EVS27
Barcelona, Spain, November 17-20, 2013

A Potential CO2 Reduction of Vehicle to Home System from Life Cycle Perspective

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Abstract

A life cycle inventory analysis is conducted in this study to evaluate the environmental merit of a vehicle to home (V2H) system towards the conventional counterpart equivalent in terms of environmental impact category global warming expressed as CO2 emissions. The V2H system comprises a residential house, a photovoltaic solar system, a battery electric vehicle and a charging system, whereas the conventional system includes a residential house, a gasoline vehicle and a petrol station. The system boundary of each components consists of its production, use and end-of-life stages, where data available. CO2 emissions are calculated by applying the data of each components and life cycle stages collected from statistics and literature surveys to the Japanese life cycle inventory database. The emissions differ by the assumptions made; therefore a sensitivity analysis is also carried out to understand the potential variation of the CO2 emissions. The result indicates that about 35—42% CO2 reduction can be expected for a V2H system in comparison with the conventional system. Since the main contributors to CO2 emissions of both systems are dwelling, residential house construction, vehicle cycle and fuel cycle stages, these stages should be included in the system boundary of V2H system and it is important to select and design the appropriate components of these stages to assure the environmental merits of V2H system in terms of life cycle CO2 reduction.

Keywords: Environment, LCA (Life Cycle Assessment), V2G (vehicle to grid), BEV (battery electric vehicle)

1 Introduction

Thanks to its high energy efficiency and zero emissions, the battery electric vehicle (BEV) has been regarded from the past as one of the solution technologies for energy and environmental problems surrounding automotive sector. Although its R&D had started in the 1970s, it has not penetrated the market mainly due to its low practicality and high cost compared with the conventional internal combustion engine vehicles. In the late 2000s, however, the performance of lithium-ion batteries for electric vehicles has improved drastically to ensure practical vehicle range and BEVs have been focused attention upon again as the promising technology for the future mobility. Indeed, some vehicle makers have launched the sales of BEVs with lithium-ion battery in Japanese vehicle market for fleet use in 2009 and personal use in 2010.

On the other hand, smart grid technologies that can efficiently manage electricity demand and supply including the use of renewable energy by using

information and communication technologies have been given worldwide attention to ensure more stability of the energy grid and realise low-carbon society. It is deemed that BEV can be a key component to be used as distributed energy storage device in the smart grid system. Vehicle to Home (V2H), which is one of the subsets of Vehicle to Grid (V2G), is a system that can share mutually the power between a vehicle and a home and is regarded as one of the key technologies in smart grid strategies. Although the system is limited in the sense that single vehicle can supply only a house, the combination of V2H system and home energy management system enables the energy savings and greenhouse gas (GHG) reduction of a household.
After the great earthquake on March 2011, Japan is facing power shortage and anticipation has increased for full-scale promotion of renewable energy including photovoltaic (PV) solar and wind power. The Japanese government has implemented feed-in-tariff scheme for renewable energy sources since July 2012 [1] to improve energy self-sufficiency, reduce GHG emissions and stimulate Japanese industries. Since the connection of such unstable powers to the grid, whose output fluctuates with the weather, may cause imbalances between electricity generation and load and lead to frequency and voltage fluctuation, demand-supply balancing capacities such as batteries (including those mounted on BEVs) are expected to play an important role to minimise the risk of a possible overload and black out and to stabilise the power supply. In this sense, the V2H system is expected not only to contribute to a stable power supply but also emergency situations where electricity is required.
Although the environmental emissions attributed to vehicle and household energy use might be reduced at a V2H system compared to the conventional counterpart system, the construction of residential house and installation of V2H system components to the house induce additional environmental emissions by their production and end-of-life stages. Therefore it is necessary that the emissions reduction effect of the total system be evaluated from a life cycle point of view. One of the quantitative methods to evaluate the environmental aspects and potential impacts associated with products, processes and services throughout their life span is life cycle assessment (LCA), which considers the assessment of products or services from “cradle to grave” perspective. The concept of LCA is applied to Well to Wheel analyses [2-4] to estimate the environmental advantages of various alternative energy vehicles over the entire automotive fuel pathway. There are also many studies that conducted LCA and estimated environmental burdens by each life cycle stage of alternative fuel vehicles including the Well to Wheel stages [5-7].
In terms of evaluating the environmental merits of a V2H system compared to the conventional system, there are few studies that carried out LCA for V2H system. For example, Sioshansi and Meisterling [8] estimated life cycle reduction effect of CO2, NOx and SOx by the introduction of V2G service using plug-in hybrid electric vehicle in Texas, USA. They utilise electric power system model and detailed driving pattern data for the estimation; however, their main focuses are upon vehicle batteries and power system so that the emissions associated with the production and end-of-life of the batteries and power systems and the other components of the system are not included in the system boundary of LCA.
In order to design a V2H system that contributes to GHG reduction, it is important to understand which components and their life cycle stages of the system account for large proportion of GHG emissions from the system. To this end, this study focuses upon the environmental impact category global warming expressed as CO2 emissions and a life cycle inventory (LCI) analysis, which is a component of LCA, of a V2H system is conducted to estimate the potential CO2 reduction from life cycle perspective compared to the conventional system.
Please note here that our estimation is based upon the data obtained by statistics and literature surveys and not by the actual V2H system or the conventional system owing to data restrictions.

