

Reusable electric conversion kit for pickups with use of a servo-controlled multi speed transmission

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Summary

Ecotuned Automobile specializes in electric conversion of pickup with the first reusable powertrain system in the world. By taking advantage of the lifetime of 1 million km of the electric motor and by drawing on the similarity between the trucks, the system is designed to be easily installed, with only standard tools, and can be reused, up to 5 times, in over 85 % of the pickup trucks. This solution allows to amortize the technology cost and to offer important savings for the customer. It also reduces GHG emissions generated from the fuel combustion, the scrapping and the manufacturing of new vehicles.

Keywords: Truck, fleet, powertrain, leasing, demonstration

1 Technology description

1.1 Issues which meets technology

Ecotuned technology provides solutions to mainly two problems affecting the fleets of corporate and governmental pickup trucks. The first issue is about the use of trucks which are expensive and harmful to the environment. In fact, these vehicle consume on average 19 litres of fuel per 100 km ^[1] which represents an approximate production of 9 tons of GES annually.

The second issue is the intensive use of 15% of fleet pickups, mostly as patrol and delivery vehicles. Their powertrain then reaches its end of life after only 2-4 years of usage. These pickups, which would require expensive repairs to remain in good working condition, are then resold at very low prices and replaced by new ones. Nevertheless, since these vehicles are mainly run on the highways, their structure and other components are still in good condition. For example, the frame, which consists of an extremely solid steel structure, does not undergo wear caused by time and road imperfections. In addition, their brakes and suspension components have not been solicited that much.

1.2 Operating Principles

The project idea is to give a second life to fleet pickup trucks used intensively by reusing them when their powertrain has reach its end of life. The aim is to create urban electric vehicles where trip distances are shorter. To do this, Ecotuned performs electric conversion of governmental and commercial pickup trucks less than 4 years old and having traveled over 200 000 km. The original thermal engine will be replaced by a new electrical architecture at the cutting edge of technology. All components used are from leading manufacturers whose technology is fully developed and certified. The integration of the new powertrain system is done as to meet the current standards of safety and certification.

1.3 Innovative character

Since the invention of the pickup truck, the H chassis principle that composes its structure has not changed much and therefore is very similar from one model to the other. By taking advantage of the longevity of the electric motor and its components, the drive train system is designed to be easily installed and subsequently reused in pickup truck. In addition, the system is designed to adapt to the future generations of batteries. Thus, the electric conversion with one reusable drivetrain system can extend the life of several pickup trucks successively. This approach is revolutionary in the automotive electrification and significantly reduces the time required for the product development and its integration into new vehicle models. This innovation meets the current trends of the three R, that is, to reduce, to reuse and to recycle.

1.4 Advancement of knowledge

The replacement of the engine with a purely electric drive requires a major change in the architecture of the vehicle, which could have a significant impact on its road behavior and occupant safety. To date, there is no public review of the standards for the electrical conversion of vehicles in North America.^[2] In the document « Electric vehicle technology roadmap for Canada », the Canadian situation in relation to the standards surrounding the electric vehicle conversion is described as follows:

« To date, no standards exist to ensure that such conversions are made without compromising the safety requirements of the initial vehicles and to ensure that the owners and drivers of such converted vehicles are not exposed to undue safety hazards. The inspection of converted vehicles is a provincial or territorial responsibility. An early effort is needed to develop an inspection protocol that could be adopted by provinces and territories thereby ensuring uniform regulations across the country. This protocol could also be part of required training programs for the mechanics and technicians who will do these conversions. »^[3]

In Quebec, unlike in the United States and other Canadian provinces where it is relatively easy to put a vehicle converted to electricity on the road,^[4,5,6] the Société de l'assurance automobile du Québec (SAAQ) requires the compliance of building standards and the support of a sophisticated engineering report before allowing the registration of such vehicle. This approach is due to the fact that in case of an accident involving an automobile, victims are compensated by the SAAQ, which is a public insurance. For the electric conversion of vehicles manufactured after September 1, 1997, the regulation stipulates that the airbag deployment must provide the same protection level for the occupants than prior to conversion. This regulation, unique in the field in North America, is certainly one of the toughest in the world given the engineering challenge that this implies (preservation of the crumple zones and the original behavior of the vehicle). In 2009, an electric vehicle conversion company, “Voitures électriques du Québec”, was born in Quebec. However, the latter experienced hardship in complying with safety standards set by the SAAQ and had to cease operations. In three years of study, we found that almost all electric conversions in the world only partially met the registration requirements of the SAAQ. It is clear that much remains to be done in the field of the safety of electric vehicle conversions.

Authorized by and in collaboration with the SAAQ, the project will develop an electric conversion process for pickup trucks that meet the strict safety automobile standards. Thus, the converted vehicle will demonstrate a road handling equivalent to the original and the changes will not affect in any way the electronic stability devices (traction control, stability control, ABS braking system, etc.) and security (the airbag deployment and conservation of the crumple zones). In collaboration with various specialists in the field of engineering, automobile and electric vehicles, this project will develop a series of documents that will contribute to the development of norms and standards surrounding the electric conversion vehicles. All engineering documents generated will be forwarded to the SAAQ and Transport Canada to contribute to the advancement of knowledge in this area. This project will also develop a highly skilled workforce as well as an expertise in the dynamic behavior of a vehicle converted to electricity.

1.5 GHG emission reduction process

In Quebec, where the energy comes almost entirely from hydropower, the use of an electric vehicle emits 215 times less greenhouse gases than a similar gasoline model. In the case of a pickup truck, the electric conversion reduces greenhouse gas emissions by nearly 9 tons per year. In addition, by extending the life of the vehicles, the project helps to reduce GHG emissions related to the scrapping and manufacturing of new pickup trucks. On the other hand, for the comfort of the occupants during the winter, the combustion engine is used to heat up the cabin. By doing so, the user must leave the engine running, even when the vehicle is

not travelling. In these conditions, the engine is not used in its most efficient operating range and therefore GHG emissions are even greater. To remedy this situation, Ecotuned uses a small Webasto diesel burner to heat up the cabin. This device offers up to 8 hours of use with only 1 liter of fuel thus increasing the vehicle's range.

