Sustainable Railways - VALE case

Edilson Jun Kina

Vale employees in Minas Gerais
Renato Stockler das Neves Filho / Agência Vale

We are Vale

- A global mining company headquartered in Brazil
- The global leader in iron ore and pellet production and the second largest nickel producer
- We also produce manganese, ferroalloys, coal, copper, cobalt, fertilizers and platinum group metals
- We invest in logistics and energy


Carajás Mine in Pará
Salviano Machado / Agência Va

1942

Created by an executive order on June 1, 1942, the company's operations were initially concentrated in Minas Gerais.

In its first year, it produced 40,000 metric tons of iron ore, the same amount it now ships out every hour.

40,000 tons

Vitória-Minas Railway in Minas Gerais
Eugênio Sávio / Agência Vale

Logistics

Vale invests more in logistics in Brazil than any other company. To ensure fast, safe transportation of our minerals, we have an integrated logistics network encompassing mines, railways, ships and ports. We have our own infrastructure, we transport cargo for third parties and we run two passenger train services in Brazil.

Strategic vision
Sustainable development

Sustainability is one of Vale's strategic pillars, based on the concept that there can only be sustainable development when companies and society work together, sharing the value generated with their stakeholders.

Railroads

Brazil - Numbers

- ~ 10.000 km of track
- ~ 20 million sleepers
- ~ 20.000 km of rail
- ~ 1500 bridges and tunnels
- 586 locomotives + 635 (VLI)
- 35.168 Wagons + 12.257 (VLI)
- 3 Shops + 11 (VLI)

Mozambique –Moatize Coal

Nacala (~938km)

~212km in construction

~78km Rebuilt

~48km Improvements

Carajás Railway - EFC

OPERATIONAL INFORMATION

- 892 km of total track length – 1.6m gauge
- 80 km/h maximum speed;
- Iron ore Trains
  - 330 wagons and 4 locomotives per train;
  - Gondola cars with 32.5 tons/axle maximum capacity;
  - Tippler unloading;
  - 4,400 HP Dash 9 / SD70 locomotives / 5,750 HP EVO.
- Long Term axle load target – 37.5 ton/axle

Vitoria Minas Railway - EFVM

OPERATIONAL INFORMATION

- 905 km of total track length – 1.0m gauge
- 65 km/h maximum speed;
- Iron ore Trains
  - 252 wagons and 3 locomotives per train;
  - Gondola cars with 27.5 tons/axle maximum capacity;
  - Tippler unloading;
  - 4,000 HP Dash 9 locomotives.

Cases

Natural Gas

Biodiesel

Composite Sleepers

Natural Gas

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PORT INJECTION KIT

TENDER CAR

DIESEL AND GAS CONSUMPTION ANALYSIS

Natural Gas - Introduction

Due to high diesel oil prices and a necessity to lower its pollutants emissions, Vale began searching for alternative fuel options, which gave birth to the Natural Gas Project in 2008.

Since the project began, **five locomotives were converted to diesel-gas operation, reaching up to 70% gas in the mixture.** There are also three liquefied natural gas (LNG) tender cars, designed to serve as fuel tanks for the locomotives.

Being the greenest of fossil fuels, natural gas allows not only the reduction of emissions, as well as costs reduction, but it is possible to maintain the **same power output from the engines of locomotives**, with only minor changes to its structure.

Dash9 1183 converted locomotive

Natural Gas - Introduction

2008 – Conversion of first locomotive with ECI Economizer kit (loco GE BB36 number 746)

2008 – Conversion of flatcar into LNG tender car prototype.

2009 – Conversion of second locomotive. ECI Retrofit kit on EMD DDM locomotive (road number 835)

2010 – Design and manufacture of two tender cars for EFVM railroad.

2010 – Conversion of first GE BB40 Locomotive, with electronic fuel injection with ECI Economizer kit (fumigation).

2011 – Conversion of two more GE BB40 locomotives with fumigation kits.

2011 – 2012: Monitored trips with fumigation kit – data acquisition.

2012 – Conversion of first GE BB40 locomotive with COMAP port-injection kit.

2013 – Conversion of second GE BB40 with port-injection kit.

2013 – Accelerated wear analysis of dual-fuel vs diesel operation.

2013 – 2015: Monitored trips with port-injection kit – data acquisition.

