

Electric bike essay



Our Electric Bicycle Project I have added an electric power assist onto a GT mountain bike. With a 3 HP peak motor, it is much more powerful than typical electric bicycles. The basic motivation to build an electric bike was to have a fun and efficient and environmentally friendly way to stay out my car for short trips around town, and also as a silent trail bike for exploring the hills. I wanted to get some exercise – this bike can still be pedaled. When I first put this together it was even more of a blast to ride than I had envisioned.

I have seen 70 year old people get on this bike and laugh like little kids – it's like a magic hand is silently boosting you along. This website will describe the background of this little electric vehicle, offer some reflections on the electric and hybrid vehicle scene, and detail most of the design and motor and batteries should you be interested in making one yourself. Though it's a bit of a project, a number of people have actually made very similar bikes based on my basic design. The Beauty of the Electric Bike

No noise – no vibration – no smog – no smog checks – no registration – no insurance – no driver's license No gasoline – no oil – no tune-ups – no parking hassles – no car payments – no more exercise (use the pedals) – no brainer

Background: Why build an electric bike? Why use such a big motor? I love the idea of electric vehicles in general and would love to have a pure electric car. I have a Prius, currently just about the closest thing available. However, battery technology hasn't advanced enough to make a pure electric car affordable yet.

I do think, however, that light-weight, low-speed, short-range vehicles are wellt within the limits of current battery-electric technology, so I set out to see what could be done to make a more powerful and longer-range motorized bike. Since I live about 3 miles from my favourite grocery store and my house is at the top of a fairly long and steep hill, biking and walking is just strenuous enough to be discouraging to me on a spur-of-the-moment basis. However I love biking. I have mountain bikes and folding bikes.

In looking for a motor to add to one of my bikes, I rode some ready-made bikes and noticed that they are really fun to ride. The silence and effortless cruising along is just magical. But the electric bikes and motor kits for sale at the time, such as the Curry USProDrive, the eBike, etc. were fairly low power and really aren't that much faster up a steep hill than an unassisted bicycle. The Wave crest was the first decently powerful ready-made bike, though the company didn't last long. (Electric vehicle companies seem to have a curious habit of making a big splash – and then vanishing beneath the waves. Now you can buy decent electric motor kits from Wilderness Energy and Crystallite, among others, but I was curious about the nuts and bolts of things, and wanted to learn more about exactly what it takes to drive a vehicle with pure electric power. I am a great fan of all electric vehicles and watch the new technologies closely. Hybrid cars are a tremendous technology that in my opinion is the first step on the road to all-electric vehicles. Hybrids will necessarily drive the development of better and cheaper batteries, which is the only missing link to the puzzle.

Hybrids of today that are only charged by their gasoline engines will lead to ' plug-in' hybrids that can be partially recharged at home or at charging

stations. This will lead to astonishingly frugal use of fuel, but these cars will need much larger battery packs, which means better and cheaper batteries will have to be produced. This will happen and is probably happening right now. Eventually batteries will become so much better that the auto companies will start to produce cars that simply leave out the combustion engine altogether – the pure battery electric vehicle.

Don't get me started on fuel cells and the much hyped future 'hydrogen economy.' This is interesting technology, but suffice it to say that there are so many technical breakthroughs and logistic problems yet to be solved, that I simply don't see it happening within the next ten or fifteen years. In other parts of this website and in the Electric Bicycle FAQ, I elaborate a little more on the near and far term technology, where I see it going, and what the most promising developments are. This is not really a build manual, however. . Experienced tinkerers may glean a lot of ideas and solutions from my pages if they want to use them and adapt them. There are parts lists and plenty of photos. This driveline is now extremely robust and probably suitable for larger electric vehicles, not just bikes, up to three to five horsepower. Over the course of this project I've made many interesting discoveries, encountered issues and problems which all electric vehicle builders must face, and finally figured out some fairly simple solutions.

I've fitted a number of different driveline systems which range from simple single vee-belts to the present double reduction using a heavy-duty toothed belt and chain. Earlier versions are shown on following pages. This bike performs well, is stone-reliable and nearly silent, and all the major components are available online or at power transmission supply houses.

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Note that I had to weld and machine key components like the jackshaft mount using ball bearings, and the chain sprocket that clamps on to the spokes at the wheel hub.

The right components and design solutions to this project were hard to come by, and I just want to share what I've learned to promote what I consider a pretty amazing form of transportation.

V1. 5 – Dual Reduction Belt/Chain Drive

The current version is what I am calling v1. 5, which is the same bike as v1. 4 but with some basic changes: a new timing belt drive system with a chain final drive. Basically, the motor drives a belt that spins an intermediate shaft or 'jackshaft' mounted next to the motor and spinning on ball bearings. This shaft then drives a chain going down to the rear bike wheel. Same motor and all other components. Earlier versions are documented on following pages.

- * Scott 24 V DC, 1 hp motor (3 hp max) – still available from cloudelectric. com
- * Gates Power Grip GT2 belt primary drive
- * 1/2" steel jackshaft on custom shaft ball bearing mount – 3: 1 reduction
- * #35 chain final drive to rear wheel – 2. 77: 1 reduction
- * 8. 44: 1 overall gearing gives top speed of about 27 mph
- * 2 x 12V Hawker AGM-type lead acid batteries, 13 Ah each; later replaced by B&B 12v 16Ah batteries (also AGM)
- * 4QD " Scooter 180" speed controller – 180 amp with optional regenerative braking
- * 24 V charger charges in 2-5 hours typically pedal in all 18 speeds
- * batteries and motor removable in 10 minutes
- * range 15 miles on the flat depending on pedal assist
- * weight 85 lbs.

Motor The Scott motor is 24 V DC, brushed, and is rated at 1 hp (746 watts) continuous power and draws 41 amps. It cost about \$250, however in 2008 I see the price is closer to \$350. This model no. 4BB-02488. This motor is available still

from cloudelectric. com. Don't let the rating fool you, this motor will put out 2. 5HP peak and can even be over-volted (judiciously) to 36V where it will put out 1. 5 HP continuous and around 4HP peak.

