:
  - Autoritat Portuària de Tarragona as long as tests are performed at all times within Port Authority's premises. On this matter, the current operations should be modified since nowadays both supply and overnight stay is performed within Adif premises.
  - Administrator: In the context of the Port of Tarragona, this would be Adif in case of using rail infrastructure owned by the administrator.
- **Full scope option:** Development of technology for its commercial exploitation.
  A risk analysis shall be performed derived from the implementation of the proposed modification, and an evaluator report about the evaluation process and the risk analysis. For this purpose it is recommended to:
  - Introduce a new LNG locomotive already accredited (in the context of the Port of Tarragona: 310/311). This might save temporal and monetary costs of accreditation, although it is necessary to count on Adif predisposition to convert them.
  - Reach out to Bureau Veritas in order to exercise as an appointed body (in the present project Bureau Veritas is proposed to exercise as designed body, given its expertise on the railway and LNG field).

Monitoring of projects of interest to follow-up:

At any event, it is recommended to stay tuned on the results and progress of the ongoing projects corresponding to the pilot test about LNG rail traction coordinated by Institut Cerdà which will be carried out in Asturias (expected outputs in 2018) whose normative framework defined may be applicable for this initiative, and on the other hand, the European project raiLNG with funds from the CEF program (Conneting Europe Facility).

Below, there is a summary of both projects mentioned above:

Characteristics of the ongoing project of the locomotive adaptation pilot.

- This pilot is the first traction railway test with LNG in Europe and the first in the world in the rail passenger sector regarding powers below 400hp.
- Objectives:
  - Reduction of environmental pollution (NOx, PM, CO) in accordance to the levels defined in Stage IIIB and with the objectives of the CleanEr-D project.
  - Reduction of noise pollution in accordance to the corresponding ETI and with the objectives of the CleanEr-D project.
  - Reduction of greenhouse gases.
  - Reduction of operating costs (fuel, maintenance).
- The scope of the transformation in Renfe's selected car for the pilot test object of this project, includes the engine, the fuel tanks and their associated circuitry as well as a programmable automaton. It has been decided to use a car from Renfe 2600 series. The Renfe 2600 Series is a narrow-track automotive vehicle model composed of diesel units that provide passenger service to the company Renfe Operadora in the northern area of Spain. They are manufactured from the reconstruction of units of the 2300 series.
- The diesel engine of one of the two paired automotive units has been replaced by another one that will consume natural gas for its propulsion and the tanks in which LNG will be stored together with all the necessary auxiliary circuitry have been installed. Specifically, the modifications have been developed in a self-propelled train of the Feve diesel park (2600). The engine chosen is the Gas ISLG 280 model from Cummings. CHART tanks: Models from its HLNG 100 catalogue will be used as the main deposit and the HLNG72 as secondary. Both connected to each other.
- The locomotive is expected to travel a distance of 12.000 / 15.000 km.

Characteristics of raiLNG project.

- Engineering and installation of an LNG Engine model G3516B ULB and auxiliary equipment on a locomotive. A diesel-powered locomotive will be set up for carrying out comparable real life trial
- The project includes the draft and detailed design, the engineering and the construction of a tender platform with 20feet ISO container of LNG with a unit of treatment to match the physical requirements of the LNG to be used as fuel in the locomotive and the connections to the locomotive
- The pilot test will aim at carrying out a significant number of real life trails for a minimum amount of 15000km

- The following parameters will be monitored and collected:
  - Instant and average fuel consumption (LNG and diesel)
  - Engines working parameters (revolutions per minute, power, temperature, etc)
  - GPS monitoring (position, speed, trip slopes, etc.
  - Weather parameters (temperature, pressure, rain, etc)
  - Pollutant and harmful emissions (CO, NOx, PM, Methane, etc.)
  - Fuelling data (times, costs, leakages, foil off, etc
  - Maintenance (pieces wearing and influence, oil consumption, etc.)
- Develop a deployment plan of LNG in the TEN-T network that will include
  - Traffic and demand analysis of selected sections within the TEN-T network
  - Location and technical requirement of LNG fuelling infrastructure
  - Investment, financial and funding resources
  - Implementing schedule proposed
  - Environmental Analysis of the implementation of the Roll Out Plan

8.2.3 Economic feasibility considerations

As mentioned at the beginning of the present study, the sensitivity analysis concluded on the non-profitability of the project of the Autoritat Portuària de Tarragona. Nevertheless, a number of variables are listed hereafter in which it is considered that the Port Authority, and by extrapolation the majority of the Port Authorities as a whole, might exercise certain control or influence to enhance the studying conditions and that condition the results achieved:

- Optimize variables that rely directly on the Autoritat Portuària de Tarragona:
  - LNG engine selection whose cost is not higher than 100.000 €.
  - Total conversion of the operating locomotives fleet (3 locomotives).
  - Intensive usage distribution of LNG traction heads among the available fleet.
- Taking into account that the external variables might increase heavily the transformation profitability:
  - Diesel cost is the most influential variable on the economic feasibility of the study: combining compliance of the variable that depends on the Port Authority with a diesel price scenario equal to or higher than 0,800 €/l results in a 13-14 years payback.
  - Demand evolution of the shunting services also leads to a key factor to determine profitability.

  - Accepting paybacks that never will be amounted to less than 7 years is indispensable.
- Contact to gas agents for LNG supply:
  - Enhancing project profitability for the gas agent (IRR>12% and payback<7years).

9. Introduction to the study of the Phase 2 and background

The preceding phase was focused on the study on economic, technical and legal feasibility for the gasification of the shunting locomotives services at the Port of Tarragona. This study was addressed in three stages with the following objectives:

- In the **first stage**, the existing infrastructure and the shunting railway services at the Port of Tarragona were identified. This has allowed to know the state, characteristics and particularities of the infrastructure and the railway services in which the project is conducted.
- The **second stage** was focused on distinguishing the technical and the legal barriers that could jeopardize the project and the potential to overcome them.
- The **third stage** was devoted to analysing the economic feasibility of the project for all the actors involved in its exploitation and the environmental impact that would suppose the transformation of a diesel locomotive to Liquified Natural Gas, henceforth called LNG.

Finally, the conclusions obtained throughout the previous stages were presented, as well as the recommendations and the next steps for the Tarragona Port Authority, for the gasification of the shunting railway services.

In this context, the second phase of the activity starts with the aim of obtaining a procedure to perform all the technical modifications necessary to implement a possible transformation of a diesel shunting locomotive to LNG traction.

Therefore, with the objective of establishing the basis from a technical point of view for a future implementation of a locomotive prototype modified to be operated with LNG, the following activity blocks have been identified for the analysis and study development:

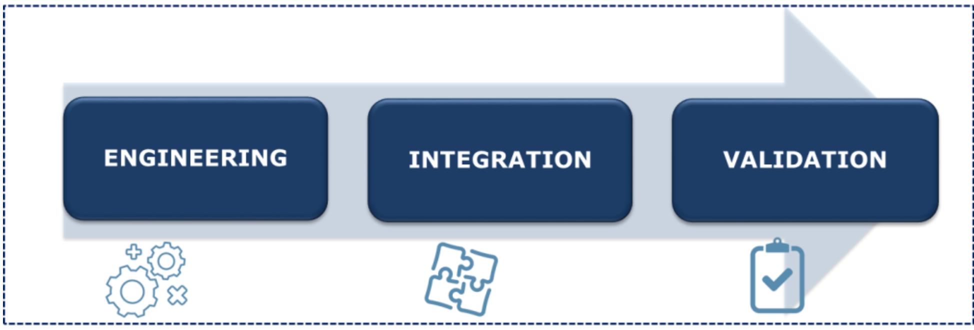


Figure 52. Diagram of the activity blocks to perform in the Phase 2

- **Engineering**: Definition of the technical requirements and study/definition of the engine and deposits to implement, as well as their affection to different areas: maintenance plans, training courses and necessary tests.
- **Integration**: Analysis and definition of the necessary works for the integration of the new system into the present locomotive.
- **Validation**: Definition of the methodology and the data to be registered during the monitoring in order to evaluate the modified locomotive.

10. Engineering

10.1. Definition of the technical requirements of the project

The second phase of the project pretends to deepen into the different aspects of the technical viability, and to define the procedure to follow in order to perform the required modifications on the diesel locomotive for its transformation to LNG. Therefore, the bases for the future construction of a LNG locomotive prototype will be established from the technical point of view.

It is placed on record that, as a result of the first phase, the Port of Tarragona considered in its Technical File EV3 the transformation of the locomotive Adif type 311 for the second phase of the project. However, after subsequent conversations and seeing that the locomotive fleet of types 310 and 311 are the same, it was deemed appropriate to consider also the technical aspects for the modification of an Adif type 310.

Locomotive Adif 311

Locomotive Adif 310

Figure 53. Pictures of the shunting locomotives in the Port of Tarragona (Adif 311, Adif 310).

Consequently, the first objective to cover in the second phase of the project is the final recommendation of the type of locomotive to be transformed according to the technical aspects and based on the criteria explained hereunder.

In addition, the technical features of the thermal engines installed in both types of locomotives will be related, according to the information provided by their manufacturers, to be compared afterwards to the data of the proposed LNG locomotive. Particularly, for each type of locomotive, the following values will be exposed:

- Maximum power / regime
- Maximum torque / regime
- Power and torque curves
- Consumption data

In the absence of credible information, the power curve of the diesel engines will be approximated according to the "engine free acceleration" methodology (or similar).

10.1.1 Locomotives general overview

The shunting locomotives of the 311 and 310 series are mixed, equipped with diesel thermal engines coupled to a triphasic generator. The electric traction is made by four asynchronous triphasic engines coupled one to each axle.

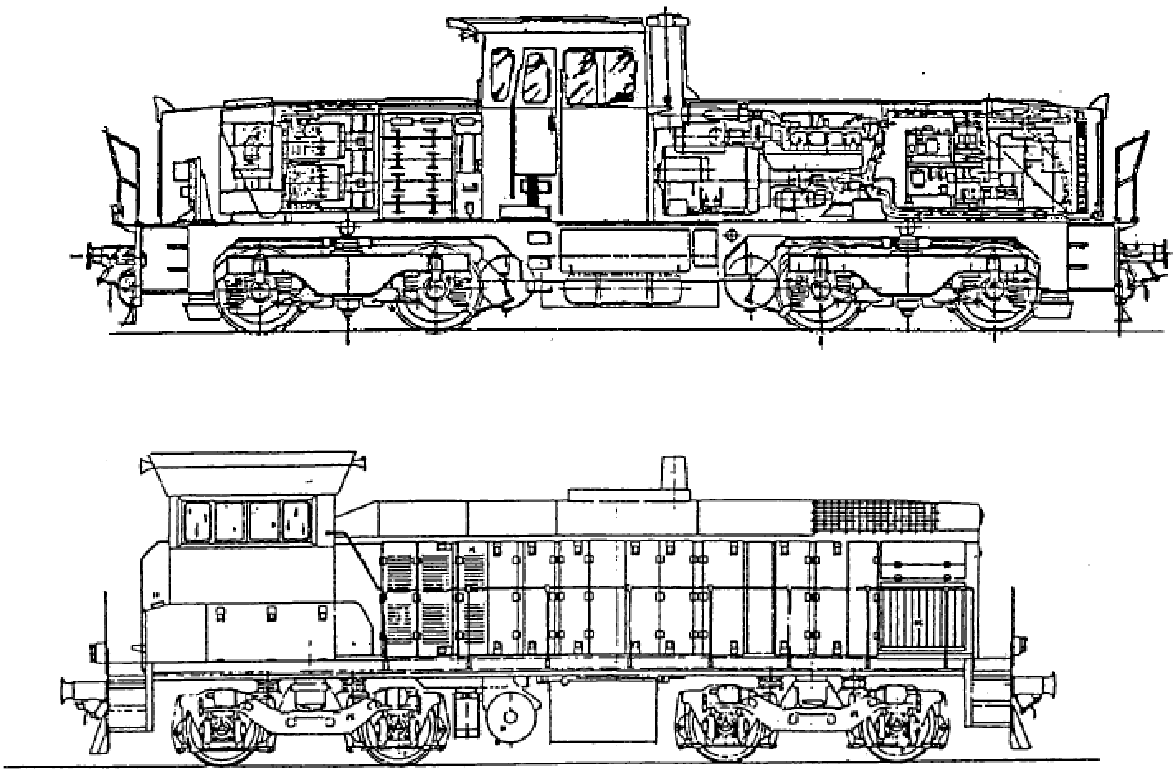


Figure 54. Scheme of the series 311 (top) y 310 (bottom).

A table summarizing the main parameters of both types of locomotives, that can be related to the purpose of this project, is presented below:

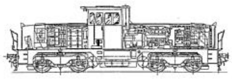
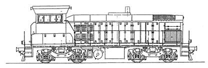
Locomotive type	**311**	**310**
		
Traction	Electric (4 engines), with energy produced by a diesel engine coupled to a triphasic generator. Bo'Bo' configuration	
Manufacturer	MTM	MACOSA / Meinfesa (with GM license)
Years of production	1990 to 1991	1989 to 1991
Units produced	60	60
Length	13050 mm	12550 mm
Width	2900 mm	3100 mm
Height	4268 mm	4305 mm
Weight	80000 kg	78000 kg
Gasoil tank's capacity	2200 l	2770 l
Traction power	705 kW	598 kW
Tractive effort	260 kN	*Not available*
Maximum speed	92 km/h	114 km/h

Table 17 Main parameters of the existing locomotives at the Port of Tarragona.

Different power data has been found during the different consultation phases, thus they must be considered as unreliable or, at least, as approximations.

10.1.2 Characteristics of the current Diesel Engines to be transformed

A table summarizing the main parameters of the diesel engines of both types of locomotives is presented below:

Locomotive type	**311**	**310**
Engine type	4-stroke Diesel	2-stroke Diesel
Brand	MTU	EMD (General Motors)
Model	8V 396TC 13	8-645-E
Power supply	Turbocharger	Charger Roots
Maximum power / regime	785 kW at 1800 rpm	750 kW at 900 rpm
Maximum torque / regime	*Not available*	*Not available*
Power and torque curves	*Not available*	*Not available*
Consumption data	*Not available*	*Not available*
Weight (without fluids)	2520 kg (*)	8622 kg (*)
Heater	*Not available*	232 kg (*)

(*) According to the "*DESCRIPTIVE MANUAL OF THE VEHICLE*" by RENFE

Table 18 Main parameters of the diesel engines of the existing locomotives at the Port of Tarragona.

As it can be observed in the previous table, the available information about both types of locomotives is limited. These engines are old and discontinued by their respective manufacturers, hence they do not provide information about them anymore.

Noteworthy is the great difference between the weights in both engines, thus these values will be considered with some reservation.

Given the disparity and the lack of reliability of the values found, it is suggested to measure the current characteristics of the engines before the locomotive transformation to LNG.

The measurement of the locomotives characteristics could be performed by the "free acceleration method" using a diesel diagnosis system. It can be also performed indirectly, connecting the generator output to a “resistor” and measuring the electric power generated by the assembly.

The measurements of the initial characteristics could be taken at the Integrator facilities. Once the modifications have been conducted, the measurements will be repeated to evaluate the final performances of the transformed locomotive.

10.1.3 New solutions to consider

The conclusions obtained from the first phase of the project performed by Institut Cerdà, consider the substitution of the original engine of the locomotive by a new dedicated LNG engine.

Considering the objectives previously mentioned in this report and the kick-off meeting of the second phase of this project, the range of possibilities will be expanded adding the solution of using Dual cycle engines (gasoil + LNG) and the possibility to transform the current engine to LNG. In short, the following solutions will be considered and analysed for both types of locomotives (311 and 310):

a) Substitution of the current engine for a dedicated LNG engine
b) Transformation of the current engine to LNG fuel
c) Substitution of the current engine for another Dual cycle engine (gasoil + LNG)
d) Transformation of the current engine to Dual cycle engine (gasoil + LNG)

The “transformation of the engine” is understood as the replacement of several components of the engine for others adapted to the new requirements of the LNG combustion, such as the buttstock, the injectors, strokes, valves, etc, maintaining the same block, pistons, crankshaft, etc.

Finally, it should be mentioned that although it is not the subject of this study, there are other alternative solutions, apart from those considered relative to LNG, to reduce emissions from diesel traction locomotives. These solutions can be consulted in the European project Ten-T CleanEr-D in which different alternatives are studied to respond to new legislation regarding emissions in the railway sector at European level. Within these solutions, the possibility of improving the efficiency of diesel engines through the introduction of particle filters as well as the introduction of new emerging technologies for future restrictions such as designs based on multi-technologies post-treatment and hybrid solutions a (diesel-electric) or with energy storage systems, are studied.

10.1.4 Criteria for the selection of the locomotive to be transformed

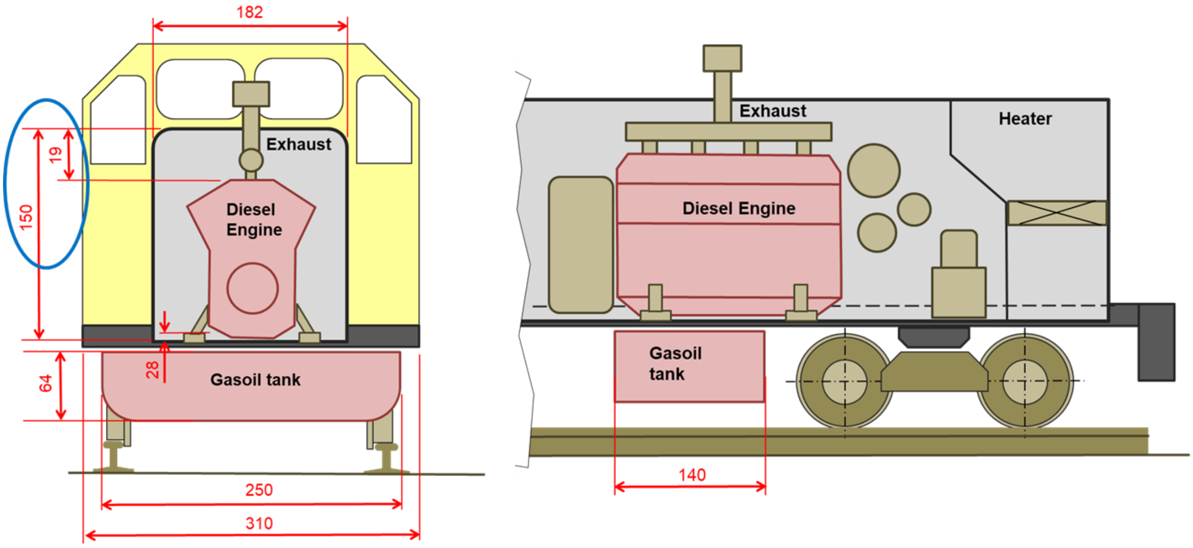
Whatever the solution recommended for the engine, the locomotive model to be transformed must be decided previously, since, as it has already been said, the locomotive fleet of both types is the same and their utilization is similar.

The following main technical aspects must be considered and evaluated:

- Space availability within the locomotive fairing, for the replacement of the engine or its transformation.
- Space availability within the locomotive fairing, for the replacement or extension of the water radiator for engine cooling.
- Ease of access to the interior of the fairing, in order to operate the replacement of the engine or its transformation.
- Location and volume of the current diesel fuel tank that allows the easy installation of the necessary cryogenic LNG tanks.

To this end, measurements in the Adif workshops in the Port of Tarragona were carried out on both units regarding the two types of locomotive, obtaining the following results characterized in the following figures:

Adif 311



Adif 310

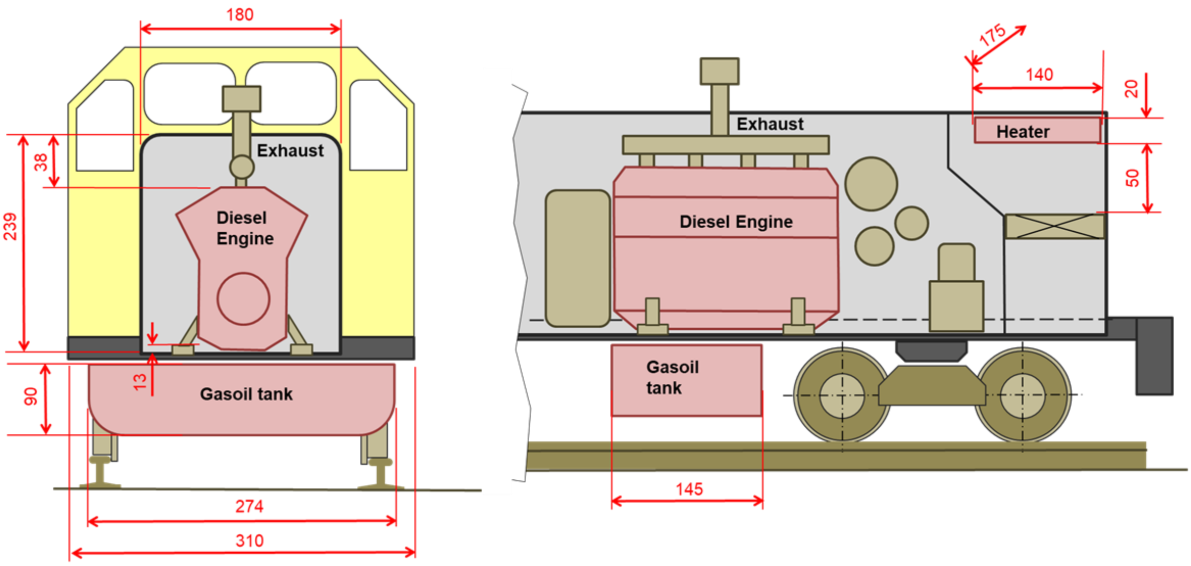


Figure 55. Details on the measurements scheme obtained in the workshops for both types of locomotives (Adif 311, Adif 310).

10.1.5 Analysis

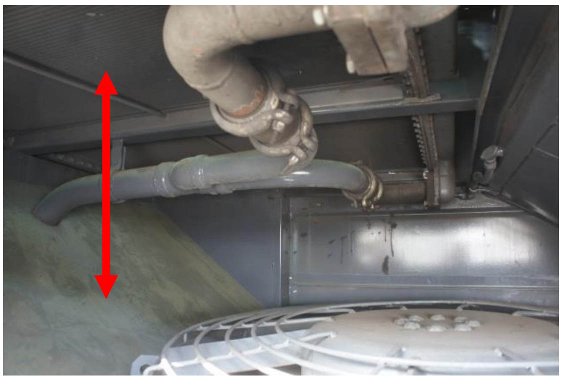
Concerning the previous figures and specially the measurements of the engine compartment, it is observed that the dimensions of the model 311, indicated with a **(x),** are significantly lower than those corresponding to the model 310. This implies that:

1. The engine of the locomotive 311 can hardly be replaced by a new one because the engines considered viable have a height greater than the dimensions available.
2. The locomotive 310 has more free space above the engine, which facilitates larger interventions.

Engine's cylinder head zone MTU – Locomotive 311

Engine's cylinder head zone EDM – Locomotive 310

3. There is more than enough space in the locomotive 310 to increase the volume of the water cooler – engine without problems.



4. The diesel tanks of both models are similar, although the tank of the 310 is larger and there are no elements on the sides that makes difficult to replace them by cryogenic deposits.

Diesel deposit – Model 311 *Diesel deposit – Model 310*

10.1.6 Conclusions

Considering all the points stated above, it is recommended to act on the locomotive **Adif 310** for its transformation from diesel to LNG.

In the following sections, advantages and drawbacks of the final solution to be adopted on the Adif 310, among the possibilities listed below, will be analysed:

a) Substitution of the current engine for a dedicated LNG engine
b) Transformation of the current engine to LNG fuel
c) Substitution of the current engine for another Dual cycle engine (gasoil + LNG)
d) Transformation of the current engine to Dual cycle engine (gasoil + LNG)

10.2. Analysis of the possible LNG and Dual engines for the project

A market research of all the LNG and Dual engines that could be used in this project has been conducted.

Within this framework, the following variables have been considered: technical features, reliability, maintenance, costs, technical support and references in use under similar conditions of all the engines considered.

10.2.1 General overview

Due to the current low demand, there are few companies offering solutions for the use of natural gas in railway applications.

The options available that could be implemented in locomotive engines are the spark ignition engines (dedicated engines) and the compression ignition engines, that are capable of mixing varying quantities of diesel and natural gas during its operating (dual engines).

The operating of the natural gas dedicated engines and the petrol engines is very similar, using a throttle valve and a spark ignition system to control the mix of LNG and air into the cylinder. In these engines, gasoil is completely replaced with the natural gas, but they require the installation of additional elements.

The principle of operation of the Otto cycle engines has an inherent loss of power and lower efficiency comparing to the diesel cycle. In any case, the continuous advances in this technology done by the manufacturers guarantee the viability of the use of natural gas in railway applications.

Dual technology in diesel engines is based on the injection of natural gas to the air intake ducts or directly to the cylinders. The amount of gasoil injected is reduced and replaced with the natural gas. The gasoil acts as a pilot starting the ignition, causing the ignition of the natural gas afterwards. Any throttle valve nor ignition system are needed in dual engines, maintaining the compression ignition advantages (diesel). Note that this system does not allow the total replacement of the gasoil with natural gas, only 80% of substitution is achieved in the best cases. The implementation of the dual technology is more economic comparing to the natural gas dedicated engine due to the retrofitting application of the current diesel engine. It should be also noted that these engines can run only with diesel in case of not having natural gas available.

The use of natural gas replacing the diesel allows significant reduction of polluting emissions and noise. This reduction of emissions, specially CO2, particles and nitrous oxides, enhance the quality of the air in the machinery zone, that is enough polluted by vessels and other machines used in the port.

To perform the research of the retrofitting processes necessary to transform a diesel-powered shunting locomotive to GNL, the two technologies existing in the market have been analysed:

- Natural gas dedicated engine
- Dual engine (diesel/natural gas)

In both cases, it is possible to find in the market the entire engine developed by the manufacturer or a conversion kit developed by a specialized company.

A comparative table showing the advantages and disadvantages of the use of each technology is presented below.

<table>
<tr><th colspan="3"></th><th>ADVANTAGES</th><th>DISADVANTAGES</th></tr>
<tr><td rowspan="2">DEDICATED ENGINE (NATURAL GAS)</td><td>A</td><td>NEW NG ENGINE</td><td>Reliability
Consumption
Low maintenance
Emissions and noise reduction</td><td>Cost
Complexity of integration
Range reduction</td></tr>
<tr><td>B</td><td>TRANSFORMATION OF THE CURRENT ENGINE TO NG</td><td>Cost
Ease of integration
Reliability
Consumption
Low maintenance
Emissions and noise reduction</td><td>Worsen performances
Range reduction</td></tr>
<tr><td rowspan="2">DUAL ENGINE</td><td>C</td><td>TRANSFORMATION OF THE CURRENT ENGINE TO DUAL</td><td>Cost
Reliability
Range
Performances</td><td>Reduced gas consumption
LNG tank integration</td></tr>
<tr><td>D</td><td>NEW DUAL ENGINE</td><td>Reliability
Range
Performances</td><td>Cost
Complexity of the engine and the LNG tank integration
Reduced gas consumption</td></tr>
</table>

Table 19 Technologies comparative

The above table reveals the necessity of prioritize the use of natural gas dedicated engines as the best form to maximize the gas consumption and to reduce the polluting emissions.

Even though the use of dual technology seems interesting, it should be noted that dual engines require a levelled engine load to offer the maximum performance which allows substitution rates close to 70-80%. The engine load of the shunting locomotives at the Port of Tarragona is in constant change so the use of dual engines is detrimental for their proper functioning.

10.2.2 Natural gas engines

These engines are based in the Otto cycle, with spark ignition and using natural gas as fuel.

All the natural gas engines available in the market that can be used for this application have been considered.

The power should be similar or slightly higher than the diesel engines that are currently being used to avoid that the minimum torque available in the Otto cycle affects the ergonomics of the driver.

The market of natural gas engines designed for railway applications is rather low, almost non-existent. For this reason, natural gas engines used in generator sets or maritime applications have been added to this study.

10.2.2.1 Natural gas engines developed by the manufacturer

The engines that have been exclusively developed by the manufacturer to use natural gas as fuel come with all the guarantees of optimum functionality.

Nevertheless, any of these natural gas engines specially designed for railway applications have been found in the market. Hence, natural gas engines that have been initially developed for other applications but with a consolidated demand, such as generator sets, have been considered. In principle, these engines could be used in a locomotive, with slight modifications that should be performed by the manufacturer.

10.2.2.2 Natural gas engines (retrofitted)

Several specialized companies develop kits to convert diesel-powered engines to LNG. This study will also consider and analyse the possibility that a system specially developed to convert locomotive engines is already existing.

In these transformations, the current diesel engine is used as the base and all the mechanical modifications are applied on it, such as the reduction of the compression ratio or the addition of spark plugs and other components.

10.2.3 Dual engines

All dual engines found in the market that can be used for this application have been considered.

The power should be similar or slightly higher than the diesel engines that are currently in use.

As in the case of the natural gas engines, the market of dual engines is rather low, so engines used in generation sets and maritime application have been also included to the study.

It is possible to find in the market dual engines developed by the manufacturer itself, and kits developed by specialised companies that convert the client's original engine.

10.2.3.1 Dual engines developed by the manufacturer

Since these engines have been developed by the manufacturer itself, they come with all the guarantees of the optimum functionality.

10.2.3.2 Dual engines (retrofitted)

Several companies develop conversion kits to dual engines adaptable to different engines. This process is known as 'retrofit'. Its main advantage is the possibility to transform the original diesel engine to dual functionality, reducing the costs significantly since there is no need to renovate the entire engine.

10.2.4 Benchmarking dedicated and dual engines

The full range of products of the following companies have been analysed:

- DRESSER-RAND (Siemens)
  - GUASCOR
- IVECO
- MAN
- Rolls Royce Power Systems
  - MTU
  - Detroit Diesel
  - Bergen Engines
- Wärtsilä
- Baudouin Moteurs
- DEUTZ
- CATERPILLAR
  - EMD
  - MWM
  - MAK
  - FG Wilson
  - PERKINS
- Mercedes Benz
- CUMMINS
- General Electric Rail
- MITSUBISHI
- Energy Conversion Inc. – ECI
- OMNITEK
- EVARM

In the following section, the specifications of the selected engines that could be used for this application will be detailed.

10.2.4.1 NG dedicated engines

10.2.4.1.1 GUASCOR (SIEMENS)

Model		SFGLD360 Lean Burn Gas Engine
Type		V-12 Turbocharged 4-stroke
Power		700 kW to 1800 min-1 503 kW to 1200 min-1
Frequency		60 Hz to 1800 min-1 60 Hz to 1200 min-1
Diameter (mm)		
Stroke (mm)		
Cylinder capacity (l)		35,9
Unladen weight (kg)		4200
Dimensions		
	Width (B) mm	1.664
	Length (A)mm	2.637
	Height (C) mm	1.738
Emissions		consult

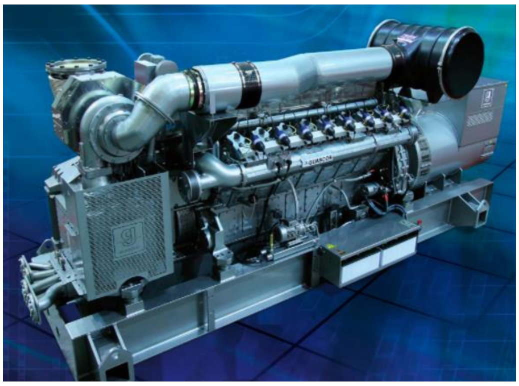


Figure 56. Engine GUASCOR SFGD360

10.2.4.1.2 MAN

Model	E3262 LE 202
Type	V-12 90º Turbocharged 4-stroke
Power	580 kW to 1800 min-1 550 kW to 1500 min-1
Frequency	60 Hz to 1800 min-1 50 Hz to 1500 min-1
Diameter (mm)	132
Stroke (mm)	157
Cylinder capacity (l)	25,8
Unladen weight (kg)	1849
Dimensions	
Width (B) mm	1.243
Length (A)mm	1.748
Height (C) mm	1.500
Emissions	

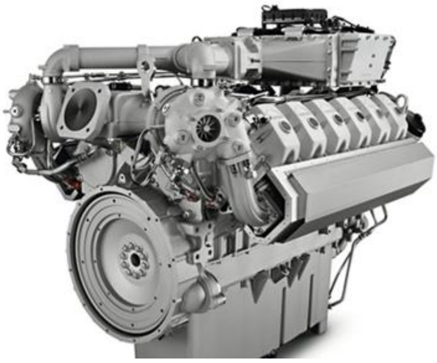


Figure 57. Engine MAN E3262

10.2.4.1.3 MWM (Caterpillar)

Model	TCG 2016 V16 C
Type	V-16 Turbocharged 4-stroke
Power	800 kW to 1500 min-1 Generator
Frequency	50 Hz 60 Hz available
Diameter (mm)	
Stroke (mm)	
Cylinder capacity (l)	35
Unladen weight (kg)	8.450 Generator
Dimensions	
Width (B) mm	1.590
Length (A)mm	4.090 Generator
Height (C) mm	2.190
Emissions	consult
Fuel	Natural gas

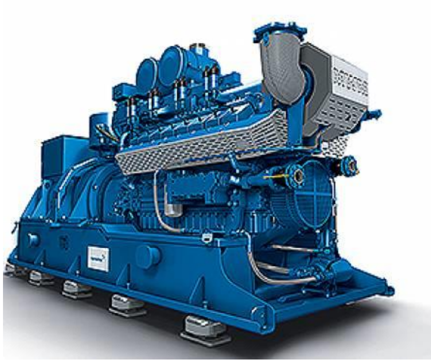


Figure 58. Engine MWM TCG 2016 V16 C

10.2.4.1.4 CATERPILLAR

Model	CG170-12
Type	V-12 Turbocharged 4-stroke
Power	1000 kW to 1500 min-1
Frequency	50 Hz 60 Hz available
Diameter (mm)	
Stroke (mm)	
Cylinder capacity (l)	
Unladen weight (kg)	
Dimensions	
Width (B) mm	
Length (A)mm	
Height (C) mm	
Emissions	consult
Fuel	Natural gas

Figure 59. Engine CATERPILLAR CG170-12

10.2.4.1.5 FG WILSON (Caterpillar)

Model	PG1250B2 Engine Perkins 4016-61TRS2
Type	V-16 Turbocharged 4-stroke
Power	1042 kW to 1500 min-1 Generator
Frequency	50 Hz
Diameter (mm)	160
Stroke (mm)	190
Cylinder capacity (l)	61,12
Unladen weight (kg)	5.820
Dimensions	
Width (B) mm	2.100
Length (A)mm	6.340 Generator
Height (C) mm	3.370
Emissions	consult
Fuel	Natural gas

Figure 60. Engine FG Wilson PG1250B2

10.2.4.1.6 PERKINS (Caterpillar)

	Perkins
Model	4000 Series 4012TESI Spark Ignited Gas Engine
Type	V-12 Turbocharged 4-stroke
Power	632 kW to 1500 min-1
Frequency	50 Hz
Diameter (mm)	160
Stroke (mm)	190
Cylinder capacity (l)	46
Unladen weight (kg)	4.680
Dimensions	
Width (B) mm	1.888
Length (A)mm	2.681
Height (C) mm	1.893
Emissions	consult
Fuel	Natural gas

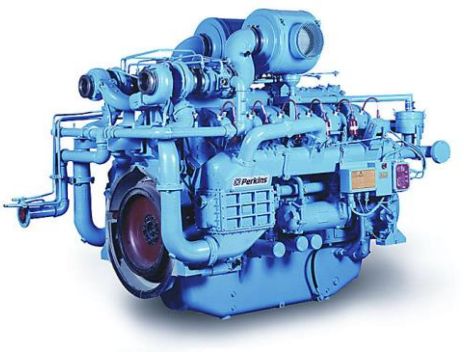


Figure 61. Engine PERKINS 4012TESI

10.2.4.1.7 MITSUBISHI

Model	GS12R-MPTK
Type	V-12 Turbocharged 4-stroke
Power	722 kW to 1500 min-1
Frequency	50 Hz 60 Hz available
Diameter (mm)	170
Stroke (mm)	180
Cylinder capacity (l)	49,03
Unladen weight (kg)	5.350
Dimensions	
Width (B) mm	1.832
Length (A)mm	2.421
Height (C) mm	2.137
Emissions	consult
Fuel	Natural gas

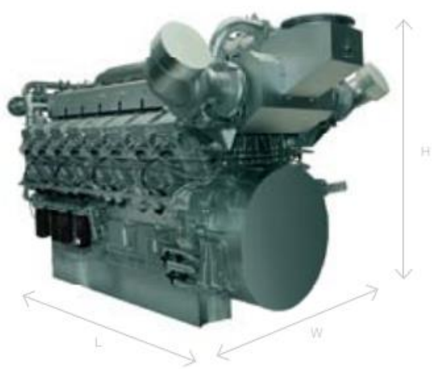


Figure 62. Engine MITSUBISHI GS12R-MPTK

10.2.4.2 Retrofitted NG engines

10.2.4.2.1 Energy Conversion Incorporated - ECI

ENERGY CONVERSIONS INC.
alternative fuel systems for high output engines

The American company ECI provides several solutions for the conversion of locomotive diesel engines to natural gas.

Among the solutions, there is a conversion kit to natural gas for the full range of EMD 645 engines, such as the one that is implemented in the Adif 310 locomotive.

The system involves:

- Modification of the cylinder head
- Pistons replacement
- Addition of an ignition system (coils, spark plugs, etc.)
- Low pressure natural gas injection system
- Detonation sensors in each cylinder
- Exhaust temperature sensors in each cylinder
- ECU for the engine
- Gas leak detection system

ENGINE MODEL	full load rated speed RPM	output continuous BHP	kW
EMD roots blown DF, & SI			
EMD 8-645 E1, E2, E6	750	800	570
	900	1050	745
EMD 12-645 E1, E2, E6	750	1200	865
	900	1500	1075
EMD 16-645 E1, E2, E6	750	1700	1210
	900	2100	1500
EMD turbcharged - DF, (SI for these models currently under development)			
EMD 8-645 E3, E4, E7	750	1200	894
	900	1525	1137
EMD 12-645 E3, E4, E7	750	1830	1364
	900	2305	1718
EMD 16-645 E3, E4, E7	750	2460	1834
	900	3070	2289
EMD 20-645 E3, E4, E7	750	3055	2278
	900	3600	2684
EMD 12-710 G4B	UNDER DEVELOPMENT		
EMD 16-710 G4B			
EMD 20-710 G4B			

DF- dual fuel, SI- spark ignited

Table 20 Model variants of the EMD 645 engine

Figure 63. EMD 12-645-E engine

10.2.4.3 Dual engines

10.2.4.3.1 MTU (Rolls-Royce)

Model	MTU 12V 4000 S83
Type	V-12 90º Turbocharged 4-stroke
Power	1500 kW to 1800 min-1
Frequency	
Diameter (mm)	170
Stroke (mm)	210
Cylinder capacity (l)	57,2
Unladen weight (kg)	6613
Dimensions	
Width (B) mm	1.582
Length (A)mm	2.386
Height (C) mm	2.015
Emissions	

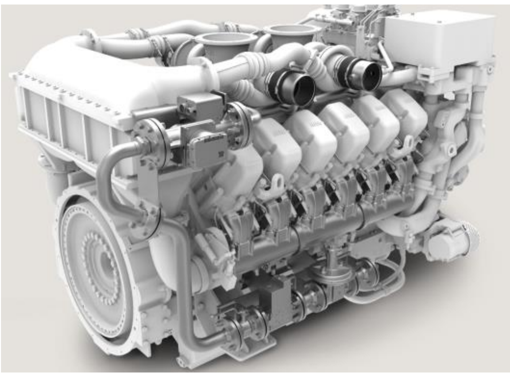


Figure 64. Engine MTU 12V 4000 S83

10.2.4.3.2 WÄRTSILÄ

Model	6L20DF
Type	L-6 Turbocharged 4-stroke
Power	960 kW to 1000 min-1 engine 920 kW to 1000 min-1 Generator
Frequency	50 Hz 60 Hz available
Diameter (mm)	200
Stroke (mm)	280
Cylinder capacity (l)	
Unladen weight (kg)	9.400
Dimensions	
Width (B) mm	1.690
Length (A)mm	3.254
Height (C) mm	2.329
Emissions	IMO Tier III
Fuel	MDO Marine Diesel Oil HFO Heavy Fuel Oil NG Natural Gas

Figure 65. Engine WÄRTSILÄ 6L20DF

10.2.4.4 *Dual engines - retrofit*

10.2.4.4.1 OMNITEK Engineering

American company that have developed their own conversion systems from diesel engines to natural gas (dual).

The company is specialized in long-haul trucks engines transformation.

They are not interested in this project and claim they see low profitability in the dual conversion for the locomotives in study.

Figure 66. Caterpillar 3406E and Mercedes Benz OM904LA engines

10.2.4.4.2 EVARM

Spanish company that have developed their own conversion systems from diesel engines to natural gas (dual).

The company is specialized in long-haul trucks' engines transformation.

They are interested in this project, but they have not enough experience to transform 2-stroke engines like the one used in type 310 locomotives.

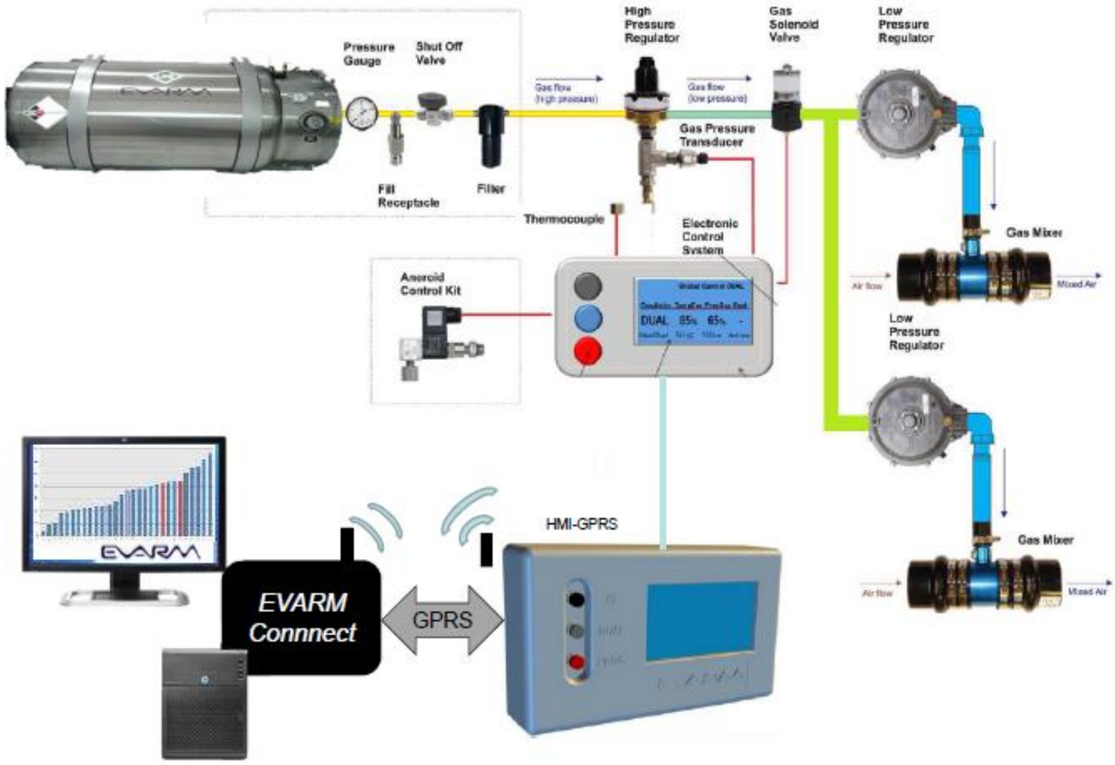


Figure 67. Dual system developed by EVARM

10.2.4.4.3 Energy Conversions Inc.

ENERGY CONVERSIONS INC. alternative fuel systems for high output engines

The American company ECI provides several solutions to convert diesel engines to natural gas (dual).

They have implemented more than 30 dual conversions of EMD 645 engines, some of them in locomotives.

Figure 68. Dual system developed by ECI

ENGINE MODEL	full load rated speed RPM	output continuous BHP kW	
EMD roots blown DF, & SI			
EMD 8-645 E1, E2, E6	750	800	570
	900	1050	745
EMD 12-645 E1, E2, E6	750	1200	865
	900	1500	1075
EMD 16-645 E1, E2, E6	750	1700	1210
	900	2100	1500
EMD turbcharged - DF, (SI for these models currently under development)			
EMD 8-645 E3, E4, E7	750	1200	894
	900	1525	1137
EMD 12-645 E3, E4, E7	750	1830	1364
	900	2305	1718
EMD 16-645 E3, E4, E7	750	2460	1834
	900	3070	2289
EMD 20-645 E3, E4, E7	750	3055	2278
	900	3600	2684
EMD 12-710 G4B	UNDER DEVELOPMENT		
EMD 16-710 G4B			
EMD 20-710 G4B			

DF- dual fuel, SI- spark ignited

Table 21 Model variants of the EMD 645 engine

10.2.4.4.4 General Electric Transportation

GE Transportation

General Electric has developed a trial version of a dual locomotive prototype. It can run using diesel and LNG, with a maximum substitution rate of 80%.

Figure 69. NG Dual system developed by General Electric (NextFuel™ Natural Gas Retrofit)

10.2.5 Engine selection

The criteria considered for the engine selection is listed below:

- Specific version to be directly used in locomotives
- Suitable dimensions to the space available
- Natural gas dedicated engine
- Ease of integration
- Cost

Even though the following sections describe the details of each of the variables considered and the reasoning used to justify the choice, in summary, it concludes that the project will be performed on the Type 310 locomotive, converting the 2-stroke diesel engine GM 8-645-E using a conversion kit to natural gas developed by the company ECI. Only Guascor as a manufacturer of dedicated natural gas engines has shown its interest in making the necessary adjustments for its application to the locomotive of the project.

By means of this transformation, it is expected to get a natural gas dedicated engine, specially adapted to use in locomotives. Its integration will be relatively easy to perform since it is only a modification of the current diesel engine.

10.2.5.1 Specific version for locomotives

All those engines without a version that has been specifically developed to be used in locomotives have been discarded.