2 Assumptions and Method for LCI Analysis

2.1 System Components, System Boundary and Functional Unit

Table 1 shows the components and their system boundary of the target systems for LCI analysis in this study. The V2H system comprises a residential house, a PV system, a power control system (PCS) and a BEV. PCS is a charging system that can not only charge the BEV but also supply electricity to the house from the BEV. Its counterpart conventional system consists of a residential house and a gasoline vehicle (GV). Since the PCS, the

Table 1: System components and boundary of this study

Target system	System components	System boundary
V2H and conventional system	Residential house	Construction
		Dwelling
		Demolition and end-of-life
	Vehicle (BEV and GV)	Production
		Use
		Maintenance
V2H	PV	Production
		End-of-life
	PCS	Production
Conventional system	Petrol station	Construction
		Demolition and end-of-life

energy charger for BEV, is included in the component of the V2H system, the petrol station is also included in the conventional system component to have equal footing for both systems.

The system boundary of each component consists of its production, use and end-of-life stages; however the end-of-life stage of a BEV, GV and PCS is not included in this study due to data restrictions.

Since the lifetime differs by each component, the life cycle CO2 (LCCO2) emissions of the component are discounted over its lifetime and the functional unit in this study is set to be annual CO2 emissions from the system (household).

In terms of V2H system installed with PV that is under demonstration or in market, electricity generated by PV can be charged first into BEV and then used as dwelling energy. Since it was impossible to obtain the raw data from the actual system, however, it should be noted that this effect is not considered in our calculations.

2.2 LCI Database Used

The life cycle inventory database IDEA (Inventory Database for Environmental Analysis) [9], which has been developed by National Institute of Advanced Industrial Science and Technology, is used to calculate the LCCO2 emissions from the target systems. IDEA covers about 3,000 basic processes in Japan including energy, chemicals, metals and nonmetals, machinery, building materials, civil construction, etc. The database is developed using statistical data, model calculation and literatures. Since the embodied CO2 emission intensity including all the upstream emissions are given per activity unit of a process (e.g. in physical or monetary unit), the amount of LCCO2 emissions can be calculated by multiplying the amount of activity to the embodied emission intensity. The embodied CO2 emission intensity of IDEA was used as the default value of the Japanese Carbon Footprint of Products (CFP) pilot project conducted in 2009—2011 financial years and IDEA is also used as the default database of the Japanese CFP Communication Programme since 2012 [10].

3 Configuration of System Components and Their LCCO2 Emissions

3.1 Residential House

3.1.1 Construction Stage

According to the latest Japanese statistics of 2008 [11], detached house accounts for 55% of the total number of residential houses and wooden house accounts for 59% of the total; therefore the residential house is represented by a detached wooden house in this study.

IDEA provides CO2 emission intensity of 434.89 [kg-CO2/m2] for the production of a wooden house. Assuming the gross floor area of detached owned houses of 132.3 [m2] [11] and the lifetime of 35 years for Japanese residential houses, the CO2 emissions associated with house construction can be calculated as 1644 [kg-CO2/household/year].

3.1.2 Dwelling Stage

The General Energy Statistics [12] provides the annual amount of each kind of energy used in residential sector by Japanese regions as depicted in Fig. 1. Using this statistics, the number of households and the CO2 intensity of each energy kind included in IDEA datasets (Table 2), the annual CO2 emissions from dwelling energy use can be calculated as Fig. 2.