If you're crazy enough to gear it up, it would propel a bike to around 50mph (please don't do this.) So the Scott is pretty heavy and suitable for slightly larger vehicles; for a bicycle, a better alternative might be one of the motors at evdeals. com such as the 500 watt 36V motor for only \$60. Cloud electric also has a selection of motors from \$80 to \$170 that would be very suitable according to your budget and power desired. A very interesting choice is their ' Motor 36 Volt 1000 Watt' model that has an integral freewheeling clutch. This can also be run at 24V to get 535 watts of power. I may have to switch over, these sounds like an ideal motor for a project like this.) You cannot just use any old motor to drive a bike. People often ask me, can I use a motor from an electric drill, or a starter motor from a motorcycle or a car. The short answer is no, these motors are generally not suitable at all. The efficiency is poor, they will overheat, they are not powerful enough, the speed is too high, they're too noisy, or any number of other reasons. The Scott is a very high quality motor with high efficiency, good cooling, and ball bearings.

At 16 pounds it is pretty heavy but motors in this power range were hard to find five years ago. If I were doing this today I would undoubtedly use a lighter motor of the type that has subsequently become available. There has been a tremendous influx of scooters and smaller electric vehicles, and many of the motors on these vehicles would be suitable for a bike. There are also a number of motors used by people making combat robots or battelbots.

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These are generally high power and quite tough. However battlebots don't really need efficiency so this is something to look out for.

Efficiency of greater than 80% should be looked for at a wide range of speeds and currents. In my opinion, a bike needs a motor of at least 400 watts and probably not more than 1000 watts. Any less and you might as well not bother, and any more and the motor will probably be large, heavy, expensive, deplete your batteries in a flash, or all of the above. The reason for a motor this powerful is simple: hills. I live on a steep hill. While a Zap or a US ProDrive bike rated at 400 watts goes a decent 17 mph on flat land, they slow to 3 to 5 mph on a decent hill. I can pedal that fast.

I have ridden a Schwinn with the Currie US Pro drive. It was actually great, I would recommend it to anyone as a very good turn-key kit solution. However I wanted to go faster and be able to get up a hill. The simple fact is that you need from 5 to 10 times as much power to go a given speed on a decent grade. This is why a car that only needs 12 hp to go 60 mph on flat roads has an engine that can put out 100 to 200 hp. The Scott motor was used in many go-carts and Electrathon vehicles. (Electrathons are efficiency competitions using ultralight closed-course battery electric vehicles carrying one person.

The point is to go the farthest distance in a given amount of time.) So the efficiency is obviously pretty good. The motor cost \$269 total shipped, and weighs about 16 pounds. It has ball bearings and massive cooling fins and is built to last. Brushes do not wear out very fast at all, this is not really a concern. It draws around 41 amps while producing a continuous 1 hp. Put a greater load on it and will draw well over 100 amps and produce up to 3 hp.

This is why it needs a 180 amp controller. More about controllers later.

Speed Reduction and Gearing: a big issue

I will spend quite a bit of time here describing the speed reduction scheme, as this is the most difficult problem to solve in fitting a motor to a bike or other small EV. The big issue with all motorization schemes on bikes is this: how to reduce the speed of a typical motor, which may turn at upwards of 3000 rpm, to the necessary speed of a bicycle rear wheel. A 26" mountain bike wheel at 20 mph is turning only about 265 rpm. The overall reduction required is therefore between roughly 8: 1 and 11: 1 depending on what top speed you wish to achieve.

Now it is certainly possible to simply bolt, say, a 130-tooth chain sprocket to the rear wheel and drive it with a 13-tooth drive sprocket off the motor. But this is a very large wheel sprocket (about 15" in diameter) and, critically, the chain would be unbearably noisy. My basic observation about chain drive is that if any chain sprocket turns faster than about 750 rpm, it will start to make a racket. If only there were a good quiet 3: 1 gearbox you could bolt on to the Scott, the final 3: 1 or 4: 1 ratio could be easily achieved with a chain and sprockets to the rear wheel.

However I don't know of such a gearbox ready made, and a gear box is very difficult to machine from scratch. Straight cut gears also tend to make a whining noise. This big problem of gearing down the motor has lead to the development of the hub motor. This is simply a bicycle wheel hub with a motor built in, which can then be spoked to a rim. Such hub motors either have gears built in, or they are very particularly designed to just turn at a

very low speed while still having good power and torque. This is a difficult trick. It's much easier to make a motor that derives its power from spinning at higher rpm.

At any rate, at the time I could not find many hub motors, and the few that were available were expensive, made a gear whine, and were underpowered. Also, a hub motor has one set gearing by design, and you can't alter it. I wanted something where I could experiment with different gear ratios, top speeds, and hill climbing ability. I have come up with this belt drive to achieve the primary speed reduction of 3: 1. The dual-reduction drive system is much more solid than anything I have tried before. It's a little more complicated but slippage is absolutely eliminated and I feel confident that this system would be able to take even more power.

This is important because the Scott motor is often bumped up to 36 volts rather than 24 and I may eventually switch over. Why belt primary drive? Wouldn't two chains be easier? Basically, as I say, belts are much quieter at high RPM. At 3000 rpm a chain would be about as loud as many small gas engines. An electric bike should be whisper quiet, and this belt drive is. Many electric go-carts use a single straight chain drive; however, they go faster while having smaller wheels, so they need less speed reduction, and the wind and tire noise and speed tend to mask the racket the chain makes. Plus, carters don't really care much about noise.

I used a Gates PowerGrip GT2 belt. This timing belt has rounded teeth so it's quieter than other belts. The teeth are closely spaced for better grip on small sprocket wheels. This is the 5mm pitch type. At 25mm wide, the short belt is

much less likely to stretch and is easily tensioned by pivoting the jackshaft mount slightly – three of the mounting holes are slotted, so the mount can pivot around the un-slotted fourth hole. Does this wide belt seem like overkill? The Gates Co. has very nice simple little engineering software they give away on their website that will tell you what size and type of belt you will need.

You plug in the power, gear reduction, speed, and a couple of other things and the program will give you some recommendations. I used the program and this was one of the recommendations and what do you know, it has been great. Has never been adjusted and and has never slipped or worn. The jackshaft itself is a 1/2" steel shaft running on two R8 sealed ball bearings. The mounting plate and bearing housing is welded aluminum. Sorry that I don't have a diagram of this but hopefully you get the general layout from the photos. If belts are so great, then why chain final drive?