Even though any engine developed to be used as a generator could be also implemented in electric traction locomotives, it should be remarked that they require specific adjustments to the engine’s management system for proper functionality. Manufacturers have shown little interest in adapting their engines to locomotives, so they have been discarded.

10.2.5.2 Engine dimensions

Another important criterion to discard engines from the selection has been their size, specially their height.

The available height for the engine in Type 311 locomotives is 1500 mm, making the installation of most of the engines unfeasible. Conversely, the available height in Type 310 locomotives is 2390 mm, what makes the engine choice more flexible. The study and the analysis performed to obtain the previous conclusions are described below.

10.2.5.2.1 Prior analysis: dimensions and weights

Type 310 locomotive:

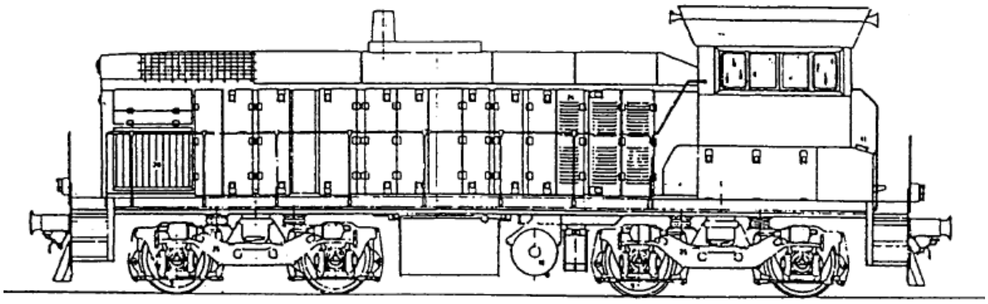
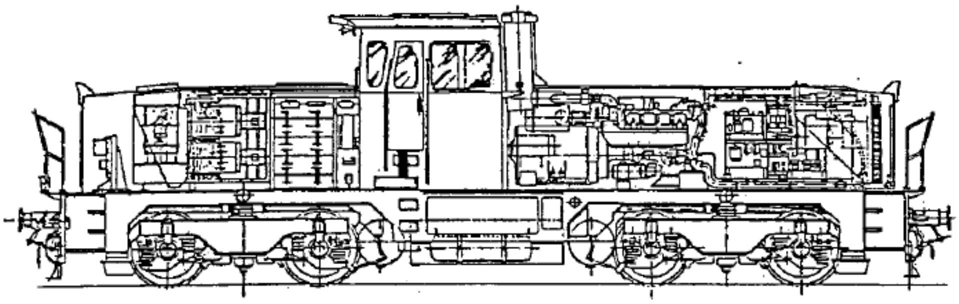
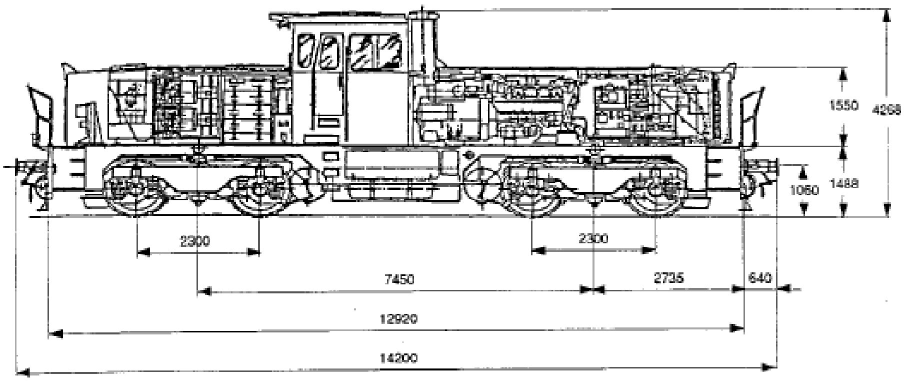


Figure 70. Type 310 locomotive

All the traction system components are located at the front side of the locomotive, facilitating the integration of the accessory elements, such as the gas lines, the cooling water system, the electrical wiring, etc.

Type 311 locomotive:





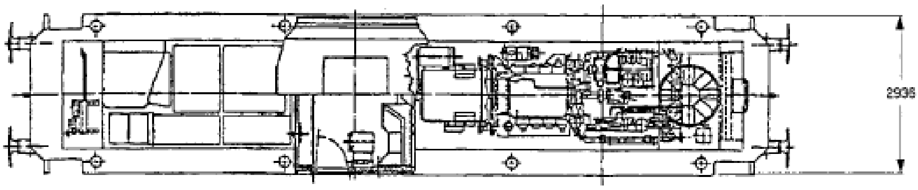


Figure 71. Type 311 locomotive

Engines' dimensions comparative:

MOTOR				MOTOR / MOTOR+GENERADOR* Length (A) mm	Width (B) mm	Heigth (C) mm	Weigth kg
Motores actuales Diesel							
MTU	MTU V8 396TC 13	Diesel	Locomotora	2013	1439	1380	2520
General Motors / EMD	GM 8-645-E	Diesel 2T	Locomotora	3632	1750	2010	8622
Motores dedicados Gas Natural							
Guascor	SFGLD360	Gas	Locomotora	2637	1664	1738	4200
MAN	E3262 LE 202	Gas	Generador	1748	1243	1500	1849
MWM	TCG 2016 V16 C	Gas	Generador	4090*	1590*	2190*	8450*
Caterpillar	CG170-12	Gas	Generador	4064*	1810*	2210*	10800*
FG Wilson	PG1250B2	Gas	Generador	6340*	2100*	3370*	5820*
Perkins	4012TESI	Gas	Generador	2681	1888	1893	4680
Mitsubishi	GS12R-MPTK	Gas	Marino	2421	1832	2137	5350
EMD Electromotive	EMD 8-645-E	Gas	Locomotora	3632	1750	2010	8622
Motores Dual							
MTU	12V 4000 S83	Dual	Generador	2386	1582	2015	6613
Wärtsilä	6L20DF	Dual	Marino	3254	1690	2329	9400
General Electric	NextFuel™ Retrofit	Dual	Locomotora	nd	nd	nd	nd
EMD Electromotive	EMD 8-645-E	Dual	Locomotora	3632	1750	2010	8622

Table 22 Engines' dimensions comparative

Figure 72. Dimensions of one engine

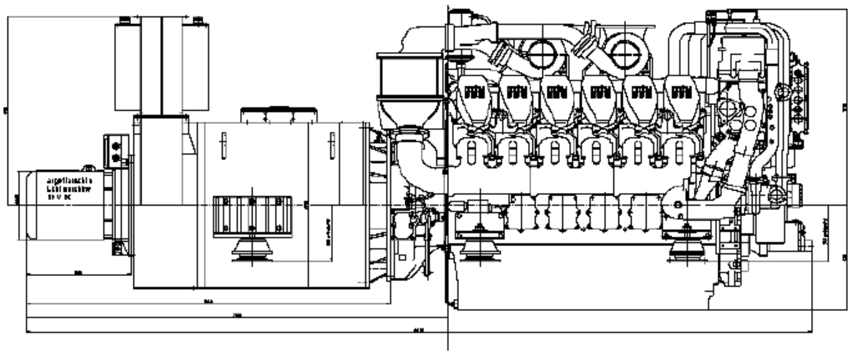


Figure 73. Engine-Generator set dimensions

10.2.5.3 Dedicated natural gas engine

Dedicated natural gas engines have been prioritised rather than the dual technology, ensuring the total substitution of gasoil by natural gas. The study and the analysis performed to obtain the previous conclusions are described below.

10.2.5.3.1 Dual engine

A duel diesel engine is based on a simple diesel engine coupled to a system that enables the natural gas entering the combustion chamber. This kind of engines uses gasoil to provoke the natural gas ignition. This process is known as pilot injection.

10.2.5.3.1.1 Low pressure dual engine

Even though other alternatives exist, the most used system for the introduction of natural gas into the engine is based on a gas mixer installed before the engine supercharging system.

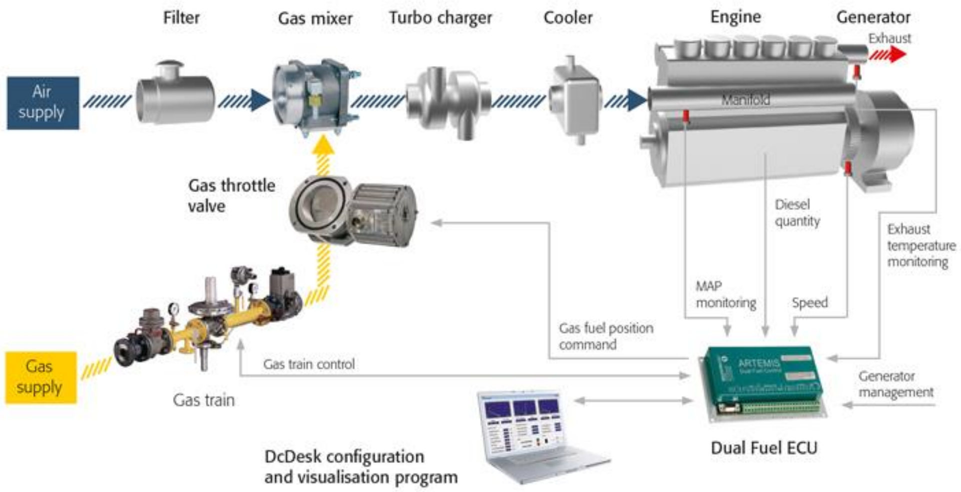


Figure 74. Dual engine with gas injection by a mixer (Source: Artemis)

The following figure shows how the pilot injection of gasoil during the compression phase provokes the gas ignition and initiate the explosion phase.

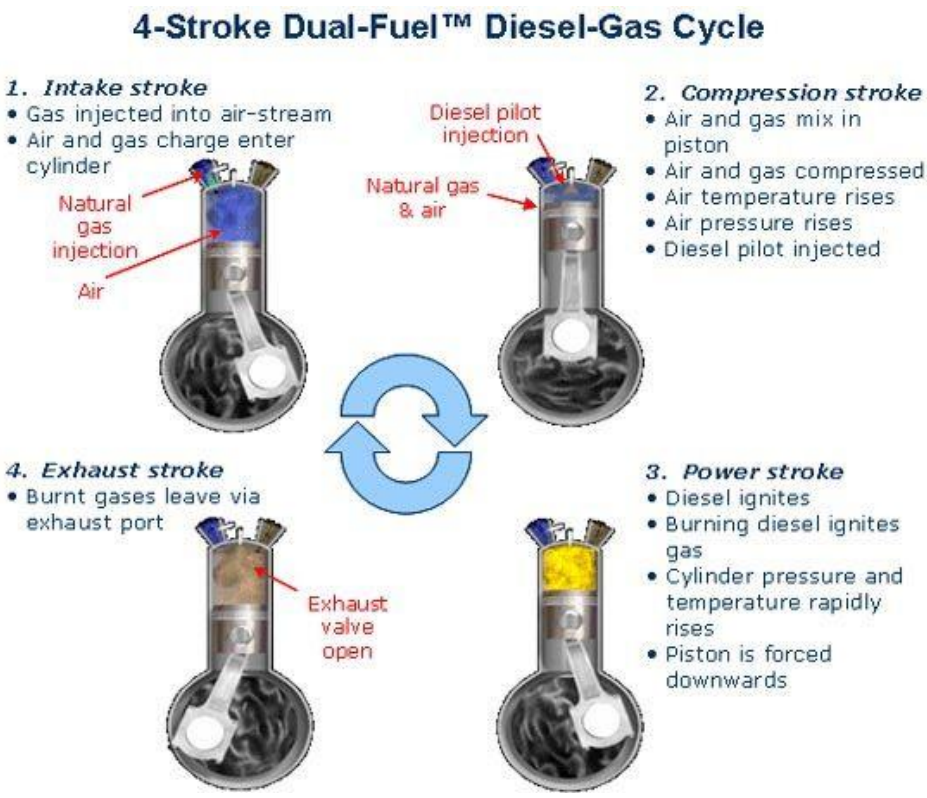


Figure 75. 4-stroke dual engine cycle

10.2.5.3.1.2 High-pressure dual engine

The company Westport has developed the system HPDI (High Pressure Direct Injection), for its application in engines of heavy transport vehicles with great success.

It is a dual system in which the gas is introduced directly to the combustion chamber at high pressure (higher than 300 bar) and using a pilot injection of gasoil to provoke the combustion.

The Westport's HPDI system was initially developed for truck Cummins engines. In 2017, the commercialization of the HPDI 2.0 was initiated, and this can be applied to other heavy-duty engines manufacturers.

Its application to locomotive engines as the one of the present project is not possible due to the flow limitation of the injectors developed so far by Westport.

Figure 76. Westport's high-pressure injector (gas/diesel)

10.2.5.3.2 Advantages and disadvantages

The advantages and disadvantages presented below, are referenced to the comparison with a natural gas dedicated engine, that is, a spark ignition engine with Otto cycle and using 100% of natural gas.

Advantages:

The main advantages of using dual engines are the followings:

- The original diesel engine is maintained and transformed so it can use natural gas. The implementation is more economic.

- Flexibility. The engine can still work properly with diesel in case of not having natural gas available.
- The performances of the original engine are maintained.
- No temperature problems in critical elements such as the valves and the exhaust manifold.
- Pilot injection acts like the ignition system, ensuring less maintenance against the spark ignition system of the traditional Otto engine.

Disadvantages:

The main disadvantages of using dual engines are the followings:

- Gasoil is also required for the engine operation.
- The level of emissions is higher compared to a natural gas dedicated engine. Specially, the NOx and particles emissions.
- The percentage of gas substitution (part of natural gas replacing gasoil during the engine operation) depends on the engine load. The maximal substitution percentage is commonly close to 80%.
- The integration of two fuel tanks, one for gasoil and another for natural gas, may be complex due to space constraints in the locomotive.

Even though the use of dual technology seems interesting, it should be remarked that dual engines require a levelled engine load to offer the maximum performance which allows substitution rates close to 80%.

The use of the shunting locomotives in the Port of Tarragona implies a continuous change in the engine load, making the use of dual engines detrimental for their proper operation. The substitution rate will difficulty reach 40-50% of the total consumption.

The difficulty in the integration of both gasoil and LNG tanks, just as the lower emissions reduction than the one achieved with the natural gas dedicated engines, have totally discarded the solution of dual engines in this project.

It has been considered that the use of natural gas dedicated engines maximizes the LNG consumption and the reduction of polluting emissions.

10.2.5.4 Ease of integration

The integration of a new engine different to the current one involves the need to redesign all its anchors and holders, as well as the adaptation of the air, water, oil and fuel conduits. All the electric system must be adapted too.

If the current engine can be maintained and successfully converted using the proper kit, the integration problems are simplified.

10.2.5.5 Cost

The cost of the dedicated Guascor natural gas engine that could be adapted to the project is very similar to the cost of the engine conversion kit developed by ECI.

If it is considered the greater complexity of the replacement of the engine: redesign and adaptation of anchors, supports, wiring of the engine, compatibility with the existing generator, as well as the costs of accreditation and validation of a new engine, it is concluded that the cost of the replacement of the engine versus the retrofit of the current engine are very similar.

10.3. Definition of the LNG tank characteristics

Considering the performance characteristics of the current engine, the capacity of the LNG tank will be determined, just as its technical features. Moreover, it will be taken into account that the deposit requires a level indicator, a pressure regulator, safety valves and a heat exchanger for the liquid vaporization.

10.3.1 Prior definitions

The natural gas is a mixture of gases mainly composed by methane. It is a combustible gas that is extracted from geological formations. Hence, it can be labelled into the non-renewable energy source.

Elemento	Formulación	%
Metano	CH_4	70-90%
Etano	C_2H_6	
Propano	C_3H_8	0-20%
Butano	C_4H_{10}	
Dióxido de Carbono	CO_2	0-8%
Oxígeno	O_2	0-0,2%
Nitrógeno	N_2	0-5%
Sulfato de Hidrógeno	H_2S	0-5%
Otros gases	A, He, Ne, Xe	trazas

Table 23 Natural gas composition

The liquified natural gas (LNG) is the liquid fluid obtained when the natural gas is cooled to -162ºC. This allows its volume to be reduced 600 times, which thereby facilitates transportation.

The natural gas combustion produces at least 25-30% less CO2 than gasoil’s, per unit of energy produced.

The natural gas enables to achieve significant reductions of polluting emissions in comparison with the gasoil:

- NO_X reduction: 35 - 40 %.
- SO_2 reduction: 98 %.
- Particles reduction: 98 %.

A cryogenic tank is the set composed by the inner container, insulation, thermal enclosure, fixing brackets, commissioning equipment, pipelines, valves, pressure gauges and other accessory elements that enables to store LNG.

The LNG vaporizer is the thermal exchanger that, using the water of the combustion engine, vaporizes the cryogenic liquid fuel so that the gas is introduced into the engine's fuel-supply system. The gas temperature ranges from -40ºC to +105ºC.

The generation of vapours into the tank due to the ambient temperature that slowly heats the liquid of the tank (while the pressure is maintained constant) is called Boil-off. The discharge of these vapours to the atmosphere is known as Vent.

The vaporization equipment is the set of elements such as vaporizers, re-heaters and pumps, with their respective accessories, whose task is to transform the stored liquid to gas for onward supply into the internal combustion engine.

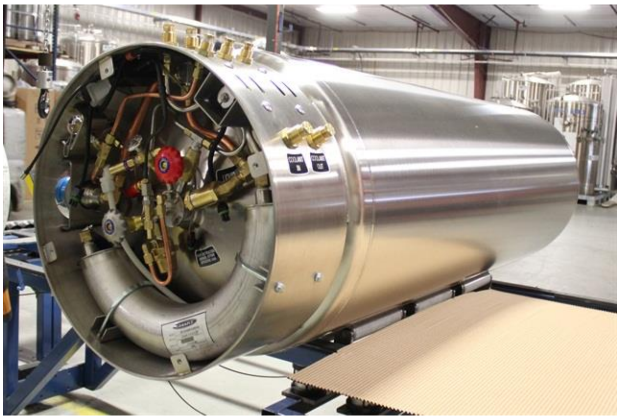


Figure 77. LNG cryogenic tank (Source: Chart)

10.3.2 Technical features

The LNG tanks must comply with the ECE R110 regulation for the use of natural gas in motor vehicles and the *ISO 12991 Liquefied natural gas (LNG) -- Tanks for on-board storage as a fuel for automotive vehicles.*

The cryogenic tank must be extremely well preserved, so it can maintain the liquid fuel inside without any external cooling system. To this end, the tank is covered with insulating material and it is closed into a vacuum-sealed container. The LNG tank and the outer cover are separated by a vacuum chamber that guarantees the maximal thermal preservation. This combination between insulation and vacuum is known as super-insulation and achieves maximum values of thermal efficiency.

The super-insulation allows periods of more than one week without gas leaks due to the boil-off. Both the inner container and the outer cover are made of stainless steel to guarantee the best performance and longevity of the system.

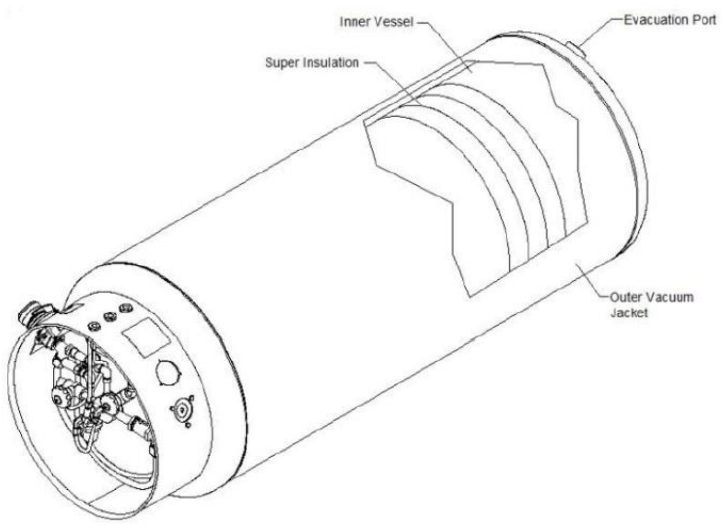
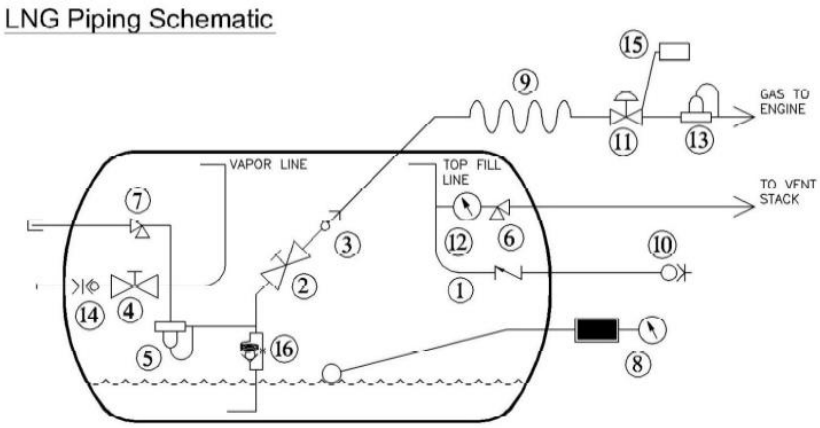


Figure 78. LNG deposit

The operating scheme of a LNG tank according to the current regulations is the following:



1- Fill check valve

2- Fuel shutoff valve

3- Excess flow valve

4- Vapor shutoff valve

5- Pressure control regulator

6- Primary relief valve PRV

7- Secondary relief valve

8- Fuel contents gauge

9- Vaporizer

10- Fill valve

11- Automatic fuel shutoff valve

12-Tank pressure gauge

13- Overpressure regulator

14- Vent connector

15- Gas temperature sensor

16- LNG fuel valve

Figure 79. ***LNG tank scheme***

The LNG vaporizer does not affect the combustible pressure, only increases its temperature causing the change from liquid to gas.

The design of the LNG tank must guarantee the maintenance of the liquid inside without applying any Vent operation for at least 5 days. This ensures that any gas emission is emitted to the atmosphere.

10.3.3 Benchmarking of cryogenic tanks

A market research to analyse the products of cryogenic tanks providers has been performed. The following technical features have been considered for all the suppliers analysed: reliability, maintenance, costs, technical support and references in use under similar conditions.

10.3.3.1 General overview

The majority of cryogenic tanks manufacturers found in the market produce them for two different basic applications:

a. Stationary use. The tank is installed and remains fixed at the same place.

b. For the transportation of cryogenic liquids to the stationary tank.

These are the two applications with more demand in the market, hence manufacturers devote most of their catalogues to meet these needs.

The use of cryogenic tanks to supply LNG to moving engines is rather low with a limited number of manufacturers.

The products provided by the following manufacturers have been analysed:

i. Chart Industries - USA

ii. Cryo Diffusion - USA

iii. Cryogenic Fuels Inc.- USA

iv. Wesport Innovations – CAN

v. SAG – Austria

Among all the manufacturers analysed, only Chart Industries and SAG provide cryogenic tanks with the ECE R110 certification.

Following the leadership of Chart in the sector, their openness to collaborate in this project and the quality of their products, this manufacturer has been selected to provide the tanks for the project.

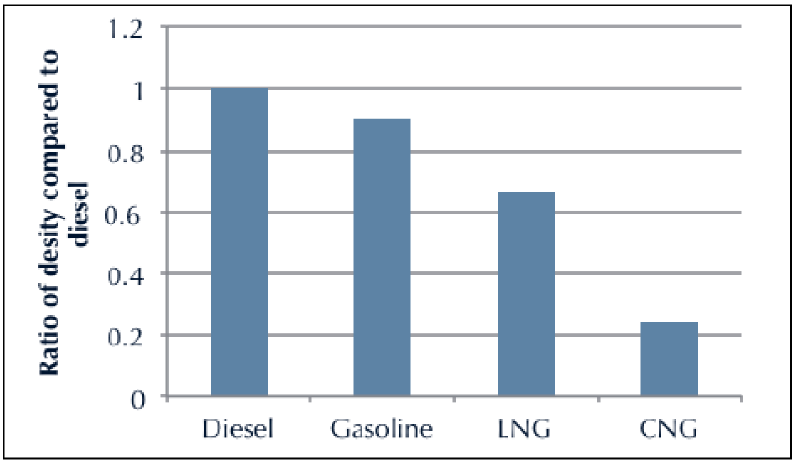
10.3.4 Tanks capacity

The following table presents the diesel consumption data (2015) of the Type 310 and Type 311 locomotives used at the premises of the Autoritat Portuària de Tarragona and Tarragona Mercancías (Tarragona clasificación).

Year	Total (l)	Total (h)	Total (km)	Consumption (l/km)
2007	270.730	14.904	73.983	3,66
2008	239.344	13.200	73.838	3,24
2009	140.378	7.711	45.919	3,06
2010	147.638	8.465	43.506	3,39
2011	198.021	9.923	54.713	3,62
2012	185.252	9.029	50.541	3,67
2013	161.733	8.555	44.466	3,64
2014	173.181	9.582	47.870	3,62

Table 24 Fuel consumption of the locomotives in the Port of Tarragona (2015)

It follows from the above table that the average consumption is 3,49 litres of gasoil per kilometre travelled. The energy density of LNG is 60% in comparison with the gasoil's. Hence, more quantity of LNG is required to produce the same amount of energy.



Source: US Energy Information Administration

Figure 80. Energy density in comparison with gasoil

In a simplified form, a litre of gasoil is equivalent to 1,63 litres of LNG.

The Type 310 locomotive has a gasoil tank of 2700 litre that is filled once a week, according to the information provided by the Autoritat Portuària de Tarragona.

To maintain an equivalent capacity, a LNG storage capacity of 4400 litres would be necessary.

The following section describes the study regarding the location of the fuel deposits, in which some alternatives for their proper placement are listed, allowing a maximum capacity of 2164 litres of LNG.

This capacity supposes that the range of the locomotives using LNG would be halved in comparison with the current diesel locomotives. The new LNG tanks must be filled twice a week. This filling frequency limits the boil-off and guarantees the lack of vents during the use of the locomotive.

10.3.4.1 Analysis of the capacity depending on the LNG tanks location into the locomotive

Once the characteristics of the LNG tank have been defined, its best location into the locomotive has been analysed. The location of the charging valve will be also determined.

The following concerns have been considered:

- Safety during the installation
- Minimize the influence on the CoG variation
- Ease of use and maintenance

10.3.4.1.1 Location of the LNG deposits

The original fuel tank capacity (gasoil) of the Type 310 locomotive is 2700 litres.

It is approximately located at the centre of the locomotive and lies on both sides. It can be filled from both laterals.

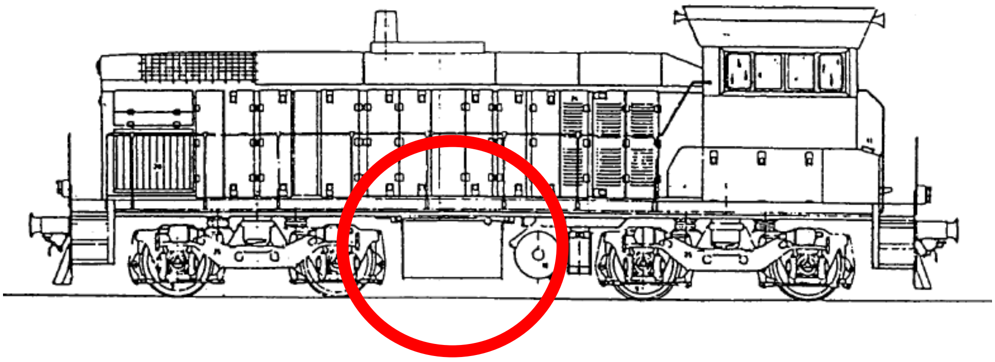


Figure 81. Location of the original fuel tank (gasoil)

Figure 82. Type 310 locomotive – General view

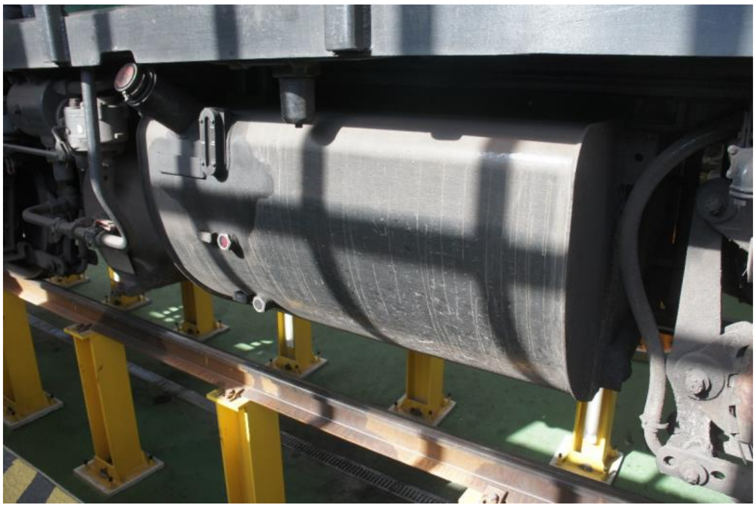


Figure 83. Type 310 locomotive - Fuel tank detail

The dimensions of the available space to locate the LNG tanks are:

Width:	1450 mm (longitudinal to the locomotive)
Height:	900 mm
Length:	3100 mm (total width of the locomotive)

The company CHART Inc., a world reference in the sector, has been selected for the supply of the LNG tanks. The deposits must be homologated, complying with the ECE R110 regulation concerning the use of cylinders to store natural gas.

The dimensions of the CHART tanks are presented in the catalogue as follows:

SEMI-FINAL PART NUMBER	DESCRIPTION	DIM "A" (mm)	DIM "B" (mm)	DIM "C" (mm)	DIM "D" (mm)	DIM "E" (mm)	LIQUID CAPACITY GROSS (L)	LIQUID CAPACITY NET (L)	ESTIMATED TARE WT (KG)
20786015	HLNG 158 BONUS	2291	660	1829	162	609,6	598	538	304
20786017	HLNG 150 LITE	2196	660	1734	162	609,6	564	511	300
20786019	HLNG 127 BONUS	1916	660	1454	162	609,6	484	435	254
20786022	HLNG 119 LITE	1821	660	1359	162	609,6	450	410	252
20768392	HLNG 150	2291	660	1829	162	609.6	564	511	297
20768389	HLNG 119	1916	660	1454	162	609.6	450	410	247
20820718	HLNG 95	1586	660	1124	162	609,6	359	319	214
20822231	HLNG 52	1027	660	565	162	609,6	196	170	164
20822387	HLNG 65	1109	706	606	178	609.6	246	217	148
20822229	HLNG 72	1281	660	819	162	609,6	272	246	193
20822381	HLNG 85	1287	706	784	178	609,6	322	289	197
20822383	HLNG 97	1414	706	911	178	609,6	367	332	213
20822230	HLNG 100	1638	660	1176	162	609,6	378	333	219
20822227	HLNG 103	1681	660	1219	162	609,6	389	350	222
20822226	HLNG 112	1815	660	1353	162	609,6	425	383	233
20822228	HLNG 140	2189	660	1727	162	609,6	529	473	283
20822225	HLNG 144	1922	706	1419	178	609,6	544	490	340
20822385	HLNG 171	2227	706	1724	178	609,6	647	582	375
20850602	HLNG 73	1186	706	683	178	609,6	287	253	211
20929729	HLNG 50	1372	559	857	137	546.1	190	171	211
20929724	HLNG 61	1575	559	1060	137	546.1	231	208	217
20999935	HLNG 86	2083	559	1568	137	546,1	325	293	237
20999945	HLNG 85	1829	609.6	1314	137	546.1	337	303	227

Table 25 LNG tanks – CHART HLNG R110

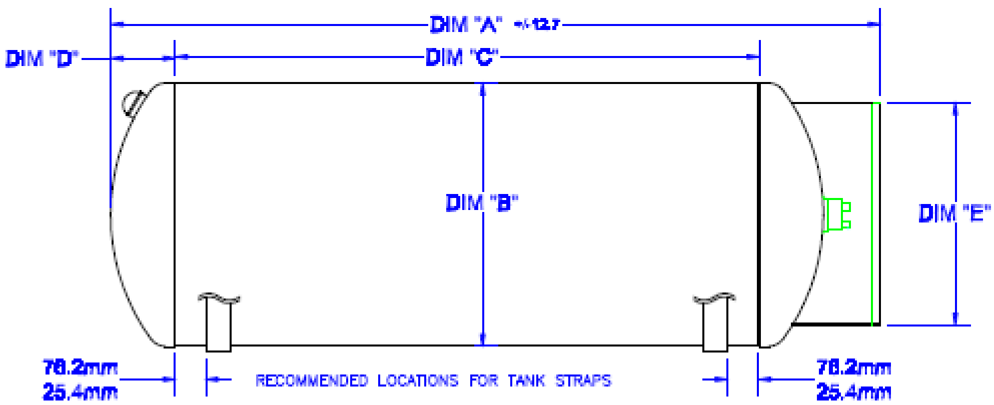


Figure 84. CHART LNG tank, Serie HNLG R110

Considering the available space into the locomotive and the available CHART tanks, the model HLNG 171 has been selected.

Two HLNG 171 tanks will be installed transversally to the locomotive axis with only one single filler neck common for both tanks.

- HLNG 171 (A x B): 2227 mm x 706 mm

The net per-unit capacity of each tank is 582 litres of LNG so that the total capacity will be 1164 litres. This capacity is much lower than the original, so the locomotive's range will be affected.

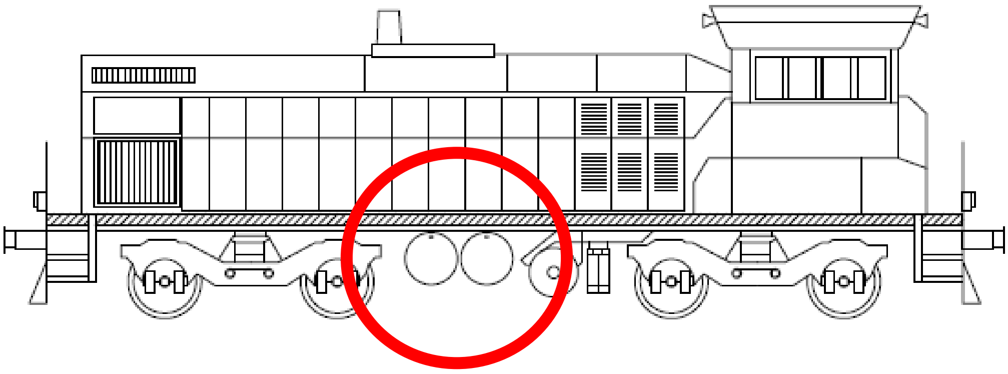


Figure 85. Location of the LNG tanks, Chart HNLG 171

10.3.4.1.2 Alternatives to increase the LNG tanks capacities

In case the new locomotive's range is considered insufficient, a set of additional tanks can be installed on the engine cover to complement the two HLNG 171.

10.3.4.1.2.1 Transversal installation

Three CHART HLNG 100 tanks will be installed transversally to the locomotive axis with only one single filler neck common for the three tanks.

- HLNG 100 (A x B): 1638 mm x 660 mm

The net per-unit capacity of each tank is 333 LNG litres, so the total additional capacity will be 999 litres.

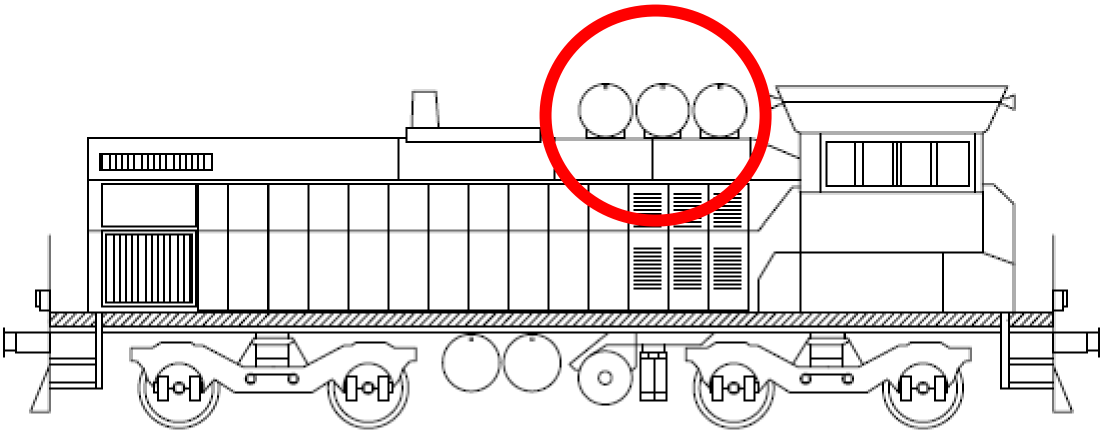


Figure 86. Location of the LNG tanks, Chart HNLG 100

10.3.4.1.2.2 Longitudinal installation

Three CHART HLNG 86 tanks will be installed longitudinally to the locomotive axis with only one single filler neck common for the three tanks.

- HLNG 86 (A x B): 2083 mm x 559 mm

The net per-unit capacity of each tank is 293 LNG litres, so the total additional capacity will be 879 litres.

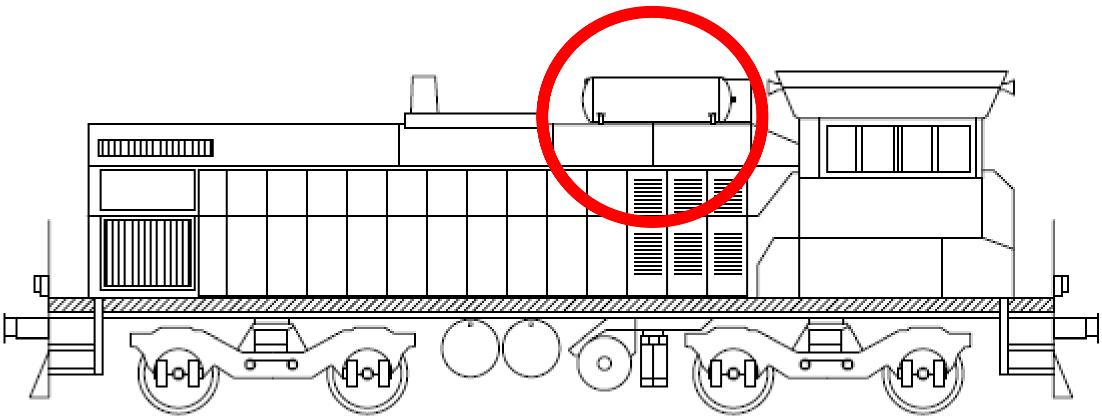


Figure 87. Location of the LNG tanks, Chart HNLG 86

During the phase of detailed project, the use of an insulating cover over the tanks to minimize the solar radiation and help to integrate visually them into the entire locomotive could be studied.

The installation of the deposits must be submitted to a risk assessment that guarantees the safety of the whole system.

10.3.5 Deposits integration

The necessity of increasing the fuel tanks capacities of the locomotive to approach the original range of the diesel engines forces the installation of several tanks. The possible location of the tanks is detailed in the previous section 10.3.4.

In all cases, the tanks will be integrated with only one LNG filling neck and one fuel outlet towards the engine. The vent duct will be also unified.

The integration of the tanks will be performed according to the regulation ECE R110, which indicates that the fuel ducts towards the engine must be joined before the overpressure regulator. To ensure a proper functioning, the section of the tubes must be the same as the one used for one single tank.

Since the section of all the tubes will be the same, the pressure in all the tanks will be equal too, except immediately after the filling operation.

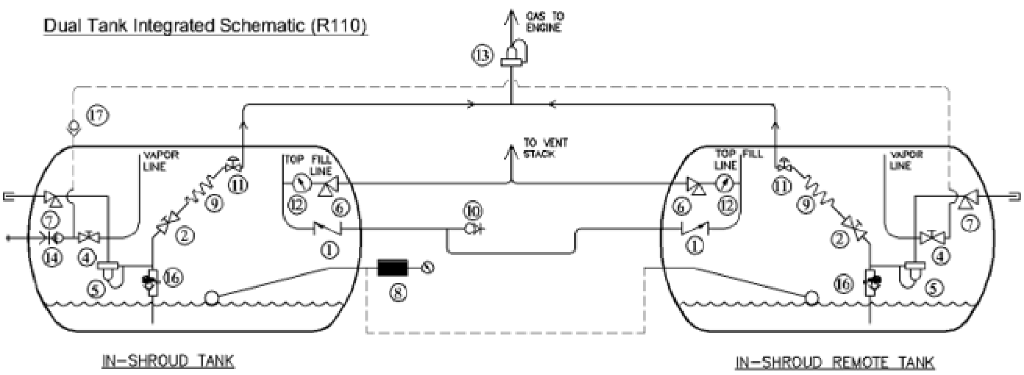


Figure 88. Scheme of the LNG tanks integration

10.4. Identification of interested manufacturers and vendors

Based on the market researches performed, the manufacturers and the vendors that may be interested in the project have been identified and related.

10.4.1 Engine transformation

As it is previously indicated, the transformation of the GM 8-645-E diesel engine to natural gas will be performed using a conversion kit developed by the company Energy Conversions Incorporated – ECI.

ENERGY CONVERSIONS INC.
alternative fuel systems for high output engines

Material: Spark Ignited Pre-chamber Conversion System – SIP

Contact:

Scott Jensen

Chief Designer and Project Coordinator

scott@energyconversions.com

ENERGY CONVERSIONS, INC.
6411 Pacific Highway East
Tacoma, WA 98424, USA
Telephone: (253) 922-6670
Fax: (253) 922-2258

http://www.energyconversions.com/

10.4.2 Fuel tanks

The LNG tanks will be provided by the company CHART Inc. through its representative in Spain. The production of cryogenic tanks is done in its Check Republic subsidiary.

CHART®

Material: GNL – HLNG R110 tanks

Contact:

Jaime Alamo

Project Manager – LNG Vehicle Fuel Systems

Jaime.Alamo@chartindustries.com

Mobile: +34 659 50 7984

- **Chart Ferox, a.s.**
  Ustecka 30
  405 30 Decin
  Czech Republic
  Telephone: +420 412 50 7111
  Fax: +420 412 510 200

  http://www.chartindustries.com/

10.4.3 Integrator company

The integrator company may be ARMF.

Material:	Project integration
Contact:	
	Manuel Ramos
	Director
	mramos@armf.net
	ARMF Mantenimiento y Proyectos Ferroviarios, SL
	Talleres: Antiguos Talleres Renfe
	Polígon Industrial "El Segre"
	25191 LLEIDA (SPAIN)
	+34973216441
	http://www.armf.net/

10.4.4 Accreditation of the locomotive

The accreditation work and the commissioning of the transformed locomotive will be performed by the enterprise Bureau Veritas.

BUREAU VERITAS

Activity: Accreditation of the transformed locomotive

Contact:

Miguel Ángel BERZOSA LOSADA

Responsable del Centro Técnico de Industria
Industry Technical Center Manager
miguel-angel.berzosa@es.bureauveritas.com

BUREAU VERITAS

C/Valportillo Primera 22-24
28108 Alcobendas (MADRID)
T. 912702256 Mov. +34647331614)

http://www.bureauveritas.com

10.5. Transformation analysis and its effects on the weight and the centre of gravity

In the previous sections, it has been defined that this project will focus on:

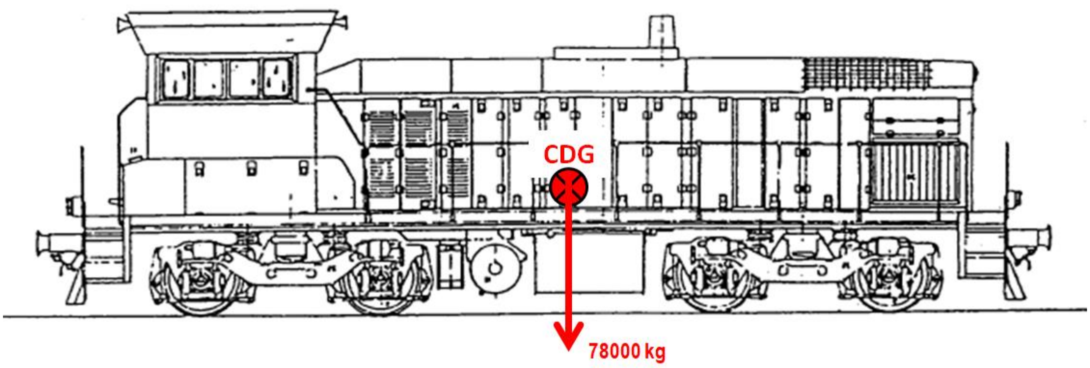
- Adapting the Type 310 locomotive to LNG.
- Transforming the 2-stroke GM engine model GM-8-645-E, to LNG fuel, replacing original components for others provided by the specialized company ECI (Energy Conversions Inc).
- Increasing the refrigeration capacity of the engine's water cooler by means of the integrator eventually selected.
- Replacing the original gasoil tank by another cryogenic container assembly provided by the firm Chart Inc.

The final weight of the locomotive will be analysed once all the proposed measures have been implemented. The variation in the centre of gravity (CoG) will be also considered.

10.5.1 Current situation, before the transformation

To perform the study on the variation in the weight and the CoG location, the values of the current locomotive must be known so they can be compared to the ones after the transformation.

To date, only the total weight of the Type 310 locomotive is known, according to the catalogue, 78000 kg. No drawing of the locomotive defining the exact coordinates of the CoG is available. Consequently, the results of the calculations presented will be considered only as approximations.



10.5.2 Impact of the modifications in the distribution of masses and the CoG location

As it has been previously said, the variation of the weight and the CoG location, caused by the transformation of the locomotive 310 to LNG, will be approximated.