Natural Gas

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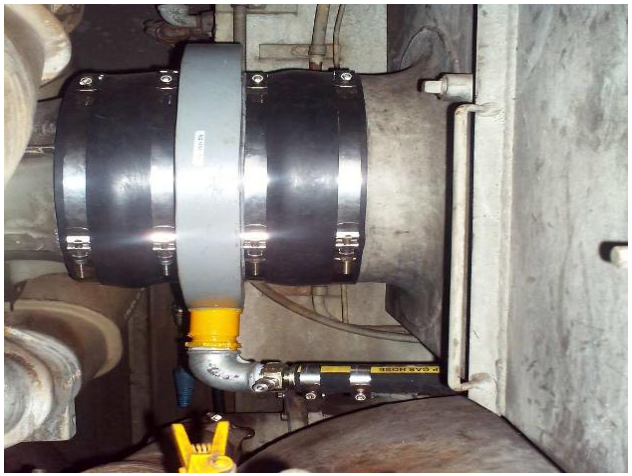
Natural Gas – Fumigation Kit

Conversion kit parts

The conversion kit is very simple, and its components can be summoned below:

- ECU (electronic control unit);
- Air, water and gas pipes;
- Temperature, pressure and knocking sensors;
- Pressure and flow regulator valves;
- Leakage sensors.

Natural Gas – Fumigation Kit



Gas diffuser

Knocking sensor

There is little need for intervention on diesel engines of locomotives. The main changes are:

- gas diffuser installed on the air intake pipe, before the cold wheel of the turbo compressor,
- knocking sensors installed on cylinders head,
- temperature sensors on intake and exhaust manifold and,
- pressure sensor on intake manifold.

Other interventions on locomotive are:

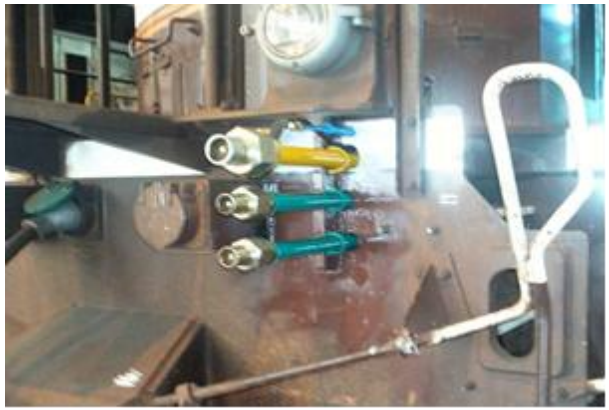
- Installation of ECU behind driver's seat,
- pressurized air pipe for tender car's opening and shutting down of valves,
- hot water supply for vaporization of liquid gas in tender car before it is sent to engine,
- cold water return pipe from tender car and,
- gas pipe for receiving gas from tender car.

Natural Gas – Fumigation Kit

ECU installed behind driver's seat

The injection amount of natural gas in the air intake pipe is controlled by the ECU, that takes into consideration many parameters, such as:

- Throttle notch position;
- Engine speed;
- Engine power output;
- Engine water temperature;
- Engine knocking;
- Intake manifold pressure;
- Intake manifold temperature (air+gas);
- Gas line supply pressure and temperature;
- Exhaust gas temperature (per bank).



Gas, water outlet and inlet

During pipes installation, it was a challenge finding places throughout the locomotive for water supply and return pipes that are necessary to circulate the engine coolant through the tender car heat exchanger.

The coolant heat is used in the tender car to transform LNG (liquefied natural gas) in NG (natural gas – gaseous state). Further two pipes/hoses are necessary to transfer the natural gas and compressed air between locomotive and tender car.

The injection of gas only begins when 650hp or higher power output is reached. This is so in order to prevent misfiring of diesel engine, which could occur in case of injection of gas during low notches of engine's operation.

Natural Gas

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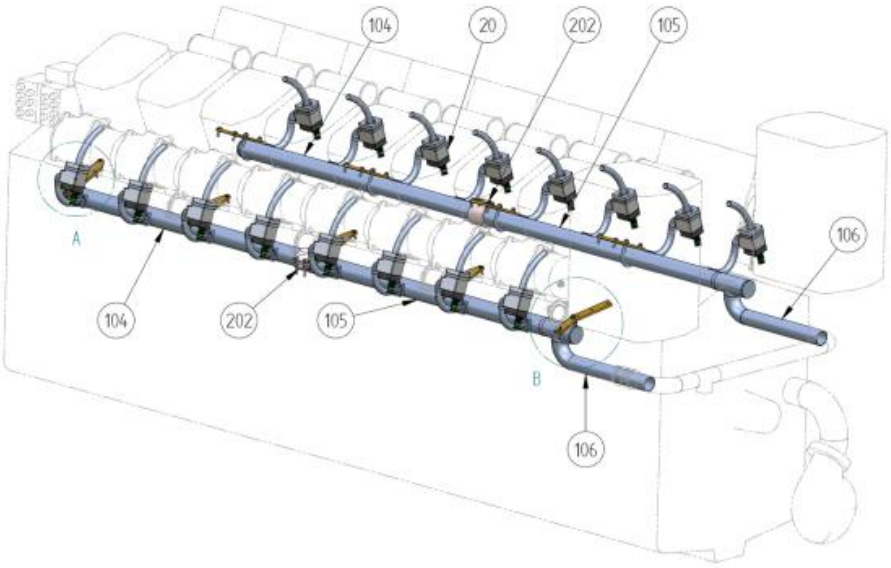
Natural Gas – Port Injection Kit

Port injection kits have one gas injector per cylinder. This provides more control over the timing and quantity of natural gas injected. Also eliminates the need of premixing the gas inside the air manifold.

