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Authors Zhao, Hengbing Burke, Andy

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Fuel Cell Powered Vehicles Using Supercapacitors

-- Device Characteristics, Control Strategies, and Simulation Results

Hengbing Zhao[†] hbzhao@ucdavis.edu Andrew F. Burke <u>afburke@ucdavis.edu</u>

Institute of Transportation Studies University of California One Shield Avenue, Davis California 95616

Abstract

The fuel cell powered vehicle is one of the most attractive candidates for the future due to its high efficiency and capability to use hydrogen as the fuel. However, its relatively poor dynamic response, high cost, and limited life time have impeded its widespread adoption. With the emergence of large supercapacitors (also know as ultracapacitors, UCs) with high power density and the shift to hybridization in the vehicle technology, fuel cell/supercapacitor hybrid fuel cell vehicles are gaining more attention. Fuel cells in conjunction with supercapacitors can create high power with fast dynamic response, which makes it well suitable for automotive applications. Hybrid fuel cell vehicles with different powertrain configurations have been evaluated based on simulations performed at the Institute of Transportation Studies, University of California-Davis. The following powertrain configurations have been considered:

(a) Direct hydrogen fuel cell vehicles (FCVs) without energy storage
(b) FCVs with supercapacitors directly connected in parallel with fuel cells
(c) FCVs with supercapacitors coupled in parallel with fuel cells through a DC/DC converter
(d) FCVs with fuel cells connected to supercapacitors via a DC/DC converter

(d) FCVs with fuel cells connected to supercapacitors via a DC/DC converter

Simulation results show that hybridization of fuel cell vehicles with supercapacitors with load leveling control can significantly reduce the stress on fuel cells electrically and mechanically and benefit fuel economy of the vehicles. Compared to fuel cell vehicles without energy storages, fuel cell-supercapacitor hybridization achieved fuel economy increases of up to 28% on the FUDS cycle and up to 24% on the US06 cycle for mid-size passenger vehicles. In general, the maximum fuel economy improvements are greater using supercapacitors than batteries. The simulation results show that the power assist control strategy is better than load-level control for batteries because of the lower losses in the DC/DC converter and batteries, but load level control is better for supercapacitors. The best approach for hybridization of the fuel cell vehicles is to use supercapacitors with load leveled control as it greatly mitigates the stress on fuel cells and results in a near maximum improvement in fuel economy and fuel cell durability.

Key words: fuel cell vehicles, fuel cell system, hybridization, supercapacitors, load leveling, power assist

1. Introduction

For reducing green house (GHG) gas emissions and fossil oil consumption, the development of next generation light duty vehicles (LDVs) has been accelerated by the government and private

sectors since early 2000s. Hybrid electric vehicles (HEVs), plug-in hybrids (PHEVs), fuel cell vehicles (FCVs), battery electric vehicles (BEVs), alternative fuel (biofuel) vehicles have been developed. Electric drive vehicles such as BEVs and FCVs appear to the best options for reaching the goal of GHG reduction. The research and development has focused mainly on hydrogen fuel cells and batteries. Hydrogen is not a primary fuel. Like electricity used to charge batteries, it is an energy carrier and the hydrogen must be produced from another energy source and stored onboard the vehicle.

In automotive applications, fuel cell systems must be able to adapt to challenging operating conditions such as frequent start-up and stop and sudden change and widely varying power demand. These conditions are much easier to cope with if the fuel cell system is hybridized using batteries and/or ultracapacitors. In addition to mitigating the stress on the fuel cell via load leveling, the energy storage permits the capture of regenerative braking energy, which will benefit vehicle fuel economy and can potentially permit downsizing the fuel cell system. Different approaches to hybridizing fuel cells and energy storage technologies have been developed. It is of interest to simulate and evaluate these different hybridization configurations with different energy storage arrangements.

Considering hybridization of fuel cell vehicles, designers have a number of choices to consider. These alternatives include the physical arrangement of the power sources, selection of the energy storage technology and devices, and the control strategy for splitting power between the fuel cell and the energy storage unit. Hybridizing fuel cell vehicles with energy storage has been extensively studied in terms of powertrain arrangements [1-9], power source sizing [6,10-13], and energy management strategies [1,2,4,8,14,15]. Evaluations of these alternatives include the type/class of vehicle, fuel economy/consumption, and performance and cost of the vehicle.

In this paper, the performance and fuel consumption of mid-size hybrid fuel cell vehicles are simulated for different power source configurations using a fuel cell vehicle program recently developed [16,17] at the Institute of Transportation Studies, University of California-Davis. The following fuel cell powertrain arrangements are considered:

Direct hydrogen fuel cell vehicles (FCVs) without energy storage FCVs with supercapacitors directly connected in parallel with the fuel cell FCVs with supercapacitors coupled in parallel with the fuel cell through a DC/DC converter FCVs with the fuel cell connected to supercapacitor dc-link via a DC/DC converter

These powertrain configurations are analyzed over the FUDS and US06 driving cycles. Simulations of fuel cell vehicles with different size of energy storage and fuel cell units are performed and analyzed. The evaluations focus on fuel economy/consumption and component /system efficiency for the same size vehicles having the same road load characteristics. Complexity and cost are not considered in the analysis.

2. Supercapacitor Characteristics

With the shift to hybridization in the late 1990s, energy storage technology for HEVs, PHEVs and FCVs has been extensively developed. Significant advances in terms of performance, lifetime and cost have been achieved. It is of interest to compare these technologies in terms of energy storage and power handling capacity. The Ragone plot of these technologies [18,19] is given in Figure 1. The solid lines show the current status and the dotted lines give an estimated

future potential of different technologies. The sloping lines indicate the ratio of power density and energy density (P/E) of the technologies, which is an indication of their relative charging and discharging times. The supercapacitors can deliver very high power and be charged in a few seconds but have limited energy storage capacity. Lithium batteries can store 10-30 kWh and be completely charged and discharged in 10-20 minutes and can provide high pulse power for a few seconds much like capacitors, but with greater losses. On the other hand, the hydrogen fuel cell system has a very high system energy density due primarily to the characteristics of the hydrogen fuel and can deliver high power for long periods, but has relatively poor dynamic response due to the compressor needed to provide the air at the cathode of the fuel cell. Hence none of the technologies meets all of the needs of electric drive vehicles. Considering the need for long range between refueling and the ability to cope with rapid changes in power demand and frequent capture of regenerative braking energy, the combination of fuel cells and supercapacitors/batteries can take advantage of the strengths of each of the technologies and achieve performance in automotive applications better than that of internal combustion engines. Lithium batteries having relatively high energy density and high power density are ideal power sources for BEVs and PHEVs.



Supercapacitors have been developed since the early 1990s. Large supercapacitors with cell capacitance ranging from 1000 Farad to 5000 Farad are commercially available from several companies including Maxwell, Ness, Power Systems, and Panasonic. The characteristics of these devices are summarized in Table 1 taken from [20]. Most of these supercapacitors utilize activated carbon and an organic electrolyte with cell voltages of 2.5-2.7V. Their useable energy density varies from 4-4.5 Wh/kg. Prototype cells with higher energy density (8-12 Wh/kg) utilize advanced carbons permitting higher voltage (3.3-3.8V). The supercapacitors have low resistance resulting in low charge and discharge losses and associated high power densities of 1000-2500 W/kg for 95% efficient pulses. As indicated in Table 2, lithium batteries also have high pulse power, but not as high as that of most supercapacitors. The highest power density lithium batteries are the lithium titanate oxide (LiTiO) cells from Altairnano. The devices used in the simulations in later sections of the paper are based on the carbon supercapacitor from APowerCap and the graphite/NiCoMnO2 Li-ion cells from EIG.

	v	C (F)	R	RC (sec)	Wh/kg †	W/kg -	W/kg	Wgt.	Vol. lit.
Device	Rated		(mOhm)			95% ††	Match.	(kg)	
							Imped.		
Maxwell*	2.7	2885	0.375	1.08	4.2	994	8836	0.55	0.414
Maxwell	2.7	605	0.9	0.55	2.35	1139	9597	0.2	0.211
ApowerCap**	2.7	55	4	0.22	5.5	5695	50625	0.009	
Apowercap**	2.7	450	1.4	0.58	5.89	2574	24595	0.057	0.045
Ness	2.7	1800	0.55	1	3.6	975	8674	0.38	0.277
Ness	2.7	3640	0.3	1.1	4.2	928	8010	0.65	0.514
Ness (cyl.)	2.7	3160	0.4	1.26	4.4	982	8728	0.522	0.38
Asahi Glass	2.7	1375	2.5	3.4	4.9	390	3471	0.21	0.151
(propylene carbonate)								(estimated)	
Panasonic	2.5	1200	1	1.2	2.3	514	4596	0.34	0.245
(propylene carbonate)									
EPCOS	2.7	3400	0.45	1.5	4.3	760	6750	0.6	0.48
LS Cable	2.8	3200	0.25	0.8	3.7	1400	12400	0.63	0.47
BatScap	2.7	2680	0.2	0.54	4.2	2050	18225	0.5	0.572
Power Sys. (activated carbon,	2.7	1350	1.5	2	4.9	650	5785	0.21	0.151
propylene carbonate) **									
Power Sys. (graphitic carbon,	3.3	1800	3	5.4	8	486	4320	0.21	0.15
propylene carbonate) **	3.3	1500	1.7	2.5	6	776	6903	0.23	0.15
Fuji Heavy Industry- hybrid	3.8	1800	1.5	2.6	9.2	1025	10375	0.232	0.143
(AC/graphitic Carbon) **									
JSR Micro (AC/graphitic	3.8	1000	4	4	11.2	900	7987	0.113	0.073
carbon)**		2000	1.9	3.8	12.1	1038	9223	0.206	0.132

Table 1 Summary of performance characteristics of supercapacitor devices [20]

 $\dagger~$ Energy density at 400 W/kg constant power, $V_{\it rated}$ to $V_{\it rated}/2$

†† Power based on $P = 9/16 \cdot (1 - EF) \cdot V^2 / R$, EF = efficiency of discharge

- * Except where noted, all the devices use acetonitrile as the electrolyte
- ** All device except those with ** are packaged in metal containers, these devices are in laminated pouches

Battery Developer	Electrode	Voltage	Ah	Resist.	Wh/kg	W/kg	Wgt.	Density
/Cell type	chemistry	range	F	mOhm		90% effic.‡	(kg)	gm/cm3
Supercap	Activated	2.7	450F	1.4	5.5	5150	0.057	1.3
Apowercap	carbon							
Supercap	Advanced	3.8	2000F	1.9	12	2080	0.206	1.6
JSR micro	carbon							
Kokam	Graphite/	4.1-3.2	30	1.5	140	1220	0.787	2.4
prismatic	NiCoMnO2							
Saft	Graphite/	4.0-2.5	6.5	3.2	63	1225	0.35	2.1
Cylind.	NiCoA1							
A123	Graphite/Iron	3.6-2.0	2.2	12	90	1393	0.07	2.2
Cylind.	Phosph.							
Altaimano	LiTiO/	2.8-1.5	11	2.2	70	990	0.34	1.83
prismatic	NiMnO2							
Altaimano	LiTiO/	2.8-1.5	3.8	1.15	35	2460	0.26	1.91
prismatic	NiMnO2							
EIG	Graphite/	4.2-3.0	20	3.1	165	1278	0.41	
prismatic	NiCoMnO2							
EIG	Graphite/Iron	3.65-2.0	15	2.5	113	1100	0.42	
prismatic	Phosph.							
Panasonic EV	Ni Metal	7.2-5.4	6.5	11.4	46	395	1.04	1.8
prismatic	hydride							

Battery power density at full charge, $P = Eff.*(1-Eff.) Voc^2/R$ Supercapacitor power density, $P = 9/16*(1-Eff.) Voc^2/R$

3. Fuel Cell Systems, Fuel Cell Vehicles and Control Strategies

3.1 Optimal Operation Conditions

As a next generation power source for automotive applications, fuel cells can deliver electricity with high efficiency. However, the operation of the on-board auxiliaries such as the air supply compressor, cooling pump and radiator fan can significantly affect the performance of fuel cell system. Hence the operating strategy and resultant transients of the fuel cell system can have a significant impact on the system efficiency and thus vehicle fuel economy. There are two operating modes for the fuel cell system: fixed back pressure operation and optimum varying back pressure operation. In both modes, the air flow stoichiometry is optimized to maximize net output power and efficiency of the fuel cell system [16]. The optimum varying back pressure operation of a fuel cell system requires varying the back pressure and air supply stoichiometry as the power demand changes.

Figure 2 shows a plot of optimized net system efficiency vs. net power for a 106 kW fuel cell stack and a 17 kW twinscrew compressor operating at fixed back pressures of 1.1 atm, 1.5 atm, and 2.0 atm and optimum varying back pressure. Compared to fixed back pressure operation, the fuel cell system with the optimum varying back pressure operation can achieve higher system efficiency over the entire operating power range and maximize the system output power. It can be seen that the peak efficiency of a fuel cell system occurs near 25% of rated power for fixed high back pressure operation and 13% of rated power for the optimal operation. The efficiency of the fuel cell system is significantly lower in the very high or very low output power regions due to the high compressor power requirement in the high power region and low compressor efficiency in the low power region. Therefore, properly sizing the fuel cell system based on the average driving power instead of the maximum power required for acceleration can benefit fuel economy of hybrid fuel cell vehicles. Optimum varying back pressure operation analysis.



Figure 2 Optimized fuel cell system efficiency vs. net power

3.2 Fuel Cell Vehicle Powertrain Configurations

The optimal operation of a fuel cell system requires varying the back pressure and air supply stoichiometry ratio according to the change of the power demand. These rapid changes in the operating conditions of the fuel cell stack can have a major impact on the lifetime of the fuel cell stack due to the mechanical stresses on the MEA and the stack accessory components. Hybridization of fuel cell vehicles with energy storage can mitigate this stress and achieve better fuel economy. Considering hybridization of fuel cell vehicles, designers have many choices. These alternatives include the physical arrangement of the power sources, selection of the energy storage technology and devices, and the control strategy for splitting power between two power sources. There are several practical arrangements of power sources. Each of the power sources arrangements has its advantages and disadvantages relative to operating conditions, control complexity, development cost, vehicle performance, and fuel economy potential. Figure 3 illustrates schematically the fuel cell powertrain arrangements considered in this paper.



Figure 3 Powertrain configurations for fuel cell vehicles

(a) <u>Direct hydrogen fuel cell vehicles without energy storage.</u> This configuration is the simplest. No DC/DC converter is employed to control the DC-link voltage. The fuel cell stack voltage is the DC-link voltage. Because the dependency of fuel cell output current on

the reactant flow rate limits its response to load transients, this configuration requires a bigger fuel cell stack and fast reactant supply system to satisfy a large variations in load power. The DC-link voltage has a large swing due to the slow response of the fuel cell system. This configuration is used as the baseline for comparing different powertrain configurations.

(b) <u>FCVs with supercapacitors directly connected to fuel cells</u>. The supercapacitors are directly connected in parallel with the DC-link (fuel cell stack). In this case, the voltages of the energy storage unit and fuel cell are equal. The relatively soft voltage-current characteristics of fuel cells allow supercapacitors to operate over a fairly wide range of voltage and to self regulate the DC-link voltage fluctuation. The supercapacitors will absorb the excess power from the stack and the regenerative braking energy and provide a fraction of transient power for vehicle acceleration. A diode is utilized before the fuel cells for preventing the DC-link from back feeding the fuel cells during vehicle regenerative braking. This configuration is less costly, less complex and more efficient.

(c) <u>FCVs with energy storage such as supercapacitors or batteries coupled in parallel with</u> <u>fuel cells through a DC/DC converter.</u> The fuel cell voltage is the DC-link voltage. The transient power provided by the energy storage is regulated by a DC/DC converter. The introduction of the DC/DC converter can maximize the utilization of supercapacitors or batteries during acceleration and cruise and regenerative braking. This configuration permits controlling the transient power from the fuel cell by applying different power split strategies such as power-assist or load-leveling control to mitigate the stress on the fuel cell stack [21]. The state of charge (SOC) of supercapacitors or batteries can be directly controlled within appropriate levels.

(d) <u>FCVs with the fuel cell coupled with energy storage unit through a DC/DC converter</u>. The energy storage voltage is the DC-link voltage. The steady power provided by the fuel cell passes through the DC/DC converter. The converter regulates the fuel cell power to avoid large fluctuation of the DC-link voltage. The SOC can be controlled indirectly.