The elements to be modified are graphically represented in the following figure:

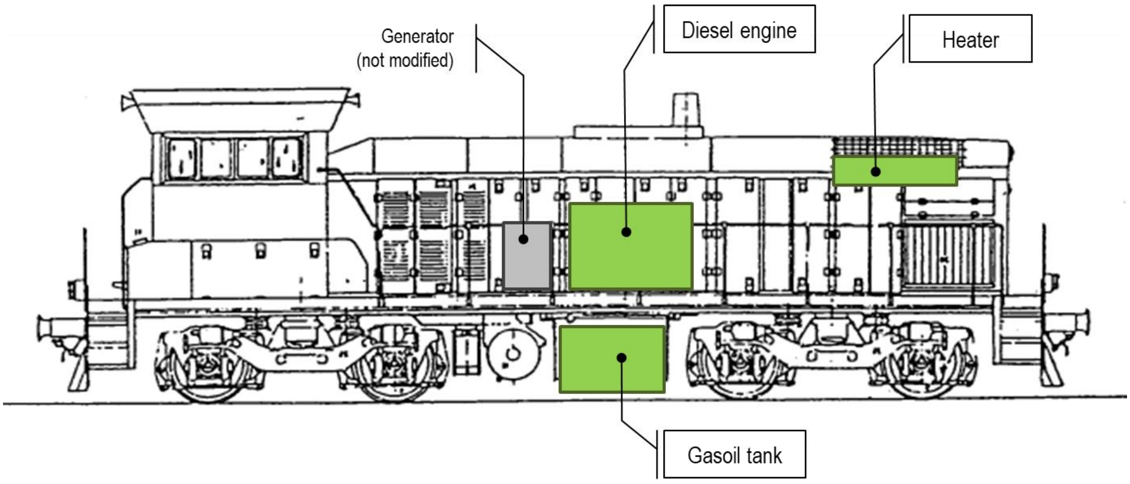


Figure 89. Elements to modify

The following table lists the weight variations due to the modifications:

A set of components will be installed at the upper part of the diesel engine, some of them replacing original elements and others added. The overweight comparing to the original situation is estimated in …	+ 60 kg
Two cryogenic containers for the LNG will replace the original gasoil tank. The overweight, comparing to the original weight, both full of fuel, is estimated in …	- 1080 kg
The engine's water cooler will be replaced by a bigger one or supplemented by more elements so that the overweight is estimated in …	+ 80 kg
Total weight variation (reduction):	**- 1060 kg**

Table 26 Weight variations due to the modifications

The weight reduction of the locomotive represents 1,36% of the original weight, that was 78000 kg according to the catalogue. Thus, it is considered as an irrelevant factor that will not influence on the proper operating of the transformed locomotive.

Conversely, all the modifications to be performed are symmetric with regard to the central, vertical and longitudinal planes so that there will not imply any transversal variation in the location of the CoG. The new CoG will remain at the same plane of symmetry without consequences in the dynamics of the transformed locomotive.

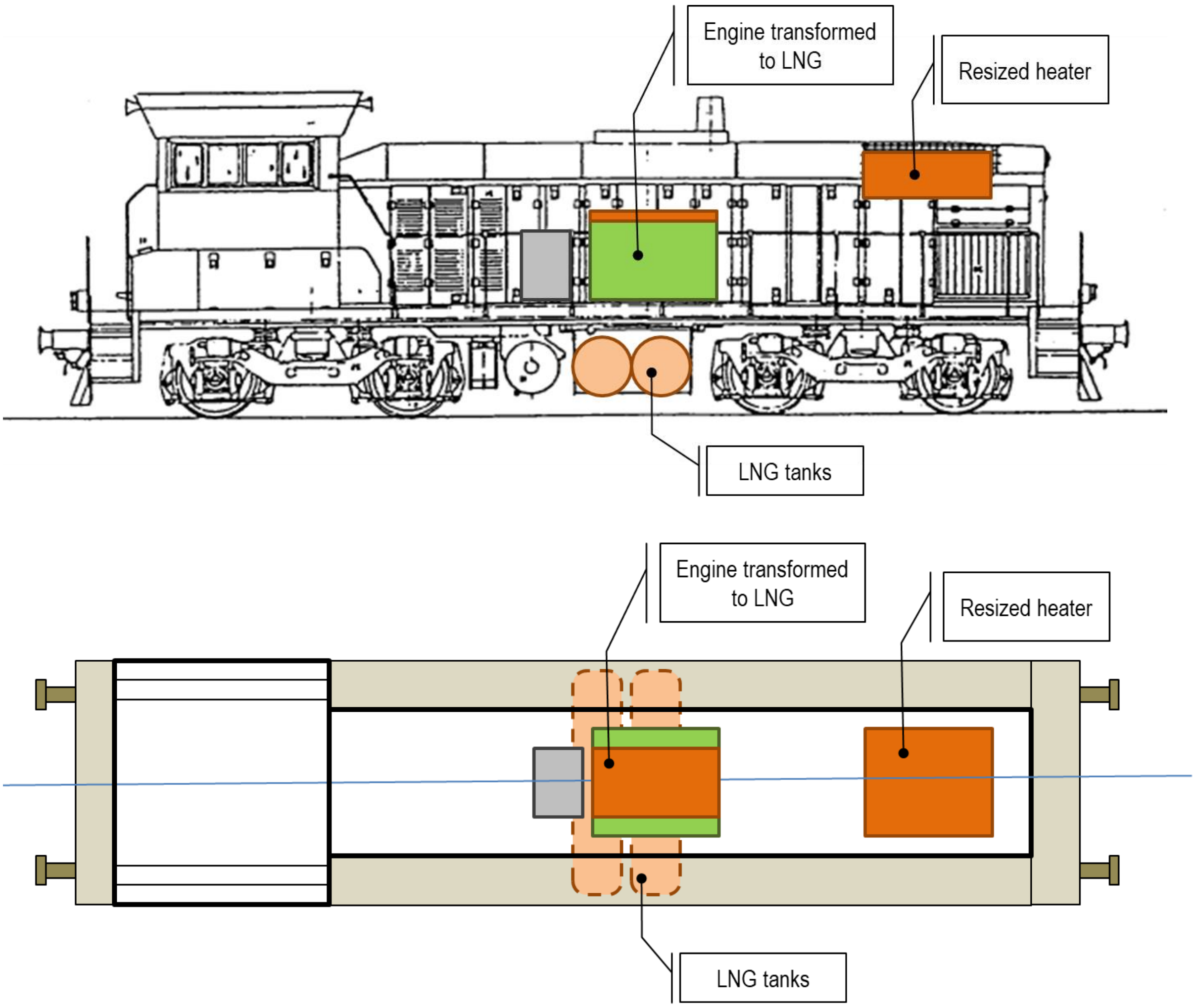


Figure 90. Planes of the location of the elements to be modified

Regarding the new location of the CoG, the mentioned hypothesis about the weight variations and geometric calculations of the new distribution of masses suppose that the new CoG will be 3,2 cm above the original position. Since this value corresponds only to the 0,77% of the total height, it will not influence the dynamics of the locomotive either.

These calculations must be verified considering the real weights of the transformed parts and the real data of the locomotive, that are currently unknown.

In case it is decided to install additional LNG tanks over the locomotive's folding hood for logistic and range purposes, a new variation in the CoG will occur.

Since at the date of this report the exact coordinates of the original locomotive CoG are unknown, the aim of the calculations is to determine its variation rather than the exact new coordinates. In the following figure, the values considered are represented, but the ones in green must be deemed as approximations.

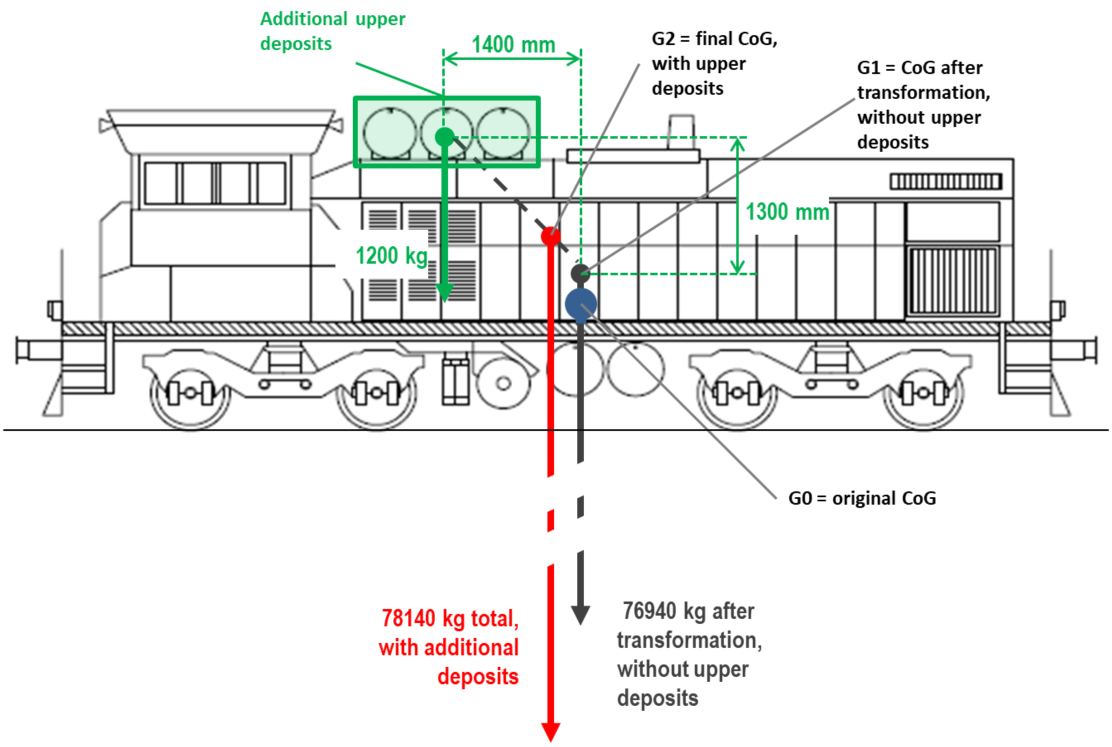


Figure 91. Graphical representation of the values considered including the additional deposits

Once the calculations and the subsequent trigonometric operations have been made, it is claimed that the new CoG with additional tanks (G2), with reference to the one previously calculated (G1), moves backwards **21,47 mm** and upwards, **19,97 mm**.

In summary, the variations of the CoG after the transformation to LNG (**G1**), and with the addition of the complementary deposits over the locomotive's folding hood (**G2**), are represented in the following figure.

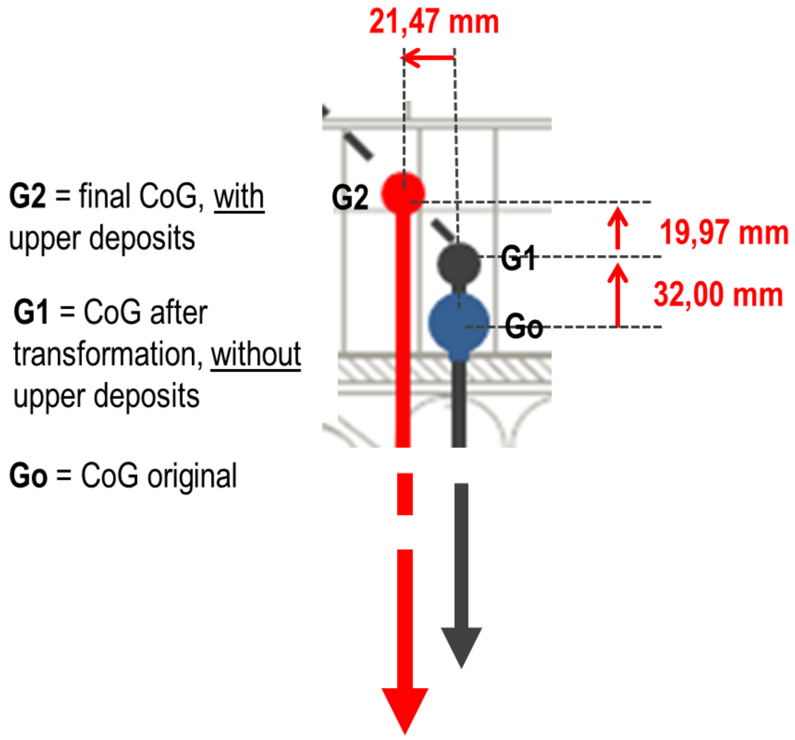


Figure 92. Variations of the CoG after the transformation to LNG (G1) and with the addition of the complementary deposits (G2)

As a conclusion after the modifications, the total displacement of the CoG is:

- Backwards: 21,47 mm
- Upwards: 51,97 mm

This total displacement is considered as **non-influent for the operating nor the dynamics** of the locomotive.

10.6. Drafting of plans

10.6.1 Maintenance and Operational plan

The locomotive **Adif 310** has a maintenance and operational plan according to its current condition regarding the diesel engine. The following pictures show the cover, preface and index of the document titled "*DESCRIPTIVE MANUAL OF THE VEHICLE*".

RENFE

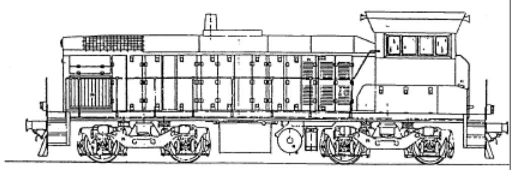
MANUAL DESCRIPTIVO

DEL VEHICULO

LOCOMOTORA DIESEL ELECTRICA DE MANIOBRAS Y DE LINEA

MODELO SW-1001AC

SERIE 310



ABRIL 1990

Meinfesa

MEDITERRANEA DE INDUSTRIAS DEL FERROCARRIL
VALENCIA - ESPAÑA

PREFACIO

Este manual describe detalladamente las operaciones para mantenimiento eléctrico y mecánico de la locomotora. propósito es de proporcionar información e instrucciones pa realizar adecuadamente la conservación y mantenimiento de locomotora.

Las operaciones tales como, reparación de component reconstrucción o revisiones profundas pueden encontrarse en l Instrucciones de Conservación editadas para esta finalidad.

Las instrucciones de conservación relativas al motor Diesel encuentran en el MANUAL DE CONSERVACION DEL MOTOR 645.

HOJAS DE DATOS DE CONSERVACION

Estas hojas se encuentran en la parte final de las secciones este Manual que lo requieren. Estas hojas porporcionan:

1.- Referencia de las Instrucciones de Conservación y manual de aplicación.

2.- Referencia de las herramientas y aparatos de ensa necesarios.

3.- Referencia de los valores en las magnitudes obtenibles ensayos y en funcionamiento.

INDICE
======

The objective of this section of the report is to define the content of an **annex** (see Annex 1) for the aforementioned "*DESCRIPTIVE MANUAL OF THE VEHICLE*", which should be written after the transformation of the unit to LNG and which will have to include the new features of the new transformed EMD engine and, in particular, the new fuel system (deposits, circuit and control of LNG).

It is envisaged, as explained in previous sections, that EMD 8-645-E engine of the locomotive model 310 will be transformed to LNG using parts and technology from the American company **ECI (Energy Conversions Inc)**, which has successful proven references in the realization of similar projects. Therefore, the new annex attached to the maintenance and operational plan will be based on the experience and documentation received from ECI, and on the data provided by the **integrator** who will finally perform the transformation.

A proposal for the Maintenance plan of the engine converted to natural gas is attached as an appendix (ANNEX 1).

10.6.1.1 Structure of the ANNEX to the Maintenance and Operational plan

The following chapters conform the detailed structure proposed for the annex to the Maintenance and operational document.

0) Introduction and index
1) Precaution during LNG manipulation
2) General description of the transformation
3) Thermal motor (mechanical parts)
4) LNG system
5) Engine control (ECU)
6) Hydraulic system
7) Cooling system
8) Instrumentation
9) Breakdown location
10) Reference data for maintenance
11) List of components

In the following sections, general lines for the content of the most relevant chapters will be developed considering that the final document should be edited once the transformation has been carried out in order to use the data of the different suppliers that have provided the components and the integrator that has executed the transformation.

In the aim to provide continuity and facilitate the understanding of this new ANNEX, its drafting and editing must follow the style of the original document *DESCRIPTIVE MANUAL OF THE VEHICLE – Diesel Electric Shunting Locomotive – Model SW-Di1001AC – Series 310*, especially concerning chapters 10) *Breakdown location* and 11) *Reference data for maintenance*.

In the ANNEX, all drawings, photographs or diagrams necessary to facilitate the assembly and disassembly of the different elements related to the transformation will be included.

Not only in this ANNEX but in any manual and descriptive texts concerning the transformed locomotive, special attention should be taken concerning **safety conditions** when handling LNG. Natural gas is as safe as any other fuel, including gasoline and diesel but like any other fuel it has properties that require special precaution for its handling.

Flammable gas warning

For the safety of people and goods, all personnel involved in the maintenance and operation of the locomotive and its filling plant must have and understanding of all the necessary and sufficient information on LNG and comply with all standards established for handling.

General danger warning

Consequently, after the introduction and Index of the new ANNEX, the following chapter will be included: 1) *Precaution during LNG manipulation*, which will describe the properties of liquefied natural gas and the basic precautions to be considered.

Low temperature warning

Moreover, throughout the text and in all chapters when the matter suggests it, **warning signs and reminders** about the dangers of defective handling should be included.

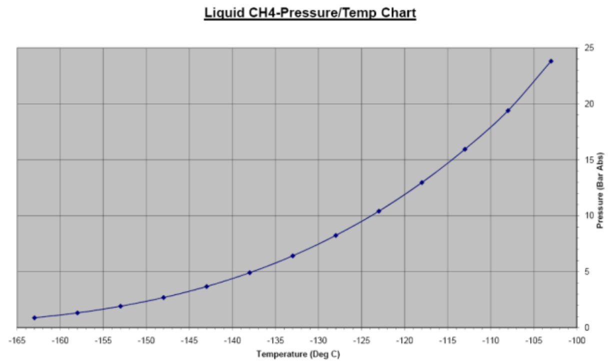
As an example, in the following section there are different texts that can be as a guide for the aforementioned chapter 1) and for the Introduction of any manual or training course, which complement and do not replace mandatory official standards.

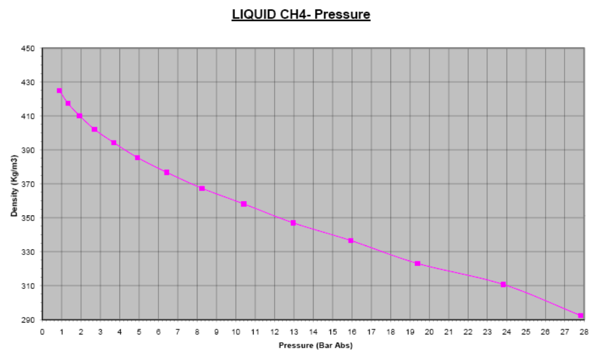
10.6.1.1.1 Precaution during LNG manipulation

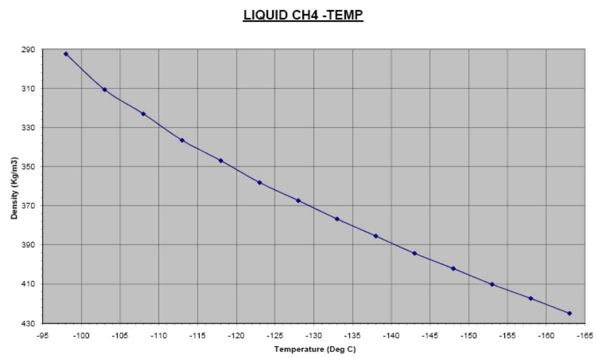
Natural gas consists mainly of (>90%) methane, which is a colourless, odourless and non-toxic gas. It is stored and transported in liquid phase for use as a fuel. Methane must be cooled below its boiling point, which is **-161ºC** and the result is known as LNG in a cryogenic state.

LNG will be loaded into the locomotive in a cryogenic state and stored in conveniently insulated tanks. Before its admission to the engine, it will be vaporized or reconverted to gaseous form by the contribution of heat to be burned in the cylinder of the engine. LNG must never reach the engine in a liquid state.

In the event of any leakage in the LNG circuits, it must be considered that the familiar "gas smell" is not from the gas itself but from an additive which is added for safety. If the converted engine used gas network, it is likely that an odoriferous was added and gas leaks could be smelled. However, with LNG fuel, it will probably not be possible to smell the gas leaks because it will not be odourised. This is because, although odorant can be added to LNG, it is difficult in conditions of extreme low temperatures. Therefore, odorant should not be relied upon to detect LNG leaks. The procedures described in the Manual should be used to verify the integrity of the connections and joints of the circuits, preferably a **portable electronic methane detector** to verify leaks.







Chemical properties of cryogenic gases such as LNG in liquid state are practically the same as in the "hot" natural state. But it must be considered that in its cryogenic state there is an additional physical property of **extreme cold** or *cryogenics*. Therefore, it is very important to consider the extreme low temperature when handling LNG.

LNG must never be touched, freshly boiled natural gas vapor or a pipe with frost. They are extremely cold and cause immediate freezing. In case of accidental contact with LNG, the burn should not be rubbed. The affected area should be soaked in warm water (not hot) and seek medical attention immediately.

LNG will not burn unless its concentration is between 5 and 15 vol%. Natural gas like helium rises in the air. These two facts mean that, provided there is adequate ventilation in the vicinity of the converted engine and the LNG supply, there is little danger of fire. However, a serious problem can arise when LNG in a gaseous state accumulates in a closed area without ventilation. In that case, the accumulated natural gas is very dangerous. Thus, **adequate ventilation** should always be maintained in the areas of the converted engine and the LNG supply. Ventilation fans and filters in the engine compartment should be checked frequently.

Before working on the LNG engine, the general-purpose manual valve, located near the fuel filter assembly, must be closed. After engine shutdown, natural gas could remain under pressure in the fuel circuit. Maintenance operations on that circuit could allow the trapped gas to be released and pass into poorly ventilated areas near the engine. To avoid this problem, the system has a gas vent valve located near the gas supply filter assembly. It is very important, for the reasons stated above, that the trapped gas could be released by the vent valve before beginning maintenance of the gas supply. A reminder should be included in the text of the manual whenever gas ventilation is required.

Moreover, just like when handling any fuel, **all possible sources of ignition**, including lit cigarettes, portable generators, kerosene heaters, electric engines, welders or anything else that could generate sparks or flame, should be eliminated before starting to work. If it is necessary to weld to repair a gas pipeline, the LNG circuit must always be purged with non-flammable gas, before starting to work.

10.6.1.1.2 General description of the transformation

A succinct and general description of the transformation carried out on the 310 locomotive will be developed, with sufficient graphic information to facilitate its understanding and the identification of the main parts incorporated or modified. It will try to offer an overview of the whole system and its operating principle. In the following points, the characteristics of the following sets will be developed in detail:

- Thermal engine (mechanical parts)
- LNG system
- Engine control (ECU)
- Hydraulic System
- Refrigeration system
- Instrumentation

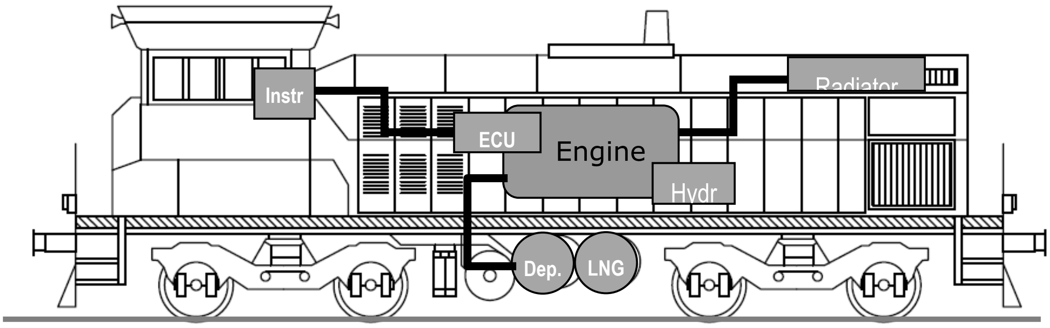
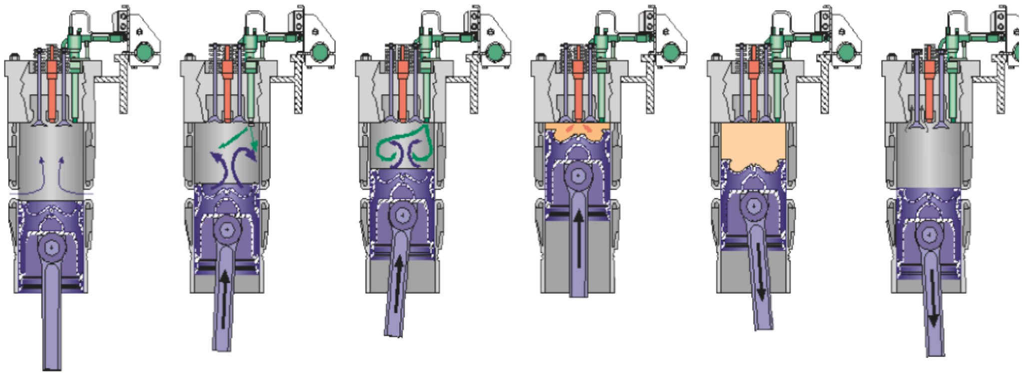


Figure 93. Disposal of the sets considered

Thermal motor (mechanical parts)

The mechanical parts that have been modified or substituted in the EMD 8-645-E engine for its transformation to LNG will be described. Its respective functions, its technical characteristics and the necessary maintenance operations will be summarized.

It will also detail the new thermodynamic cycle that the engine will follow after the transformation. Previously *diesel cycle* and after, *Otto cycle* or ignition by spark.



Air intake	*Compression, gas injection and mixing formation*	*Spark ignition of the gas into the pre-chamber*	*Expansion*	*Exhaust of combustion gases*

Figure 94. Cycle of the engine transformed to LNG

Technical characteristics, assembly/disassembly instructions and possible faults of the modified or replaced mechanical parts of the engine itself will be specified:

- Pistons
- Butts
- LNG injection
- Ignition system

Technical specifications will be accompanied by sufficient explanatory graphic information such as:

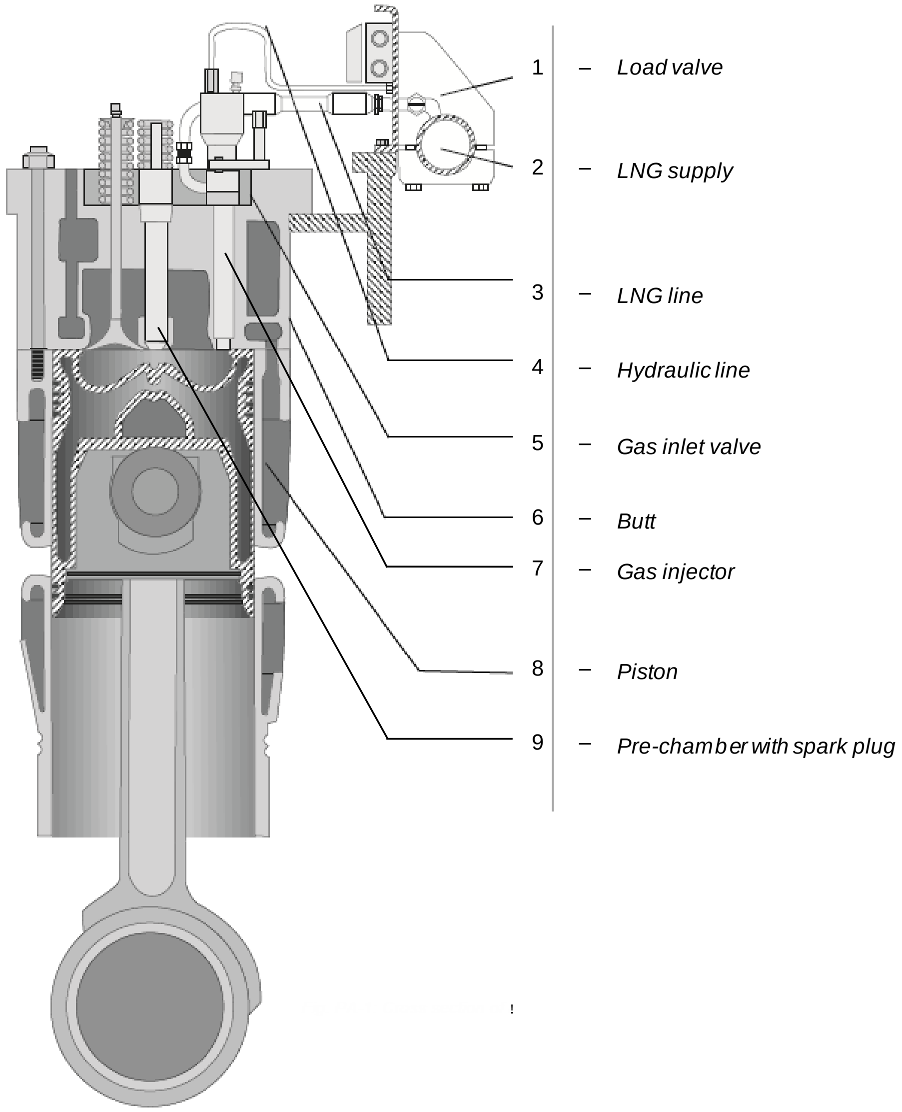
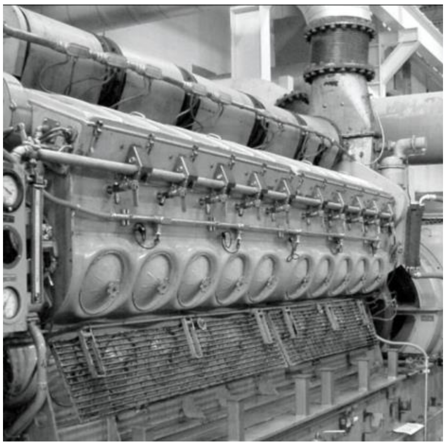


Figure 95. Engine section



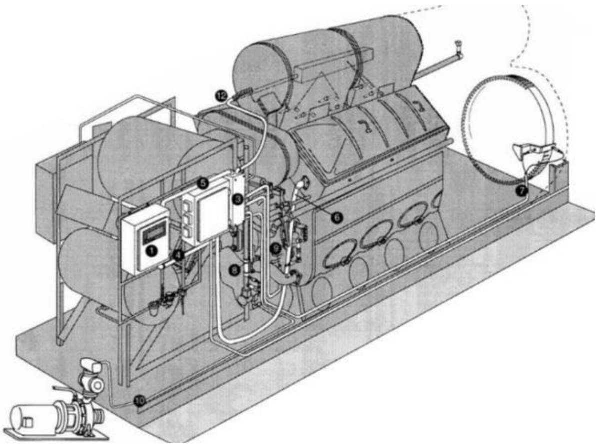


Figure 96. Lateral view of the modified engine (left) and components location (right)

Modified cylinder (lower compression ratio)

Cylinder assembly modified

LNG injector installation

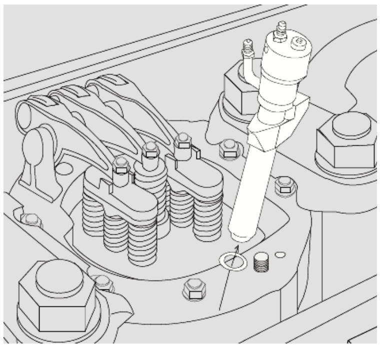


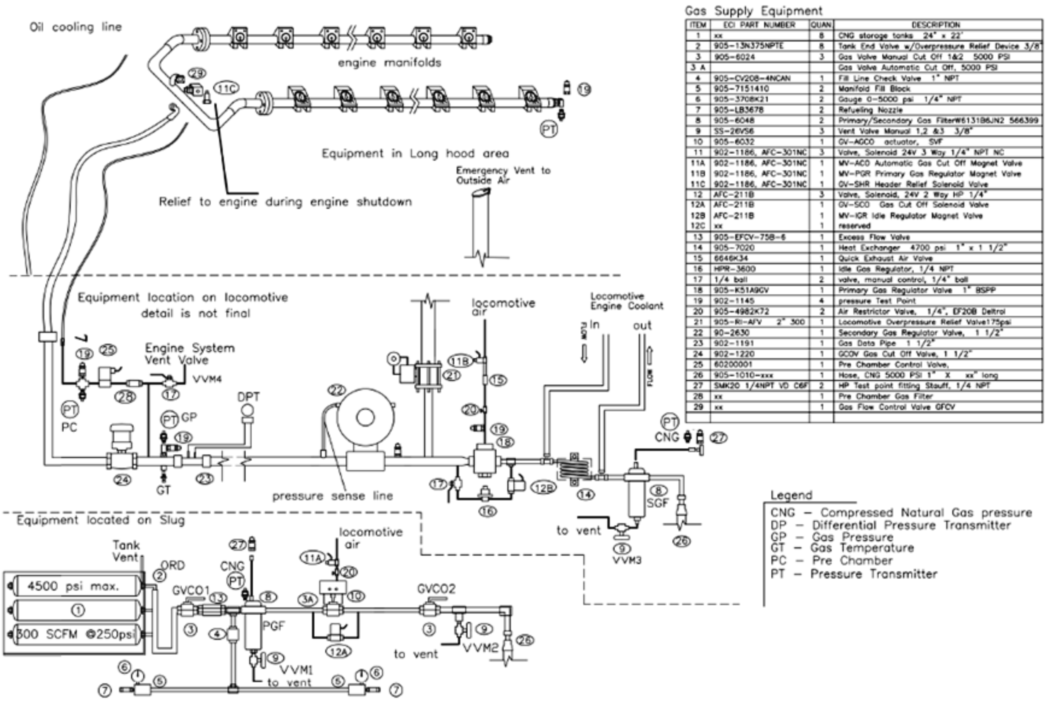
Figure 97. Components detail

LNG fuel system

The outline of the LNG circuit must be developed, from the filling of its tank to its entrance to the engine. It will therefore include the following points:

1. Cryogenic LNG filling and storage system
2. LNG circuit to the engine, regarding its valves, sensors, regulators, etc
3. LNG distribution on the engine up to the cylinder heads.

As an example, a diagram of an equivalent transformation is inserted below:



Gas Supply Equipment

ITEM	ECI PART NUMBER	QUAN.	DESCRIPTION
1	xx	8	CNG storage tanks 24" x 22'
2	905-13N375NPTE	8	Tank End Valve w/Overpressure Relief Device 3/8"
3	905-6024	3	Gas Valve Manual Cut Off 1&2 5000 PSI
3 A			Gas Valve Automatic Cut Off, 5000 PSI
4	905-CV208-4NCAN	1	Fill Line Check Valve 1" NPT
5	905-7151410	2	Manifold Fill Block
6	905-3708K21	2	Gauge 0-5000 psi 1/4" NPT
7	905-LB3678	2	Refueling Nozzle
8	905-6048	2	Primary/Secondary Gas FilterW6131B6JN2 566399
9	SS-26VS6	3	Vent Valve Manual 1,2 &3 3/8"
10	905-6032	1	GV-AGCO actuator, SVF
11	902-1186, AFC-301NC	3	Valve, Solenoid 24V 3 Way 1/4" NPT NC
11A	902-1186, AFC-301NC	1	MV-ACO Automatic Gas Cut Off Magnet Valve
11B	902-1186, AFC-301NC	1	MV-PGR Primary Gas Regulator Magnet Valve
11C	902-1186, AFC-301NC	1	GV-SHR Header Relief Solenoid Valve
12	AFC-211B	3	Valve, Solenoid, 24V 2 Way HP 1/4"
12A	AFC-211B	1	GV-SCO Gas Cut Off Solenoid Valve
12B	AFC-211B	1	MV-IGR Idle Regulator Magnet Valve
12C	xx	1	reserved
13	905-EFCV-75B-6	1	Excess Flow Valve
14	905-7020	1	Heat Exchanger 4700 psi 1" x 1 1/2"
15	6646K34	1	Quick Exhaust Air Valve
16	HPR-3600	1	Idle Gas Regulator, 1/4 NPT
17	1/4 ball	2	valve, manual control, 1/4" ball
18	905-K51A9GV	1	Primary Gas Regulator Valve 1" BSPP
19	902-1145	4	pressure Test Point
20	905-4982K72	2	Air Restrictor Valve, 1/4", EF20B Deltrol
21	905-RI-AFV 2" 300	1	Locomotive Overpressure Relief Valve175psi
22	90-2630	1	Secondary Gas Regulator Valve, 1 1/2"
23	902-1191	1	Gas Data Pipe 1 1/2"
24	902-1220	1	GCOV Gas Cut Off Valve, 1 1/2"
25	60200001	1	Pre Chamber Control Valve,
26	905-1010-xxx	1	Hose, CNG 5000 PSI 1" X xx" long
27	SMK20 1/4NPT VO C6F	2	HP Test point fitting Stauff, 1/4 NPT
28	xx	1	Pre Chamber Gas Filter
29	xx	1	Gas Flow Control Valve GFCV

Figure 98. Equivalent transformation diagram

Regarding the identification of the components and their characteristics, they will be related to the same style and detail as stated in the previous section for the thermal motor:

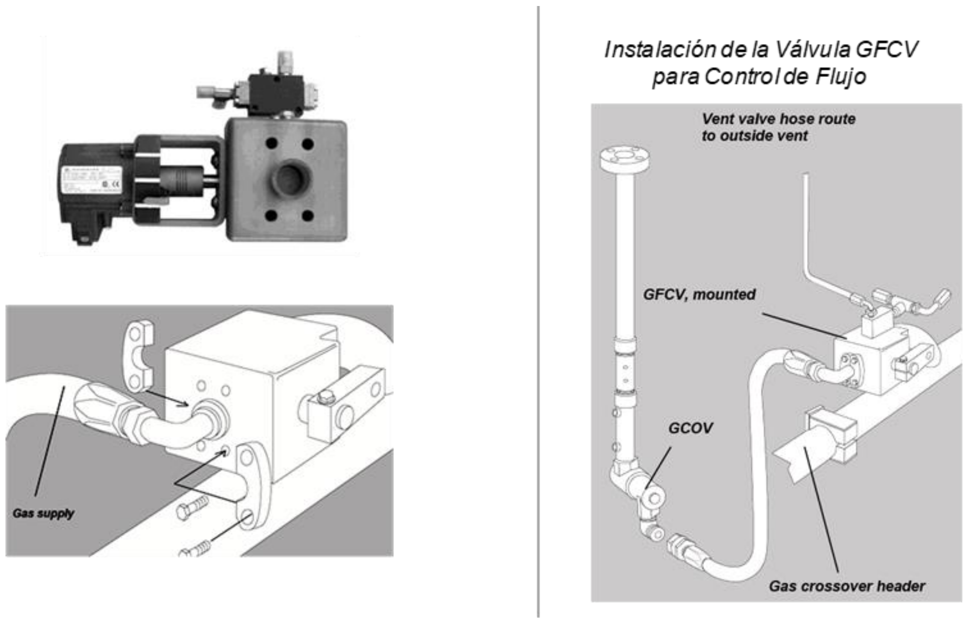


Figure 99. Diagram of the components identification

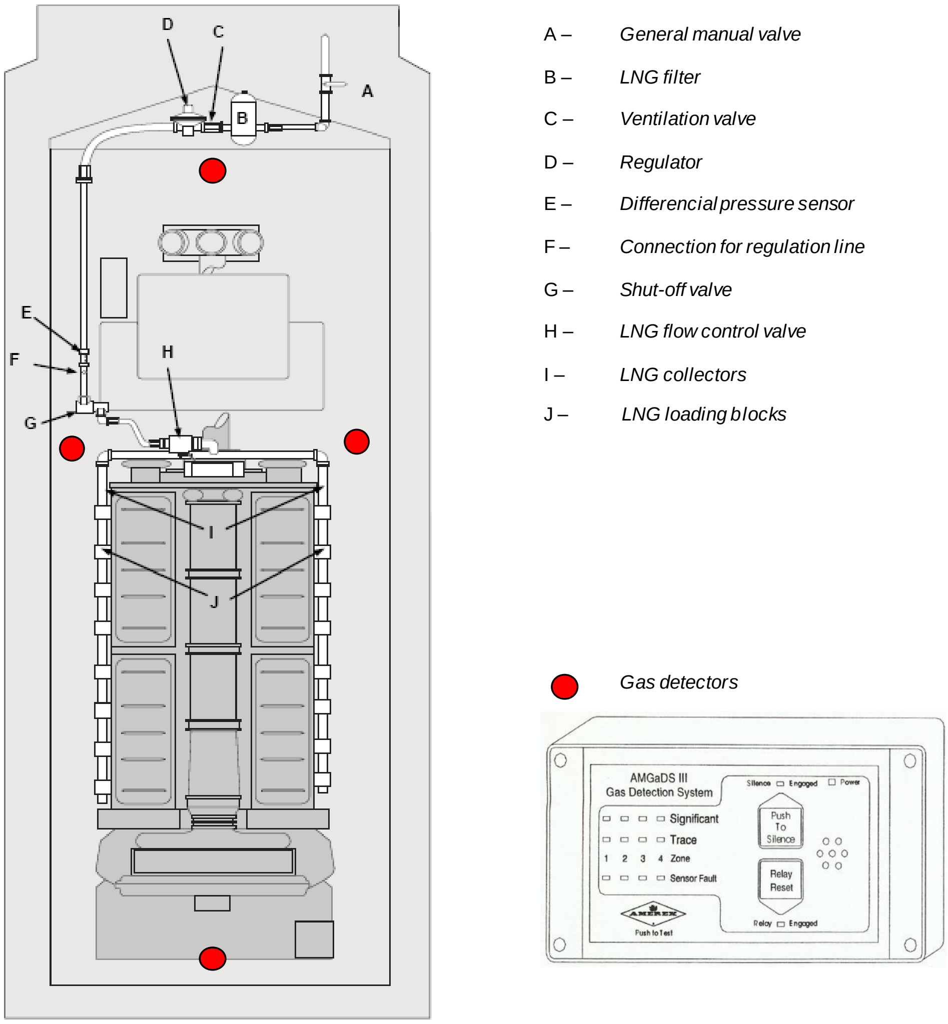


Figure 100. LNG circuit around the engine

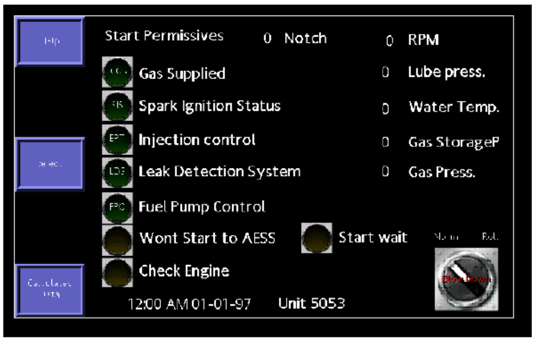
The **gas leak detection system** is of special importance, which consists of four sensors strategically located in the engine compartment which trigger a first level alarm when the gas concentration reaches 20% of the lower flammability level (1% gas in air). If the concentration reaches 50% of that limit (2,5% gas in air), the system will automatically activate the closing of the main LNG valves.

Engine control (ECU)

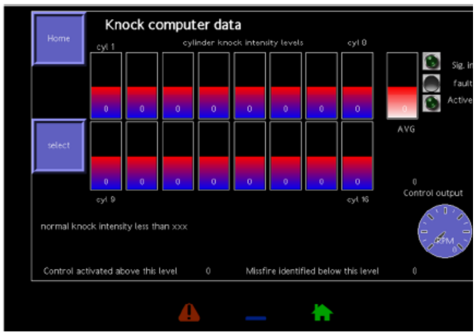
The characteristics and functions of the new electronic system for the control of the engine must be detailed. That is to say, the Engine Control Unit or **ECU** and its peripheral units, which are:

- Engine Control display (ECU)

- Connection box for digital signals
- Connection box for analogue signals
- Connection box for digital control output signals

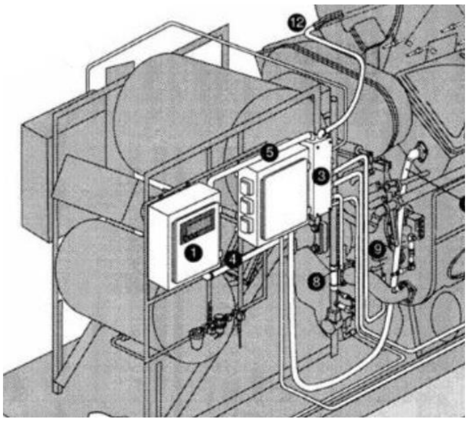


EDC main screen



Detonation check screen

ECU is the basic tool for the operation and maintenance of the engine system of the transformed locomotive. Thus, it has an **interactive screen** (EDC) for information on the status of the system and notifications of operation and errors.



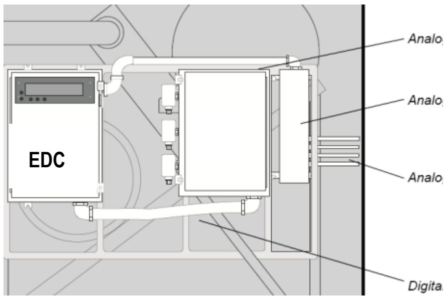


Figure 101. EDC screens and connexions box

ECU is the basic control system for the proper functioning of the whole system after adapting the engine (diesel before) to the new gas combustion process. Moreover, it is an electronic unit based on a microprocessor which monitors and controls the main parameters of the motor, such as:

- Rotation speed

- Gas circuit
- Engine performance
- Monitoring and diagnostic parameters

The main hardware of the ECU will replace the previous diesel engine control unit and will consist of a standard chassis type rack for electronic cards. In the ANNEX to the Manual the status of its components, wiring, test points, …will be specified.

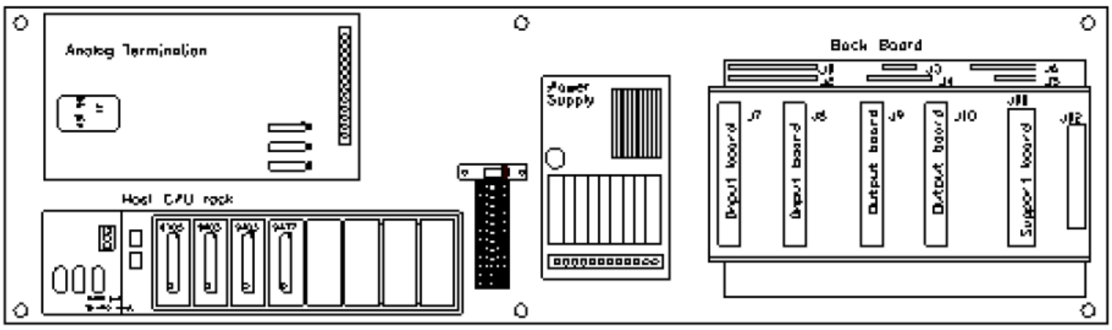


Figure 102. Rear view of the ECU chassis and location of its components

Likewise, all analogue and digital input and output signals will be listed, as well as the description of the notification codes, especially the errors of the system.

