The MIRAI

Life Cycle Assessment Report

for communication

TÜVRheinland CERTIFIED
Comparative Life Cycle Assessment
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Contents

List of abbreviations

ADP	Abiotic depletion potential
AP	Acidification potential
BOM	Bill of materials
CEP	Clean Energy Partnership
CFRP	Carbon fiber reinforced plastic
CML	Centrum voor Mileukunde Leiden (Centre for Environmental Sciences, Netherlands)
COD	Chemical Oxygen Demand
CO_2	Carbon dioxide
e, eq	Equivalent
EP	Eutrophication potential
FCV	Fuel cell vehicles
GaBi	Ganzheitliche Bilanzierung, by Thinkstep
GV	Gasoline vehicles
GWP	Global warming potential
HC	Hydrocarbons
HV	Hybrid vehicles
JAMA	Japan Automobile Manufacturers Association, Inc.
JLCA	The Life Cycle Assessment Society of Japan
JRC	European Commission Joint Research Centre
kg	Kilogram
kW	Kilowatt
LCA	Life Cycle Assessment
LIME2	Life-cycle Impact assessment Method based on Endpoint modelling
Mizuho	Mizuho Information & Research Institute
NEDC	New European Driving Cycle
NEDO	New Energy and Industrial Technology Development Organization
NMVOC	Non-methane volatile organic compounds
NOx	Nitrogen oxides
POCP	Photochemical ozone creation potential
PO_4^{3-}	Phosphate
ppm	Parts per million
SOx	Sulphur oxides
t	tonnes
TN	Total nitrogenous matter
TP	Total phosphorous matter

Report on LCA of MIRAI

1. Goal of the Study

Background

There are multiple kinds of powertrains which show outstanding environmental performance in reduction of emissions and pollutants during use phase of vehicles. However assessment of the environmental performance should consider all impacts throughout life cycle of a vehicle from cradle to grave. On release of the world first volume production fuel cell vehicle the “MIRAI”, TOYOTA conduct life cycle assessment (hereinafter referred to as “LCA”) over the comparable gasoline and gasoline hybrid vehicles as reference models.

Objectives

We have been conducting LCA for all our passenger vehicles and components from 1997, and observed all of them achieve better environmental performance than their predecessors. The summary of the results have been transparently displayed in each brochure to potential customers and to the public.

Now we release the results of the “MIRAI”, compared with the relevant reference models, GV and GV hybrid. This time, the assessment procedures are substantially focused on its unique conditions in its powertrain the “Fuel Cell” and the energy source “Hydrogen”. We consider the impacts of sources of the hydrogen used to propel the “MIRAI” as well as the fuel cell components’ efficiency, its constitution of materials and production processes. (Environmental gains of fuel cell vehicles, whose energy source is hydrogen, depend on how the hydrogen is produced and transported and how effectively it is converted. We are considering the multiple options of hydrogen sources from fossil fuels to renewable energy, transportation methods, on-site or off-site.)

Target audience

The results will be used to communicate externally not only with customers but also with hydrogen suppliers and governmental organizations of each region. Simultaneously, we internally feedback analysed results, such as what material or process has big impact on total vehicle life to our development divisions to help improve future models.

2. Function

The function is defined as the transportation of passengers for a lifetime distance of the vehicles.

Referenced vehicles compared with MIRAI are gasoline vehicle and hybrid vehicle, which are also premium saloons.

Table1: Technical data

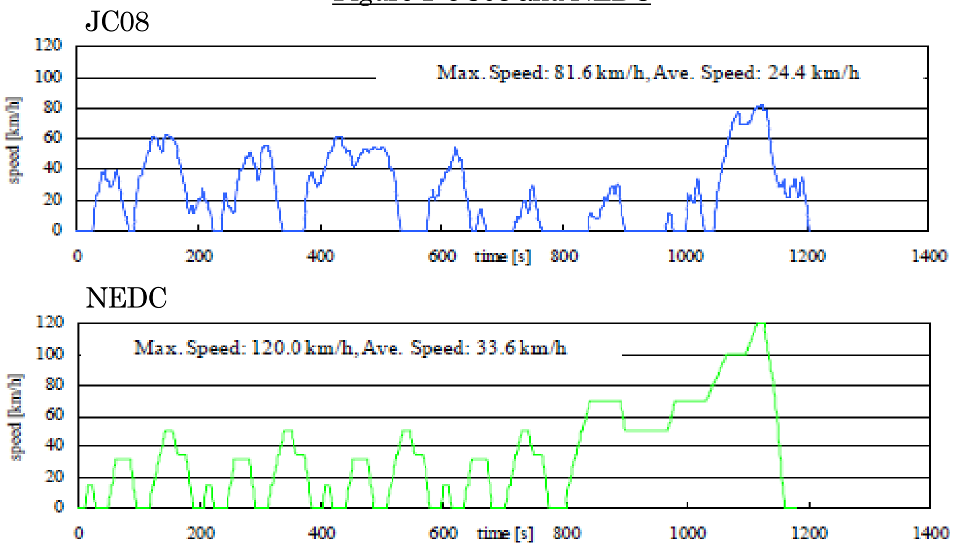
	GV	HV	MIRAI
Fuel	Gasoline	Gasoline	Hydrogen
Engine capacity (cm3)	2499	2493	-
Engine max output (kW)	149 kW	131 kW	-
Engine max torque (Nm)	243 Nm	221 Nm	-
Electric Motor max output	-	105 kW	113 kW
Electric motor max torque (Nm)	-	300 Nm	335 Nm
Fuel cell max output	-	-	114kW
Transmission	6AT	eCVT	-
Vehicle mass	1540 kg	1630 kg	1850 kg
Vehicle dimensions Outer(mm)	4895x1800x1460		4890x1815x1535
Fuel economy (Japan) In USE phase (JC08)	11.4 km/L	23.2 km/L	*2
Fuel economy (EU) In USE phase (NEDC)*1	8.5 L/100km	4.3 L/100km	0.76 kg-H2/100km

*1 CO2 emissions in NEDC were calculated from JC08 homologated value, according to the coefficient of same class vehicles.

*2 Full tank 4.6kg with 700km distance at latest station (Toyota in house data according to JC08).

The assessment was conducted with the vehicle weight inclusive driver (68kg) and luggage (7kg) as well as with fuel tank 90% full, determined in accordance with Directive 92/21/EEC as amended (04/2009). Transported distance is assuming 2 patterns. For Japan, 100,000 km in the new Japanese driving cycle (JC08) and for Europe, 150,000 km in the new European Driving Cycle (NEDC) both in 10 years life time with 10 years maintenance and required parts.

Figure 1: JC08 and NEDC

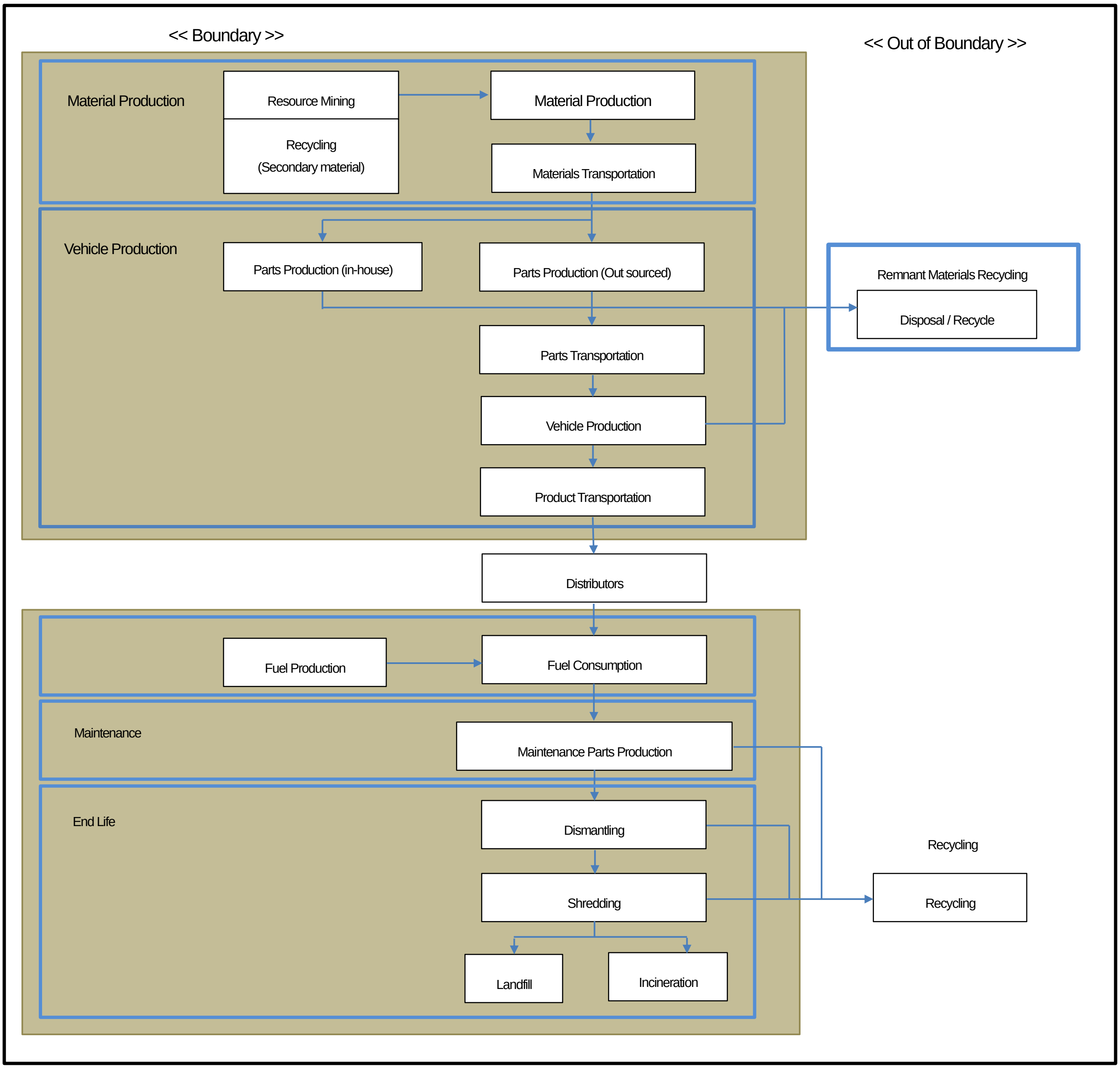


3. Scope of assessment

We define the scope of the assessment to include all energy, materials, substances and processes as far as we can consider. To include new models, materials and parts suppliers' as well as our in-house divisions' cooperation is necessary. For fuel cell powertrain, in-house development divisions and manufacturing divisions provided with necessary data to assess all life cycle phases for all new parts.

Diagram 1 shows a schematic diagram of the scope.

Diagram 1: Scope of the assessment



4. Life cycle inventory analysis

General description of the inventory analysis

- the Toyota LCA System
- Input: Relevant resources
- Out put: 5 substances (CO_2, NOx, SOx, PM, NMHC)
- 5 phases (Material, Production, Use, Maintenance, End life)

The basic unit data and the calculation formula were prepared as follows.

(1) Materials production

The basic units are focused on the JLCA database as this is the Japan production case. Over 60 types of basic unit were prepared and when required, by supplementing the data through literature searches, etc. Each basic unit took into account the upstream process back to the mining of raw materials. The impact of material recycling was also included within the material production stage.

<Inventory calculation formulae>

Materials production = (mass of materials per vehicle / manufacturing process yield rate) × materials production basic unit+ modelled transportation distance ×mass / (load × ratio) × (modelled emissions (land/oversea) per transported distance)

(2) Vehicle production

1) In-house parts

The yearly updated data (April 2013 to March 2014) were used to generate the manufacturing basic units. The factory data were managed on a per-process basis and normalized using the mass of parts produced by the relevant process.