Since the jackshaft is now speed-reduced to 1000 rpm max, running a chain down to the rear wheel now makes sense. There is a reason so many bikes and motorcycles still use steel chain final drive. It makes sense here because the run is longer and the available space narrower, and chain is much stronger and less stretchy than a long narrow belt. At this speed the chain may be slightly audible at top speed, but not noisy, and the wind and tire noise while riding will actually be louder. A chain doesn't need to be tensioned nearly as tightly as a belt.

Finally, chains have a master link which makes assembly and removal much easier, like when changing tires and repairing flats. (Belts are endless.) The

#35 chain is a very common American size. It has a shorter pitch than bicycle chain but is much stronger. (Bicycle chain is made flexible to allow for the side to side misalignment resulting from different derailleur gear combinations.) You will notice the extra bar running in between the chain, from the jackshaft to the axle. This is a reinforcement and has an adjuster nut at the lower end to establish proper chain tension.

The bar acts to maintain proper driveline rigidity – the Scott motor can put out a tremendous amount of torque and the motor mount and bicycle frame will twist and compress under heavy power loads without this bar. Actually it attaches to the bike frame near the axle using the stock rack mount on the dropout. The driveline parts are as follows They were ordered from Bearing Belt Chain in Las Vegas at www.bearing.com. * belt: GATES POWER GRIP GT2 5MR-400-25 Gates part # 9390-8080 \$11.35 * motor sprocket: GATES P21-5MGT-25-MPB Gates part # 7709-5021 \$17.00 * jackshaft sprocket GATES P64-5MGT-25-1610 Gates part # 7709-2064 \$30.52 * sprocket hub mount for above: GATES 1610 1/2" TAPER LOCK BUSHING part # 7858-1608 * jackshaft ball bearings: MRC part # R8Z \$11.56 ea. (2) * jackshaft: machined from 1/2" stainless steel stock * jackshaft chain sprocket: #35 chain, 13 tooth MARTIN 35BS13HT 1/2" bore \$6.91 * rear wheel chain sprocket: #35 chain, 36 tooth MARTIN 35B36 \$11.56 (modified on my lathe to fit) * chain: #35 chain that I had lying around – length is 50 links (100 rollers) – 37-1/2" long

A number of machining, fabrications, and modifications I had to do myself. The jackshaft mount is the most elaborate part to make and took some time. The jackshaft and motor need to be very rigidly connected and aligned, yet <https://assignbuster.com/electric-bike-essay/>

adjustable to set the belt tension. I used a 1/4" aluminum plate and welded a 1-1/4" alum. tube to this. There are two diagonal braces welded to these – you can only see the upper one in the photos. The braces just clear the motor. Then the tube was bored in the lathe for the two ball bearings. It also has ring grooves for retaining rings to hold the bearing in place.

The 1/2" shaft is about 5" long, also with ring grooves. There are a total of 4 stainless steel 1/4-20 allen bolts holding the whole thing to the face of the Scott motor using the existing tapped holes. As I mentioned, three of the holes in the jackshaft plate are actually curved slots to allow for adjustment to tension the belt, the whole thing pivoting a little around the fourth bolt. The 21-tooth motor sprocket was bored to 5/8" on my lathe. It is fixed to the motor shaft with a 1/8" steel split pin or 'roll pin'. I had to drill a hole for this pin through the sprocket and motor shaft.

Roll pins are much stronger than set screws, and they are pressed or driven in, so they don't come loose. They're also easier to machine than Woodruff key-ways. The large 64 tooth belt sprocket arrived in solid steel and was ridiculously heavy. Aluminum was not available. So I drilled it out extensively to lighten it as you can see. The chain sprocket bolts to the hub of the belt sprocket with two 10-32 allen screws, the holes for which I drilled and tapped. The motor is mounted to the bicycle frame on a specially made 1/8" thick stainless steel bracket. The whole bracket bolts to tabs welded to the bike frame with three allen bolts.

The chain, drive belt and motor can be removed from the bike in about 3 minutes. Finally, I had to attach a sprocket to the rear wheel. I finally decided

to just try clamping a sprocket to the spokes. This may seem like a clumsy solution but I have seen it done on a number of other applications. It has been reliable and has not damaged the spokes at all. Sometimes simple and direct wins the day. For those of you familiar with the Currie US ProDrive, a very popular electric drive kit for bikes, this is basically the same way they bolt their motor plate to the bike wheel.

Looks somewhat unsophisticated? Fine, but it works, bolts quickly to a completely unmodified bike wheel, and has been trouble free. I started by boring out a standard type-B 36-tooth sprocket (the kind with an integral offset hub) to where the hole would just fit around the protruding wheel hub. This locates the sprocket nicely on the hub center. Then I basically faced the hub down to nearly nothing on the lathe, just enough to space the sprocket out away from the spokes. Then I drilled 9 holes for 10-32 screws. The screws go through the spaces where the spokes cross.

I made three curved clamp plates with three holes each for the inside of the wheel. For off-road use I intend to get a different wheel with a knobby tire and a larger sprocket to lower the gearing for better hill climbing. A couple of extra chain links will make it easy to switch out. The net of all this is that finally I have got it really right. I can whack the throttle open and closed at any speed and there will be no belt slippage of any kind. The first thing I did was to go down the street and climb this steep rocky trail that gave the old bike problems. Even with the relatively high gearing, the new driveline shot me right up the thing. I even popped a little wheelie over the top of it. That sure never happened before. Now I can finally use all of the torque this Scott motor can put out. DESIGN & COMPONENT DETAILS BATTERIES There is no

question that the battery is the single thing, the one and only, overriding thing, that is holding back the development and mass proliferation of electric vehicles. At this point in time most of us are still stuck with using lead acid batteries. I am now using B&B 16 Ah batteries, made in China.

Originally I used Hawker Odyssey batteries model PC545, 12 lbs. each, which are basically the same as the Hawker Genesis G13EP. All of the batteries I have used are deep-cycling, AGM (Absorbed Glass Matt) sealed lead acid batteries (SLA) and are about the best quality lead acid battery available. They can be mounted in any position except upside down and they are sealed and maintenance free. They are much like the Optima batteries used in many advanced electric vehicles like the EV-1 and the Sparrow but are available in a wider variety of smaller sizes. I got them at Thunderstruck-EV.com.

They now run about \$50 each. It is nice that there is some competition now in this type of battery and the prices are coming down by about half from what I paid for my first set. Of course lithium ion batteries of some kind would be the great enabler. Lithium is just now entering the market, they are still quite expensive and something of a question mark. Conventional lithium cells, as used in laptops, have a thermal runaway potential – meaning they tend to catch fire, in some cases like a Roman candle. New materials and chemistries based on lithium are attempting to address the safety problem.