The electrical diagrams of the entire measurement and control system will be included with descriptive drawings of the cable routes and location of the sensors and valves. For example:

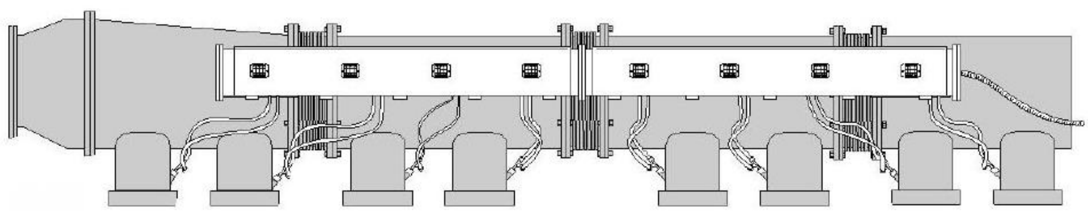


Figure 103. Installation of thermocouples for temperature measurement in the exhaust manifold

Hydraulic system

The LNG conversion system uses a hydraulic circuit to operate the gas injection valves on the cylinders of the transformed engine.

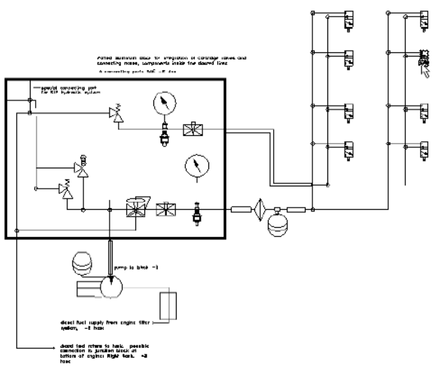
The characteristics of the new high pressure hydraulic system as well as the circuit will be specified, with mention of the necessary operations for its correct function and maintenance.

The system consists of an oil tank, high pressure pump, filters, accumulators, distribution valve block and connections.

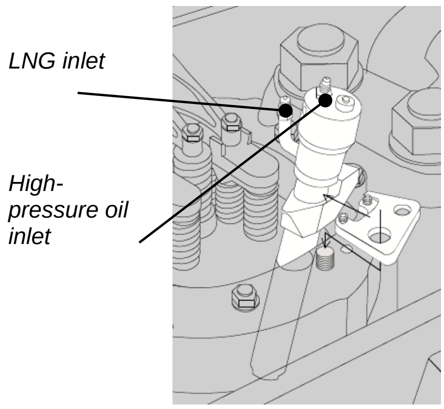
The distribution block incorporates six valves to perform different control operations and pressure sensors.

It is important to highlight that in every gas injections a small amount of oil will be lost so that this consumption should be taken into account in maintenance operations.

The most common faults in the hydraulic system are oil contamination and overheating. A frequent check of the oil level and the circuit should be recommended to detect possible leaks. Likewise, the frequency of the change of oil and filters must be specified.



Hydraulic circuit scheme



LNG injection valve

High-pressure hydraulic pump

Distribution valves block

Figure 104. Hydraulic system and components scheme

Cooling System

In any LNG transformation of a diesel engine, it is necessary to recalculate the water cooling needs for the engine due to the higher temperatures that occur during the gas combustion.

Once the necessary refrigeration power is calculated, it will be decided whether it is convenient to change the existing heater in the locomotive 310 or whether it is sufficient to add an additional element to the current one. In both cases, the operating principle and the maintenance operations will be the same as the ones of the present locomotive configuration.

Figure 105. Cooling system

Instrumentation

As a result of the transformation to LNG, a series of indicators of the measures coming from the sensors incorporated in the new circuits must be installed in the cockpit control stations to allow an effective control:

1. Engine revolutions
2. Engine oil lubrication pressure (in/out)
3. Engine oil lubrication temperature (in/out)
4. Gas pressure at the entrance of the supply conduct
5. Gas pressure at the end of the supply conduct
6. Gas temperature
7. Admission air temperature in the collector
8. Admission air pressure in the collector
9. Cooling water temperature (in/out)
10. Combustion gases temperature in exhaust manifold
11. Oil pressure of the hydraulic circuit (in/out)
12. Oil temperature of the hydraulic circuit

In addition, it is recommended to install a repeater of the Motor Control Display (ECD), which will provide better data for the maintenance works, such as error codes and special readings (eg: indicator of the cylinders detonations).

Breakdown location

This chapter will follow a scheme similar to the one used in section 13, part B (General plan for the location of breakdown) of the *DESCRIPTIVE MANUAL OF THE VEHICLE – Diesel Electric Shunting Locomotive – Model SW-Di1001AC – Series 310* (page 357 and following), with the aim to maintain the same logical system used for the other systems of the locomotive and thus facilitate its understanding and the work of specialists and maintenance operators.

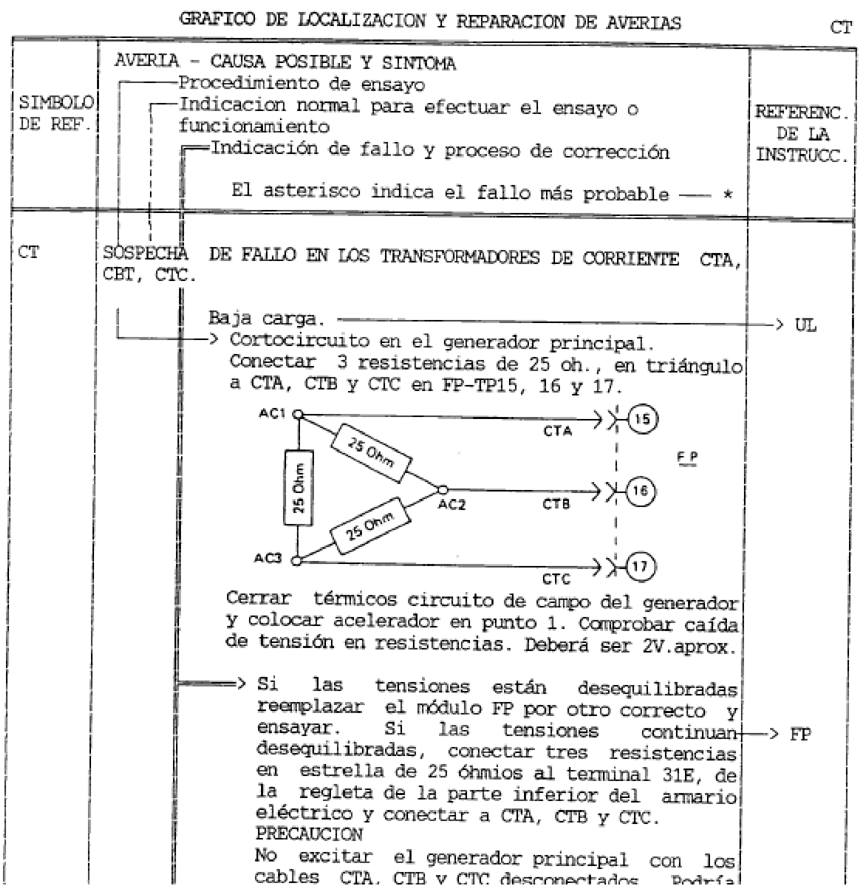


GRAFICO DE LOCALIZACION Y REPARACION DE AVERIAS CT

SIMBOLO DE REF.

AVERIA - CAUSA POSIBLE Y SINTOMA
Procedimiento de ensayo
Indicacion normal para efectuar el ensayo o funcionamiento
Indicación de fallo y proceso de corrección
El asterisco indica el fallo más probable — *

REFERENC. DE LA INSTRUCC.

CT

SOSPECHA DE FALLO EN LOS TRANSFORMADORES DE CORRIENTE CTA, CBT, CTC.

Baja carga. → UL

Cortocircuito en el generador principal.
Conectar 3 resistencias de 25 oh., en triángulo a CTA, CTB y CTC en FP-TP15, 16 y 17.

Cerrar térmicos circuito de campo del generador y colocar acelerador en punto 1. Comprobar caída de tensión en resistencias. Deberá ser 2V.aprox.

Si las tensiones están desequilibradas reemplazar el módulo FP por otro correcto y ensayar. Si las tensiones continuan desequilibradas, conectar tres resistencias en estrella de 25 óhmios al terminal 31E, de la regleta de la parte inferior del armario eléctrico y conectar a CTA, CTB y CTC. → FP

PRECAUCION
No excitar el generador principal con los cables CTA, CTB y CTC desconectados. Podría

Figure 106. Example of localization and repair of faults

Decision diagrams will be included to facilitate breakdown locations, such as the following example:

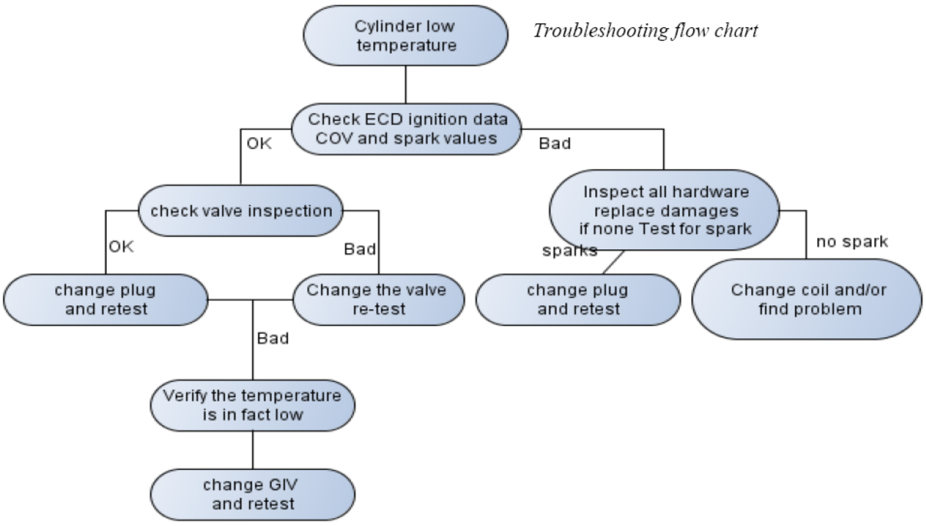


Figure 107. Example of decision diagram

A special section dedicated to possible gas leaks in the LNG circuit will be drafted, with mention of its maintenance, calibration of sensors and the related electronics.

Reference data for maintenance

This chapter aims to complete the section 16 of the *DESCRIPTIVE MANUAL OF THE VEHICLE – Diesel Electric Shunting Locomotive – Model SW-Di1001AC – Series 310* (page 328 and following), with the new reference data, that will need to be verified in maintenance operations to ensure that the operation of the new systems or the modified sets are within their correct specifications.

DATOS GENERALES DE MANTENIMIENTO. SECCION 16

MECANICOS.

Carrera cilindros de freno 57 mm.

Prueba de estanqueidad de radiadores 4,2 Kg/cm² durante 10 minutos.

Altura de centrotope a cara superior carril 1040 mm.

Cojinetes de apoyo motor tracción: eje montado

Holgura total longitudinal, testas, 0'99 ÷ 2'66 mm.
Holgura total radial 0'381÷ 0,782 mm.

Figure 108. Maintenance general data example

As an annex, all PID diagrams, wiring diagrams, instrumentation, indicators…that are necessary for the correct and easy reading of the measures or verifications to be made, will be included.

In particular, new sensors and transmitters incorporated in the engine and gas circuit will be listed, mentioning the expected values of the output signal of each one.

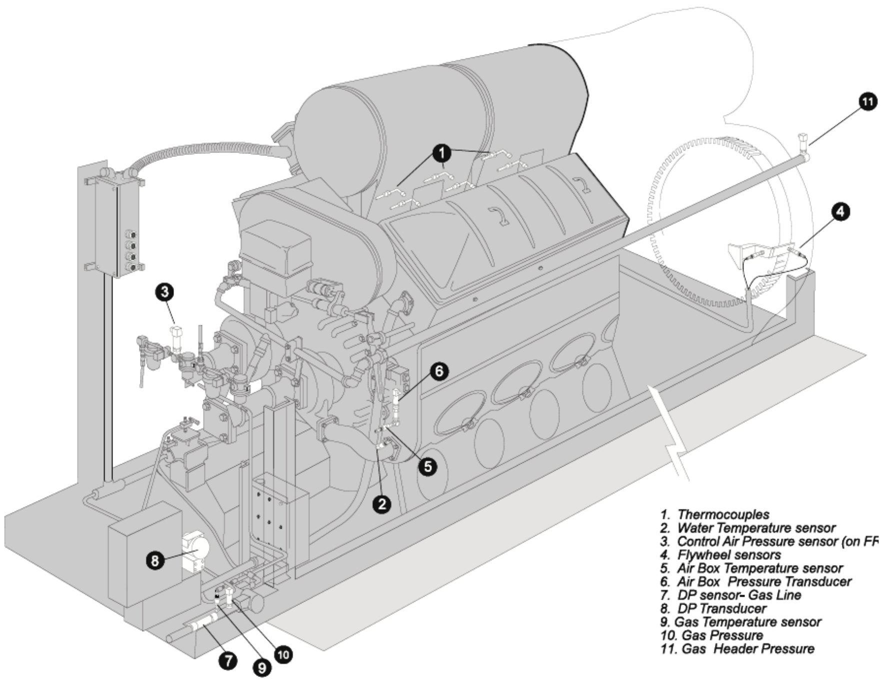


Figure 109. Location of control sensors

For each sensor and transmitter, data must be specified for its correct calibration and the process to follow for this.

List of components

In the final chapter of the ANNEX of the manual, a table will be included with the list and description of each of the components, parts or subsets that conform the transformation, with detailed mention to:

1. Name of the element
2. System or set to which it belongs
3. Description and function
4. Brand / Model
5. Specifications and technical data
6. Observations
7. Provider (name, address, telephone, e-mail)
8. Stock available [yes (quantity)] - [no]

10.6.2 Training plan

The objective of this section is to establish the bases that must be followed to include all the necessary training contents to redact a Training plan for Operators and Maintainers.

Regarding operators, all changes concerning the habitual locomotive handling associated to the change in motorization and to those indications and alarms that are newly incorporated in the locomotive will be included.

Regarding the maintainers, all changes in preventive and corrective maintenance will be included that, according to the EN13306 regulation, are necessary to locate faults and for the preventive operations/reviews of new incorporation in maintenance routines.

10.6.2.1 Background

The documents, *DESCRIPTIVE MANUAL OF THE VEHICLE – Diesel Electric Shunting Locomotive – Model SW-Di1001AC – Series 310*, and its future ANNEX, are established as the reference in the previous section 10.6.1 dedicated to Maintenance and Operational Plan, which specifies all the changes related to the maintenance of the transformed locomotive.

The ANNEX based on the Maintenance and Operational Plan, pending a more detailed edition after the transformation, will follow a similar structure to the Descriptive Manual, detailing the new particularities of the locomotive with the transformed EMD engine.

The other three documents, at the moment unknowing the existence of others equivalent, include chapters and general descriptions of the type 310 locomotive and of its transformation to LNG. These documents can be used as the guide or textbook to train the operators and maintainers.

It is suggested to structure the extension of the Training Plan specific for the transformation to LNG, adding the following chapters into the current general programme:

1. Initial basic training course (common for both operators and maintainers)

2a. Specific course for operators

2b. Specific course for maintainers

Hereunder, the general content of each course is described, and an example is given for them.

10.6.2.2 Initial basic training course (Operators and Maintainers)

All training course must be initiated with a description of the LNG properties and the security precautions to be considered during its manipulation. Furthermore, it is suggested that the LNG provider contributes with its knowledge and related documents.

It will follow a general description of the modifications performed for the conversion to LNG, with enough graphical information to facilitate its understanding and the identification of the main parts that have been modified. It will give a general overview of the assembly and its operating principle.

Specifically, the changes performed in the following elements must be exposed:

- Thermal engine (mechanical elements)
- LNG system
- Engine's control (ECU)
- Hydraulic system
- Cooling system
- Instrumentation

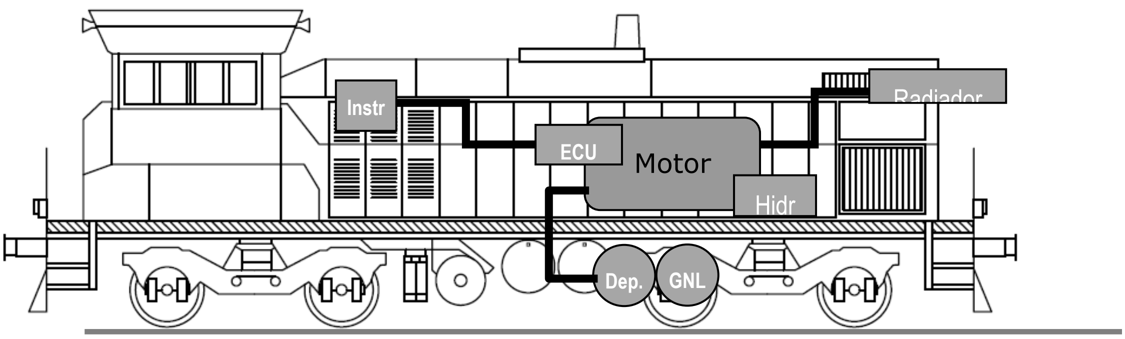


Figure 110. General overview of the transformed system

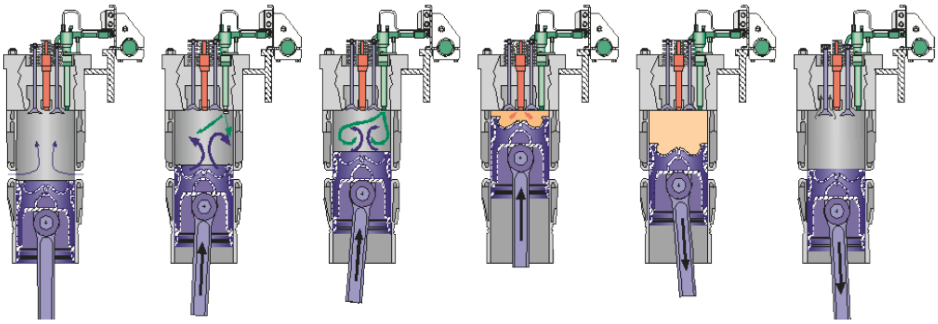


Figure 111. Cycle of the LNG engine

The course will finish with a demonstration of the start and the stop of the locomotive.

The syllabus to be followed of this additional course to the complete programme for the 310 locomotive, could be similar to the one presented below:

	Topic	***Duration (h)***
1	LNG properties	1
2	Precautions during the LNG loading	1
3	Precautions during the operation and the maintenance	1
4	General overview of the transformation to LNG	2
5	Transformed engine (cycle, new performances, etc)	2
6	LNG system (deposits, circuit, sensors, etc)	2
7	Engine's control (object and ECU's screen)	1
8	Hydraulic system (object and situation of the components)	0,5
9	Cooling system (object)	0,5
10	Instrumentation in the cabin (situation of the controllers and the indicators)	1
11	Demonstration of the start and stop of the engine (prior inspection of the system, precautions, etc)	2
	Total duration:	14

Table 27 Initial basic training course (Operators and Maintainers)

10.6.2.3 Course for Operators

This course will be more focused on the characteristics of each modified system, with special attention to their operation, ECU's location and indicators, reference values for all the parameters (temperatures, pressures, etc), most common fault symptoms, inspection and precautions before the locomotive start and stop, etc. This course will be dispensed both in the classroom and in the locomotive.

An idea of this course syllabus could be the following:

	Topic	***Duration (h)***
1	Pre-starting inspection of the locomotive	1
2	LNG engine functioning (injection, ignition, etc)	2
3	Location of sensors and actuators in the engine	1
4	LNG circuit functioning	2
5	Location of sensors and valves in the LNG circuit	1
6	Practices in the locomotive	4
7	ECU functioning (screens, errors, etc)	2
8	Practices in the locomotive	4
9	Hydraulic system (circuit, functioning, sensors)	1
10	List of reference values for parameters	1
11	Cabin instrumentation	2
12	Start, movement and stop of the locomotive	4
	Total duration:	25

Table 28 Course for Operators

10.6.2.4 Course for maintainers

This course will be more focused on the characteristics of each modified system, with special attention to their maintenance requirements, as well as the most common fault symptoms and their repair. This course will be dispensed both in the classroom and in the locomotive.

An idea of this course syllabus could be the following:

	Topic	***Duration (h)***
1	General information and LNG engine start	1
2	Fuel system maintenance	2
3	LNG tank emptying	0,5
4	Pre-chamber ignition system	1
5	Gas injectors – (Gas Inlet Valve - GIV)	2
6	Engine speed control	0,5
7	Revision and maintenance of the gas pipelines	1
8	Charging valve – Adjustment and sway of the engine	2
9	Sensors (Temperature, differential pressure, detonation….)	3
10	ECU – Diagnosis and monitoring	3
11	Hydraulic circuit	1
12	Gas leakage detector	1
13	Practise in the locomotive	4
	Total duration:	22

Table 29 Course for maintainers

10.7. Definition of the necessary tests to perform

10.7.1 LNG circuit leak tests

It is based on the elaboration of a specific leak testing protocol of the LNG circuit, defined according to the indications given by the engine and the cryogenic tanks manufacturers.

Once all the components of the natural gas tubes circuit are bound, it is necessary to check if the installation is entirely watertight. Otherwise, the gas would go outside, causing risk situations. The leak test consists in introducing an inert gas, commonly nitrogen, into the installation with enough pressure to verify the existence of leaks.

10.7.1.1 Necessary material

The following elements are required to perform the test:

1. Nitrogen cylinder
2. Manometer and hoses
3. Soapy water

Nitrogen cylinder:

The nitrogen is stored in pressurized bottles of different capacities, which are characterised by its black colour. They have a gas relief valve that can be connected to a pressure reducer that enables to reduce and regulate the outlet pressure. The pressure reducer has two manometers, the one with more amplitude (about 300 bar) measures the prevailing pressure into the cylinder; the lower amplitude (about 40 bar) measures the outlet pressure. The outlet pressure can be controlled turning the regulation lever.

Manometer and hoses:

To fill the nitrogen into the circuit, several devices can be found in the market consisting in a set of hoses with their respective fittings to connect the cylinder to the filling valves, and a manometer with the appropriate amplitude to perform the test. The shut-off valve allows to close the hose and take the cylinder away once the nitrogen has been introduced.

Soapy water:

The soapy water is frequently used as a detection method, since it enables to visualize clearly the exact location of the leakage. The soapy water is easily made with a proportion of 50% water, 40% liquid soap and 10% glycerine. It can be also found in the market as an aerosol, which allows an easier and quicker application.

Once the mixture is obtained, it must be shaken until there is foam on its surface. The mixture must be poured with a brush to all the suspected leak spots. In such cases, air bubbles will appear.

10.7.1.2 Leak test performance

To proceed with the test using natural gas, it is necessary to be assured that all the installation will be subjected to the test pressure. The LNG tanks will be at a pressure that will depend on the temperature of the inner liquified natural gas and can vary from 1 bar (at -162ºC) to 10 bar (at -125ºC).

The leak test is conducted in two phases:

Phase 1: Large leak detection. The aim of the first phase is to detect large leaks that can be identified just hearing. These leaks can be occurred by a loose hose, a loose threaded joint, a significant hole in a weld, etc. It simply consists in introducing the nitrogen at low pressure (1,5 bar) and listen in order to detect possible leaks.

Phase 2: High-pressure leak test. In this second phase of the test, the nitrogen is introduced at high pressure (15 bar, value recommended by the tanks manufacturer).

The introduction of nitrogen must be slow, with the aim to detect possible leaks perceptible by the ear. Once the test pressure has been achieved and stabilized, it is necessary to maintain it invariable. It is recommended, for higher safety, to maintain the installation at the test pressure until the following day.

A slight decrease of the pressure during this period of time may indicate the existence of leaks. Its detection will be conducted using soapy water.

10.7.2 Commissioning and acceleration static test in tests bench

It is necessary to define the commissioning and acceleration static tests in tests bench.

A distinction is made between the definition of three differentiated test protocols:

1. Specific protocol of the modifications implemented to the engine.
2. Overall static tests protocol: commissioning, compressor load, verification of acoustic and optical indications, braking circuit, braking line load, emergency elements actuation, etc.
3. Dynamic tests protocol: accelerations, decelerations, braking distances, rolling, etc.

10.7.2.1 General overview

Below is a list of tests to be accomplished to validate the locomotive operating once the transformation of the engine to LNG and the adaptation of the cryogenic deposits have been conducted.

10.7.2.1.1 Validation of the LNG installation and the gas distribution in the engine

The validation procedure of the gas installation implies the realisation of the following tests:

Leak tests:

Accomplishment of the circuit leak tests according to the indications found in the section 10.7.1.

First filling of the LNG tanks:

When a LNG tank is installed for the first time, it is considered as a hot deposit, so it will generate pressure rapidly during the first filling while de container gets cold. This fact can provoke that the supply installation stops the filling process upon detecting the rapid pressure increment.

It is recommended to introduce only from 40 to 80 LNG litres during the first tank filling to verify the system is leak-free, and then proceed to start the engine for 20-

30 minutes so the fuel is consumed. This methodology allows the pressure to decrease until its normalization. Afterwards, with the engine stopped, the tank can be normally filled to its full capacity.

This procedure is also recommended for deposits that have been emptied and out of use for more than 10 days.

Increase in pressure test into the LNG tanks:

To establish the increment of pressure in a LNG fuel system, the following test must be conducted:

Fill the tank between ½ and ¾. Start the engine for 10-15 minutes until the pressure and the temperature are stable. Stop the engine and, after 15 minutes, write the pressure down. Wait for 8 hours and write again the pressure of the tank. Check whether the pipe is not frozen, and, in such case, this is the increment of pressure for the fuel system.

10.7.2.1.2 Validation of the conversion kit to LNG

The procedure to validate the engine conversion to its functioning with natural gas is initiated with a revision of all the components in the installation and the validation of the associated electric system.

Engine ignition:

The new engine ignition is conducted similarly to the original diesel engine. It is recommended to stop the engine after a set-up time. A new display with the information about the system status is installed in the cabin and the engine commissioning is done from there.

The engine will not start without the ECU nor the spark plugs without voltage. The ECU takes about 40 seconds to start after the initial ignition. The values shown in the screen indicate that the ECU is ready. When the engine is stopped, the ECU and the Spark Ignition System are waiting to receive speed and position signals from the engine, as well as the FPC (Fuel Pump Contactor) relay signal to identify the ignition status.

By pressing the start button, the FPC relay is activated, feeding the fuel supply circuit. With the interlocks of the leak detection system closed, the fuel supply electromagnetic valves are activated, and the gas can supply the engine.

When the engine starts rotating, the ECU monitors several signals to ensure the proper ignition. The controlled signals include the FPC, the status of the ignition system, the status of the leak detection system, the hydraulic system pressure among others. Any problem that may occur will be indicated in the control display of the engine located inside the cabin.

When the engine starts running, the oil pressure and the water temperature are monitored. Moreover, the position of the throttle and the status of the temperature switch of the valve (VTS) are also indicated in the display. These signals are considered as essentials and if their values are not normal, the engine will not start.

During a normal ignition cycle, the FPC signal will be recognised and, as the engine speed exceeds the minimum thresholds, the ignition system will spark the plugs and will confirm its correct operating on the ECU.

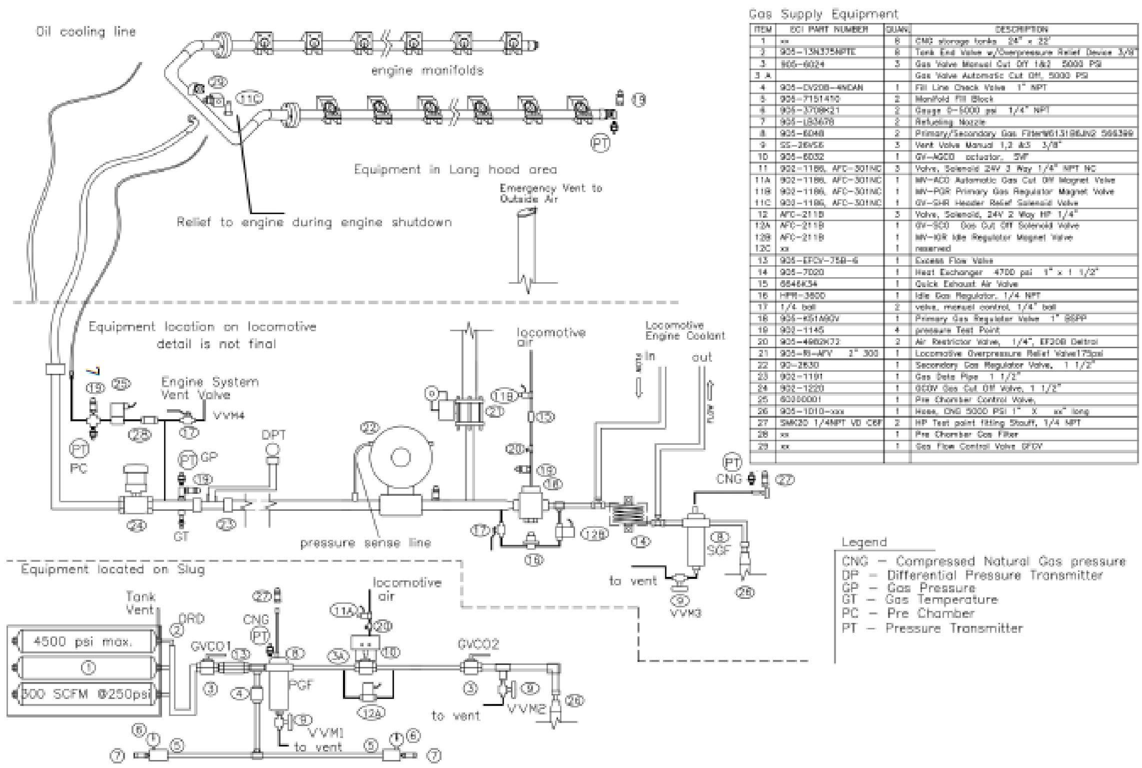


Figure 112. Natural gas system scheme

The ECU will control the status of all the signals necessary to guarantee the correct operating of the engine. The gas flow control valve (GFCV) and the gas injectors will start functioning while the gas cut-off valve remains opened.

The gas injected starts the ignition into the cylinders and the engine comes into operation. Hold the start button down until the engine reaches 125 min^{-1}. The ECU is still verifying the correct status of all the signals. The engine is still idling with the speed and the fuel flow controlled by the ECU.

If the ECU determines that there is a problem impeding the ignition (that is, without gas pressure), a message will appear on the screen and the gas supply will be automatically disconnected.

The system is designed to minimize the starting time of the engine. A selector switch allows the engine to rotate the engine without gas supply, and can be used for maintenance works.

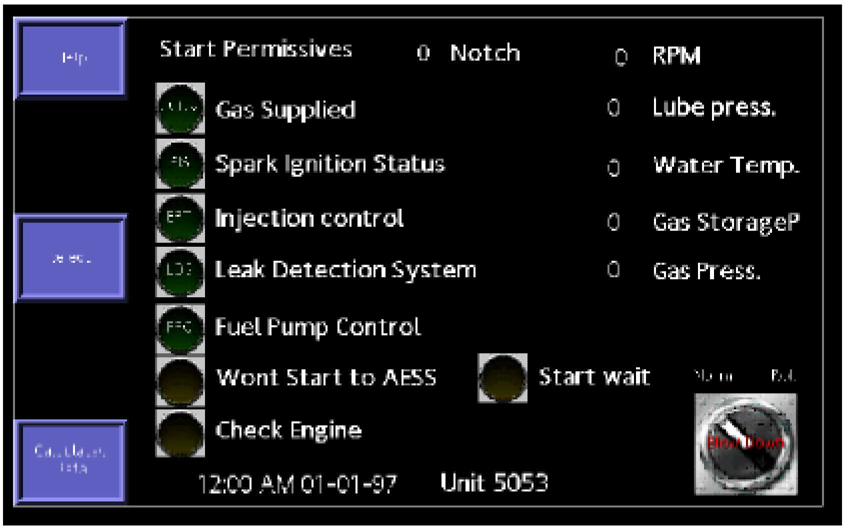


Figure 113. Engine control system display

Engine fitting and balancing:

The power generated by each cylinder depends on the amount of gas supplied and it is a key element for a constant power supply and minimum polluting emissions.

For the fitting and balancing of the engine, the gas flow supply and the exhaust gas temperature of each cylinder will be considered. High exhaust temperatures do not necessarily indicate an excess of fuel into the cylinder.

NOTE: Do not adjust unnecessarily the load blocks.

The combustion pressure is the best indicator of the correct operating of the combustion into the cylinder. In this chapter of the report, a procedure to measure and adjust the engine to operate within the correct limits will be explained, relating its proper functioning with the maximum combustion pressure.

The adjustment must be inspected annually or every time that there are regular failures in the exhaust temperature, as long as the failures are not produced by a defective spark plug or by failures in the gas supply valve or the GIV valves.

The engine must be adjusted in two situations:

1. The first time the system is initiated
2. During the maintenance inspections of the engine or when an injector has been replaced

The engine balancing works must be conducted with an engine load higher than 75%. The evaluation starts with the load position 6 and it is increased at the same time the balance is adjusted. An adjusted engine to the maximum power will probably be unbalanced to the 50% of the load. Once the engine is balanced, it should not require additional adjustments and it should not be handled. Write down the reference points of the load valves in case a new adjustment is required.

Figure 114. Block and load valve assembly

For a correct fitting and balancing of the engine, the appropriate personnel and tools are required. The load block valves enable the balancing adjustment of the cylinder in accordance with the exhaust temperature, according to the measurements taken by the ECU. An additional specific screen informing about the exhaust temperatures is available to conduct the adjustments.

The adjustment is performed when the engine works at high load (more than the 75% of the total load).

1. Select the display showing the temperatures of the cylinders.
2. Review the values and write the cylinders temperatures down.
3. Check the load valve positions in the engine and write their original position down before making any changes. In case a cylinder shows a low temperature, turn the valve one clockwise turn. In case the temperature is too high, turn it one anti-clockwise turn.

4. Repeat these adjustments for all the cylinders until all the temperatures are balanced.
5. After adjusting all the valves, hold the load valve screw using a screwdriver, and tighten the locknut at 15-20 ft-lbs.

NOTE: consider that some imbalances may occur due to different elements of the engine and not necessarily due to the gas injection system.

Practise and experience are necessary to recognise the normal operating of the engine.

Validation of the engine cooling system:

It seems clear that the converted engine to natural gas will require an increment of the cooling capacity due to the lower efficiency of the Otto cycle.

For this reason, the over-dimensioning of the cooling system is included with the other modifications of the locomotive, through the installation of a new heater with higher capacity. The increment of refrigeration required is about the 15-20%.

The power test previously described must be used to validate the suitability of the new heater installed. To this end, the water temperatures must be controlled at the inlets and outlets of the engine and the heater, checking that any of them is above the maximum permissible values indicated by the manufacturer.

Engine power test:

Below is the procedure to be followed to conduct the load tests and the power normalization. To evaluate the operating of the engine and the auxiliary equipment, precise and normalized values must be used to indicate possible anomalies or excessive output power. The correction of anomalies will enhance the engine performances and will avoid its premature wear.

The pages of service data provide the following information:

- Plans and other publications references
- Maintenance team
- Specifications affecting components and circuits
- Power and load resistance graphs, as well as the power factor correction.

Preparation of the load test

1. Stop the engine and withdraw the starter fuse.

2. Check if the fuel tanks are filled enough to perform the load test (about 1200 LNG litres for 90 minutes of operation).
3. Check the oil level in:
    a. Engine
    b. Air compressor
    c. Governor
    d. Hydraulic system
4. Check the cooling water level of the engine.
5. Check the engine's sweep chamber. Verify the status of the segments and the cylinder surfaces.
6. Get a thermometer to measure the room temperature.

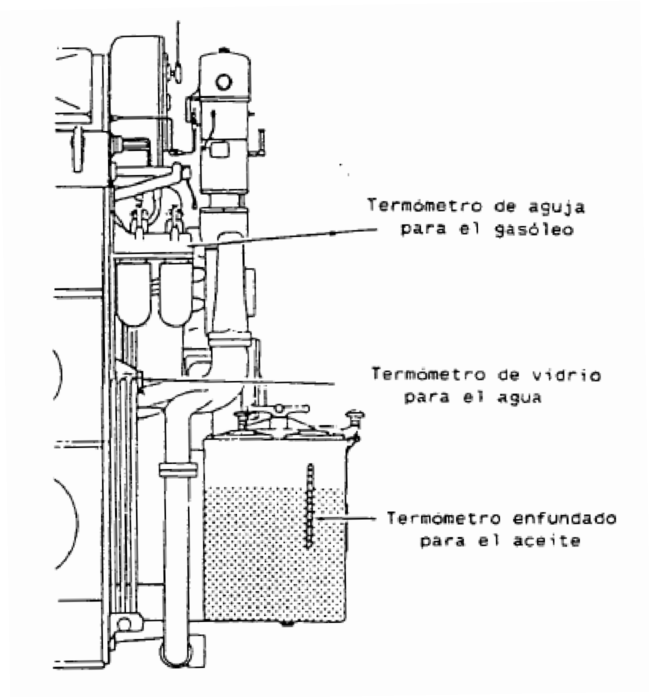


Figure 115. Location of the thermometers for the power test

7. Find the fuel temperature (gas) in the control panel.
8. Measure the air temperature at the engine inlet.
9. Measure the engine's oil temperature.

Preparation for the load test

ATTENTION: Make sure all the connections have been conducted correctly.

1. Connect two 775724 cables to the GP bus of the main generator. Connect the other extreme of the cables to the positive terminal of the external load.

NOTE: do not proceed with the connection of the second phase before starting the engine, unless the external load is equipped with a switch which isolates the load during the engine ignition.

2. Connect two 775724 cables to the GN bus of the main generator. Connect the other extreme of the cables to the positive terminal of the external load.
3. Connect a voltmeter to the positive and the negative terminals of the load test shunt in the test panel (TP1 and TP2).
4. Disconnect and withdraw the bus from the shunt panel of the main generator.
5. Place the test switch of the test panel in the position *Load Test.*
6. Connect a 0-1500 VDC voltmeter to indicate the main generator voltage (positive to GP and negative to GN of the test panel).
7. Select the appropriate load resistor for the load curve displayed in *Service Data*.

Test run

1. Connect again the starter fuse. Start the engine and turn the controls in power mode for the operation (IS switch in the position MARCHA).
2. Turn the accelerator to the position 1 and verify:
    a. Appropriate engine oil pressure
    b. No water, oil nor fuel leaks
    c. Discharged compressor
    d. Load box fans run properly
    e. Values for voltage and electric current in the generator are displayed.
3. Turn the accelerator to the position 3 and let the engine to reach a temperature higher than 55ºC before applying full load.
4. Turn the accelerator step by step until it reaches full load and full speed. Observe the functioning of the heater fan and the blinds. There is a test button in the engine temperature switch.
5. With the accelerator at the position 8, observe that the load controller is at its midpoint and not at its maximum field range position.
6. Connect the pushbutton (normally open) between the SCC G1 and the BF H. Then, the pushbutton will close, and the load controller will move to the

minimum field range position. Releasing the switch, the load controller should move to its midpoint.

7. Close all the doors of the engine enclosure and leave the engine at full load until it stabilizes (about 30 minutes if only checking the power and about 60 minutes if checking the operating of the oil cooler). The blinds can be partially blocked in case the temperature requires a more adjusted control.
8. Check the engine water temperature until there is no difference between the readings displayed within 15 minutes.
9. When the conditions are stable, observe and record all the following temperatures:
    a. Fuel temperature
    b. Water temperature at the water pump outlet
    c. Engine oil temperature at the strainer
    d. Air temperature at the heater inlet.
10. Measure again the temperatures after 15 minutes and after 30 minutes.

Power calculation and normalization

1. Based on the observations obtained, calculate the corrected power using the formulas, the correction factors and the auxiliary power values presented in the *Service Data*.
2. If the total corrected power in normal conditions is not within the range considered permissible indicated in *Conservation Data*, conduct the adequate verifications to find the discrepancies: the adjustment of the zippers, injectors and valves synchronization, controller adjustment, air filter cleaning, power set status and excitation of the main generator.
3. If the inlet temperature of engine lube oil is higher than the maximum indicated in the conservation instruction M.I.928 for the proper operating of the cooler, the oil cooler must be cleaned.

Service data

The following table shows the power of the diesel engine and the transformed engine to natural gas.

	Diesel	GNL (ECI Conversion)
Manufacturer	General Motors / EMD	General Motors / EMD
Model	GM 8-645-E	GM 8-645-E
Type	8V Supercharged 2-stroke 45ºV	8V Supercharged 2-stroke 45ºV
Power	684 KW / 930 CV 900 min-1	745 KW / 1013CV 900 min-1

Table 30 Specifications of the diesel and LNG engines.

Formulas

$$Generator\ inlet = Generator\ power =$$

$$= \frac{V(Main\ gen.)\ x\ I\ (Main\ gen.)}{Conversion\ Factor\ W\ to\ HP\ (*)}$$

(*) Value recommended = 700

Total power adjusted to the AAR Standard conditions =

$$= \frac{HP(Main\ gen.) + \ HP\ (Aux.)}{A\ x\ B\ x\ C\ x\ D}$$

Where:

- A - Correction factor for air temperature. Standard 15,5ºC
- B - Correction factor for height. Standard to sea level: 759,5 mmHg
- C - Correction factor for fuel density.
- D - Correction factor for fuel temperature. Standard 15,5ºC

AUXILIARY POWER TABLE	HP	kW
Auxiliary generator	7.0	5.2
Generator fan and Motor drive	19.0	14.2
Cooler fan (Opened blinds)	55.0	41.1
Compressor (Discharged)	15.0	11.2
TOTAL AUXILIARIES	96.0	71.7

Table 31 Power of the auxiliary elements

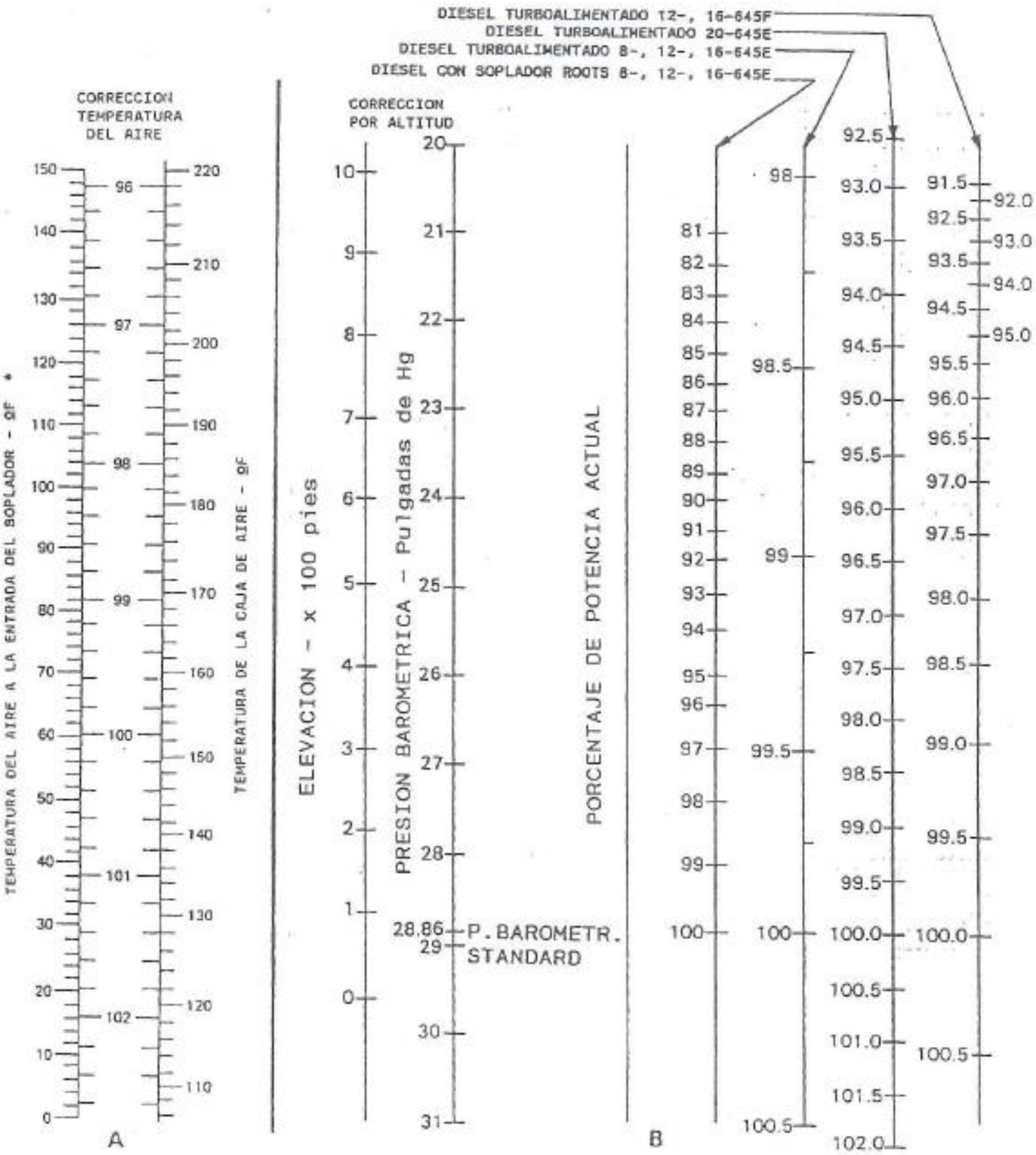


Figure 116. Nomographs of barometric correction factors by models (1/2)

These nomographs must be used according to the instructions described in the manual *Service of the Locomotive* for the power correction at the standard barometric pressure of 28.85 pulg.Hg.

* Sum 24ºC to the room temperature to obtain the air inlet temperature.