<Inventory calculation formulae>

In-house manufacturing basic unit (g/kg) = Energy consumption per process ÷ Mass of parts processed in the respective process ×Energy combustion basic unit)

2) Outsourced parts

The data obtained from the suppliers' factories for FY2013 were used to calculate the manufacturing basic units per unit weight of parts produced. The factory data used were the aggregated annual usage data from the department that produced the particular part, normalized by product weight (the basic units for parts manufactured in-house were obtained on the basis of each manufacturing process, as opposed to the basic units for externally produced parts, which were obtained on the basis of sets of manufactured parts). Upstream suppliers were also included in the survey data. It was also assumed that it is acceptable to use basic units based on Japanese supplier data.

<Inventory calculation formulae>

External manufacturing basic unit (emissions/kg)

= Energy consumption at corresponding parts factory ÷ Parts mass ×Energy combustion basic unit

3) Transportation basic unit (parts/vehicles): basic units for transportation by 10 tonne truck/5-vehicle carrier car and sea freight (international shipping) were obtained from the JLCA database.

(3) Use (Fuel production)

1) Fuel production secondary data source:

(Gasoline)

Japan: other than NMHC: JLCA

NMHC: GaBi4

Europe: GaBi4

(Hydrogen)

Japan: Mizuho

Europe: CO2: European Commission Joint Research Centre

Other than CO2: Mizuho

Table 2: Hydrogen production pathways

120MJ/kg-H2

Region	H2 path	CO2 (g/MJ)	NOx (g/MJ)	SOx (g/MJ)	PM (g/MJ)	HC (g/MJ)	Sources
Japan	Caustic soda byproduct	※					Mizuho Information & Research Institute (Not disclosed)
Europe	NG (Natural gas): Piped natural gas from North Sea/Russia (4,000km) central reforming	99.86	※				CO2:European Commission Joint Research Centre(JRC) http://iet.jrc.ec.europa.eu/about-jec/sites/about-jec/. WELL-TO-TANK Report Version 4.0 others:Mizuho Information & Research Institute(Not disclosed)
	RE (Renewable): Electrolysis with wind powered renewable energy	12.10					CO2:European Commission Joint Research Centre(JRC) http://iet.jrc.ec.europa.eu/about-jec/sites/about-jec/. WELL-TO-TANK Report Version 4.0 others:Mizuho Information & Research Institute(Not disclosed)

Japan:

The hydrogen as byproduct of caustic soda which is filled when the customers receive the vehicle is used for this study. ※The environmental intensity of this case is not available therefore, Mizuho and TOYOTA implemented joint research but the results are not disclosed at this moment.

Europe:

The hydrogen pathways in the first launch countries; the UK, Germany and Denmark are used for this study.
One is central reforming from natural gas piped from North Sea and from Russia and the other the electrolysis using renewable energy from wind power. For CO2 emissions of both pathways, European Commission Joint Research Centre database are originated. Other emissions originate from equivalent pathways of Mizuho research results.

(For reference) - Actual conditions and policy per country

UK: Pathways: Max case is 100% Piped natural gas from North Sea, central reforming

Policy: NA

Denmark: Pathways: 100% Electrolysis with wind powered renewable energy

Policy: Regulation, 100% renewable, certificates of green power are mandatory

Germany: Pathways: 50% Piped natural gas from North Sea or from Russia, central reforming

50% Electrolysis with wind powered renewable energy

Policy: Clean Energy Partnership policy (50% or more renewable)

http://cleanenergypartnership.de/

(4) Use (Driving)

The analysis was performed both for Japan case and Europe case.

<Inventory calculation formulae>

- Use (Driving) in CO_2= Emissions of fuel consumption values per vehicle x distance travelled in life time
- Use (Driving) in other emissions=Regulatory emission values x distance travelled in life time

1) CO2 emissions (gasoline/hydrogen) while driving:

Japan: The homologated value in Japan cycle (JC08)

Europe: MIRAI: The homologated European fuel consumption values (NEDC)

GV, HV: Converted value from JC08 to NEDC

2) NOx, PM, NMHC emissions while driving:

Japan: The regulatory values in Japan with 75% reduction

Europe: European regulatory values (EURO6).

Table 3: Emissions during the Use phase

	UNIT	GV	HV	MIRAI	Driving cycle /Regulation
CO2	g/km	204	100	0	JC08
NOx	g/km	0.013	0.013	0	JAPAN 75% reduction
PM	g/km	0.005	0.005	0	–
NMHC	g/km	0.013	0.013	0	JAPAN 75% reduction

	UNIT	GV	HV	MIRAI	Driving cycle /Regulation
CO2	g/km	196	101	0	NEDC
NOx	g/km	0.06	0.06	0	EURO6
PM	g/km	0.0045	0.0045	0	EURO6
NMHC	g/km	0.068	0.068	0	EURO6

(5) Maintenance

Three parts were identified as requiring servicing (replacement) during the usage stage as they cover 80% of CO2 emissions of that of all parts to be replaced in 10 years of a vehicle lifetime according to the study of the Japan Automobile Manufacturers Association on 31 March, 2011. The parts and their maintenance intervals are shown in Table 5.

Table 3: Maintenance part requirements

Part name	Maintenance intervals
Lead battery	Every 2 year
Tyre	Every 33,000km
Engine oil (only for GV, HV)	Every 10,000km

<Inventory calculation formula>

Maintenance = Product mass ×basic unit per process× times serviced in life time

Conditions for the recycling process were set, presupposing the fulfilment of the 2015 target rates for the European Directive on ELVs: 85% reuse and recycling, 95% recovery.

(6) End life

The basic units for the disposal were calculated from the JLCA database and values from NEDO literature, which is adopted both for Japanese case and for European case.

The following processes are involved in recycling and disposing of a vehicle:
The transportation of the vehicle, collection and destruction of freon, dismantling (removal of engine/fuel cell stack & tyres, airbags, etc), shredding, thermal energy recovery, incineration and landfill.
The calculation was performed by taking the basic units of the above processes and multiplying by the mass. For this assessment, it was assumed that the distance the vehicle must be carried is 100 km.

<Inventory calculation formulae>
End life = Vehicle transportation + Freon treatment + Dismantling + Shredding+ Thermal energy recovery + Incineration + Landfill

5. Inventory analysis results

Results from the inventory assessment for each stage of the life cycle are shown in Figure 2, 3.

For European condition, 2 patterns of hydrogen production cases are observed to range according to the best case and the worst case of current available production pathways.

Figure 2: Inventory results (Japan)

MIRAI Hydrogen=by product caustic soda

(GV= 1000)※1 (NMHC GV = 1)※2

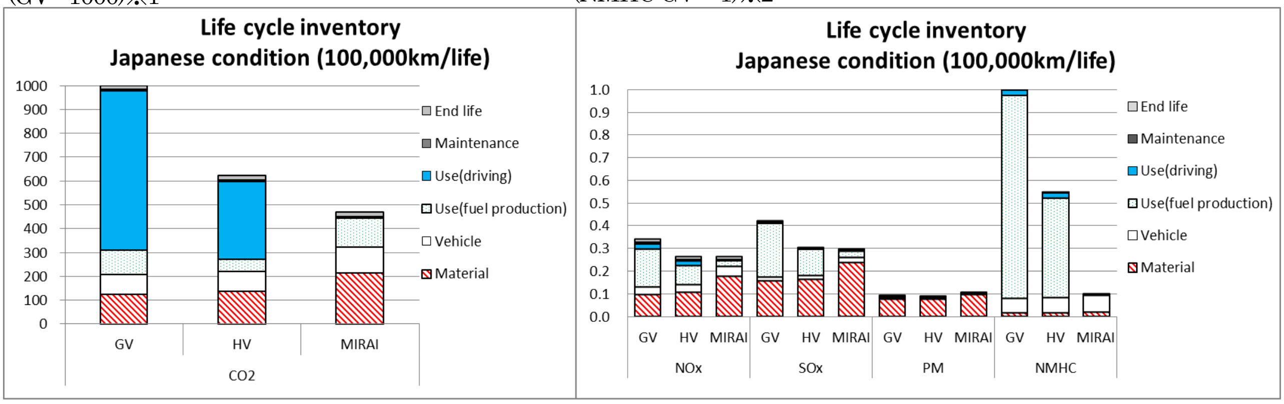
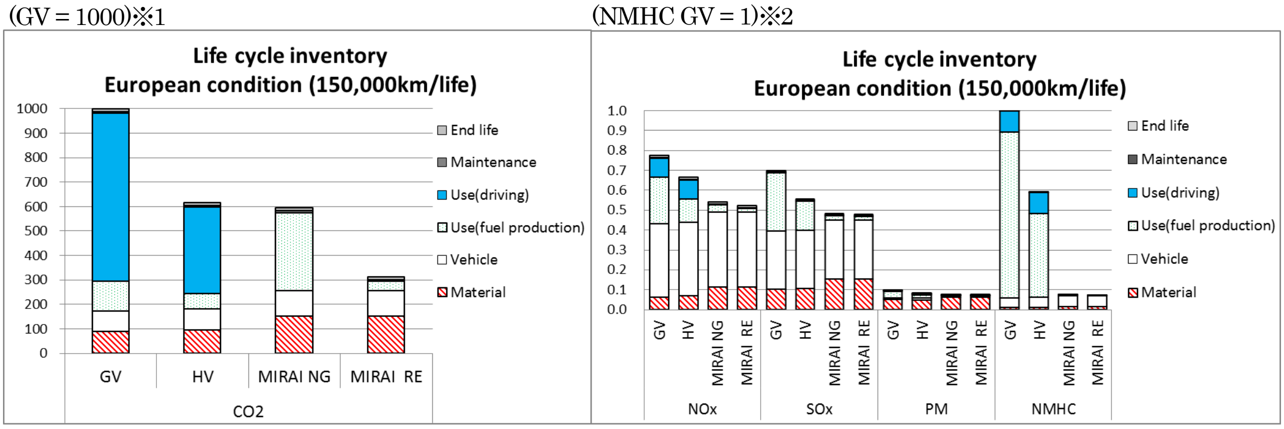


Figure 3: Inventory results (Europe)

MIRAI Hydrogen= NG: Piped Natural gas central RE: Renewable, Electrolysis from wind

(GV = 1000)※1 (NMHC GV = 1)※2



※1 CO2 is emitted by the ton and the others by the kg therefore,CO2 is expressed by the thousand in this case.

※2 The maximum value out of the emissions(NOx, SOx, PM, NMHC) is set to be 1.0 as the baseline for comparison.

There are multiple sources of hydrogen production pathways. In case of Japan, a hydrogen pathway of by-product caustic soda is chosen with which the MIRAI is filled when it is released in Japan, where the MIRAI shows better or equivalent results comparing to HV in each inventory. For Europe, there was uncertainty in actual hydrogen pathways but we refer to all current available hydrogen stations and their pathways in the UK, in Germany and in Denmark where the MIRAI will be released; both piped natural gas central reforming, and renewable, electrolysis from wind power show preferable results with the MIRAI.

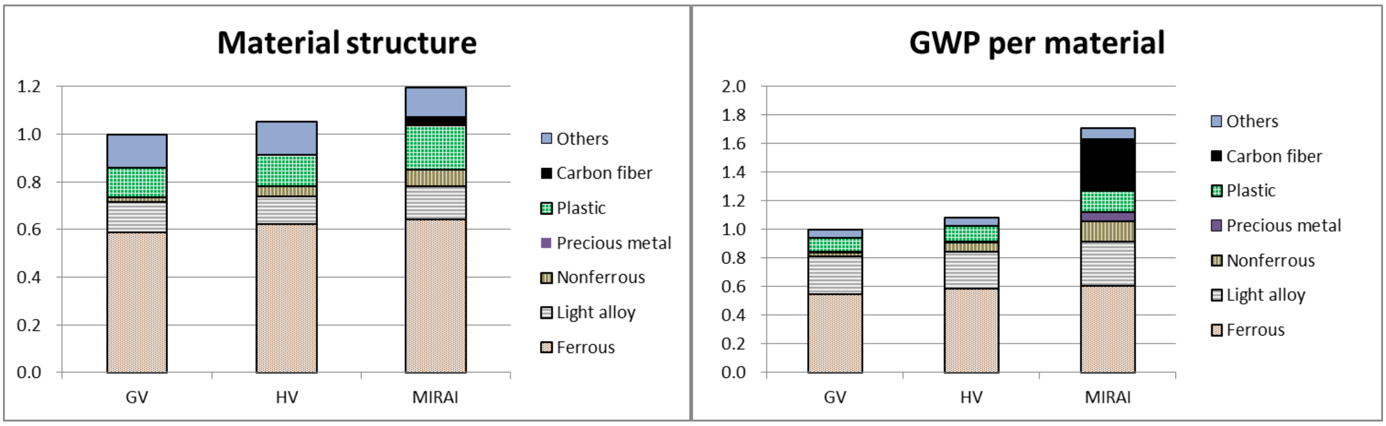
Not as much as being affected compared to the Use phase, but material constitution of powertrain is different between the MIRAI and conventional gasoline or gasoline hybrid vehicles.