I have seen batteries called LiFePo₄ – lithium iron phosphate – offered for sale at various websites selling electric bikes and accessories. They are claiming no fire problems, At this point, it looks like a decent battery pack for

a bike like this would cost around \$1000 or more. That is a lot of money to spend on a battery with a 1-year or 2-year warranty. In my opinion, these batteries need to come down to the sub-\$300 range before I would really be interested. A battery is rated in voltage and amp-hours. Voltage times amps times hours equals watt-hours and this is the total energy available from the battery.

So my battery pack has $2 \times 12V \times 16Ah = 384$ watt hours. In other words it will give 384 watts for an hour. But actually, it won't. The "16 Ah" is a rating to be taken with a very large grain of salt. An essential thing to know about batteries is that they give a lesser amount of total energy when discharged at a high rate. Read that last sentence again and absorb it, it's important. A battery's electrical power is not like a glass of water. If you drain that glass quickly or slowly, it contains the same amount of water. Batteries, not so. Draw high amperage, and your total amount of energy is less!

Because of this, batteries are often rated nominally at a slow 10-hour discharge rate, in which case they will give more total energy and thus seem like a better battery. Bikes and all electric vehicles use energy at a very high rate. A bike can easily draw enough current to discharge a battery pack fully in under half an hour, so batteries will not give their rated output under these conditions. Another tempting choice for cheap batteries might be Panasonic or Powersonic or Sonnenschein gel-cell /lead acid batteries. Gel cells are the typical batteries that come with most stock electric bicycles and kits.

They are not AGM. Longevity is not as good, though the stated juice per weight ratio seems better, and they are available in a variety of smaller sizes if weight were more of an issue than range. Hawker makes slightly larger AGM batteries such as the G16EP like my B&B which have a little more juice but are also heavier. The Hawkers are very well made. Another great thing about AGM type batteries is that they can be charged quickly at much higher amps than other kinds of lead acid batteries. Likewise they have the ability to give high current with no problems.

AGM batteries are also unique among almost all battery types in that they retain a full charge for months with no ‘ charge leakage. ‘ One of the big drawbacks of of NiMH batteries is that they discharge about 1% to 2% per day. Regular lead acid batteries will just go dead in a few months as well. Because of this, AGM batteries are also marketed to people with antique cars and snow plows – vehicles that aren’t used very often and are likely to have a dead battery when you finally want to start it up. All lead acid batteries have two big drawbacks. They are quite heavy for the total amount of power they deliver.

And even these so called “ deep cycle” batteries really should not be deep-cycled too often, as repeated deep discharging dramatically shortens their useful lifespan. This is where NiCads have lead acid beat, as they are more power dense and can be run down pretty much all the way without much damage. Of course large NiCads are much more expensive and must be recycled carefully due to the toxic cadmium. So until better batteries like NiMH or Lithium Ion are more widely available in vehicle sizes and less

expensive, Hawkers and other AGM type lead acid are about the best we can do.

More ruminations on the Great Battery Quest below. Batteries and 120 amp speed controller mounted in the main frame space. SPEED CONTROLLER A speed controller or motor controller is essential in applying the voltage and power that is delivered to the motor from the batteries. All decent electric vehicles need a motor controller of some kind. On a bike with a very small motor it might be possible to just have an on-off arrangement, and I suppose there are other less expensive and much cruder ways to control speed but I feel that a decent controller is absolutely necessary with a powerful motor like this.

The controller is a rather expensive electronic black box with no moving parts. A modern PWM or ‘ pulse width modulation” controller is very reliable as long as it’s current limit is not exceeded. Unfortunately a high ampere capable controller is not cheap and may cost about as much as the motor. Curtis controllers are well known in golf carts and other industrial vehicles, however I am using a Scoota 180 amp speed controller from 4QD. – www.4QD.co.uk . This is a small company in England, that specializes in smaller and cheaper controllers for light electric vehicles. The controller with a matching thumb-lever throttle was \$248.

It is capable of regenerative braking, thought you can easily disable this function. Previously I tried a Scoota 120 amp model that was nearly identical. It failed after a few months. I was just working it too hard and the output connections overheated and melted. The 4QD factory has a nice policy of

repairing their controllers and exchanging them for different ones if you want, with a very fair exchange allowance. The new 180 amp model gets a little warm but has been quite dependable for well over three years now. I originally used an Eagle 80 amp controller from the same company. It was \$120.

It failed due to overheating but that was completely my fault for using a much too-small controller. If I lived on flat terrain I think it would have been fine and would have lasted a long time, especially since I added a finned aluminum heat sink from an audio power amplifier – try a decent electronics store, maybe even Radio Shack. You need to size your controller at about 3 times the rated power of your motor. My motor is rated at 41 amps continuous, HOWEVER it will draw a lot more than that at full throttle under load. Manufacturers tend to state their controllers at intermittent current limits.

For example a Scoota 120 will put out 120 amps for a short time but should not be run that high continuously. Regenerative braking – nice idea but . . . A lot of people inquire about regenerative braking. Hybrid car manufacturers often tout the ability to reclaim electrical energy when the car is going downhill. I don't know how much energy they are getting back in a car, but on a little electric bicycle, it is almost certainly never worth the added trouble, expense, and operational hassles. You would be much better off with a freewheeling setup. Let me explain how I've come to this conclusion.

The speed controller I use has regenerative braking available. After trying it out for a while, adjusting it and testing it every which way, I ended

up disabling it. Regenerative braking means that as you brake or coast downhill the controller will use the motor in reverse as a generator to recharge the batteries. On my route to the market, for instance, I am on flat terrain for a while and then go downhill for about a mile to reach the store. Conceivably this could mean that I arrive at the store with nearly full batteries, which would make the ride back less likely to drain the batteries completely.

However, the regenerative braking is a function of the speed controller. If you have the region set up for maximum regeneration, the throttle can be quite touchy. And if you just suddenly release the throttle, which is fairly normal behaviour, the braking effect would be full. It is really not very good to have the throttle set up to brake that hard. I found myself about launching over the handle bars every time I lost forgot and snapped the throttle off. Also, this is a good way to have other people ride your bike and crash it. Note there is no freewheel on the electric side of my bicycle.