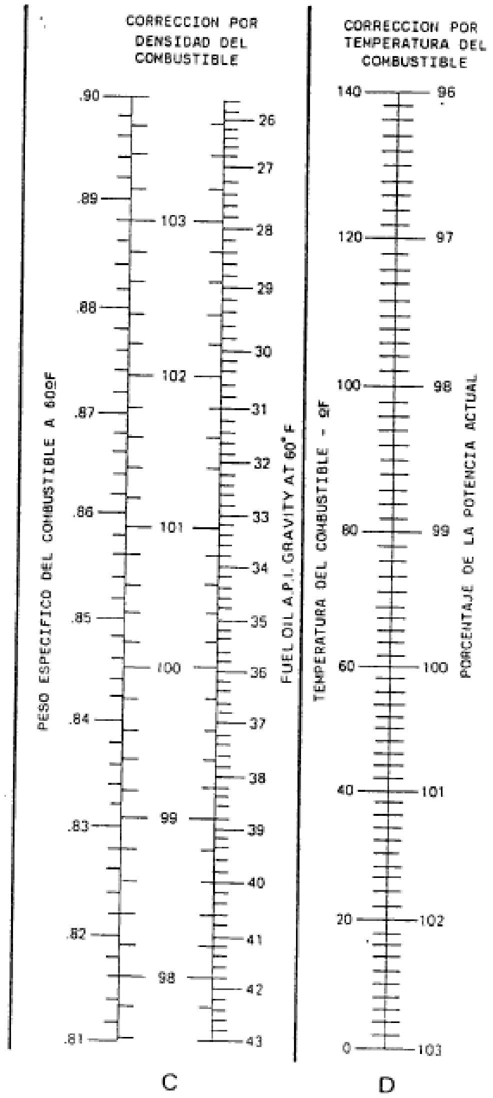


Figure 117. Nomographs of barometric correction factors by models (1/2)

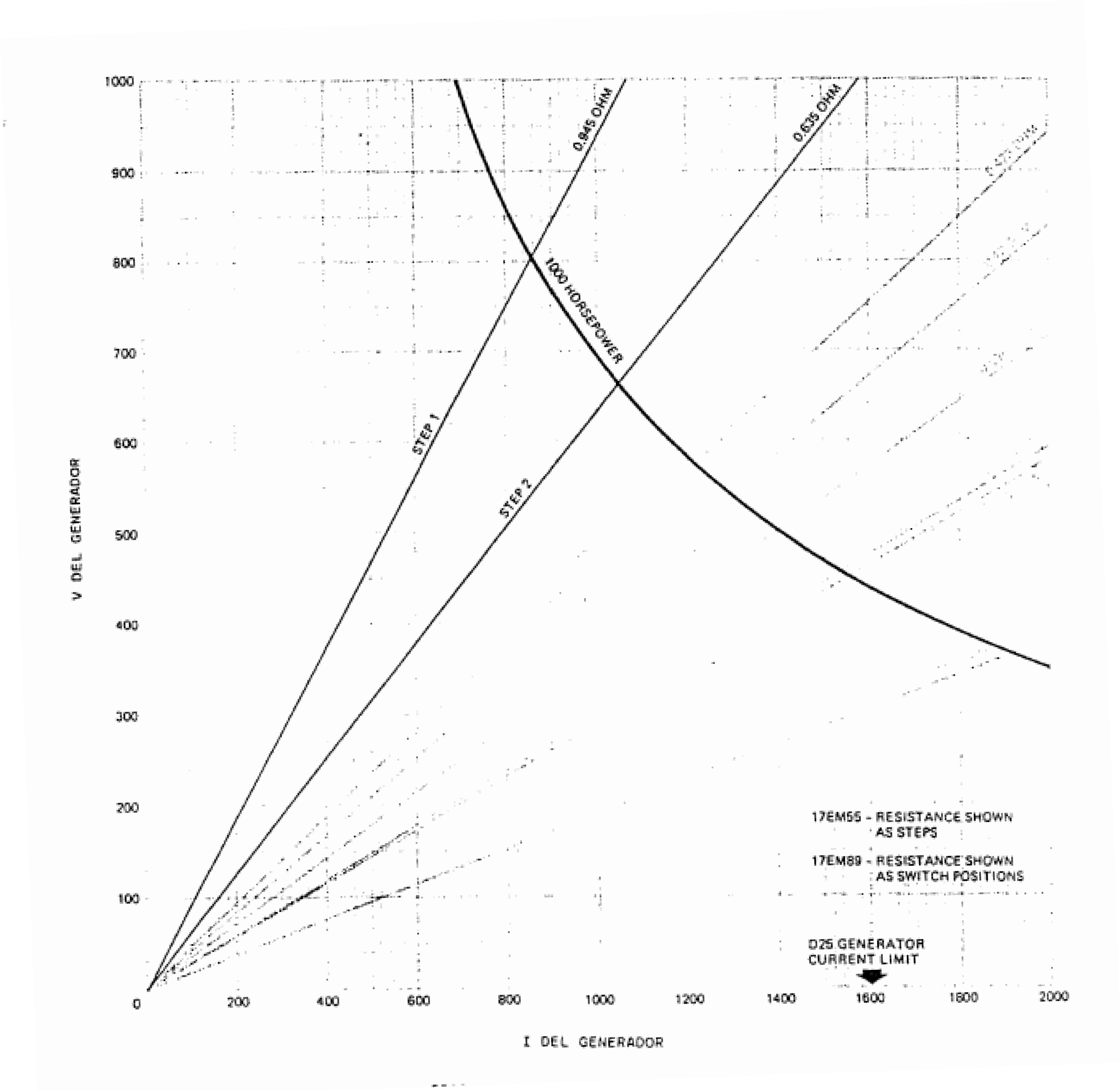


Figure 118. Graph for the 1000 HP generator load

Validation of the gas leak detection system:

It is recommended to use a gas leak detection system with continuous monitoring, even if it is not required under the local regulations. It is an autonomous system that uses 4 sensors to monitor continuously the air inside the engine zone.

If the methane concentration of the air is the 20% (or higher) of the lower flammability limit (1% of gas in air), the system will indicate it with an alarm. When the concentration reaches the 50% of the lower flammability limit (2.5% of gas in air), the system will activate a relay which will close all the gas supply valves.

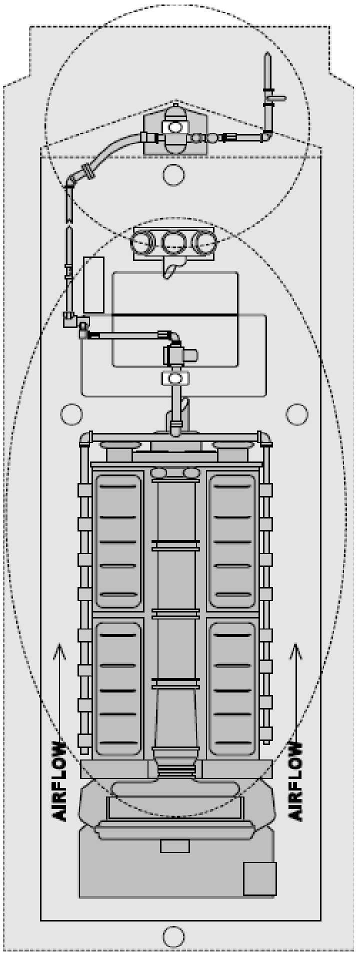


Figure 119. Gas sensors location

The natural gas is lighter than the air, hence all the sensors will be placed at the upper part of the zone to be controlled. One sensor will be located into the main electrical cabinet. Another sensor will be placed at each side of the engine front side (locomotive rear side). The last sensor will be placed above the gas pressure regulating valve.

The sensors are robust elements, however, they must be located far from the engine's exhaust manifold and firmly attached to avoid that the vibrations affect their outcomes.

The validation of the installation must be performed by qualified personnel that validate the location of the sensors and check their correct functioning.

General validation of the locomotive:

In addition to the static tests defined in the previous chapters, some additional dynamic tests will be conducted in the provider's rails.

Also, the tests requested by Adif, detailed in the following section, will be added to the locomotive validation, whenever practicable at the integrator facilities.

10.7.3 Definition and identification of the necessary tests requested by Adif

As it has been introduced in the previous section, the documentation and the procedure to materialise the modification will be defined for the purpose of collecting all the documentation requested by Adif and the AESF.

On 3 May 2016, the Agencia Estatal de Seguridad Ferroviaria, henceforth AESF, published a guide for modifications of railway vehicles - "Guía sobre el contenido del Expediente de Modificación de un Vehículo Ferroviario".

The present section presents the procedure to accredit and authorize the commissioning of the modified locomotive to LNG according to this guide.

10.7.3.1 Procedure

Royal Decree 1434 of 5 November 2010, about interoperability of the railway system of the Red Ferroviaria de Interés General (henceforth RFIG), incorporated into the Spanish legislation the Directive 2008/57/CE of the European Parliament and Council of 17 June 2008, about the interoperability of the railway system within the community.

Article 15, about commissioning of existing subsystems after retrofitting or rehabilitation, establish that, the contracting entity or the manufacturer will deliver to the AESF an information folder with the description of the project, so that this organism studies the folder and, considering the commissioning strategy indicated in ETI, decides whether the scope of the actuations to perform make necessary, or not, a new commissioning authorization (henceforth AES).

This procedure will apply in case the modification is implemented for commercial exploitation.

The following table lists the Directives, FOM orders and Council Recommendations, that must be considered to perform the process.

DOCUMENT	DESCRIPTION
Royal Decree 1434 of de 5 November 2010	Interoperability of the railway system of the Red Ferroviaria de Interés General (henceforth RFIG)
Directive 2008/57/CE of 17 June 2008	Interoperability of the railway system within the Community
Directive 2004/49/CE of 29 April 2004	About the security of the Community railways
Order FOM/233/2006	Regulates the conditions for the subsystems commissioning
Implementing Regulation (EU) nº 402/2013 of the commission, of 30 April 2013	Common security approach for the evaluation and assessment of risks
Regulation (EU) nº 1077/2012 of the commission of 16 November 2012	Common security approach
Technical specifications of relative interoperability to the subsystems Rolling material	Application guide
Order FOM/167/2015, of 6 February	Modifies previous FOM. Regulates the conditions for the subsystems commissioning
Commission Recommendation of 29 March 2011	Recommendation about the conditions for the subsystems commissioning
Recommendation 2014/897/EU of the commission 5 December 2014	Replaces previous Recommendation. Issues addressing the commissioning and the use of subsystems of structural nature and vehicles in conformity with the Directives 2008/57/CE and 2004/49/CE of the European Parliament and Council.

Table 32 Reference documentation and Implementing legislation

10.7.3.1.1 New AES requirement

The modified rolling stock, previously authorized, will only require a new AES that replaces the previous one when, according to the established procedure in chapter II (procedure for commissioning authorization) of the heading (vehicles) of the Order FOM 167/2015, it corresponds to any of these cases:

a) The modification affects the "CE" declaration of conformity or suitability for the use of any interoperability component or subsystem, and as long as the global security level of the vehicle could be affected.

b) The thresholds established into the Technical Specifications of Interoperability (ETIs) or the Railway Instructions (IFs) are exceeded, supposing that the modification has an impact on the basic characteristics of the subsystem design, so it requires a new AES.

c) The modification affects the compatibility of the vehicle with the infrastructure.

d) The modification supposes a variation on the initial performances defined in the AES, or a change of the vehicle category that was assigned in its initial authorization.

e) The modified vehicle, due to the new basic characteristics, can be considered as a type different to the one that was used as the base for its initial authorization.

f) The modification involves a change of the European vehicle numeration.

10.7.3.1.2 Consideration of significant modification

Regardless of the necessity (or not) of emission of a new AES for the modified vehicle, the alterations introduced to the railway rolling stock with previous authorization will have the consideration of significant modification when, affecting any equipment or components included in Annex 2, it corresponds to any of these cases:

- The consequences resulting from a fault in the modified elements, considering the existence of external security barriers, would suppose several damages to people, infrastructure or the material itself.
- The modification involves high technical complexity.
- The change supposes a high level of technological innovation on its implementation, referring both to the innovation in the railway sector and the novel for the organization who implements the modification.
- The change is considered as irreversible.
- Difficulties exist for the monitoring of the modification performance during all its lifetime.
- Any other modification expressly considered as significant by the Implementing legislation.

For the evaluation of these circumstances, the cumulative effect of the successive modifications that could be implemented to the vehicle during its lifetime will be considered, in relation to the original state that was used as the base for its AES, since an accumulation of minor modifications could lead to an important change.

Furthermore, the age of the vehicle to be modified will be taken into account, considering also the lifetime of certain elements or components. Particularly, the consideration of significant changes affecting the frame or any security element will be the Agency's criteria, according to the evaluation and assessment of risks process defined in the Implementing Regulation (EU) nº 402/2013.

It corresponds to the owner of the vehicle to appear in the national register of vehicles assigned to the existent vehicle, either by itself or through a delegation to the entity responsible for the maintenance (EEM), the railway company or the manufacturer (the "applicant"), the valuation of these aspects and the pronouncement, based on experts' judgements, about whether the modifications can be considered as significant or not. In case the applicant does not own a security management system listed in the Regulation of the circulation security of the RFIG, approved by the Royal Decree 810/2007 or it is not an EEM certified by the Regulation (EU) nº 445/2011 having the corresponding maintenance management system, the consideration of non-significant modification will necessarily require the compliance, previous to the implementation of the modification, of the AESF, that can request the report from the railway infrastructure administrator, that is presumed as favourable if it is not emitted within the period established by the AESF.

10.7.3.1.3 Elaboration and presentation of the modification request

The modification request of railway rolling stock that must be presented to the AESF consists of the following data and documentation:

a) Applicant's details.

b) Identification details of the vehicles affected by the modification, including the European number of the vehicles (NEV).

c) Compliance of the owner of the vehicle and the EEM, with the forthcoming modification.

d) Descriptive technical report of the modification, which shall be annexed to the following documents and information:

d.1) List of technical features of the fundamental equipment and/or components corresponding to their original and planned states.

d.2) Drawings, diagrams, or other technical documents defining the modification.

d.3) Number or identifier of the modification. For each of the vehicles mentioned in the preceding section b), the modifications history included to their respective maintenance file will be provided, explaining its relationship with other modifications previously performed, if any.

d.4) Production and tests plans, when appropriate.

d.5) Expected impact of the modification over the vehicle's maintenance plan.

d.6) In case the vehicle or the subsystem may be subject to exceptions in the ETI application, or possible disconformities with the national rules, the technical documents will be annexed with, at least, a description of the subsystem parts subject to the exception or disconformity, accompanied by a justificatory report. Reference shall be made to the ETI application paragraph, or specific national rule, to with the exception or disconformity refers.

i) Informe de conclusiones del solicitante, que irá suscrito por un responsable, debidamente acreditado para estas competencias por su organización, en el que, a su juicio y en congruencia con los documentos antes mencionados, se concluya la necesidad, o no, de someter el material modificado a una nueva AES.

e) When the modification supposes affection to any fundamental security component or concept included into the Annex of this guide, the applicant pronouncement will be provided, based on experts' judgements, about whether the modification can be considered as significant or not.

f) In case the modification can be considered as significant, the request will be accompanied by a process of risk management derived from the proposed modification implementation and from the report of the evaluation organism about risk analysis and evaluation process, in accordance with the Implementing Regulation (EU) nº 402/2013. This report may be completed once the verification process of the modification is finished.

g) Furthermore, the applicant will provide a proposal of the characteristics and/or trials that require a new verification, and will be performed by an appointed or notified organism, as appropriate.

h) When the applicants own a security management system regulated into the Regulation of the circulation security of the RFIG, approved by the Royal Decree 810/2007 or it is not an EEM certified by the Regulation (EU) nº 445/2011, the request must include the compliance of the body responsible for the railway security of the company or the certified EEM.

i) Applicant's findings report, signed by a person responsible, duly accredited for these competences by its organization, in which, with his/her own judgements and in concurrence with the documents previously mentioned, it concludes the necessity, or not, to submit the modified material to a new AES.

The request for modification of railway rolling stock will be sent to the AESF in all cases, regardless of the final consideration regarding the need or not of new AES, and always before beginning the process of implementing the modification. The AESF may request a report from the Railway Infrastructure Administrator, which will be presumed favourable if it does not issue it within the established period.

In addition to the above, the applicant, by itself or through the owner or EEM of the modified vehicle, should inform any railway company that is going to operate the vehicle, about the modification introduced in it, in order that they could proceed with the corresponding evaluation through its security management system on whether the entry into operation of the modified vehicle is a significant change, either for the entire rail system or on its security management system.

10.7.3.1.4 Modifications that require a new AES

If AESF, in view of the request made, decides that a new AES is necessary, the general procedure regulated in chapters II and III of Title VI of the Order FOM/167/2015 will be followed.

When the execution of the vehicle modification operations is initiated, the authorizations of entry into service corresponding to it will be suspended. The new AES will suppose the revocation of the previous authorization of which it was arranged.

10.7.3.1.5 Modifications that do not require a new AES

If AESF, in view of the request made, decides that a new AES is not necessary, the existing authorization will remain in force, and the request will be incorporated into the vehicle's history. In this case it will be sufficient for the applicant to refer the following information to the AESF:

a) The final technical documentation of the modification.

b) The results of the tests or verification reports designated by the organisation or notification of the characteristics affected by the modification.

c) The new maintenance plan, approved by the EEM. If the modification of the plan is not considered necessary, it will be duly justified.

The AESF will request additional or clarifying information that it may deem necessary, and may suspend and revoke at any time the prior authorization for entry into service if the analysis of the submitted documentation considered above in the authorization is not adequately justified in the new situation, because of the modification to be introduced.

If, due to the modification, it is necessary to change some of the data listed in section 5 of the Special Railway Register (REF) and / or in the ERATV, the corresponding registration form must be completed in the REF.

For the modification files that do not require the issuance of a new AES, but do require the updating of the data contained in the authorization for commissioning and / or circulation available under the regime established in the Order FOM/233/ 2006, due to the inclusion of new restrictions, limits and conditions of use, or new technical characteristics of the rolling stock, the previous authorization will be replaced by a new authorization in which the characteristics of the network infrastructure will be indicated in a generic way and not circumscribed exclusively to one or several lines in particular.

10.7.3.1.6 Experimental modifications or prototypes

Those vehicles that had installed new elements for experimental purposes, temporarily and to verify their operation, would not be considered as modified vehicles.

The realization of tests with the vehicle where changes has been made, entails the impossibility of providing commercial service outside the test schedule, this impossibility being corroborated with the suspension of the corresponding authorization of the vehicle. However, there may be a case in which the conditions of use of the authorization available to the vehicle in question, would allow such tests without the need to suspend their authorization, in which case it would be necessary to demonstrate that there is no risk in the circulation.

All this without prejudice to the need for the realization, on the part of the proponent of the vehicle change on an experimental basis, of the process of risk management and independent evaluation, established by means of Implementing Regulation (EU) nº 402/2013.

If after the testing period, it was decided not to replace the vehicle back to its initial configuration, the system established in the Order 167/2015 would apply, and the corresponding file must be delivered.

10.7.3.1.7 Application to the project transformation of a LNG locomotive

The process of accreditation and commissioning of modified engine material is essential for the implementation of rail traction with LNG when manoeuvring in the port environment, but not mandatory in the testing phase.

Two cases can be distinguished:

- **Construction of a prototype**

In this case it will be sufficient to obtain a Provisional Circulation Authorization, issued by Adif when the unit is going to circulate through infrastructures of its competence. This authorization allows to carry out the necessary tests for the development of the prototype.

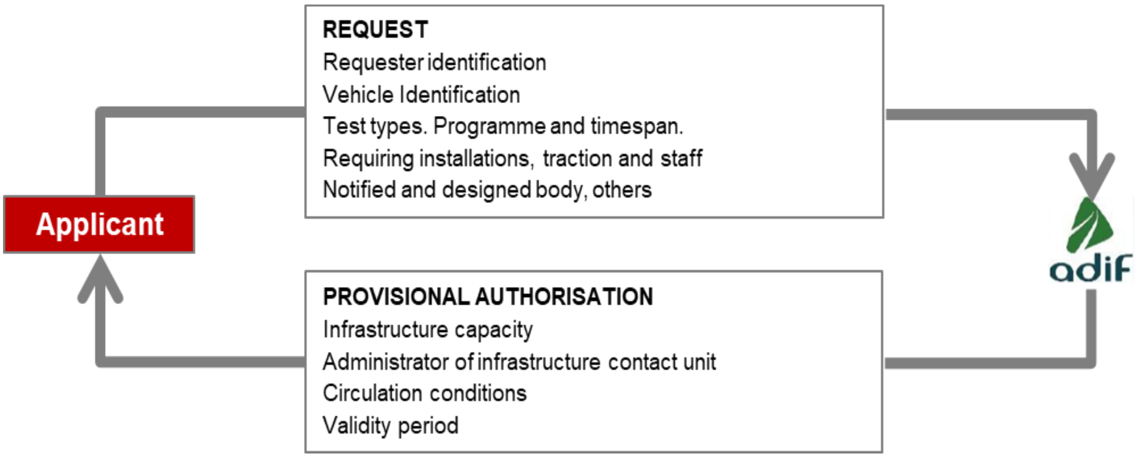


Figure 120. Process to obtain authorization (use of the prototype)

- **Development for commercial exploitation**

If the modification would be implemented for commercial exploitation, the procedure described in this document must be carried out, determining which are the elements that can be treated as a significant modification and therefore require the realization of:

- Risk analysis
- Report from an independent evaluator

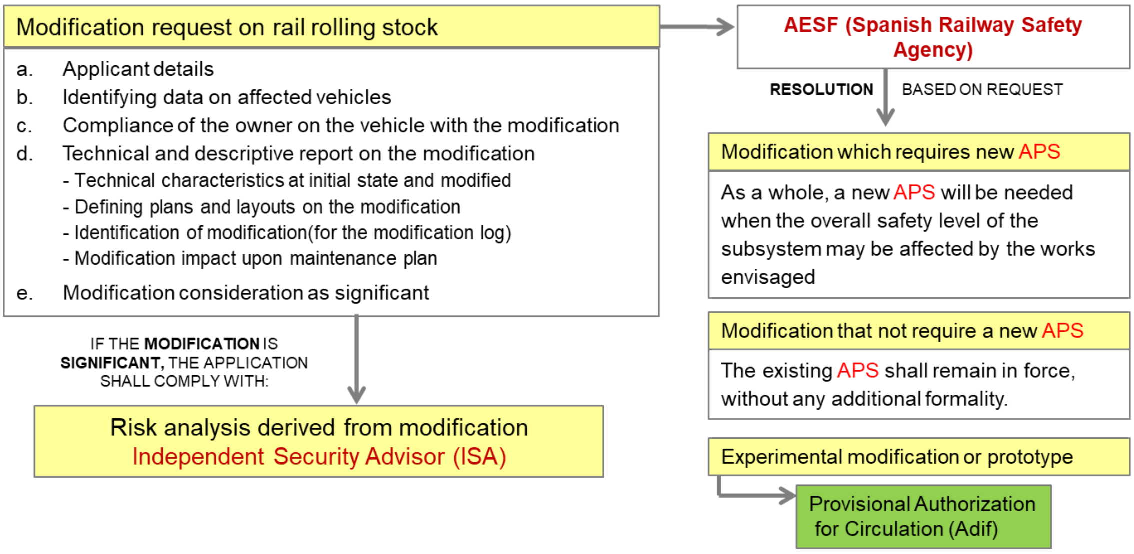


Figure 121. Process to obtain authorization (to use in commercial exploitation)

From the review of the list in Annex 2, the components that may require the completion of a report by an evaluation organisation are the following:

8. SYSTEM OF FIRE PROTECTION

8.1. Fire control system (including software)

It would be necessary to analyse the need to adapt the existing system to the use of LNG, and extend the system to the LNG tanks if necessary.

The new gas leak detection system should be integrated into the locomotive's alarm system.

8.5. COMPARTMENTALIZATION

At least initially, the existing compartmentalization remains unchanged, but the added LNG tanks may involve some modification or expansion.

10. OTHER CONCEPTS AND SYSTEMS

10.2. DRIVING DYNAMICS

The substitution of the diesel fuel tank for LNG tanks, as well as the modifications made to the engine, electrical panels, etc ... may cause a change in the total weight and weight distribution in the locomotive, and consequently in its CoG.

The activities planned by Bureau Veritas for the Accreditation of the modified locomotive consist on:

- Conformity assessment ETH's (Technical specification of homologation)
- Risk evaluation and assessment

In both cases, the engineering performing the project will draft the necessary reports so that Bureau Veritas can handle by the AESF the required accreditations.

In addition to the previous activities, it is possible that AESF may request the verification of a third part of the risks study of the GNL assembly system.

If necessary, the safety studies will be carried out to validate the location and installation of the cryogenic deposits, always in accordance with the requirements made by the AESF.

In Annex 5 of this document, the list of the aspects considered in the risk analysis carried out for the project to replace the diesel engine by a natural gas engine on a 2600 Series automotive vehicle in 2017 is attached.

11. Integration

11.1. Market research of integrator companies

A market research of the different companies that could perform the integration of the system has been made. The experience, the technical capacity and the references in similar projects will be valued.

11.1.1 Background

The railway safety is present in all the elements that compose the railway system, from the rails, the personnel or the rules to the operation regulations. All the stakeholders in the system, from the ones directly involved – such as the infrastructure administrators or the railway companies – to the services providers – such as the entities in charge of the maintenance or the manufacturers -, contribute to achieve the collective security and safety.

The **Agencia Estatal de Seguridad Ferroviaria** – AESF, is a one of this pieces into the system and exercises the role of the authority responsible of the railway safety, according to the 2004/49 directive of the railway safety, for the *Red Ferroviaria de Interés General*.

The AESF has the competences to grant the type-approval of the maintenance centres and, if required, to suspend and withdraw it, as well as the certification for the entities in charge of the maintenance.

AESF AGENCIA ESTATAL DE SEGURIDAD FERROVIARIA

In compliance with the order FOM 233/2006, the rolling stock maintenance centres must dispose of a type-approval emitted by the safety authority.

11.1.2 Integrator companies

To select the integrator company, the homologation given by the Agencia Estatal de Seguridad Ferroviaria – AESF has been considered necessary.

The companies homologated by the AESF for the rolling stock maintenance works are the followings:

Figure 122. Certified companies by AESF

From all the previous companies, three companies were selected for being the ones that fit better with the necessities of the project:

- ARMF
- DTA
- TRADINSA

While all these three enterprises demonstrated capacity and experience to develop the project, ARMF was the one chosen, as it is the only one with previous experience in the transformation of diesel locomotives to natural gas.

Material: Project integration

Contact:

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Director

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11.2. Definition of the works and materials necessary for the integration

In this section, the required work and materials for the integration of the engine and the cryogenic tank will be defined.

The activities to perform for the integration of the engine and the cryogenic tank into the locomotive will be represented in a detailed chronogram.

11.2.1 General overview

The objective is to describe the required works for the transformation of the type 310 locomotive for its functioning with LNG.

As it is abovementioned, the conversion of the original diesel engine of the locomotive (GM 645-8 E) will be performed by means of a conversion kit developed by the company Energy Conversions Incorporated – ECI.

Through this transformation, the engine will operate with Otto cycle using 100% of natural gas as fuel.

The report is based on the technical documentation provided by the suppliers of the system, specially ECI (Energy Conversions Inc.), provider of the transformation kit to natural gas and Chart Industries, provider of the cryogenic tanks.

It has been divided into the following parts:

- Diesel engine conversion to natural gas
- Installation of the LNG tanks
- Cooling system
- System integration
- Commissioning tests
- Accreditation and commissioning

11.2.2 Diesel engine conversion to natural gas

11.2.2.1 Engine preparation

During the drilling systems, it is important to use a vacuum aspirator that minimizes the possibility to contaminate the engine with metal chips.

Drills for Load Blocks:

Holes must be drilled in the head cover for anchoring the injection gas rails and other auxiliary elements. The template for the implementation of these holes it is included in the transformation kit.

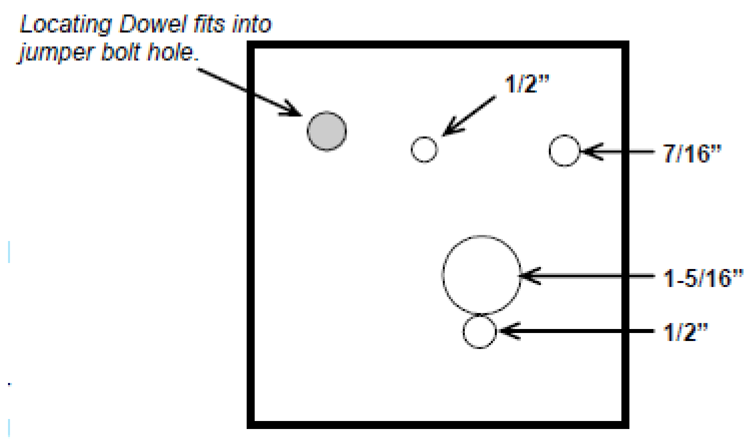


Figure 123. Template for the anchoring holes of load blocks

1. Take the bolt away from the head cover's fuel pipe and insert the template for the new anchoring holes according to **Figure 124** Insert the centring of the template into the original pin hole.

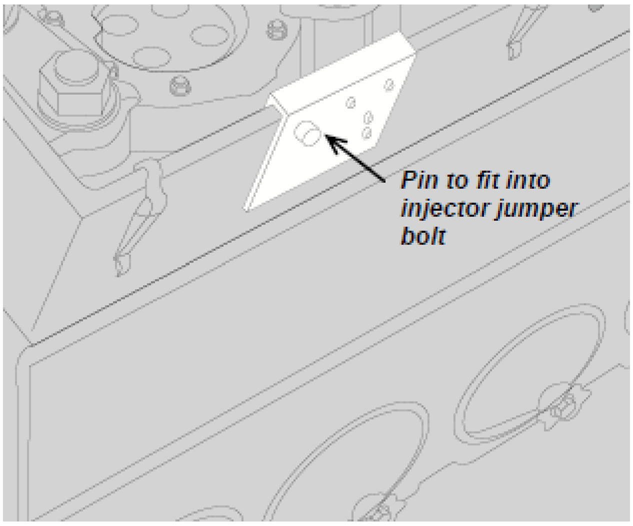


Figure 124. Detail of the template installation

**** NOTE *** Make sure to maintain the template tight against the base to ensure the proper implementation of the bores.*

2. Drill 1/8 " pilot holes through the perforation guides of the template.

3. Take the template away and drill the holes with the corresponding dimensions specified in **Figure 123**.

4. Eliminate the hole burrs.

5. Clean up carefully all the remaining splinters.

6. Take the fuel rail pin away from the end, in the last cylinder at the left part of the engine.

7. Drill the existing threaded hole in the extreme block of the guide rail with a 7/16” diameter.

8. Clean up carefully all the remaining splinters.

9. Use the socket head bolt provided (7/16 "X 2") to latch the extreme load block. (See further detailed information about the load block installation in the chapter dedicated to gas pipelines).

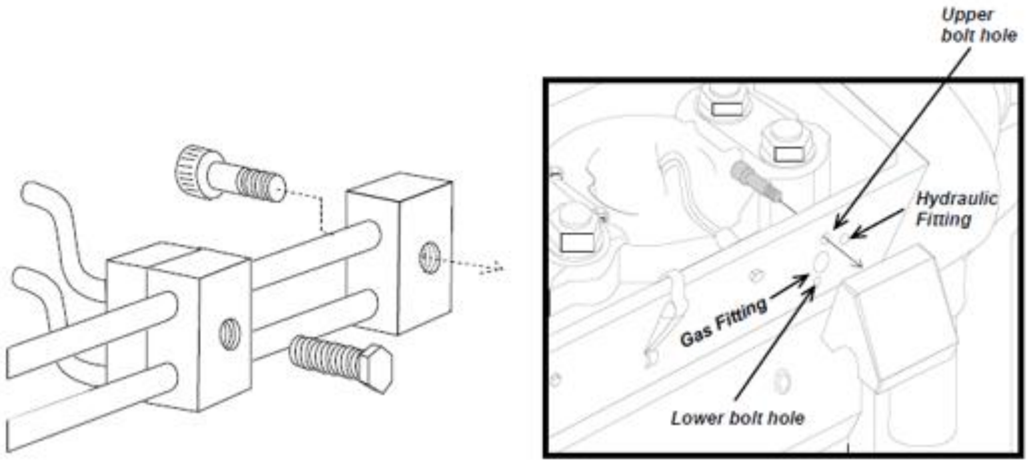


Figure 125. Load block installation details

Drills for GIV (Gas Inlet Valve):

**** NOTE *** Both sides of the head cover must be drilled as shown in* ***Figure 126****. To accommodate the GIV connector and the cylinder sensor. All holes have the same dimensions.*

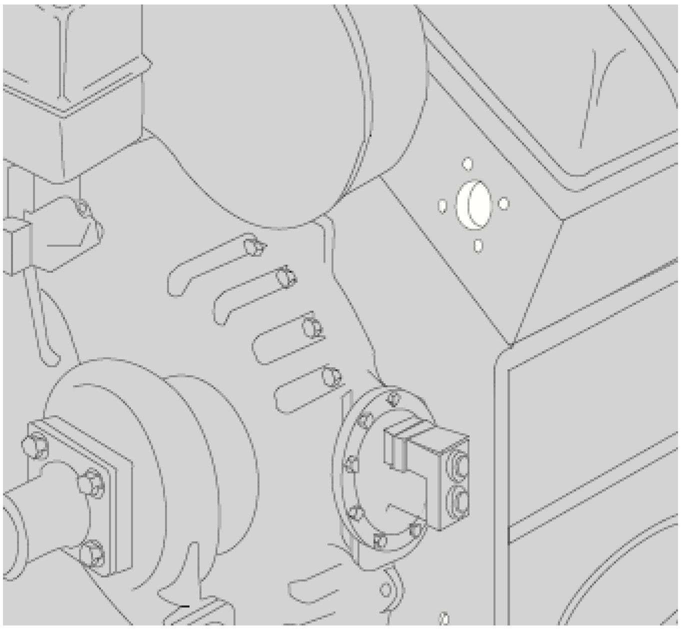


Figure 126. Anchorages location

1. Mark and align the five holes in the centre according the indications shown in **Figure 126**.
2. Drill pilot holes with 1/8 " brit.

3. Drill the central hole with 2.5 " diameter.
4. Drill the four holes for anchor bolts using a 21/64 " brit.
5. The single outer hole is for the hydraulic return line 9/16 ".

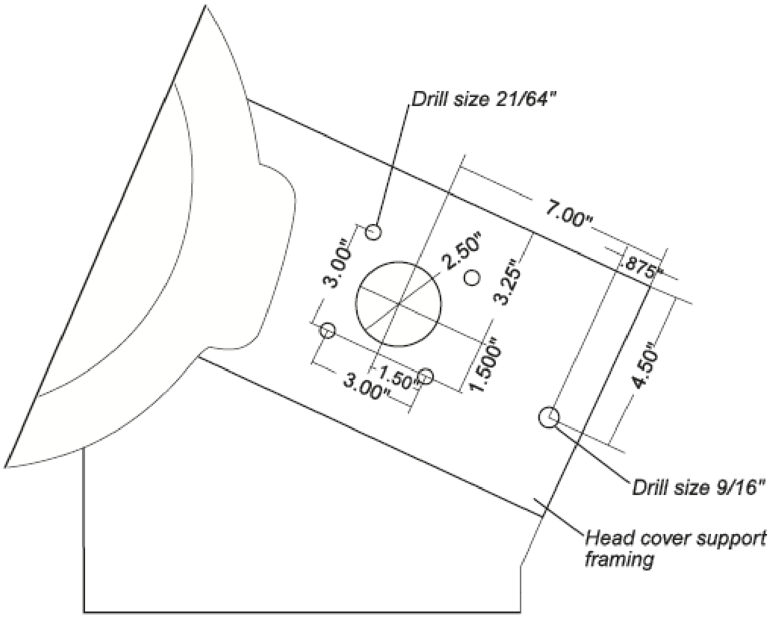


Figure 127. Dimensions and location of the drills

11.2.2.2 Mechanical modifications

The engine conversion for its functioning with natural gas implies several mechanical modifications, such as the cylinders replacement and the adaptation of the cylinder heads.

Cylinder head:

The main difference in the cylinder head consists in the modification necessary for the installation of the gas injectors (GIV-Gas Injector Valve). The drill for the GIV installation must be modified according to the following specifications:

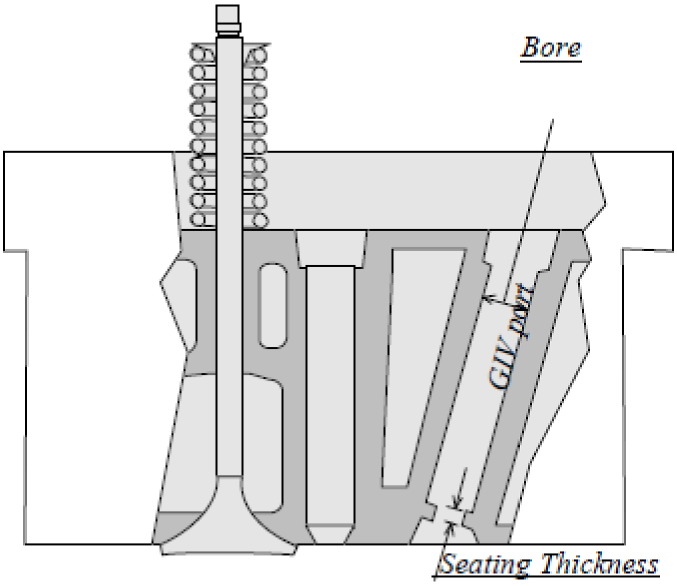


Figure 128. Gas injection gas (GIV)

Inner diameter	1.1875”-1.1975”
Seat thickness	0.300”, 0.250” minimum

Piston:

The pistons must be replaced by the ones included in the kit, with the aim to reduce the engine compression ratio up to suitable values with the natural gas combustion.

Figure 129. Piston of the natural gas engine

The assembly tolerances of the new pistons with the cylinder must comply the following values:

Nominal tolerance	0.125”
Maximum tolerance	0.145”
Minimum tolerance	0.085”

11.2.2.3 Natural gas pipelines

General overview:

The installation procedure for the natural gas power supply is described from the engine’s supply point to the set of LNG tanks.

It is recommended to assembly all the main pipes and the hose upstream the gas flow control valve (GFCV) before welding any pipe support, to facilitate the placement of the assembly, without unnecessary efforts in the joints and connections.

Fasten the pipe supports to the chosen base while they are joined with the pipe. Then, loosen the pipe before the final weld, to not melt the plastic holders of the supports. Each application is unique, and the location of the pipe routing can vary to better adapt its particular situation.

Follow the manufacturer’s guidelines and use the proper tools to assembly the Swagelok accessories.

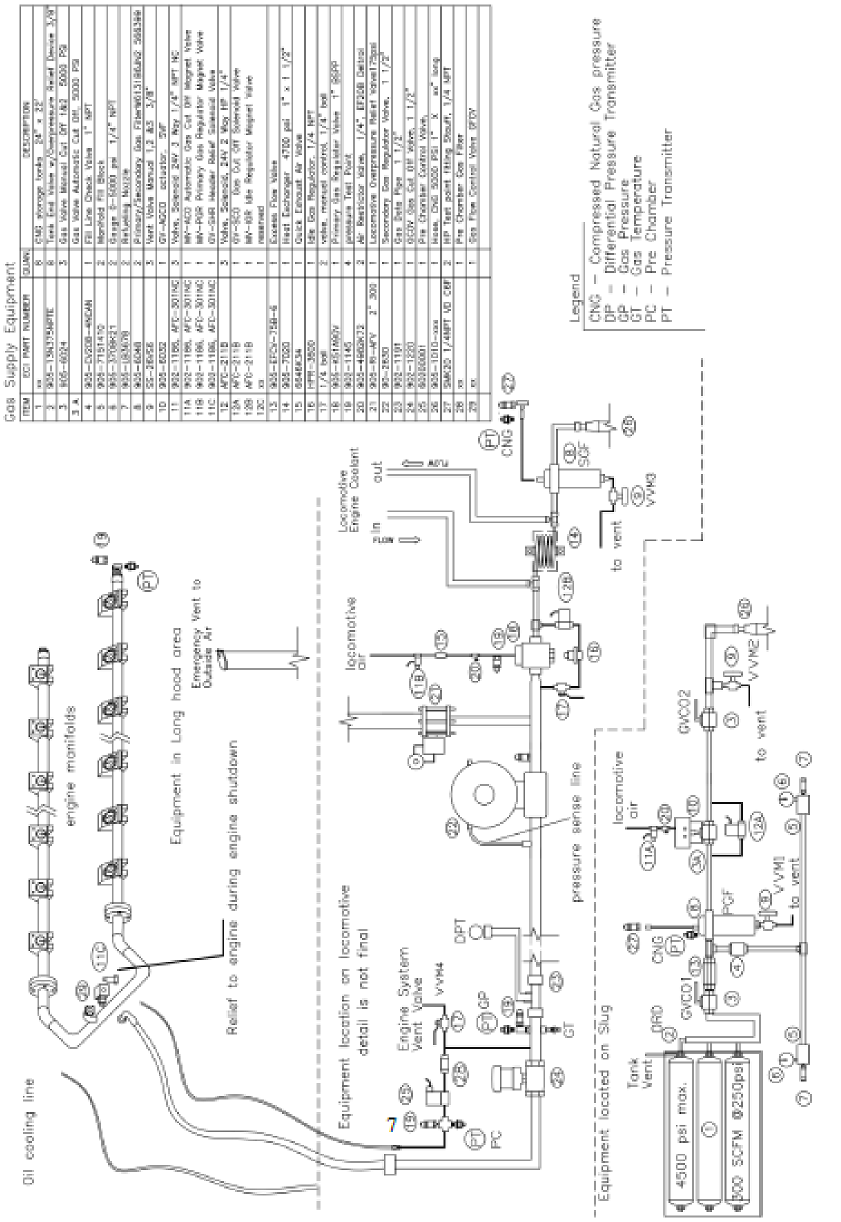
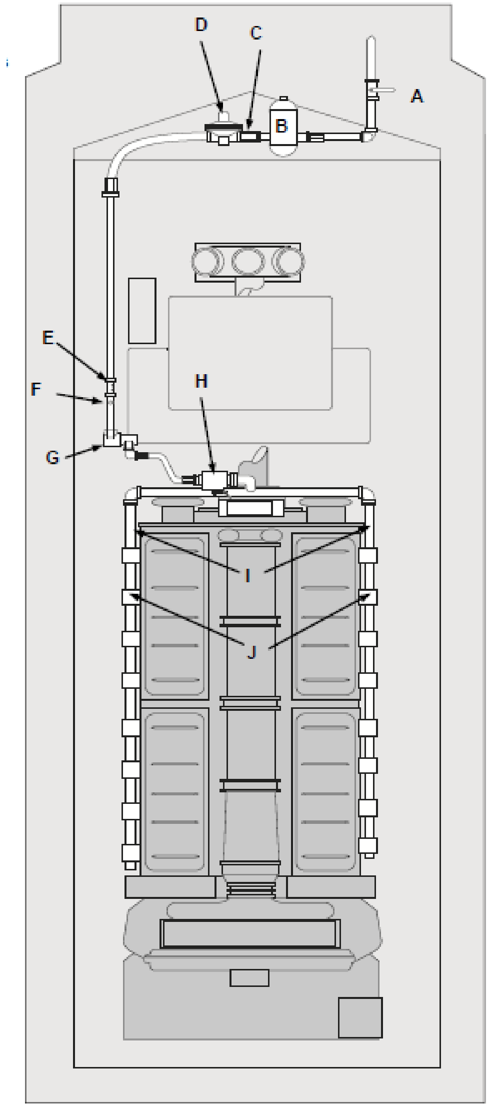


Figure 130. Gas circuit scheme

Pipeline routing:

The **Figure 130** shows an overall design of the low-pressure gas supply pipelines.

Although it is important to maintain the order of the components, its real location and the pipe routing must be adapted to the system needs.



A. Manual shut-off valve (optional)

B. Fuel filter assembly

C. Vent valve

D. Regulator

E. Differential Pressure sensor

F. Port for regulator sensor line

G. Gas cut-off valve (GCOV)

H. Gas flow control valve (GFCV)

I. Gas headers (manifold)

J. Load blocks

Figure 131. Gas circuit routing

Gas circuit installation:

Gas pipelines

1. The gas connection line with the LNG tanks will be performed with a special CNG manufactured by Parker. The 1" hose will be connected to the high-pressure pipe through the locomotive platform.

2. Generally, gas leaks come from connection points. It is recommended to minimize the connections bending the pipes whenever possible.

3. The manual gas cut-off valve will be located in the circuit beside a vent valve to release pressure to facilitate the connection and the maintenance works.

4. The LNG conditioning system must be installed in a protected location. Generally, LNG tanks are installed at the same gasoil tanks space.

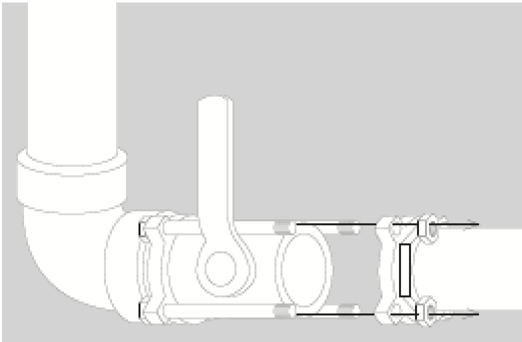


Figure 132. Manual gas supply cut-off valve

The pipes provided by ECI hold tap connectors and couplings for several sensors.

5. Check whether the manual gas cut-off valve (GCOV) is firmly installed in the upstream extreme below the provided pipe sections.

6. Although the differential pressure sensor (DP) is preinstalled in the corresponding pipe section, it is recommended to check the direction of the arrow indicating the flow direction in the sensor (direction of the gas towards the engine). The sensor must remain accessible to facilitate the maintenance works.

7. Connect the upstream extreme of this pipe set to the supply line (now equipped with the manual gas cut-off valve and the filter), ensuring the proper closure in all directions.

8. This set must be modified to enhance its functionality. The location of the pipelines must not interfere any other existing structure. The pipe must be held only the supports provided in the kit.

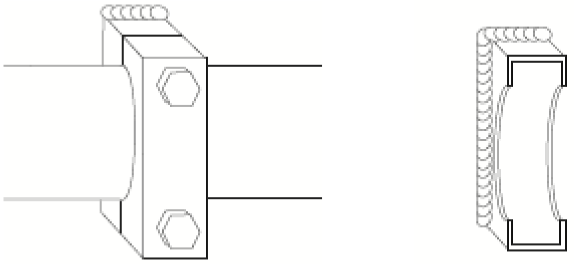


Figure 133. Supports to hold the line

9. Place the pipe supports in the desired positions, securing the assembly with melting points.

10. Remove the pipe set and all the plastic components to avoid being melt or damaged upon finishing to welt the support.