Figure 4 shows the materials that go into making a single vehicle. Noteworthy characteristics of the make-up of the MIRAI are that it includes carbon fiber and precious metal (Platinum, etc). Carbon fiber is used as CFRP with a mixture of plastic and is mainly used for fuel tank for hydrogen. Those unique materials have big impact in respect of GWP and other impact categories. Future approach for these materials is the key to improve material production.

Figure 4: Material constitution and GWP

Material constitution/vehicle (kg) GWP (t-CO2-e)

(GV= 1) (GV= 1)



6. Life cycle impact assessment

Impact assessment methodology

Used methodologies:
LIME2 which is used by Japanese manufacturers and CML (Centre for Environmental Sciences, Leiden University) are chosen for the assessment. The production site in this case is in Japan therefore, LIME2 may be preferable to be used for production related phases as it considers Japanese regional impact mainly, comparing to the CML considers European and world condition for the Use and the latter phases in case of European market.
But different methods for each phase make the analysis complicated. One method for one study result would be better. What the differences between them are to be studied also. Both the methods were investigated, compared, compiled if required and used as follows.

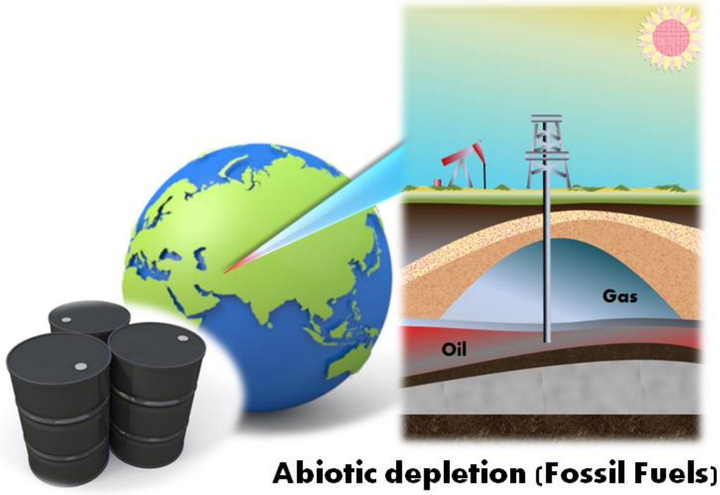
(Japanese market) LIME2 for main assessment for whole LCA with CML results as a reference
(European market) CML for main assessment for whole LCA with LIME2 results as a reference

Categories:
1. Abiotic Depletion Potential (ADP) Fossil fuel
2. Abiotic Depletion Potential (ADP) Elements
3. Photochemical Ozone Creation Potential (POCP)
4. Global Warming Potential (GWP)
5. Acidification Potential (AP)
6. Eutrophication Potential (EP)

The definition, results and interpretation (Japan market)

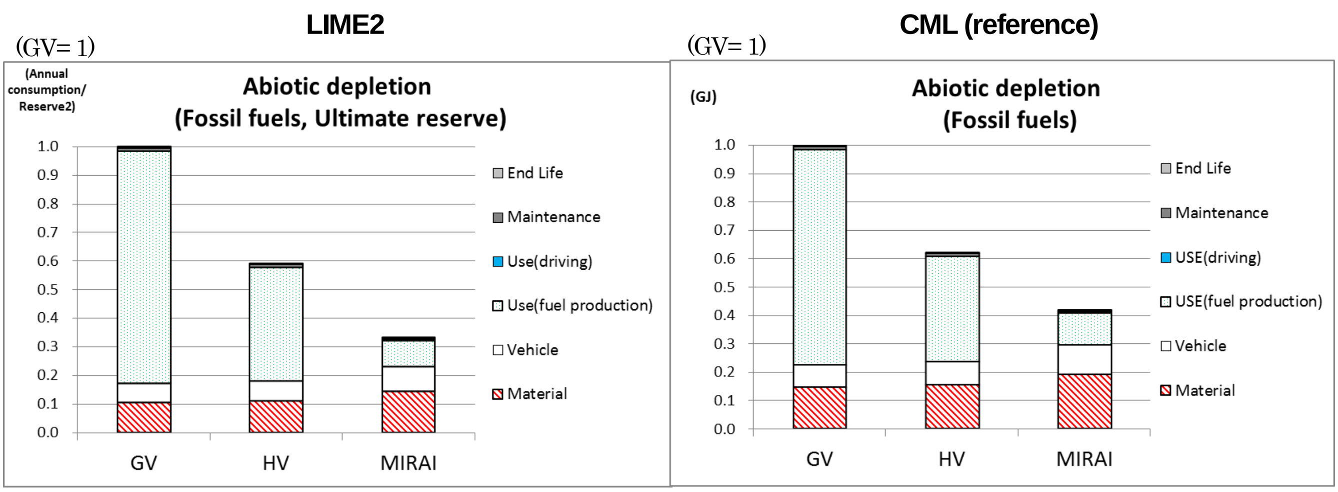
(1) Abiotic Depletion Potential (ADP) in Fossil fuel

represents how much fossil resources are consumed for energy supply to produce the vehicle itself including material, parts and vehicle transportation, and to produce the energy to propel the vehicle during the Use phase in unit of annual consumption/reserve[2].



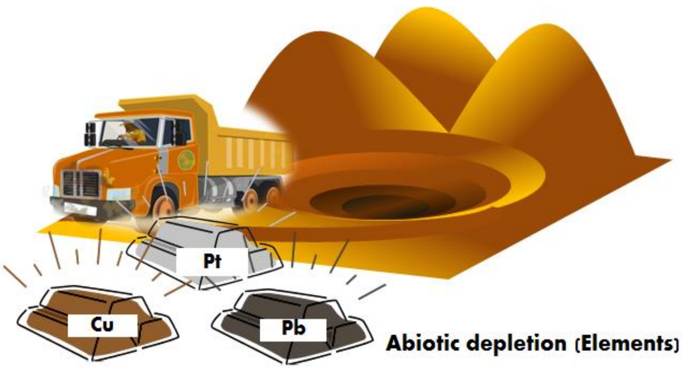
The main focus is fuel supply to propel the vehicle for life time distance of 100,000km, where GV and HV consume gasoline and the MIRAI consumes hydrogen from by-product caustic soda. HV has reduced gasoline consumption and the MIRAI shows substantial advantage in fuel production in case of this hydrogen production case. The reference results of CML have different figures with different units but the results of relative evaluation appear mostly the same.

Figure 5: Impact assessment results for Japan market —ADP (fossil fuel)



(2) Abiotic Depletion Potential (ADP) Element

represents how much natural resources are extracted from the earth.

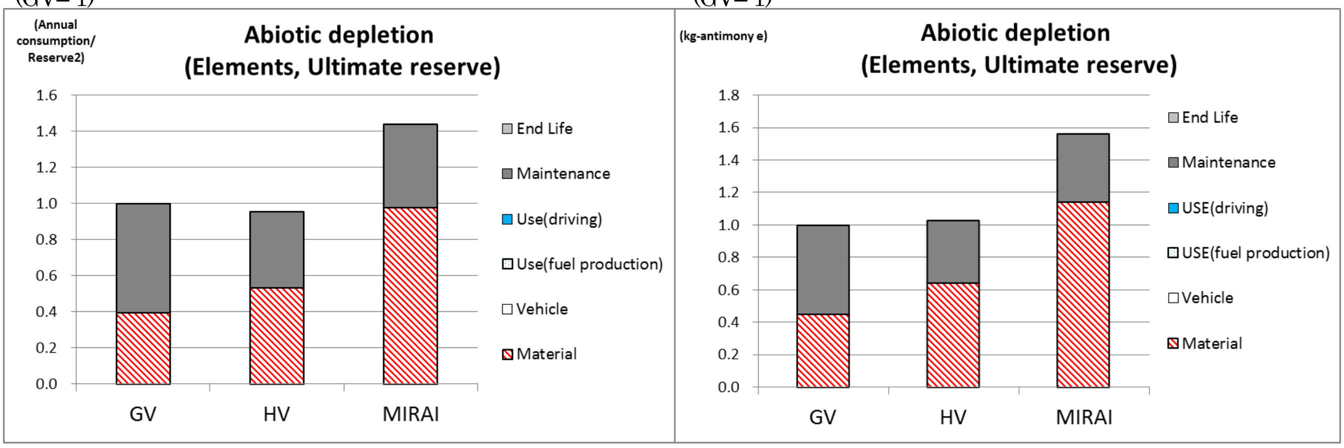


LIME2 indicates those impacts in annual consumption per ultimate reserve of all over the world. CML as a reference shows in different unit; antimony equivalent but same results.

Figure 6: Impact assessment results for Japan market —ADP (element)

LIME2 CML(reference)

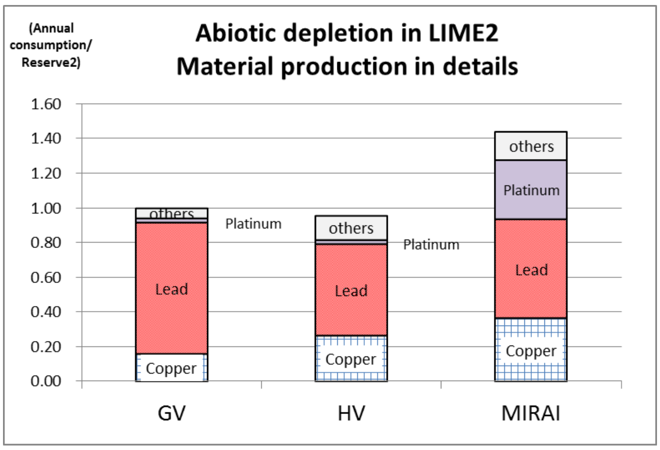
(GV= 1) (GV= 1)



The main reason of the comparably large amount of the total of the MIRAI is due to additional use of rare metals like platinum, copper for its unique parts. On the other hand, lead for auxiliary battery with every 2 year replacement has almost same impact but slightly different according to battery size.