A custom freewheel is yet another surprisingly difficult mechanical part to machine or to buy. Of course the pedal-drive freewheel still works, which means that you can motor without the pedals being forced to turn. However, if you pedal the motor will necessarily be turning, which is a drawback if the batteries die. The regenerative braking function requires a solid connection to the wheel. However, after some time with this bike, using the regen function of the special speed controller, I came to a surprising conclusion against using regen. As I say I bought a controller with regenerative braking.

With this set-up, I could basically use the thumb-throttle carefully as a fairly powerful rear brake. The amount of braking could be adjusted to make it less grabby, but I never could get it to the point where I liked it at all. It was obtrusive and difficult to control. I suppose if you could hook it up to a pressure sensitive brake lever, it would work better, however, that is a bit beyond the level of sophistication I think is really necessary on a little electric bike. Luckily the regen function can be defeated which is what I finally decided to do. Realize, all vehicles are “regenerative” going down a hill.

Turning the engine off down a long hill in your car and coasting – this is reclaiming the energy spent to climb the hill. Unless the vehicle is very heavy and/or has great aerodynamics, most of the energy going down a hill will just be used to overcome air resistance, with little left over to recharge the batteries. Normally on a bicycle, very little braking is ever necessary, and top speed down most hills is quickly limited by poor aerodynamics. The net result, I felt, is that the regen on my ebike was just slowing me down and creating heavy backloading on the drive train needlessly.

It would be better to put the motor on a freewheel and adopt a method of getting up to speed and coasting as often as possible with the motor shut off. This riding technique is apparently very effective at extending your range, probably more so than having regen. Many people who deal even with larger EVs and hybrids have also formed the opinion that a pure freewheeling function would be better in many instances than regenerative braking. The regenerative braking function of hybrid cars, for instance, is vastly overstated. Hybrids work by generating their electric power onboard using the

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gas engine; they have a power generation function built-in, it is central to the entire concept. So why not use it for braking as well? Sure, but in reality this produces very little in the way of reclaimed power. The batteries in hybrid cars are charged at least 95% by the using the gas engine as a generator; and the reason they are so efficient in city driving is simply because they can run at slow speeds very efficiently on predominantly electric power. It is only while driving at higher speeds down long steep grades that any decent power is truly regenerated to the batteries.

How much of this describes typical driving conditions? Coasting with minimal drag from the motor is actually much more efficient. While coasting the vehicle uses no juice whatsoever. It is common practice during mileage or efficiency runs with a hybrid like the Honda Insight, to accelerate to speed, then go into neutral and coast for a ways. This actually produces the greatest mileage and efficiency. On an electric bike it is undoubtedly most efficient to pulse the motor on till you get up to speed, and coast on downhills, or pedal on the flat to maintain speed. Having the motor freewheel would be a big advantage.

Unfortunately, a decent ready made right-hand drive doesn't seem to be available, at least for a reasonable price. A minor drawback. THROTTLE At first I simply got a \$2.00 10K potentiometer from Radio Shack, wired it up to the 4QD wiring and mounted it on a plastic spacer beneath the right-hand hand grip. There was no spring return, you had to turn it down to slow down, but on the other hand it was cheap and simple and the brakes can easily overcome the motor in an emergency stopping situation. Also, it worked

perfectly as a cruise control. Then with the new larger motor controller I got a box-mounted thumb lever throttle.

This is just a short-throw 10k pot with a return spring and lever mounted on the end. There are now motorcycle-style twist grip throttles with built in pots widely available at scooter shops for about \$50, such as the Magura. The Scoota controller requires an on-off switch – I got a small rocker thumb switch from an electronics store, and mounted it in the throttle box. thumb-lever throttle and on-off switch BATTERY CHARGER I found a great 24-volt 5 amp automatic charger made for the now-defunct e-bike EV Warrior from All Electronics surplus in LA. It was 20 bucks, it's compact and works wonderfully.

What a bargain – I got two. These may not still be available but there are a few sites that deal with scooters and electric bikes now that have similar chargers for \$50 to \$80. When I was first building this bike, in the new world of electric vehicle hobbyists, a good non-12V charger (or any decent component for that matter) was hard to come by cheaply. For instance, I scoured the surplus electric suppliers looking for a decent, powerful, cheap 12V or 24V motor and basically came up empty. Before this I used a Sears 12V auto battery charger, charging each battery separately.

This worked fine but remembering to go out and switch the charger between batteries was very inconvenient. The EV Warrior charger shuts off automatically, the bike is always charged and ready to ride. COST AND CONSTRUCTION DETAILS I used high quality parts and the total cost of all the added components including charger came to about \$950. Not cheap, but

my new mountain bike cost more than that – and you have to pedal it. You can get a turn-key electric motor kit for around \$400-700, or a readymade e-bike for \$1000-2000, but of course the motors and batteries are all only 1/3 as powerful as this. Weight

At 85 pounds, this is pretty heavy for a “ bicycle,” but I think of it more as an ultra light moped. And it is a true “ mo-ped” in that you can still meaningfully pedal it. Plus I can still lift it into my pickup or my car trunk if needed. My old Peugeot moped weighed twice as much at 150 pounds with similar speed capability, and pedalling it was a joke – the pedals were geared really low, purely for starting the motor. Brakes The old brakes on this bike were okay for 12 mph but hair-raising at 30 mph. A new side pull “ vee brake” as used on decent Modern Mountain bikes luckily bolted right onto the old brake mount posts.

Regular bicycles are too light and top heavy to use the front brake as the main squeeze, but as any motorcyclist can tell you, on any heavier two wheeler the front brake does 90% of the work. The vee-brake kit was about 25 bucks on sale at a bike dealer, and came with a new lever for the handle bar. I only replaced the front brake, as the rear posts are in the wrong place. A number of people have written to ask me where the rear brake is – it looks like there is no rear brake at all. Look closely in the photos: the rear brake on this GT mountain bike is mounted down low, on the chain stays, just aft of the pedal crank.

Frame I would encourage people doing this kind of conversion to use a heavy duty steel mountain bike frame. The components can take the added force

and weight of the motor system. Mountain bike components now are amazingly strong and durable – they are made to take off-road abuse. The wider wheels especially are much better for the additional weight and power. Also, a steel frame is easier to weld or braze motor and battery mounts onto. Stay away from aluminum unless you can figure a way to bolt or clamp everything on without welding. Welding onto an aluminum frame will likely ruin the tempering and severely weaken it.

