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Hyperdrive as Powertrain Successor

Dr. Alex Severinsky
Theodore Louckes
Robert Templin
Nathanael Adamson
David Polletta
Paice Corporation

ABSTRACT

Recent availability of high-voltage power semiconductors has allowed implementation of a unique, highly efficient, Hybrid-Electric powertrain, the Hyperdrive. It uses an innovative method of control for the internal combustion engine (ICE). Comparative analysis of an application of the Hyperdrive to a popular American SUV is presented, including performance, fuel economy, emissions and costs. In summary, the Hyperdrive, which provides near-thermodynamic-limit fuel efficiency over a wide range of vehicle sizes covering almost all the automotive market, has the potential to succeed conventional powertrains. Vehicle design freedom is considerably enhanced, performance is improved and safety is not compromised. Substantial socio-economic effects are presented.

INTRODUCTION

The latest advancements in high voltage power semiconductors and lead-acid battery applications have permitted implementation of a unique method of internal combustion engine control (1,2,3). This method of control together with required electrical, electronic, and lead-acid cell components produces a heretofore-unattainable combination of improved driving performance, efficiency and environmental benefits, without requiring any compromise in vehicle safety or operating convenience. This combination of attributes makes it a potential successor to the existing automotive powertrains for the 21st century. It can become the natural successor because it requires only those component technologies currently present in automotive drive trains, but in different relationships, under the control of the type of software currently used in aircraft.

In this paper, we present the basics of the Hyperdrive, the first version of the Power Amplified Internal Combustion Engine (PAICE) and its expected socio-economic benefits.

To become a true successor to well-accepted modern power trains, the Hyperdrive must meet the following fundamental requirements:

- Operate on readily available hydrocarbon fuels and convert these to energy, under all driving conditions, at efficiencies so high as to be limited only by thermodynamics. Surprisingly, a simple ICE, if its operation is limited to only the speed/load conditions of near-minimum BSFC fulfills this requirement.
- Provide exhaust emission levels below ULEV or even SULEV without resorting to modified fuel compositions or costly fuel infrastructure changes
- Provide acceleration performance equal or better than in today's existing, but less efficient powertrains.
- Require absolutely no compromise for safety, climatic conditions or customer convenience over present well-accepted vehicle designs and sizes.
- Use only those materials that have been proved economically and strategically compatible with high-volume manufacture.
- Use component designs that are compatible with existing manufacturing skills, processes and equipment.
- Have control system software sophisticated enough to provide flawless operation, transparent to the driver, compatible with today's driver skills and experience.
- Cost no more in total expense, including acquisition, maintenance, operation and depreciation than today's vehicle.
- Have maintenance and field diagnostic requirements compatible with today's service skills and equipment.

- Provide no new or unmanageable hazard to the public, vehicle transport, delivery and parking systems.
- Impose fewer constraints on the freedom of body design and styling with respect to component size, packaging, weight distribution and aerodynamics.

We have designed a proof-of-concept Hyperdrive, as well as made all the components and their control software. We then tested them for overall performance on a dynamometer at a load representative of a luxury automobile. These test results were used to calibrate our component models and control algorithms in Matlab/Simulink. Because the Hyperdrive system consists of components whose efficiencies can be individually modeled, we then used these calibrated models to accurately predict Hyperdrive performance over a wide range of applications. We have confirmed that it provides comparable benefits over a range of vehicles with test weights from 2000 lb. to 20,000 lb. (5). It is also applicable to even larger vehicles but this is beyond the scope of this paper.

In this paper, we present the application of the Hyperdrive in a popular American SUV.

BENCHMARK AMERICAN SUV

We have analyzed performance of a number of popular SUVs. On Fig. 1 below we show the typical appearance of such a benchmark SUV.

Fig. 1: Popular American SUV used for Hyperdrive implementation.

The performance data summarized below in Table 1 is an average blend for numerous vehicles and are not specific to the one shown on Fig.1. We will use these data as a benchmark.