Figure 7: Detailed study for Japan market —ADP (element)

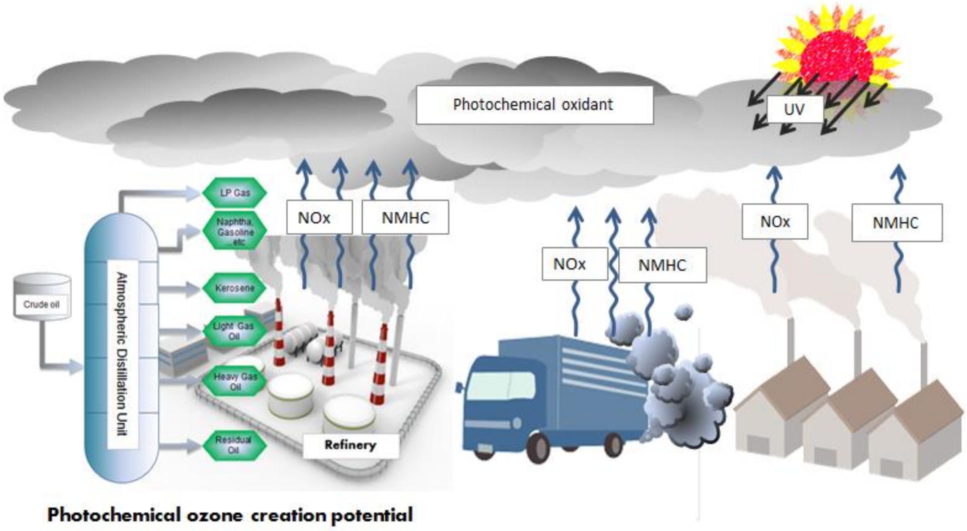
(GV= 1)



(3) Photochemical ozone creation potential

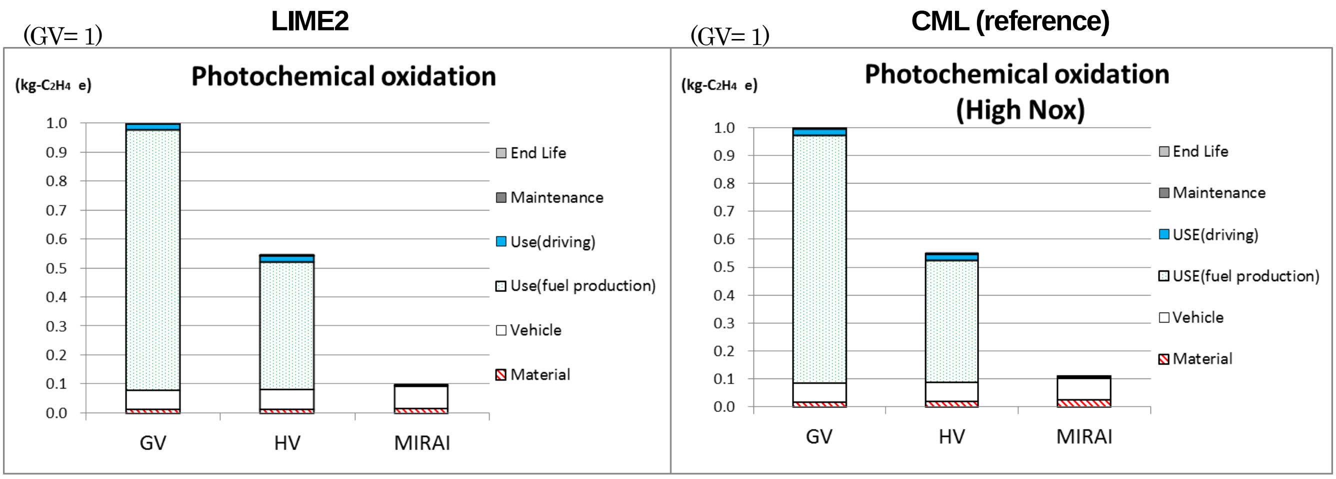
represents the potential of photo oxidants formed from NOx, NMHC, etc. therefore we refer to NOx and NMHC as relevant inventories.

The reference substance is ethylene (C_2H_4).



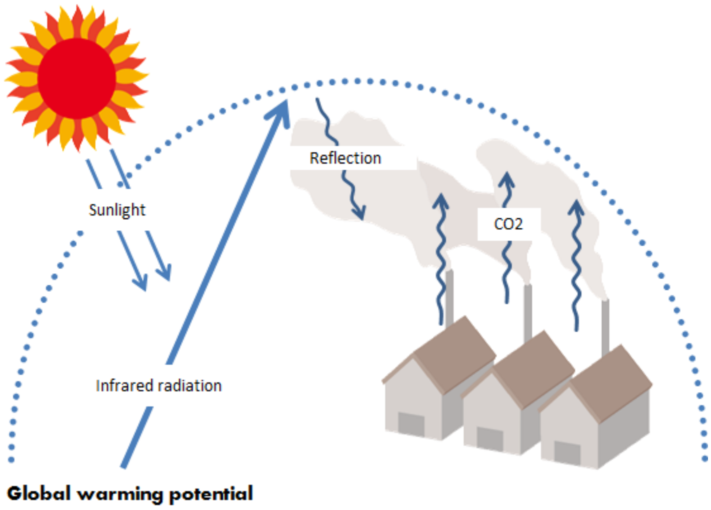
Here the MIRAI shows big advantage comparing to those which requires gasoline production to be supplied for their combustion engines. The main driver is the hydro carbons emitted during gasoline production and transportation. CML as a reference shows the similar results.

Figure 8: Impact assessment results for Japan market —POCP



(4) Global Warming Potential (GWP)

represents the green housing gases emitted to the atmosphere in vehicle life cycle expressed in the unit of CO_2e as the reference substance is CO_2.



The MIRAI has advantages comparing to both GV and HV in total.

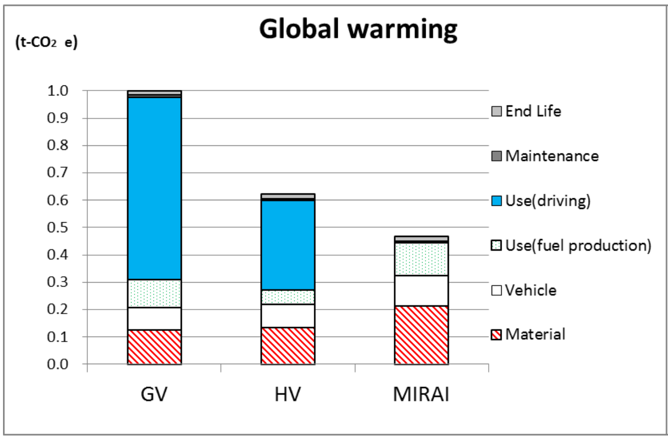
The Use phase (fuel production and driving) has so much impact that automakers must watch the well to wheel efficiency of fuels seriously especially in case of FCV as hydrogen can be produced through the multiple ways.

Another important thing for the vehicle manufacturers is the reduction of production phases even for the new technology, as completely new materials and new processes may be added. Some can reduce vehicle weight with better efficiency of the Use phase but trade-off can occur also; in many cases the lightweight materials need additional production processes which emit more gases comparing to the reduced gases during the Use phase.

Figure 9: Impact assessment results for Japan market —GWP

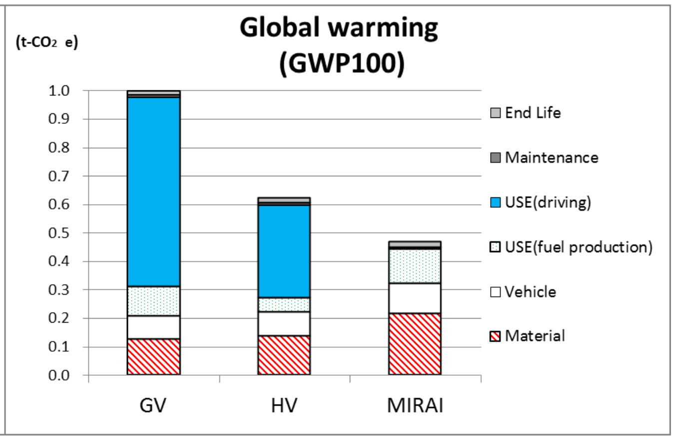
LIME2

(GV= 1)



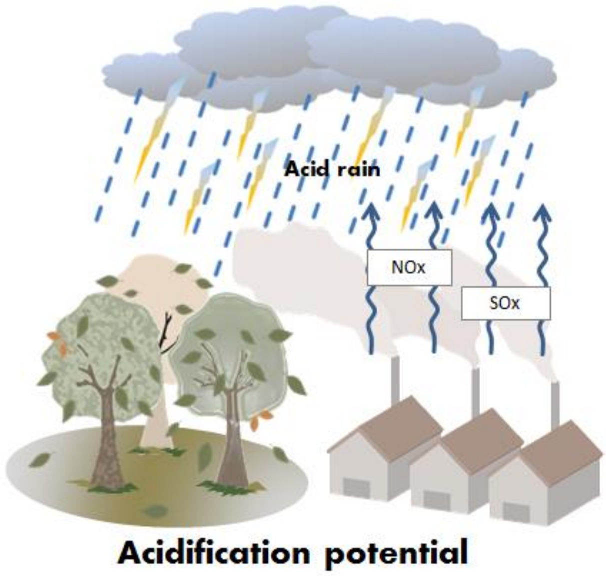
CML(reference)

(GV= 1)



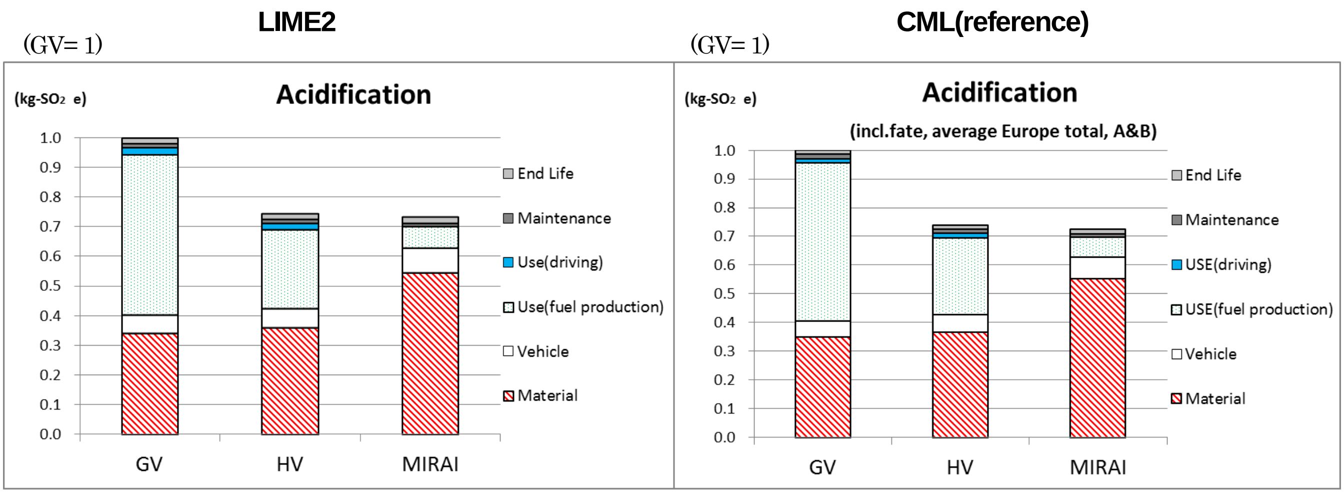
(5) Acidification Potential (AP)

represents the emissions of acidifying substances like NOx, SOx in the unit of SO2e.



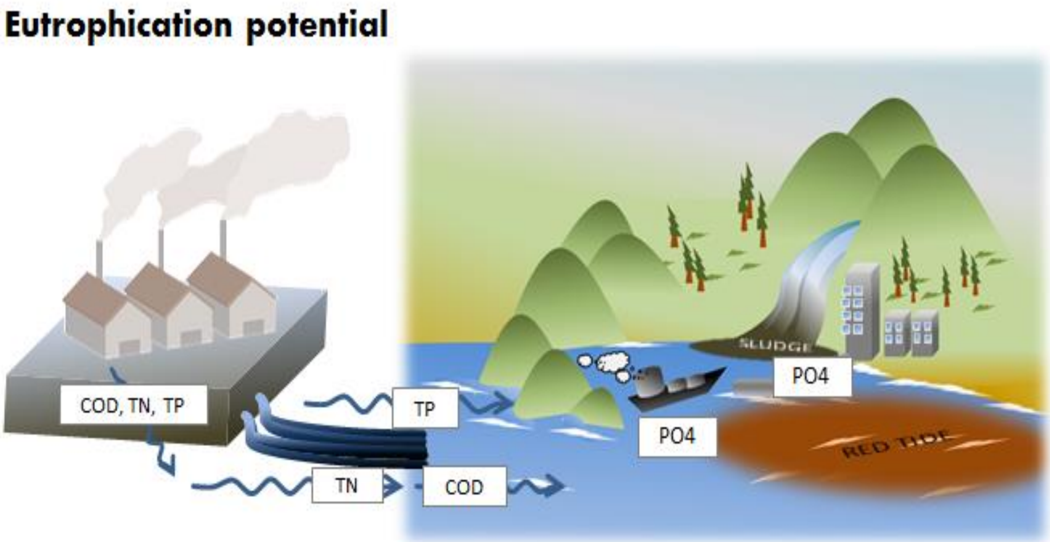
The results show that the MIRAI has more impact in material production, comparing to others as it has specific parts with different materials, like carbon fiber reinforced plastic (CFRP). The CFRP is used for the hydrogen tank and the tank frame. High temperature processes to fabricate carbon fiber result in the high NOx, SOx, etc. The CFRP has technological merits and light weight potential to reduce the Use phase efficiency. Future challenge is expected between material manufacturers and vehicle manufacturers to reduce the production phase.