It can be confirmed from Fig. 2 that the major contributor of the emissions from dwelling stage is electricity. According to Annual Statistics of Residential Energy [13], which gives the breakdown of energy use by energy kind, more than 70% of the emissions by electricity are attributed to lighting and power for home electrical appliances. The other energy sources are mainly used for hot water and heating; however kerosene is the main source for heating in cold areas

Table 2: CO2 intensity data used for estimation

	Production	Combustion	Total
Kerosene [g-CO2/MJ]	4.84	67.9	72.7
LPG [g-CO2/MJ]	12.3	59.5	71.8
City gas [g-CO2/MJ]	14.9	49.8	64.7
Electricity [g-CO2/kWh]			463
Gasoline [g-CO2/MJ]	11.5	67.1	78.6

(Hokkaido and Tohoku, which are located in northern part of Japan).
Although the LCCO2 emissions calculation in this study uses the Japanese average of Fig. 2 as the default case, it should be noted that the emissions from residential sector differ by the target area assumed.

3.1.3 Demolition and End-of-Life Stage

Usually the waste from house demolition is treated as industrial waste. Although the exact amount of CO2 emitted by industrial waste treatment differs by the specification of a residential house, it can be approximated using the assumed gross floor area of 132.3 [m2] assumed at 3.1.1 and the data included in IDEA as follows:

- According to the house construction data used to produce IDEA datasets, about 0.8 [t/m2] of materials is required for constructing a house and almost all the materials are treated as industrial waste at its end-of-life stage.
- IDEA provides the embodied CO2 emissions of 3.893 [g-CO2/Japanese yen (JPY)] (381 [g-CO2/USD] using the currency conversion rate of 1 USD = 97.8 JPY, 25 June 2013) for industrial waste treatment.

Industrial waste is traded in the market with the price of about several thousand JPY per ton. The default case in this study assumes 5000 [JPY/ton]. Although the CO2 emissions from this stage may change according to the price of industrial waste, Architectural Institute of Japan [14] calculates that the emissions from this stage only accounts for about 1% of the total emissions from a residential house and therefore it can be said that its contribution to LCCO2 emissions is small (Fig. 3).

Figure 1: Japanese regions

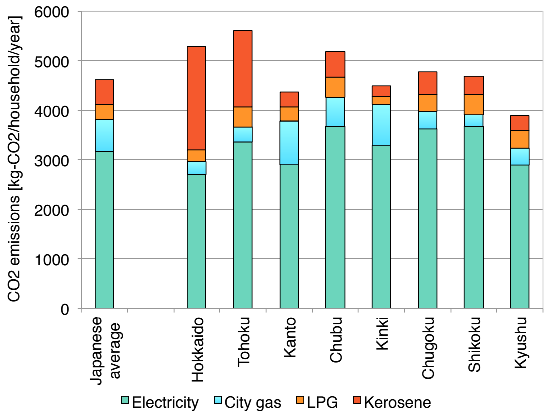

Figure 2: CO2 emissions from dwelling stage

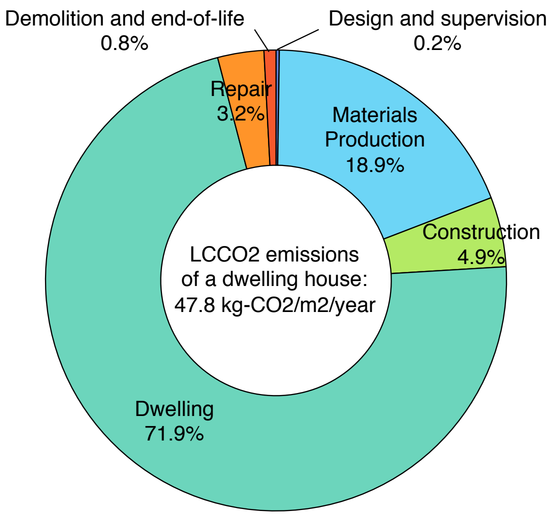

Figure 3: LCCO2 emissions from a dwelling house [14]

3.2 PV Solar Panel System

Among the various studies that calculated LCCO2 emissions of PV solar panel system, CRIEPI [15] and Mizuho [16] reports reflect the state-of-the-art PV technology. Table 3 shows the specifications of the assumed PV system and their system boundaries. While CRIEPI provides detailed material and energy inputs required for producing a PV system, its end-of-life stage is out of the system boundary. On the other hand, end-of-life stage is included in Mizuho calculation but the material and energy data for production are not provided. Therefore in this study, the LCCO2 emissions of PV system are estimated using both reports.

