date: September 26, 2006

by: Jim Kor, P.Eng.

<u>re: Ultra-Efficient Hybrid Drive for Low HP Applications</u>

Introduction

In this memo I describe our hybrid drive system, its advantages and its applications.

I have assumed the reader to have some knowledge of hybrid drives as applied to current automobiles. Even when up to speed on hybrids, it would be of benefit to first read the June 10, 2006 article ‘Plugging into the Future’ in The Economist Technology Quarterly. This article, which I’ve included as an Adobe file for you to look over, describes the current state of affairs and future trends in automotive hybrids.

As will hopefully become apparent after reading the above article and this memo, the KOR hybrid system adopts the latest technologies and is in synch with global trends. Its uniqueness is that it focuses on powertrains with relatively low overall horsepower (in the 20 hp range, at the tires). Also, that power is handled in the most efficient manner possible, minimizing energy losses, in order to maximize the possibility that our drivetrain is eventually ‘fueled’ by solely renewable energy.

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Executive Summary

KOR Product Design is an international engineering consultancy that has focused a thirty-year career into researching energy-efficient and environmentally responsible transportation. KOR currently is developing what may become the simplest, most energy-efficient, and least polluting hybrid powertrain visualized to date. Once production-ready, this design finds first application in hundreds of thousands of small utility vehicles. As automobiles shrink in size and weight, and become more energy-conscious over the coming century, KOR's hybrid design finds eventual application in city-cars. As the global car fleet mushrooms past a billion units well before century's end, it will likely be mandated to have a significant portion of new cars powered by renewable and clean energy. KOR's hybrid drive, designed from the onset with this in mind, can make an important contribution to this end. By licensing its matured technology to manufacturers worldwide, KOR and its partners can reduce environmental impacts in developing countries such as China and India. As these countries modernize, they inevitably embrace the public mass appeal of the private automobile. Cars multiplying exponentially, however, can prove to be highly destructive. The 'correct' powertrain for a city-car, one specifically designed to run on a limited amount of sunlight, wind, hydro, and bio-fuels, can go a long way to averting technologically-induced, ecological catastrophes within these emerging nations.

The System

The system being researched and developed by KOR is an electric/gas hybrid drivetrain. It is primarily an electric propulsion system with the inclusion of an internal combustion (IC) engine. This IC engine strictly provides back-up, range extension, and high-speed capability.

The electric motors are sized for acceleration and low-speed cruising, while the IC engine and fuel tank are sized for high speeds and long-distance driving. With cars, the ratio of energy needed for acceleration compared to that for cruising is in the range of 10:1, meaning that a dramatically smaller IC engine is needed under this hybrid arrangement (somewhere around 10 times smaller than in a conventional IC drive).

Simply restated, the KOR system is a conventional electric drive with a small IC engine added. In the engineering literature, this is a well understood hybrid arrangement. Technically ours is classified as a series-parallel hybrid (for details, reference textbook 'Modern Electric, Hybrid Electric, and Fuel Cell Vehicles -Fundamentals, Theory, and Design'). This arrangement eliminates the majour disadvantages of electric vehicles, which include short overall range for the vehicle and long 'refueling' times for the on-board energy storage (typically a battery bank that needs charging overnight). The KOR hybrid drive improves on the pure electric drive in that it has virtually unlimited range and, when necessary, can be quickly refueled as an ordinary 'gas' car. The KOR hybrid arrangement improves on the conventional IC engine powered drivetrain in that it offers improved fuel efficiency, reduced emissions, and the capability to accomplish short trips in a cleaner and quieter manner (on electric power alone, without the need to ever start the IC engine during most trips). Therefor, the KOR hybrid, like other similar hybrid systems, appears to provide the advantages of both the electric vehicle and the IC ‘gas’ vehicle, without the disadvantages.

In the KOR system, the electric motors are powered by a combination of batteries and ultracapacitors (meaning that this hybrid powertrain also has a hybrid, on-board, storage device). These two energy storage devices are electrically connected in parallel. The batteries store energy primarily from the mains (the electrical grid), making this a ‘plug-in hybrid’ vehicle. The ultracapacitors absorb energy primarily during regenerative braking and on downhill runs, and they release this energy during vehicle acceleration or hill-climbing. This arrangement is more energy-efficient under regeneration (more energy can be recovered than when using just batteries). It is also less demanding on the batteries under acceleration and deceleration (the ultracapacitors buffer the current seen by the batteries, making the batteries last significantly longer before needing replacement).