Basic Configuration	
Engine	3.0L V-6
Transmission	4-speed AT
Drive wheels	4X4
Max towing capacity	3,500 lbs.
Fuel Economy	
ETW	3,800 lbs.
FUDS	20 MPG
HWFET	30 MPG
Combined (55/45)	24 MPG
Performance	
PTW	4,000 lbs..
0-60 MPH	11 sec
55-75 MPH	7 sec
35-55 MPH	4 sec
Top Speed Continuous	105 mph
Continuous Gradeability	
GCW	8,200 lbs..
Gradeability @ 80 MPH	5.5 %
Starting Grade	30 %
Emissions	
CO	8.1 g/mi
NOx	0.9 g/mi
HC	0.2 g/mi

Table 1: Benchmark SUV Fuel economy, Performance, Emissions

HYPERDRIVE FOR BENCHMARK SUV

There are three main principles on which the Hyperdrive is based:

1) Control the engine near minimum BSFC;
2) Minimize electrical energy losses in the powertrain through an electrical system design based on high voltage - higher than in today's HEVs;
3) Use the same readily available and low cost materials as exist in current production powertrains.

On Fig. 2, we present a functional diagram of Hyperdrive for this benchmark SUV.

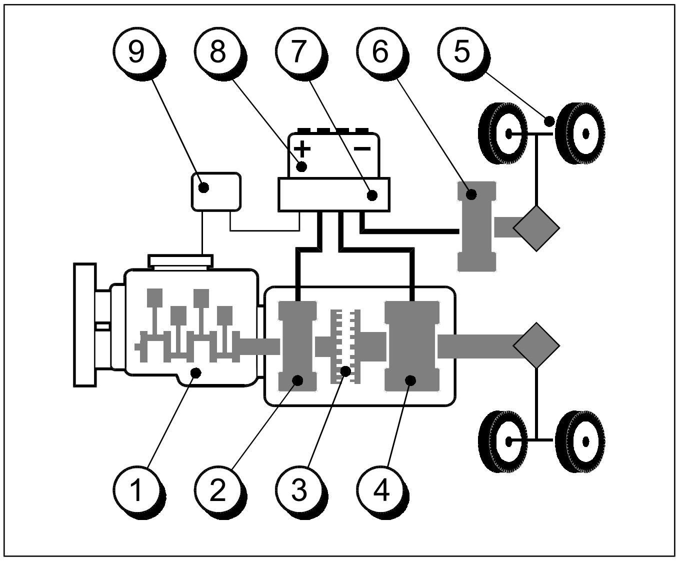


Fig. 2: Hyperdrive configuration for benchmark SUV.
Legend:
1 - 2.0L TC I-4
2 - 20 hp starter/charger motor
3 – Clutch
4 – 60 hp traction motor
5 - Front wheels
6 – 20 hp traction motor
7 – Inverters
8 - Batteries, 16 modules, 48V, 18 lb each, lead-acid
9 - Drive and battery controller.

SELECTION OF COMPONENTS

The ENGINE is selected to meet gradeability specifications at all speeds on a continuous basis, except starting grade.

The battery can't be used on a continuous basis for obvious reasons. The most economical engine type is a spark-ignition ICE with a mild turbocharger, which is normally off (3). Nothing in the Hyperdrive prohibits a choice of Diesel ICE, however, depending on the customer's desires or regulatory requirements.

All electric motors together must have enough combined starting torque to assure mobility on a steep incline. A key feature of induction motors is their "transmission"-like capability below rated speed. Their typical constant power range of operation is over a 4:1 speed range.. Additionally, the sum of peak power and its duration must assure high acceleration and passing performance.

The CHARGER/STARTER MOTOR is selected to load the engine in de-clutched condition to provide the best ratio of BSFC/motor cost. There are varieties of well-known ways of mechanical coupling of this motor to the engine shaft, which are dependent on mechanical packaging for a specific vehicle.

The TRACTION MOTORS must provide main torque for starting on a grade. This is in addition to the torque of the charger/starter motor minus engine motoring torque. From a power standpoint, the traction motors together must be able to drive the SUV when the engine is declutched. The ratio of power rating of these motors is defined by the needs of vehicle dynamics. This arrangement of electrical 4x4 offers substantial flexibility to automotive engineers in improving vehicle handling and safety under variable load, load distribution, and variable road conditions. Both motors are coupled mechanically to the drive shafts in a customary way with the overriding criteria of the minimal Hyperdrive cost.