There is an isolated cooling system in order to gasify the LNG prior to injecting it to the cylinders. This configuration allows to have both locomotives on the head of the train, ahead of the tender car.

The downside is that as there are much more components in the kit, maintenance is more complex and expensive.

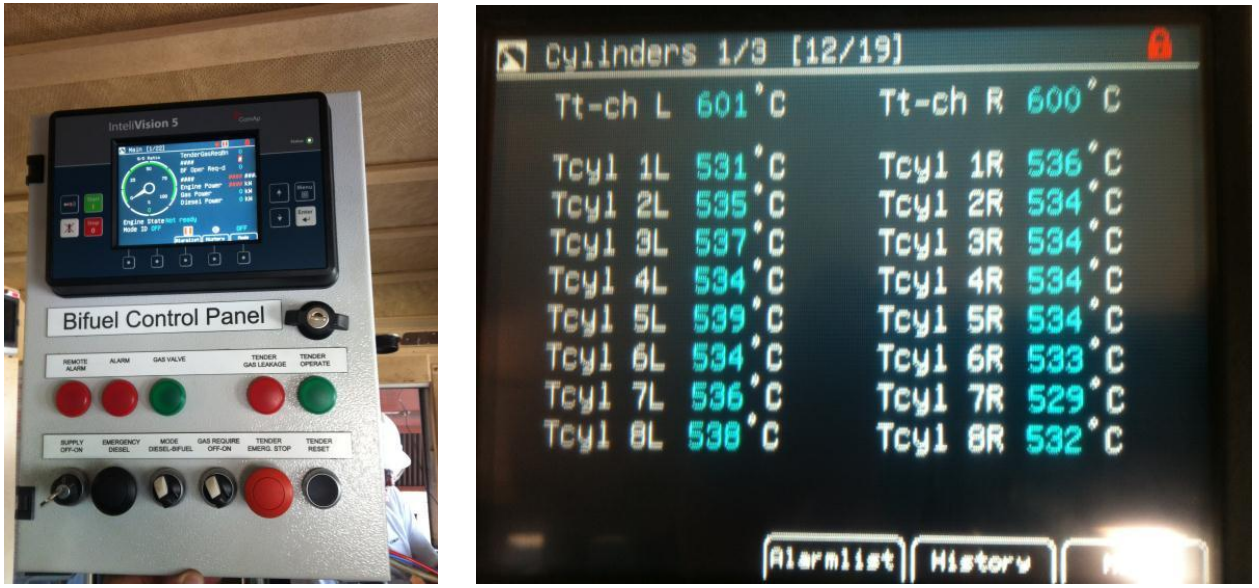


Scheme of gas injectors on engine (left) and picture (right)

Natural Gas – Port Injection Kit

Thermocouples installed on the engine provide feedback to the panel about the exhaust temperatures. There are also available through the panel:

- Water temperature and pressure,
- Gas temperature and pressure,
- Pre-turbo air temperature,
- Intake air pressure and temperature,
- Among others…

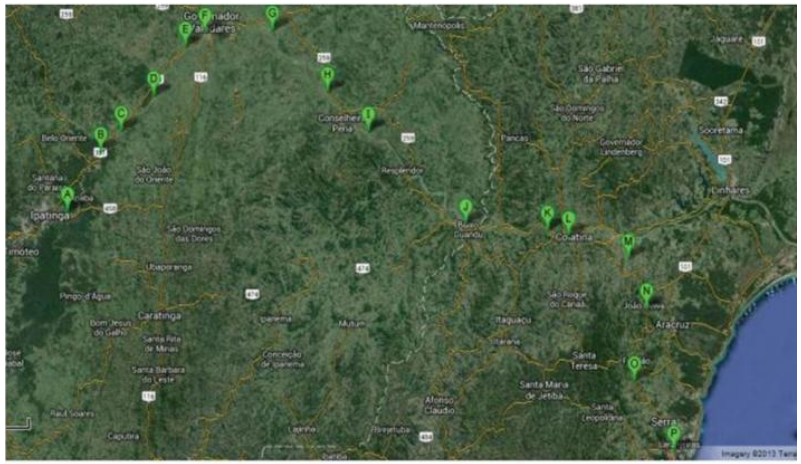


Dual-fuel system panel (left) and individual cylinders temperature (right)

Natural Gas – Port Injection Kit

Water reservoir (left) and piping of the cooling system (right)

NÚMERO	DATA	NÚMERO	DATA
1	20/06/13	15	30/09/13
2	04/07/13	16	02/10/13
3	19/07/13	17	05/10/13
4	29/07/13	18	09/10/13
5	29/08/13	19	11/10/13
6	31/08/13	20	14/10/13
7	02/09/13	21	16/10/13
8	04/09/13	22	19/10/13
9	06/09/13	23	21/10/13
10	13/09/13	24	24/10/13
11	15/09/13	25	01/11/13
12	22/09/13	26	03/11/13
13	26/09/13	27	05/11/13
14	28/09/13	28	08/11/13



Assisted gas train trips

Natural Gas

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DIESEL AND GAS CONSUMPTION ANALYSIS

Natural Gas – Tender Car

The tender cars are completely designed and manufactured to serve the special needs of Natural Gas Project.
These special tender cars are called TGE and have the **capacity to carry around 38.000 liters of LNG.**
It is interesting to note that the **LNG volume is approximately 580 times smaller than NG**, hence liquefying the gas.