Various FCV developers use different powertrain configurations and energy storage technology in their vehicles. There is a need to model the various fuel cell vehicle configurations and to simulate their performance/hydrogen consumption for different size fuel cell stacks and type and size of energy storage unit.

In practical applications, it is not necessary to maintain a constant DC-link voltage. A relatively slow change of the DC-Link voltage is acceptable for control purposes. In this study, the four fuel cell vehicle configurations (a-d) are evaluated via vehicle simulations. Supercapacitors are used in configurations (b), (c) and (d). NiMH and Li-ion batteries are utilized in the configuration (c) for comparison with the systems using supercapacitors.

3.3 Power Splitting Control Strategies

The fuel cell operation (power, voltage, current vs. time) and hydrogen consumption (fuel economy) are closely related to the strategy utilized to split power between the fuel cell and the energy storage as the vehicle is operated over various driving cycles. The general objective of any control strategy is to operate the fuel cell system only in its high efficiency region, avoiding operation in the very low power and very high power regions. Power assist and load leveling control strategies can be used in hybrid fuel cell vehicles. Power assist control splits the power/current demand of the traction motor i_{motor} based on the fuel cell voltage V_{fc} and the

energy storage SOC. The current command for the energy storage device i_{ess} is expressed in equation (1) with the fuel cell providing the remaining current (equation 2).

$$i_{ess} = f_{fc}(V_{fc}) \cdot f_{ess}(SOC) \cdot i_{motor}$$
(1)
$$i_{fc} = i_{motor} - i_{ess}$$
(2)

where f_{fc} and f_{ess} are factors related to fuel cell voltage and energy storage device *SOC*, respectively. If the fuel cell voltage remains relatively high, it will provide most of the current to the motor. When the fuel cell voltage becomes low, the energy storage device will provide a large fraction of the current demanded by the motor.

In load leveling control, the fuel cell provides relatively steady power and the energy storage device provides transient power. The fuel cell current command i_{fc} is calculated by averaging

the traction motor current i_{motor} over a specified time period such as 60 seconds.

$$i_{fc} = i_{av,60sec}$$
(3)
$$i_{ess} = i_{motor} - i_{av,60sec}$$
(4)

The implementation of the control strategies for power split is schematized in Figure 4. Both control strategies maintain the *SOC* of the supercapacitor or battery within a specified range. Compared to the power assist control, load leveling control permits the fuel cell to operate within a relatively narrow high efficiency region. This mitigates the stress on the fuel cell and maximizes fuel cell life by utilizing the energy stored in the supercapacitor or battery to meet high power transients. However, a significant fraction of the transient power passes through the DC/DC converter for leveling the fuel cell current, which introduces significant losses in the power electronics. A previous study [21] study showed that the load leveling approach can improve vehicle fuel economy over most of driving cycles.



Figure 4 Schematic of power split control

For fuel cell vehicles with supercapacitors coupled directly in parallel with the fuel cell, no dc/dc converter is employed. The voltages of the supercapacitor unit and fuel cell are equal. The current of the supercapacitors is governed by the differential equation (5).

$$\frac{dV}{dt} = \frac{i_{cap}}{C} + R_{cap} \frac{di_{cap}}{dt}, \ \frac{dV_{cap}}{dt} = \frac{dV_{fc}}{dt}$$
(5)

4. Vehicle simulation

Simulations of the operation of hybrid fuel cell vehicles using various powertrain arrangements and energy storage technologies (supercapacitors and NiMH and Li-ion batteries) were performed using the UCD fuel cell vehicle simulation program [16,17]. The UCD fuel cell vehicle model is

a forward-looking vehicle model developed using Matlab-Simulink[®], which can simulate both the dynamics of the fuel cell system and the vehicle. Simulations were performed using both the power assist and load leveling control strategies. In the case of the load leveling control strategy, the fuel cell provides the average power requested by the vehicle over a specified period and the transient behavior of the air supply system can be ignored when the energy storage is coupled with fuel cell through power electronics. In that case, the quasi-steady model of the fuel cell operation was employed.

In addition to the choice of powertrain arrangements and energy storage technologies, the simulation have been run with different sizes (kW) of fuel cells and energy storage (Ah or Wh) in order to evaluate the potential of downsizing the fuel cell as a means of reducing system cost. The characteristics of the vehicle, energy storage and the fuel cell system are listed in Table 3. Increasing the averaging time in the load leveling control strategy leads to a larger fraction of transient power passing through the energy storage unit and results in greater losses in the charging and discharging of the energy storage unit. In this study, a 60-second simple moving average is used for leveling the power requirement for the fuel cell system.

Regenerative braking is limited by the maximum power of the traction motor and maximum *SOC* and voltage limits of the energy storage units. Permitting a large battery *SOC* swing can lead to a shortened cycle life for NiMH and Li-ion batteries. Hence the battery *SOC* is limited to the range between 0.6 and 0.8. In addition, the regenerative braking currents are limited to protect the batteries from over voltage. The minimum voltage of the supercapacitor is set as 50 percent of its rated voltage. The maximum usable energy is then 75 percent of the total energy stored in the capacitor. The supercapacitor *SOC* = 1- [($V_{rated} - V$)/($V_{rated}/2$)] is controlled to be between 0.98 and 0.1. Empirical data of an APowerCap 450 F supercapacitor and an EIG NiCo 20 Ah Li-ion cell obtained from testing at UC Davis are utilized and scaled in the energy storage unit models (see Table 2). Data files for the NiMH battery in ADVISOR were used for that battery.

	Case 1	Case 2
Vehicle and System Parameters		
Drag Coefficient	0.3	0.3
Frontal Area (m2)	2.2	2.2
Rolling Resistance	0.01	0.01
Vehicle Hotel Load (kW)	0.3	0.3
Vehicle Mass without energy storages (kg) §	1500	1460
Electric Motor (kW)	75	75
Fuel Cell Stack and Auxiliaries		
Max. Net Power (kW)	87.6	58.4
Gross Power (kW)	106	71
Number of Cells	440	440
Cell Area (cm2)	510	340
Compressor (kW)	17.2	13.5
Energy Storages		
Supercapacitor Capacity (Wh)	80/100/12	:0/150/200
Supercapacitor Module No. in Series	1	50
Li-ion Battery Capacity (Ah)	6.0/7	.5/9.0
Li-ion Battery Module No. in Series	8	7
NiMH Battery Capacity (Ah)	6.0/7	.5/9.0
NiMH Battery Module (11 cells) No.	2	4

Table 3 Vehicle simulation parameters

[§] Without energy storage mass, recalculated based on the size and type of energy storages in the model.

Simulations were performed for mid-size vehicles without energy storage, with supercapacitors directly connected in parallel with the fuel cell, with the fuel cell connected to supercapacitor DC-Link via a DC/DC converter, and with supercapacitors, NiMH or Li-ion batteries coupled with the fuel cell through a DC/DC converter. All the powertrains were simulated in the same vehicle having the road load characteristics shown in Table 3 (column: case 1). A fuel cell stack having 440 cells with an active area of 510 cm² was used in the simulations. The fuel cell system employed a twinscrew compressor of 17.2 kW and generated a net output power of 87.6 kW. The total vehicle mass was adjusted to reflect the type and capacity of energy storage and was recalculated based on the specific energy of energy storage units. The rated traction motor power was 75 kW for all cases. An empirical efficiency map of a bi-direction DC/DC converter, indexed by the input/output voltage ratio and the output power, was employed in the model.

The simulation results for fuel cell vehicles with 60sec load leveling control over five FUDS and US05 cycles are summarized in Appendix I. The results show that hybridization with supercapacitors or batteries can improve the fuel economy of the fuel cell vehicles. The increases of the fuel cell system efficiency were small, about 1-3 percentage points for the fuel cell-supercapacitor hybridization with/without power electronics on both FUDS and US06 cycles, and 3-4 percentage points for hybridization with NiMH batteries or Li-ion batteries on both FUDS and US06 cycles. The increases of fuel cell system efficiency for fuel cell hybrids were much smaller than for conventional engine-hybrids for which the average engine efficiency is significantly increased by hybridization (by more than 50%).

It can also be seen that hybridization with supercapacitors can recover more regenerative braking energy than using batteries due to lower internal resistance and high power density of supercapacitors. The higher internal resistance of batteries not only limits the maximum braking power that batteries can absorb, but also introduces significant losses during charging and discharging batteries. Supercapacitors can achieve round-trip efficiency of 94-99% compared to 86-91% for Li-ion batteries and 82-87% for NiMH batteries on the FUDS and US06 cycles. Hence, supercapacitors are the best choice for load level control of fuel cells due to their high round-trip energy efficiency and high power density.



Figure 5 Fuel Economy Improvement of Various Fuel Cell-Supercapacitor Hybrid Vehicles on the FUDS cycle



Figure 6 Fuel Economy Improvement of Various Fuel Cell-Supercapacitor Hybrid Vehicles on the US06 cycle



Figure 7 Fuel Economy Improvement of Various Fuel Cell-Battery Hybrid Vehicles on the FUDS and US06 cycles

The improvement in fuel economy of hybrid fuel cell vehicles using supercapacitors and batteries with 60sec load leveling control over the FUDS and US06 cycles are shown in Figure 5-7 compared with fuel cell vehicles without energy storage. The fuel cell-supercapacitor hybrid configurations result in fuel economy improvement of 11-28% on the FUDS cycle and of 4-24% on the US06 cycle, even with small supercapacitors. Fuel cell/Li-ion battery hybrids achieved improvement of fuel economy of less than 6% due to the efficiency losses in the batteries. NiMH batteries are not suitable for fuel cell hybrids with load leveling control because the improvement of fuel cell system efficiency and the recaptured regenerative energy are completely offset by the efficiency losses in the batteries.

Fuel cell vehicles with supercapacitors connected directly in parallel with fuel cell achieved the highest fuel economy improvement due to elimination of losses in the DC/DC converter. Fuel economy improvements for the FUDS and US06 cycles increased with an increase of the supercapacitor Wh capacity because the larger supercapacitor unit can capture more regenerative braking energy. However, this improvement for the FUDS cycle tapers off for fuel cell vehicles having a DC/DC converter when the Wh capacity of supercapacitor reaches 120 Wh. Therefore, sizing the supercapacitor should consider both meeting the transient acceleration power demand and maximizing regenerative braking energy recovery for improving fuel economy.

The simulation results for the current, cathode back pressure and air mass flow rate of the fuel cell stack with/without supercapacitors and power electronics, are given in Figure 8, 9, and 10, respectively, for the US06 driving cycle. The results of fuel cell vehicles having NiMH or Li-ion batteries coupled to the fuel cell dc-link via a DC/DC converter are also plotted for comparison. A 60 second load leveling control was used in fuel cell hybrids with a DC/DC converter. Comparison of the simulated results indicated that the supercapacitors significantly load-leveled the fuel cell operation mitigating the stresses on the fuel cell electrically and mechanically. In addition, load leveling makes downsizing the fuel cell stack feasible. Fuel cell-battery hybrids achieved limited load leveling due to battery power limitations. The profiles of the supercapacitor/battery *SOC* in Figure 10 show that compared to the fuel cell-supercapacitor hybrid vehicles without power electronics, fuel cell vehicles having power electronics can utilize a large fraction of the energy stored in the capacitors.



Figure 8 Comparison of the fuel cell stack current of fuel cell vehicles with different powertrain arrangements on the US06 Cycle (60s load leveling)



Figure 9 Comparison of the fuel cell cathode back pressure of fuel cell vehicles with different powertrain arrangements on the US06 Cycle (60s load leveling)



Figure 10 Comparison of the fuel cell air mass flow rate of fuel cell vehicles with different powertrain arrangements on the US06 Cycle (60s load leveling)



Figure 11 Comparison of the Supercapacitor/battery SOC of fuel cell vehicles with different powertrain arrangements on the US06 Cycle (60s load leveling)



Figure 12 Fuel economy improvement on the FUDS cycle by downsizing the fuel cell system (60s load leveling)



Figure 13 Fuel economy improvement on the US06 cycle by downsizing the fuel cell system (60s load leveling)

The above simulations show that hybridization with supercapacitors/batteries can significantly reduce the fuel cell peak current requirement. This indicated that potential downsizing of the fuel cell system was possible. Downsizing fuel cell will shift the system peak efficiency to lower load region, which can potentially improve the average system efficiency for low power driving cycles, but decrease it over more aggressive driving cycles like the US06. Simulations with a lower power fuel cell were performed for the FUDS and US06 cycles. A fuel cell stack of 440 cells with active area of 340 cm² was utilized in the simulation. Simulation parameters are given in Table 3 (case 2). Compared to fuel cell vehicles with a larger fuel cell (case 1), the improvement of fuel economy for the FUDS and US06 cycles by downsizing the fuel cell system is given in Figure 12-13, respectively. The figures show that implementation of downsizing the fuel cell results in an improvement of 2-4% in fuel economy for the FUDS cycle and approximately 3% deterioration for the US06 cycles. Therefore, fuel cell system downsizing from 75 kW to 50 kW in a fuel cell-supercapacitor hybrid does not necessarily improve fuel economy like conventional hybrid vehicles. However, the main reason for downsizing the fuel cell is cost rather than fuel economy.

Vehicles with supercapacitors, NiMH and Li-ion batteries coupled with fuel cells via a DC/DC converter were also simulated using a power assist control strategy. The detailed simulation results for power assist control over 5 FUDS and US06 cycles are given in Appendix II. Figure 14-16 show the fuel economy improvements for hybridization with supercapacitors, NiMH batteries and Li-ion batteries, respectively. Compared to load leveling control, power assist control can significantly improve fuel economy for battery hybrids over the FUDS and US06 cycles due to less power losses in batteries using the power assist strategy. The results indicate that increasing the size of energy storage units slightly benefits fuel economy for both load level and power assist control. Table 4 lists some simulation results for comparison of different powertrain configurations and power splitting strategies. Fuel cell vehicles having supercapacitors coupled with fuel cells via a DC/DC converter with load leveling control is the best approach in term of improving fuel economy and mitigating the stress on the fuel cell.

Power assist control is well suited for the fuel cell-battery hybrids in terms of fuel economy improvement.

Powertrain Configuration	Fuel Economy FUDS/US06	Comments
Supercapacitors Connected to Fuel Cells Directly (120 Wh)	85.9/60.3	Highest fuel economy; Less costly; Moderate reduction in stress on fuel cells
Supercapacitors Coupled with Fuel	79.7/55.8 (Load Leveling, 60sec)	Suitable power splitting strategy: Load leveling;
Cells via a Converter (120 Wh)	80.1/57.9 (Power Assist)	High fuel economy and lowest stress on fuel cells
Li-ion Batteries Coupled with Fuel	70.6/51.8 (Load Leveling, 60sec)	Suitable power splitting strategy: Power Assist
Cells via a Converter (7.5 Ah)	77.0/54.5 (Power Assist)	High fuel economy and low stress on fuel cells

Table 4 Comparison of different powertrain configurations and power splitting strategies





Figure 14 Comparison of fuel cell-supercapacitor battery hybrids with load leveling (60sec) and power assist control over the FUDS and US06 cycles



NiMH Battery Coupled to FC DC-Link via a Converter

Figure 15 Comparison of fuel cell-NiMH battery hybrids with load leveling (60sec) and power assist control over the FUDS and US06 cycles



Figure 16 Comparison of fuel cell/Li-ion battery hybrids with load leveling (60sec) and power assist control over the FUDS and US06 cycles



Figure 17 Comparison of fuel cell stack current for fuel cell hybrid vehicles with load leveling (60sec) and power assist control

The profile of the fuel cell stack current in Figure 17 shows that supercapacitor hybridization with load leveling control significantly smoothes fuel cell current. Since a longer averaging time in load leveling control leads to higher fraction of transient power passing through energy storage, this increases losses and lower fuel economy. The fuel cell vehicles having a 120 Wh

supercapacitor and 7.5 Ah NiMH and Li-ion batteries coupled to the fuel cell via a DC/DC converter were run with different averaging times. The simulation results for FUDS and US06 cycles are summarized in Appendix III. The effect of the averaging time on fuel economy improvement on the FUDS and US06 cycles are given in Figure 18 and Figure 19, respectively. The simulation shows that increasing the averaging time increases fuel economy for fuel cell-supercapacitor hybrids due to the improvement of fuel cell system efficiency and the increase of captured regenerative energy, and will slightly decreases the fuel economy for fuel cell-battery hybrids. However, the averaging time has little effect on fuel economy when the averaging time is larger than 60 seconds.