3.2.1 Production Stage

Fig. 4 represents the CO2 emissions from PV system production stage, which was calculated from input data of CRIEPI and IDEA datasets. It can be confirmed that 80% of the emissions are attributed to materials required for PV components.

3.2.2 End-of-Life Stage

NEDO estimates CO2 emissions of 972.7 [kg-CO2/kW-system] from production stage and 2.1 [kg-CO2/kW-system] from end-of-life stage for a PV system whose specifications are shown in Table 3. Since the assumed system power generation capacities of both reports are almost the same, the emissions from this stage are approximated as 9.6 [kg-CO2/system] by multiplying the CO2 emissions ratio of production stage vs. end-of-life stage to the production stage estimate shown in Fig. 4.

3.2.3 Life Cycle CO2 Emissions

As can be confirmed from Table 3, the assumed annual power generation and lifetime of the PV system significantly differ by CRIEPI [15] and Mizuho [16], although both reports assume almost the same power generation capacity. This indicates that a variety of assumption can be made for the solar insolation and other conditions, which strongly affects to the LCCO2 estimates of a PV system. Therefore the default case in this study assumes the average of annual power generation and lifetime of CRIEPI and Mizuho parameters in Table 3, which gives the LCCO2 emissions of 46.9 [g-CO2/kWh].

Table 3: PV specification and system boundary of CRIEPI [15] and Mizuho [16]

		CRIEPI [15]	Mizuho [16]
PV type		Polycrystalline silicon	
Cell	Size [mm]	155x155	
	Thickness [mm]	0.2	
Module	Size	900x1165	1326x1008
	No. of cells	42	48
	Capacity [W]	160	186
	Efficiency [%]	13.9	
System	No. of modules	24	21
	Capacity [W]	3.84	3.9
	Weight [kg]	574	579
	Annual power generation [kWh]	5046	3863
	Lifetime [years]	30	20
System boundary	Cell and module production	√	√
	Mounting production	√	√
	Control devices production	√	√
	Products transport	√	√
	Spare parts production	√	√
	End-of-life	-	√

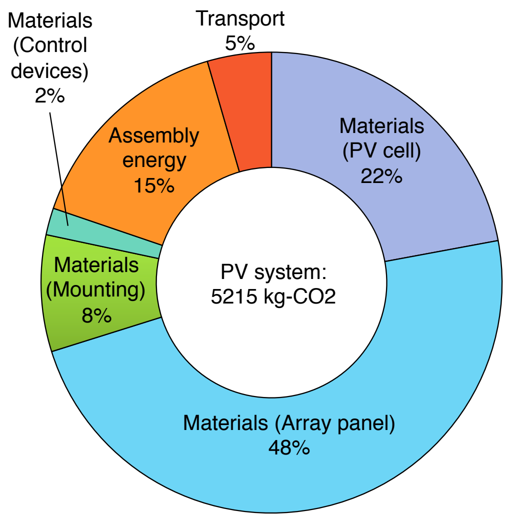

Figure 4: CO2 emissions from PV system production

3.3 Power Control System

PCS is the key component of V2H system; however, the detailed input data for a PCS is not available. Therefore we assume that the inventory of a PCS can be approximated by the power conditioner of a PV system with the emission of 98.6 [kg-CO2] as calculated from Fig. 3, in which the direct current of PV is converted to alternate current used in households. Since the lifetime of a PCS is about 10 years, it is assumed that 4 PCSs are required during the 35 years lifetime of a dwelling house.