1.6 Advantages over other available products

The benefits of the powertrain system engineered by Ecotuned compared to other products are numerous. For 3 years, more than twenty engineers participated in the technology development. This is based on three very advanced technical aspects, that are, mechanical, electrical and programming. In fact, the product is distinguished since:

- It uses only pieces from recognized manufacturers whose technology is fully developed and certified
- It can fit and be reused on various pickup trucks models thanks to a universal attachment system and computer.
- It is equipped with a powerful 160 kW motor with a service life of 1 million km
- It is equipped with a transmission with two servo-controlled speeds
- It is safe (conservation of the crumple zones, ESP, ABS, airbag, etc.)
- It is able to adapt to future generations of batteries.

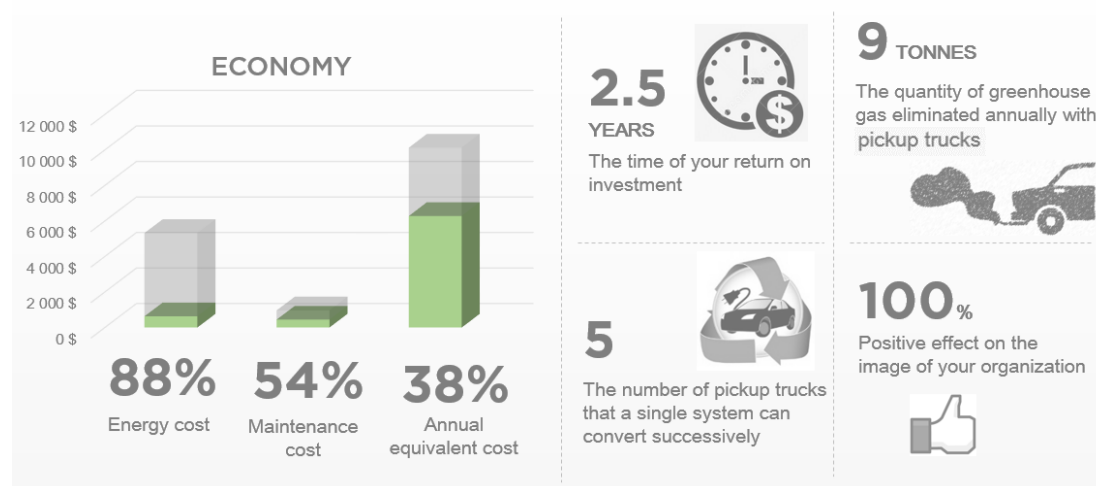


Figure1: Advantages of the technology

1.7 Cost of the technology

The revenue model proposed by Ecotuned is the free conversion of the customer's pickup in exchange of a monthly payment of \$ 700 per vehicle for a 3-year lease. This rental model conversion kit includes installation, maintenance, as well as product and parts warranty. This approach has the benefit of cutting the cost of replacement and purchase of a new pickup for \$ 35,000 as well as the fuel operating cost of over \$ 5,000 per year. Overall, the customer's economy is above \$ 15,000 over 3 years. During this period, monthly payments received by Ecotuned would have repaid the cost of the system. At that point, the system can then be reused in another vehicle (or the same if it still enables it) for a new lease. Profits for Ecotuned will be generated from the 4th year of operation and are estimated to be more than \$ 7,000 annually per installed units. Note that the service life of 1 million km powertrain allows to reuse the system up to 5 times consecutively. The batteries will be replaced after 9 years with a new generation more efficient and less expensive.

2 Work done

2.1 Design of the powertrain system

The powertrain system was designed so that it could meet the required performance for truck under normal operation. To do this, a numerical analysis was performed to estimate the performance system and power consumption in various conditions (temperature, road type, duty cycle, load in the vehicle, etc.) as to define the best combination. According to the results, the system must be equipped with a drive unit of at least 173 kW, 650 Nm and battery pack of about 50 kWh. The calculations take into account the differential ratio (3.73), the rolling radius (390mm), the rolling resistance, the aerodynamic drag and an efficiency ranging from 95 to 100%, depending on the speed and the transmission system. It is possible to vary inversely torque and engine RPM.