The IC engine is a conventional 4-stroke, overhead valve, single cylinder unit. This can be thought of as a typical lawnmower engine, although its design would be quite a bit more sophisticated in the application of automotive technology (for improved fuel efficiency and cleaner burning). This engine is fueled by either gasoline, ethanol, or a combination of the two (such as gasohol, E15, E85, etc.). Its power requirements are largely steady-state which allows the design of the engine to be optimized. This allows maximizing the fuel efficiency and minimizing the harmful emissions produced by the engine, well beyond current automotive standards. And well beyond the most sophisticated current production IC engine running on gasoline and undergoing transient behavior (varying speed up and down).

Gasoline, of course, is a conventional fuel readily available today (plentiful and relatively cheap). However, gas has major downfalls. This non-renewable resource will undoubtedly become harder to find and become more expensive to buy in the future. Upon ‘burning’ within engines, it unavoidably releases its previously sequestered Carbon into the air, causing the greenhouse gas Carbon Dioxide to increase in the atmosphere (an undesirable situation that could lead to disastrous consequences if this leads to climate disruption).

Ethanol has been around as an alternate fuel for automobiles ever since the car was invented. Back then it was known as the ‘farmer’s fuel’ because farmers grew the crops that the fuel was made from. The first Model T Fords were designed to run on only ethanol. Ethanol is currently gaining some mainstream popularity primarily because it is totally renewable and because it typically produces less harmful pollutants than gasoline (it burns cleaner). Ethanol is also Carbon-neutral. Upon burning, the Carbon released into the atmosphere is the very Carbon initially absorbed from the atmosphere when the ethanol ‘fuel-crop’ grew from seeds into plants. Therefor, burning ethanol does not add overall to the greenhouse gases in the atmosphere. However, ethanol also has some downfalls. To make ethanol requires productive farmland and this requirement can easily intrude on human food production. Ethanol production also has low net energy gain under conventional agricultural practices (some studies even show a net energy *loss,* whereby it takes more energy to make the ethanol than you get out when burning it). In spite of these current disadvantages, and because of its advantages over gasoline, running the IC engine on pure ethanol is viewed as the most desirable solution for the future. But, this holds true only if the total quantity of ethanol needed by society can be minimized (so as not to affect food production) and if its net energy gain during the making of ethanol can be improved (through modified growing and production practices, where energy inputs are minimized).

In short, if a vehicle can accomplish most of its travel using electricity from the mains and if the IC engine, when needed, operates extremely fuel-efficiently, then ethanol requirements become minimal and likely practical to produce on a mass scale. The societal issue will then become to manufacture this ethanol energy-efficiently and to produce the required grid electricity in a renewable and clean manner (utilizing hydro, wind, solar, etc.). Both are seen as doable, but only if overall energy requirements of the vehicle are absolutely minimized. Therefor, the drive system must be ultra-energy efficient.

To attain ultra-efficiency, two approaches are fundamental:

- minimizing the power requirements of the vehicle itself (so that the power needed at the tire to road interface is as low as possible)
- minimizing losses throughout the energy transfers that occur as electricity and liquid fuel are transformed into vehicle motion.

The above two approaches are related, but our project is primarily concerned with optimizing the powertrain within the vehicle. Optimizing the overall vehicle includes approaches such as more task-specific design, reducing unnecessary capacity and excess, improving air and rolling resistance, and reducing overall vehicle weight. In the future, as vehicles are designed more efficiently, then the power needed to drive them becomes significantly lower and potentially within the range of the powertrain we are developing. This will only broaden the current range of applications for the drive system we are developing here.