11. Paint the welted areas with an appropriate colour before reinstalling the pipes set.

12. Reinstall the pipe and the supports, and connect the manual gas supply cut-off valve, Tighten all the bolts, firstly at 30 ft-lbs, and then up to 65-70 ft-lbs.

13. Place the 1/2" diameter pipe from the pressure regulator until the differential pressure sensor.

Load blocks

1. After drilling all the appropriate holes (see section 10.1.1 – Engine preparation), sand the surface of the head cover to prepare it for the closure with the load blocks O-rings. Remove all paint or metal residues bigger than 0,40 mm.

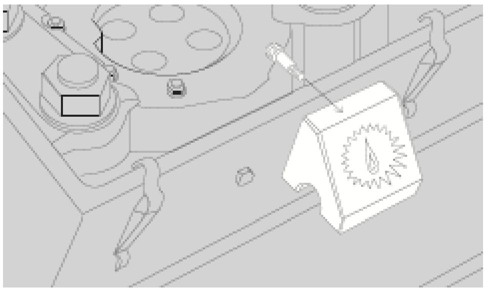
2. Insert the O-rings and place all the load blocks above the head cover supports. Adjust the upper bolt to enable little alignment adjustments.

3. Hold loosely the header (see **Figure 134**) leaving space to instar the joints.

4. Align the holes of the load blocks and the header, positioning the header drilling marks upward.

5. Align properly the special Teflon joints between the headers and the load blocks. Adjust the clamps, paying special attention to the alignment between the header and the joints while tighten. Tighten the bolts only to avoid the pipe to be accidentally moved. The pipes may need to be slightly rotated to be aligned with the bolts.

NOTE: the perforation mark in the upper header must be aligned with the front edge of the load block to ensure that both sides have the proper length.



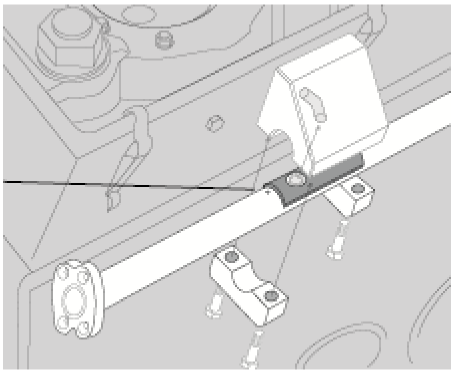


Figure 134. Load blocks installation

Gas rails

1. Connect the two lateral rails to the cross-duct in front the engine. Insert the O-rings into the flanges of the four bolts.

2. Fasten the supports to the engine's water pumps using the upper bolts of the pumps (see **Figure 135**).

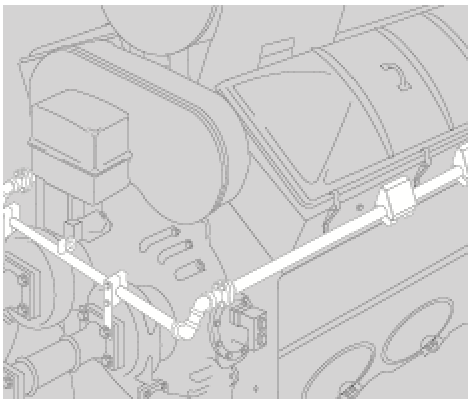
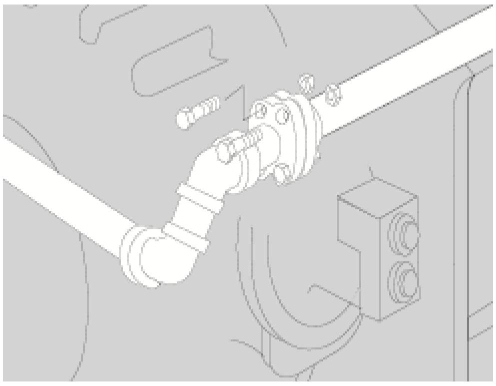


Figure 135. Fastening the rail to the water pumps

3. Tighten all the bolts of the load blocks at 30 ft-lbs and the bolts of the collector flanges at 40 ft-lbs, approximately.



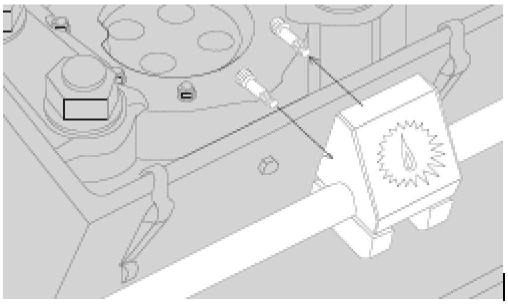


Figure 136. Details of the gas rails installation

Gas Flow Control Valve (GFCV)

The gas Flow control valve is installed in the middle of the pipe joining both gas rails (see **Figure 135**).

Figure 137. Gas Flow Control Valve – GFCV

1. Insert the O-ring into the flange.

2. Mount the GFCV valve into the flange using the four bolts provided. Tighten at 15-20 ft-lbs.

3. Connect the gas supply hose from the GCOV valve to the GFCV. The extreme of the hose is a conic connector JIC. Tighten at 60 ft-lbs.

NOTE: In case the direction of the JIC (90º) must be adjusted, care will be taken to not tighten the JIC too much to avoid damaging the valve.

4. The extreme of the GFCV valve is connected through a flange to an O-ring mounted directly over the valve. Tighten the four bolts at 25-30 ft-lbs.

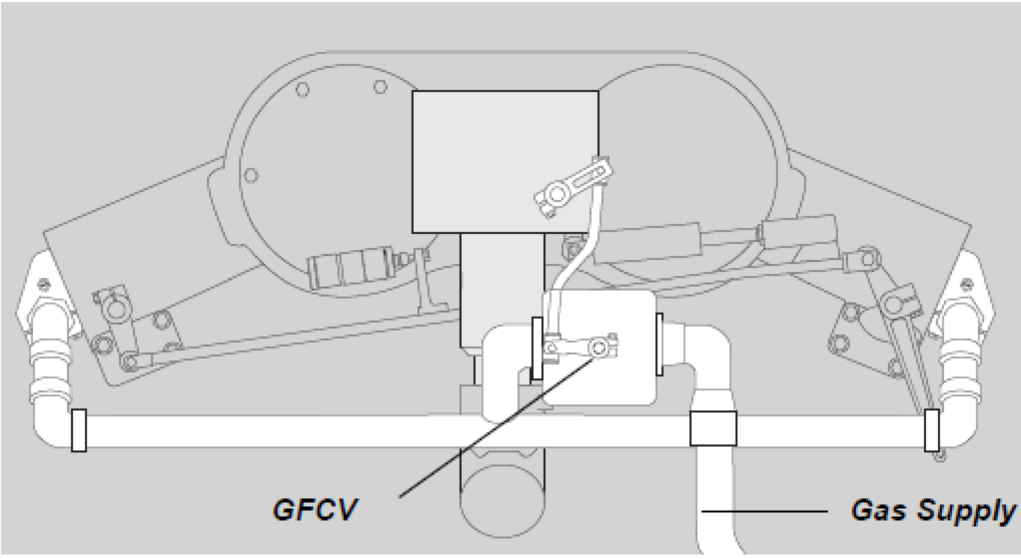


Figure 138. Gas Flow Control Valve – GFCV location

A vent valve will be installed joined to the upper part of the GFCV to purge the excess of gas and reduce the pressure when the gas system is not in use (see **Figure 139**). As it is described in the chapter about the air hose routing, a hose must be connected from the valve to the engine's air intake or to the air filter.

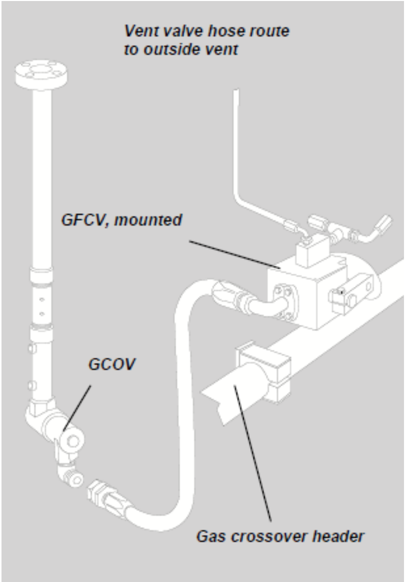


Figure 139. Gas Flow Control Valve – GFCV connection

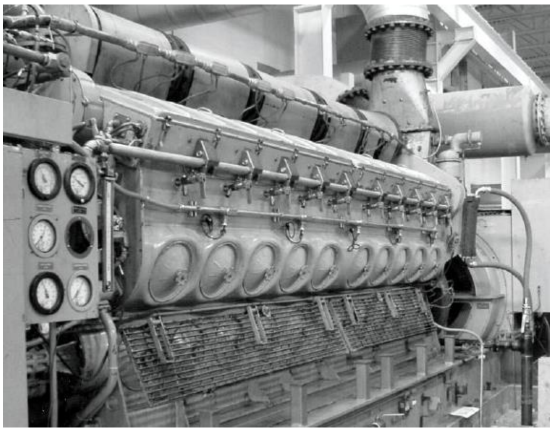


Figure 140. View of the load blocks and the gas mains

11.2.2.4 Power Pack

General overview:

Power Pack is defined as the set of valves and gas pipes added to the engine in order to configure its functioning with natural gas.

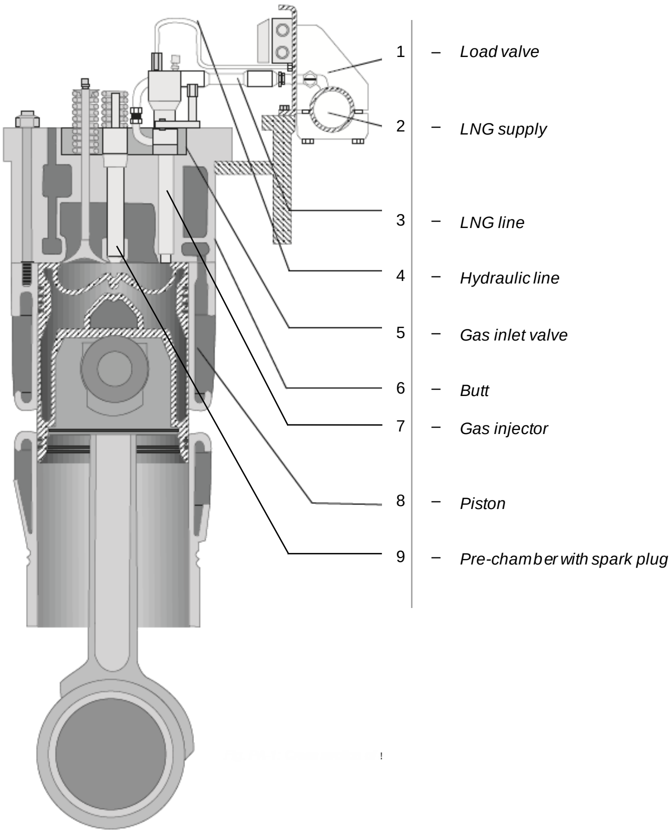


Figure 141. ECI's Power Pack section

Power Pack assembly:

Cylinder pressure relief valve

The pressure relief valves provided by ECI, replace the original blowdown valves of the engine. They reduce the excess of pressure of the cylinder that can be produced due to the high-pressure combustion. These valves must not be raised or have idling leaks (or low load leaks).

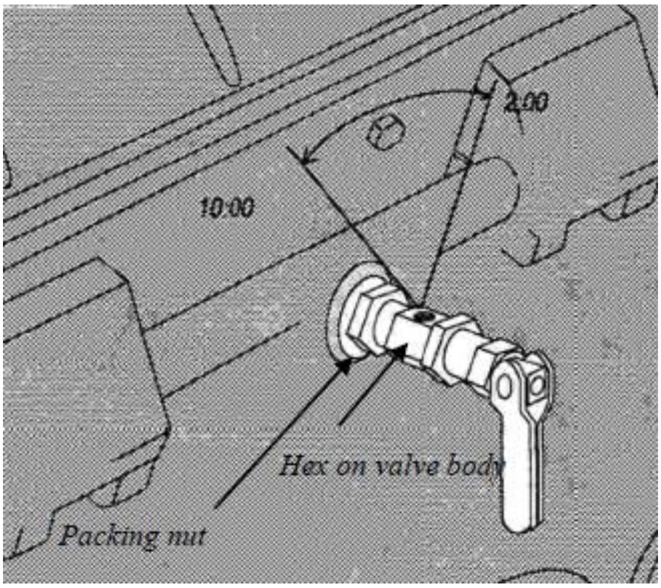


Figure 142. Pressure relief valve

When the engine is running, the valve lever must remain loose to avoid reducing the spring's closing pressure.

The device can be equipped with an adapter, so a manometer can be connected to measure the valve set pressure, useful for the diagnosis and the engine's analysis. Changing the direction of the valve lever enables to measure pressure, purge the engine and test it.

The elevation of the pressure relief valves to high loads, may indicate a low-quality fuel, defective high temperatures or instability of the engine. If the relief valves are elevated frequently with high-load, the system must be examined to verify its proper functioning.

The service and the calibration of the valves require duly equipped and capacitated personnel.

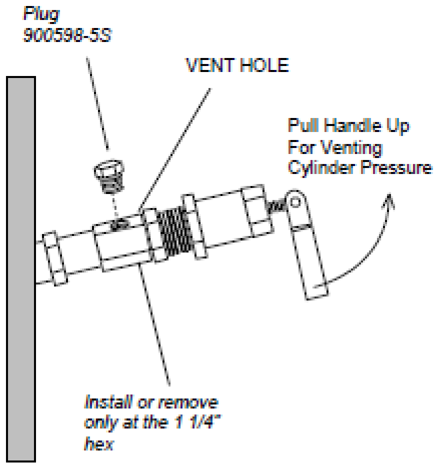


Figure 143. Detail of the relief valve installation

After the installation, one of the two test ports should be pointing between 10 and 2 o'clock (see **Figure 143**). Install the plug no. 900598-5s into the upper vertical vent hole, using the copper washer provided.

NOTE: Any accessory or connector not provided by ECI could cause damage and malfunction of the system if installed in the vent valve hole.

Gas Inlet Valve (GIV) installation

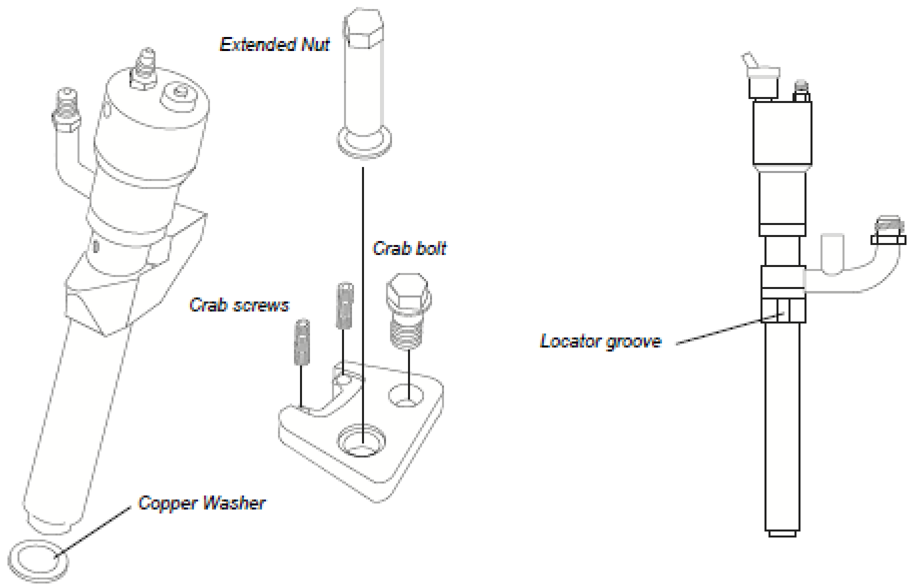


Figure 144. Gas Inlet Valve

1. Wash the gas entry points of the head cover if necessary.

2. Bond the copper washer on the GIV's lower part using grease.

3. Align the positioning slot of the GIV with the head cover (see **Figure 144**).

4. Insert the GIV partially into the gas entry port, place the anchor plate around the GIV as shown in **Figure 145**, then continue moving the valve downward until it reaches its seat. Install the washer on the bolt.

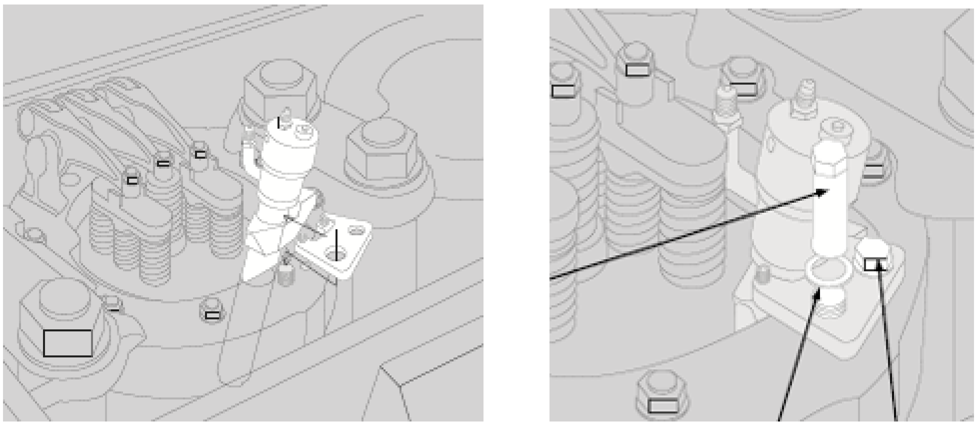


Figure 145. Detail GIV assembly

5. Install the extended nut on the anchor plate. Tighten at 240 ft-lbs.

6. Screw the hose of gas supply with the fingers, helping its alignment. Generally, it is easier to connect the side of the engine first and then the injector.

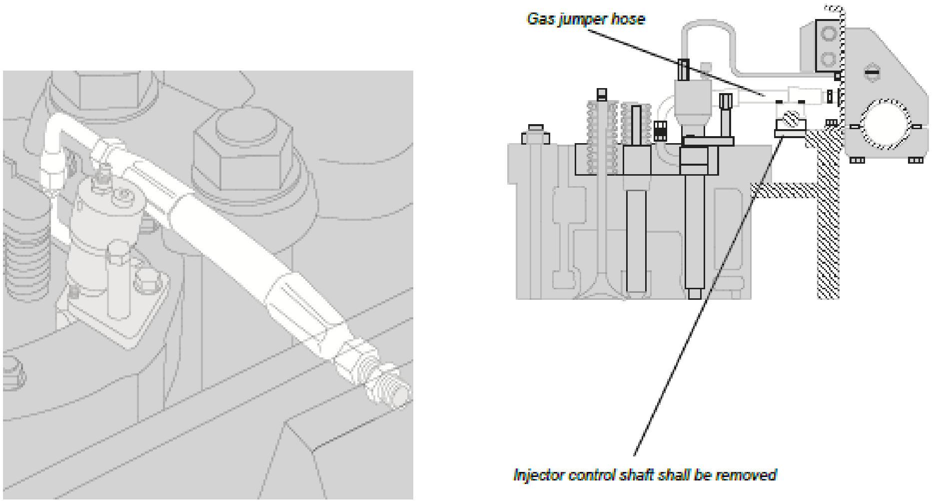


Figure 146. Gas supply assembly detail

7. Use a socket wrench and an extension to tighten the anchor plate crab screws. Tighten both screws alternately with 90 degrees increments until reaching 22 ft-lbs tight. If not conducted properly, the washer closure will not be ensured, and leaks may occur in the future.

8. *** NOTE *** *Make sure to use an Allen key during the entire route. The 22ft-lbs must be guaranteed to ensure the correct operating of the system.*

9. Finish tightening the gas hose using the proper key and extension. Tighten these connections at 40-45 ft-lbs, approximately. Pay attention to the assembly of the extreme of the valve.

10. Guide the straight extreme of the hydraulic hose until the connection point of the hydraulic rail. Connect the 90 degrees extreme to the hydraulic connection of the GIV valve. Tighten both sides at 15-17 ft-lbs.

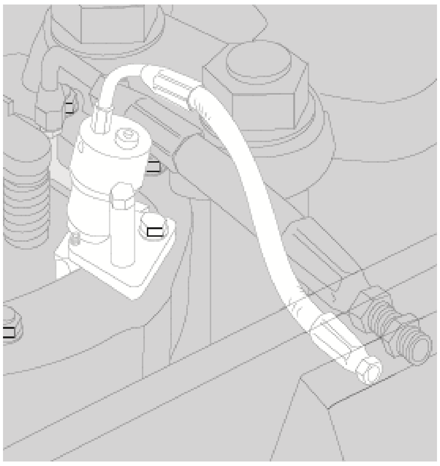


Figure 147. Hydraulic hose installation

PART	TORQUE (FT. LBS.)
EXTENDED NUT	240
CRAB BOLT	80
CRAB SCREWS	22
GIV GAS HOSE	40-45
GIV HYDRAULIC LINE	15-17

Table 33 Tightening torque for the GIV valve connections

11.2.2.5 Electric system

The electric system of the transformation system is formed by the following elements:

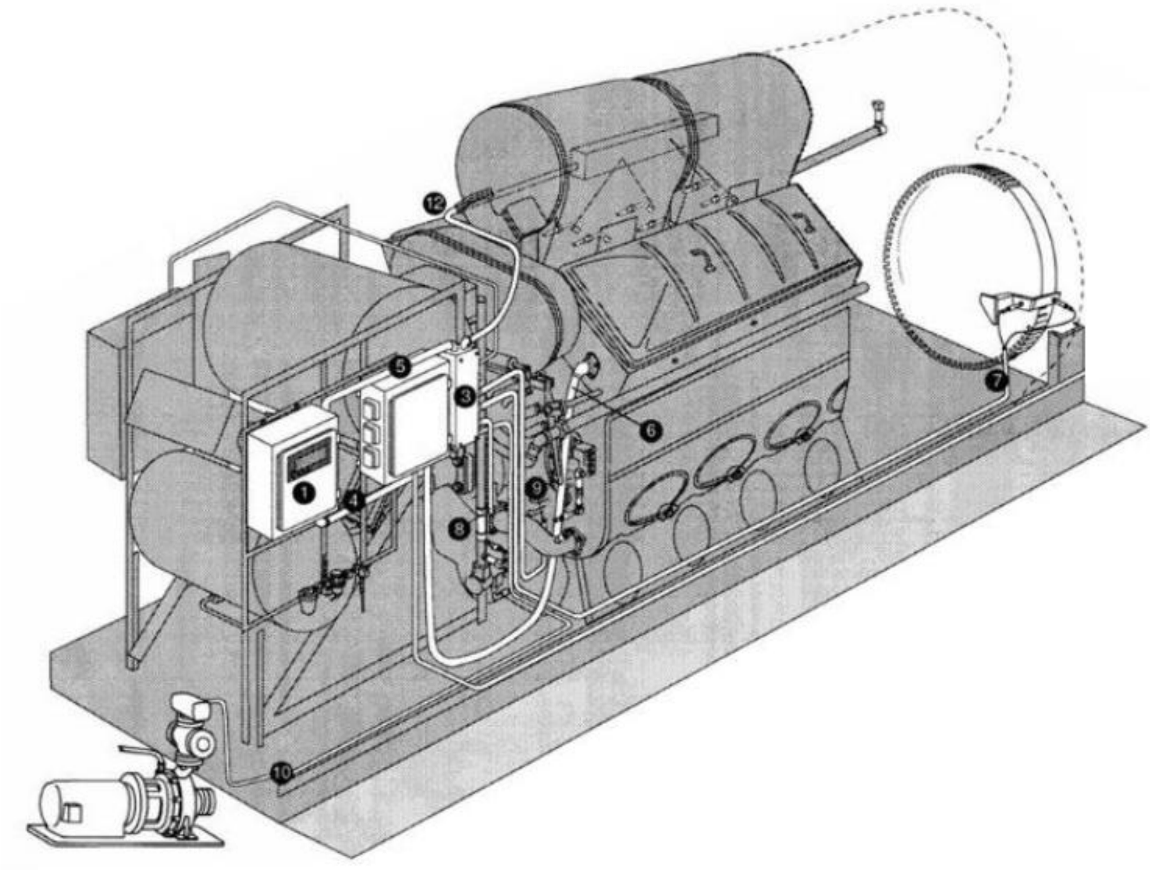


Figure 148. Electric components of the kit

1. Engine control unit (ECU)
3. Analog termination box
4. Digital conduit
5. Analog conduit
6. GIV wire bundle
7. Flywheel sensor tee & flex conduit
8. Gas sensor flex conduit
9. Air & water sensor conduit
10. Water flow control valve conduit
12. Exhaust flex conduit

Electric and electronic systems:

This section will be used with the wiring section and the system drawings. The wiring routing will be specific for each project. The procedures shown down below are general, without strict rules, to route the electric and electronic wiring of the system. The following figures indicate a possible scenario for the location and the assembly of the electric panels and boxes included in the system.

It may be necessary to locate the components in the opposite side of the accessories rack, or in an alternative location. However, the configuration shown maximizes the utility and reduce the required space for the installation of the entire system. The installer must provide the ducts and the accessories suitable for each design. Whenever possible, the use of flexible, sealed, hermetic and resistant to vibration tubes will be preferred.

NOTE: the wiring must be conveniently fixed at the end of the installation to ensure the correct protection of the wires. Insufficiently strapped wirings may damage the inner part of the wires.

Location of the electric panels:

The ECI system is formed by four main electric panels:

- Electronic Control Unit (ECU)
- Digital Terminal Box
- Analog connections box
- Ignition spark box

Apart from the display modules in the cabin.

Read all the following steps before starting the installation the panels to obtain a better understanding of its design and the relation among them.

1. Provide the panels in the appropriate position considering its accessibility, the wiring entrance and the mobility ease.

2. If necessary, built an appropriate support to hold the panels.

NOTE: consider the accessibility of other design components.

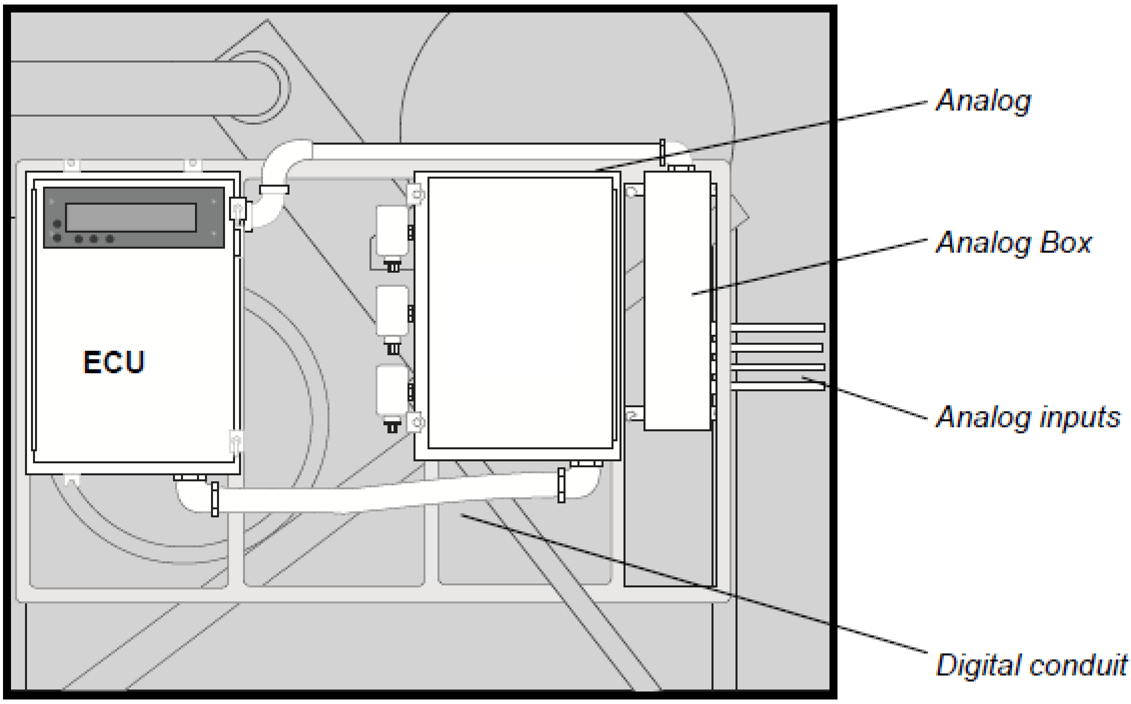


Figure 149. Electric panels location

Electronic Control Unit (ECU):

The Electric Control Unit controls the main functions of the gas injection system. It is based on an essential electronic system for the engine operating and it is subject to wear. Take caution when unpacking the electronic system to avoid possible damages.

The ECU must be installed in the backside of the locomotive, in the upper part of the electric panel beside the ignition spark system.

1. Built the necessary supports to hold the upper and lower parts of the panel.

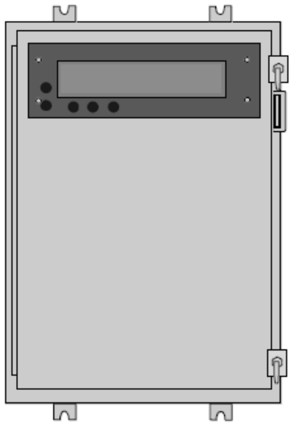


Figure 150. ECU box

Digital Terminal Box - DTB:

The digital connections box (DTB – Digital Terminal Box) provides a terminal strip for the connection of the digital signals of the system.

The DTB is designed to be assembled below the charge controller of the engine.

1. Place properly the DTB to the existing space using the appropriate support. It is important to consider the movement of the box's door and the wiring after the assembly.

Digital conduit:

A flexible hose of 1′ ½′′ (**Figure 148**, point 4) houses the digital signal wires of the system from the ECU to the DTB.

1. Connect the duct 1′ ½′′ accessory from the lower part of the DTB.

2. Extend a 1′ ½′′ flexible wire from the DTB to the right box the ECU.

3. Route the GIV's wiring (**Figure 148**, point 6) from the ECU's box to the right side of the right bank of the engine.

Analog connections box:

The analog connections box is mounted with supports welded to the accessories carriage, as described in the previous chapter about the location of the electric boxes.

1. Mount the box in the support.

2. Mount a 2″ right angle or another accessory suitable to hold the wiring.

3. Route the wiring towards the left box of the ECU.

4. Drill and position tube bushings for the wiring according to the design requirements.

Analog conduit:

The analogic conduit consists on a tube connecting the analogic signal wires and the analogic termination box. Generally, it is preferred to mount all the sensors first and then, distribute the wiring as required. The wiring scheme is designed for every specific project; hence it is not included in this report.

1/2 " wiring routed to the sensor set of the engine flywheel (7).

1/2 " flexible wiring containing the gas differential pressure sensor, the gas temperature sensor and the gas pressure sensor located near the gas supply cut-off valve (8).

1/2 " wiring containing the wire to the temperature and pressure sensors of the air box, and the water temperature sensor (8).

1/2 " wiring routed to the water flow control valve located in the water pump/ valve set (10).

1/2 " or 3/4 " wiring to the engine control panel, housing the Kilowatt transducer and the ECU’s remote display (if applicable) (11).

3/4 " wiring (12) routed between the analogic box and the escape conduit.

NOTE: The wiring connections must be tightened when the installation is over. A loosen wiring my damage the wire.

Escape wiring:

Generally, the escape wiring is installed at the right side of the escape collector of the engine. A special metallic conduit is installed in the exhaust manifold using the existing supports to distribute the wiring. The wiring equipped with a flexible metallic tube joints the escape zone with the analogic box.

1. Mount two supports, one in each extreme, in the manifold using the bolts provided. The engines with 8 and 12 cylinders have two supports.

2. Mark and drill the holes corresponding to the holes of the bores of the support to mount the wiring.

3. Screw the conduit to the supports so that the doors can be opened downwards (it is better for the service).

4. Connect the wiring of the analog box to the front extreme of the wiring box using the appropriate connectors. Make sure the connections are tightened.

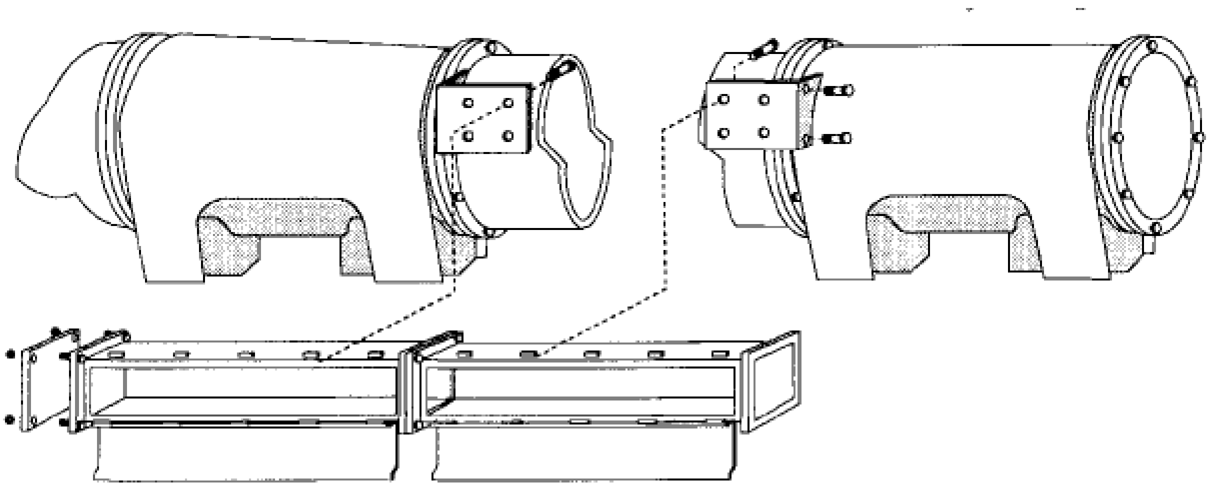


Figure 151. Exploded view of the exhaust manifold and the metallic conduit

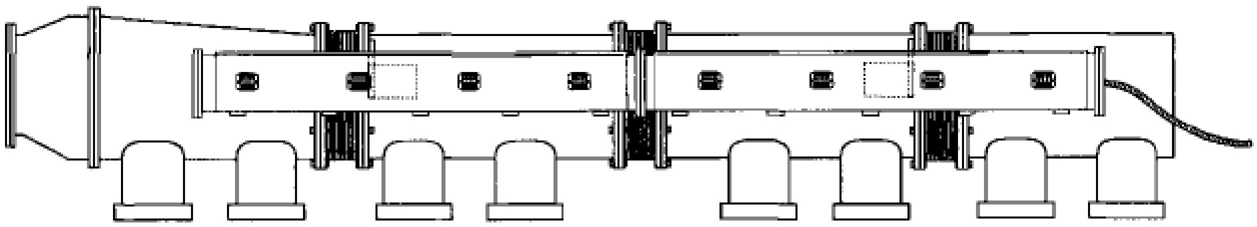


Figure 152. Exhaust manifold and metallic conduit mounted

11.2.2.6 Hydraulic system

****NOTE*** It is indispensable to keep the hydraulic tubes clean for a proper operation. Dirt contamination may cause failures in the gas entrance valves (GVI).*

1. Install the tube sections prefabricated to the two load blocks located at the front part of the engine. These spare parts have been designed to wrap the front side of the engine's block and the casings. The Nº 955-1500 tubes are located at the left side of the engine; the Nº 955-1510 corresponds to the right side.

2. Place a T-piece into each nozzle of the load block (except in the last cylinder of each bench that will require an elbow). Tighten enough to keep them enough. These joining pieces are designed so that once the splint has been strung, it cannot slide over the connector.

3. Join the tubes with the T-piece in the centre in front the first cylinder in each face of the engine. Please note that it may be necessary to cut the tubes, so they can be adjusted to the available space. Take measures for each section assuring that the tubes are enough long to ensure the proper insertion of each connector. To ensure a free-leaks joint, the tube must be projected, at least, 1/4 " from the splint's extreme.

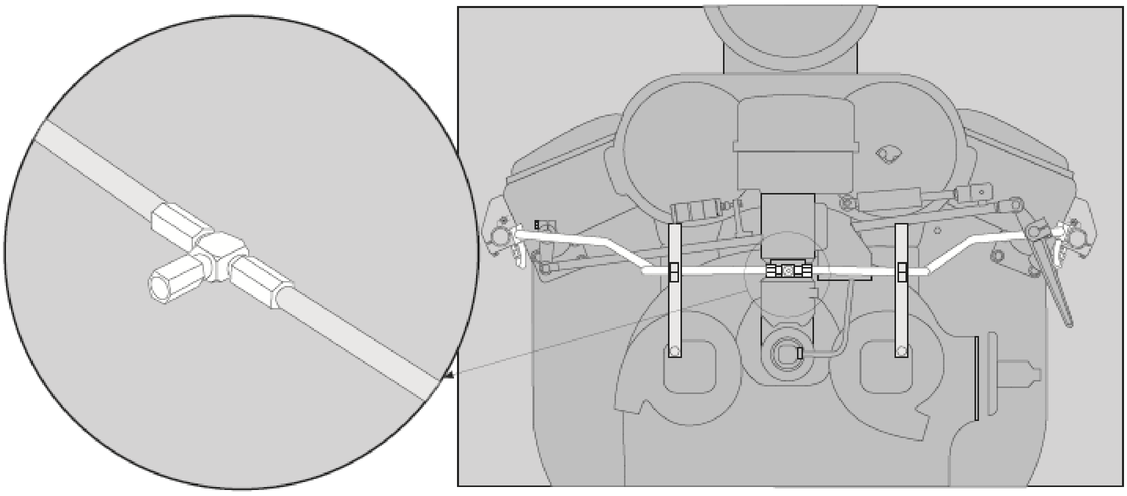


Figure 153. Hydraulic pipeline and supports

4. Starting from the front extreme of the engine, keep the first T-connection in the stainless thread socket. Remove the next line of adjustment in T and insert the tube with the screw and the splint into the T-accessory. Tighten it.

5. Install the second connector (the next in the line) with the bushings and the screw in the tube. Connect again the connector to the next load block. Continue with the procedure until all the connectors are installed.

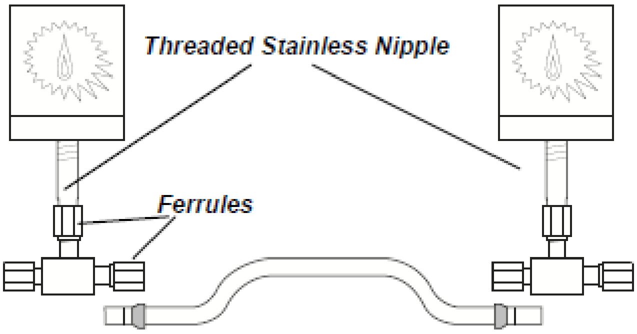


Figure 154. Hydraulic system - connectors

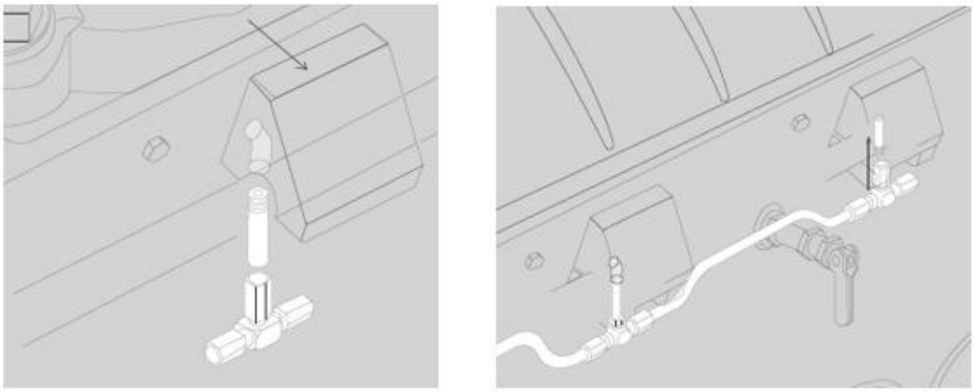


Figure 155. Hydraulic system connection

6. When all the tubes are prepared with the connectors, they must be tightened conveniently to minimize the risk of leakage and extend its lifetime. Avoid over-tightening the connectors. Fasten the body of the connector properly with a key and avoid applying excessive tightening to the load block, maintaining the alignment of the assembly. A new connector must be tightened, firstly by hand and then applying a 1 1/4" turn with the key.

7. Use the proper supports to fix the hydraulic tube to the cylinder head (see **Figure 156**).

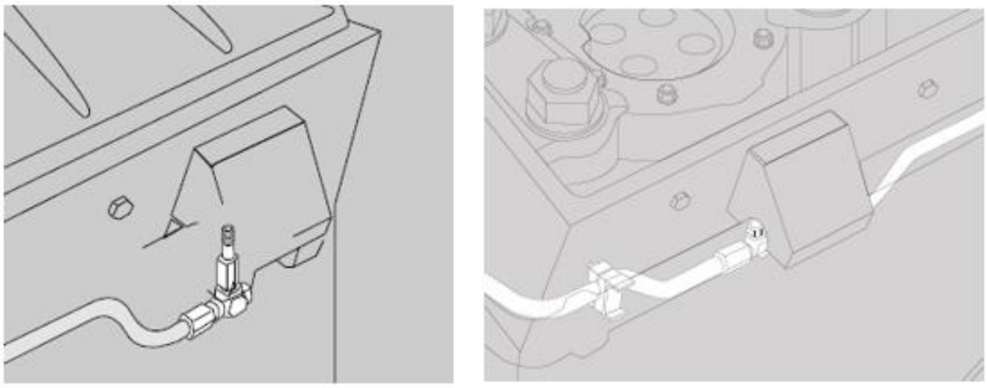


Figure 156. Details of the hydraulic circuit

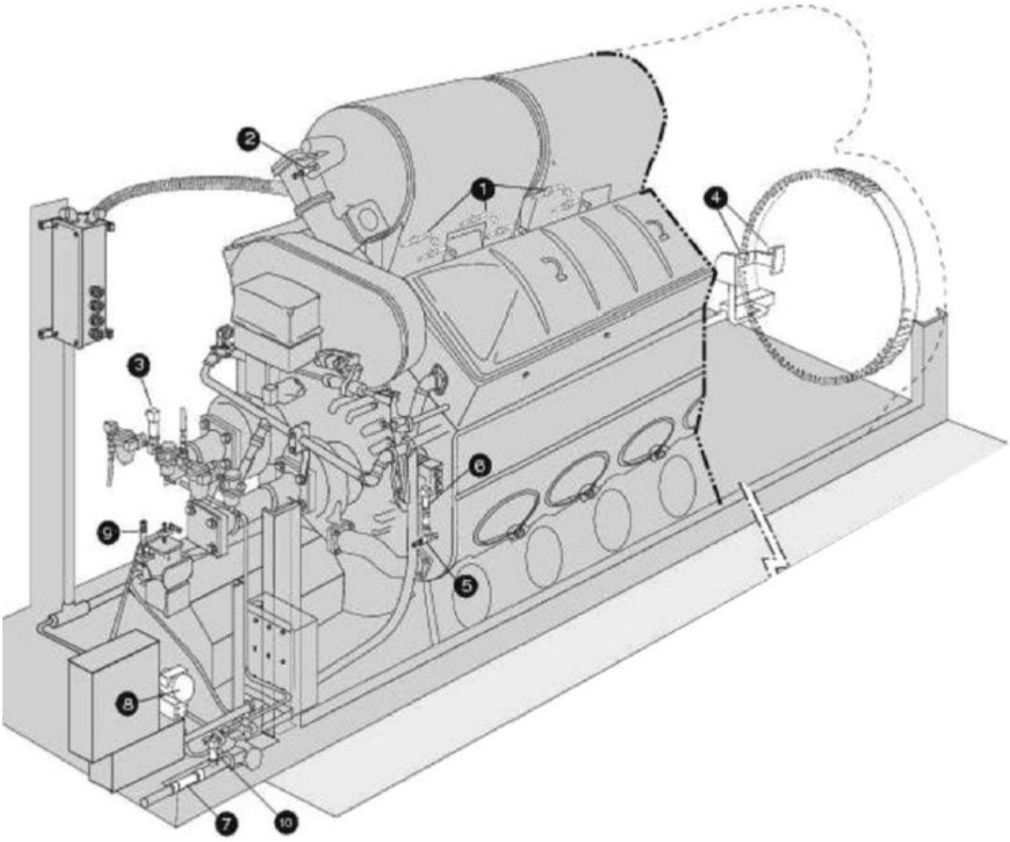
Similarly, install the hydraulic return lines in each bench of the engine. The tubes must fit correctly and effortlessly. On the contrary, conduct all the necessary modifications to do so. See **Figure 154**,**155 and 156** indicating the correct fitting.

Place the aluminium supports in each fastening closure of the valve covers (see **Figure 157**).

Figure 157. Aluminium fixing flanges of the hydraulic tubes

11.2.2.7 Sensors installation

The following figure shows the locations of the engine's sensors.



1	Exhaust thermocouples	6	DP transducer
2	Water temperature sensor	7	DP sensor - gas line
3	Flywheel sensors	8	Gas pressure sensor
4	Air box temperature sensors	10	Gas header pressure
5	Air box pressure transducer	11	Knock detection sensors

Figure 158. Placement of the sensors

Exhaust temperature probes:

A thermocouple will be installed in the exhaust manifold to control the gas exhaust temperature in each cylinder. The location of each thermocouple is detailed in the **Figure 158**.