TGE tender car

Natural Gas – Tender Car

TGE is a state-of-the-art car **designed for fuelling the dual-fuel locomotives**. The design includes a jumper cable through the car so the driver can command the rear locomotive. **The tare is much higher than a regular car in order to keep its stability during operation**, and the **brake commands are independent from the other wagons** – this reduces impact from asynchronies between the leader and lead locomotives.

The TGE's are designed to be able to **supply natural gas for two locomotives during a round trip from port to mine, and back to port** and are provided with a PLC and all safety features such as leakage detection, fire, pressure, temperature, volume and flow sensors.

In order to make operation of tender car as simple as possible for the driver**, all the commands that are available on locomotive cabin are: stop and restart supply of gas**.

Tender car fire sensor

Tender car panel inside locomotives cabin

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DIESEL AND GAS CONSUMPTION ANALYSIS

Natural Gas – Diesel and Gas Consuption

The economic feasibility study needs, amongst other parameters, the correlation between diesel saved and natural gas used to replace it. Two parameters were adopted to compare them. **The first is called replacement index and shows the diesel saved percentually**. It is obtained dividing the diesel consumption when running the mixture of diesel+gas by the diesel consumption when using only diesel, and the formula is shown on equation (1):

Replacement index formula

$$replacement\_index(\%) = \frac{Diesel\_consumption\_diesel + gas(L)}{Diesel\_consumption\_diesel\_only(L)} * 100$$

The other parameter used is called diesel-gas correlation. It intends to show **how many normalized cubic meters of natural gas are used to replace each liter of diesel saved**. It is obtained dividing the amount of natural gas (Nm^3) by the diesel amount saved (L). The diesel-gas correlation equation (2) is shown below:

Diesel-gas correlation formula

$$diesel - gas\_correlation = \frac{Natural\_gas\_consumption(Nm^3)}{Diesel\_saved(L)}$$

The parameters are obtained from each notch, and based on the railway duty cycle, the final value is calculated.

Biodiesel

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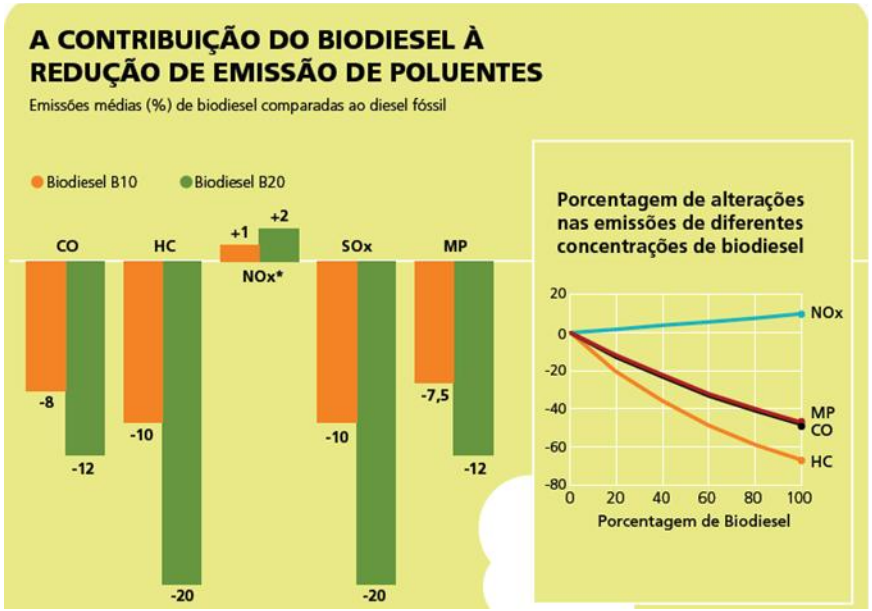
Biodiesel - Introduction