Figure 10: Impact assessment results for Japan market —AP



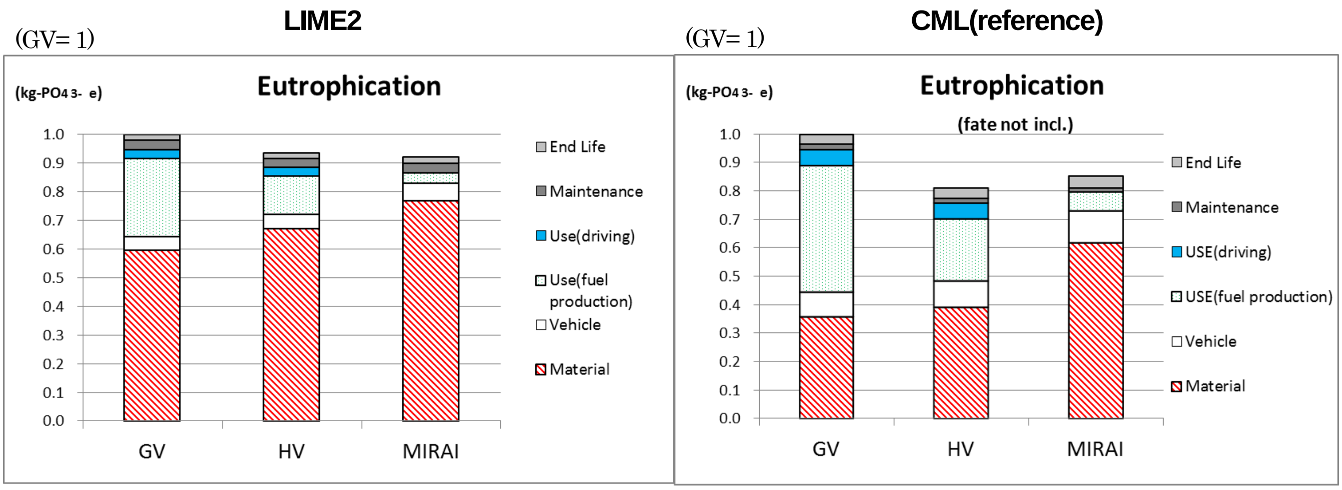
(6) Eutrophication Potential (EP)

represents undesirable input of nutrients emitted and input into ambient water or soil expressed in the unit of $PO_4{}^{3-}e$ as the reference substance is $PO_4{}^{3-}$



The different or additional materials consist of the MIRAI increase the emission during material production but the total amount doesn't exceed GVs. The results of the CML as a reference consider NOx emission more than LIME2 does. Therefore, intensity of carbon fiber use is expressed largely. Also, the unit and coefficient between the two methods are different according to the different thinking ways of impacts with different regional conditions to be considered; LIME2 considers for Japan and CML for Europe.

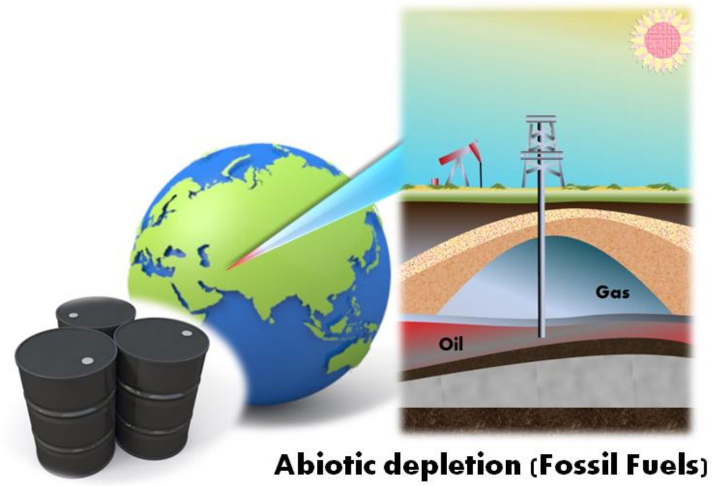
Figure 11: Impact assessment results for Japan market —EP



The definition, results and interpretation (European market)

(1) Abiotic Depletion Potential (ADP) in Fossil fuel

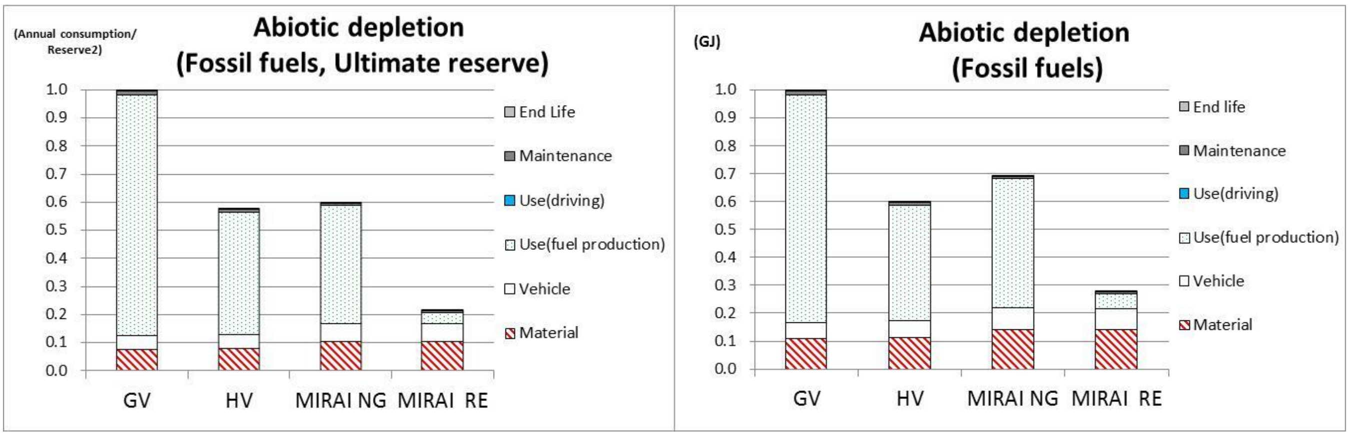
represents how much fossil resources are consumed for energy supply to produce the vehicle itself including material, parts and vehicle transportation, and to produce the energy to propel the vehicle during the Use phase in unit of giga joule



The main focus is fuel supply to propel the vehicle for life time distance of 150,000km, where GV and HV consume gasoline and the MIRAI consumes hydrogen. The main issue is how the hydrogen is prepared and transported in the base of life cycle. The MIRAI NG in the following graphs shows the case with the hydrogen from natural gas, and the MIRAI RE stands for the case with the hydrogen from the electrolysis, originating to JRC report. The MIRAI NG in the left is less than conventional gasoline GV but slightly worse comparing to HV. Electrolysis in the right is much better than both of them. This is because of used fossil fuel, gasoline for GVs and natural gas for MIRAI NG. LIME2 as a reference shows a little better for the MIRAI NG, seems to have lighter weighting for natural gas comparing to gasoline.

Figure 12: Impact assessment results for European market —ADP(fossil fuel)

(GV= 1) **LIME2 (reference)** (GV= 1) **CML**



(2) Abiotic Depletion Potential (ADP) (Elements, ultimate reserves) in CML
represents the impact on the reserve of the resources in the earth crust, which is shown in the unit of antimony equivalent.

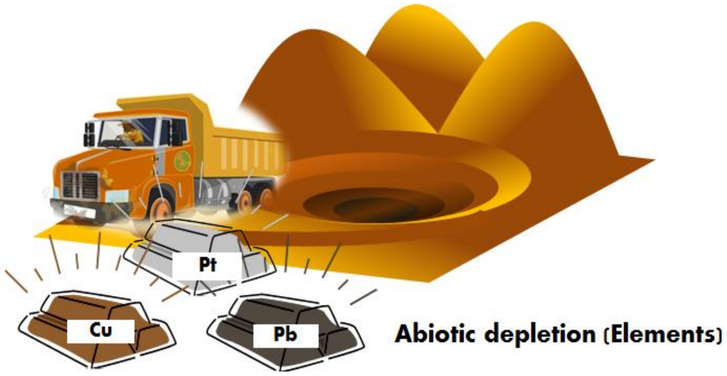
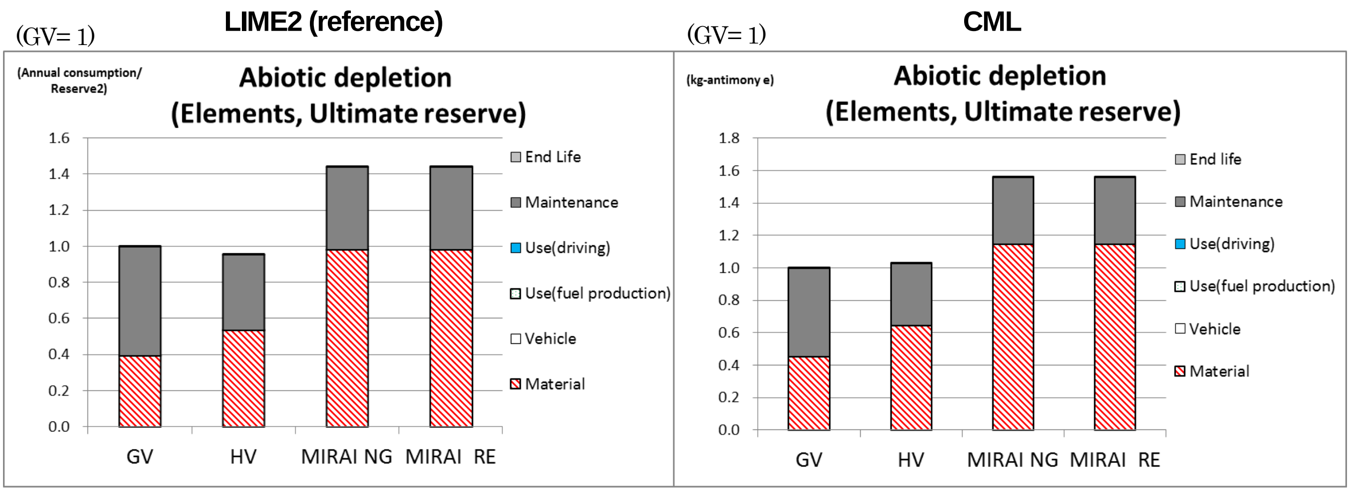
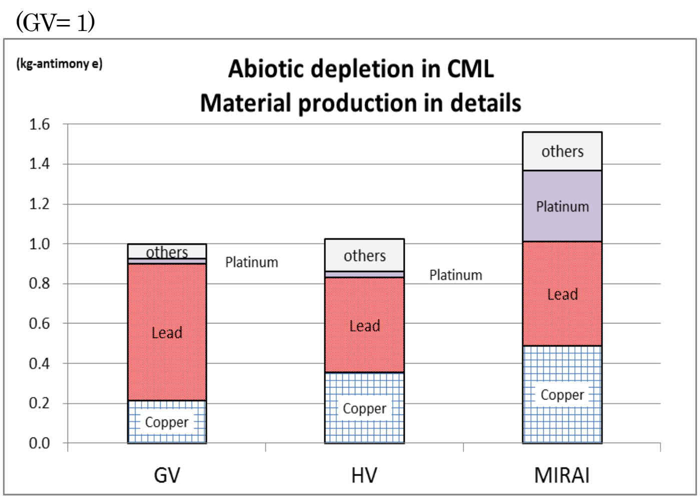


Figure 13: Impact assessment results for European market —ADP(element)



The main reason of the comparably large amount of the total of the MIRAI is due to additional use of rare metals like platinum, copper for its unique parts. On the other hand, lead for auxiliary battery with every 2 year replacement has almost same impact but slightly different according to battery size.