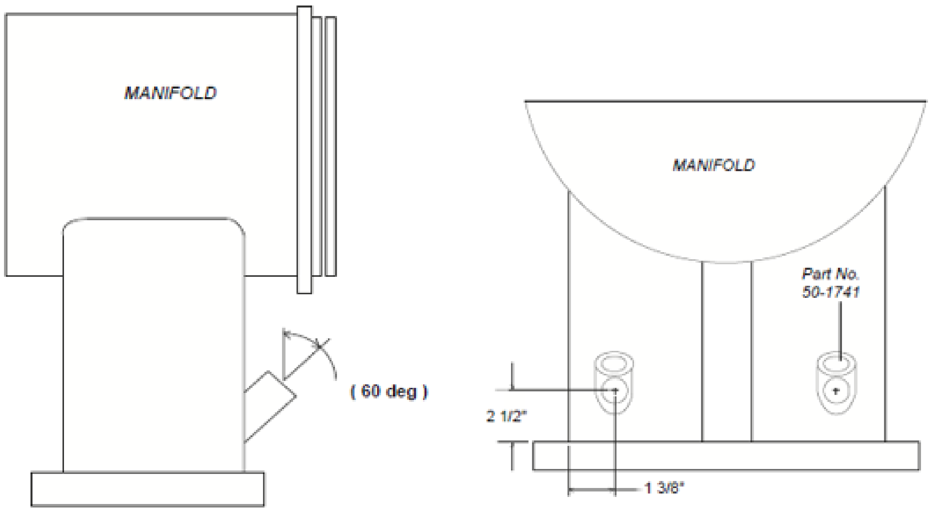


Figure 159. Thermocouples of the exhaust manifold

1. Disassembly the exhaust manifold and drill as described in **Figure 159**. Ensure the holes are large enough so that once the accessory provided is welded, the probes still have enough space to fit without touching the manifold wall.
2. Weld the accessories provided (Ref nº50-1741) into the holes. Clean the zone up and assembly again the manifold.
3. Install the thermocouples lubricating previously the threads with a rust and high-temperatures resistant compound tightening at 20-25 ft-lbs.
4. Place and adjust the cable of each thermocouple in the cylinders using the metallic tray of the manifold. Connect each probe cable to the corresponding terminal strip of the analogic connectors box.

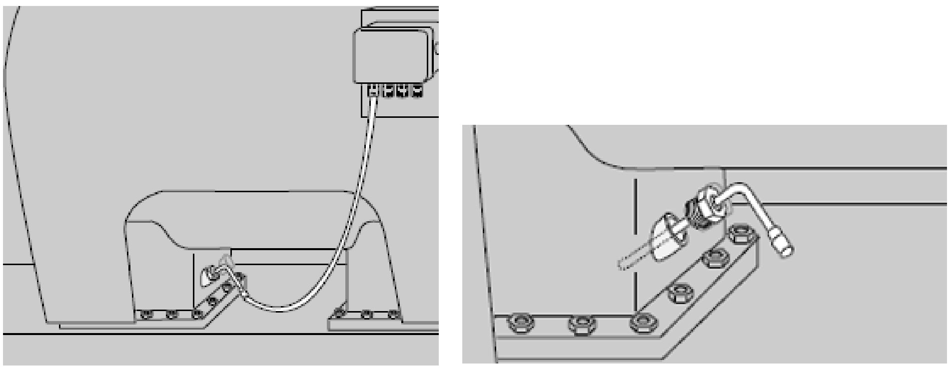


Figure 160. Details of the thermocouples installation in the exhaust manifold

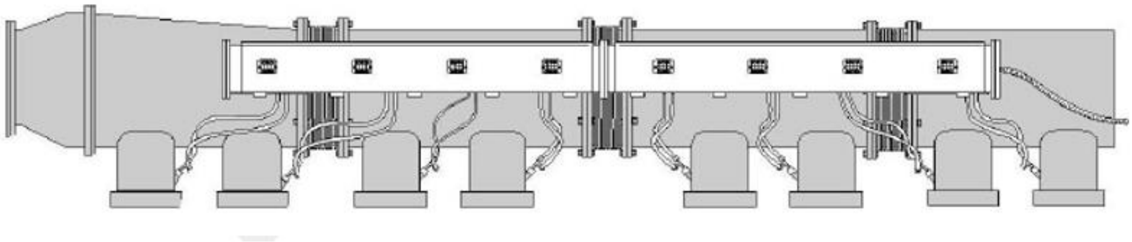


Figure 161. Exhaust manifold with thermocouples installed

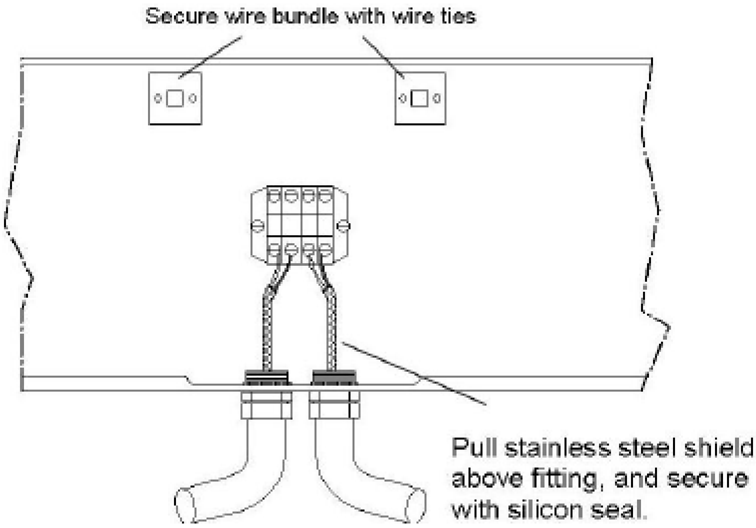


Figure 162. Sealing of the metallic cable duct

Water temperature sensor:

The water temperature sensor provided can be installed at any point of the engine's water circuit considered appropriate. One possibility is to install it at the left side of the engine, at the pump's water outlet using the existent threaded hole. See **Figure 163**. If this hole is already occupied by another sensor, install it at the left side. In any case, there are several spots in the engine where the sensor can be easily installed.

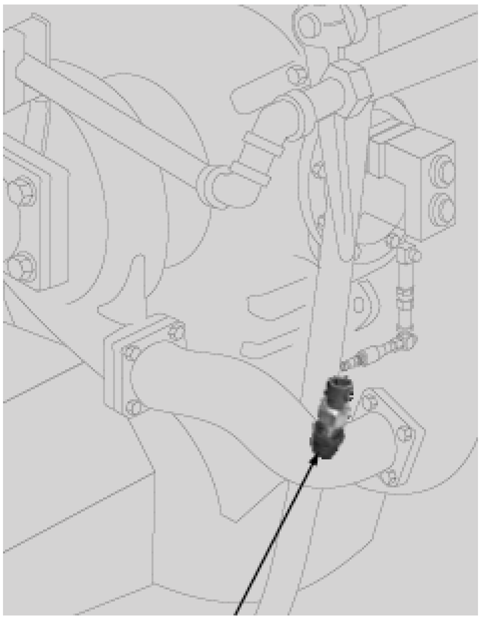


Figure 163. Water temperature sensor

Temperature sensor of the air box:

Drill a hole in the cover and weld a 3/8” NPT thread. Commonly, the probe is placed at the first cylinder from the left (see **Figure 164**).

Figure 164. Temperature sensor of the air box

Pressure sensor of the air box:

The pressure sensor of the air box is usually installed in the existing hole at the front left part of the engine. The temperature of the air box is measured using the probe placed at the front left part of the engine.

1. Remove the existing accessory and install the adapter to place the pressure transducer of the air box.
2. Install the pressure transducer (**Figure 165**), apply a sealant and tighten at 10 ft-lbs. Do not over tighten.
3. Wire the transducer to the analog connections box.

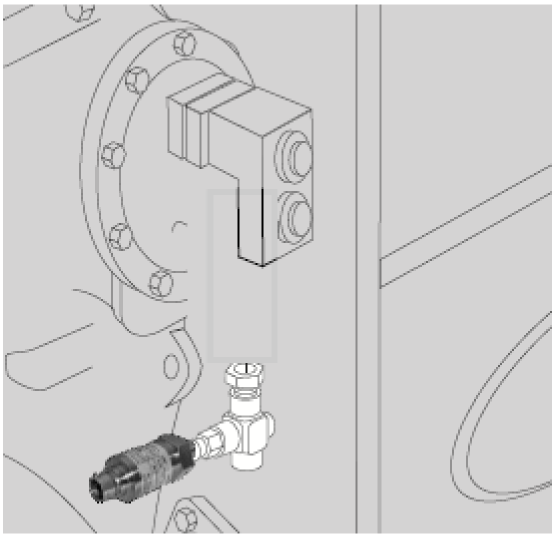


Figure 165. Pressure sensor of the air box

NOTE: Other protector systems of the engine may require the access to the air box. It may be necessary to modify the assembly to fit all the sensors.

Gas sensors:

1. Install the differential pressure (DP) transducer with the adapter provided in the gas line beside the gas differential pressure sensor (**Figure 166**).

NOTE: the differential pressure transducer can be oriented by means of the support to any direction, with the condition to maintain the two anchor screws in horizonal position. This is necessary to maintain the calibration of the transducer's internal diaphragm.

2. Link all the connectors of the transducer using the thread sealant.

3. Tighten at 15ft.lbs.

4. Place the hoses from the gas tube to the DP sensor. Control the low and high-pressure connections.

NOTE: The hoses are not interchangeable and must operate in the correct position.

a. Differential Pressure Transducer
b. DP Mounting Bracket
c. Differential Pressure Sensor
d. 3/4" electrical conduit from analogue box
e. Gas Cut Off Valve (GCOV)
f. Gas Temperature Sensor

g. Gas Pressure Sensor, 0 to 200 psi

h. Sense line port to gas line Regulator

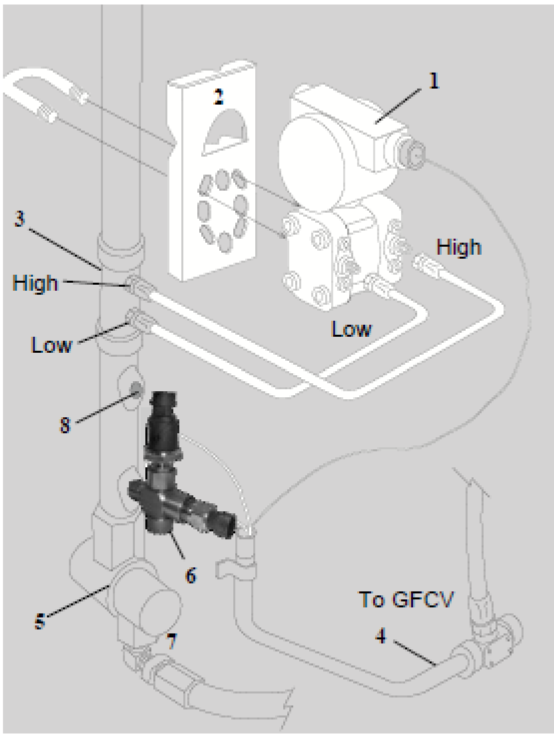


Figure 166. Location of the gas sensors

Knock detection sensors:

A knock detection sensor will be installed in each cylinder.

1. Place the knock sensor to the extended screw of the head cover as shown in **Figure 167**. Use the screws provided and tighten at 10-12 ft-lbs.

NOTE: An over-tighten sensor may destroy it.

2. Assure the wires to avoid that the vibrations can cause problems.

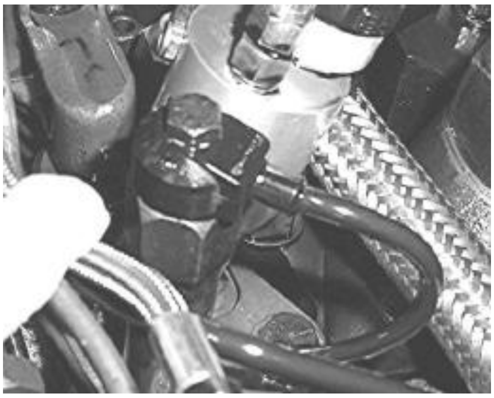


Figure 167. Knock detection sensor installed in the cylinder head

Flywheel sensor and synchronization of the engine:

The two sensors are installed in the engine flywheel by means of the support provided.

Support

1. Disassembly the three screws from the hood of the gear case at the left side of the engine.

2. Install the support provided using the new screws (1/2" -NF 18 X 2 1/4") as shown in **Figure 168**.

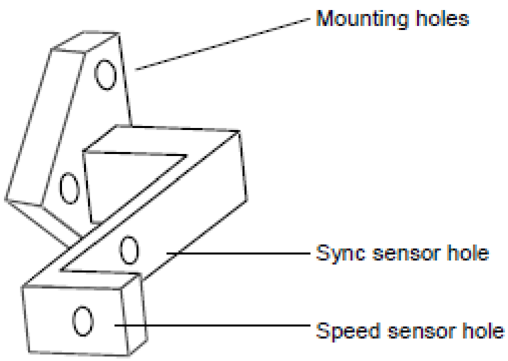


Figure 168. Support of the flywheel sensor and synchronization of the engine

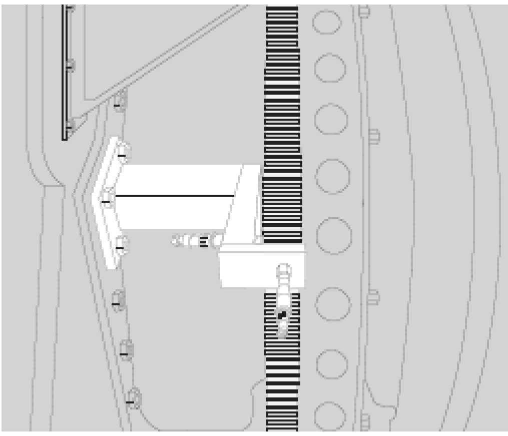


Figure 169. View of the support of the sensors installed

Adjustment of the sensor

1. Before drilling the actuator disc, verify the pointer position calibration of the engine flywheel, according to the engine standard procedure.

2. Turn the engine flywheel until the pointer is 337,5 degrees.

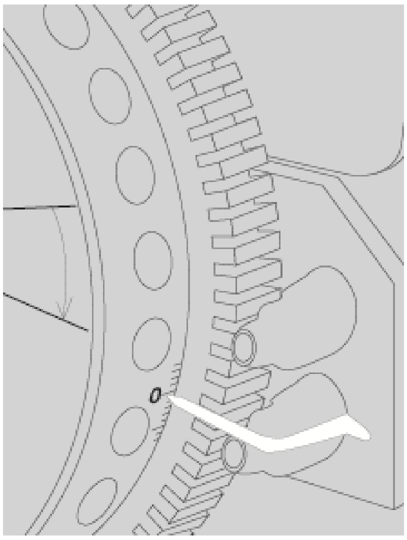


Figure 170. Adjustment of the engine flywheel pointer

3. Install the guide screw (provided by ECI) at the sensor's location ensuring that there is enough space to drill a hole of, at least, 3/4 " depth.

4. Drill the hole with a size "C" cobalt bit (0.242 ") (provided by ECI) to a 3/4 "+/- 1/32" depth.

NOTE: The actuator disc is made by a very tough steel, thus the use of refrigerant is required during the boring.

5. Ream within the hole (0.248 ").

6. Install the roll pin provided leaving the actuator disc surface at least 1/4" extended beyond (**Figure 171**).

** THIS OPERATION MUST BE PERFORMED WITH MAXIMUM PRECISION*

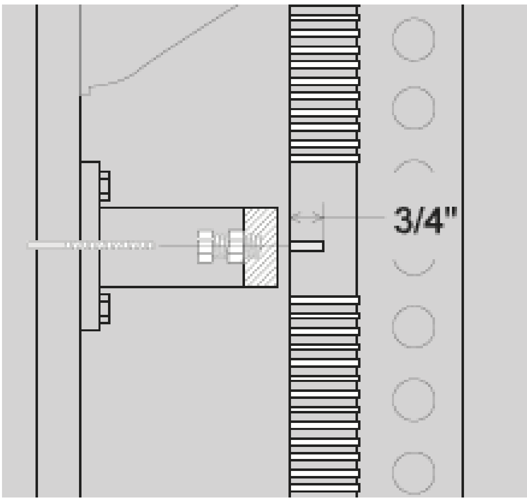


Figure 171. Engine flywheel drill

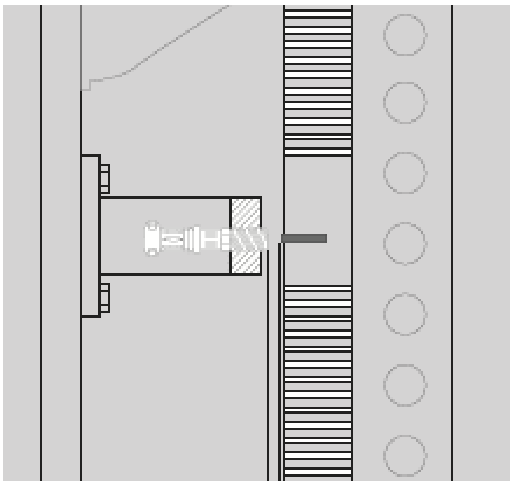


Figure 172. Roll pin insertion

Placement of the flywheel sensor

Install the two flywheel sensors, ensuring that the reference gear tooth is aligned with the middle of the sensor when adjusting its distance.

1. Screw the speed sensor up until it reaches the gear tooth. Turn it one turn backwards. Tighten the locknut. The clearance must be between 0.040-0.070". Tighten at 16-20 ft-lbs. Do not over-tighten.

2. Install the synchronization sensor in the same way: drill the sensor until it reaches the gear and then rotate it two turns backwards to get a clearance of 0.100". Each turn provides 55/1000 inches.

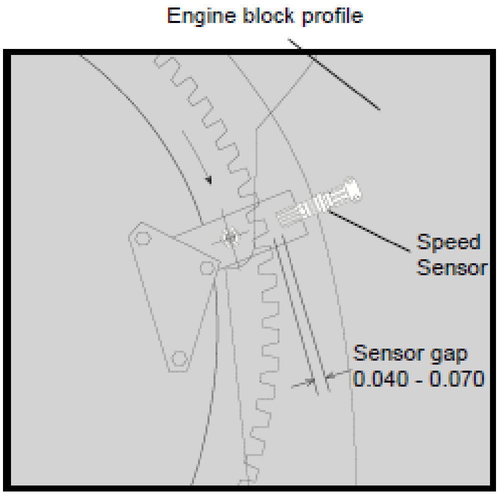


Figure 173. Adjustment of the flywheel sensor

The **Figure 173** and **Figure 174** show the sensors installed. The speed sensor measures directly over only one gear tooth; hence it must consider the specified tolerance. The synchronization sensor must be configured with the tolerance indicated in **Figure 173.**

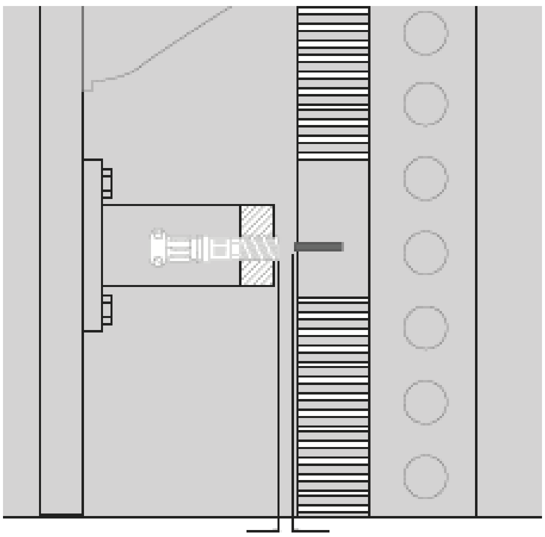


Figure 174. Synchronization sensor tolerance: 0.100-0.125

Gas pressure sensor

1. Insert the gas pressure sensor in the duct extreme. Note that it can be installed in the left or the right bench of the engine.

2. Consider the different options into route the sensor wiring. The wiring tray of the flywheel sensors might be the most appropriate option.

3. Route the sensor cable through this tray until the analog connections box.

4. See the diagrams and the electric schemes to perform the connection.

An adapter can be placed to install an additional pressure manometer (**Figure 175**).

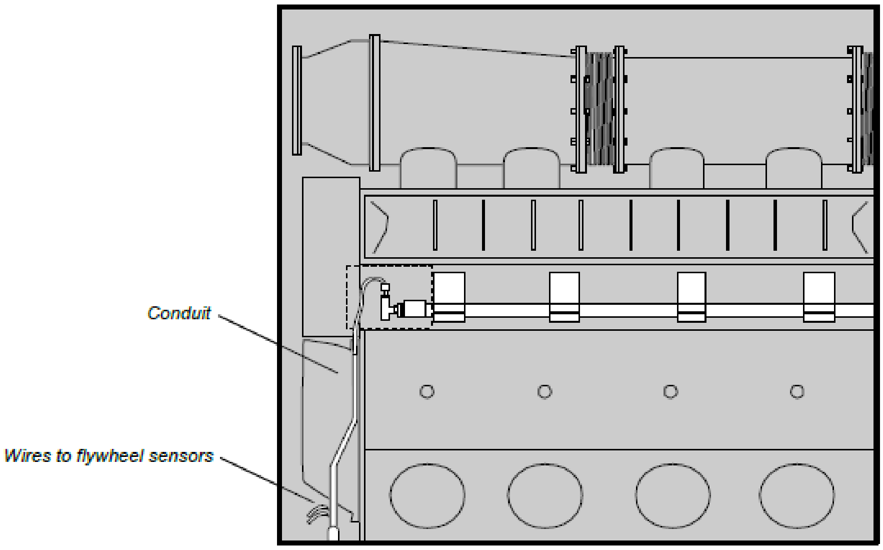


Figure 175. Location of the gas pressure sensor

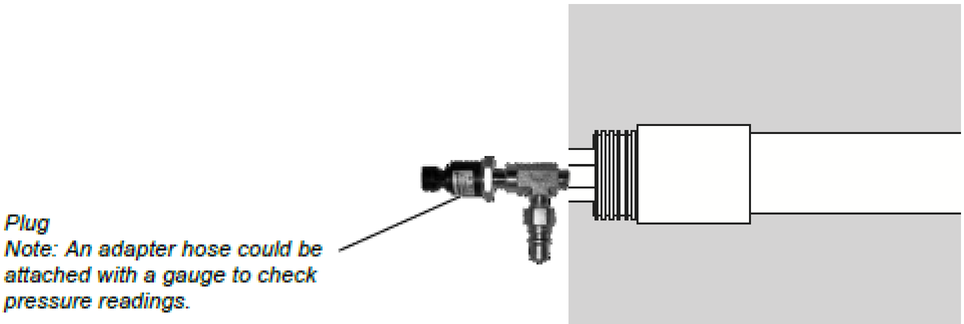


Figure 176. Gas pressure sensor with the adapter

Other sensors of the SIP system:

The lube oil pressure is controlled to guarantee the engine security. This sensor must be connected to the same point as the original engine.

A pressure sensor and a back-pressure sensor are included into the hydraulic system provided that has been added to manage the gas injection valves.

The pressure before the chamber (PCP) is the gas pressure supplied to the pre-chamber. It is measured for diagnosis and monitoring. This sensor will be placed after the control valve.

The voltage and the intensity of the main generator, as well as the room temperature, are monitored with a sensor located outside the locomotive.

11.2.2.8 General wiring

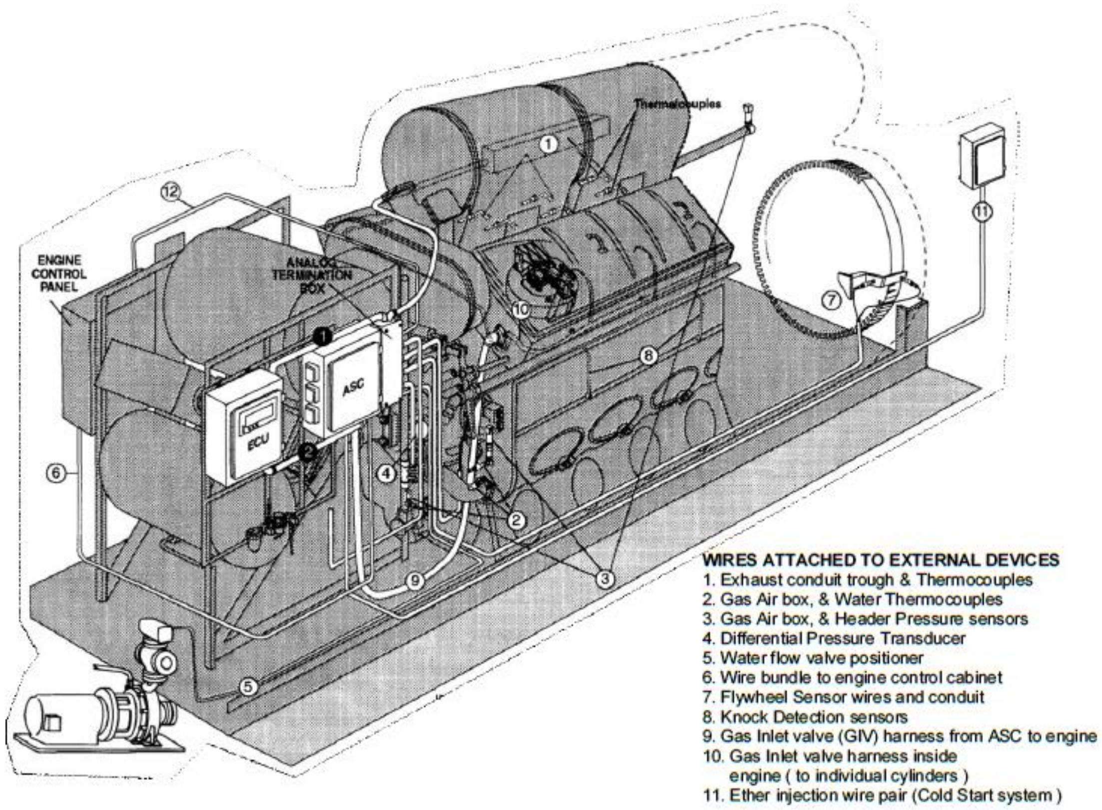


Figure 177. General wiring of the engine

The wiring design of the conversion kit is presented so that the wiring harnesses can be connected to the ECU and routed to the control terminal strips through the corresponding hoses. Similarly, the cables of the external devices are joined and distributed through the hoses until the terminal strip. The harnesses are assembled at the factory to ensure the installation ease.

Some cables cannot be premanufactured for the conversion kit since the required lengths are unknown. This part of the wiring must be performed in-situ by the installer.

The system documentation includes a plan with the view of all its elements and its wiring diagrams. It is the best available resource to obtain an overview description of the wiring and the plans of the system.

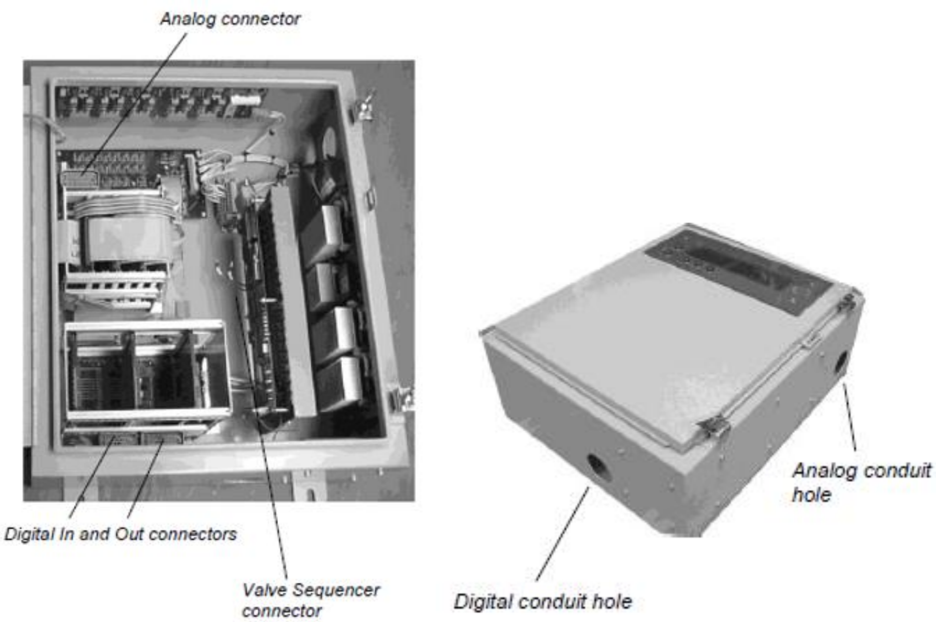


Figure 178. Analogic and digital electric connections box

Wiring installation:

To install the different wiring parts, firstly, it is recommended to familiarize with them and determine where they must be installed. For instance, the tray between the ECU and the DTB will possibly hold three different hoses. Join all the wires from their respective devices to the electrical cabinet, before routing them through the tray. Join them every few meters with the proper clearance, starting from the electrical cabinet to the final devices. Make sure there is enough clearance to open and close the cabinet doors.

NOTE: the lengths of the wiring bundles may not be the same. This is not so relevant since they can be cut as convenient once connected to the terminal strip. Mark the extremes of the wires with safety labels and protect them so are not lost inside the duct. The wiring scheme is part of the documentation provided.

Figure 179. Wiring handling

Gas Inlet Valve Wire Harness:

The GIV valves conduit is divided into two parts. The longer part crosses through the front side of the engine below the camshaft. The wiring is designed to fit between the engine's front block and the cylinder head cover. The cylinder head cover must be disassembled in order to install the wiring properly. Then the two wiring sections can be installed between the injectors and the engine relief valve. See **Figure 180** and **Figure 181**.

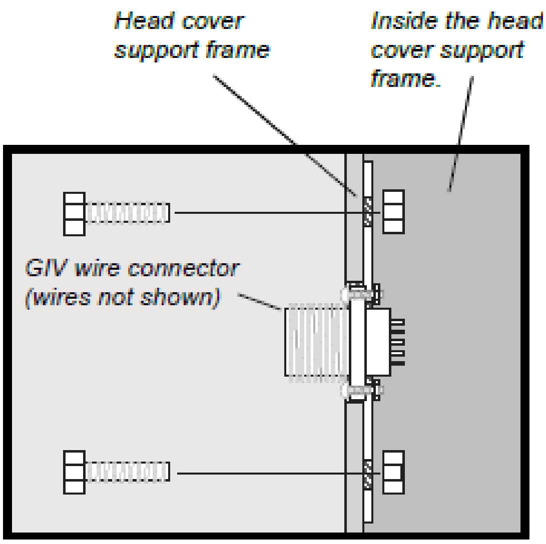


Figure 180. GVI wirings

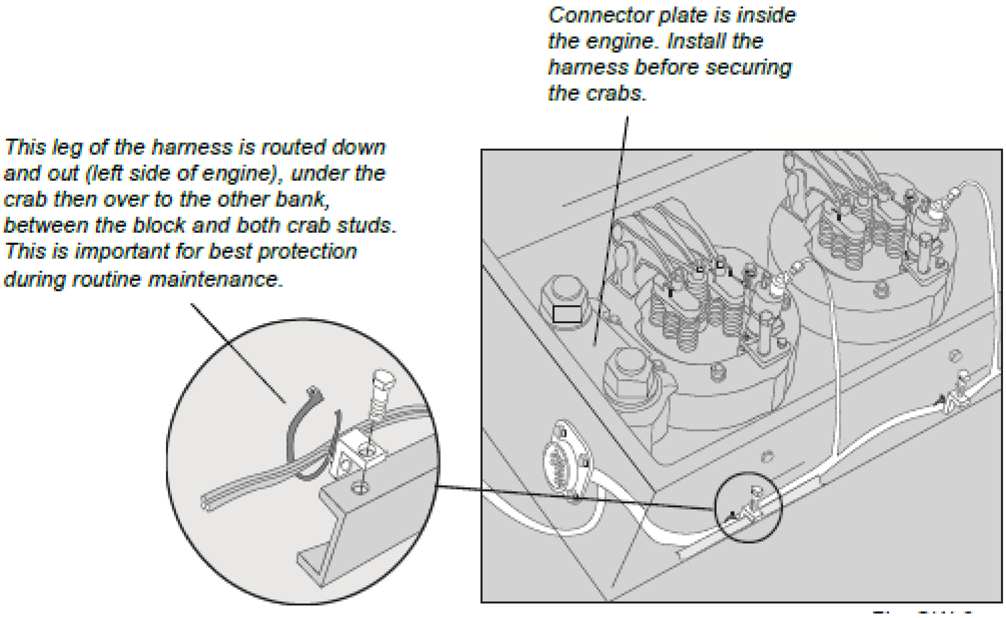


Figure 181. Detail of the GVI wiring

Place the GIV connector to the engine (**Figure 182**) and connect the male plug of the GIV wires bundle. Route this bundle to the ECU.

Connect the GIV wires bundle within the ECU panel as specified in the electrical scheme provided. Adjust the length of wires when necessary.

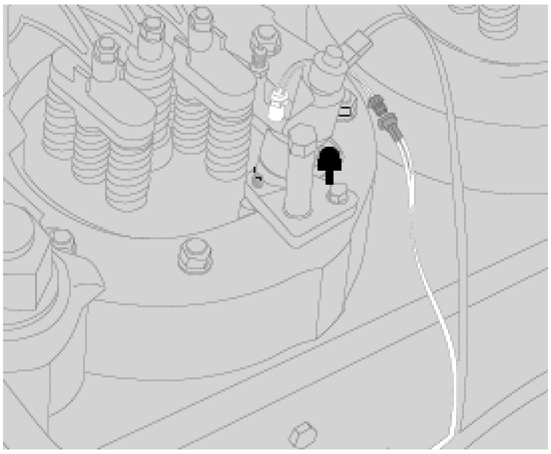


Figure 182. Detail of the GVI wiring inside the cylinder head

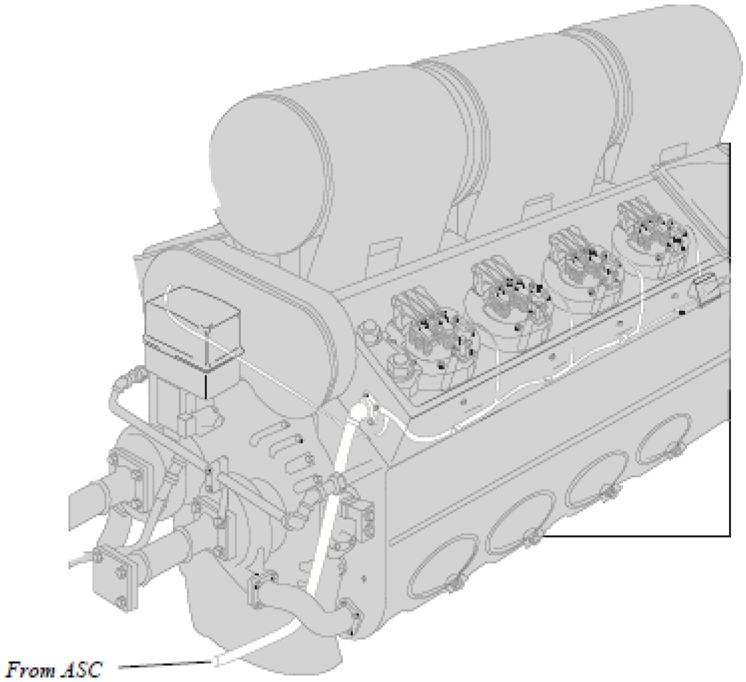


Figure 183. General view of the GVI wiring

11.2.2.9 Gas leak detection system

It is recommended the usage of a continuous gas leak detection system, avoiding the possibility of a leakage to be trapped causing an explosion.

This manual does not include a specific description of the gas leak detection installation since each application is different, so the requirements are also different. The system must be designed to monitor the engine performances and detect all the possible leakages. Specially, at the upper part of the locomotive where the gas could be accumulated.

The system must include indicator lights or warning horns to control and stop the gas supply into the engine area.

The sensors must be placed in areas where the leakages are more likely to occur, considering the air flow direction around the engine.

The following figure shows a possible distribution of the gas leakage detection system.

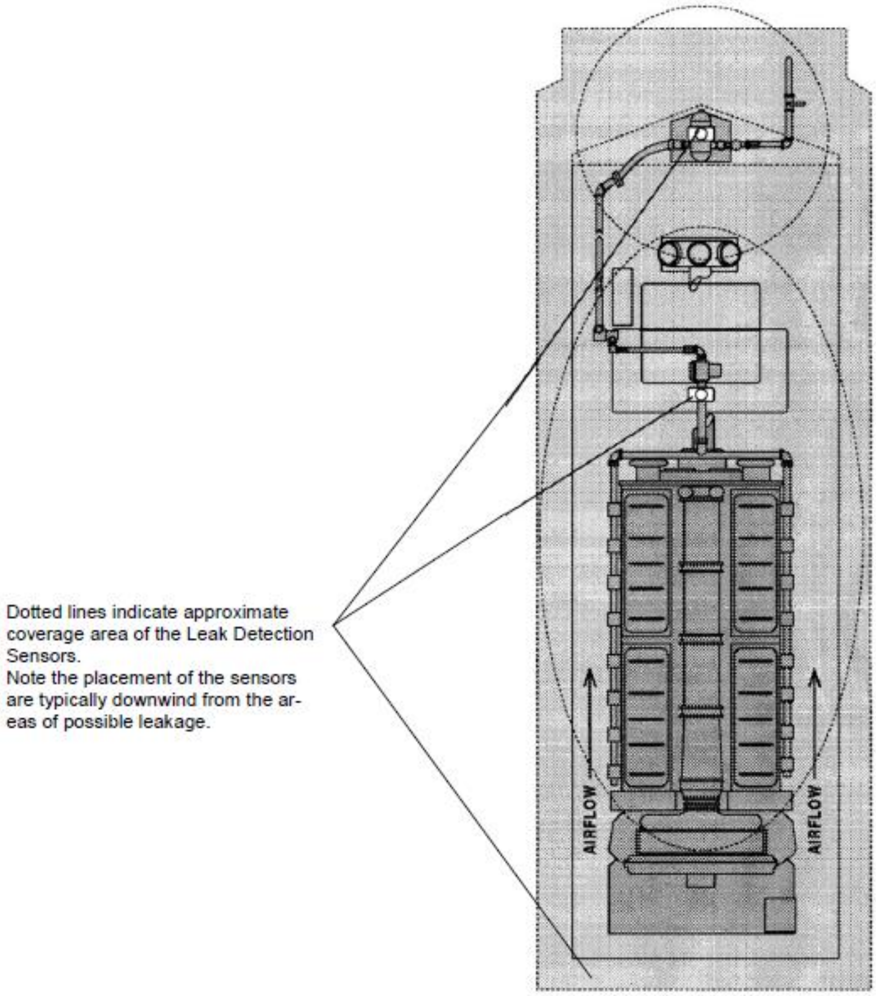


Figure 184. Gas leakage detection system

11.2.2.10 LNG tanks

The engineering section of this report details the technical characteristics and the location of the tanks in the locomotive. The original gasoil deposit of the locomotive must be replaced by two LNG cryogenic tanks.

The same anchor points of the original deposit will be used, in which the appropriate supports will be screwed on, so the installation can be reversible.

For the tanks installation over the engine cover, a suitable support must be constructed.

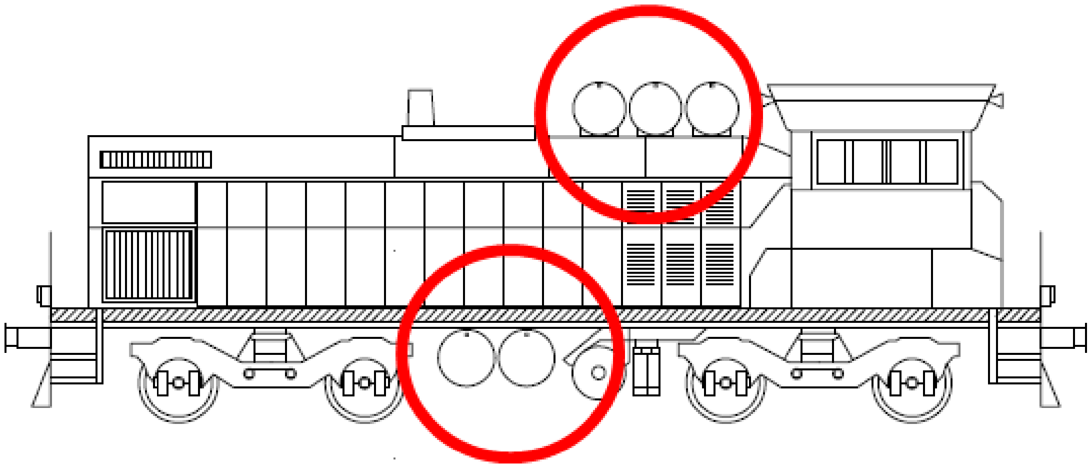


Figure 185. Location of the LNG tanks

Gas pipelines:

The tanks manufacturer will provide the assembly scheme of the locomotive's five LNG deposits. The majority of the pipes will be unified to obtain a similar operating than one single tank.

All the gas lines must be capable to resist the consequences of the low temperatures with no problems. The use of stainless steel series 300 pipes is strongly recommended for the LNG transportation.

The filling and the distribution tubes can be flexible or rigid, metallic or non-metallic, but in all cases, they must be certified for its usage with cryogenic liquids. The vent and the over-pressure tubes will be flexible or suitable hoses to be used with natural gas. The system must include a low draining point for condensed water that may appear.

The tubes assembly must allow the thermal expansion caused by the changes of the cryogenic temperature to room temperature. This is commonly solved adding S curves to the rigid ducts. Generally, if one extreme of the tube can move about 13 mm while the other stay fixed, it will be enough flexible for the low temperatures.

It is recommended to use tubes of the following dimensions and thicknesses:

- 3/8" OD x 0.035" (10mm x 1.0mm)
- 1/2" OD x 0.049" (12mm x 1.0mm)
- 3/4" OD x 0.065" (20mm x 2.0mm)

Fittings:

The union of the rigid tubes will be performed by means of fittings (Parker, Swagelok, or equivalents)

All the fittings must be installed using Teflon tape. After applying the tape to the fitting, it must be tightened clockwise until its final position. Note that in case of over-tightening beyond the final point, it is not possible to turn it anticlockwise. It must be disassembled, and all the operation must be restarted.

If the tube has more than one fitting, make sure to use two keys in order to maintain the adjustment of each thread. There are many pipelines available. Chart recommends the use of NPTF accessories because their leakage resistance. When stainless steel tubes are used, it is recommended to use brass gaskets to avoid the excoriation during the installation.

During the maintenance operations, replace the brass elements when necessary. It is not recommended to use stainless steel threads to stainless steel due to excoriation problems, or in such case, use an anti-excoriation compound such as the nickel tape. This tape is available at www.chartparts.com (PN:11811511). Make sure the threads are clean and dry when applying the tape.

Pipelines supports:

The pipelines and tubes must be leant along its length to protect them against the vibrations. Generally, supports are required every 30 cm of tube. Either stainless steel, polyethylene or polypropylene clamps can be used. Give special attention to the support placement to allow the thermal expansion and contraction of the lines.

LNG tanks:

The deposits must be held to the locomotive chassis with the corresponding support. Stainless steel belts will be used and placed with a minimum separation of 2" from any weld. The belts must incorporate a flexible rubber preventing the rotation or the slide of the tank once installed.

According to the NFPA 25 guiding principles, the assembly system must be enough strong to bear eight times the tank weight.

Heat exchanger:

The Chart integrated tanks include the heat exchanger in its standard equipment.

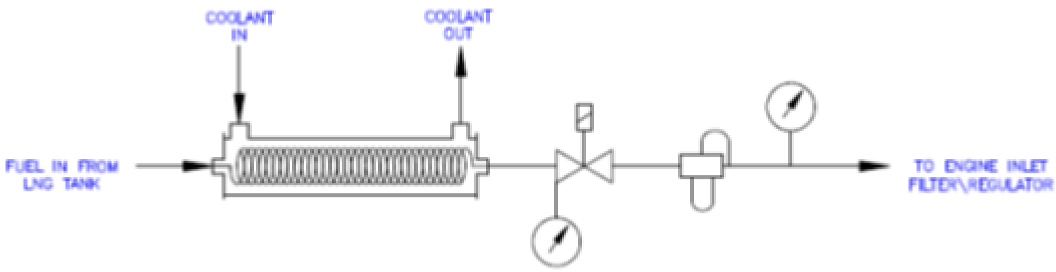


Figure 186. Exchanger installation scheme

Automatic valve:

The automatic valve will be installed at the hot gas outlet of the exchanger. Even though this valve will be threaded directly over the exchanger outlet, it is recommended to add a specific support to bear the valve weight.

The valve will close when the engine ignition is cut. It is recommended to add a low-temperature alarm in the hot water line, to prevent damages downstream the tube in case of malfunctioning of the exchanger. The Chart integrated deposits already include this valve in the standard equipment.

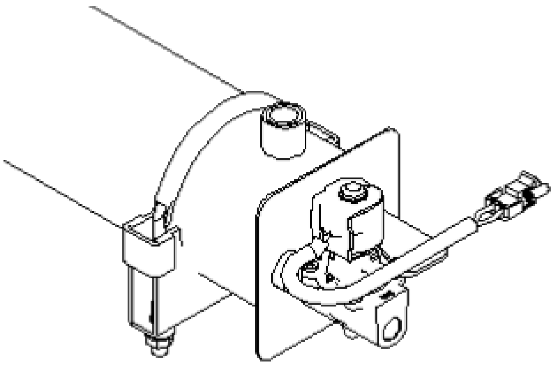


Figure 187. Automatic valve

Vent security valve:

The vent valve must be located in a safe point of the locomotive. Generally, the natural gas is piped through the upper part of the locomotive with the flow directed upwards since it is naturally elevated. This line enables to relieve liquid; hence its discharge trajectory must be away from people, ignition sources or materials that can be damaged at cryogenic temperatures. It must be prevented the possibility of water accumulation and freeze in the vent line including a low drainage point.

The minimum recommended size for the vent tube is 1/2 "(12 mm).

Filling line:

Due to the installation of several LNG tanks, the filling line will be defined by the tanks provider during the project.

Engine supply line:

The fuel line from the automatic shut-off valve to the engine can be a metallic or non-metallic tube suitable for natural gas supply. If non-metallic tubes are used, an additional low-temperature shut-off valve will be added to the fuel system.

The fuel line of the engine must have a diameter larger than the LNG line in the heat exchanger to prevent flow restrictions, due to the liquid expansion when it is vaporized.

Fuel level indicator:

The fuel level indicator is composed by two parts: the sender and the measuring device. The sender is the sealed unity that is mounted in the fuel tank. It is connected to the vehicle through a Weatherpak female connector with three pins.

The system must be protected by a 1-Amp fuse. The measuring device VDO provided must be mounted on the dashboard into the locomotive.