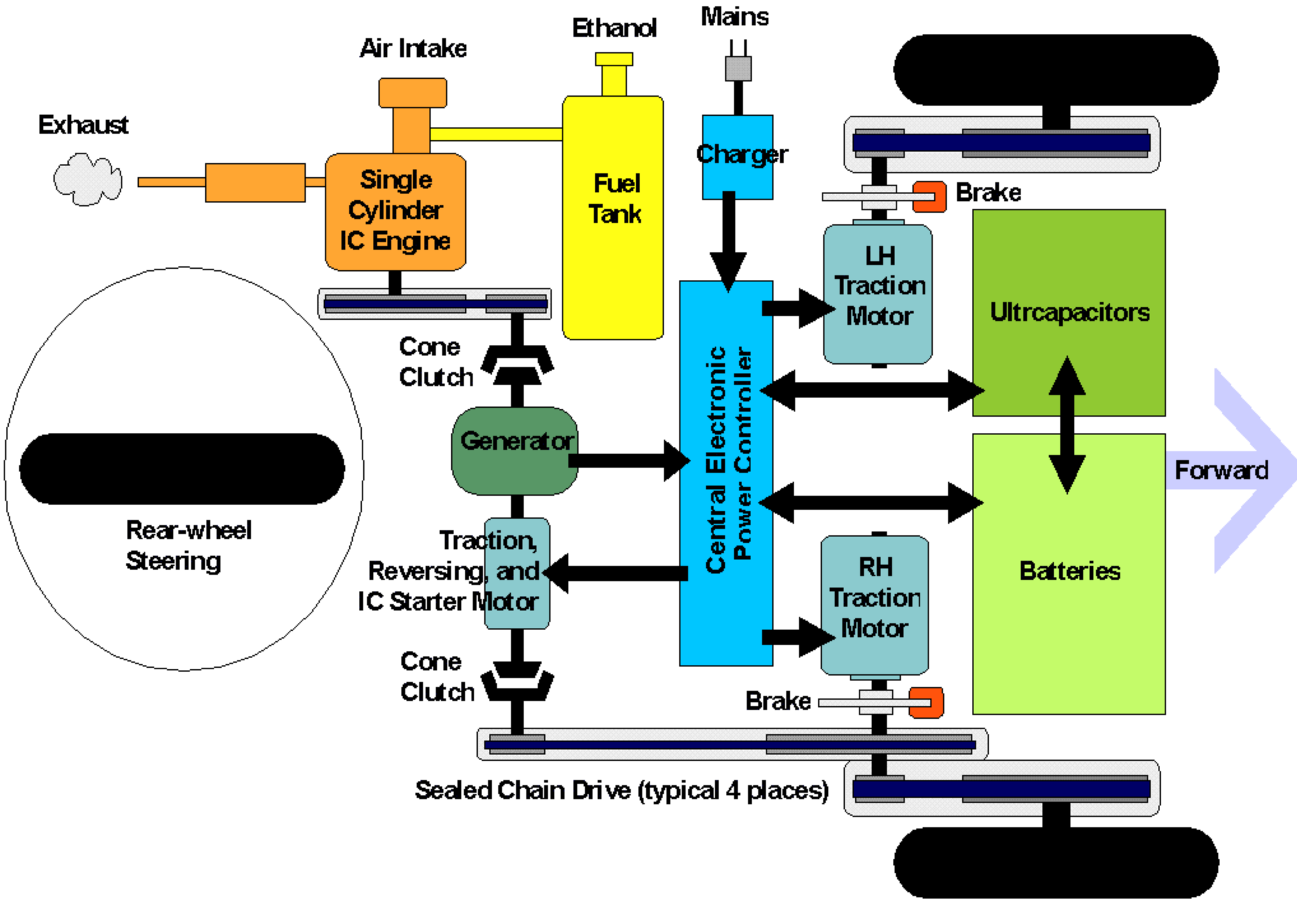
In regards to details, the low-horsepower, ultra-efficient, hybrid drive being developed by KOR contains the following ten major components. I've included approximate values for each in order to reinforce the scale of this hybrid drive, but realize that these specifications may vary slightly with further development:

1. **Two electric traction motors**, series-wound, permanent magnet, 36 volts DC, 4 continuous horsepower each, 8 peak horsepower each (this means that for the complete vehicle there is available 8 continuous hp and 16 peak hp under electric traction)
2. **Battery bank**, sealed lead-acid, quantity 6 of 6-volt batteries connected in series for 36 volt system, total battery bank capacity of 10 hp-hour at 20-hour rate and 6 hp-hour at the 2-hour rate, total wet weight of 400 pounds, life expectancy of 10 years or 1300 deep-draw cycles