Figure 18 Effect of moving average time on fuel economy improvement over the FUDS cycle



Figure 19 Effect of moving average time on fuel economy over the US06 cycle

5. Summary

Fuel cell hybrid vehicles with different powertrain configurations have been simulated on the FUDS and US06 cycles. Hybridization with supercapacitors can significantly reduce the stress on fuel cells through load leveling control. Compared to fuel cell vehicles without energy storage, fuel cell-supercapacitor hybrid vehicles can achieve a fuel economy increase of up to 28% on the FUDS cycle and up to 24% on the US06 cycle depending on the Wh capacity of the supercapacitor unit. Fuel cell vehicles with supercapacitors directly coupled in parallel with the fuel cell achieved the highest fuel economy improvement due to elimination of losses in the power electronics. Fuel cell vehicles having a DC/DC converter coupling the fuel cell and supercapacitors can utilize a large fraction of the energy stored in the supercapacitors for loadleveling the fuel cell. Power assist control is well suited for the fuel cell-battery hybrids in terms of fuel economy improvement because that mode of control reduces the losses in the DC/DC converter electronics and batteries. For both supercapacitors and batteries, the load leveling control strategy results in a greater mitigation of stress on the fuel cell than the power assist strategy. Fuel cell vehicles with supercapacitors coupled to fuel cells via a DC/DC converter is likely to be the best approach considering mitigating the stress on the fuel cell and achieving high fuel economy for optimal fuel cell system operation.

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Appendix I

Fuel cell hybrid vehicles with load leveling control (60sec) over five FUDS and US06 cycles (con'd) Case 1 (cell number: 440; cell active area: 510 cm²)

		FCVs	FCVs Ha	ing Ultrac	apacitors	Connecte	d to Fuel	FCVs Having Fuel Cells Connected to					
Powertrain		w/o	Cell DC-L	.ink via a D	DC/DC Ca	nverter		Ultracapa	citor DC-l	_ink via a D	DC/DC Ca	nverter	
Configuration		ESS	(APower(Cap)				(ApowerC	ap)				
ESS	Capacity		80 Wh	100 Wh	120 Wh	150 Wh	200 Wh	80 Wh	100 Wh	120 Wh	150 Wh	200 Wh	
FUDS: 5 cycle:	S	Λ						Λ					
Fuel Economy	mpgge	68.0	77.3	78.8	79.7	80.1	80.3	75.4	77.7	78.2	78.7	79.2	
Wheel	Regenerative	0.000	-2.693	-2.887	-3.003	-3.063	-3.124	-2.452	-2.771	-2.859	-2.952	-3.041	
Energy	Accelerating	7.141	7.168	7.179	7.192	7.211	7.244	7.171	7.177	7.188	7.206	7.240	
(kWh)	Mech. Brake	3.267	0.560	0.372	0.263	0.215	0.172	0.804	0.486	0.403	0.322	0.251	
DCDC & ESS	Loss (kWh)	0	0.65	0.65	0.64	0.64	0.64	0.72	0.73	0.72	0.72	0.71	
Motor	Regenerative	0.000	0.805	0.814	0.817	0.817	0.818	0.801	0.815	0.816	0.816	0.817	
Efficiency	Accelerating	0.784	0.770	0.770	0.771	0.771	0.771	0.770	0.770	0.771	0.771	0.771	
FCS	Efficiency	0.572	0.583	0.584	0.586	0.586	0.587	0.585	0.586	0.586	0.587	0.588	
DCDC	Charge eff		0.941	0.941	0.941	0.941	0.941	1.000	1.000	1.000	1.000	1.000	
Converter	Discharge eff		0.949	0.950	0.951	0.952	0.952	0.934	0.929	0.928	0.926	0.925	
Efficiency	Round-trip eff		0.893	0.894	0.895	0.896	0.896	0.934	0.929	0.928	0.926	0.925	
Energy	Charge eff		0.988	0.990	0.992	0.994	0.995	0.989	0.990	0.992	0.994	0.995	
Storage	Discharge eff		0.987	0.989	0.991	0.993	0.995	0.987	0.990	0.991	0.993	0.995	
Efficiency	Round-trip eff		0.975	0.980	0.983	0.987	0.990	0.976	0.980	0.984	0.987	0.990	
US06: 5 cycles		Λ						Λ					
Fuel Economy	mpgge	50.7	54.0	55.0	55.8	56.8	57.9	52.9	53.8	54.5	55.6	57.0	
Wheel	Regenerative	0.000	-1.685	-1.905	-2.091	-2.281	-2.492	-1.503	-1.690	-1.851	-2.065	-2.352	
Energy	Accelerating	11.418	11.443	11.452	11.462	11.474	11.520	11.461	11.471	11.483	11.488	11.529	
(kWh)	Mech. Brake	3.462	1.756	1.540	1.357	1.170	0.992	1.958	1.774	1.618	1.401	1.140	
DCDC & ESS	Loss (kWh)	0	0.58	0.59	0.59	0.59	0.57	0.74	0.71	0.69	0.66	0.61	
Motor	Regenerative	0.000	0.846	0.850	0.857	0.865	0.874	0.857	0.853	0.853	0.859	0.873	
Efficiency	Accelerating	0.870	0.860	0.860	0.860	0.860	0.860	0.860	0.860	0.860	0.860	0.860	
FCS	Efficiency	0.542	0.558	0.561	0.563	0.566	0.569	0.557	0.560	0.562	0.564	0.568	
DCDC	Charge eff		0.957	0.959	0.959	0.959	0.960	1.000	1.000	1.000	1.000	1.000	
Converter	Discharge eff		0.958	0.960	0.960	0.961	0.964	0.964	0.965	0.965	0.965	0.965	
Efficiency	Round-trip eff		0.917	0.920	0.921	0.921	0.925	0.964	0.965	0.965	0.965	0.965	
Energy	Charge eff		0.972	0.977	0.980	0.983	0.987	0.969	0.975	0.979	0.982	0.986	
Storage	Discharge eff		0.970	0.975	0.978	0.982	0.986	0.971	0.976	0.979	0.983	0.987	
Efficiency	Round-trip eff		0.943	0.952	0.958	0.965	0.973	0.941	0.951	0.958	0.965	0.973	

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								uine NiMLI	Dottorioo	Connocto	ving Li-ion dita Euclu	
Downstrain			. I litraaan	aaitara Ca	opported t	o Fuel	Connorte	ving Nimi Nito Euclu		Linkuin n		Cell DC-
Configuration			inti Diment	acitors of	Innecteu (u Fuei	Connecte		Cell DC-			
Configuration	0		INK DIRECT	iy (APowe	rCap)	200 \44	Link via a]	0.41
ESS	Сараску	80 vvn	100 Wh	120 Wh	150 Wh	200 vvn	ьAn	7.5 An	9 An	b An	7.5 An	19 An
FUDS: 5 cycle:	S											
Fuel Economy	mpgge	83.4	85.0	85.9	86.7	87.6	64.1	64.4	65.1	68.4	70.6	71.9
VVheel	Regenerative	-2.805	-2.985	-3.096	-3.212	-3.267	-1.149	-1.305	-1.492	-1.689	-2.008	-2.195
Energy	Accelerating	7.107	7.122	7.135	7.156	7.191	7.235	7.282	7.326	7.148	7.161	7.174
(KWh)	Mech. Brake	0.412	0.242	0.138	0.035	0.001	2.127	2.002	1.842	1.545	1.234	1.054
DCDC & ESS	Loss (kWh)	0.06	0.06	0.06	0.05	0.04	1.42	1.39	1.34	1.20	1.16	1.11
Motor	Regenerative	0.807	0.814	0.820	0.824	0.825	0.555	0.589	0.629	0.654	0.706	0.729
Efficiency	Accelerating	0.769	0.770	0.770	0.770	0.770	0.772	0.773	0.773	0.771	0.771	0.771
FCS	Efficiency	0.572	0.574	0.576	0.578	0.582	0.599	0.598	0.598	0.597	0.599	0.599
DCDC	Charge eff	1.000	1.000	1.000	1.000	1.000	0.918	0.925	0.929	0.927	0.934	0.936
Converter	Discharge eff	1.000	1.000	1.000	1.000	1.000	0.950	0.950	0.950	0.949	0.950	0.950
Efficiency	Round-trip eff	1.000	1.000	1.000	1.000	1.000	0.872	0.879	0.883	0.880	0.887	0.889
Energy	Charge eff	0.992	0.993	0.994	0.995	0.996	0.957	0.959	0.963	0.965	0.967	0.971
Storage	Discharge eff	0.991	0.992	0.993	0.994	0.995	0.880	0.896	0.908	0.923	0.933	0.942
Efficiency	Round-trip eff	0.983	0.985	0.987	0.988	0.991	0.842	0.859	0.874	0.891	0.903	0.914
US06: 5 cycles												
Fuel Economy	mpgge	58.9	59.6	60.3	61.4	63.2	50.5	50.1	49.7	52.1	51.8	52.0
Wheel	Regenerative	-1.991	-2.193	-2.363	-2.583	-2.873	-0.894	-0.814	-0.743	-1.113	-0.965	-1.018
Energy	Accelerating	11.362	11.384	11.400	11.421	11.454	11.483	11.533	11.583	11.356	11.376	11.389
(kvvh)	Mech. Brake	1.396	1.211	1.051	0.843	0.572	2.539	2.651	2.756	2.241	2.403	2.358
DCDC&ESS	Loss (kWh)	0.14	0.14	0.14	0.13	0.12	0.80	0.90	0.99	0.78	0.84	0.92
Motor	Regenerative	0.847	0.859	0.869	0.880	0.894	0.608	0.595	0.583	0.653	0.617	0.628
Efficiency	Accelerating	0.859	0.859	0.859	0.859	0.859	0.860	0.860	0.861	0.860	0.860	0.860
FCS	Efficiency	0.553	0.555	0.557	0.559	0.562	0.560	0.564	0.567	0.565	0.570	0.573
DCDC	Charge eff	1.000	1.000	1.000	1.000	1.000	0.933	0.945	0.957	0.953	0.966	0.967
Converter	Discharge eff	1.000	1.000	1.000	1.000	1.000	0.963	0.964	0.963	0.963	0.963	0.963
Efficiency	Round-trip eff	1.000	1.000	1.000	1.000	1.000	0.898	0.910	0.921	0.918	0.930	0.931
Energy	Charge eff	0.981	0.984	0.986	0.988	0.990	0.950	0.951	0.951	0.955	0.954	0.956
Storage	Discharge eff	0.981	0.983	0.984	0.986	0.989	0.861	0.864	0.867	0.902	0.906	0.909
Efficiency	Round-trip eff	0.963	0.967	0.970	0.974	0.979	0.818	0.822	0.824	0.861	0.864	0.869

Appendix II

										FCVs Hav	ving Li-lon	Batteries
		FCVs Ha	ving Ultrac	apacitors	Connecte	ed to Fuel	FCVs Ha	ving NiMH	Batteries	Connecte	d to Fuel (Cell DC-
Powertrain		Cell DC-L	_ink via a [DC/DC Ca	onverter		Connecte	ed to Fuel	Cell DC-	Link via a	DC/DC C	onverter
Configuration		(APower	Cap)				Link via a	DC/DC C	onverter	(EIGNiCo)	
ESS	Capacity	80 Wh	100 Wh	120 Wh	150 Wh	200 Wh	6 Ah	7.5 Ah	9 Ah	6 Ah	7.5 Ah	9 Ah
FUDS: 5 cycle	s											
Fuel Economy	mpgge	78.1	79.2	80.1	80.8	81.4	73.8	74.6	75.4	76.0	77.0	77.9
Wheel	Regenerative	-2.6853	-2.8684	-3.0014	-3.1205	-3.237	-2.1476	-2.2688	-2.3863	-2.328	-2.4752	-2.6064
Energy	Accelerating	7.1644	7.1752	7.1872	7.2063	7.2387	7.2578	7.297	7.3358	7.1536	7.1664	7.1796
(kwh)	Mech. Brake	0.5652	0.3878	0.2611	0.1527	0.0546	1.1517	1.0531	0.9579	0.9115	0.7717	0.6482
DCDC & ESS	Loss (kWh)	0.32	0.33	0.34	0.34	0.34	0.27	0.26	0.26	0.26	0.27	0.27
Motor	Regenerative	0.8042	0.8117	0.816	0.8198	0.8232	0.7149	0.7331	0.7488	0.7454	0.7644	0.7784
Efficiency	Accelerating	0.77	0.7702	0.7703	0.7708	0.7711	0.7717	0.7722	0.7726	0.7702	0.7704	0.7705
FCS	Efficiency	0.5677	0.5677	0.5677	0.568	0.5685	0.5725	0.5725	0.5725	0.5725	0.5725	0.5725
DCDC	Charge eff	0.9452	0.9476	0.9499	0.9522	0.9551	0.8985	0.9116	0.9206	0.9179	0.9281	0.9355
Converter	Discharge eff	0.869	0.8742	0.8768	0.8787	0.8802	0.8663	0.8666	0.867	0.8674	0.8671	0.8666
Efficiency	Round-trip eff	0.8213	0.8285	0.8329	0.8367	0.8407	0.7783	0.79	0.7982	0.7962	0.8048	0.8107
Enerav	Charge eff	0.9909	0.9925	0.9936	0.9948	0.9959	0.9644	0.9665	0.968	0.9721	0.9739	0.9753
Storage	Discharge eff	0.9966	0.9971	0.9975	0.998	0.9985	0.9611	0.9688	0.9739	0.9788	0.9834	0.9863
Efficiency	Round-trip eff	0.9875	0.9896	0.9912	0.9927	0.9944	0.9269	0.9363	0.9428	0.9515	0.9578	0.9619
US06: 5 cvcles	5											
Fuel Economy	mpgge	56.2	57.3	57.9	58.7	59.6	51.6	51.7	52.1	53.7	54.5	55.2
Wheel	Regenerative	-2.1201	-2.3563	-2.5085	-2.6893	-2.9351	-1.0773	-1.1652	-1.3365	-1.4918	-1.6862	-1.8851
Energy	Accelerating	11.4419	11.4547	11.4661	11.4847	11.5163	11.4898	11.5395	11.5818	11.3742	11.3962	11.4164
(KVVh)	Mech. Brake	1.3205	1.0915	0.9451	0.7744	0.5461	2.3628	2.3069	2.1598	1.8806	1.7025	1.518
DCDC&ESS	Loss (kWh)	0.28	0.28	0.27	0.27	0.28	0.48	0.47	0.47	0.41	0.40	0.40
Motor	Regenerative	0.864	0.8805	0.8859	0.8948	0.9011	0.631	0.6495	0.6753	0.7069	0.74	0.7709
Efficiency	Accelerating	0.8593	0.8594	0.8594	0.8594	0.8595	0.86	0.8601	0.8602	0.8594	0.8594	0.8595
FCS	Efficiency	0.5505	0.5513	0.5514	0.552	0.5528	0.5554	0.5568	0.5574	0.5566	0.5577	0.5584
DCDC	Charge eff	0.947	0.9501	0.9498	0.9528	0.9559	0.9029	0.9115	0.919	0.9198	0.9319	0.9417
Converter	Discharge eff	0.9293	0.9323	0.9355	0.9381	0.9399	0.9355	0.9374	0.9385	0.9374	0.9386	0.9375
Efficiency	Round-trip eff	0.8801	0.8858	0.8885	0.8938	0.8985	0.8447	0.8544	0.8625	0.8623	0.8747	0.8828
Energy	Charge eff	0.9796	0.983	0.9855	0.9882	0.9909	0.9621	0.964	0.9654	0.9657	0.9664	0.9662
Storage	Discharge eff	0.9889	0.9906	0.9916	0.993	0.9946	0.9017	0.9132	0.9222	0.9361	0.9445	0.9533
Efficiency	Round-trip eff	0.9687	0.9738	0.9773	0.9813	0.9855	0.8675	0.8803	0.8903	0.904	0.9127	0.9211

Fuel cell vehicles with power assist control over five FUDS and US06 cycles Case 1 (cell number: 440; cell active area: 510 cm²)

Appendix III

Fuel cell vehicles with load leveling control over one FUDS and US06 cycles Case 1 (cell number: 440; cell active area: 510 cm^2)