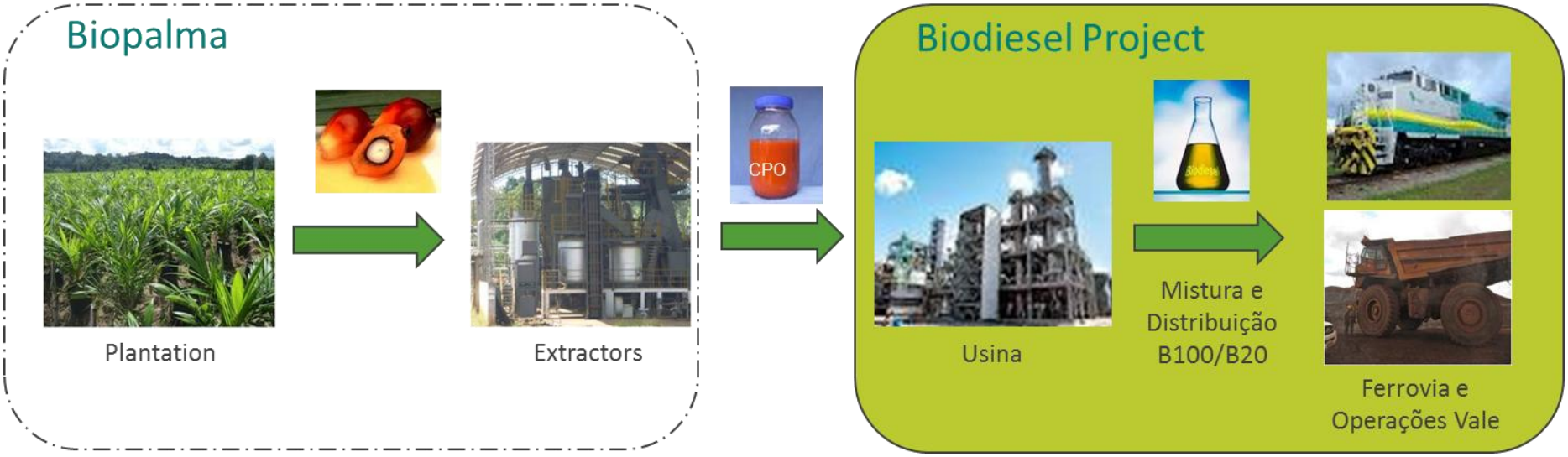
The project's goal is to allow the use of B20 (20% biodiesel in the mix of diesel) in the North Valley system operations in order **to ensure sustainability of its operations by reducing emissions of greenhouse gases** (GHG *) and **promoting the development of the region where it operates**.

- Currently, under Brazilian law, biodiesel is mixed with diesel at a ratio of 7% (B7);
- Vale is a major consumer of diesel, representing approximately 3% of total Brazilian consumption.



Biodiesel is a substance free of sulfur, which mixed with traditional diesel fuel, reduces carbon dioxide, carbon monoxide and particulates associated with traditional fossil fuels, which are pollutants

Biodiesel - Introduction



- Potencial of generating more than 6,000 direct jobs in the region, considering agricultural and industrial operation;
- Generation of foreign exchange and taxes to the municipality and the state. Local market strengthening;
- GHG emission reduction: it is estimated a potential reduction of approximately 10 MM tons CO2 equivalent (*) in 25 years, by replacing the B5 diesel for B20 in locomotives and heavy equipment of Vale's operations. In addition to the CO2 uptake by the palm plantation.

Biodiesel

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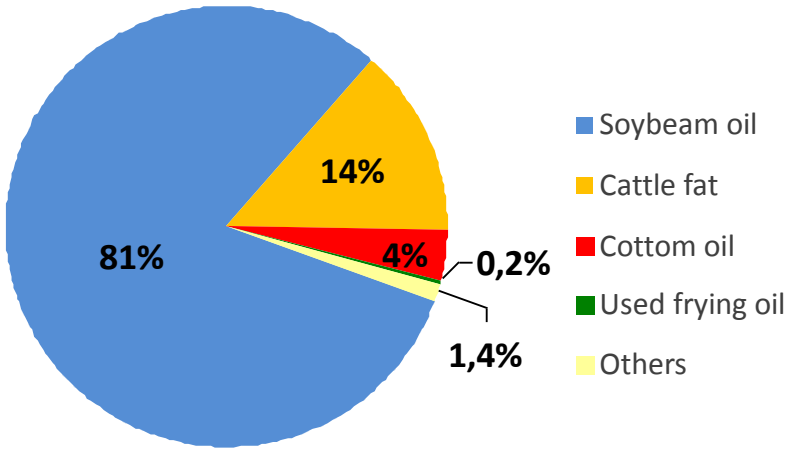
Biodiesel - Palm