3. **Ultracapacitor Module**, 36 volts DC, Capacitance of 145 farads, specific energy of 35 Wh or .05 hp-hour, specific power of 2900 W or 4 hp, total weight of 35 pounds, volume of 0.8 cubic feet, maximum current of 600 amps
4. **On-board battery charger**, 36-volt DC nominal (42 volt DC charging), powered by mains of 110 volt AC and 15-amp service, typical charging time 6 hours for depleted battery bank, extra-long electrical cord for charger has auto-retracting reel built-in for convenience in plugging in vehicle.
5. **Alternator**, 42-volt, to charge battery bank via IC engine and also utilized during regenerative braking
6. **Electric starter motor** for IC engine, series-wound, permanent magnet, 36 volts DC, 1 horsepower continuous, also utilized for steady-state cruising on pure electric (this is more energy-efficient than steady-state cruising on electric traction motors)
7. **Internal Combustion Engine**, 4-stroke, overhead-valve, single cylinder, 250 cc, air-cooled, producing around 5 hp at 3500 rpm when optimized for fuel efficiency and emissions reduction, 30 pounds dry weight, uses approx. 0.2 Imperial Gallons per hour from an 8 Imperial gallon fuel tank, catalytic converter and electric pre-heating before starting (to minimize warm-up emissions), optimally this IC engine is designed to run on pure ethanol, but can also be designed to run on gasoline or any mixture of gasoline and ethanol (gasohol) with minimal modification although resulting in increased harmful emissions
8. **Two Cone Clutches**, pneumatically operated (electrically produced air pressure), used to engage IC engine to alternator, starter motor, or vehicle wheels (for highway cruising), also used to engage alternator during regenerative braking, and engage starter motor to vehicle wheels during electric cruising
9. **Electronic controller**, centrally and singularly located, this 'black box' is the brains of the system, gathering and feeding information through a minimum of hard wiring external to the box, includes all electric motor speed controls, clutch controls, charging and current limiting functions, IC engine controls, etc.
10. **Three chain drives** are used within the system, these include: from the traction motors to the wheels (approx. 4.5:1 reduction), from one driven wheel to the first cone clutch (1:2 speed increaser), and from the second cone clutch to the IC engine (2:1 speed reduction). All chain drives are highly energy efficient (in the order of 96 to 98%), are sealed in oil and virtually maintenance-free.

The above components describe the basic drive being developed by KOR. Enclosed is a graphic representation of the KOR drivetrain for you to study. The black arrows indicate energy transfers within the powertrain, all being managed by a central controller.

If interested in understanding more about the system, I have also included a short slide-show presentation that graphically indicates the various modes of vehicle operation, and how the KOR drivetrain accommodates each.



Top View Schematic of KOR Hybrid Drive
(illustrated in a 3-wheeled vehicle platform)

Advantages

In general, the KOR hybrid drive uses existing technology in a novel way (a unique choice of reasonably standard components arranged in a different manner).

In developing this drive, KOR has importantly paid strict attention to energy paths within the drivetrain and minimized all energy losses as much as technically and economically feasible. All losses turn hard-fought and expensive energy capture and employment into wasteful heat, not into vehicle movement. All heat eventually leaks into the air and beyond the atmosphere into Outer Space, never to be used by mankind again. Heat is the tell-tale of inefficiency. Heat is degraded energy, lost forever to the Universe. To avoid energy losses, only those established technologies best suited for the precise job at hand are employed, and the optimal requirements for each technology are strictly adhered to in order to maximize energy transfer. For example, an IC engine is best suited for operating at near its maximum load, at steady speed, and to be run for some time once warmed up (this is precisely its requirements in a series-parallel hybrid such as within KOR's system). As another example, staying well within the abilities of economical and proven lead-acid batteries (by hybridization of the energy storage with ultracapacitors) allows for reliable and long battery life.

Aside from all the many detail design choices made for many good reasons, ultimately the advantages of the hybrid system over a pure gas or electric powertrain can be summarized by its performance and economy. We anticipate the KOR system to be advantageous for primarily the following reasons:

- vehicle is able to run on electricity, when needed, with a range in the order of 30 miles on lead-acid batteries, increasing to 90 miles with the equivalent weight of Lithium-Ion as on-board batteries. This usefully accommodates most trips while only under electric power (no IC engine running)
- provides virtually unlimited range in city or highway driving when using IC engine (constantly running IC engine in typical city driving charges batteries as quickly as they are depleted; under highway operation the IC engine operates as in a typical gas car, although in KOR's system the engine is closer to optimum operating conditions than in a typical gas car).
- Prior to starting IC engine, the KOR system is able to pre-warm the engine using the on-board electrical energy storage source (the batteries), thereby eliminating greatest source of pollution (which typically occurs within first few minutes of cold running an IC engine). Since IC engine is not needed at the start of trip (the car can move as an electric while IC engine undergoes pre-warming), this will not prove inconvenient (no waiting is required). Pre-warming the IC engine and catalytic converter is a known strategy to reduce emissions, but becomes highly practical in the KOR system with its large on-board battery and its tiny IC engine. This provides lots of energy to warm a small package (the opposite is true on a typical modern gas car, which has a small battery and big engine). Pre-warming also makes running on pure ethanol practical in extreme cold weather (in winter cold, ethanol is harder to ignite than gasoline).
- the IC engine runs at optimum state (most fuel efficient and least emissions), runs steadily (non-transient), and runs for long periods at a time; these all being optimum for an IC engine application
- the IC engine is as small and light as possible while maintaining optimum internal surface area to chamber volume ratio (the single cylinder engine is 250cc, which at most fuel efficient and cleanest burning rpm will produce between 5 and 7 horsepower); therefor this IC engine is carried in vehicle as a reserve power source, not as the primary power source. The advantage being that many trips can be made as a pure electric vehicle (likely the cleanest mode of travel, especially when the electricity is generated by renewable means).
- the IC engine in the KOR system is the least complicated imaginable relative to its achievements in fuel efficiency and cleanliness (single piston, 2 overhead valves, and 4-stroke with basic fuel injection). This simple engine should prove more reliable and more economic in a vehicle than would a multi-cylinder engine optimized for transient behavior

through integration of magnitudes more technological complexity (such as direct fuel injection, electric valve timing, variable compression ratio, and the like).

- The hybrid energy storage system of batteries and ultracapacitors allows the batteries to see far less current draw (in and out) which makes them last years longer (therefor requiring replacement every ten years or longer).
- the KOR system, as can many hybrids, recovers a portion of braking energy through regenerative braking. The KOR system will recover a larger portion of this energy as it has optimized this energy path and has employed ultracapacitors (which are better suited to absorb large doses of energy in a short period of time, as when braking).

In summary, we anticipate the following benefits for the KOR system:

- efficiently turns on-board electrical energy into movement
- efficiently recovers movement energy and transforms a significant portion of this to on-board storage again (to be used yet again under acceleration)
- fuel-efficient when the gas engine is running under highway conditions (optimized at turning fuel into distance covered at highway speeds)
- clean burning when gas engine is running (minimizing emissions)
- simplest design of hybrid imagined to date (the least complex hybrid)
- should prove reliable and long-lasting by nature of its design

All designs are, in the end, a compromise. Proponents of emerging technologies tend to inadvertently ignore the near-infinite trade-offs necessitated by design. Claims for a design can easily be overstated and the downsides of the design never highlighted. This can too easily lead to the ultimate failure of the product in the marketplace. Therefor, the negatives of the KOR hybrid are clearly understood and stated to be as follows:

- the KOR hybrid powertrain is physically larger and heavier than either the pure gas or electric system it replaces. Anticipated to be by about 20% to 30% greater, this is assumed to be manageable within the vehicle.
- the KOR hybrid is also likely more complicated than the pure gas or electric system it replaces (even though the KOR system is a relatively simple *hybrid*)
- the KOR hybrid, in light of all of the above, is likely more expensive than the pure electric or gas system it replaces (perhaps by a similar ratio to size or weight)
- although the cleanliness of the IC engine is constant, its fuel efficiency varies dependent on which mode of travel. It is most fuel efficient (turning fuel into distance) at highway speeds. It is least fuel efficient when used to charge on-board batteries, a result of inescapable losses as fuel is transformed into electricity and then into vehicle movement (this is why IC engine should be used as back-up only for city travel).

It is felt, at this time during the development program, that the advantages of overall improved fuel efficiency and overall greater cleanliness outweigh these disadvantages. Highlighting these disadvantages from the onset alerts the developers of the KOR hybrid, throughout the R&D program and as much as technically feasible, to minimize size, weight, complexity, and production costs.