		ECVs Ha	wing Elltra	ranacito	rs Conne	cted to Fi	uel Cell F	ECVs Hav	ina Euel (Cells Con	nected tr	Ultracar	acitor
		DC-Link	via a DC/	DC Conv	erter (AF	owerCap) (120	DC-Link vi	a a DC/E	C Conve	rter (Apo	werCap)	(120
Powertrain	Configuration	Wh)					<u>``</u>	/Vh)					`
ESS	Capacity	15s	30s	45s 🛛	60s ;	75s 9	90s (*	15s 3	30s -	45s	60s	75s -	90s
FUDS: 1 cycle													
Fuel Economy	mpgge	76.5	78.5	79.4	79.6	79.8	79.7	74.4	77.0	78.1	78.4	78.3	78.1
Wheel	Regenerative	-0.5333	-0.576	-0.5938	-0.5973	-0.5978	-0.5947	-0.4451	-0.5225	-0.5637	-0.5763	-0.5747	-0.5637
Energy	Accelerating	1.4379	1.4385	1.4386	1.4386	1.4387	1.4386	1.4374	1.4379	1.4379	1.4378	1.4383	1.4382
(KVVh)	Mech. Brake	0.1194	0.0774	0.0596	0.0561	0.0557	0.0588	0.2071	0.1303	0.0891	0.0764	0.0783	0.0893
Motor	LUSS (KVVII)	0.12	0.13	0.015	0.0105	0.0100	0.0100	0.7705	0.0010	0.14	0.0466	0.0170	0.0170
Efficiency	Accelerating	0.7973	0.0090	0.0153	0.0100	0.0169	0.0169	0.7705	0.0010	0.0130	0.0100	0.0170	0.0172
Enclency	Efficiency	0.7705	0.7703	0.7703	0.7705	0.7703	0.7705	0.7707	0.5854	0.7705	0.7705	0.5874	0.7705
	Charge eff	0.5770	0.3023	0.3040	0.3030	0.3003	0.3000	0.3004	0.3034	0.0001	0.3003	0.3074	0.3072
Converter	Discharge eff	0.0400	0.0402	0.9505	0.9502	0.9501	0.9505	0.9481	0.9405	0.9319	0.9287	0.9272	n 9289
Efficiency	Round-trip eff	0.8898	0.8988	0.8967	0.8953	0.8948	0.8951	0.9481	0.9405	0.9319	0.9287	0.9272	0.9289
Energy	Charge eff	0.9929	0.992	0.9917	0.9919	0.992	0.9921	0.9933	0.9928	0.9919	0.9919	0.9917	0.9923
Storage	Discharge eff	0.9925	0.9911	0.9909	0.991	0.9908	0.9908	0.9924	0.9912	0.991	0.9911	0.9909	0.9909
Efficiency	Round-trip eff	0.9854	0.9832	0.9826	0.983	0.9828	0.983	0.9858	0.9841	0.9829	0.9831	0.9827	0.9833
US06: 1 cycle		<i>n</i>		•					•				
Fuel Economy	mpgge	53.6	55.3	55.7	56.1	56.4	56.4	52.3	54.2	54.5	54.9	55.3	55.4
Wheel	Regenerative	-0.3617	-0.4103	-0.4221	-0.4341	-0.4461	-0.4472	-0.3035	-0.3705	-0.3772	-0.3941	-0.411	-0.4148
Energy	Accelerating	2.2931	2.2926	2.2924	2.2923	2.2918	2.2909	2.2953	2.2954	2.2952	2.2963	2.297	2.297
(kWh)	Mech. Brake	0.3287	0.2795	0.2675	0.2554	0.243	0.2411	0.3892	0.3222	0.3154	0.2997	0.2835	0.2798
DCDC&ESS	LOSS (KVVh)	0.13	0.13	0.0570	0.0010	0.0004	0.007	0.14	0.14	0.14	0.14	0.000	0.0724
Motor	Regenerative	0.8302	0.8558	0.8573	0.8616	0.8661	0.867	0.8359	0.852	0.859	0.8612	0.8664	0.8724
FCS	Efficiency	0.8594	0.8595	0.8595	0.663	0.8595	0.8595	0.8598	0.8599	0.8599	0.66	0.6627	0.8599
	Charge eff	0.0042	0.0004	0.0010	0.505 0.9591	0.0004	0.505	0.0011	0.0001	0.0007	0.0010	0.0027	0.0020
Converter	Discharge eff	0.000	0.0001	0.0004	0.0001	0.9597	ае п	0.9675	0.9647	0.9646	0.9646	0.9646	0.9645
Efficiency	Round-trip eff	0.9167	0.92	0.9212	0.9199	0.92	0.9201	0.9675	0.9647	0.9646	0.9646	0.9646	0.9645
Enerav	Charge eff	0.9782	0.9793	0.9795	0.9794	0.9797	0.9796	0.9745	0.9783	0.978	0.9781	0.9783	0.9776
Storage	Discharge eff	0.9787	0.9771	0.9772	0.9776	0.9771	0.9776	0.9791	0.978	0.9781	0.9784	0.9779	0.9783
Efficiency	Round-trip eff	0.9573	0.9569	0.9571	0.9574	0.9572	0.9577	0.9542	0.9568	0.9566	0.957	0.9567	0.9564
						•							
Powertrain		FCVs Ha	ving NiM⊦	- I Batterie	s (7.5 Ah) Connec	ted to	FCVs Ha	aving Li-la	on Batterie	es (7.5 A	h) Conne	cted to
Powertrain Configuration		FCVs Ha Fuel Cell	ving NiMF DC-Link	l Batterie via a DC/	s (7.5 Ah DC Conv) Connec verter	ted to	FCVs Ha Fuel Cel	aving Li-lo	on Batteria	es (7.5 A /DC Cor	h) Conne verter (E	cted to IGNiCo)
Powertrain Configuration ESS	Capacity	FCVs Ha Fuel Cell 15s	ving NiM⊦ DC-Link 30s	IBatterie via a DC/ 45s	s (7.5 Ah DC Conv 60s) Connec /erter 75s	ted to	FCVs Ha Fuel Cel 15s	aving Li-lo I DC-Link 30s	on Batterie via a DC 45s	es (7.5 A /DC Cor 60s	h) Conne verter (E 75s	cted to IGNiCo) 90s
Powertrain Configuration ESS FUDS: 1 cycle	Capacity	FCVs Ha Fuel Cell 15s	ving NiMH DC-Link 30s	l Batterie via a DC/ 45s	s (7.5 Ah DC Conv 60s) Connec /erter 75s	ted to	FCVs Ha Fuel Cel 15s	aving Li-lo I DC-Link 30s	on Batterie via a DC 45s	es (7.5 A /DC Cor 60s	h) Conne verter (E 75s	cted to IGNiCo) 90s
Powertrain Configuration ESS FUDS: 1 cycle Fuel Economy	Capacity	FCVs Ha Fuel Cell 15s 65.3	ving NiMH DC-Link 30s 63.7	HBatterie via a DC/ 45s 63.9	s (7.5 Ah DC Conv 60s 64.1) Connec verter 75s 64.1	ted to 90s 64.3	FCVs Ha Fuel Cel 15s 71.1	aving Li-lo I DC-Link 30s 69.8	on Batterie via a DC 45s 70.0	es (7.5 A /DC Cor 60s 70.3	h) Conne verter (E 75s 70.5	cted to IGNiCo) 90s 70.8
Powertrain Configuration ESS FUDS: 1 cycle Fuel Economy Wheel	Capacity mpgge Regenerative	FCVs Ha Fuel Cell 15s 65.3 -0.3249	ving NiMH DC-Link 30s 63.7 -0.2688	H Batterie via a DC/ 45s 63.9 -0.2712	s (7.5 Ah DC Conv 60s 64.1 -0.2751) Connec /erter 75s 64.1 -0.2763	ted to 90s 64.3 -0.2824	FCVs Ha Fuel Cel 15s 71.1 -0.4192	aving Li-lo I DC-Link 30s 69.8 -0.3757	on Batterie via a DC 45s 70.0 -0.3787	es (7.5 A /DC Cor 60s 70.3 -0.3859	h) Conne verter (E 75s 70.5 -0.3926	cted to IGNiCo) 90s 70.8 -0.3963
Powertrain Configuration ESS FUDS: 1 cycle Fuel Economy Wheel Energy	Capacity mpgge Regenerative Accelerating	FCVs Ha Fuel Cell 15s 65.3 -0.3249 1.4566	ving NiMH DC-Link 30s 63.7 -0.2688 1.4562	H Batterie via a DC/ 45s 63.9 -0.2712 1.457	s (7.5 Ah DC Conv 60s 64.1 -0.2751) Connec /erter 75s 64.1 -0.2763 1.4571	ted to 90s 64.3 -0.2824 1.4572	FCVs Ha Fuel Cel 15s 71.1 -0.4192 1.4322	aving Li-lo I DC-Link 30s 69.8 -0.3757 1.4322	on Batteria via a DC 45s 70.0 -0.3787 1.4325	es (7.5 A /DC Cor 60s 70.3 -0.3869 1.4325	h) Conne verter (E 75s 70.5 -0.3926 1.4324	cted to IGNiCo) 90s 70.8 -0.3963 1.4326
Powertrain Configuration ESS FUDS: 1 cycle Fuel Economy Wheel Energy (KWh)	Capacity mpgge Regenerative Accelerating Mech. Brake	FCVs Ha Fuel Cell 15s -0.3249 1.4566 0.3364	ving NiMI- DC-Link 30s 63.7 -0.2688 1.4562 0.3921	H Batterie via a DC/ 45s 63.9 -0.2712 1.457 0.3907	s (7.5 Ah DC Conv 60s 64.1 -0.2751 1.4571 0.3868) Connec /erter 75s 64.1 -0.2763 1.4571 0.3856	ted to 90s 64.3 -0.2824 1.4572 0.3795	FCVs Ha Fuel Cel 15s 3 71.1 -0.4192 1.4322 0.2288	aving Li-lo I DC-Link 30s -0.3757 1.4322 0.2723	on Batteria via a DC 45s -0.3787 1.4325 0.2697	es (7.5 A /DC Cor 60s 70.3 -0.3859 1.4325 0.2625	h) Conne verter (E 75s 70.5 -0.3926 1.4324 0.2557	cted to IGNiCo) 90s 70.8 -0.3963 1.4326 0.2521
Powertrain Configuration ESS FUDS: 1 cycle Fuel Economy Wheel Energy (kWh) DCDC & ESS	Capacity mpgge Regenerative Accelerating Mech. Brake Loss (kWh)	FCVs Ha Fuel Cell 15s -0.3249 1.4566 0.3364 0.233	ving NiMH DC-Link 30s 63.7 -0.2688 1.4562 0.3921 0.27 0.272	H Batterie via a DC/ 45s -0.2712 1.457 0.3907 0.281	s (7.5 Ah DC Com 60s 64.1 -0.2751 1.4571 0.3868 0.28) Connec verter 75s 64.1 -0.2763 1.4571 0.3856 0.2007	ted to 90s 64.3 -0.2824 1.4572 0.3796 0.28	FCVs Ha Fuel Cel 15s -0.4192 1.4322 0.2288 0.19	aving Li-lo IDC-Link 30s 69.8 -0.3757 1.4322 0.2723 0.22	on Batterie via a DC 45s -0.3787 1.4325 0.2697 0.238	es (7.5 A /DC Cor 60s 70.3 -0.3859 1.4325 0.2625 0.23	h) Conne verter (E 75s -0.3926 1.4324 0.2557 0.23 0.200	cted to IGNiCo) 90s 70.8 -0.3963 1.4326 0.2521 0.23
Powertrain Configuration ESS FUDS: 1 cycle Fuel Economy Wheel Energy (kWh) DCDC & ESS Motor Efficiency	Capacity mpgge Regenerative Accelerating Mech. Brake Loss (KWh) Regenerative Accelerative	FCVs Ha Fuel Cell 15s -0.3249 1.4566 0.3364 0.633 0.6637 0.772e	ving NiMI- DC-Link 30s 63.7 -0.2688 1.4562 0.3921 0.27 0.5939 0.7725	l Batterie via a DC/ 45s -0.2712 1.457 0.3907 0.28 0.5917 0.5275	s (7.5 Ah DC Conv 60s 64.1 -0.2751 1.4571 0.3868 0.599 0.599 0.775) Connec /erter 75s 64.1 -0.2763 1.4571 0.3856 0.28 0.6007	ted to 90s 64.3 -0.2824 1.4572 0.3796 0.26 0.6063 0.7726	FCVs Ha Fuel Cel 15s -0.4192 1.4322 0.2288 0.19 0.7203	aving Li-lo I DC-Link 30s -0.3757 1.4322 0.2723 0.22 0.6864 0.7705	on Batterie 45s 70.0 -0.3787 1.4325 0.2697 0.23 0.6865 0.6865 0.7706	es (7.5 A /DC Cor 60s 70.3 -0.3859 1.4325 0.2625 0.23 0.6956 0.7700	h) Conne verter (E 75s -0.3926 1.4324 0.2557 0.23 0.7009	cted to [GNiCo] 90s -0.3963 1.4326 0.2521 0.2521 0.7045 0.7705
Powertrain Configuration ESS FUDS: 1 cycle Fuel Economy Wheel Energy (KWh) DCDC & ESS Motor Efficiency FCS	Capacity mpgge Regenerative Accelerating Mech. Brake Loss (kWh) Regenerative Accelerating Efficiency	FCVs Ha Fuel Cell 15s -0.3249 1.4566 0.3364 0.23 0.6537 0.7726 0.5867	ving NiMH DC-Link 30s -0.2688 1.4562 0.3921 0.27 0.5939 0.7725 0.5939	Hatterie via a DC/ 45s -0.2712 1.457 0.3907 0.28 0.5917 0.7725 0.5017	s (7.5 Ah DC Com 60s 64.1 -0.2751 1.4571 0.3868 0.5999 0.7725 0.5725) Connec ////////////////////////////////////	ted to 90s 64.3 -0.2824 1.4572 0.3795 0.225 0.6063 0.7726	FCVs Ha Fuel Cel 15s 2 71.1 4 -0.4192 2 1.4322 5 0.2288 3 0.19 5 0.7706 5 0.7706	aving Li-lo DC-Link 30s -0.3757 1.4322 0.2723 0.22 0.6864 0.7706	on Batterii via a DC 45s 0.0.3787 1.4325 0.2697 0.23 0.6885 0.7706	es (7.5 A /DC Cor 60s 70.3 -0.3859 1.4325 0.2625 0.23 0.6956 0.7706 0.7981	h) Conne verter (E 75s -0.3926 1.4324 0.2557 0.23 0.7009 0.7706	cted to [GNiCo] 90s -0.3963 1.4326 0.2521 0.23 0.7045 0.7706 0.7996
Powertrain Configuration ESS FUDS: 1 cycle Fuel Economy Wheel Energy (kWh) DCDC & ESS Motor Efficiency FCS DCDC	Capacity mpgge Regenerative Accelerating Mech. Brake Loss (kWh) Regenerative Accelerating Efficiency Charge eff	FCVs Ha Fuel Cell 15s -0.3249 1.4566 0.3364 0.23 0.6537 0.7726 0.5867 0.9302	ving NiMH DC-Link 30s -0.2688 1.4562 0.3921 0.27 0.5939 0.7725 0.7725 0.975	H Batterie via a DC/ 45s -0.2712 1.457 0.3907 0.28 0.5917 0.7725 0.5957 0.5957 0.5922	s (7.5 Ah DC Com 60s 64.1 -0.2751 1.4571 0.3866 0.28 0.5999 0.7725 0.5981 0.9214) Connec ////////////////////////////////////	ted to 90s 64.3 -0.2824 1.4572 0.3795 0.226 0.6063 0.7725 0.5996 0.5996	FCVs Ha Fuel Cel 15s -0.4192 1.4322 0.2288 0.199 0.7203 0.7706 0.5867 0.944	aving Li-lo DC-Link 30s -0.3757 1.4322 0.2723 0.22 0.6864 0.7706 0.5936	on Batterii via a DC 45s 0.03787 1.4325 0.2697 0.23 0.6886 0.7706 0.5966 0.9398	es (7.5 A /DC Cor 60s -0.3859 1.4325 0.2625 0.23 0.6956 0.7706 0.5981 0.9332	h) Conne verter (E 75s -0.3926 1.4324 0.2557 0.23 0.7009 0.7706 0.599 0.9333	cted to IGNiCo) 90s -0.3963 1.4326 0.2521 0.23 0.7045 0.7706 0.5996 0.3344