It's quite difficult to weld on thin aluminum. My old GT was too heavy for a good mountain bike these days but just the ticket for an electric motor project. The peculiar geometry of the GT rear frame design actually makes a perfect place for the motor. Construction I had to weld a motor mount onto the rear frame behind the seat. The chain just clears the wheel and frame and it was critical to get the motor solidly mounted. With such a powerful motor, the motor mount must be strong, and it's really pretty important to have a ball-bearing motor. The motor mount is removable from the frame with three allen head screws.

I have a TIG welder and lots of metal working tools so it was not a big deal for me but I don't see why all this couldn't be done on a steel bike frame with silver solder or brazing rod and a gas torch. The batteries also have a very solid welded-on mount with a screw-down top retaining rail. The batteries are heavy and need a good solid mount with shock padding. These batteries are narrow and don't interfere at all with pedalling. In this arrangement they are also low and keep the center of gravity down. LEGAL ISSUES OF ELECTRIC BICYCLES At 20 mph this bike is basically legal as an unregistered motorized bicycle in Calif.

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I believe the Federal laws now allow up to a 750 watt motor, which is what the Scott is (1 horsepower = 746 watts.) Also, the Federal Law limits such bikes to 20 mph. I fully expected the Feds to cripple these vehicles with a something like a 400 watt limit, but for once was pleasantly surprised – it's actually a rational and reasonable law and probably promotes good electric bikes rather than underpowered toys that no one will buy. Geared for 30 mph this would technically have to be registered and insured as a motorized cycle or possibly as a full motorcycle.

Not sure exactly what the difference is but I believe there is a technical distinction. However, used judiciously, most people are still going to assume that it's just a particularly fast bicycle, especially if it's being pedaled.

Actually I have no problem with a legal limit of 20 mph. Slow is not bad. The wind noise is less and you can actually hear the world. A bike limited to 20 with no registration and no insurance and no driver's license (and no noise and no vibration and no gasoline and no mechanics and no smog checks and no smog and no parking hassles and no car payments . . .) Not a bad tradeoff, to put it mildly.

I would not recommend riding on bike paths or foot trails. Most of these bar motorized vehicles of any kind, even if it's not posted. It is tempting since the bike is silent and by pedaling, most people will not even notice that you've got a motor. I think speed is the key. If I must ride on a bike path, I use the pedals and just don't go any faster than a gently pedaled bicycle. It is hard to argue with that, and no one ever has. I think eventually there will be a lot more electric bicycles and other small powered vehicles and it will probably become a problem competing with pedestrians, roller bladers, etc.

The advent of affordable lithium batteries will mean that electric vehicles of all kinds will become radically better, and immensely popular. It's just inevitable. There's already enough friction between these groups on crowded paths and trails. This is another reason why keeping maximum speeds under 20 mph is probably a good idea. FUTURE IMPROVEMENTS, VARIATIONS AND POSSIBILITIES It's the batteries, stupid. This bike is great fun right now but I can see a lot of room for improvement. Ah, batteries, ever the Achilles' heel of the electric vehicle.

Oh how I hate lead acid batteries but – still stuck with them. NiMH, Lithium Ion, or Nickel Zinc batteries would improve the juice-to-weight ratio enormously, and would probably double the range, which is the single least satisfactory thing about this and all electric bikes. The batteries now weigh over 25 pounds and are the heaviest single component. There are some reasons for hope. The increasing numbers of hybrid cars are generally using NiMH batteries which should trickle down eventually and be very suitable for electric bikes.

Other battery chemistries as well have made it to market, though success always seems elusive. The biggest promise right now is that GM and Toyota are really pushing to put lithium batteries in the next generations of hybrid cars and plug-in hybrids. GM's Chevy Volt, due out by 2010, will only work if they succeed in mass producing lithium ions, and getting the cost down. It's kind of a chicken and egg problem: huge mass production will bring the cost down, but until they're cheaper, there isn't enough demand to mass produce them.

The soaring price of motor fuels and the resulting demand for more and better hybrid cars is probably what will convince manufacturers to bite the bullet and build the factories. The promise of lithium ion. Certainly the lithium battery has the greatest potential of all the next-generation chemistries. It has the most energy per pound and is well proven in smaller applications like cell phones and laptops. A practical battery with this capacity would almost instantly put battery vehicles on a competitive footing with gasoline powered ones.

Current conventional lithium ions have a serious weakness – they die completely after about 2 to 3 years, no matter what. But again, if GM and Toyota succeed in getting lithium batteries into hybrids, as they say they will within the next two years, it will mean that they have largely eliminated or minimized these drawbacks. Progress with this battery seems to be steady. They are now being used in some cordless power tools, which use bigger cell sizes and draw heavier loads than electronic devices. They don't use any heavy metals. There are a number of new types of lithium cells that don't burst into flames when overheated or pierced. A123 has some of the most successful new cells, and Toshiba has even demonstrated cells that can be recharged almost fully in just a few minutes. Chinese cells are now on the market especially for bicycles called LiFePo4. These cells are available in a battery pack for small electric vehicles called the Eonyx, as well as from other packagers. They are still something of an unknown quantity. Once these get into more people's hands, we will be able to get a reading on their longevity and performance.

Right now they are still about ten or fifteen times as expensive as lead acid batteries. Well, what about fuel cells? Of course the concept and demonstrations of this still-experimental technology is very compelling, but there has been so much hype on the subject that it is still hard to say if this is all just incredibly successful marketing spin by the FC developers. I also think that in the early 2000's there was an element of clever subterfuge by the auto industry to take the heat off the fact that average fuel economy in this country was decreasing due to ever more popular and larger SUVs.

It is so much easier and cheaper for an auto company like GM to run a relatively small early research project on fuel cells, than it is to do serious engineering on real live production-ready hybrid development. Even in 2006 there are still basically no economically practical fuel cells in actual use and even their promoters say that any commercially viable model is at least 5 years off and maybe 10. It is the running joke that the day of widespread fuel cells and the hydrogen economy always seems to be 20 years off – no matter when the question is asked.