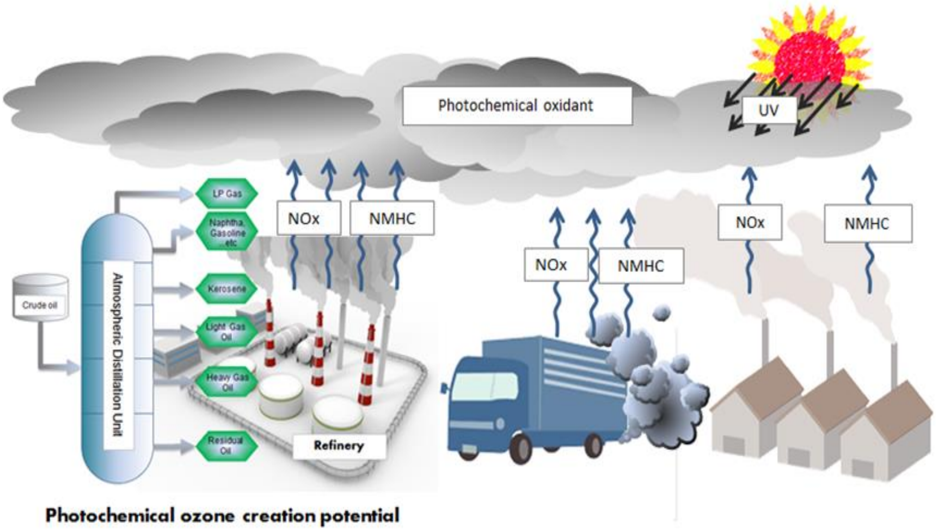
Figure 14: Detailed study for Japan market —ADP (element)



(3) Photochemical ozone creation potential

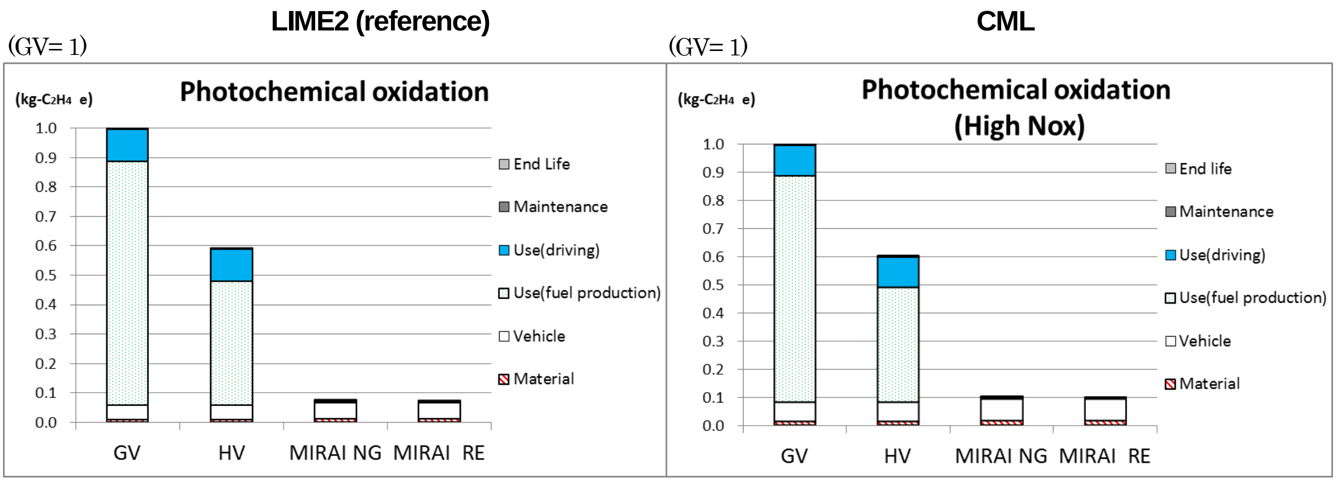
represents the potential of photo oxidants formed from NOx, NMVOC, NMHC, etc.

The reference substance is ethylene (C_2H_4) in both cases.



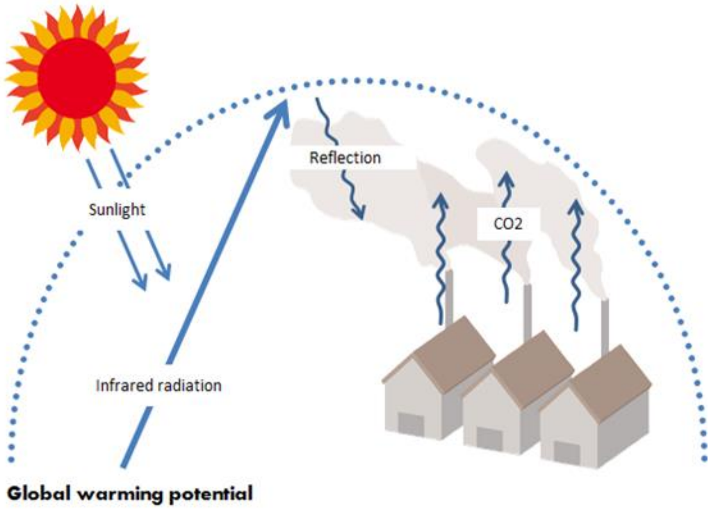
Here the MIRAI shows big advantage comparing to those which requires gasoline production to be supplied for their combustion engines. The main driver is the hydro carbons emitted during gasoline production and transportation. LIME2 as a reference shows the similar results.

Figure 15: Impact assessment results for European market —POCP



(4) Global Warming Potential (GWP)

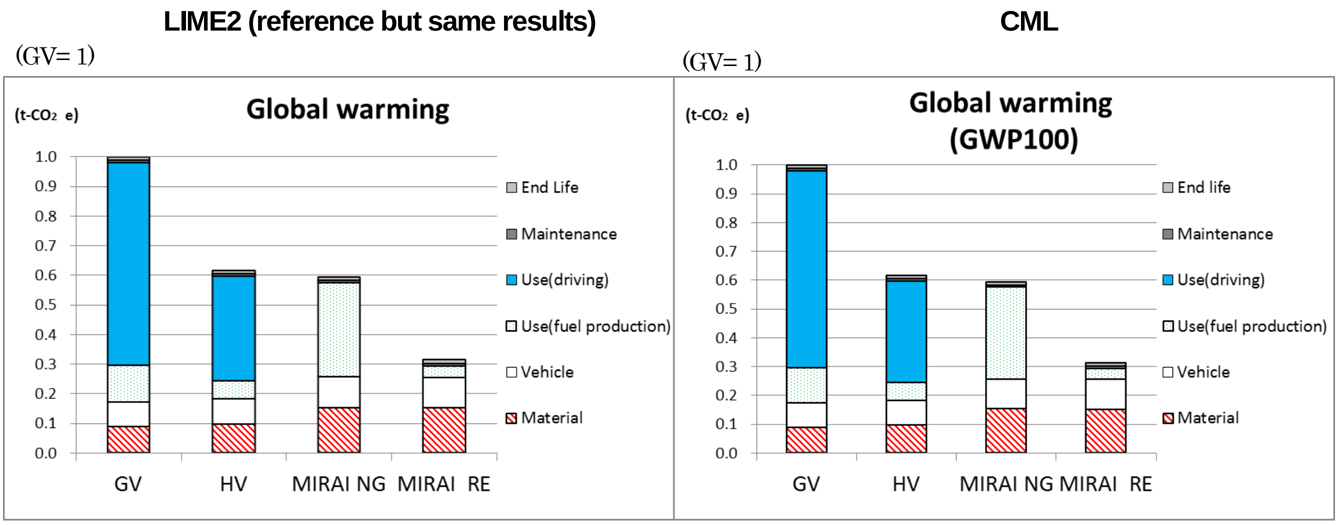
represents the green housing gases emitted to the atmosphere in vehicle life cycle expressed in the unit of CO2e as the reference substance is CO2.



The MIRAI NG has advantages comparing to GV and well compete HV in total. The MIRAI RE has substantial advantages comparing to both GVs. Use phase (fuel production and driving) has so much impact that automakers must watch the well to wheel efficiency of fuels seriously especially in case of FCV as hydrogen can be produced through multiple ways.

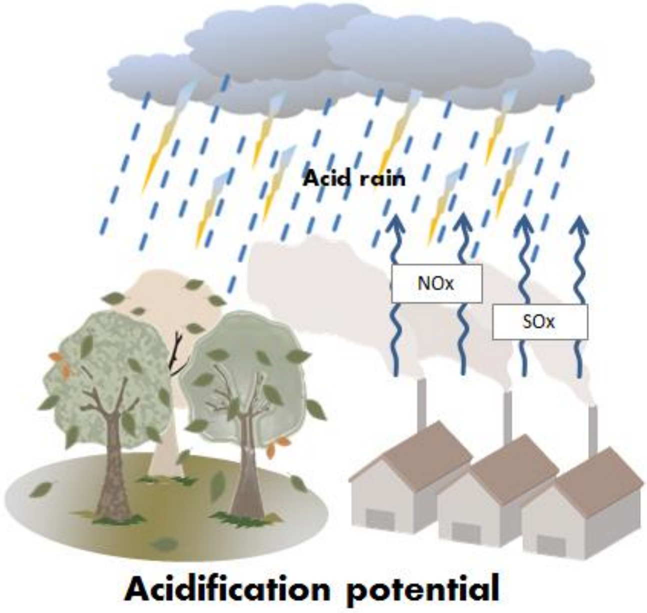
Another important thing for the vehicle manufacturers is the reduction of production phases, even for the new technology as completely new materials and new processes may be added. Some can reduce vehicle weight with better fuel efficiency in the Use phase but trade-off can occur also; in many cases lightweight materials need additional production processes which emit more gases compared to the reduced gases during the Use phase.

Figure 16: Impact assessment results for European market —GWP



(5) Acidification Potential (AP)

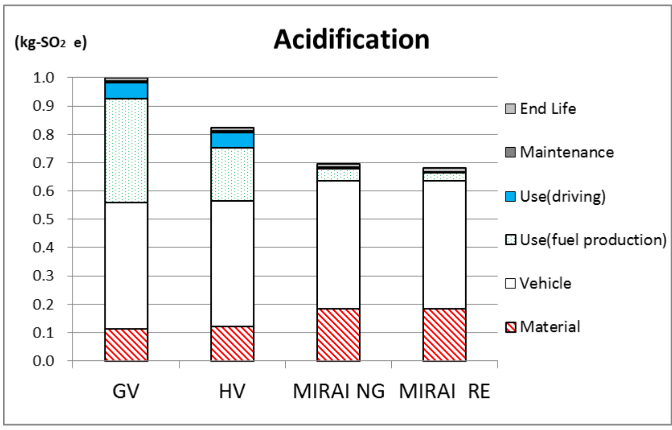
represents the emissions of acidifying substances like NOx, SOx in the unit of SO_2 e.