Powertrain Configuration ESS FUDS: 1 cycle Fuel Economy Wheel Energy (kWh) DCDC & ESS Motor Efficiency FCS DCDC Converter	Capacity Regenerative Accelerating Mech. Brake Loss (KWh) Regenerative Accelerating Efficiency Charge eff Discharce eff	FCVs Ha Fuel Cell 15s -0.3249 1.4566 0.3364 0.23 0.6537 0.7726 0.5867 0.9302 0.9451	ving NiMI- DC-Link 30s 63.7 -0.2688 1.4562 0.3921 0.27 0.5939 0.7725 0.5938 0.925 0.9512	l Batterie via a DC/ 45s -0.2712 1.457 0.3907 0.28 0.5917 0.7725 0.5967 0.9622 0.9601	s (7.5 Ah DC Com 60s 64.1 -0.2751 1.4571 0.3868 0.28 0.5999 0.7725 0.5991 0.9214 0.9497) Connec /erter 75s 64.1 -0.2763 1.4571 0.3856 0.28 0.6007 0.7724 0.699 0.9215 0.9491	ted to 90s 64.3 -0.2824 1.4572 0.3796 0.326 0.6063 0.7725 0.6996 0.9225 0.9996 0.9225 0.9497	FCVs Ha Fuel Cel 15s -0.4192 -0.4192 -0.4192 -0.2088 0.0208 0.7706 0.7706 0.7706 0.7706 0.7706 0.944 0.944	aving Li-lo DC-Link 30s -0.3757 1.4322 0.2723 0.22 0.6864 0.7706 0.5936 0.9366 0.9365	on Batterie via a DC 45s 70.0 -0.3787 1.4325 0.2897 0.23 0.6885 0.7706 0.5966 0.5966 0.938 0.938	es (7.5 A /DC Cor 60s -0.3859 1.4325 0.2625 0.23 0.6956 0.7706 0.5981 0.932 0.9491	h) Conne verter (E 75s -0.3926 1.4324 0.2557 0.23 0.7009 0.7706 0.699 0.9333 0.9431	cted to IGNiCo) 90s -0.3963 1.4326 0.2521 0.23 0.7045 0.7706 0.5996 0.5996 0.59344 0.9344
Powertrain Configuration ESS FUDS: 1 cycle Fuel Economy Wheel Energy (kVth) DCDC & ESS Motor Efficiency FCS DCDC Converter Efficiency	Capacity mpgge Regenerative Accelerating Mech. Brake Loss (kWh) Regenerative Accelerating Efficiency Charge eff Discharge eff Round-trip eff	FCVs Ha Fuel Cell 15s -0.3249 1.4566 0.3364 0.23 0.6537 0.7726 0.5867 0.9302 0.9451 0.8791	ving NiMI- DC-Link 30s 63.7 -0.2688 1.4562 0.3921 0.27 0.5939 0.7725 0.5938 0.925 0.9512 0.9599	l Batterie via a DC/ 45s -0.2712 1.455 0.3807 0.28 0.5917 0.7725 0.5967 0.922 0.9501 0.876	s (7.5 Ah DC Com 60s 64.1 -0.2751 1.4571 0.3868 0.28 0.5999 0.7725 0.5981 0.9214 0.9492 0.8746) Connec /erter 75s 64.1 -0.2763 1.4571 0.3856 0.28 0.6007 0.7724 0.599 0.9215 0.9491 0.8746	ted to 90s 64.3 -0.2824 1.4572 0.3296 0.3296 0.6063 0.7725 0.5996 0.9925 0.99492 0.876	FCVs Ha Fuel Cel 15s 71.1 -0.4192 1.4322 1.4322 0.2288 0.703 0.5867 0.5867 0.944 0.9445 0.8921	aving Li-lo I DC-Link 30s -0.3757 1.4322 0.272 0.6864 0.7706 0.5936 0.9366 0.9512 0.8905	on Batteria via a DC 45s 70.0 -0.3787 1.4325 0.2697 0.23 0.6885 0.7706 0.5966 0.9388 0.9596 0.9596	es (7.5 A /DC Cor 60s 70.3 -0.3869 1.4325 0.2625 0.23 0.6956 0.7706 0.5981 0.9332 0.9491 0.8658	h) Conne verter (E 75s -0.3926 1.4324 0.2557 0.23 0.7009 0.7706 0.599 0.9333 0.9491 0.8657	cted to IGNiCo) 90s -0.3963 1.4326 0.2521 0.23 0.7045 0.7706 0.5996 0.9344 0.9491 0.8688
Powertrain Configuration ESS FUDS: 1 cycle Fuel Economy Wheel Energy (kWh) DCDC & ESS Motor Efficiency FCS DCDC Converter Efficiency Energy	Capacity mpgge Regenerative Accelerating Mech. Brake Loss (kWh) Regenerative Accelerating Efficiency Charge eff Round-trip eff Charge eff	FCVs Ha Fuel Cell 15s -0.3249 1.4566 0.3364 -0.23 0.6537 0.7726 0.5867 0.9302 0.9451 0.9451 0.9575	ving NiMI- DC-Link 30s 	l Batterie via a DC/ 45s -0.2712 1.457 0.3907 0.28 0.5917 0.7725 0.5967 0.922 0.9501 0.9501 0.976	s (7.5 Ah DC Conv 60s 64.1 -0.2751 1.4571 0.3868 0.28 0.5999 0.7725 0.5981 0.9214 0.9492 0.8746 0.9492 0.8746) Connec verter 75s 64.1 -0.2763 1.4571 0.3856 0.28 0.6007 0.7724 0.599 0.9215 0.9491 0.8746 0.8746 0.9612	ted to 90s 64.3 -0.2824 1.4572 0.3799 0.28 0.6063 0.7725 0.5996 0.9225 0.9492 0.9492 0.876 0.9605	FCVs Ha Fuel Cel 15s 0.112 0.2288 0.2288 0.2288 0.2288 0.700 0.7703 0.7703 0.7703 0.7703 0.7867 0.944 0.945 0.945 0.945 0.945	aving Li-lo DC-Link 30s -0.3757 1.4322 0.2723 0.22 0.6864 0.7706 0.5938 0.9366 0.9512 0.8909 0.9672	on Batteria via a DC 45s 70.0 -0.3787 1.4325 0.2897 0.23 0.6885 0.706 0.5966 0.9338 0.95 0.8871 0.958	es (7.5 A /DC Cor 60s 70.3 -0.3859 1.4325 0.2625 0.23 0.6956 0.7706 0.5981 0.9332 0.9391 0.8568 0.568	h) Conne verter (E 75s 70.5 -0.3926 1.4324 0.2557 0.23 0.7009 0.7706 0.6599 0.9333 0.9491 0.8657 0.9678	cted to (GNiCo) 90s 70.8 -0.3963 1.4326 0.2521 0.705 0.70706 0.5996 0.3344 0.9491 0.8868 0.9674
Powertrain Configuration ESS FUDS: 1 cycle Fuel Economy Wheel Energy (kWh) DCDC & ESS Motor Efficiency FCS DCDC Converter Efficiency Energy Storage	Capacity mpgge Regenerative Accelerating Mech. Brake Loss (kWh) Regenerative Accelerating Efficiency Charge eff Discharge eff Charge eff Discharge eff Discharge eff	FCVs Ha Fuel Cell 15s 0.3249 1.4566 0.3364 0.637 0.7726 0.5867 0.9302 0.9451 0.975 0.975 0.9901	ving NiMI- DC-Link 30s 63.7 -0.2688 1.4562 0.3921 0.3921 0.5939 0.7725 0.5938 0.925 0.9512 0.9512 0.8799 0.9593 0.9593 0.8922	l Batterie via a DC/ 45s 63.9 -0.2712 1.457 0.3907 0.28 0.5917 0.722 0.5967 0.922 0.9601 0.876 0.961 0.8843	s (7.5 Ah DC Conv 60s 64.1 -0.2751 1.4571 0.3868 0.5999 0.7725 0.5981 0.9214 0.9492 0.8746 0.9611 0.864) Connec verter 75s 64.1 -0.2763 1.4571 0.3856 0.28 0.6007 0.7724 0.599 0.9215 0.9491 0.8746 0.9612 0.8949	ted to 90s 64.3 -0.2824 1.4572 0.3799 0.225 0.6063 0.7725 0.5996 0.9225 0.9492 0.9492 0.9492 0.9492 0.9492 0.9492 0.9492 0.9492 0.9492 0.9663 0.9663 0.92555 0.9255 0.9255 0.9255 0.9255 0.9255 0.9255 0.9255 0.	FCVs Ha Fuel Cel 15s 71.1 0.4192 1.4322 0.2288 0.7203 0.7203 0.7203 0.7203 0.7203 0.7203 0.7203 0.945 0.945 0.945 0.9921 0.9955	eving Li-lo DC-Link 30s -0.3757 1.4322 0.2723 0.22 0.6864 0.7706 0.5938 0.9365 0.9365 0.9365 0.9365 0.9512 0.8905 0.9672 0.9672	on Batteria via a DC 45s 70.0 -0.3787 1.4325 0.2897 0.23 0.6885 0.706 0.9338 0.955 0.8871 0.958 0.951 0.958	es (7.5 A /DC Cor 60s 70.3 -0.3659 1.4325 0.2625 0.23 0.6956 0.7706 0.5981 0.9332 0.9491 0.8868 0.968 0.968	h) Conne verter (E 75s 70.5 -0.3926 1.4324 0.2557 0.23 0.7009 0.7706 0.599 0.9333 0.9491 0.8867 0.9678 0.9326	cted to (GNiCo) 90s 70.8 -0.3963 1.4326 0.2521 0.23 0.7045 0.7706 0.5996 0.9344 0.9491 0.8868 0.9674 0.9335
Powertrain Configuration ESS FUDS: 1 cycle Fuel Economy Wheel Energy (kWh) DCDC & ESS Motor Efficiency FCS DCDC Converter Efficiency Energy Storage Efficiency	Capacity mpgge Regenerative Accelerating Mech. Brake Loss (kWh) Regenerative Accelerating Efficiency Charge eff Discharge eff Charge eff Discharge eff Round-trip eff Round-trip eff	FCVs Ha Fuel Cell 15s -0.3249 1.4566 0.3364 0.633 0.6537 0.7726 0.5867 0.9302 0.9451 0.8791 0.9755 0.901 0.8628	ving NiMI- DC-Link 30s 63.7 -0.2688 1.4562 0.3921 0.3939 0.7725 0.5938 0.925 0.9512 0.8799 0.96593 0.8659	l Batterie via a DC/ 45s 63.9 -0.2712 1.457 0.3907 0.28 0.5917 0.725 0.5967 0.922 0.9501 0.876 0.8961 0.8963 0.8695	s (7.5 Ah DC Conv 60s 64.1 0.2751 1.4571 0.3868 0.28 0.725 0.5939 0.7725 0.5931 0.9214 0.9492 0.8746 0.9611 0.8954 0.8606) Connec verter 75s 64.1 -0.2763 1.4571 0.3856 0.28 0.6007 0.7224 0.599 0.9215 0.9491 0.8746 0.9612 0.8949 0.8601	ted to 90s 64.3 -0.2824 1.4572 0.3795 0.225 0.6063 0.7225 0.9395 0.9492 0.9492 0.9492 0.9492 0.9492 0.9606 0.9606 0.8605 0.8605 0.8605	FCVs Ha Fuel Cel 15s 71.1 0.4192 1.4322 0.2288 0.199 0.7706 0.5867 0.944 0.945 0.944 0.945 0.945 0.965 0.965	eving Li-lo DC-Link 30s -0.3757 1.4322 0.2723 0.22 0.6864 0.7706 0.5938 0.9368 0.9368 0.9368 0.9512 0.8909 0.9672 0.931 0.9004	on Batterie via a DC 45s 70.0 -0.3787 1.4325 0.2697 0.23 0.6885 0.7706 0.5966 0.9338 0.955 0.8871 0.968 0.9318 0.968 0.9318	es (7.5 A /DC Cor 60s 70.3 -0.3659 1.4325 0.2625 0.23 0.6956 0.7706 0.5981 0.9332 0.9491 0.8658 0.9329 0.968 0.9329 0.9039	h) Conne verter (E 75s 0.3926 1.4324 0.2557 0.23 0.7009 0.7706 0.9333 0.9491 0.8857 0.9678 0.9326 0.9026	cted to (GNiCo) 90s -70.8 -0.3963 1.4326 0.2521 0.23 0.7045 0.7706 0.5996 0.9344 0.9491 0.8868 0.9674 0.9335 0.903
Powertrain Configuration ESS FUDS: 1 cycle Fuel Economy Wheel Energy (KWh) DCDC & ESS Motor Efficiency FCS DCDC Converter Efficiency Energy Storage Efficiency USD8: 1 cycle	Capacity mpgge Regenerative Accelerating Mech. Brake Loss (kWh) Regenerative Accelerating Efficiency Charge eff Discharge eff Discharge eff Discharge eff Round-trip eff	FCVs Ha Fuel Cell 15s 0.3249 1.4566 0.3364 0.23 0.6637 0.7302 0.9451 0.8791 0.9575 0.901 0.8628	ving NiMI- DC-Link 30s 63.7 -0.2688 1.4562 0.3921 0.7725 0.5938 0.925 0.5938 0.925 0.9512 0.8799 0.9593 0.8922 0.8599	l Batterie via a DC/ 45s 63.9 -0.2712 1.457 0.3907 0.28 0.5917 0.7725 0.5967 0.922 0.9501 0.876 0.961 0.8943 0.8595	s (7.5 Ah DC Conv 60s 64.1 0.2751 1.4571 0.3868 0.28 0.725 0.5999 0.7725 0.5981 0.9214 0.9492 0.8746 0.9611 0.8954 0.8666) Connec /erter 75s 64.1 -0.2763 1.4571 0.3856 0.28 0.6007 0.7724 0.599 0.9215 0.9491 0.8746 0.9612 0.8949 0.8041	ted to 90s 64.3 -0.2824 1.4577 0.3796 0.225 0.6063 0.725 0.5996 0.9225 0.9492 0.9492 0.876 0.8962 0.8063	FCVs Ha Fuel Cel 15s 0.71.1 0.4192 1.4322 0.2288 0.19 0.7203 0.7706 0.5867 0.944 0.945 0.944 0.945 0.9932 0.9932 0.9053	aving Li-lo IDC-Link 30s -0.3757 1.4322 0.2723 0.22 0.6864 0.7706 0.5938 0.9366 0.9366 0.9512 0.8909 0.9672 0.931 0.9004	on Batterie via a DC 45s 70.0 -0.3787 1.4325 0.2697 0.23 0.6885 0.706 0.5966 0.9338 0.955 0.8871 0.968 0.9318 0.902	es (7.5 A /DC Cor 60s 70.3 0.3659 1.4325 0.23 0.6956 0.7706 0.5981 0.9332 0.9491 0.8656 0.9332 0.9491 0.8656 0.9332 0.9332 0.9332	h) Conne verter (E 75s 0.3926 1.4324 0.2557 0.23 0.7009 0.7706 0.599 0.9333 0.9491 0.8657 0.9678 0.9326 0.9026	cted to IGNiCo) 90s 70.8 -0.3963 1.4326 0.2521 0.23 0.7045 0.7706 0.5996 0.9344 0.9491 0.8688 0.9674 0.9335 0.903