And then, where do we get all the hydrogen? Seems to me hydrogen is and will remain way more expensive than any petro fuel and I have never seen any realistic ideas to overcome this problem. And we store it in 10, 000 psi cylinders in the trunk? Uh, OK . . . Believe me I would love to be proved wrong and initially was excited about this technology like everyone else, but increasingly I am thinking the emperor has no clothes. Maybe a loincloth. Motors are already pretty much perfected, right? Well, yes and no. My Scott motor is starting to look like a dinosaur, it ould stand to lose some weight. The power is actually about right for a bicycle but just look at it, it's too big

and heavy. There are tons of little scooters out there and it would be possible to get a 500 watt or 750 watt scooter motor, which is would undoubtedly work well. Currently (July 2009) I see that a 24V Currie 600 watt motor is available for around \$130. It is compact and powerful. The MAC 600W motor might be a better choice but is \$279. Try evdeals.com for an updated motor availability. I would love to get a Lemco pancake motor, www.lemcoltd.com – they are light, powerful, and efficient but expensive. This company is now making even smaller motors that would be perfect for high-powered bikes but \$800 for a motor is a bit much. And of course my whole motorization scheme, with the belt and chain, is not terribly clean or elegant. I personally think the “ hub motor” is the obvious solution for electric bikes, as used on Lee Iacocca’s E-bike and the Wavecrest (which seems to have died and resurrected as the E+) and others. Heinzmann of Germany seems to still be making a variety of hub motors, as are other companies.

Try Heinzmann’s site www.estelle.de for some pretty interesting ideas – I guess they are now selling bikes, complete kits, motors, batteries and controllers. However, at this point they are still only about 300 watts = 1/3 HP which is about 1/3 of what they ought to be. Also, Heinzmann motors tend to be a little noisy and expensive. A hub wheel motor replaces the normal wheel hub and obviously needs no other transmission, chain, or belt which is a huge simplification – although of course this can also be a slight drawback in that the gear ratio can’t be changed.

A very popular and reasonably priced hub motor made in China seems to be the Crystalyte, though I haven’t used one myself. There is a similar system

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sold by Wilderness Energy. These are sold in kits where the hub motor is basically spoked to a bike wheel rim of your choice and you just replace your old wheel with the motorized one. They tend to go on the front wheel but can also be installed at the rear. The kits include a pretty slick speed controller, throttle, and brake-switches to cut the power. Often batteries are a separate purchase.

The hubs themselves are made in various voltages, powers, and rotational speeds to match various wheel sizes and top speed requirements. This seems to be a decent site with links to dealers in the US and Canada – www.evsolutions.net. The gearing, for my use, could certainly benefit from a nice simple two-speed transmission. One speed for the hill and the other for the flat. Electric motors have such great torque throughout the RPM range that more than two speeds just isn't necessary unless the motor is severely underpowered. The obvious thing to me would be a hub motor with two or three speeds built in. I have never seen such a beast.

I think with better batteries and motor, this bike could easily weigh 25 pounds less or have twice the range, maybe both. The frame and wheels are no lightweights either, at 36 pounds. That's a good 10 pounds more than my new mountain bike, and it's got a suspension fork. So in short with modern components this type of bike could easily weigh less than 50 lbs.

Performance would improve, it would be easier to pedal and you could even carry it on a car roof rack. How about a solar cell battery charger? They sell these to RV owners. Actually there's no reason why you couldn't throw a solar cell on your roof and charge the batteries all day.

Imagine – this is real-world fully solar powered transportation, doable today. As further work on the existing bike, I would love to put a suspension fork on the front and maybe a suspension seat post. Lights would be nice. At this point this bike would be an amazing transportation unit by any standards, not just electric vehicles. Also, this starts to become a pretty intriguing possibility for a trail bike. I used to have dirt bikes but they are dirty and noisy and environmentally a big problem. A dirt bike is a blast but you're not exactly communing with nature.

A completely silent electric trail bike would be much more like hiking aesthetically, and would open up long-range trails – can't wait to get some better batteries and go up to the mountains. I can also see going to a higher voltage system. 36 or even 48 volts would be a lot better and keep the current draw down. I started with a 12 V system for simplicity's sake but the power was low and the current draw was high. I won't go into the basics of electric power except to say that lower voltage is bad because it leads to higher current which creates more heat and requires a much bigger motor controller.

Controllers are basically sold by amperage or current capacity, and high amperage controllers are much more expensive than lower amperage ones. The same controller can put out twice as much power at the same amperage level if the system voltage is doubled. I have even considered simply adding another battery on this bike and just over-volting the motor to 36 volts. The motor is probably able to take it (though I'm sure the manufacturer wouldn't recommend it) and my controller can easily be switched to 36 V. The bike would be heavier, faster, and have better range.

It's just a trade off. Intriguing. (Note that most controllers have voltage limitations and must be altered or jumpered to make system voltage changes.) That's what's neat about electrics for the tinkerer – you can change motors, change batteries, change controllers, change gearing – it's all so easy and interchangeable compared to an internal combustion vehicle. Imagine a having an old Vespa scooter, and you think one day “ Gee, wouldn't it be interesting to put a nice new Honda 200cc engine in that thing” – you'd have to be half nuts to even consider it.

Turnkey solutions. So you don't have a TIG welder and a metal lathe? You just want to bolt something onto your bicycle? As I've mentioned the turnkey kits made by Wilderness Energy and Crystalyte seem to be the simplest and cleanest ways to electrify a bicycle. Since I made this bike there have been some developments in the electric bike world. The popular Curry USProDrive bolt-on kit that I eschewed as too undepowered was always a decent kit but I don't think it's available at all anymore.

The batteries were not AGM quality, the stock controller was jerky and mounted inside the motor where it's hard to keep cool, and the drive train was not terribly robust, but all in all a decent kit, and they sold quite a few of them. A similar concept called Lashout seems to be available. This kit has a built-in freewheel on the motor which is nice. MISCELLANEOUS THOUGHTS Here in 2008, with the cost of gas now at \$4. 50 a gallon, true pain is being felt by almost everyone at the fuel pumps, and by the sellers of old fashioned gas burning vehicles. Big cars and SUV's are sitting on dealers lots. There are 4 month waits .

There is now tremendous pressure to come up with solutions. This should, finally, lead to some real improvements in pure electric transportation. I love the idea of electric vehicles but the practical electric car is still not quite a reality. The electric bike to me is now a real-world, affordable and practical solution. The limited range is not a big deal for errands around town and short commutes. Given that really nice batteries are going to be expensive for the foreseeable future, it makes so much more sense to use a couple of small ones on a bike than try to pay for 300 big ones for a car.