The CLUTCH acts as a switch. It is either engaged or disengaged by the controller when the two shafts angular positions and first derivative over time are equal within an error of measurements, for example 1^o. When so controlled, it can be a low cost mechanical device.

The Lead-Acid Battery System (LABS) consists of 16 modules. The module content is so different from a traditional battery that we call it a Hybrid Energy Module HEM. Each HEM contains 24 lead-acid cells of 5 Ah each with open cell voltage around 2.1 V so the HEM unloaded voltage is around 50 V. The HEMs are connected in series to form an 800 V string. The center point of this string is connected to the chassis for improved safety and cost. This allows rating the insulation of motors, semiconductors, and all other components for only 400 VDC. Each HEM has an internal normally-open disconnect with an air-gap. This assures absence of any voltage on the HEM terminals during shipping, assembly, service, accident or when the vehicle is turned off . This disconnect is inexpensive as currents are similar to those found in residential house wiring. The HEM contains two important subsystems – a thermal equalizer/ electronic operational conditioner, and a computer interface. Further details are too voluminous to fit into this paper and will be reported separately.

The CONTROLLER (PCM) –The Paice Control Module takes the place of an Engine Control Module (ECM), but is even more important. An existing ECU becomes a peripheral device along with each motor controller, each HEM, and a few other peripheral controllers customary in vehicles. The controller hardware must support a massively parallel DSP computation. The key elements of the Hyperdrive that allows it to deliver the advantages in both performance and cost are in the control algorithms.

TYPICAL MODES OF OPERATION

There are four typical modes of operation that we use to demonstrate the basic functionality of the Hyperdrive. Beside these four, there are a number of other modes as defined in the control algorithms.

First, there is a discrete position device, a clutch. The most frequent condition controlling its state is vehicle road load. Only if this load is sufficient for the engine to operate at its near-minimum BSFC is the clutch engaged, otherwise it is disengaged.

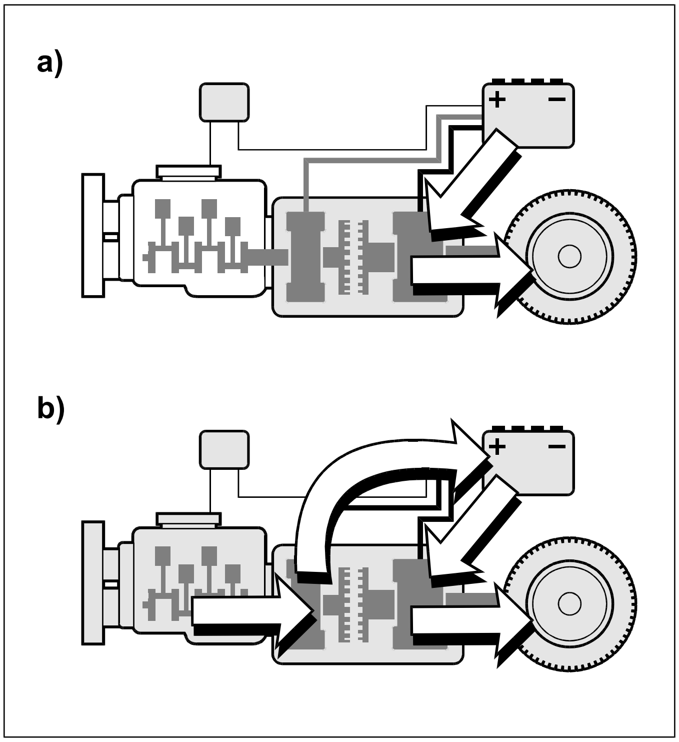


Fig. 3. Typical Hyperdrive operation in city driving. A) An Electric Car; B) A Serial Hybrid and a Range Extender

In figure 3, the clutch is disengaged.. In part (A) of Fig. 3, the battery system (LABS) is above its minimum state of charge, and the vehicle is driven by two traction motors. This is the pure electric car mode of operation. Contrary to typical electric car operation however, the battery is used only over a narrow range of discharge, roughly in a range of 50 to 70% state of charge (SOC) to assure long battery life.. The amount of energy used in this electric only mode is well below the PNGV definition of “dual mode hybrid”. Hyperdrive operates primarily as an electric car during this city operation..