Powertrain Configuration ESS FUDS: 1 cycle Fuel Economy Wheel Energy (kWh) DCDC & ESS Motor Efficiency FCS DCDC Converter Efficiency Energy Storage Efficiency USD6: 1 cycle Fuel Economy	Capacity mpgge Regenerative Accelerating Mech. Brake Loss (KWh) Regenerative Accelerating Efficiency Charge eff Discharge eff Discharge eff Discharge eff Round-trip eff Round-trip eff Round-trip eff Round-trip eff	FCVs Ha Fuel Cell 15s 0.3249 1.4566 0.3637 0.7726 0.5667 0.9025 0.9451 0.86791 0.9575 0.901 0.8628 50.3	ving NiMI- DC-Link 30s -0.2688 1.4562 0.3921 0.25939 0.7725 0.5938 0.9512 0.9512 0.9512 0.8799 0.9593 0.8529 0.8559 	l Batterie via a DC/ 45s 0.3.9 -0.2712 1.457 0.328 0.5917 0.7725 0.5967 0.922 0.9601 0.876 0.961 0.843 0.8595 49.9	s (7.5 Ah DC Con 60s 64.1 -0.2751 1.4571 0.3868 0.2868 0.5999 0.7725 0.5981 0.9214 0.9492 0.8746 0.9611 0.8654 0.8666) Connec verter 75s 64.1 -0.2763 1.4571 0.3856 0.288 0.6007 0.7724 0.599 0.9215 0.9491 0.8746 0.9612 0.849 0.8601 49.9	ted to 90s 64.3 -0.2824 1.4577 0.3796 0.22 0.6063 0.7726 0.5996 0.9222 0.9492 0.876 0.9606 0.9606 0.8662 0.8662 0.8662	FCVs Ha Fuel Cel 15s 	aving Li-lo IDC-Link 30s -0.3757 1.4322 0.2723 0.222 0.6864 0.7708 0.9366 0.9366 0.9366 0.9672 0.931 0.9004 52.6	on Batterie via a DC 45s 70.0 -0.3787 1.4325 0.2697 0.23 0.6885 0.7706 0.5966 0.9338 0.958 0.938871 0.968 0.9318 0.902	es (7.5 A /DC Cor 60s 70.3 0.3659 1.4325 0.232 0.6956 0.7706 0.5981 0.9332 0.9491 0.8658 0.968 0.9329 0.903	h) Conne verter (E 75s 70.5 1.4324 0.2567 0.23 0.7009 0.7706 0.599 0.9333 0.9491 0.8667 0.9678 0.9326 0.9026	cted to IGNiCo) 90s 70.8 0.3963 1.4326 0.2521 0.23 0.7045 0.7706 0.5996 0.5996 0.5996 0.5996 0.5934 0.5888 0.9674 0.9335 0.903 51.7
Powertrain Configuration ESS FUDS: 1 cycle Fuel Economy Wheel Energy (kWh) DCDC & ESS Motor Efficiency FCS DCDC Converter Efficiency Energy Storage Efficiency US06: 1 cycle Fuel Economy Wheel	Capacity mpgge Regenerative Accelerating Mech. Brake Loss (kWh) Regenerative Accelerating Efficiency Charge eff Discharge eff Discharge eff Discharge eff Round-trip eff Round-trip eff Round-trip eff Round-trip eff Round-trip eff	FCVs Ha Fuel Cell 15s -0.3249 1.4566 0.3637 0.7726 0.5867 0.9302 0.9451 0.98791 0.9575 0.901 0.8628 -0.8688 0.961 0.8628	ving NiMI- DC-Link 30s -0.2688 1.4562 0.3921 0.5939 0.7725 0.5938 0.925 0.9512 0.8799 0.9593 0.8922 0.8659 -0.8659 -0.1641	l Batterie via a DC/ 45s -0.2712 1.457 0.307 0.5917 0.7725 0.5967 0.922 0.9501 0.876 0.961 0.843 0.8695 -49.9 -0.1622	s (7.5 Ah DC Con 60s 64.1 -0.2751 1.4571 0.3868 0.28 0.5399 0.7725 0.5381 0.9214 0.9492 0.8746 0.9611 0.8954 0.8606 49.9 -0.1622) Connec verter 75s 64.1 -0.2763 1.4571 0.3856 0.28 0.6007 0.7724 0.599 0.9215 0.9491 0.8746 0.9612 0.8949 0.8601 49.9 -0.1626	ted to 90s 64.3 -0.2824 1.4572 0.3796 0.282 0.6063 0.7725 0.5996 0.9225 0.9492 0.9492 0.8765 0.9606 0.8965 0.8965 0.8605 0.8605	FCVs Ha Fuel Cel 15s 71.1 -0.4192 1.4322 1.4322 0.2288 0.706 0.5867 0.5867 0.9445 0.9445 0.9445 0.945 0.9362 0.9362 0.9362 0.9362 2.0.9362 0.9053	aving Li-lo DC-Link 30s -0.3757 1.4322 0.2723 0.2723 0.2722 0.6864 0.7706 0.5938 0.9512 0.8909 0.9672 0.931 0.9004 -0.9014 -0.9004	on Batteria via a DC 45s 70.0 -0.3787 1.4325 0.2897 0.233 0.6885 0.7706 0.5966 0.9388 0.9388 0.9318 0.96871 0.9688 0.9318 0.902 0.5266 -0.1992	es (7.5 A /DC Cor 60s 70.3 -0.3869 1.4325 0.225 0.233 0.6966 0.7706 0.5981 0.9332 0.9491 0.8658 0.9329 0.903 0.903 0.903	h) Conne verter (E 75s -0.3926 1.4324 0.2567 0.233 0.7009 0.7706 0.599 0.9333 0.9491 0.8857 0.9678 0.9326 0.9026 51.7 -0.1951	cted to (GNiCo) 90s -70.8 -0.3963 1.4326 0.2521 0.7706 0.5996 0.9344 0.9491 0.8688 0.9674 0.9335 0.903 51.7 -0.1975
Powertrain Configuration ESS FUDS: 1 cycle Fuel Economy Wheel Energy (kVM) DCDC & ESS Motor Efficiency FCS DCDC Converter Efficiency Energy Storage Efficiency US06: 1 cycle Fuel Economy Wheel Energy	Capacity mpgge Regenerative Accelerating Mech. Brake Loss (kWh) Regenerative Accelerating Efficiency Charge eff Discharge eff Round-trip eff Discharge eff Round-trip eff mpgge Regenerative Accelerating	FCVs Ha Fuel Cell 15s -0.3249 1.4566 0.3364 0.23 0.6537 0.7726 0.5667 0.9302 0.9451 0.9675 0.901 0.8628 -0.8291 0.8628 -0.1846 2.3059	ving NiMI- DC-Link 30s 1.4562 0.3321 0.2539 0.7725 0.5938 0.925 0.9512 0.8799 0.8799 0.8593 0.8922 0.8559 0.8559 0.8559 0.8559 0.8559 0.8559	l Batterie via a DC/ 45s 63.9 -0.2712 1.457 0.3907 0.7725 0.5967 0.5967 0.922 0.9501 0.876 0.961 0.8943 0.8595 49.9 -0.1622 2.3065	s (7.5 Ah DC Com 60s 64.1 -0.2751 1.4571 0.3868 0.28 0.5999 0.7725 0.5981 0.9214 0.9492 0.8746 0.8606 0.8606 49.9 -0.1622 2.3065) Connec verter 75s 64.1 -0.2763 1.4571 0.3856 0.28 0.6007 0.7724 0.599 0.9215 0.9491 0.8746 0.9612 0.8949 0.8601 49.9 -0.1626 2.3066	ted to 90s 64.3 -0.2824 1.4572 0.3796 0.282 0.6065 0.7725 0.9996 0.9225 0.9492 0.8065 0.8065 0.8655 0.8655 0.85555 0.85555 0.85555 0.85555 0.85555 0.85555 0.85555 0.85555 0.85555 0.85555 0.855555 0.855555 0.855555 0.8555555 0.8555555555555555555555555555555555555	FCVs Ha Fuel Cel 15s 17s 1.4322 1.4322 1.4322 1.4322 0.2288 0.7206 0.5867 0.5867 0.9445 0.9445 0.945 0.945 0.945 0.945 0.945 0.945 0.9382 0.9053 0.9053	aving Li-lo DC-Link 30s -0.3757 1.4322 0.2723 0.2723 0.222 0.6864 0.7706 0.9366 0.9512 0.8909 0.9672 0.9316 0.9004 -0.2024 2.2748	on Batteria via a DC 45s 70.0 -0.3787 1.4325 0.2897 0.23 0.6885 0.7706 0.5966 0.9388 0.956 0.9388 0.951 0.8871 0.9888 0.9318 0.9902 52.6 -0.1992 2.2748	es (7.5 A /DC Cor 60s 70.3 -0.3859 1.4325 0.2825 0.23 0.6956 0.7706 0.5981 0.9332 0.93491 0.8656 0.968 0.968 0.968 0.9329 0.903 51.7 -0.1926 2.2751	h) Conne verter (E 75s -0.3926 1.4324 0.2557 0.23 0.7009 0.7706 0.599 0.9333 0.9491 0.8857 0.9678 0.9326 0.9026 51.7 -0.1951 2.2755	cted to (GNiCo) 90s -70.8 -0.3963 1.4326 0.2521 0.7046 0.5996 0.3344 0.9491 0.8868 0.9674 0.9335 0.903 51.7 -0.1975 2.2752
Powertrain Configuration ESS FUDS: 1 cycle Fuel Economy Wheel Energy (kWh) DCDC & ESS Motor Efficiency FCS DCDC Converter Efficiency Energy Storage Efficiency US06: 1 cycle Fuel Economy Wheel Energy (kWh) DCDC	Capacity mpgge Regenerative Accelerating Mech. Brake Loss (kWh) Regenerative Accelerating Efficiency Charge eff Discharge eff Discharge eff Discharge eff Round-trip eff Charge eff Round-trip eff	FCVs Ha Fuel Cell 15s 0.3249 1.4566 0.3364 0.6537 0.7726 0.5867 0.9302 0.9451 0.9575 0.901 0.8628 50.3 -0.1846 2.3059 0.5079 0.5079	ving NiMI- DC-Link 30s 63.7 -0.2688 1.4562 0.3921 0.5939 0.7725 0.5938 0.925 0.9512 0.8593 0.8922 0.8559 0.9593 0.8922 0.8559 -0.1641 2.3064 0.5289	l Batterie via a DC/ 45s 63.9 -0.2712 1.457 0.3907 0.28 0.5917 0.7725 0.5967 0.922 0.9501 0.876 0.8943 0.8595 49.9 -0.1622 2.3065 0.5309	s (7.5 Ah DC Conv 60s 64.1 -0.2751 1.4571 0.3868 0.5999 0.7725 0.5981 0.9214 0.9492 0.8746 0.9611 0.8954 0.8606 49.9 -0.1622 2.3065 0.5399) Connec verter 75s 64.1 -0.2763 1.4571 0.3856 0.28 0.6007 0.7724 0.599 0.9215 0.9491 0.8746 0.9612 0.8949 0.8609 -0.1626 2.3066 0.5305 0.5305 -	ted to 90s 64.3 -0.2824 1.4572 0.3799 0.282 0.9025 0.9996 0.9225 0.9492 0.9492 0.8605 0.8	FCVs Ha Fuel Cel 15s 71.1 -0.4192 1.4322 0.2288 0.703 0.7703 0.7703 0.7703 0.7703 0.7703 0.7703 0.7703 0.9445 0.9445 0.9445 0.9382 0.94480000000000000000000000000000000000	aving Li-lo DC-Link 30s 69.8 -0.3757 1.4322 0.2723 0.22 0.6864 0.9706 0.9912 0.8909 0.9672 0.931 0.9004 52.8 -0.2024 2.2746 0.4707 0.4707	on Batteria via a DC 45s 70.0 -0.3787 1.4325 0.2897 0.23 0.6885 0.7706 0.5966 0.9338 0.956 0.9388 0.95 0.8871 0.968 0.9318 0.902 52.6 -0.1992 2.2748 0.4741	es (7.5 A /DC Cor 60s 70.3 -0.3859 1.4325 0.2625 0.23 0.6956 0.7706 0.5981 0.9332 0.93491 0.8656 0.968 0.968 0.968 0.9329 0.903 51.7 -0.1926 2.2751 0.4809	h) Conne verter (E 75s 70.5 -0.3926 1.4324 0.2557 0.23 0.7009 0.7706 0.599 0.9333 0.9491 0.9678 0.9326 0.9026 51.7 -0.1951 2.2755 0.4789	cted to (GNiCo) 90s 70.8 -0.3963 1.4326 0.2521 0.7045 0.7706 0.5996 0.9344 0.9491 0.9491 0.9491 0.9335 0.9074 0.9335 0.903 51.7 -0.1975 2.2752 0.4762
Powertrain Configuration ESS FUDS: 1 cycle Fuel Economy Wheel Energy (kWh) DCDC & ESS Motor Efficiency Efficiency Efficiency Energy Storage Efficiency US06: 1 cycle Fuel Economy Wheel Energy (kWh) DCDC&ESS	Capacity mpgge Regenerative Accelerating Mech. Brake Loss (kWh) Regenerative Accelerating Efficiency Charge eff Discharge eff Discharge eff Round-trip eff Charge eff Round-trip eff Charge eff Round-trip eff Round-trip eff Accelerating Mech. Brake Loss (kWh)	FCVs Ha Fuel Cell 15s -0.3249 1.4566 0.3364 0.6337 0.7726 0.5867 0.9302 0.9451 0.9575 0.901 0.8628 -0.1846 2.3059 0.5079 0.17 0.5079	ving NiMI- DC-Link 30s 63.7 -0.2688 1.4562 0.3921 0.3921 0.5938 0.925 0.9512 0.9512 0.9512 0.9512 0.9512 0.8559 0.9525 0.8559 -0.1641 2.3064 0.5289 0.186	l Batterie via a DC/ 45s 63.9 -0.2712 1.457 0.3907 0.28 0.5917 0.7725 0.5967 0.922 0.9601 0.876 0.961 0.8943 0.8595 49.9 -0.1622 2.3065 0.5309 0.19	s (7.5 Ah DC Conv 60s 64.1 -0.2751 1.4571 0.3868 0.28 0.5999 0.7725 0.5981 0.9214 0.9492 0.8746 0.9611 0.8954 0.8606 49.9 -0.1622 2.3066 0.5309 0.19) Connec verter 75s 64.1 -0.2763 1.4571 0.3856 0.28 0.6007 0.7724 0.599 0.9215 0.9491 0.8746 0.9612 0.9491 0.8949 0.8601 49.9 -0.1626 0.5305 0.19 0.7926 0.5305 0.19	ted to 90s 64.3 -0.2824 1.4572 0.3799 0.225 0.6063 0.7722 0.5996 0.9225 0.9492 0.9492 0.9492 0.9492 0.9492 0.9605 0.9	FCVs Ha Fuel Cel 15s 71.1 0.4192 1.4322 1.4322 0.2288 0.193 0.7203 0.7203 0.7203 0.7203 0.7203 0.7203 0.944 0.9456 0.9456 0.9456 0.9382	aving Li-lo DC-Link 30s -0.3757 1.4322 0.2723 0.22 0.6864 0.7706 0.9356 0.9512 0.9366 0.9512 0.9064 0.9512 0.9071 0.9072 0.931 0.9004 -0.2024 0.4707 0.17 0.070	on Batteria via a DC 45s 70.0 -0.3787 1.4325 0.2897 0.23 0.6885 0.7706 0.5966 0.9338 0.956 0.8711 0.968 0.9318 0.9902 52.6 0.9318 0.902 2.2748 0.4741 0.17	es (7.5 A /DC Cor 60s 70.3 -0.3659 1.4325 0.2625 0.23 0.6956 0.7706 0.5981 0.9332 0.9491 0.9332 0.9491 0.9329 0.903 51.7 -0.1926 2.2751 0.4809 0.17	h) Conne verter (E 75s 70.5 -0.3926 1.4324 0.2557 0.23 0.7099 0.7709 0.9333 0.9491 0.8857 0.9678 0.9326 0.9026 51.7 -0.1951 2.2755 0.4789 0.17	cted to (GNiCo) 90s 70.8 -0.3963 1.4326 0.2521 0.23 0.7045 0.7045 0.7045 0.7045 0.7045 0.7045 0.7045 0.9344 0.9335 0.903 51.7 -0.1975 2.2752 0.4762 0.4762 0.17