3.4 Petrol Station

CO2 emissions of gasoline and electricity shown in Table 2 are equivalent to Well to Wheel CO2 emissions intensity. The Well to Wheel analyses usually considers only the energy flow to produce automotive energy over the life cycle and emissions attributed to construction of infrastructures are not included. In order to calculate the CO2 emissions associated with construction and end-of-life stages of the infrastructures required, the authors have reviewed various kinds of Well to Wheel studies and LCA of petroleum refineries; however we couldn’t come up with the analyses whose detailed material components of a petrol station are provided. Although the emission from a petrol station should vary according to the size and specification of its components such as operator’s premise, shed area, tank container, fuel dispenser, etc., we approximate its emissions from construction and end-of-life stages in the same manner as the residential house estimates as described in 3.1.1 and 3.1.3. The data for the default case calculation are as follows:

- Assuming a petrol station of steel-reinforced concrete (SRC) structure, IDEA gives the embodied CO2 emissions for a SRC office construction of 1551.6 [kg-CO2/m2].
- According to the IDEA datasets, about 2.5 [t/m2] of materials is required for a SRC office construction and almost all the materials are treated as industrial waste at their end-of-life stage.
- Industrial waste is traded in the market with the price of about several thousand JPY per ton. The default case in this study assumes 5000 [JPY/ton].
- IDEA provides the embodied CO2 emissions of 3.893 [g-CO2/JPY] for industrial waste treatment.

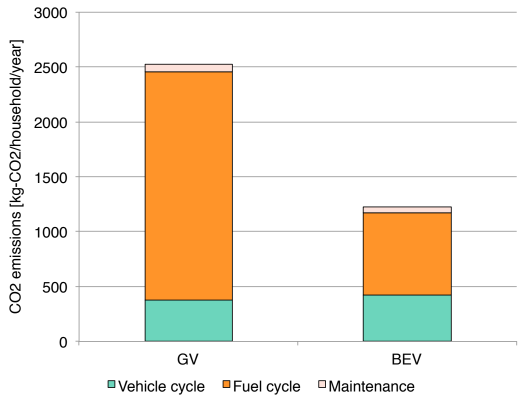

Figure 5: CO2 emissions of a GV and a BEV

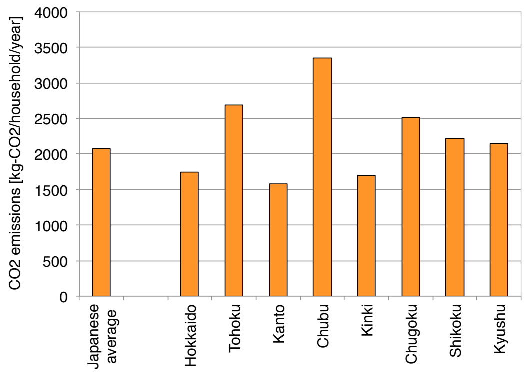

Figure 6: CO2 emissions attributed to GV use

The CO2 emissions from construction and end-of-life stages of a petrol station ($CO2_p$[kg-CO2/year]) can be approximated using equation (1), assuming that the total amount of emissions by construction and end-of-life stages of all the petrol stations that exist nationwide are attributed to and shared with all the passenger vehicles owned in Japan.

$CO2_p = (E_c A_p + E_w W_p P_w A_p) \times N_p / N_v / t$ (1)

Where E_c is the embodied CO2 emissions of a SRC office construction [CO2/m2], A_p is the ground area of a petrol station [m2], E_w is the embodied CO2 emissions for industrial waste treatment [CO2/JPY], W_p is the amount of industrial waste from a petrol station demolition [t/m2], P_w is the price of industrial waste [JPY/t], N_p is the number of petrol station, N_v is the number of vehicle owned and t is the lifetime of the petrol station [year] (assumed to be 30 years in this study), respectively.

3.5 GV and BEV

In this study, the lifetime of GV and BEV is assumed to be 11 years, which is average for Japanese passenger vehicles. Another assumption made here is that a single household owns one vehicle (either a GV or a BEV).

Figure 5 represents the LCCO2 emissions of a GV and BEV assumed in this study. The assumptions made for the calculations are as follows.

3.5.1 Vehicle Cycle

CO2 emissions of GV and BEV production stage (4.12 [t-CO2] and 4.65 [t-CO2] for GV and BEV respectively), which were estimated by Kudoh [5], are used in this study.

3.5.2 Fuel Cycle

CO2 emissions attributed to GV use can be calculated as Fig. 6 using Table 2 and the Annual Statistics of Automobile Transport [17], which provides the annual amount of gasoline used for passenger vehicles by households (for private use).