Table1: Consumption in function of the speed and weight

Consommation (kWh/km) vs. vitesse, et poids (Avec une efficacité moteur de 80%)																		
	Poids (kg)																	
	0	2000	2400	2600	2800	3000	3200	3400	3600	3800	4000	4200	4400	4600	4800	5000	5200	5400
Vitesse (kph)	0	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
	20	0,16	0,19	0,21	0,23	0,24	0,26	0,27	0,29	0,30	0,32	0,33	0,35	0,36	0,38	0,40	0,41	0,43
	30	0,18	0,22	0,23	0,25	0,27	0,28	0,30	0,32	0,33	0,35	0,36	0,38	0,40	0,41	0,43	0,45	0,46
	40	0,21	0,24	0,26	0,28	0,30	0,31	0,33	0,35	0,37	0,38	0,40	0,42	0,43	0,45	0,47	0,49	0,50
	50	0,24	0,28	0,29	0,31	0,33	0,35	0,37	0,39	0,40	0,42	0,44	0,46	0,48	0,50	0,51	0,53	0,55
	60	0,28	0,31	0,33	0,35	0,37	0,39	0,41	0,43	0,45	0,47	0,49	0,51	0,52	0,54	0,56	0,58	0,60
	70	0,32	0,36	0,38	0,40	0,42	0,44	0,46	0,48	0,50	0,52	0,54	0,56	0,58	0,60	0,62	0,64	0,66
	80	0,36	0,40	0,42	0,45	0,47	0,49	0,51	0,53	0,55	0,57	0,59	0,61	0,63	0,66	0,68	0,70	0,72
	90	0,41	0,46	0,48	0,50	0,52	0,54	0,57	0,59	0,61	0,63	0,65	0,68	0,70	0,72	0,74	0,76	0,79
	100	0,47	0,51	0,54	0,56	0,58	0,61	0,63	0,65	0,67	0,70	0,72	0,74	0,77	0,79	0,81	0,84	0,86
	110	0,53	0,58	0,60	0,62	0,65	0,67	0,70	0,72	0,74	0,77	0,79	0,82	0,84	0,86	0,89	0,91	0,94
	120	0,59	0,64	0,67	0,69	0,72	0,74	0,77	0,79	0,82	0,84	0,87	0,89	0,92	0,94	0,97	0,99	1,02
	130	0,67	0,72	0,74	0,77	0,80	0,82	0,85	0,87	0,90	0,93	0,95	0,98	1,00	1,03	1,05	1,08	1,11
	140	0,74	0,80	0,82	0,85	0,88	0,90	0,93	0,96	0,99	1,01	1,04	1,07	1,09	1,12	1,15	1,17	1,20
	150	0,83	0,88	0,91	0,94	0,96	0,99	1,02	1,05	1,08	1,10	1,13	1,16	1,19	1,22	1,24	1,27	1,30
	160	0,91	0,97	1,00	1,03	1,06	1,09	1,12	1,14	1,17	1,20	1,23	1,26	1,29	1,32	1,35	1,38	1,41
	170	1,01	1,07	1,10	1,13	1,16	1,19	1,22	1,25	1,28	1,31	1,34	1,37	1,40	1,43	1,46	1,49	1,52
	180	1,11	1,17	1,20	1,23	1,26	1,29	1,32	1,35	1,39	1,42	1,45	1,48	1,51	1,54	1,57	1,60	1,63
	190	1,21	1,28	1,31	1,34	1,37	1,40	1,44	1,47	1,50	1,53	1,56	1,60	1,63	1,66	1,69	1,72	1,76
	195	1,27	1,33	1,36	1,40	1,43	1,46	1,49	1,53	1,56	1,59	1,62	1,66	1,69	1,72	1,75	1,79	1,82
	197	1,29	1,35	1,39	1,42	1,45	1,48	1,52	1,55	1,58	1,62	1,65	1,68	1,71	1,75	1,78	1,81	1,85
	220	1,56	1,63	1,67	1,70	1,74	1,77	1,81	1,84	1,88	1,91	1,95	1,98	2,02	2,05	2,09	2,12	2,16
	230	1,69	1,76	1,80	1,84	1,87	1,91	1,94	1,98	2,02	2,05	2,09	2,13	2,16	2,20	2,23	2,27	2,31

Table2: Range (km) depending on the weight and speed

Autonomie (km) mot vs. vitesse, et poids																		
	Poids (kg)																	
	0	2000	2400	2600	2800	3000	3200	3400	3600	3800	4000	4200	4400	4600	4800	5000	5200	5400
Vitesse (kph)	0	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
	20	259,26	218,10	202,06	188,22	176,15	165,54	156,13	147,74	140,20	133,39	127,21	121,58	116,43	111,70	107,33	103,30	99,56
	30	230,05	195,39	181,70	169,80	159,37	150,14	141,93	134,56	127,92	121,91	116,44	111,43	106,84	102,62	98,71	95,09	91,73
	40	202,02	173,47	162,02	151,99	143,13	135,24	128,18	121,82	116,06	110,82	106,03	101,64	97,60	93,87	90,41	87,20	84,21
	50	176,43	153,22	143,76	135,41	127,97	121,30	115,30	109,86	104,91	100,39	96,24	92,42	88,90	85,63	82,59	79,76	77,12
	60	153,80	135,05	127,29	120,37	114,17	108,57	103,50	98,88	94,65	90,78	87,20	83,90	80,84	77,99	75,34	72,86	70,54
	70	134,17	119,04	112,68	106,97	101,81	97,13	92,86	88,94	85,35	82,03	78,96	76,11	73,47	70,99	68,68	66,52	64,49
	80	117,32	105,09	99,88	95,16	90,87	86,95	83,35	80,04	76,99	74,15	71,52	69,07	66,78	64,64	62,63	60,74	58,97
	90	102,94	93,01	88,73	84,82	81,25	77,96	74,93	72,12	69,52	67,10	64,84	62,73	60,76	58,90	57,15	55,51	53,95
	100	90,69	82,58	79,04	75,80	72,81	70,05	67,48	65,10	62,89	60,82	58,88	57,06	55,35	53,73	52,21	50,78	49,42
	110	80,25	73,58	70,64	67,93	65,42	63,09	60,92	58,89	57,00	55,22	53,55	51,98	50,50	49,10	47,77	46,52	45,33
	120	71,32	65,80	63,35	61,07	58,96	56,98	55,14	53,40	51,78	50,25	48,81	47,45	46,16	44,94	43,78	42,68	41,64
	130	63,66	59,06	57,01	55,09	53,29	51,61	50,03	48,55	47,15	45,83	44,58	43,40	42,27	41,21	40,20	39,23	38,31
	140	57,07	53,21	51,48	49,85	48,32	46,88	45,52	44,25	43,04	41,89	40,81	39,78	38,80	37,86	36,97	36,13	35,32
	150	51,37	48,12	46,64	45,25	43,94	42,70	41,54	40,43	39,38	38,38	37,44	36,54	35,68	34,86	34,08	33,33	32,61
	160	46,43	43,66	42,40	41,20	40,08	39,01	38,00	37,04	36,12	35,25	34,43	33,63	32,88	32,16	31,47	30,81	30,17
	170	42,11	39,75	38,66	37,63	36,66	35,73	34,85	34,01	33,21	32,45	31,72	31,03	30,36	29,73	29,11	28,53	27,96
	180	38,33	36,30	35,36	34,47	33,62	32,81	32,05	31,31	30,61	29,94	29,30	28,69	28,10	27,53	26,99	26,47	25,96
	190	35,01	33,25	32,44	31,66	30,92	30,21	29,54	28,89	28,28	27,68	27,12	26,57	26,05	25,55	25,06	24,60	24,15
	195	33,50	31,86	31,10	30,37	29,68	29,02	28,38	27,78	27,20	26,64	26,11	25,59	25,10	24,63	24,17	23,73	23,30
	197	32,92	31,32	30,58	29,88	29,20	28,56	27,94	27,35	26,78	26,24	25,72	25,22	24,73	24,27	23,82	23,39	22,98
	220	27,16	25,98	25,43	24,91	24,40	23,92	23,45	23,00	22,57	22,16	21,76	21,37	21,00	20,64	20,29	19,95	19,63
	230	25,09	24,05	23,57	23,10	22,65	22,22	21,81	21,41	21,02	20,65	20,29	19,95	19,61	19,29	18,97	18,67	18,38