Powertrain Configuration ESS FUDS: 1 cycle Fuel Economy Wheel Energy (KWh) DCDC & ESS Motor Efficiency Efficiency Energy Storage Efficiency US06: 1 cycle Fuel Economy Wheel Energy (KWh) DCDC&ESS Motor Energy (kWh)	Capacity mpgge Regenerative Accelerating Mech. Brake Loss (kWh) Regenerative Accelerating Efficiency Charge eff Discharge eff Charge eff Discharge eff Round-trip eff Round-trip eff Round-trip eff Round-trip eff Round-trip eff Accelerating Mech. Brake Loss (kWh) Regenerative	FCVs Ha Fuel Cell 15s 0.3249 1.4566 0.3364 0.637 0.7726 0.5867 0.9302 0.9451 0.8791 0.971 0.8628 50.3 -0.18469 2.3059 0.5079 0.17 0.6335	ving NiMI- DC-Link 30s 63.7 -0.2688 1.4562 0.3921 0.27 0.5938 0.925 0.9512 0.9512 0.8569 0.9522 0.8659 -0.180 2.3064 0.5289 0.18 0.5289 0.18	l Batterie via a DC/ 45s 63.9 -0.2712 1.457 0.3907 0.28 0.5917 0.7725 0.5967 0.922 0.9601 0.876 0.961 0.876 0.961 0.8843 0.8695 49.9 -0.1622 2.3065 0.5309 0.19 0.5945	s (7.5 Ah DC Conv 60s 64.1 -0.2751 1.4571 0.3868 0.5999 0.7225 0.5981 0.9214 0.9492 0.8746 0.9611 0.8954 0.8606 49.9 -0.1622 2.3065 0.5309 0.19 0.5947) Connec verter 75s 64.1 -0.2763 1.4571 0.3856 0.28 0.6007 0.7724 0.5399 0.9215 0.9491 0.8746 0.9612 0.8949 0.8601 49.9 -0.1626 2.3066 0.5305 0.19 0.5945	ted to 90s 64.3 -0.2824 1.4572 0.3795 0.26 0.9996 0.9996 0.9996 0.9966 0.9966 0.9966 0.9806 0.8605 0.85555 0.85555 0.85555 0.85555 0.85555 0.85555 0.85555 0.85555 0.85555 0.85555 0.85555 0.85555 0.85555 0.85555 0.85555 0.855555 0.855555 0.855555 0.8555555 0.8555555555555555555555555555555555555	FCVs Ha Fuel Cel 15s 71.1 0.4192 1.4322 0.2288 0.199 0.7203 0.7203 0.7203 0.7203 0.7203 0.7203 0.0.944 0.945 0.945 0.945 0.945 0.945 0.965 0.970 0.770 0.970 0.970 0.970 0.770 0.0700000000	aving Li-lo DC-Link 30s -0.3757 1.4322 0.2723 0.22 0.6864 0.7706 0.9365 0.9365 0.9365 0.9365 0.9365 0.9512 0.8909 0.9672 0.9311 0.9004 -0.2024 2.2746 0.4707 0.17 0.6323	on Batteria via a DC 45s 70.0 -0.3787 1.4325 0.2697 0.23 0.6885 0.7706 0.5966 0.9338 0.955 0.8711 0.968 0.9388 0.955 0.8711 0.968 0.9318 0.9318 0.902 52.6 -0.1992 2.2748 0.4741 0.17 0.6283	es (7.5 A /DC Cor 60s 70.3 -0.3659 1.4325 0.2625 0.23 0.6956 0.7706 0.5981 0.9332 0.9491 0.8858 0.9329 0.903 51.7 -0.1926 2.2751 0.4809 0.17 0.6156	h) Conne verter (E 75s 70.5 -0.3926 1.4324 0.2557 0.23 0.7009 0.7706 0.599 0.9333 0.9491 0.8857 0.9678 0.9326 0.9026 51.7 -0.1951 2.2755 0.4789 0.17 0.618	cted to (GNiCo) 90s 70.8 -0.3963 1.4326 0.2521 0.23 0.7045 0.706 0.5996 0.9344 0.9491 0.8868 0.9674 0.9335 0.903 51.7 -0.1975 2.2752 0.4762 0.4762 0.4762 0.4762
Powertrain Configuration ESS FUDS: 1 cycle Fuel Economy Wheel Energy (kWh) DCDC & ESS Motor Efficiency Energy Storage Efficiency USD8: 1 cycle Fuel Economy Wheel Energy (kWh) DCDC&ESS Motor Efficiency Energy (kWh) DCDC&ESS	Capacity mpgge Regenerative Accelerating Mech. Brake Loss (KVM) Regenerative Accelerating Efficiency Charge eff Discharge eff Discharge eff Round-trip eff Round-trip eff Round-trip eff Regenerative Accelerating Mech. Brake Loss (KVM) Regenerative Accelerating Efficiency	FCVs Ha Fuel Cell 15s 0.3249 1.4566 0.3637 0.7726 0.90575 0.901 0.8687 0.90575 0.901 0.8628 50.3 -0.1846 2.3059 0.5079 0.177 0.6335 0.664 0.664	ving NiMH DC-Link 30s -0.2688 1.4562 0.3921 0.5939 0.7725 0.5938 0.9512 0.9512 0.8799 0.9593 0.8599 0.8599 -0.1641 2.3064 0.5289 0.18 0.5956 0.8604 0.55956	l Batterie via a DC/ 45s 0.3.9 -0.2712 1.457 0.328 0.5917 0.7725 0.5967 0.920 0.8943 0.8545 0.8643 0.8595 49.9 -0.1622 2.3065 0.5309 0.19 0.5945 0.8604	s (7.5 Ah DC Conv 60s 64.1 0.2751 1.4571 0.3868 0.28 0.5999 0.7725 0.5981 0.9214 0.9492 0.8746 0.9611 0.8954 0.8606 49.9 -0.1622 2.3665 0.5309 0.19 0.5947 0.5947 0.5947) Connec verter 75s 64.1 -0.2763 1.4571 0.3856 0.28 0.6007 0.7224 0.5399 0.9215 0.9491 0.8746 0.9612 0.8949 0.8649 0.5305 0.199 0.5345 0.53555 0.53555 0.53555 0.53555 0.5355555 0.55	ted to 90s 64.3 -0.2824 1.4572 0.3795 0.225 0.6063 0.725 0.9492 0.9492 0.9492 0.9492 0.9492 0.9492 0.9492 0.9492 0.9606 0.9606 0.8765 0.8602 0.8602 0.5936 0.59	FCVs Ha Fuel Cel 15s 15s 14322 1.4322 1.4322 0.2288 0.199 0.7203 0.7203 0.7203 0.7203 0.706 0.944 0.945 0.944 0.945 0.944 0.945 0.944 0.965 0.932 0.9053 0.9532 0.9532 0.22448 0.22448 0.4279 0.155 0.7014 0.6598	aving Li-lo DC-Link 30s -0.3757 1.4322 0.2723 0.22 0.6864 0.7706 0.5936 0.9366 0.9512 0.8909 0.9672 0.8909 0.9672 0.9314 0.9004 -0.2024 2.2746 0.4707 0.17 0.6323 0.8596 0.9552	on Batterie via a DC 45s 70.0 -0.3787 1.4325 0.2697 0.23 0.6885 0.7706 0.5966 0.9338 0.955 0.8871 0.968 0.9388 0.951 0.8871 0.968 0.9318 0.9318 0.932 2.2748 0.4741 0.17 0.6283 0.4741 0.17 0.6283	es (7.5 A /DC Cor 60s 70.3 -0.3659 1.4325 0.2625 0.23 0.6956 0.7706 0.5981 0.9332 0.9491 0.8658 0.9329 0.9329 0.9329 0.9329 0.9329 0.9329 0.9491 0.8658 2.2751 0.4809 0.403 0.48597 0.4655	h) Conne verter (E 75s 70.5 -0.3926 1.4324 0.2557 0.23 0.7009 0.7066 0.599 0.3333 0.9491 0.8657 0.9678 0.9326 0.93	cted to (GNiCo) 90s 70.8 -0.3963 1.4326 0.2521 0.23 0.7045 0.7706 0.5996 0.9344 0.9491 0.8688 0.9674 0.9305 0.9305 0.9305 0.9305 0.177 0.1975 2.2752 0.4762 0.47762 0.4762 0.4762 0.47762 0.4762 0
Powertrain Configuration ESS FUDS: 1 cycle Fuel Economy Wheel Energy (kWh) DCDC & ESS Motor Efficiency ECC Converter Efficiency Energy Storage Efficiency US06: 1 cycle Fuel Economy Wheel Energy (kWh) DCDC&ESS Motor Efficiency FCS DCDC	Capacity mpgge Regenerative Accelerating Mech. Brake Loss (kWh) Regenerative Accelerating Efficiency Charge eff Discharge eff Discharge eff Round-trip eff Round-trip eff Round-trip eff Regenerative Accelerating Mech. Brake Loss (kWh) Regenerative Accelerating Efficiency Charge eff Charge eff Coss (kWh)	FCVs Ha Fuel Cell 15s -0.3249 1.4566 0.3637 0.7726 0.5867 0.9302 0.9451 0.8791 0.9575 0.901 0.8628 -0.1846 2.3059 0.6079 0.17 0.6336 0.8604 0.6634 0.458	ving NiMI- DC-Link 30s 63.7 -0.2688 1.4562 0.3921 0.5939 0.7725 0.5938 0.925 0.9512 0.8799 0.9593 0.925 0.9512 0.8799 0.9559 0.9559 0.8559 49.9 -0.1641 2.3064 0.5956 0.8604 0.5956 0.8604 0.6804 0.	l Batterie via a DC/ 45s 63.9 -0.2712 1.457 0.307 0.5917 0.7725 0.5967 0.922 0.9501 0.876 0.961 0.843 0.8695 49.9 -0.1622 2.3065 0.5309 0.192 0.5305 0.5309 0.192 0.5945 0.8604 0.5642 0.9645	s (7.5 Ah DC Com 60s 64.1 -0.2751 1.4571 0.3868 0.238 0.5399 0.7725 0.5381 0.9214 0.9492 0.8746 0.8606 49.9 -0.1622 2.3065 0.5309 0.192 0.5947 0.8604 0.5647 0.8604) Connec verter 75s 64.1 -0.2763 1.4571 0.3856 0.288 0.6007 0.7724 0.599 0.9215 0.9491 0.8746 0.9612 0.8949 0.8601 49.9 -0.1626 2.3066 0.5305 0.1626 2.3066 0.5305 0.6399 0.5945 0.8604 0.6539 0.9645 0.8604 0.6539 0.9645 0.8604 0.6539 0.9645 0.8604 0.6539 0.9645 0.8604 0.6539 0.9645 0.8604 0.6539 0.9645 0.8604 0.6539 0.9645 0.8604 0.6539 0.9645 0.8604 0.6539 0.9645 0.8604 0.6539 0.9645 0.8604 0.6539 0.9645 0.8604 0.6539 0.9645 0.8604 0.6539 0.9645 0.8604 0.9645 0.8604 0.9645 0.8604 0.9645 0.9	ted to 90s 64.3 -0.2824 1.4572 0.3796 0.225 0.5996 0.9225 0.9492 0.9492 0.8065 0.8065 0.8065 49.6 -0.1632 2.3064 0.5296 0.1632 2.3064 0.5296 0.91632 2.3064 0.5386 0.8604 0.5636 0.96666 0.96666 0.9666 0.9666 0.9666 0.9666 0.9666 0.9666 0.9666 0	FCVs Ha Fuel Cel 15s 3 71.1 -0.4192 1.4322 0.2288 0.7706 0.5867 0.9445 0.9445 0.9445 0.9445 0.945 0.945 0.945 0.945 0.945 0.945 0.945 0.945 0.945 0.9362 0.9	Aving Li-lo DC-Link 30s -0.3757 1.4322 0.2723 0.2723 0.2723 0.5938 0.9512 0.9512 0.9512 0.9612 0.9612 0.9672 0.931 0.904 -0.2024 2.2748 0.4707 0.177 0.6323 0.8598 0.57 0.9572	on Batteria via a DC 45s 70.0 -0.3787 1.4325 0.2897 0.233 0.6885 0.7706 0.5966 0.9338 0.9368 0.9378 0.9388 0.9378 0.9687 0.9688 0.9318 0.902 52.6 -0.1992 2.2748 0.4741 0.177 0.6283 0.8597 0.5718 0.9678	es (7.5 A /DC Cor 60s 70.3 -0.3869 1.4325 0.2625 0.233 0.6966 0.7706 0.5981 0.9332 0.9491 0.8688 0.9329 0.903 51.7 -0.1926 2.2751 0.4809 0.17 0.6155 0.8597 0.6685 0.96857	h) Conne verter (E 75s -0.3926 1.4324 0.2567 0.233 0.7009 0.7706 0.599 0.9333 0.9491 0.8857 0.9678 0.9026 51.7 -0.1951 2.2755 0.4789 0.17 0.618 0.8597 0.6582 0.90648	cted to (GNiCo) 90s 70.8 -0.3963 1.4326 0.2521 0.2521 0.2521 0.7706 0.5996 0.9344 0.9491 0.8868 0.9674 0.9335 0.903 51.7 -0.1975 2.2752 0.4762 0.4762 0.4762 0.4762 0.6255 0.8598 0.5677 0.9645
Powertrain Configuration ESS FUDS: 1 cycle Fuel Economy Wheel Energy (kWh) DCDC & ESS Motor Efficiency FCS DCDC Converter Efficiency Energy Storage Efficiency Energy Wheel Energy (kWh) DCDC&ESS Motor Efficiency FCS COC&ESS Motor Efficiency FCS DCDC&C Converter	Capacity mpgge Regenerative Accelerating Mech. Brake Loss (kWh) Regenerative Accelerating Efficiency Charge eff Discharge eff Round-trip eff Charge eff Round-trip eff mpgge Regenerative Accelerating Mech. Brake Loss (kWh) Regenerative Accelerating Efficiency Charge eff Discharge eff Discharge eff	FCVs Ha Fuel Cell 15s -0.3249 1.4566 0.3364 0.233 0.6537 0.7726 0.5867 0.9302 0.9451 0.8791 0.9675 0.901 0.8628 -0.1846 2.3059 0.5079 0.017 0.6335 0.8604 0.563 0.8604 0.563	ving NiMI- DC-Link 30s 63.7 -0.2688 1.4562 0.3921 0.27 0.5939 0.7725 0.5938 0.9512 0.8799 0.96533 0.8922 0.8659 -0.1641 2.3064 0.5289 0.188 0.5956 0.8604 0.5956 0.8604 0.5632 0.9653 0.9653 0.9653 0.9653 0.9654 0.5956 0.8604 0.5652 0.9653 0.9653 0.9653 0.9654 0.5956 0.8604 0.5652 0.9653 0.9653 0.9653 0.9654 0.5652 0.9653 0.9653 0.9654 0.5652 0.9653 0.9654 0.5655 0.5653 0.9654 0.5655 0.9653 0.9654 0.5655 0.9653 0.9654 0.5655 0.9653 0.9653 0.9654 0.9655 0.9653 0.9654 0.9654 0.9655 0.9654 0.9655 0.9555	l Batterie via a DC/ 45s 0.3.9 -0.2712 1.457 0.307 0.228 0.5917 0.7725 0.5967 0.922 0.9501 0.876 0.961 0.8943 0.8695 -0.1622 2.3065 0.6309 0.19 0.5345 0.8604 0.5642 0.96468	s (7.5 Ah DC Com 60s 64.1 -0.2751 1.4571 0.3868 0.238 0.5399 0.7725 0.5381 0.9214 0.9214 0.9214 0.9214 0.9492 0.8746 0.8606 0.8606 0.5309 0.199 0.5947 0.8604 0.5647 0.8604 0.9643) Connec verter 75s 64.1 -0.2763 1.4571 0.3856 0.238 0.6007 0.7724 0.599 0.9215 0.9491 0.8746 0.9612 0.8949 0.8604 0.8604 0.8053 0.505 0.1626 2.3066 0.5305 0.5305 0.9457 0.9595 0.95555 0.95555 0.95555 0.9555 0.9555 0.9555	ted to 90s 64.3 -0.2824 1.4572 0.3796 0.282 0.6065 0.7725 0.9992 0.9492 0.9492 0.9492 0.9492 0.9606 0.8962 0.8606 0.8606 0.1632 2.3064 0.5296 0.1632 2.3064 0.5295 0.8604 0.5936 0.9464 0.5635 0.9644	FCVs Ha Fuel Cel 15s 71.1 0.4192 1.4322 1.4322 0.2288 0.706 0.5867 0.9445 0.9445 0.9445 0.9455 0.9382 0.9053 0.9053 0.9053 0.9053 0.9053 0.0144 0.8596 0.05648 0.9642 0.9642	aving Li-lo DC-Link 30s -0.3757 1.4322 0.2723 0.2723 0.6864 0.7706 0.5936 0.9512 0.9366 0.9512 0.9366 0.9512 0.9366 0.9672 0.931 0.9004 -0.2024 2.2746 0.4707 0.177 0.6323 0.8596 0.57 0.9659 0.9659 0.9659	on Batteria via a DC 45s 70.0 -0.3787 1.4325 0.2697 0.23 0.6885 0.7706 0.5966 0.9388 0.955 0.8711 0.9688 0.9318 0.902 52.6 -0.1992 2.2748 0.4741 0.177 0.6283 0.8697 0.5718 0.96666	es (7.5 A /DC Cor 60s 70.3 -0.3859 1.4325 0.2625 0.23 0.6956 0.7706 0.5981 0.9332 0.9491 0.8568 0.9688 0.9688 0.9688 0.9688 0.9689 7.0.6685 0.8697 0.6685 0.96655 0.96655	h) Conne verter (E 75s -0.3926 1.4324 0.2567 0.23 0.7009 0.7706 0.599 0.9333 0.9437 0.9678 0.9326 0.9026 51.7 -0.1951 2.2755 0.4789 0.917 0.518 0.8697 0.518 0.8697 0.5682 0.9646 0.9646	cted to (GNiCo) 90s 70.8 -0.3963 1.4326 0.2521 0.706 0.5996 0.3344 0.9491 0.8688 0.9674 0.9335 0.903 51.7 -0.1975 2.2752 0.4762 0.4762 0.4762 0.6577 0.6225 0.8598 0.5677 0.9645 0.9645