This study assumes a BEV with battery capacity of 24 [kWh], vehicle range of 160 [km] and charging efficiency of 0.85. According to the statistics [17, 18], the transport volume of passenger vehicles and the total number of passenger vehicles owned in Japan is 368919 [thousand vehicle-km] and 40528 [thousand vehicles] respectively, from which Japanese average annual driving distance is estimated to be 9100 [km] for a passenger vehicle. Using these parameters and Table 2, the default CO2 emissions by the use of a BEV per household can be estimated.

3.5.3 Vehicle Maintenance Stage

The following assumptions are made for emissions from vehicle maintenance stage, in the same manner as Kudoh's estimates [5].

- Vehicle tires should be replaced by every 30000 km driving. During the lifetime of 11 years with annual driving distance of 9100 km, each of the 4 tires is replaced 3 times during its lifetime. CO2 emissions are 206 [kg-CO2/4 tires] by their production.
- Engine oil for GV should be replaced by every 5000 km driving. Namely, it is replaced 19 times during its lifetime. 3.5 kg (3.9 litres) of engine oil is required for replacement and its CO2 emissions are 5.72 [kg-CO2/3.5kg-engine oil].
- Lead acid battery for GV should be replaced by every 25000 km driving, which leads to 3 time replacements during its lifetime. CO2

Table 4: Assumed parameters for sensitivity analysis

Cases	Parameters
Default case	Gross floor area of a detached owned house: 132.3 [m2] (3.1.1), Target area for dwelling stage: Japanese average of Fig. 2 (3.1.2), Amount of industrial waste from a house demolition: 0.8 [t/m2] (3.1.3), Price of industrial waste: 5000 [JPY/t] (3.1.3 and 3.4), PV annual power generation: 4455 [kWh] (3.2), PV lifetime: 25 [years] (3.2), Amount of industrial waste from a petrol station demolition: 2.5 [t/m2] (3.4), Ground area of a petrol station: 1000 [m2] (3.4), Target area for fuel cycle: Japanese average of Fig. 6 (3.5), Annual driving distance of vehicles: 9100 [m] – Japanese average (3.5.2), Tire replacements: 3 times (3.5.3), Engine oil replacements: 19 times (3.5.3), Lead acid battery replacements: 3 times (3.5.3)
Minimum CO2 case	Gross floor area of a detached owned house: 99 [m2] (3.1.1), Target area for dwelling stage: Kyushu area of Fig. 2 (3.1.2), Amount of industrial waste from a house demolition: 0.6 [t/m2] (3.1.3), Price of industrial waste: 1000 [JPY/t] (3.1.3 and 3.4), PV annual power generation: 5046 [kWh] (3.2), PV lifetime: 30 [years] (3.2), Amount of industrial waste from a petrol station demolition: 1.9 [t/m2] (3.4), Ground area of a petrol station: 500 [m2] (3.4), Target area for fuel cycle: Kanto area of Fig. 6 (3.5), Annual driving distance of vehicles: 8400 [m] – Kanto area (3.5.2), Tire replacements: 3 times (3.5.3), Engine oil replacements: 18 times (3.5.3), Lead acid battery replacements: 3 times (3.5.3)
Maximum CO2 case	Gross floor area of a detached owned house: 165 [m2] (3.1.1), Target area for dwelling stage: Tohoku area of Fig. 1 (3.1.2), Amount of industrial waste from a house demolition: 1 [t/m2] (3.1.3), Price of industrial waste: 10000 [JPY/t] (3.1.3 and 3.4), PV annual power generation: 3863 [kWh] (3.2), PV lifetime: 20 [years] (3.2), Amount of industrial waste from a petrol station demolition: 3.1 [t/m2] (3.4), Ground area of a petrol station: 1500 [m2] (3.4), Target area for fuel cycle: Chubu area of Fig. 6 (3.5), Annual driving distance of vehicles: 9400 [m] – Chubu area (3.5.2), Tire replacements: 3 times (3.5.3), Engine oil replacements: 19 times (3.5.3), Lead acid battery replacements: 3 times (3.5.3)