Table3: Required capacity for a range of 80 km depending on the speed and weight

kWh pour 80km d'autonomie vs. vitesse, et poids																	Range kWh	35	50
	Poids (kg)																Range requis	80 km	
	2000	2400	2600	2800	3000	3200	3400	3600	3800	4000	4200	4400	4600	4800	5000	5200	5400		
Vitesse (kph)	0	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		
	20	13,08	15,55	16,79	18,02	19,26	20,49	21,73	22,96	24,19	25,43	26,66	27,90	29,13	30,37	31,60	32,84	34,07	
	30	14,74	17,36	18,67	19,98	21,28	22,59	23,90	25,21	26,52	27,82	29,13	30,44	31,75	33,06	34,36	35,67	36,98	
	40	16,79	19,55	20,94	22,32	23,70	25,08	26,46	27,84	29,23	30,61	31,99	33,37	34,75	36,14	37,52	38,90	40,28	
	50	19,23	22,14	23,59	25,05	26,51	27,96	29,42	30,88	32,33	33,79	35,24	36,70	38,16	39,61	41,07	42,53	43,98	
	60	22,05	25,12	26,65	28,18	29,71	31,24	32,77	34,30	35,84	37,37	38,90	40,43	41,96	43,49	45,02	46,55	48,09	
	70	25,28	28,50	30,10	31,71	33,32	34,92	36,53	38,14	39,74	41,35	42,96	44,56	46,17	47,78	49,39	50,99	52,60	
	80	28,91	32,28	33,96	35,64	37,33	39,01	40,69	42,38	44,06	45,74	47,43	49,11	50,79	52,48	54,16	55,84	57,53	
	90	32,95	36,47	38,23	39,99	41,75	43,51	45,27	47,03	48,79	50,55	52,31	54,07	55,83	57,59	59,35	61,11	62,87	
	100	37,40	41,08	42,91	44,75	46,59	48,43	50,26	52,10	53,94	55,78	57,61	59,45	61,29	63,13	64,96	66,80	68,64	
	110	42,27	46,10	48,02	49,93	51,85	53,76	55,68	57,59	59,51	61,43	63,34	65,26	67,17	69,09	71,00	72,92	74,83	
	120	47,56	51,55	53,54	55,54	57,53	59,53	61,52	63,52	65,51	67,50	69,50	71,49	73,49	75,48	77,48	79,47	81,46	
	130	53,28	57,43	59,50	61,58	63,65	65,72	67,80	69,87	71,94	74,02	76,09	78,16	80,24	82,31	84,39	86,46	88,53	
	140	59,43	63,74	65,90	68,05	70,20	72,36	74,51	76,66	78,82	80,97	83,12	85,28	87,43	89,58	91,74	93,89	96,05	
	150	66,03	70,49	72,73	74,96	77,20	79,43	81,67	83,90	86,13	88,37	90,60	92,84	95,07	97,31	99,54	101,77	104,01	
	160	73,06	77,69	80,01	82,32	84,64	86,96	89,27	91,59	93,90	96,22	98,53	100,85	103,16	105,48	107,79	110,11	112,43	
	170	80,55	85,34	87,74	90,14	92,53	94,93	97,33	99,73	102,12	104,52	106,92	109,32	111,71	114,11	116,51	118,91	121,30	
	180	88,48	93,45	95,93	98,41	100,89	103,37	105,85	108,33	110,81	113,29	115,77	118,25	120,73	123,21	125,69	128,17	130,65	
	190	96,89	102,01	104,58	107,14	109,70	112,27	114,83	117,40	119,96	122,52	125,09	127,65	130,21	132,78	135,34	137,90	140,47	
	195	101,26	106,47	109,08	111,68	114,29	116,89	119,50	122,11	124,71	127,32	129,92	132,53	135,13	137,74	140,34	142,95	145,55	
	197	103,04	108,29	110,91	113,53	116,16	118,78	121,40	124,02	126,64	129,27	131,89	134,51	137,13	139,76	142,38	145,00	147,62	
	220	124,91	130,55	133,36	136,18	139,00	141,82	144,63	147,45	150,27	153,09	155,91	158,72	161,54	164,36	167,18	169,99	172,81	
	230	135,21	141,02	143,92	146,83	149,73	152,64	155,54	158,44	161,35	164,25	167,15	170,06	172,96	175,87	178,77	181,67	184,58	

2.1.1 Traction System

Originally, the prototype truck was equipped with an 8-cylinder engine of 310 hp and 365 lb.-ft. coupled to a 6-speed automatic transmission. To achieve an electric traction system meeting the various specifications required, the team chose a combination of a controller TM4 CO115 X2 and a permanent magnet motor Remy Motors HVH215-115. Concerning the transmission, the original could not be reused due to its efficiency and some compatibility problems with the electric motor. A new gearbox with two speed servo-controlled has been developed in collaboration with the company Bert Transmission.

2.1.2 Battery

For the battery, the team opted for a combination of two packs of nickel cobalt manganese lithium oxide (LiNiMnCo) batteries, used in the Nissan Leaf / Renault Fluence. Combined in a "2S2P" layout, the capacity of the supply system amounts to 48 kWh at a voltage of 360 volts.

2.1.3 Steering and braking system

The original steering and braking system could not be reused in the new design due to the elimination of the drive belts of the original engine. To overcome this problem, the team used electric vacuum pumps to design, on one hand a 100% electric system for the brake booster and on the other hand an electro-hydraulic system for the power steering.

2.1.4 Cooling system

For cooling, all the powertrain system components require the glycol to function except for the electric motor that requires the Dexron VI oil. To avoid the use of a complex dual hydraulic closed loop system, the team chose to use a one fluid system based on the Dexron VI oil. To ensure that this change is adequate, the manufacturers of the parts requiring glycol were contacted to validate the compatibility with the oil. Various aspects were taken into consideration, such as the chemical compatibility of the seals and the heat dissipation. Work has also been done in order to improve the thermal management of the power system. Batteries Cooling was originally done by Pelletier-effect using only the smallest cell surface in conjunction with a forced air system. However, this approach is not aligned with the new design that positions the supply system outside the cabin, exposed to the weather and road debris. Therefore, the technical team has developed a cell convection cooling system by using the box walls as radiator.