Powertrain Configuration ESS FUDS: 1 cycle Fuel Economy Wheel Energy (kVVh) DCDC & ESS Motor Efficiency FCS DCDC Converter Efficiency US06: 1 cycle Fruel Economy Wheel Energy (kVVh) DCDC&ESS Motor Efficiency	Capacity mpgge Regenerative Accelerating Mech. Brake Loss (kWh) Regenerative Accelerating Efficiency Charge eff Discharge eff Discharge eff Round-trip eff Charge eff Round-trip eff mpgge Regenerative Accelerating Mech. Brake Loss (kWh) Regenerative Accelerating Efficiency Charge eff Discharge eff Round-trip eff	FCVs Ha Fuel Cell 15s -0.3249 1.4566 0.3364 -0.23 0.6537 0.7726 0.5867 0.3002 0.9451 0.9575 0.901 0.8628 -0.1846 2.3059 0.5079 0.5079 0.5079 0.5079 0.5079 0.177 0.6335 0.8604 0.563 0.9458 0.9458 0.9458	ving NiMI- DC-Link 30s 63.7 -0.2688 1.4562 0.3921 0.5939 0.7725 0.5938 0.925 0.9512 0.8799 0.9593 0.8922 0.8569 	l Batterie via a DC/ 45s 63.9 -0.2712 1.457 0.3907 0.28 0.5917 0.7725 0.5967 0.922 0.9501 0.876 0.961 0.8943 0.8695 	s (7.5 Ah DC Com 60s 64.1 -0.2751 1.4571 0.3868 0.28 0.5999 0.7725 0.5981 0.9214 0.9492 0.8746 0.9611 0.8954 0.8606 49.9 -0.1622 2.3065 0.5309 0.19 0.5309 0.19 2.3065 0.5309 0.19 0.564 0.564 0.9632 0.564 0.9632 0.9613) Connec verter 75s 64.1 -0.2763 1.4571 0.3856 0.28 0.6007 0.7724 0.599 0.9215 0.9491 0.8746 0.9612 0.8949 0.8601 0.8746 0.8049 0.5305 0.19 0.5305 0.19 0.5305 0.19 0.5305 0.19 0.5305 0.9457 0.9647 0.9	ted to 90s 64.3 -0.2824 1.4572 0.3799 0.225 0.9022 0.9492 0.9225 0.9492 0.8060 0.8962 0.8602 0.8602 0.1633 0.5296 0.153 0.5296 0.1535 0.5964 0.5536 0.9644 0.5636 0.9644 0.96	FCVs Ha Fuel Cel 15s 71.1 -0.4192 1.4322 0.2288 0.019 0.7206 0.5867 0.944 0.9445 0.9445 0.945 0.9445 0.945 0.945 0.9462 0.9462 0.9462 0.9382 0.9053 3 53.2 0.2448 2.2742 0.4279 0.015 0.5648 0.9642 0.9642 0.9642 0.9642 0.9648	aving Li-lo DC-Link 30s -0.3757 1.4322 0.2723 0.222 0.6864 0.7706 0.5938 0.9366 0.9512 0.9366 0.9512 0.9366 0.9672 0.931 0.9004 -0.2024 2.2748 0.4707 0.17 0.6323 0.8598 0.4707 0.17 0.6323 0.8598 0.9617 0.9659 0.9617 0.9265	on Batteria via a DC 45s 70.0 -0.3787 1.4325 0.2697 0.23 0.6885 0.7706 0.5966 0.9338 0.938 0.938 0.938 0.9318 0.902 52.6 -0.1992 2.2748 0.4741 0.17 0.6283 0.8597 0.5718 0.9669 0.9628 0.9628	es (7.5 A /DC Cor 60s 70.3 -0.3859 1.4325 0.2625 0.23 0.2966 0.7706 0.5981 0.9332 0.93491 0.9332 0.93491 0.8656 0.9686 0.9329 0.903 51.7 -0.1926 2.2751 0.4809 0.17 0.6155 0.8597 0.5685 0.9665 0.9626 0.9224	h) Conne verter (E 75s 70.5 -0.3926 1.4324 0.2557 0.23 0.7009 0.7706 0.599 0.9333 0.9491 0.8557 0.9678 0.9326 0.9026 51.7 -0.1951 2.2755 0.4789 0.17 0.618 0.8597 0.5682 0.9648 0.9633 0.9926	cted to (GNiCo) 90s 70.8 -0.3963 1.4326 0.2521 0.23 0.7045 0.7706 0.5996 0.3344 0.9344 0.9335 0.903 51.7 -0.1975 2.2752 0.4762 0.47
Powertrain Configuration ESS FUDS: 1 cycle Fuel Economy Wheel Energy (kVh) DCDC & ESS Motor Efficiency FCS DCDC Converter Efficiency Efficiency US06: 1 cycle Fuel Economy Wheel Energy (kVh) DCDC&ESS Motor Efficiency	Capacity mpgge Regenerative Accelerating Mech. Brake Loss (kWh) Regenerative Accelerating Efficiency Charge eff Discharge eff Discharge eff Round-trip eff Charge eff Round-trip eff Regenerative Accelerating Mech. Brake Loss (kWh) Regenerative Accelerating Efficiency Charge eff Discharge eff Charge eff Charge eff Charge eff Charge eff Charge eff Charge eff	FCVs Ha Fuel Cell 15s -0.3249 1.4566 0.3364 0.6537 0.7726 0.5867 0.9302 0.9451 0.9451 0.9575 0.901 0.8628 -0.1846 2.3059 0.5079 0.17 0.6335 0.8604 0.563 0.9458 0.9458 0.9459 0.9497	ving NiMI- DC-Link 30s 63.7 -0.2688 1.4562 0.3921 0.5939 0.7725 0.5938 0.925 0.9512 0.8593 0.8922 0.8559 0.9559 0.9593 0.8922 0.8559 0.9593 0.8922 0.8559 0.9503 0.9621 0.9453 0.9621 0.9901	l Batterie via a DC/ 45s 63.9 -0.2712 1.457 0.3907 0.28 0.5917 0.7725 0.5967 0.922 0.9601 0.876 0.9611 0.8943 0.8595 	s (7.5 Ah DC Conv 60s 64.1 -0.2751 1.4571 0.3868 0.5999 0.7725 0.5981 0.9214 0.9492 0.8746 0.9611 0.8954 0.8606) Connec verter 75s 64.1 -0.2763 1.4571 0.3856 0.28 0.6007 0.7724 0.599 0.9215 0.9491 0.8746 0.9612 0.8949 0.8601 -0.1626 2.3066 0.5305 0.19 0.5955 0.19 0.5955 0.19 0.5945 0.5055 0.19 0.5945 0.6039 0.9645 0.9645 0.9647 0.9645 0.9647 0.9645 0.9647 0.9645 0.9655 0.96555 0.965555555 0.96555555555555555555555555555555555555	ted to 90s 64.3 -0.2824 1.4572 0.3799 0.282 0.9996 0.9225 0.9492 0.9492 0.9492 0.9492 0.9492 0.8605 0.8605 0.8602 0.5296 0.15 0.5296 0.15 0.5936 0.9644 0.5636 0.9644 0.9644 0.9644 0.9644 0.9644 0.9122 0.9461 0.9644 0.9122 0.9461 0.9644 0.9122 0.9461 0.9644 0.9122 0.9461 0.9644 0.9122 0.9461 0.9644 0.9122 0.9461 0.9644 0.9122 0.9461 0.9644 0.9122 0.9461 0.9644 0.9122 0.9461 0.9644 0.9122 0.9461 0.9644 0.9122 0.9461 0.9644 0.9122 0.9461 0.9644 0.9122 0.9461 0.9644 0.9122 0.9461 0.9644 0.9122 0.9461 0.9644 0.9122 0.9461 0.9644 0.9644 0.9122 0.9461 0.9644	FCVs Ha Fuel Cel 15s 115 114 10.4192 1.432 1.432 1.43	xving Li-lo DC-Link 30s -0.3757 1.4322 0.2723 -0.22 0.6864 0.9366 0.9512 0.9366 0.9512 0.8909 0.9672 0.9311 0.9004 -0.2024 2.2746 0.4707 0.17 0.6323 0.4707 0.17 0.6323 0.8598 0.9617 0.9658 0.9617	on Batteria via a DC 45s 70.0 -0.3787 1.4325 0.2697 0.23 0.6865 0.7706 0.5966 0.9338 0.956 0.9388 0.956 0.9318 0.962 0.9318 0.902 52.6 -0.1992 2.2748 0.4741 0.17 0.6283 0.6893 0.95718 0.9666 0.9628	es (7.5 A /DC Cor 60s 70.3 -0.3859 1.4325 0.2625 0.23 0.6956 0.7706 0.5981 0.9332 0.9332 0.9368 0.9329 0.9339 0.9339 0.9339 0.9339 0.9339 0.9339 0.9339 0.9339 0.9339 0.9339 0.9339 0.9359 0.9656 0.9626 0.9626 0.9626	h) Conne verter (E 75s 70.5 -0.3926 1.4324 0.2557 0.23 0.7006 0.599 0.9333 0.9491 0.8697 0.9678 0.9326 0.9026 51.7 -0.1951 2.2755 0.4789 0.17 0.618 0.8937 0.5682 0.9646 0.9633 0.9252 0.9564	cted to (GNiCo) 90s 70.8 -0.3963 1.4326 0.2521 0.23 0.7045 0.7046 0.5996 0.9344 0.9491 0.8637 0.903 51.7 -0.1975 2.2752 0.4762 0.47
Powertrain Configuration ESS FUDS: 1 cycle Fuel Economy Wheel Energy (KWh) DCDC & ESS Motor Efficiency Efficiency Efficiency US06: 1 cycle Fuel Economy Wheel Energy (KWh) DCDC&ESS Motor Efficiency Efficiency Energy (KWh) DCDC&ESS Motor Efficiency Energy (KWh) DCDC&ESS Motor Efficiency Efficiency Energy (KWh) DCDC&ESS Motor Efficiency Efficiency Energy Converter Efficiency Efficiency Efficiency Energy Storage	Capacity mpgge Regenerative Accelerating Mech. Brake Loss (kWh) Regenerative Accelerating Efficiency Charge eff Discharge eff Discharge eff Round-trip eff Charge eff Round-trip eff Accelerating Mech. Brake Loss (kWh) Regenerative Accelerating Efficiency Charge eff Discharge eff Charge eff Discharge eff Discharge eff Discharge eff	FCVs Ha Fuel Cell 15s -0.3249 1.4566 0.3364 0.6537 0.7726 0.5867 0.9302 0.9451 0.9975 0.901 0.9575 0.901 0.8628 -0.1846 2.3059 0.5079 0.177 0.6336 0.5039 0.5079 0.177 0.6356 0.8663 0.9458 0.9693 0.9073 0.9455	ving NiMI- DC-Link 30s 63.7 -0.2688 1.4562 0.3921 0.3921 0.5939 0.7725 0.5938 0.925 0.9512 0.8593 0.9523 0.8529 0.9593 0.8529 0.8559 0.9553 0.8522 0.8559 0.1641 2.3064 0.5289 0.18 0.5632 0.9453 0.9621 0.9095 0.9901 0.9656	l Batterie via a DC/ 45s 63.9 -0.2712 1.457 0.3907 0.28 0.5917 0.7725 0.5967 0.922 0.9601 0.876 0.9611 0.8943 0.8595 49.9 -0.1622 2.3065 0.5309 0.19 0.5945 0.5642 0.96468 0.9628 0.9468 0.9466 0.9466 0.9466	s (7.5 Ah DC Conv 60s 64.1 -0.2751 1.4571 0.3868 0.28 0.5999 0.7725 0.5981 0.9214 0.9492 0.8746 0.9611 0.8954 0.8606 49.9 -0.1622 2.3065 0.5309 0.19 0.5309 0.19 0.5647 0.8644 0.9642 0.9632 0.9115 0.9463 0.9632) Connec verter 75s 64.1 -0.2763 1.4571 0.3856 0.28 0.6007 0.7724 0.599 0.9215 0.9491 0.8746 0.9612 0.9491 0.8601 49.9 -0.1626 0.5305 0.19 0.5305 0.19 0.5455 0.9457 0.9645 0.9645 0.96457 0.9645 0.9645 0.96457 0.9645 0.96457 0.9645 0.96457 0.9645 0.96457 0.9645 0.96457 0.9645 0.96457 0.96457 0.9645 0.96457 0.9645 0.96457 0.9645 0.96457 0.9645 0.96457 0.96457 0.9645 0.96457 0.9645 0.96457 0.9645 0.96457 0.9645 0.96457 0.96457 0.9645 0.96457 0.96457 0.9645 0.96457 0.96457 0.96457 0.9645 0.9645757 0.9645757 0.9645757 0.9645757 0.964575757 0	ted to 90s 64.3 -0.2824 1.4572 0.3799 0.225 0.6063 0.7722 0.5996 0.9225 0.9492 0.9492 0.9492 0.9492 0.8605 -0.1632 0.8605 -0.1632 0.5296 0.1536 0.5296 0.1536 0.5296 0.1536 0.5296 0.1536 0.9461 0.9644 0.9124 0.9124 0.9462 0.9462 0.9461 0.9644 0.9124 0.9124 0.9462 0	FCVs Ha Fuel Cel 15s 115s 1111 100,4192 11,4322 11,4322 10,2288 00,193 10,7203 10,7203 10,7203 10,7203 10,7203 10,7203 10,944 10,945 10,945 10,945 10,945 10,945 10,945 10,945 10,945 10,945 10,945 10,945 10,945 10,945 10,945 10,945 10,945 10,945 10,958 10	xving Li-lo DC-Link 30s -0.3757 1.4322 0.2723 0.222 0.6864 0.7706 0.9352 0.9365 0.9512 0.9365 0.9512 0.9064 0.9707 0.9672 0.9672 0.9074 0.2274 0.4707 0.177 0.6323 0.8599 0.9677 0.9659 0.9677 0.9659 0.9617 0.9659 0.9617	on Batteria via a DC 45s 70.0 -0.3787 1.4325 0.2697 0.23 0.6865 0.7706 0.5966 0.9338 0.955 0.8871 0.968 0.9318 0.968 0.9318 0.902 2.2748 0.4741 0.172 0.6283 0.4741 0.17 0.6283 0.6283 0.95718 0.9666 0.9628 0.9307 0.9528	es (7.5 A /DC Cor 60s 70.3 -0.3659 1.4325 0.2625 0.2625 0.23 0.6956 0.7706 0.5981 0.9332 0.9491 0.9332 0.9491 0.9329 0.9033 51.7 -0.1926 0.2751 0.4809 0.17 0.6156 0.8597 0.5685 0.9626 0.99294 0.9655 0.9626 0.9041	h) Conne verter (E 75s 70.5 -0.3926 1.4324 0.2557 0.23 0.7099 0.7706 0.599 0.9333 0.9491 0.8857 0.9678 0.9326 0.9026 51.7 -0.1951 2.2755 0.4789 0.17 0.618 0.897 0.5682 0.9646 0.9633 0.9292 0.9646 0.9633	cted to (GNiCo) 90s 70.8 -0.3963 1.4326 0.2521 0.23 0.7045 0.7045 0.7045 0.7045 0.7045 0.7045 0.7045 0.9335 0.9335 0.9033 51.7 -0.1975 2.2752 0.4762 0.4

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