In the Part B) of Fig. 3, the LABS has reached its minimum state of charge 50%, and the engine is started by the charger/starter motor. Once started, the engine is loaded by the same motor (now a generator) as a charger and is operated at its near-minimum BSFC point. The power produced by the charger is split. One part is delivered to the traction motor. The Hyperdrive is now operating as a serial hybrid. The rest of the power recharges the LABS. This makes Hyperdrive also a range extender. When the LABS reaches the maximum SOC level, the engine is stopped.

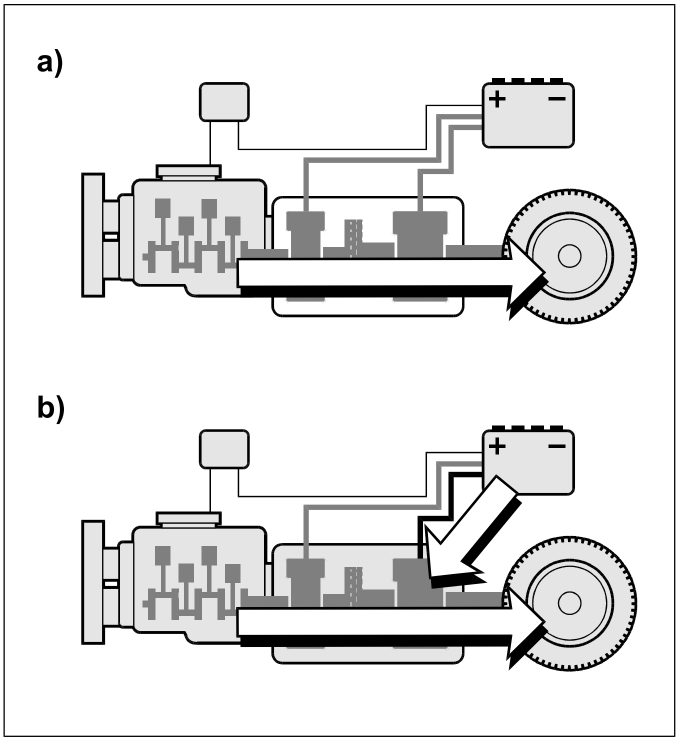


Fig. 4. Typical Hyperdrive operation in highway driving. A) An ICE car; B) Parallel Hybrid

When the sensor determines there is enough road load torque to allow ICE operation at the near-minimum BSFC region, the clutch is engaged. If the engine was off before this controller demand, the engine is started and synchronized. Now it is the engine that provides the average power level demands (less transient demands) of the vehicle. It becomes a conventional drivetrain. This is depicted in Part A)
of Fig. 4.

For vehicle acceleration or deceleration, all motors are used as a function of minimum energy loss in all electrical and electronic components. The controller is assuring this on millisecond-by-millisecond basis. The acceleration with only one traction motor is shown in Part B) of Fig. 4A. It is a parallel hybrid. The engine torque is lagging motor torque to assure operation at only stoichiometric air/fuel mixture, which is the basis for the optimum emission control provided by the three-way catalyst control system. As electric motors provide essentially instant torque response to the driver’s demands, noticeable levels of car responsiveness can be provided, even varying the shape of this response to optimize traction capability

PRINCIPLE #1
EFFICIENT USE OF THE ENGINE

On Fig. 5A, we present the range of loading of the engine in the benchmark SUV, while driving on Federal Urban Driving Schedule, the ubiquitous FUDS. For ease of engineering judgment, we also calculated the average point based on the integral of fuel flow and the average engine speed. In this case, the average BSFC is 0.62 lbs./hp-h.