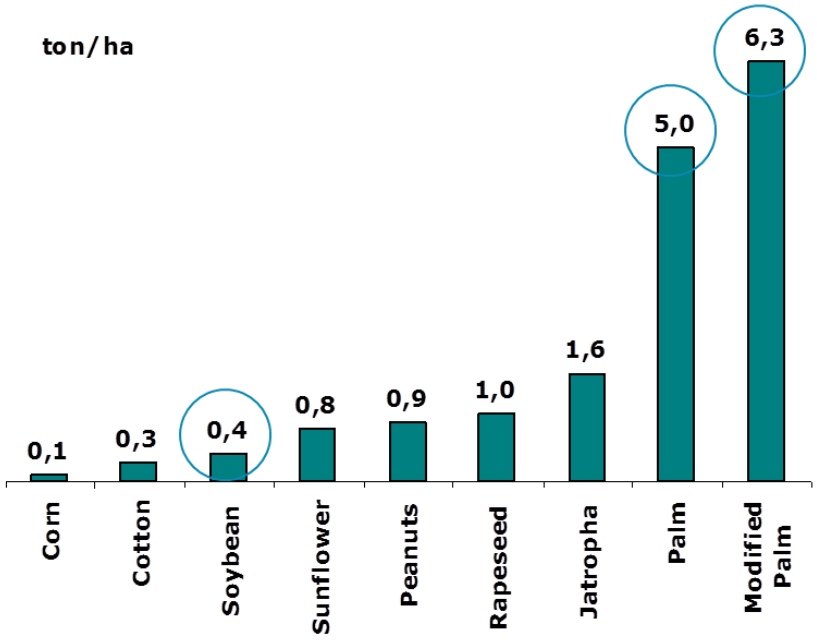
Biodiesel - Palm

Palm oil is a much more competitive source than soy for biodiesel production

- Soybeans are the main raw material of the national biodiesel, and much of their production is not vertical.



- Palm Productivity is 10X larger than the soybean.

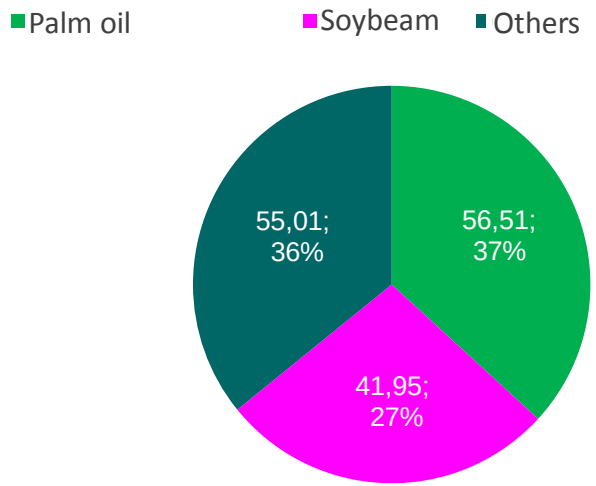


Biodiesel - Palm

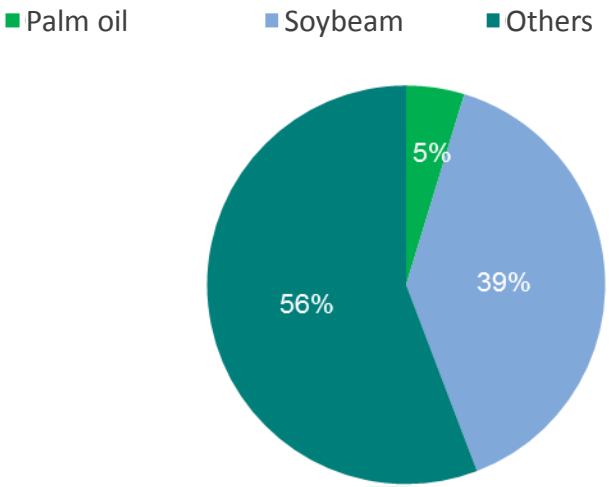
Palm oil production is much less intensive in natural resources (land) and more intensive hand labor than other oils.

- Palm oil production is much less intensive in natural resources (land) and more intensive hand labor than other oils;
- Brazil, despite having the world's largest area with agricultural potential for the cultivation of palm oil is importing this product, producing only 250 thousand tons year on a total planted area of approximately 100 hectares, less than 0.5% of world production.