2.2 Design of the mechanical system

For the mechanical integration of the powertrain, the team had to design an attachment system allowing modularity and interoperability of the electric powertrain in several pickup trucks models. Furthermore, it should maintain the deformable zones of the vehicle as well as the original response time of the air bags. During an impact, momentary spikes in g-forces and the energy dissipation curves vary depending on the position in the vehicle. The anchor brackets should therefore consider these aspects and withstand at least the pullout forces recommended by the SAAQ forces, namely 20g frontally, 15g laterally and 10g vertically.

To do the job, two pickup sizes of different generations have been used as reference, namely the Ford 2008 F-150 SuperCab 2x4 with a 144.5-inch wheelbase and the 2010 Ford F-150 SuperCab 2x4 with a 163.2 inches wheelbase. The team began by identifying the geometry, the available space and the anchor points of these two models in order to identify similarities. The team then studied the behavior of these vehicles during impacts through destructive testing videos from the US federal agency responsible for road safety, the National Highway Traffic Safety Administration (NHTSA). In addition, Transport Canada has generously provided the photos, videos and telemetry data from several destructive testing of Ford F-150 2004 and earlier.

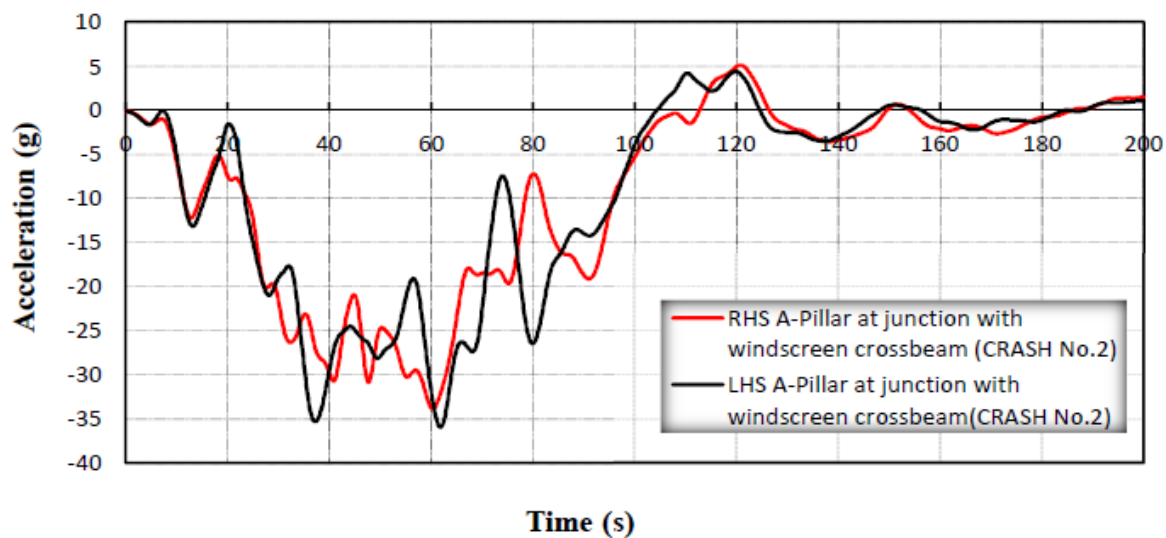


Figure2: Example of the internal analysis of Ford F-150 crash test

The architecture of an electric drive system is very different from the one of a thermal powertrain system. Indeed, the electric motor is much simpler, smaller and lighter than the petrol engine. However, the volume and weight required for the storage of energy are much higher than those of its counterpart. Substituting these two systems modifies loads and can influence the crumple zones of the vehicle and thereby the response time of the airbags. It is therefore essential to use advanced techniques to ensure that changes to the vehicle maintain all safety features.

The finite element analysis is one of the techniques used for the behavioral study of the vehicle. Its accuracy enables to simulate complex phenomena of highly nonlinear structural deformation. To do this, the analysis must take into account the phenomena of large deformation and large displacement, the elastic-plastic behavior of materials and structural contacts between elements. These theories are now available to engineers through the use of dynamic finite element analysis software such as LS-Dyna, for the design of vehicles that must respond to extreme stress. However, this is an area where the combination of these theories renders the analysis quite complex and that requires rigorous preliminary analysis in order to avoid convergence problems, erroneous results and unrealistic behavior predictions.