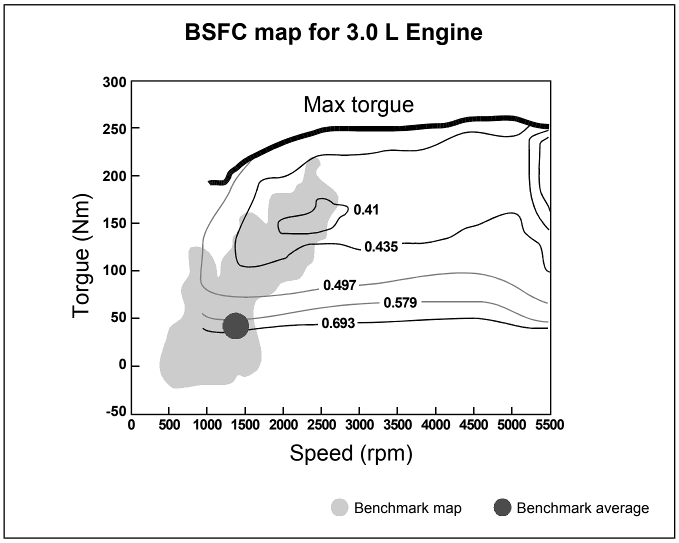


Fig. 5A. Map of engine operation on FUDS in the Benchmark SUV. Map and average operating point.

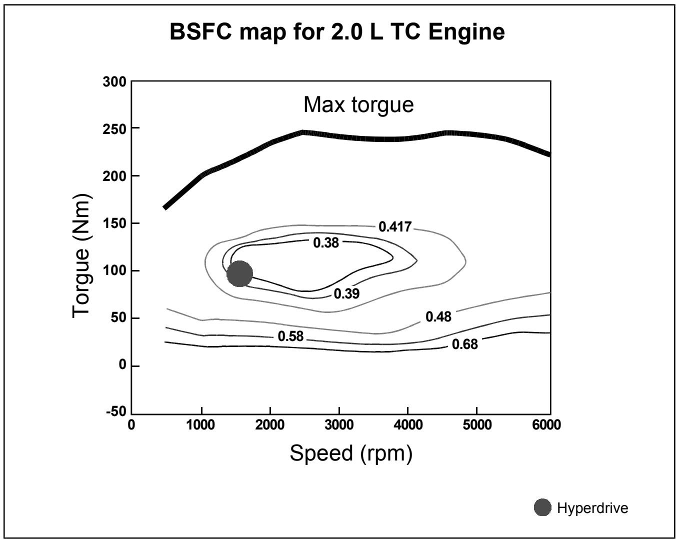


Fig. 5B. Map of engine operation in the Hyperdrive on FUDS. One operating point.

On Fig. 5B, we present the operating point of the engine in the Hyperdrive on the same FUDS with clutch always in the disengaged position. Now, the BSFC is 0.39 lbs./hp-h. This is a 37% reduction in fuel usage by the engine over the benchmark SUV.