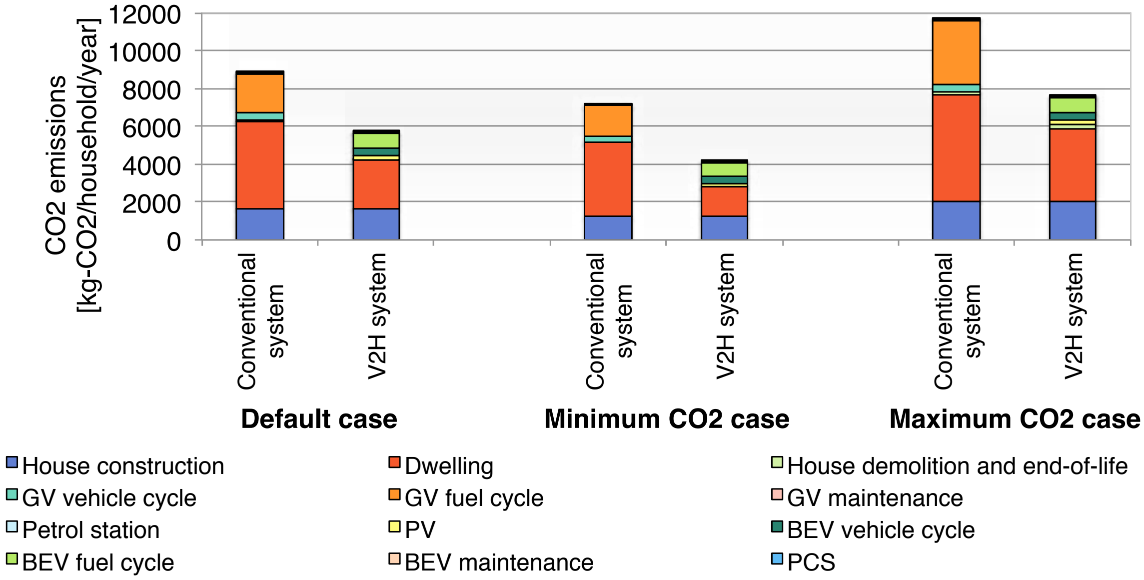

Figure 6: LCCO2 emissions from conventional and V2H system

emissions from lead acid battery production are 18 [kg-CO2].

- For the lithium ion battery mounted on the assumed BEV, no replacement is required during their lifetime by considering the cycle life of the battery.

3.6 LCCO2 Emissions of the Target Systems

The potential LCCO2 emissions of the target system can be estimated by summing all the CO2 emissions from the components and their life cycle stages as shown in Table 1. The emissions vary by the assumptions made; therefore a sensitivity analysis is conducted in this study to capture the minimum and maximum LCCO2 emissions to indicate potential variation. We assumed 3 cases for the calculation whose parameter settings are shown in Table 4.

Fig. 6 depicts the potential LCCO2 emissions of the target systems. The estimated emissions from V2H system are 5.7 [t-CO2/household/year], which show 36% reduction compared with the baseline conventional system of 8.9 [t-CO2/household/year] for the default case. The emissions of minimum CO2 case are 4.1 and 7.2 [t-CO2/household/year] for V2H and conventional systems, while they are 7.6 and 12 [t-CO2/household/year] for maximum CO2 case, respectively. Such findings as follows can also be made from Fig. 6 regarding the CO2 emissions of the V2H system:

- The largest contributor of CO2 emissions is the residential energy use, which accounts for 38—55% of the total emissions.
- Emissions from residential house construction stage accounts for 17—30% of the total CO2 emissions.
- Fuel cycle and vehicle cycle of BEV account for 10—17% and 6—10% of the total CO2 emissions and those of GV account for 22—29% and 3—5% respectively.
- PV production and end-of-life account for 4% of the emission from the V2H system.
- The emissions from other stages (house demolition, maintenance stages of vehicles, petrol station construction and demolition, PCS production) are smaller than 2% of those from the target system in any cases in Fig. 6, which indicates that those can be excluded from the system boundary.

4 Conclusion and Discussions

In order to approximate the potential CO2 emissions from a V2H system and its conventional counterpart, a LCI study is conducted in this study and LCCO2 emissions of the target systems are evaluated. The result indicates that 35—42% CO2 reduction can be expected by a V2H system using a PV system and a BEV in comparison with the conventional residential house using a GV. Since the main contributors to CO2 emissions of both systems are dwelling, residential house construction, vehicle cycle and fuel cycle stages, it can be said that these components and their life