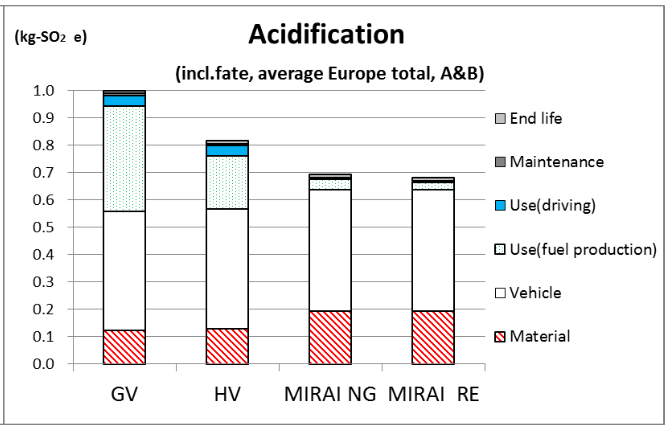
In material production, MIRAI has more impact compared to others as it has specific parts with different materials, like carbon fiber reinforced plastic (CFRP). The CFRP is used for a part of the fuel cell powertrain; the hydrogen tank and the stack frame. High temperature processes to fabricate carbon fiber result in the high NOx, SOx, etc. The CFRP has technological merits and light weight potential to reduce the Use phase efficiency. Future challenge is expected between material manufacturers and vehicle manufacturers to reduce the production phase impact.

Figure 17: Impact assessment results for European market —AP

(GV= 1) LIME2(reference)

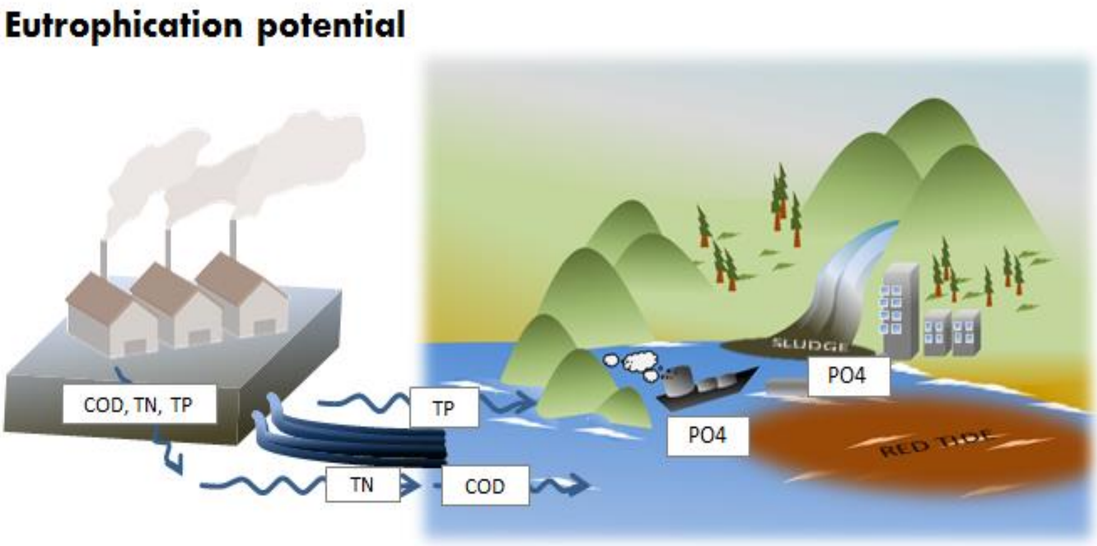


(GV= 1) CML



(6) Eutrophication Potential (EP)

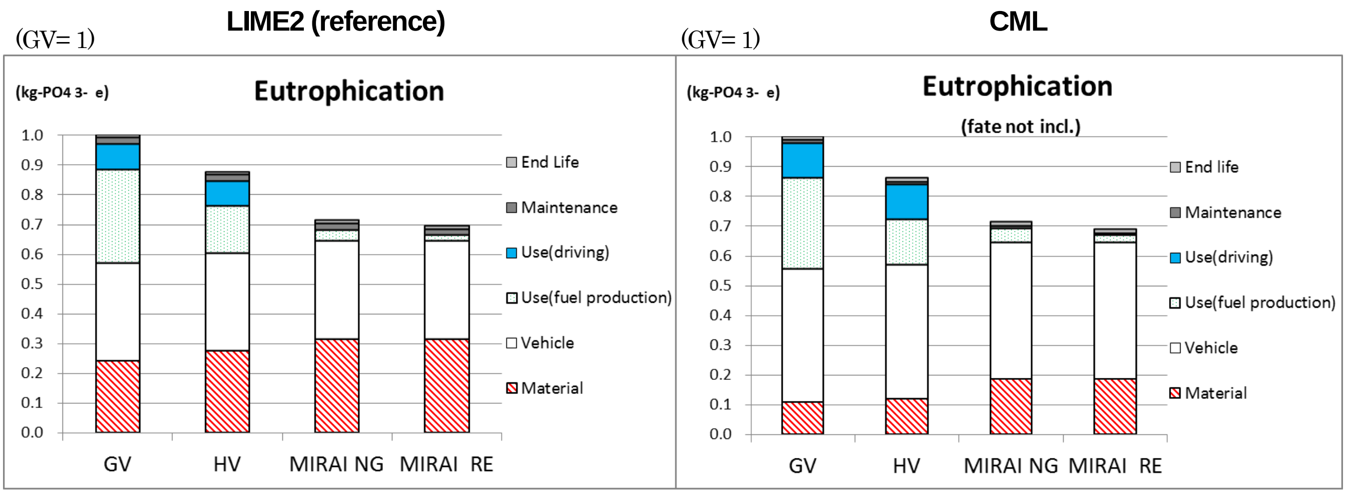
represents undesirable input of nutrients emitted and input into ambient water or soil expressed in the unit of PO_4^{3-} e as the reference substance is PO_4^{3-}.



The different or additional materials consist of the MIRAI increase the emission during material production but the reduction in fuel production help reduce total amount in both hydrogen production cases, doesn't exceed the results of GVs.

In case of Europe, comparing to Japanese case in page 29, Vehicle production phase is much bigger. This is because of NOx and SOx emissions during oversea transportation from Japan port to European port. However influence of those emissions to the atmosphere on the open sea can be considered to be different from those to the bay and to the land. The open sea may not have too much eutrophication. The bay may have concentration partially due to transportation by ships but mainly via river from the land which has no relation with oversea transportation.

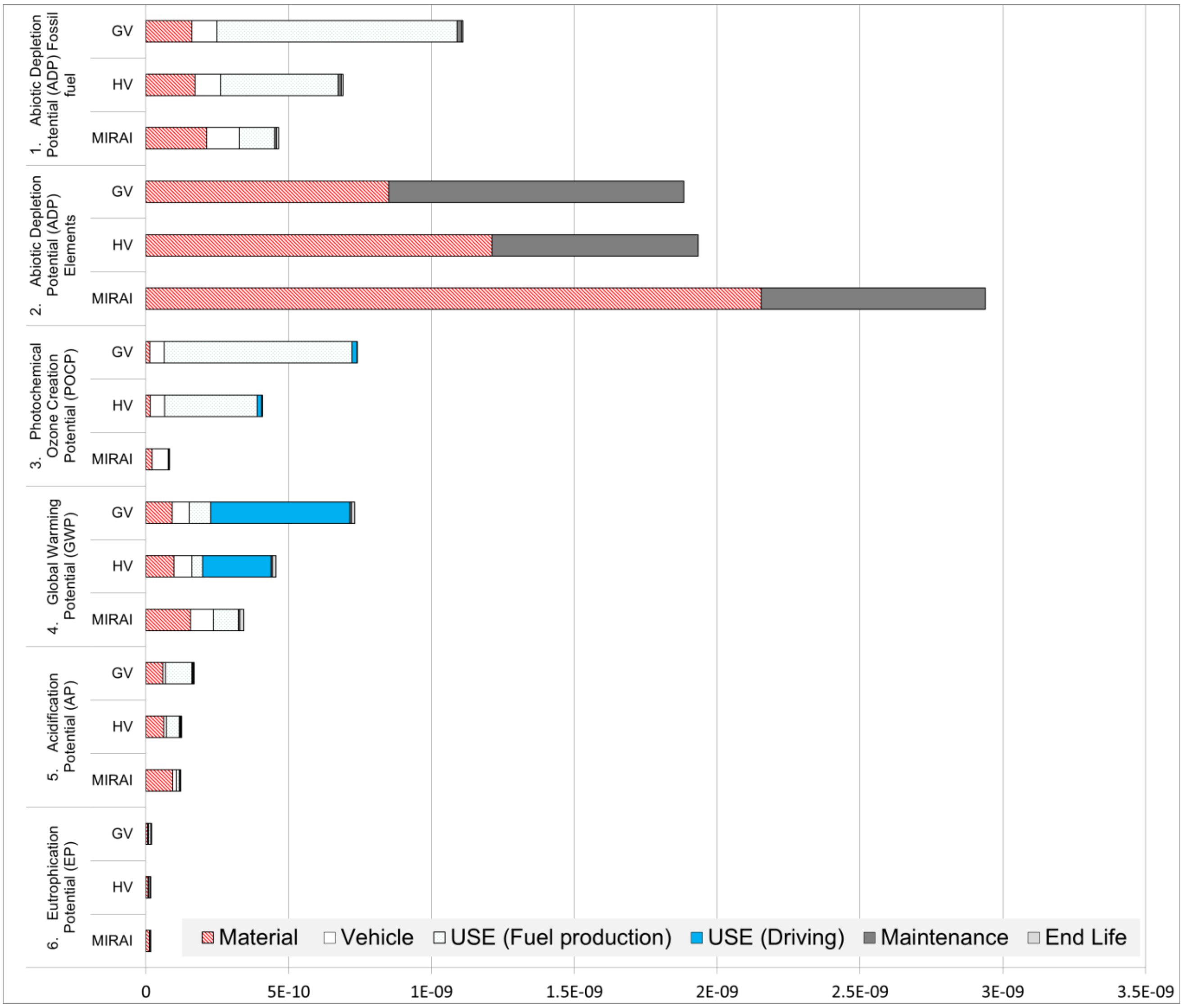
Figure 18: Impact assessment results for European market —EP



Normalized results (only CML available)

Japanese condition (100,000km/lifetime): world, 2000 (Wegener Sleeswijk et al., 2008)

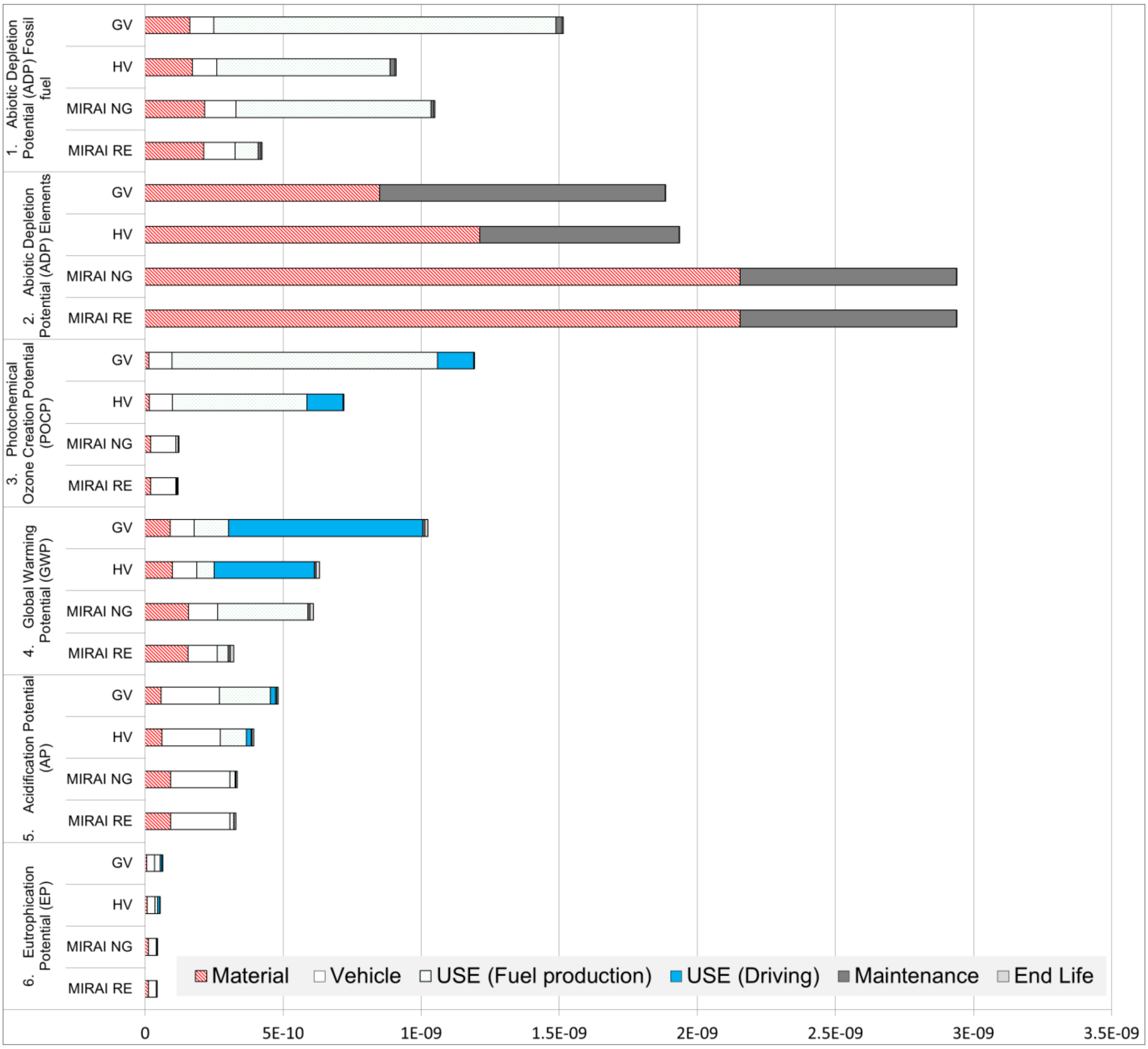
The results of CML method for Japanese case world impact show as follows.