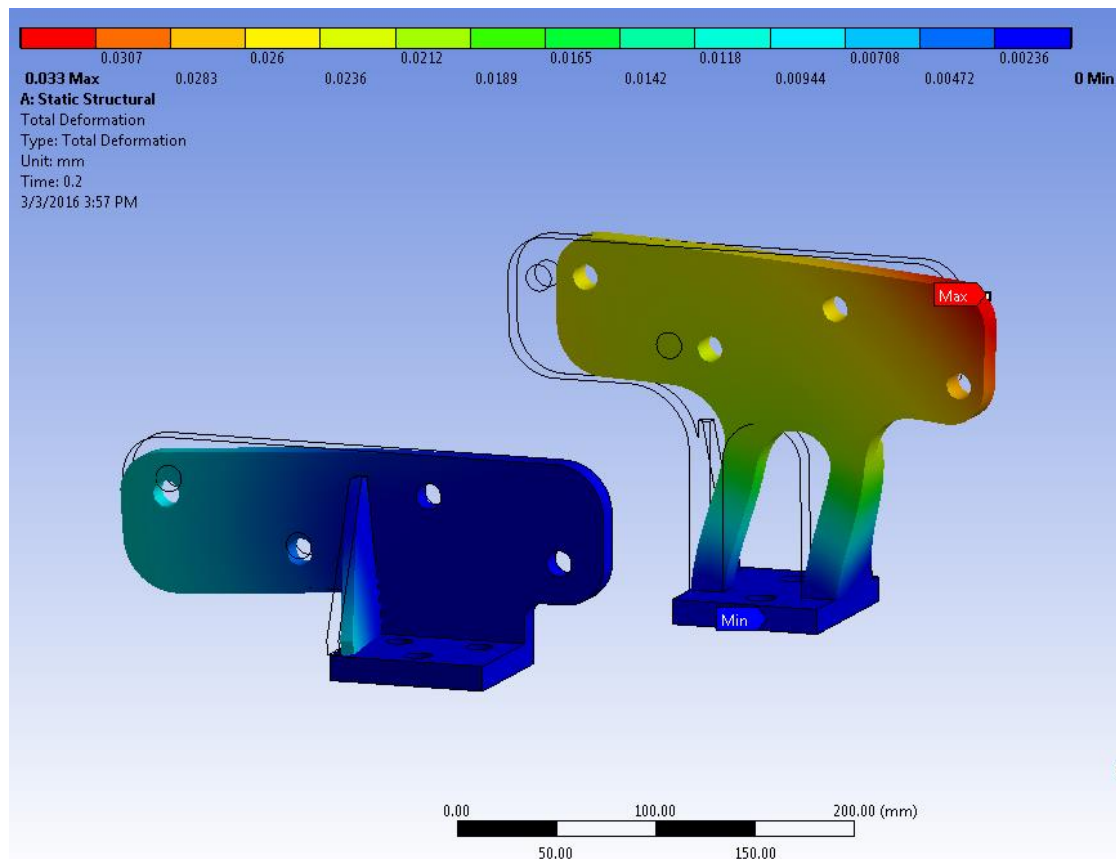


Figure3: Example the element analysis of the attachment system

Thus, for positioning the powertrain components without mitigating the action of the crumple zones, the electric motor and the transmission were located in a central position. The batteries are distributed in the proportion of 1/3 to the front and 2/3 to the rear. This new configuration of the powertrain improves the center of gravity of the vehicle compared to the original. For the component support, the electric motor, the transmission and the batteries are fixed via a front subframe. The attachment points are the two original engine mounts and the rear cross member which support the original transmission. The use of interchangeable adapters that are fitted between the new front subframe and the original engine mounts allows the installation of the system architecture on several pickups. As for the rear batteries, they are secured through custom-made cross-members that are fitted onto each side of the chassis beam. These approaches offer an integration without any drill, cut or weld to the original structure.

2.3 Design of the electrical system

The electrical system of a motor vehicle is a complex architecture. It includes several simple passive elements, such as lights from the cabin, the operator interface, etc., but also a vast network of intelligence headed by a bidirectional communication link between the most advanced components. For example, the safety electronic subsystems, such as the Anti-Slip Regulation (ASR), the Anti Blocking System (ABS), the Electronic Stability Control (ESC), the Roll Stability Control (RSC), use informations from several sensors (wheel speed, steering wheel position, vehicle trajectory, state of the inertia unit, roll rate and cornering, etc.) to identify a loss of control. When activated, these subsystems communicate with one another to transmit appropriate control commands to the braking system and engine control system.

Because of the replacement of the powertrain by an electric motor and that the operation strategies are completely different, it is impossible to reuse the original computer and therefore a new engine electronic control module is required. Editing this 'neural' network demands a thorough knowledge of its operating mode. In addition to the low voltage circuits contained in the vehicle, the integration of the traction unit inside the vehicle is also a major challenge because of the potential problems of electromagnetic compatibility between the different circuits. One of the difficulties that must be overcome is to develop an expertise on the

CAN bus communication network that is specific to each manufacturer. This communication protocol allows the different security features of the vehicle to interact together in order to maintain the vehicle stability.

For the electrical integration of the powertrain, three aspects were taken into account, the low voltage 12 volts, the high voltage 360 Volts and the communication network. For the low voltage, the team began by identifying the components that require 12 volts to create a wiring diagram. Thereafter the consumption of these subsystems was characterized by simulating several seasonal usage patterns in order to define the current peaks and, by extension, validating the ability of the DC / DC converter. For the high voltage, a wiring diagram has been created. It takes into account various elements such as the cables dimensioning, the energy control by relays and the network protection by fuses.