Applications





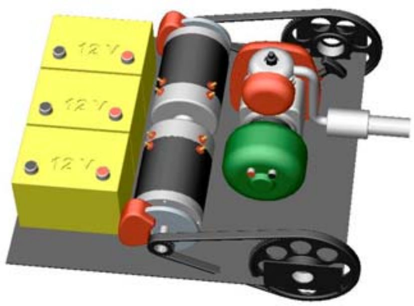
Applications for the KOR hybrid drive exist in current production vehicles. Some of these would be transformed from either gas or electric versions into hybrid powertrains. Existing applications are illustrated above. Appearing clockwise from the upper left corner, they include:

- people-carriers at parks, zoos, theme parks, and other events
- local mail service vehicles
- vehicles specifically used by the Police to administer parking tickets
- neighborhood electric vehicles (NEVs)
- golf carts
- all-terrain utility vehicles (the John Deere Gator shown here).

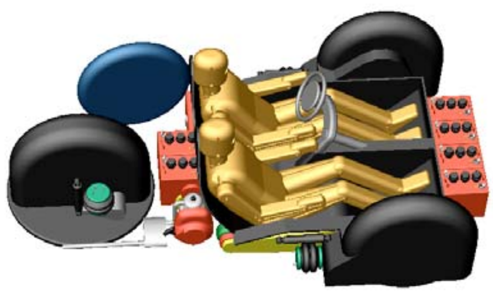
Immediate application for the KOR hybrid drive is being found in the following prototype vehicles (illustrated on next page):

- the KOR hybrid drive is being incorporated into a single-person, scaled-down, army tank being developed for a client in Arizona. These tanks will be manufactured for the expanding paint-ball amusement industry in North America.
- KOR is currently building a small city car that will contain the KOR hybrid drive. This research project has its roots in earlier work on energy-efficient vehicles accomplished by KOR. This research is largely self-funded, with some financial assistance gratefully received from City, Provincial, and Federal Governments, and from Manitoba Hydro. The KOR city car is designed to be street legal and yet run on solely renewable energy.

KOR hybrid drive in initial mini-tank :



KOR hybrid drive in prototype city-car :



When a longer view of the future is taken, one can visualize automotive applications for the KOR hybrid drive. In particular, this pertains to the areas of the world marching towards modernity (such as China and India). Car populations in these areas of the world are on the cusp of experiencing exponential growth over the next century. The type of fuel that powers all of these new cars, and how efficiently these cars use that fuel, will become of strategic importance in avoiding environmental catastrophe when dealing with mushrooming car numbers.

The Society of Automotive Engineers (SAE), with its hundred-year history and 80,000 members located in over 100 countries, is the leading authority on anything to do with the car. At a recent Congressional meeting of SAE, former President Syed Shahed shared his insights regarding the direction car design should take in India.

According to Syed, India should be careful to not follow the “mindless growth” that has occurred in the United States, filling the streets with larger cars and larger engines that demand more gasoline and can ultimately cause ecological disaster down the road.

Instead, Syed suggests that the focus in India should be on sustainable technologies that will help the country grow its automotive industry in a way that is environmentally beneficial not only for itself but for the world at large. He believes that with this focus, environmentally friendly technologies developed in India can be marketed to other nations.

It is important, Shahed continued, that the country’s very road-transportation mix be taken into account when companies develop vehicles and vehicle technologies. Safety is especially at issue because bicycles and motorcycles make up a large percentage of the vehicle population. As well, there is heavy pedestrian traffic in this “urban mobility melange,” he said, so small *urban* cars are in order.

Only a few groups today are researching and developing such an environmental ‘urban’ car as pointed to by Syed Shahed. KOR is one of these groups, with their researched city-car and ultra-efficient hybrid drive. Below are a few ecological prototypes recently created by the automotive industry, which points to the possible shape of things to come.

Conclusions

Designing a low horsepower ultra-efficient hybrid drivetrain is technically very challenging. To attain real-world applications by replacing drivetrains of existing 'gas' or 'electric' vehicles of similar power (in the 20 horsepower range), the KOR hybrid drive must prove to be economical, light weight, and compact. Above all, to achieve these requirements, the hybrid drive must be simple in its design.

Outwardly simple designs that work well, are reliable, long-lasting, and sell to a global market, are never easy to achieve. But that is our goal with this drivetrain: to articulate possibly the simplest, most energy-efficient, and least polluting hybrid drive visualized to date. One that can initially power hundreds of thousands of small utility vehicles. And eventually power a significant portion of the global fleet of automobiles, likely over a billion by century's end, on predominantly renewable energy.

Jim Kor