Word Production of Major Vegetable Oils - Million Tonnes in 2012



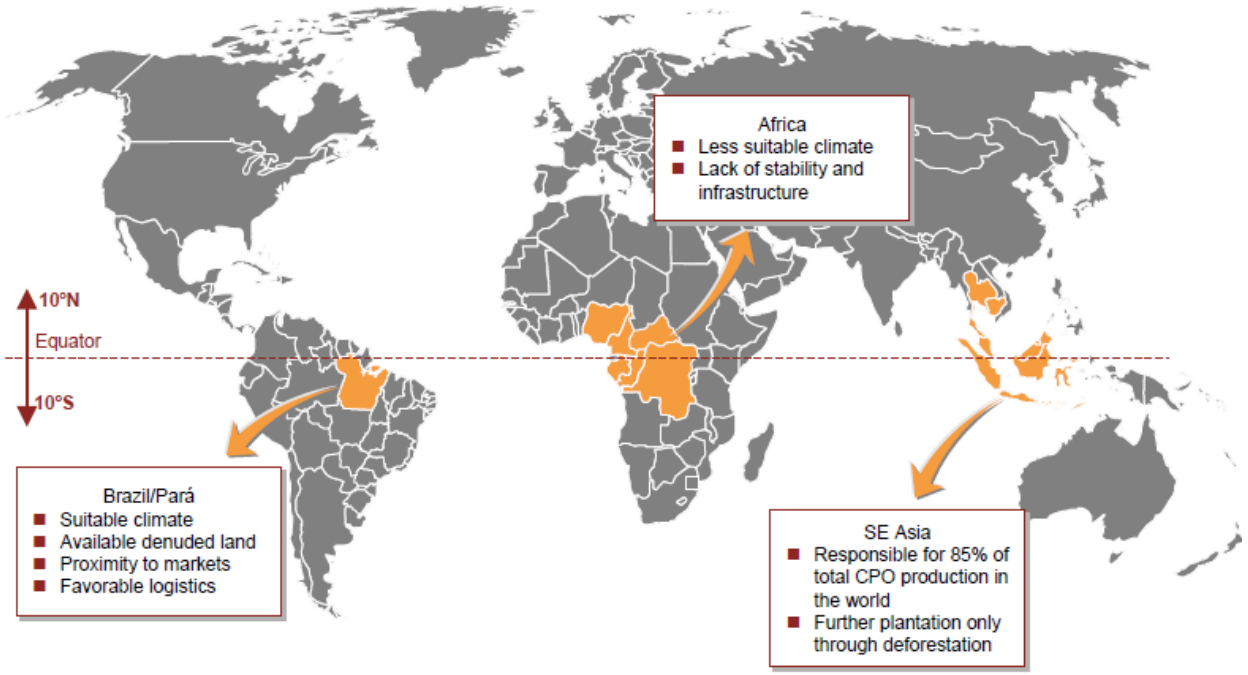
Cultivation Area of Major Vegetable Oils - Million Hectares in 2012



Biodiesel - Palm

Pará has ideal conditions for palm planting

- Availability 5 million ha of degraded land for planting in good condition;
- Suitable climatic conditions;
- Life of the agricultural base of about 30 years;
- Permanent crop yields throughout the year.



PAÍS	PRODUÇÃO (MIL TPA)
Angola	58
Brasil	110
Camarões	165
Colômbia	830
Congo	175
Costa do Marfim	320
Costa Rica	285
Equador	340
Filipinas	70
Gana	120
Guatemala	155
Guiné	50
Honduras	165
Índia	50
Indonésia	19.700
Malásia	17.400
Nigéria	820
Papua-Nova Guiné	425
Tailândia	1.400
Venezuela	54

Fonte: Bloomberg 2008

Biodiesel

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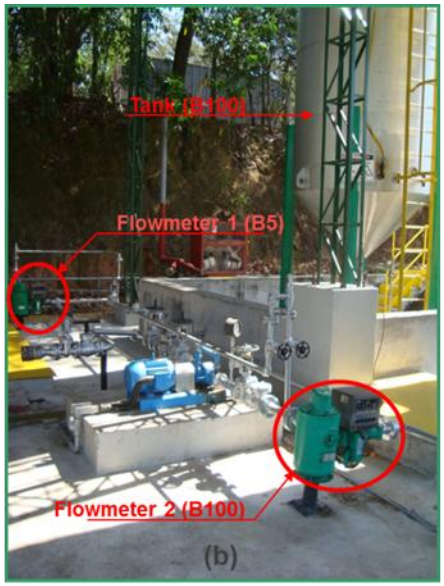
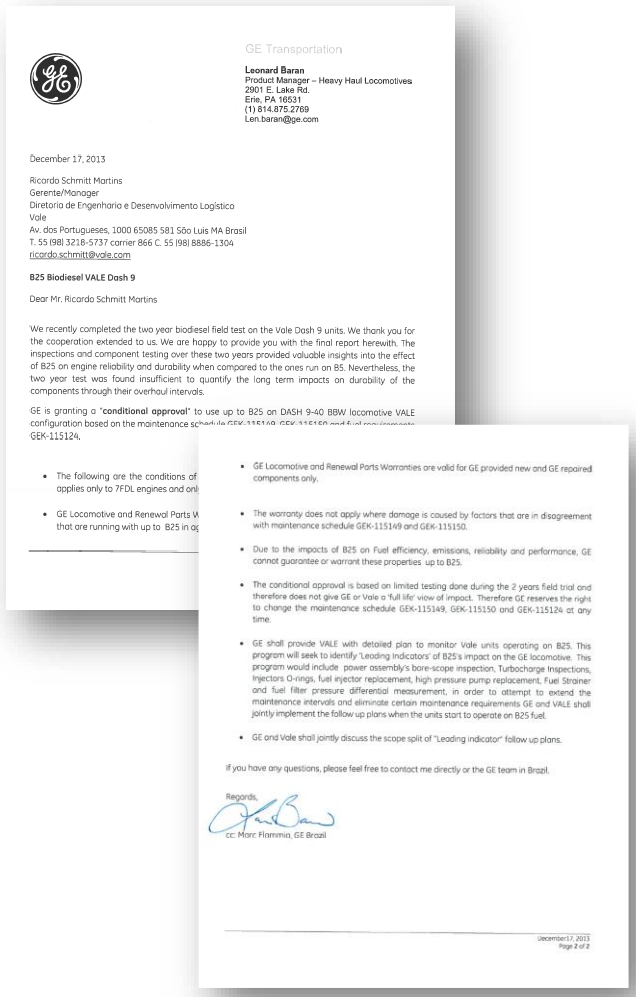
Biodiesel - Tests