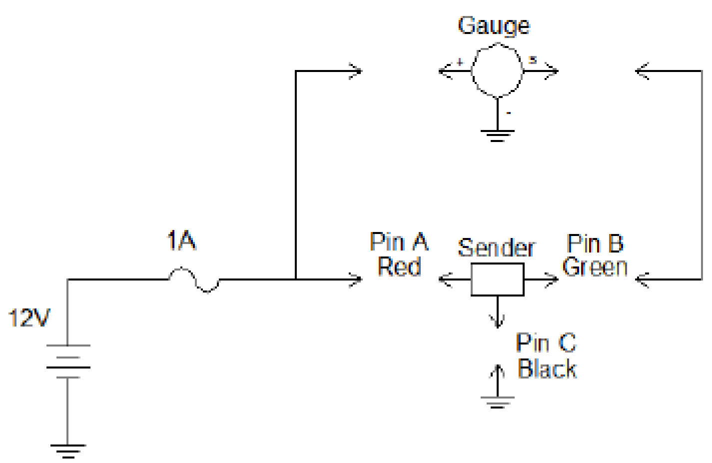


Figure 188. Scheme of the fuel level indicator

Installation of several tanks:

For the installation of several tanks in the same vehicle, the filling, the vent, the ventilation, the safety valve and the measuring lines are simply connected in parallel according to the following recommendations:

The tanks will be filled independently but they will act as a single system, as if it was only one larger deposit.

During the refuelling, it is normal that some tanks are filled before the others, causing pressure and flow changes. This fact may produce alarms to the automatic filling systems.

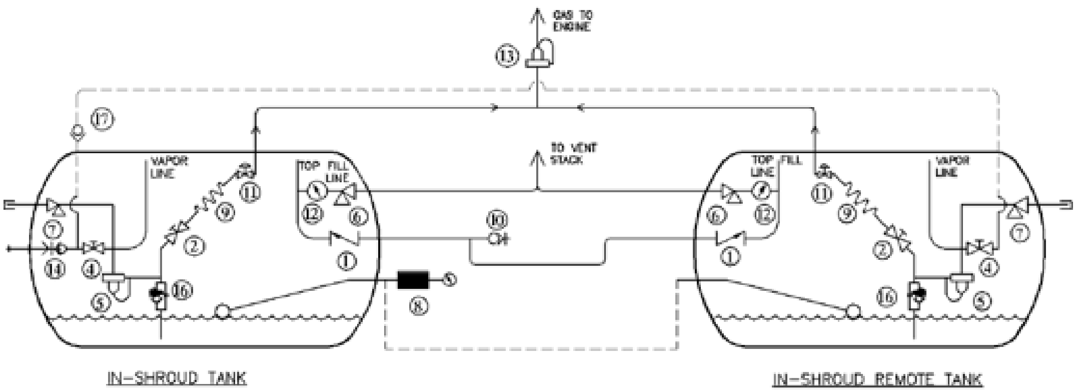


Figure 189. Scheme of the fuel tanks integration (R110)

12. Validation

12.1. Monitoring and evaluation of the modified locomotive

For the purpose of monitoring and testing the operating of the new locomotive power train, and guaranteeing the proper project's results follow-up and its comparison with the original situation, the following actions are defined in this technical report:

- Locomotive monitoring protocol and data to be registered
- Evaluation methodology of the locomotive operating and KPIs
- Comparison of the locomotive operating with the original diesel situation

12.1.1 Locomotive monitoring

It is supposed that there are currently records of the operations performed by each locomotive and of the preventive and corrective maintenance on every vehicle. Nevertheless, the following tables are presented providing an example that can be used as the monitoring methodology and evaluation of the transformed locomotive.

The first record proposed is the one for the locomotive operability, that will enable to determine the operating hours, the distance travelled and the LNG consumption for a given period of time (eg: a month):

OPERATIONS LOG						Locomotive 310 GNL		Num	xxx-xx
Nº	Date	Start time	Ref OT	Load	Operating time	Route	Stop time	LNG load	Notes
				Tm	horas	km		kg	
1	dd/mm/yy	hh:mm	OT1234	500	6	22	hh:mm	200	
2								--	
3									
4									
...									

Table 34 Operations log

To control the operations and the maintenance cost, the following tables are proposed, the first one related to the preventive maintenance and the second one to repairs.

MAINTENENACE LOG								Locomotive 310 GNL		Num	XXX-XX
Nº	Date of entry	Start time	Type of scheduled review					Reparation	Date of departure	Departure time	Notes
			A	B	C	D	E	See report nº			
1	dd/mm/yy	hh:mm		X				--	dd/mm/yy	hh:mm	
2	dd/mm/yy	hh:mm						2017 - 3	dd/mm/yy	hh:mm	
3											
4											
...											

A = Monthly B = Six-monthly C = Yearly D = Three-yearly E = Predictive

REPAIRING LOG					Locomotive 310 GNL		Num	XXX-XX
Nº	Date of entry	Start time	Failure origin or intervention	Repaired system or element	Spare parts replaced	Date of departure	Departure time	Notes
1								
2								
3	dd/mm/yy	hh:mm	ECU error	Measure RPM	Wire to ECU	dd/mm/yy	hh:mm	
4								
...								

Table 35 Preventive maintenance and repairing log

These two records will enable to know the stopping times per maintenance and repairing actuations, as well as their costs.

For later comparison of the transformed locomotive operating in relation to the original situation, it will be necessary to dispose of records on the current diesel locomotive similar to the ones suggested in this report.

12.1.2 Evaluation of the transformed locomotive operating

With the data registered using the records suggested in the previous section, it will be possible to define a set of baseline KPI (Key Performance Indicators) that will be used to evaluate the transformation profitability and its proper operating.

The following KPIs are proposed:

Symbol	Name	Origin or Calculation
KPI related to Times		
T1	Working time	Operations log
T2	Standby time	Operations log
T3	Maintenance time	Maintenance log
T4	Repairing time	Repairing log
KPI related to Consumptions		
C1	Consumption per working hour	Operations log
C2	Consumption per km travelled	Operations log
KPI related to Maintenance		
M1	Maintenance costs per working hour	Maintenance and Operations log, and costs of workshop and spare parts
M2	Repairing cost per working hour	Repairing and Operations log, and costs of workshop and spare parts

Table 36 Proposal of KPIs to evaluate the profitability of the transformation and its proper functioning

The previous KPI are the minimums proposed but, logically, some additional indicators can be set to obtain further information and statistics.

The previous KPI can be also plotted in the desired graphs to facilitate the monitoring of the main parameters of the locomotive operability.

For instance:

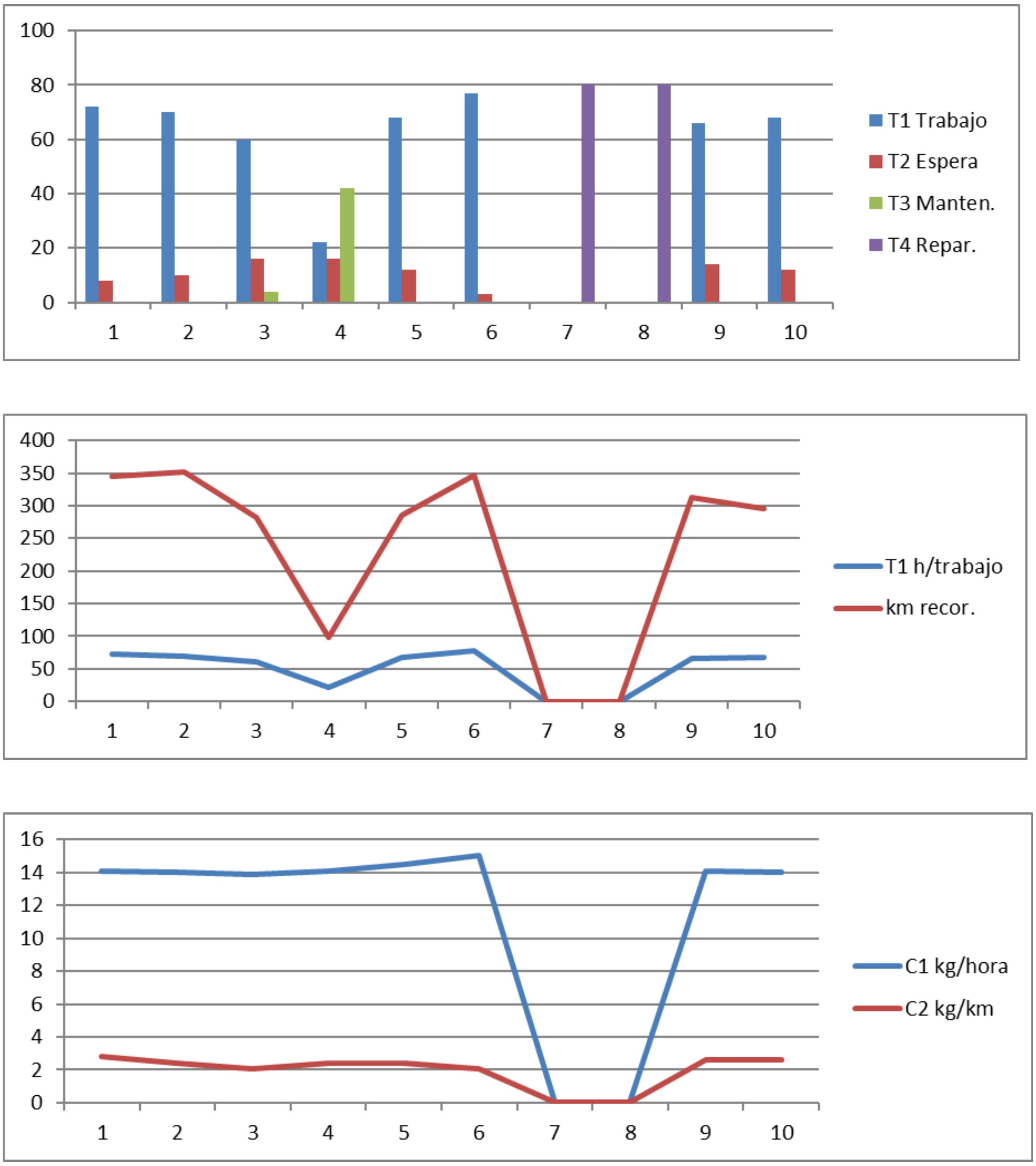


Figure 190. Operability (hours), route (km) and consumptions (kg/km and kg/h) graphs from top to bottom to facilitate the monitoring of the main parameters of the locomotive operability.

12.1.3 Comparison between the transformed locomotive (LNG) and the original (diesel)

The set of KPI registered and their corresponding graphs enable to make an easy comparison between the performances of the original diesel locomotive and the one transformed to LNG.

To this end, before the transformation, the data must be registered from the original locomotive with sufficient time in advance to obtain representative historical data, and then proceed with the comparison of the operating costs based on the consumptions.

These KPI could be also used in the future to compare the modified locomotive to new locomotives using state-of-art diesel engines, or other hybrid types systems etc.

12.2. Definition of the recommended additional instrumentation

The transformation of the diesel locomotive to LNG implies the addition of new instrumentation related to the following systems

- Gas system information
- Level of LNG in deposits
- Gas leakage detection system

Details on the functionalities of each system are described below.

12.2.1 Engine Control Display (ECD)

The electronic management system developed by ECI (so-called ECD – Engine Control Display) includes an additional display in the cabin that provides information about the proper engine operating.

The ECD display provides real-time operational information. It is a 7" touchscreen connected to the ECU via Ethernet. The ECD is an independent visualization device that executes its own software. It is programmed to generate two types of records, one with operating data and the other with failures messages. Both files are saved on a SD memory and can be easily loaded using a USB memory. The ECD is also capable to run as a web server and allows the remote monitoring and diagnosis using the appropriate hardware.

The ECD includes several screens allowing the visualization of data records and help sections with lists of acronyms and control devices pictures to help and guide the operator. It is an intuitive and simple system to be used.

The ECD does not provide any configuration to change the controller, it only provides information and failure messages that can be reset.

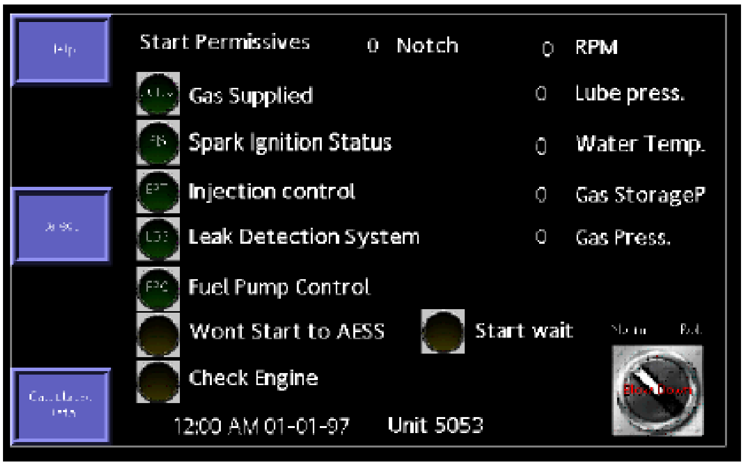


Figure 191. ECD main display (Engine control)

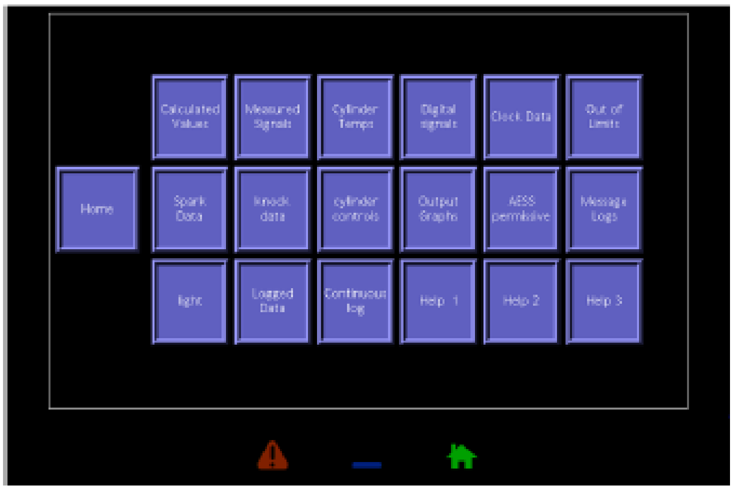


Figure 192. ECD selection display (Engine control)

The ignition system used is the Altronic model CPU95, and its unit is installed at the engine compartment. It provides one screen for the diagnosis and the communication with the main system located in the electrical cabinet of the locomotive cabin.

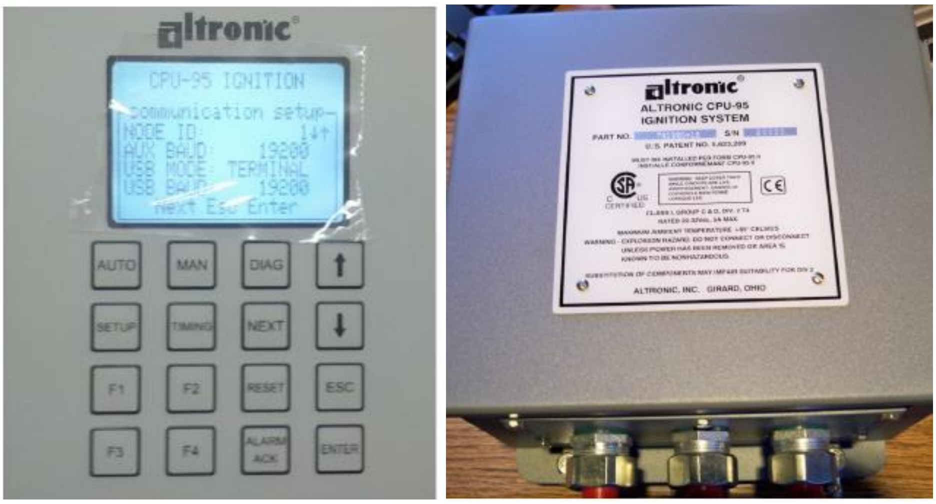


Figure 193. Ignition and diagnosis system

The diagnosis information is easily accessible through the engine control display located in the cabin (see **Figure 193**).

The information provided by the ignition module Altronic CPU95 arrives to the ECD through a RS485 connection. Hereafter, some images of the information provided by the ignition module to the ECD are shown.

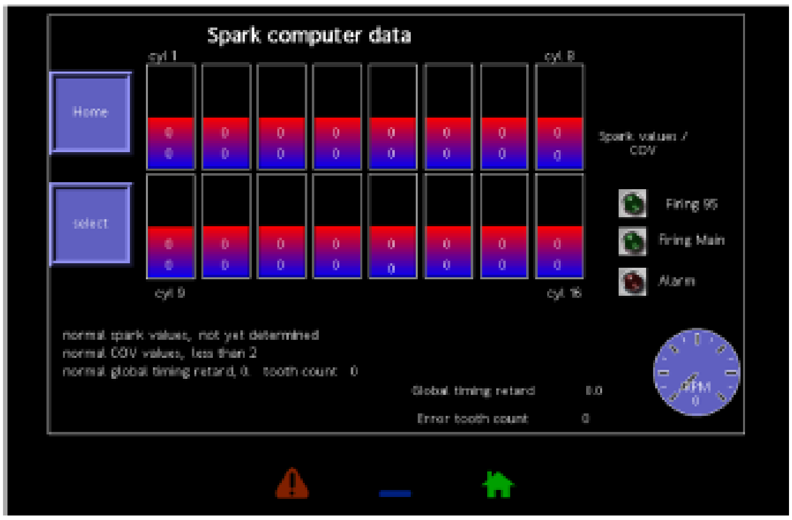


Figure 194. Ignition verification screen

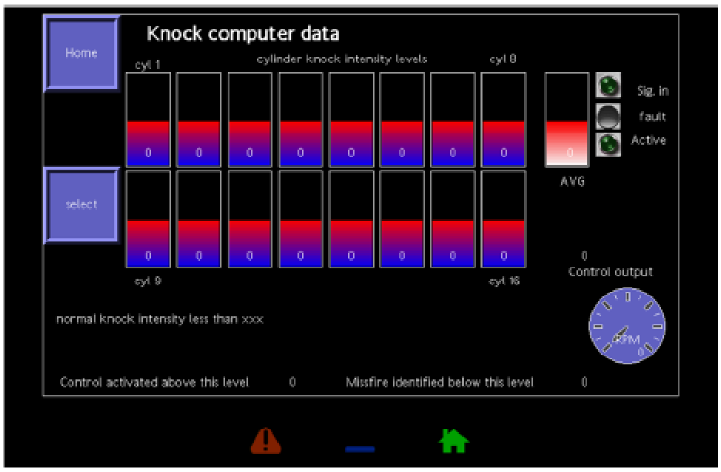


Figure 195. Detonation verification screen

The ECD display provides information about:

- Engine revolutions
- Pressure of the engine lubricant oil (inlet/outlet)
- Temperature of the engine lubricant oil (inlet/outlet)
- Pressure of the gas at the supply line inlet.
- Pressure of the gas at the supply line outlet.
- Gas temperature
- Temperature of the manifold intake air
- Pressure of the manifold intake gas
- Temperatures of the cooling water (inlet/outlet)
- Temperatures of the combustion gases in the exhaust manifold
- Pressure of the hydraulic circuit oil (inlet/outlet)
- Temperature of the hydraulic circuit oil
- GIV valves situation
- Alarms
- Ignition test (spark plugs and coils)
- Among others

12.2.2 Fuel level

Each LNG tank is equipped with an electronic system that indicates the fuel level. The system is composed of two parts:

- The fuel lever transmitter installed inside the tank

- The clock indicator located at the cabin display

The transmitter converts the electronic signal of the fuel level probe to a signal compatible with the board display. The system is designed so it is not affected by the state, the pressure nor the temperature of the product. The effects of the acceleration, braking, curves and slopes are minimized but may produce some variations in the measure.

The fuel meter is a standard calibrated meter used in automotive applications. The measurement accuracy of one tank is ± 1/16.

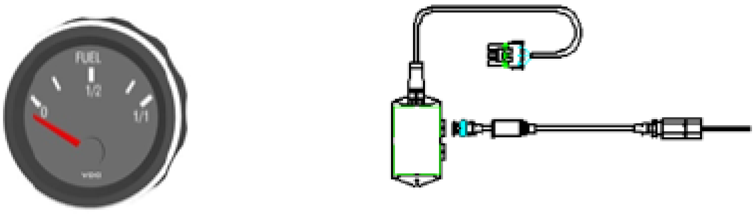


Figure 196. Clock indicator and fuel level transmitter

The system can be configured so only one clock indicates the fuel level of several tanks as they were only one single deposit.

12.2.3 Gas leak detection system

The gas leak detection system is performed using the AMEREX AMGasDS III system.

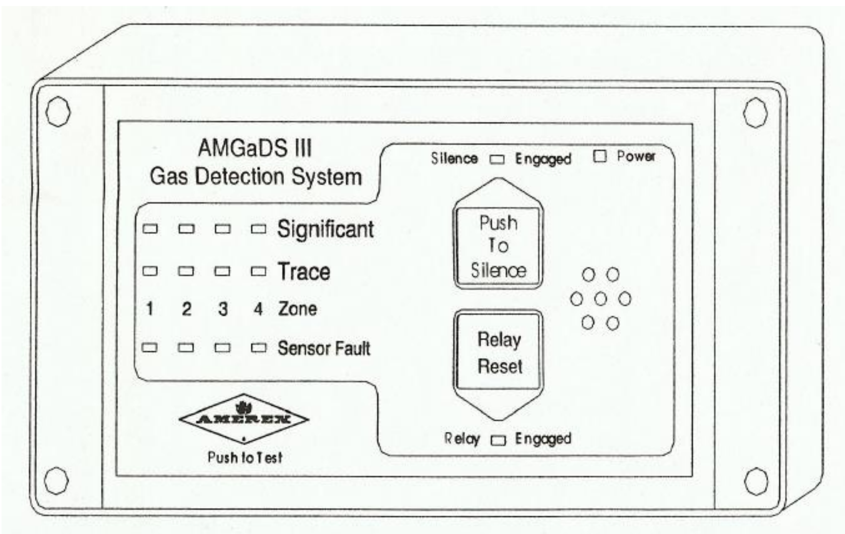


Figure 197. Alarm centre of the AMGasDS III

The alarm centre of the gas leakage detection system will be installed into the cabin, beside the locomotive control panel in such a way that all the indications are easily visible by the operator.

12.3. Modifications to the manuals

In the engineering section corresponding to the Maintenance and Operational Plan, the general lines of the main chapters content are described, considering that the final and definitive text must be edited after performing the transformation with the specific data given by the different providers.

The manual in the ANNEX, will include all the pictures, drawings or schemes necessary to facilitate the assembly and disassembly of the elements used during the locomotive transformation.

The Maintenance and Operational Plan also includes a proposal of maintenance activities to perform due to the modifications introduced for the locomotive transformation to LNG. These activities may also be used as a guide to draft the annex of the locomotive's original manual once the transformation has been developed and has entered into operation.

13. Overall conclusions of the study: Phase 1 y Phase 2

From now on, main conclusions are presented down below derived from the feasibility study conducted in Phase 1 of the project, in which, despite the existence of some barriers for the gasification of the shunting manoeuvres in the Port of Tarragona, all of them can be solved with time and cost as it has been proved in Phase 2.

Regarding the **technical feasibility**, the following conclusions are presented:

- **LNG engine** for the railway traction is not yet within a standardised market (listed in a catalogue). Only one out of five providers (Guascor) has a LNG engine available in a catalogue which might be used for the shunting railway services at Port of Tarragona since it **meets the requirement requested**. Therefore, this might increase cost and supply time.
- In principle, the acquisition of a **LNG tank** for the rail traction does not entail **any** major **problem**: few of them are shown in catalogue (3 out of 7 providers contacted –Chart, Enric Group and Ingesic- have them listed in catalogue).
- **LNG engine** and **cryogenic tank** shall not imply a **modification higher than +/- 10%** than the weight with respect to the engine and diesel tank, in order to barely shift the gravitational centre over the accepted normative standards.

With reference to the **legal feasibility**:

- The **accreditation process** involves the main legal barrier (since LNG is not considered as fuel for the locomotive sector to date). However, the LNG railway project coordinated by Institut Cerdà will achieve a substantial progress to this matter.
- If the modification approach on the already accredited rolling stock (310/311 locomotive) is chosen, Adif shall approve it as the locomotives' owner.
- The necessity of developing **documentation with no framework of reference** in terms of gas. In the case of considering a prototype of locomotive with LNG traction, **a Provisional Authorization for its Circulation** will be required. On the other hand, if the technology is intended to be implemented for its commercial exploitation, then it will be requested to follow the following steps:

- **Risk assessment** arising from the implementation of the proposed amendment.
- An **independent assessor**'s report about evaluation process and risk analysis.

Finally, in relation to the **economic feasibility**, the analysis conducted to determine whether the LNG railway traction is profitable for the operator and the gas agent, the following conclusions can be drawn:

- The viability of the transformation for the gas agent is **conditioned** to the LNG minimum prices. Those should be higher than or equal to **0,295 €/l** by the time 3 locomotives are converted, when only 2 locomotives are transformed the prices should be higher than or equal to **0,320 €/l**. By assuming these minimum prices, all scenarios evaluated present a **lower payback of 7 years** and IRR superior to 12% for the gas company.
- **Diesel cost** is the **most influential variable** to affect the project profitability for the railway operator. As long as the election of the type of engine, number of the converted locomotives and LNG locomotive equitable usages on the available fleet (variables upon which the Autoritat Portuària de Tarragona possess a vast influence) are added up alongside diesel cost higher than or equal to 0,800 €/l and most favourable conditions for **railway demand** and **accreditation** costs (variables on which the PAT do not possess any influence), the payback for the railway operator might reach 7,3 years on the **optimal scenario**, although by no means being reduced less than 7 years.

Based on the conclusions presented above, the second phase of the project is initiated in order to obtain a procedure for the realisation of all the required technical modifications to implement the transformation of the diesel locomotive to LNG. To achieve this goal, three differentiated action blocks have been identified and their main conclusions are presented below:

- **ENGINEERING:**
  - **Selection of the locomotive to be transformed:** Even though the study of the Phase 1 was based on the locomotive 311, the appropriateness of the locomotive model has been deliberated again. The variables considered for its selection are based on the following parameters:
    - Available space for the engine replacement or transformation, as well as for the cooling system.

        - Accessibility to operate inside the vehicle.
        - Location and available space for the deposit.

        Based on these variables, the model Adif 310 locomotive has been selected as the base to define the required transformation process in phase 2.

    - **Final solution selection:** 4 possible alternatives have been proposed:
        - Replacement of the present engine by another engine with LNG fuel.
        - Transformation of the current engine to LNG fuel.
        - Replacement of the current engine by another engine with Dual cycle (gasoil + LNG).
        - Transformation of the present engine to Dual cycle (gasoil + LNG):
            - **Engine selection:** the solution considered is to transform the current engine by means of a conversion kit to natural gas from the company ECI. The choice has been made based on the following parameters:
                - *Dedicated natural gas engine:* prioritizing the use of natural gas engines (dedicated) as the best solution to maximize the gas consumption and reduce the polluting emissions. The engine load of the shunting locomotives at the Port of Tarragona is in constant change so the use of dual engines is detrimental for their proper functioning.
                - Specific version to use in locomotives.
                - Suitable dimensions to the available space.
                - Ease of integration.
            - **Selection and location of the deposit:**
                - The Type 310 locomotive have a fuel tank of 2.700 litres of gasoil that, according to the information provided by the Port of Tarragona, is filled once a week. To maintain an equivalent capacity, the transformed locomotive should have a storing capacity of 4.860 litres of LNG.

        - Considering the availability of models and the available volume in its location, it is concluded that the maximum capacity of LNG can be 2.164 litres.
        - This capacity implies that the locomotive new range will be halved. The LNG tanks must be filled twice a week.
        - Regarding its location, the following parameters have been considered: the safety during the installation, minimizing its affection to the CoG and the ease of use and maintenance.
      - **Analysis of the impact in the total weight of the vehicle and the modification of its centre of gravity due to the transformation:** it is considered that the CoG shift does not affect either the operating nor the dynamics of the locomotive.
  - **Maintenance plans:** a proposal of annex to the present *DESCRIPTIVE MANUAL OF THE VEHICLE* has been drafted, including the new particularities of the engine and the fuel system (tanks, circuit and LNG control).
  - **Tests to conduct:** a study on the identification of the tests necessary to perform in case of implementing the transformation:
    - *Leak tests* for the LNG circuit.
    - *Static tests* of commissioning and acceleration of the vehicle in tests bench to validate the locomotive operating once the transformation has been implemented.
- **INTEGRATION:** the following works necessary for the integration of the new system to the original locomotive have been identified:
  - Conversion of the diesel engine to LNG and its pertinent mechanical modifications: substitution of the cylinders and adaptation of the engine cylinder head.
  - Installation of the natural gas supply system from the engine to the LNG deposits set.
  - Electrical-electronic system, hydraulic system, general wiring and installation of the engine sensors.
- **VALIDATION:** the operating procedures to evaluate the modified locomotive and validate its proper functioning have been defined. The

transformation implies the addition of complementary instrumentation related to the following systems:

- Gas system information.
- LNG level in the deposits.
- Gas leaks detection system.

14. ANNEX 1 – Maintenance plan EMD 8-645-E LNG

*****ATTENTION*****

Maintenance of the locomotive

.

The access to maintenance workshops must be conditioned to ensure that they have adequate safety measures when working with locomotives that run on natural gas. The workshops must be equipped with adequate ventilation and detectors to guarantee safety in case of gas leaks. In the event that it is essential to access some non-conditioned workshops, the complete emptying of the LNG tanks is mandatory.

In the maintenance plan presented below, all the systems and equipment that have not been affected by the natural gas transformation of the locomotive have been omitted.

The activities to be carried out and their periodicity should be understood as a proposal that must be validated when it is integrated with the locomotive's current maintenance plan.

The definition of a preventive maintenance system based on the following time intervals has been considered:

1. Monthly maintenance
2. Semi-annual maintenance
3. Annual maintenance
4. Three-year maintenance
5. Predictive maintenance

1. MONTHLY

System	Part	Action
Engine	Engine oil	Check level
ECU	Error messages	Review
Hydraulic	Oil	Check level
Refrigeration	Water level	Check level
Refrigeration	Engine oil	Check function
Instrumentation	Box	Check function

2. SEMI-ANNUAL

System	Part	Action
Engine	Engine oil	Analyse
Engine	Air filter	Check differentia pressure
Engine	Air filter	Clean
Engine	Actuators	Check function
Engine	Straps	Check status
Engine	Engine flywheel sensor	Check function
Engine	Sensor	Check function
LNG	General valve	Check function
LNG	Speed control valve	Check function
LNG	Loading valve	Check function
Hydraulic	Valves	Check function
Refrigeration	Thermostat	Check function
Refrigeration	Fans	Inspect and clean
Refrigeration	Radiators	Inspect and clean

Refrigeration	Pressurised cap	Check function
Instrumentation	Switches	Check function
General	Engine	Check cleaning
General	Oil	Check leaks
General	Water	Check leaks
General	LNG	Check leaks
General	Hydraulic	Check leaks
General	Painting	Check status and oxides
General	Batteries	Check status

3. ANNUAL

System	**Part**	**Action**
Engine	Gas injectors	Check function
Engine	Spark plugs	Change
Engine	Temperature sensors	Calibrate
Engine	Pressure sensors	Calibrate
Engine	Cylinder screws	Check tightening
Engine	Starting motor	Check function
Engine	Coils and wiring	Check status
LNG	Gas circuit	Check tightness
LNG	Temperature sensors	Calibrate
LNG	Pressure sensors	Calibrate
LNG	Valves	Check function
Hydraulic	Oil filter	Change
Hydraulic	Temperature sensors	Calibrate
Hydraulic	Pressure sensors	Calibrate

Refrigeration	Water sensors	Pressure test
Refrigeration	Temperature sensors	Calibrate

4. THREE-YEAR

System	Part	Action
LNG	Cryogenic deposits	Vacuum test

5. PREDICTIVE

System	Part	Action
Engine	Engine oil	Analyse and change (results)
Engine	Oil filters	Analyse and change (results)
Engine	Air filters	Analyse and change (results)

15. ANNEX 2 – List of components and equipment

Hereunder, a list of components and equipment, whose modification can have the consideration of significant and, therefore, require a report of a security evaluation agency concerning the corresponding risk management process.

1. BOGIE / ROLLING ORGAN

1.1. FULL ASSEMBLED AXLE

1.2. PRIMARY SUSPENSION

1.3. SECONDARY SUSPENSION

1.4. BOGIE FRAME/ YUGO

1.5. RODAL

1.6. SHOCK ABSORBERS

1.7. REDUCER

1.8. SILENTBLOCKS

1.9. WIDTH CHANGE SYSTEM

2. COUPLINGS

2.1. AUTOMATIC, FRONT AND INTERMEDIATE COUPLING SYSTEM (includes electrical communication)

2.2. TRACTION ASSEMBLY

2.3. UNION SYSTEM BOX-BOGIE

2.4. COUPLINGS / EMERGENCY BLOCKS

3. BOX / VARIOUS

3.1 BOX STRUCTURE (including front end)

3.2. SCROLLING SYSTEM (including software)

3.3. SYSTEMS OF CLAMPING OF LOADS

3.4. COLLISION ASSEMBLY

3.5. EXTERNAL DOORS (including software)

3.6. RAMPS, BRACES. AND ACCESS LADDERS

3.7. FRONT GLASS

3.8. LATERAL GLASS

3.9. ASIDEROS AND HANDRAILS

3.10. SECURITY CLAMPS

4. BRAKE SYSTEM

4.1. BRAKE EQUIPMENT, ANY OF ITS COMPONENTS

4.2. BRAKE CONTROL SYSTEM

4.3. BRAKE TIMONRY

4.4. BRAKE SHOES AND FITTINGS

4.5. ALARM HANDLES

4.6. BRAKE DISCS

4.7. INTERFACES WITH THE BRAKE SYSTEM

4.8. HEAVY VALVE

4.9. SOFTWARE

5. CONTROL AND SUPERVISION SYSTEMS

5.1. SYSTEMS:

5.1.1. HEAT UP DETECTION

5.1.2. DETECTION OF INSTABILITY

5.1.3. CHANGE OF WIDTH

5.1.4. ANTIBLOCKING

5.1.5. ANTI-SLIP

5.1.6. BLENDING

5.1.7. SUSPENSION / TILT CONTROL

5.2. SOFTWARE

5.3. TCN NETWORK

6. HIGH VOLTAGE AND RETURN FOR GROUND CONNECTION

6.1. PANTOGRAPH

6.2. GROUND CONNECTION SYSTEM

6.3. BRAKE RESISTORS

6.4. BRAKE RECOVERY

7. SECURITY EQUIPMENT

7.1. LEGAL AND EVENT RECORDERS

7.2. ASFA

7.3. ERTMS

7.4. LZB

7.5. EBICAB

7.6. ATP

7.7. TRAIN TO WAYSIDE OR OTHER COMMUNICATION EQUIPMENT OF THE DRIVING POSITION

7.8. DEAD MAN

7.9. OTHER SIGNALING SYSTEMS

7.10. PASSENGER ALARM DEVICE

8. SYSTEM OF FIRE PROTECTION

8.1. FIRE CONTROL SYSTEM (including software)

8.2. MATERIALS: INTERIOR DESIGN, WIRED, ETC.

8.3. PAINTS FOR INTERIOR

8.4. COMMUNICATION SYSTEM (including software)

8.5. COMPARTMENTALISATION

8.6. BARRIERS

8.7. FIRE EXTINGUISHERS

8.8. EMERGENCY LIGHTING

9. TRACTION EQUIPMENT

9.1. MAIN TRANSFORMER

9.2. TRACTION CONVERTER

9.3. TRACTION ENGINES

9.4. ELECTRONIC CONTROL AND POWER EQUIPMENT

9.5 INPUT FILTERS

9.6. CONVERTERS FOR THE SUPPLY OF ELECTRICAL POWER TO AUXILIARY SYSTEMS

9.7. EXTRA-FAST CIRCUIT BREAKER

9.8. SECURITY SOFTWARE IN TRACTION EQUIPMENT.

10. OTHER CONCEPTS AND SYSTEMS

10.1. GAUGE

10.2. DYNAMICS OF MARCH

10.3. ELECTRICAL SAFETY

10.4. ENVIRONMENTAL CONDITIONS

10.5. FRONTAL SIGNALS

10.6. TAIL LAMPS

10.7. REAR VIEW MIRRORS

10.8. HORNS

10.9. ELECTROMAGNETIC COMPATIBILITY

10.10. HARMONIC CURRENTS

10.11. WEIGHT DISTRIBUTION BY AXIS

10.12. ACCESS AND LOCATION OF P.M.R.'s

10.13. ADRESS SYSTEM

16. ANNEX 3 – Schedule of the transformation process

Hereunder, the estimated schedule for the transformation process is presented.

TRANSFORMATION OF A DIESEL SHUNTING LOCOMOTIVE TO LNG																																																
ACTIVITIES	MONTH 1				MONTH 2				MONTH 3				MONTH 4				MONTH 5				MONTH 6				MONTH 7				MONTH 8				MONTH 9				MONTH 10				MONTH 11				MONTH 12			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
ENGINE CONVERSION																																																
ENGINE PREPARATION																																																
Drill for Load Blocks																																																
Drill for GIVs (Gas Inlet Valve)																																																
MECHANICAL MODIFICATIONS																																																
Cylinder head modification																																																
Pistons replacement																																																
NATURAL GAS PIPELINES																																																
Pipelines installation																																																
Gas valves																																																
POWER PACK																																																
Power Pack components installation																																																
ELECTRIC SYSTEM																																																
Electronic Control Unit (ECU) installation																																																
Ignition system installation (spark plug, coils etc.)																																																
Analogic and digital wiring to sensors and actuators																																																
Exhaust temperature probes wiring																																																
SENSORS INSTALLATION																																																
Installation of exhaust temperature and air intake probes																																																
Installation of the air intake pressure and gas pressure sensors																																																
Installation of the detonation sensors																																																
Installation of the flywheel and engine synchronization sensors																																																
Installation of other sensors of the SIP system																																																
LNG DEPOSIT																																																
Disassembly of the current fuel deposit																																																
Preparation of the new supports																																																
Installation of the new LNG tanks																																																
Installation of the gas pipelines																																																
Heat exchanger connections																																																
Installation of the supply automatic valve and the vent security valve																																																
Installation of the filling line and the gas supply line to the engine																																																
Fuel level indicator connections																																																

TRANSFORMATION OF A DIESEL SHUNTING LOCOMOTIVE TO LNG

ACTIVITIES	MONTH 1				MONTH 2				MONTH 3				MONTH 4				MONTH 5				MONTH 6				MONTH 7				MONTH 8				MONTH 9				MONTH 10				MONTH 11				MONTH 12			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
INTEGRATION																																																
ELECTRIC SYSTEM																																																
Electric panels installation																																																
Digital connections box - DTB																																																
Analogic connections box																																																
LNG TANKS																																																
LNG tanks integration																																																
HYDRAULIC SYSTEM																																																
Installation and connections of the hydraulic system																																																
ENGINE COOLING SYSTEM																																																
Modification of the cooling system (if required)																																																
GENERAL WIRING																																																
GAS LEAK DETECTION SYSTEM																																																
Installation of the gas leak sensors																																																
Installation and connections of the alarms box																																																
VALIDATION AND COMMISSIONING TESTS																																																
Gas circuit pressure test																																																
Power test with resistors																																																
General operating tests																																																
ACCREDITATION																																																
Validation and Certification																																																
Commissioning authorization																																																
TRAINING																																																
Initial basic training course																																																
Specific course for operators																																																
Specific course for maintainers																																																

17. ANNEX 4 - Budget of the transformation process

Hereunder, the estimated Budget of the transformation process developed by the engineering GPO, responsible of the study, is presented:

Port of Tarragona

LNG locomotive

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SUBJECT: **PRELIMINARY DRAFT BUDGET**

PROJECT DESCRIPTION:

Retroffiting of a diesel shunting locomotive to LNG. Includes:
- Engine transformation to LNG
- Fuel deposit replacement
- Gas leak detection system
- System integration

ASSUMPTIONS:

Estimated costs according to the preliminary design and calculations of the project.
The prices include supply, installation and commissioning.
This budget is a preliminary estimation that will be developed according to the final project.

ITEM	Units	Quantity	SUBTOTAL (€)	TOTAL (€)
1. CONVERSION KIT TO LNG				**225.000 €**
ECI SIP Conversion Kit LNG for EMD 8-645 E	Set	1	201.000	
Gasification system	Un	1	18.000	
Gas leak detector	Set	1	6.000	
2. LNG TANKS				**55.500 €**
Deposit Chart HNLG 171	Un	2	24.000	
Deposit Chart HNLG 100	Un	3	31.500	
3. INTEGRATION				**196.000 €**
System integration	Un	1	110.000	
Accessories and additional material	Un	1	25.000	
Commissioning / technical support	Un	1	41.000	
Power test with resistors	Un	1	20.000	
4. ACCREDITATION				**163.000 €**
Validation and certification (1st unit) / Estimation	Un	1	160.000	
Commissioning authorization (1st unit)	Un	1	3.000	
5. INDIRECT COSTS				**268.000 €**
Engineering + Risks analysis	Un	1	140.000	
Project Management	Un	1	80.000	
Contingencies	Un	1	48.000	
6. TRAINING				**7.000 €**
Initial basic training course	Un	1	1.500	
Specific course for operators	Un	1	3.000	
Specific course for maintainers	Un	1	2.500	
BUDGET - CONVERSION TO LNG			**TOTAL**	**914.500 €**

18. ANNEX 5 -Risk analysis (Automotive Series 600)

As an orientation, the aspects to be considered in the risk analysis carried out for the project related to the pilot test of the automotive series 600 are exposed below.

a. Identification of legal requirements and other requirements (standards, norms) of application in the project.
b. HAZID risk identification study with the following criteria:
    i. Train risks
        1. Derailment
        2. Collision
        3. Gas leakage due to broken pipes while the train is running
        4. Gas leakage due to broken pipes with the train stopped in a semi-confined place
        5. Combustion gases at a higher temperature than in the diesel system
        6. Fire in the engine
    ii. External risks
        1. External fire
        2. Domino effect
    iii. Natural/environmental risks
        1. High temperature atmosphere
        2. Extreme wind
        3. Flood
        4. Iron
        5. Electric storm
        6. Subsidence
    iv. Maintenance risks
        1. SIMOPS (simultaneous operations)
    v. Risks in refuelling operations
        1. Sources of ignition
        2. External personnel presence within the security perimeter
    vi. Health risks
        1. Surfaces at extreme temperatures
        2. Projection of fragments
        3. Noise
c. Operating procedures of the unit: start-up, maintenance of the unit, loading and emptying, shutdown in normal and emergency conditions.
d. Functional analysis of HAZOP

i. Nodes considered
    1. LNG power system
    2. The models of HLNG 100 catalogue will be used as the main deposit and the HLNG 72 as secondary. Both connected to each other.
    3. Filling operation of LNG tanks.

ii. Causes
    1. Human error. Manual valve closure for LNG or CNG consumption.
    2. Spurious closure of the solenoid valve downstream of the filter.
    3. Failure of pressure reducing valve opening completely.
    4. LNG blocked between valves.
    5. Engine stoppage
    6. Loss of heat exchange in the evaporator
    7. Filter fouling
    8. Tube break in evaporator
    9. Maintenance operation that requires purging
    10. Reduction valve lock in maximum opening position by freezing
    11. Refueling operation in hot tank or out of regular use (including first load)
    12. LNG tank has not been depressurized prior to filing operation
    13. Ice formation in the mouth of the LNG pistol due to poor expertise in the filling operation or lack of cleanliness
    14. The train is not connected to the ground station

e. Establish classification zones according to UNE-EN 60079-10
f. Establish the safety distances based on a quantitative risk analysis.
g. Establish an emergency action plan against the scenarios included in the risk analysis.
h. FMECA analysis with the following failure modes:
    i. Subframe breakage
    ii. Vehicle outside static gauge
    iii. Breakage of the subframe anchors to the structure of the vehicle
    iv. Breakage of rolling elements
    v. Load per axle above the limits
    vi. Vehicle out of dynamic gauge.
    vii. Impact on the dynamics
    viii. Untimely traction
    ix. Lack of traction upon request

x. Vehicle is not able to stop at the set distance
xi. Direct contacts to people
xii. Indirect contacts to people
xiii. Overload
xiv. Derivations
xv. Electromagnetic disturbances
xvi. Incorrect maintenance
xvii. Exploit
xviii. Operation below the expected performance
xix. Structural failure or vibration absorption
xx. Does not acoustically isolate
xxi. Does not insulate thermally
xxii. Obstruction
xxiii. Loss of mechanical rigidity or loosen
xxiv. Structural failure of pressure equipment
xxv. Gas leakage in inappropriate area
xxvi. Incorrect pressure at the engine input
xxvii. Leaks
xxviii. Incorrect evaporation
xxix. Mechanical failure in the motor crown
xxx. Batteries are not charged
xxxi. Lack of protection of ATEX boxes
xxxii. Lack of refrigeration
xxxiii. Breakage of the gas line

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20. List of Acronyms and Abbreviations

ADIF	Railway Infrastructure Administrator
AESF	Railway Security Government Agency
APS/AES	Commissioning Accreditation and Authorization
APT	Tarragona Port Authority
CE	"Conformité Européene"
CIAF	Railway Accident Investigation Commission
CNG	Compressed Natural Gas
CNMC	National Authority on Markets and Competition
CoG	Centre of gravity
DeBo	Designated body
DP	Differential Pressure
DTB	Digital Terminal Box
ECE	Economic Commission for Europe
ECU	Engine Control Unit
EDC	Engine Control Display
EMD	Electro-Motive Diesel
ETH	Technical Specification for Approval
ETI	Technical Specification for Interoperability
FPC	Fuel Pump Contactor
GCOV	Gas Cut-off Valve
GDP	Gross Domestic Product
GFCV	Gas Flow Control Valve
GIV	Gas Inlet Valve
IRR	Internal Rate of Return
ISO	International Organisation for Standardisation

KPI	Key Performance Indicator
LNG	Liquified Natural Gas
LSF	Rail Sector Act
NFPA	National Fire Protection Association
NG	Natural Gas
NoBo	Notified Body
NPV	Net Present Value
NSA	National Safety Authority
PID	Piping and Instrumentation Diagram/Drawing
PM	Particulate matter
PCP	Pre-Chamber Pressure
RFIG	General Interest Rail Network
SIS	Spark Ignition System
UIC	"Union Internationale des Chemins de Fer"
VTS	Valve Temperature Status