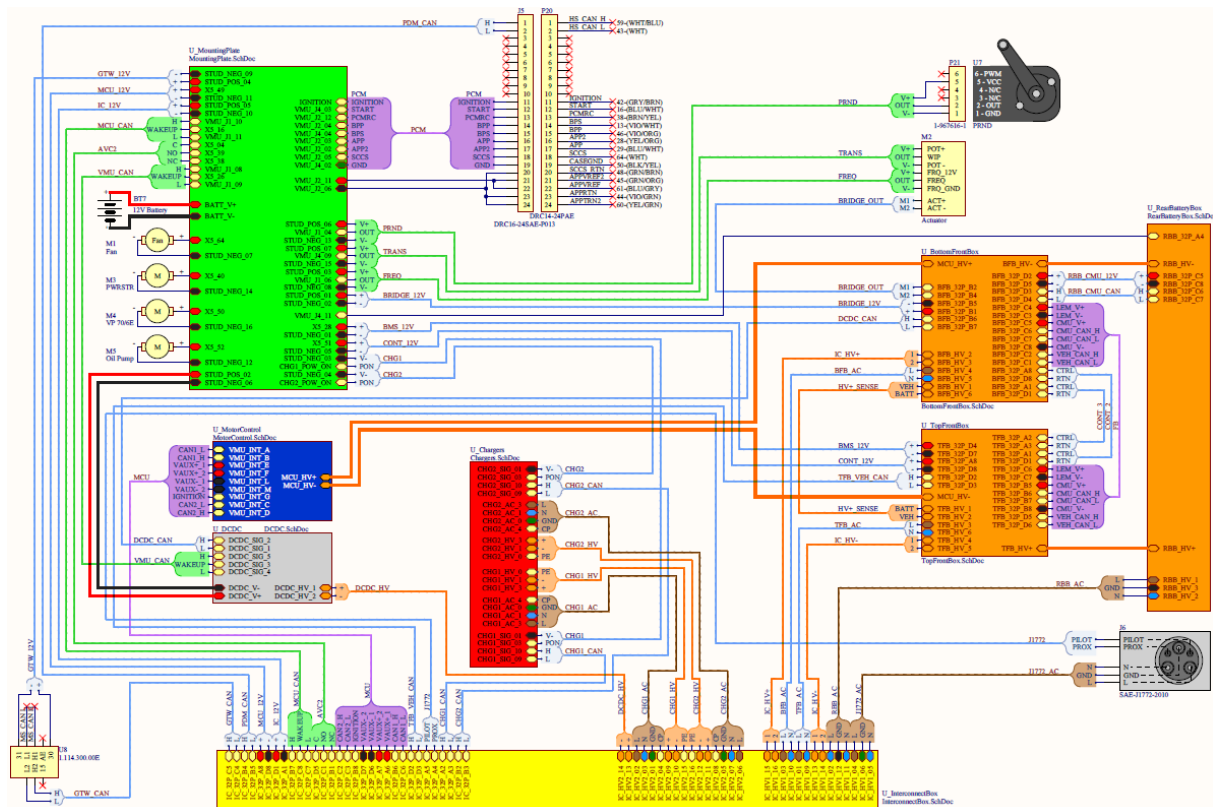


Figure4: Overview of the main wiring diagram

Concerning the programming, control algorithms were created for the management of the powertrain system, operator interface and the original subsystems of the vehicle. A work of reverse engineering was performed in order to interpret the vehicle's CAN bus communication and thus harmonize the electric drive system with it. About messages from the electronic stability control of the vehicle (ESC), they are extremely difficult to interpret and cannot be retrieved since the torque of the electric system differs largely from the gasoline powertrain's. In addition, the braking behavior and the reaction time for the trajectory correction are unknown and difficult to predict. To overcome these difficulties, the team analyzed two possible approaches, which are to consider exclusively the Boolean state and the active time of the signal sent set to the motor and then to apply a non-linear decay curve of the torque.

2.4 Achievements

The result of the actual work was to obtain an electric powertrain system capable of converting a pickup truck into an electric vehicle. This project was conducted in collaboration with various specialized organization, such as the Ministry of Transport (SRMC), the École de Technologie Supérieure (ETS), the automobile insurance Society of Quebec (SAAQ), the company Bert transmission and the German multinational Senvion. So far, more than sixty students of the ETS from all levels and various programs contributed to the project.