Concept	Development	Sustainability
5 locomotives running with B25 (1267, 1268, 1269, 1271, 1272) 2 Reference locomotives running with B5 (1273, 1274)	2 years running with B25. Physical chemistry analysis of lube oil. Wear analysis of parts.	Biodiesel reduce the emissions on atmosphere. Renewed fuel.

Biodiesel - Tests



Biodiesel - Tests



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December 17, 2013

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B25 Biodiesel VALE Dash 9

Dear Mr. Ricardo Schmitt Martins

We recently completed the two year biodiesel field test on the Vale Dash 9 units. We thank you for the cooperation extended to us. We are happy to provide you with the final report herewith. The inspections and component testing over these two years provided valuable insights into the effect of B25 on engine reliability and durability when compared to the ones run on B5. Nevertheless, the two year test was found insufficient to quantify the long term impacts on durability of the components through their overhaul intervals.

GE is granting a "**conditional approval**" to use up to B25 on DASH 9-40 BBW locomotive VALE configuration based on the maintenance schedule GEK-115149, GEK-115150 and fuel requirements GEK-115124.

- The following are the conditions of
  applies only to 7FDL engines and onl
- GE Locomotive and Renewal Parts W
  that are running with up to B25 in a

- GE Locomotive and Renewal Parts Warranties are valid for GE provided new and GE repaired components only.
- The warranty does not apply where damage is caused by factors that are in disagreement with maintenance schedule GEK-115149 and GEK-115150.
- Due to the impacts of B25 on Fuel efficiency, emissions, reliability and performance, GE cannot guarantee or warrant these properties up to B25.
- The conditional approval is based on limited testing done during the 2 years field trial and therefore does not give GE or Vale a 'full life' view of impact. Therefore GE reserves the right to change the maintenance schedule GEK-115149, GEK-115150 and GEK-115124 at any time.
- GE shall provide VALE with detailed plan to monitor Vale units operating on B25. This program will seek to identify 'Leading Indicators' of B25's impact on the GE locomotive. This program would include power assembly's bore-scope inspection, Turbocharge Inspections, Injectors O-rings, fuel injector replacement, high pressure pump replacement, Fuel Strainer and fuel filter pressure differential measurement, in order to attempt to extend the maintenance intervals and eliminate certain maintenance requirements GE and VALE shall jointly implement the follow up plans when the units start to operate on B25 fuel.
- GE and Vale shall jointly discuss the scope split of "Leading indicator" follow up plans.

If you have any questions, please feel free to contact me directly or the GE team in Brazil.

Regards,

cc: Marc Fiammia, GE Brazil

December17, 2013
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GE is granting a "**conditional approval**" to use up to B25 on DASH 9-40 BBW locomotive VALE configuration based on the maintenance schedule GEK-115149, GEK-115150 and fuel requirements GEK-115124.

- Monitoring plan of the cylinder liners ;
- Reduce the turbocharger overhaul interval from 26.000 MWh to 18.000 MWh;
- The fuel injectors replacement (PN 41C640857P2) should be performed every 6 months;
- Fuel pumps shall be replaced every 12 months;
- Fuel filters may be replaced at 45 days intervals when using B25;
- Replace fuel transfer pump every 3 years;
- Engine oil drain period of 92 days;
- Oil filters shall be replaced at 92 days intervals and Generation 4 Long Life engine oil are to be used.
- The current fuel Injector O-ring deteriorated in service when using B25.
- It is recommended to replace the LP Fuel Hoses every 2 years.

Composite Sleepers

Sleepers Application - EFVM		
Year	Wood Sleepers (units)	Steel Sleepers (units)
2011	-	140,605
2012	43,401	150,460
2013	39,493	114,261
2014	49,943	144,778

- Wood sleepers that are taken from service are re-used in rail yards, given to landscaping projects and recycled into charcoal;
- Since 1986, EFVM uses only steel sleepers in the main line, but still uses wood sleepers on tunnels, bridges, viaducts, switches and circuits;

Year	Wood Sleepers Aquisition (units)
2011	33.520
2012	25.600
2013	11.678
2014	41.976

Composite Sleepers - Tests

Thank You!

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