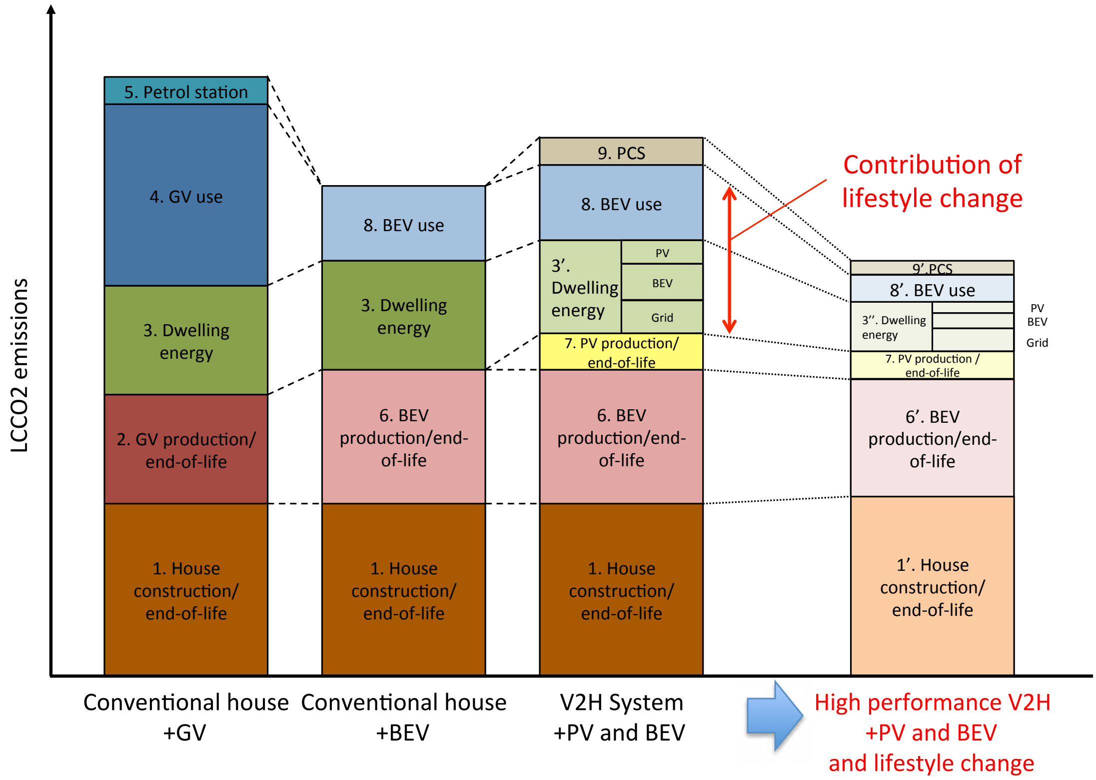

Figure 7: The system boundary framework and CO2 emissions for V2H system evaluation

cycle stages should be included in the system boundary of V2H system when conducting LCAs. It also indicates that it is important to select and design the appropriate components of these stages to assure the environmental merits of V2H system.

Fig. 7 shows an example of the system boundary for a LCA of V2H system and its potential CO2 emissions. If a household substitutes a BEV for a GV (comparison of "Conventional house + BEV" with "Conventional house + GV" in Fig. 7), the dwelling energy use will not change and only the difference between the targets is either using a GV or a BEV, whose differential is almost equivalent to conventional LCA studies comparing LCCO2 emissions of GV and BEV. The comparison made in this study corresponds to extending the system boundary, which includes all the CO2 emissions from potential life cycle stages of a V2H with a PV system and its counterpart conventional system (comparison of "V2H + PV and BEV" with "Conventional house + GV" in Fig. 7).

It should be noted again that our estimation in this study uses the data obtained by statistics and literature surveys and neither by the actual V2H system nor the conventional system due to some data restrictions. For a more detailed analysis of a V2H system, we think it necessary to use the raw data obtained from the actual system for the calculation, if available. Especially for the residential house of a V2H system, its heat insulation and air tightness properties are usually better than the conventional house, which may lead to more CO2 emissions from the house construction stage but less emissions from the dwelling stage.

Also it is likely that the people living in such high value-added houses as V2H may have a higher awareness for energy saving and the energy use for living and vehicle use may be reduced according to their change in their lifestyle. As shown in "High performance V2H + PV and BEV + lifestyle change" of Fig. 7, it is therefore recommended to conduct a consequential LCA study and discuss the environmental merit of an actual V2H system, which considers all the causal effect induced by introduction of V2H system and includes the indirect effects into the estimation.

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