Most people won't justify a limited range full-size electric car just for groceries and errands, but many people could throw an e-bike or two in their garage without thinking twice. Grown adults giggle when they ride my bike. It is very quiet – it's like some genie is pedaling for you. The silence is very important – it just completely changes the whole picture. You can actually hear things and stop and pull up onto the sidewalk and talk to your neighbors when you ride down the street. I have pulled up directly into my ATM booth and people hardly give me a second glance – not even thinkable on a motorcycle.

Electrics are not intimidating like a motorcycle or even a scooter – to most people, they're just a bicycle you don't have to pedal. There's no clutch, no gears to shift, no kickstarter. They aren't just environmentally friendly – they're neighborhood and people friendly. Another amazing thing to me: this is not rocket science technology. This is lead acid batteries powering a DC motor on a steel bike frame – this bike could pretty much have been made 80 or 100 years ago! Those new-fangled high pressure pneumatic tires may

be the most modern component! Why has it taken so long for e-bikes to take off?

I offer these design and component ideas to anyone who can make use of them and encourage anyone with a garage and some tools to make an electric bike or buy a kit or a ready-made. At my house we have a very fast motorcycle, a hybrid car and a pickup, but the e-bike is the most fun – I use it almost every day. And the most amazing thing that I have learned after all of this – you really don't need 4000 pounds of gasoline powered steel-rubber-plastic-and-glass, \$30, 000-120-mph marvel-of-modern-transportation-engineering to go a mile and a half for a quart of milk, a loaf of bread and a newspaper.

EARLY VERSIONS V1. 0 had just one long vee-belt from the motor to the rear wheel. It had a top speed of around 30 which was great but slowed to about 12 mph on the steep hill near my house. However, other people building their own have asked about using the single vee-belt because it is easier to put together without machine tools, and it works pretty well on the flat. The goals were these: * gear reduction from a 3000 rpm motor – in the neighborhood of 8: 1 to 10: 1 * retain existing pedal function – derailleur and freewheel * rear wheel drive * simplicity * quiet operation * use available parts can be grafted onto the existing bike wheel * power transmission efficiency * stay away from friction tire-drive – too much slippage and tire wear * stay away from chain drive – at 3000 rpm a chain is too noisy The single belt reduction runs from a 1. 75" drive wheel on the motor directly to a 16" driven pulley mounted to the left side of the rear wheel. This is actually a 20" bicycle rim mounted to the wheel hub using half of the rim's spokes

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through additional spoke holes drilled into the wheel hub. This setup gives a reduction of about 8 to 1. ^ The vee-belt setup, giving a reduction ratio of 8:1 V1. After using the single vee-belt reduction for a while, it seemed that I needed to gear the bike down some more. At full throttle the belt would slip on really steep hills off-road. Also it was overheating on my hill and ended up burning out my 80 amp controller. So after some thought I added an idler shaft or “jackshaft” for an initial belt reduction. I have a metal lathe and fabricated a bearing housing for a 1/2” shaft running on ball bearings. This is mounted on a pivoting system in order to get the belt tensioned correctly. With the pulley combination pictured below I have an overall reduction of 17 to 1.

This translates into a top speed of 13 mph and good hill climbing ability. The most critical thing on a setup like this is to mount the jackshaft very solidly so that it stays parallel to the motor shaft under belt tension and during high power loads. This required a lot of reinforcement of the mounting bracket, as the whole thing mounts to the motor face using two bolts, and flex was a problem. Double reduction using toothed belt to a jackshaft running on ball bearings I suspected the ideal gear ratio for my needs lies somewhere in the middle. I will probably settle on a top speed of about 20 mph. The good thing about his setup is that I can change the gearing fairly easily with just a couple of different toothed belt wheels and possibly a slightly different length belt. The primary belt I added is a Gates Powergrip XL belt. I actually had a bunch of belts and wheels lying around from other motorization projects but these are available from ball bearing and rubber belt industrial suppliers. This belt is really way too small and narrow for a motor this size at full

throttle, but hey it was free. 80 AMP CONTROLLER Controller with added heat sink mounted to the top tube This is the previous Eagle 80 amp controller from 4QD.

It melted down from driving over 100 amps for extended lengths of time. It is really too small for the Scott 1hp motor but worked surprisingly well for quite a while. Like the Scooter 120, it has adjustable acceleration and deceleration curves, but no regenerative function. V1. 4 had a single long timing belt. After experimenting with a single vee-belt and an earlier two stage belt reduction, I tried to simplify in the name of efficiency. I especially wanted to get rid of the vee-belt completely, which would slip on really steep hills and also is less efficient than a timing belt.

This setup was less than ideal because the belt is so long. There was not enough room for a wider belt and this belt was simply not strong enough for the amount of power being delivered. Also, this Type L timing belt was noisier than I had expected. The trapezoidal tooth shape is noisy, and the idler tensioning wheel added a surprising amount of racket even though it was running on the “ flat” side of the belt. I. WHAT IS MEANT BY “ POWER ASSIST”? A power assist is any vehicle with any number of wheels that is primarily or partly human powered, and assisted by a small motor.

An electric bicycle is probably the most common such vehicle. Power assist enthusiasts are typically interested in simple human-scaled transportation that is earth-friendly, fun, non-intimidating, and affordable. Transportation that either extends the range of their bicycling, allows them to arrive at work without needing a shower, or allows them to leave the car at home more

often. Many people are somewhat familiar with old-style mopeds, which are technically power assists. However they are too heavy to really be pedalled more than to start the engine.

Mopeds are really lightweight scooters with pedals and limited top speeds which allow them to qualify in most parts of the world for lesser registration and insurance classifications. Many people feel that a more useful set of pedals is important. This means the vehicle must be light enough to pedal meaningfully, either with or without the motor energized. Practically speaking it should weigh less than 75 lbs. or 35 kg and of course the lighter, the better. A power assist is not meant to entirely replace human power. The exact amount of assist desired, however, is really up to the individual.

Today electric vehicles are becoming more popular, but there are still internal combustion engine (ICE) power assists that perform well. They both have their adherents, but really they each have their place as their strengths and weaknesses are in different areas. ELECTRIC ASSISTS – today's practical electric vehicle The practical electric car has become a kind of Holy Grail and is the subject