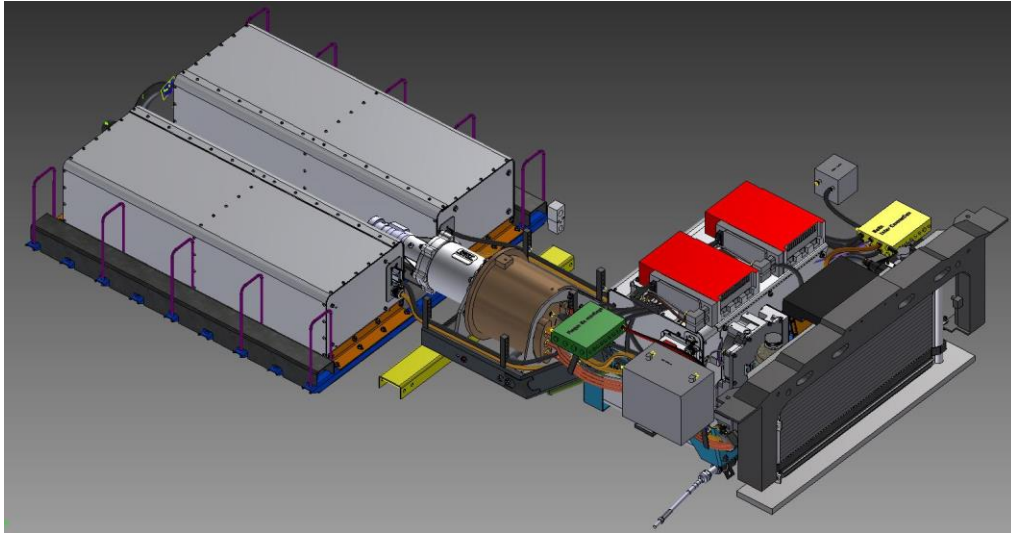


Figure5: Ecotuned reusable conversion kit

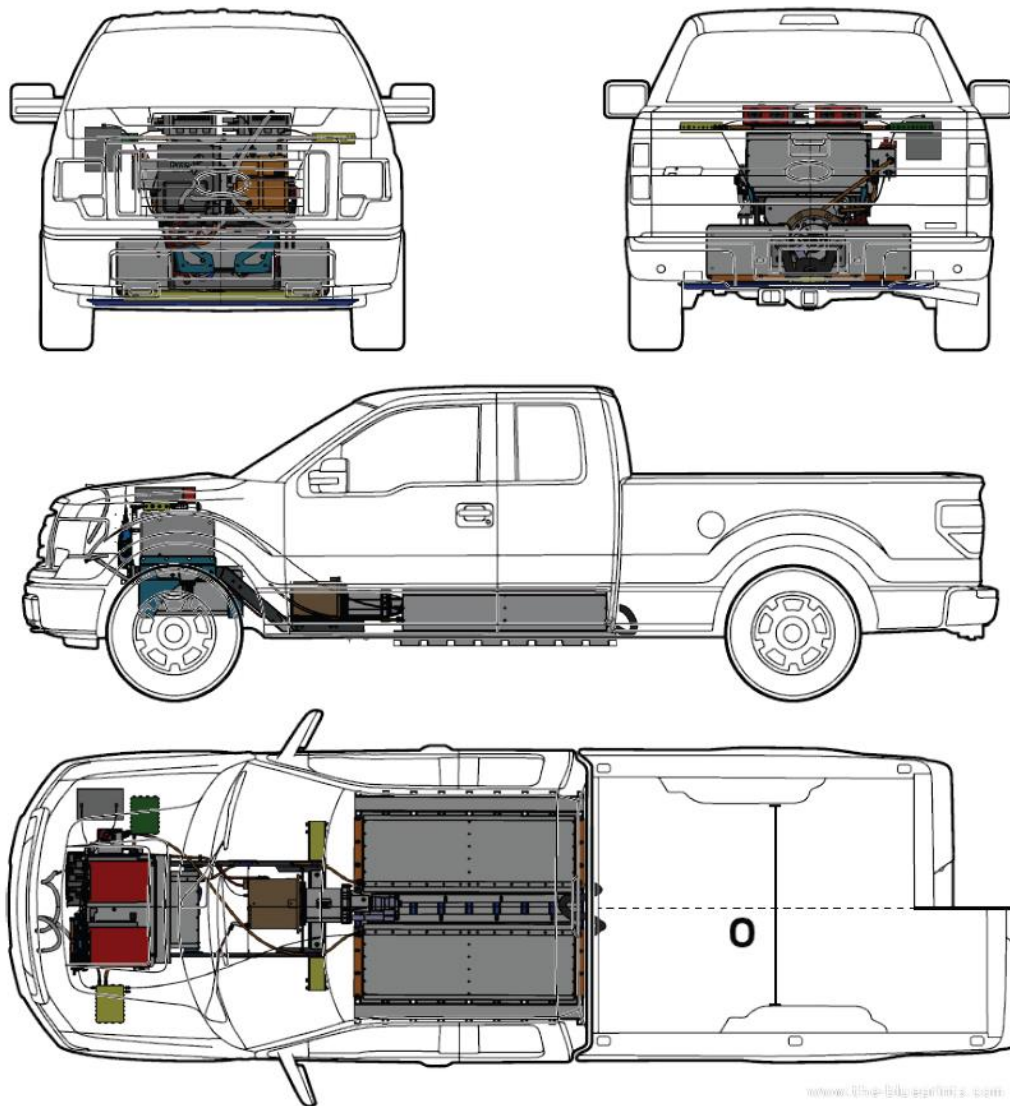


Figure6: Overview of the system in the truck



Figure7: Electric conversion of two government vehicles in progress

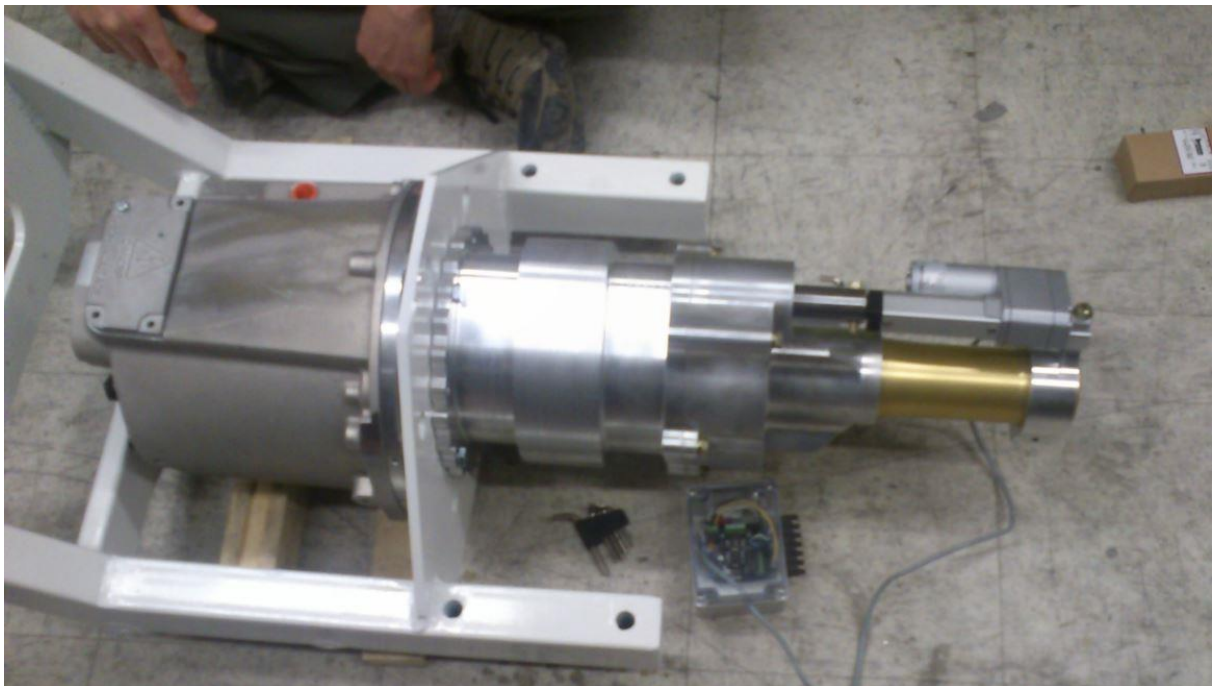


Figure8: The 160 kW electric motor and the servo-controlled multi speed transmission



Figure9: Prototype being tested

3 Market

The market is huge. Indeed, every year in Canada and in the US, more than 1.2 million new pickup trucks are sold. Our customer target is the managers of public and private vehicles fleets. Our estimation shows that every year, over 60,000 fleet's pickups that have their manufacturer's warranty expired may be converted to electricity rather than being replaced. From this figure, our conservative forecast is the conversion of 1 000 units within 4 years through a network of accredited garages-installers across the Canada and the US. Our revenue model is the leasing of the conversion kits. We propose to convert freely the pickup truck that otherwise would have been replaced, against a 35% lower installment, compared to the conventional model. This represents a saving of \$ 5 500 per year for the customer. With this approach, our gross margin reaches 60%.

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Authors



Andy Ta has been interested in automobiles since his childhood, and worked as an automobile electronics technician after his studies at college in 2004. During these years of experience, he acquired excellent technical and practical knowledge in the automobile domain. In 2010, during his studies in engineering at the École de technologie supérieure (ETS), he decided to take advantage of his sense of entrepreneurship and creativity to realize a project which he had in mind for several years: to implant a purely electrical motorization into an existing automobile without compromising its comfort, reliability and performance. His perseverance to lead projects, his interpersonal skills, as well as his capacity to quickly realize the potential in people allowed him to surround himself with many collaborators. Andy Ta's functions within Ecotuned are the product and market vision, corporate strategy, business development and customer relations