ADP (Fossil) is the world impact of fossil fuel use per vehicle life. The results for ADP (Fossil) show much stronger than for GWP of which automakers tend to take care more. In ADP (Elements), use of rare metals is shown strongly. We assume that all material conditions are those which just extracted from the earth but no recycling paths are included even in case of Platinum, most of which is recycled actually. Main driver of POCP is NMHC emissions in gasoline production, and AP and EP have less impact, comparing to other categories.

Europe condition (150,000km/lifetime): world, 2000 (Wegener Sleeswijk et al., 2008)

The results of CML method for European case world impact show as follows.



Similar with Japanese results but HV and the MIRAI NG in 1. ADP (Fossil) is different.

1. ADP (Fossil) is the world impact of fossil fuel use per vehicle life. The results for ADP (Fossil) show much stronger than for GWP of which automakers tend to take care the most. The MIRAI NG also uses fossil fuel (natural gas), HV with reduced gasoline consumption compared to GV conventional has better result than the MIRAI..

In ADP (Elements), use of rare metals is shown strongly.

We assume that all material conditions are those which just extracted from the earth but no recycling paths are included even in case of Platinum, most of which is recycled actually.

Main driver of POCP is NMHC emissions in gasoline production, and AP and EP have less impact , comparing to other categories.

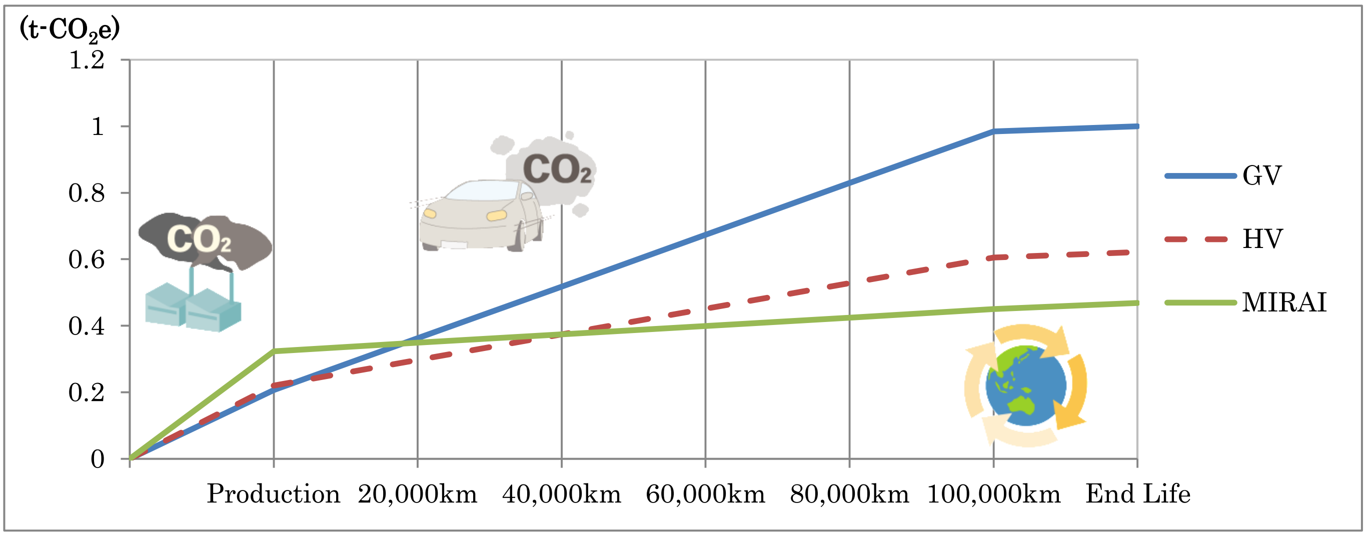
7. Sensitivity analysis

Conditions for the Use phase (driving) for fuel consumption and emission values are the results from the homologated figures, and modelled distance. We defined as 100,000km for Japan and 150,000km for Europe but actual driving distance depends on each user.

Japanese condition:

The initial demerit with production phase of the MIRAI can be retrieved in the early stage of the life, in case of GV, less than 20,000 km and HV around 40,000 km, respectively. The gap continues to increase in the later stage of the life in both cases.

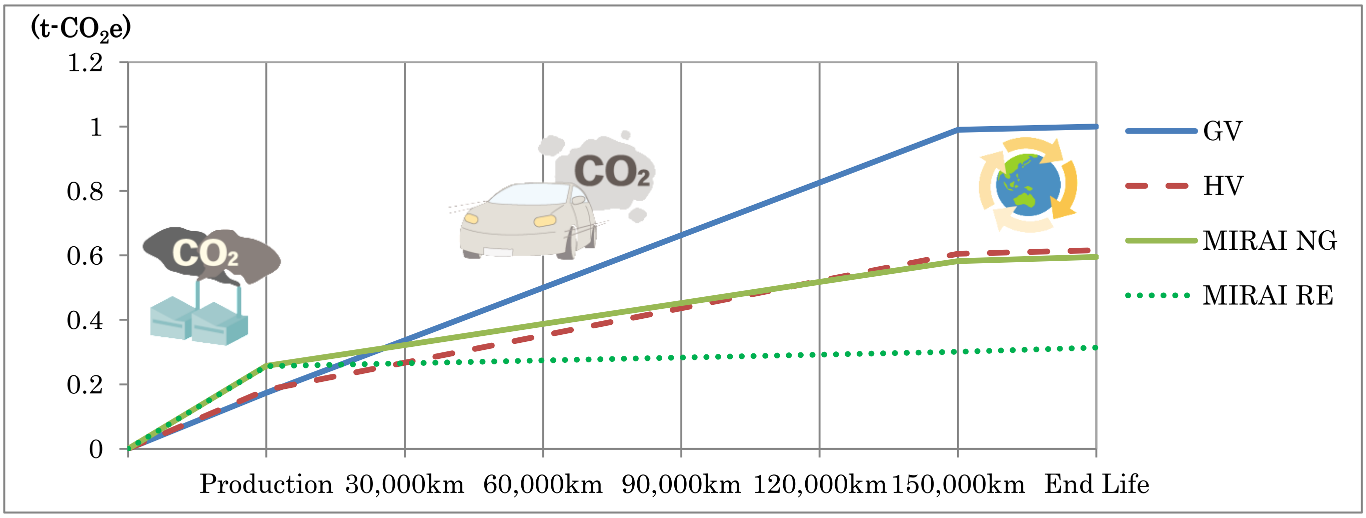
The following graph shows the relation between the CO_2 emission and the distance to balance with GV and HV.



European condition:

The MIRAI with maximum case of hydrogen, in this case Natural gas has cross point with GV hybrid but rather latter stage. The minimum hydrogen case Renewable retrieves the merit in the early stage.

Both the MIRAI cases cross GV gasoline in their early stages.



8. Limitations of LCA

- For this assessment, GV was chosen as the comparison vehicle as it is in the same class as the MIRAI. It is a valid choice, considering the target customers, but no exact same class vehicle exists.

- Most of the secondary data were sourced from the JLCA database for Japan and we refer to GaBi database for other countries. Both databases contain basic units that include upstream energy production, but sometimes boundaries between them are not consistent with different estimation condition or sometimes with missing processes, resulted in big gap of LCA results between them. For example, we refer to JLCA for gasoline production but NMVOC amount is very low with some missing upstream processes. In this case Gabi processes are confirmed and substituted but the GaBi results are very high and details are not disclosed.

- Conditions for the Use phase of driving for fuel consumption and emission values are the results from the homologated figures or regulatory figures, and there will be a disparity between them and real-world driving data. Also, real-world conditions vary from person to person, e.g. travel distance, pedal operation, etc.

- In this study, only Japan and Europe are covered by geographical conditions, as they are the only possible regions which meet requirements enough to be assessed. For other regions, equivalent level of method, primary and secondary data with sufficient completeness, quality and consistency are required.

- There is not a single solution for LCA which covers global conditions, but are multiple geographically unique assessment methods. Considering different production place and market place, we studied two methodologies before use, e.g. tracing of data source and assessment process, deep analysis of ambient information

9. Conclusion

The MIRAI shows substantial environmental performance in many life cycle impact categories in both market cases in Japan and in Europe. In case of GWP, which is the greatest concern of automakers, MIRAI shows reduction of 40~70% compared with conventional gasoline. Followings are main outcomes to be conveyed to the related functions to lead future improvement.

- Material

  FCV uses CFRP for its hydrogen tanks and stack frame, which has big intense on GWP and on other impact categories. CFRP has technological merits with light weight, high strength and high rigidity. Collaboration between automakers and material suppliers are the key to improve environmental performance in whole life cycle of the vehicle, keeping with these technological merits. Even the case when lightweight approach for better use phase with reduced fuel consumption is made, less increase of impact in the production phase compared with the reduction in use phase is to be considered. LCA enables the visualization of the results of such increase/decrease trade-off, helping approach to environment-friendly materials to be adopted in the vehicle.

  The results of CML impact assessment showed stronger for abiotic depletion than for GWP of which automakers take care most. There are two reasons. One is that current FCV needs more abiotic resources like platinum than GV and HV do. The other can be assumed that in CML methodology, all material conditions are those which just extracted from the earth but no recycling paths are included even in case of Platinum, most of which is recycled actually. For former, reduction of use per vehicle of noble metals is being studied, considering total volume on the earth. For latter, further interpretation is needed for CML methodology like how the total volume in the world market and ultimate reserve are set as a prerequisite or an assumption.

- Production

  New processes for new unique component for FCV are investigated in details. Production processes in the initial stage of the development prioritize in quality, tending to lack in care of the environmental aspects. In accordance with the increase of production volume, concrete measurements will be implemented step by step. Successor models are to be assessed for their improvement comparing to the first generation MIRAI.

- Use

  There are multiple pathways in hydrogen supply for the MIRAI. The real world hydrogen infrastructures are being prepared but it is just the beginning. In this study, actual hydrogen pathways when the vehicles are or will be delivered to the customer are investigated by TOYOTA. The hydrogen pathways of natural gas still competes the HV, which yet achieved substantial fuel efficiency as a gasoline fuelled vehicle. Future improvement in hydrogen pathways and vehicle efficiency improvement is expected.

This is the case of FCV, and further detailed studies for all coming new technologies will be conducted. (End of report)

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Date 2016-12-14

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