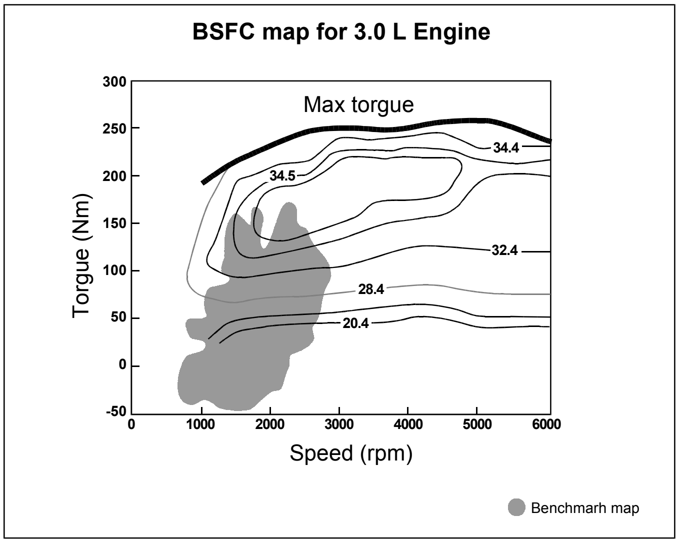


Fig. 6A. Map of engine operation in the benchmark SUV on HWFET

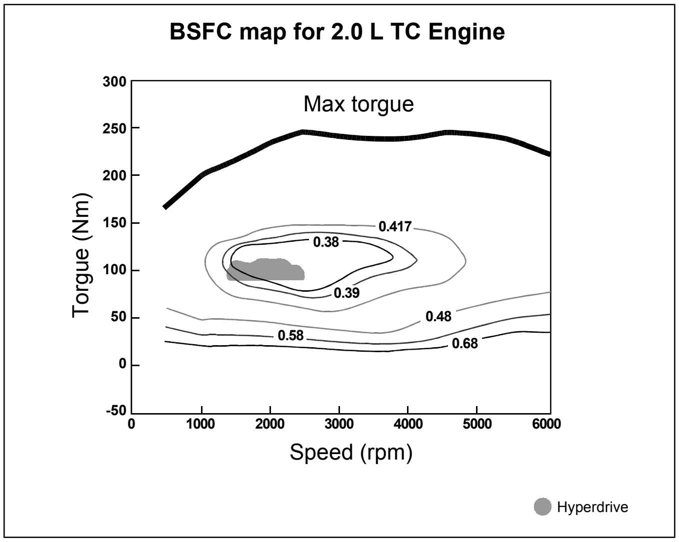


Fig. 6B. Map of engine operation in the Hyperdrive on HWFET.

In Fig. 6 A and B, we present the same comparison on HWFET (Highway Fuel Economy Test procedure), formerly FHWC. During this driving cycle, the clutch is mostly engaged. One can easily note that in the Hyperdrive, the engine is not used below some minimum torque level. We depicted just a straight line, but other functions are even more desirable for even better fuel economy.

The new method of the engine control opens a new chapter for engineering the next generation of ICEs for

Hyperdrive. These opportunities were presented by one of the co-authors last year (4).

IMPROVED SUV PERFORMANCE

In Table 2 below we present the results of Matlab/Simulink modeling of the Hyperdrive in the benchmark SUV.

Basic Configuration		
	Benchmark	Hyperdrive
Engine	3.0L V-6	2.0L I-4 TC
Transmission	4-speed AT	None
Drive wheels	4X4	4X4
Max towing capacity	3,500 lbs.	3,500 lbs.
Fuel Economy		
ETW	3,860 lbs.	3,860 lbs.
FUDS	20 MPG	40 MPG
HWFET	31 MPG	38 MPG
Combined (55/45)	**24 MPG**	**39 MPG**
Performance		
PTW	3,970 lbs.	3,970 lbs.
0-60 MPH	10.8 sec	7.4 sec
55-75 MPH	6.7 sec	4.7 sec
35-55 MPH	4.3 sec	2.7 sec
Top Speed Continuous	106 mph	106 mph
Continuous Gradeability		
GCW	8,200 lbs.	8,200 lbs.
Gradeability @ 80 MPH	5.5 %	5.6 %
Starting Grade	30.0 %	30.1 %
Emissions		
CO	8.1 g/mi	0.1 g/mi*
NOx	0.9 g/mi	0.03 g/mi*
HC	0.2 g/mi	0.004 g/mi*

* - Proportional to test results below

Table 2: Hyperdrive comparative performance.

The Hyperdrive, not only meets all the gradeability and top speed requirements, but also offers performance improvements:

Acceleration time is 7.4 seconds for 0-60 mph compared to 10.8 for the benchmark, an improvement of 30%. It also has superior passing performance, 4.7 sec in 55-75 mph speed change versus 6.7 sec. in the benchmark, an improvement of 30%. In addition, what is not shown is that when climbing grades near top speed, the Hyperdrive still has passing ability, not present in the benchmark.

While the whopping improvement in fuel economy from the Hyperdrive will be extremely attractive in overseas markets, where operating fuel bills will be significantly lower, the relative economic importance of this feature to the customer in the US market is still open to question because of our much lower fuel prices.

The societal value of the fuel economy improvement to the US strategic and balance-of-payments issues, however, is without question.

From a manufacturer's standpoint, the fuel economy gains, since they approach the maximum theoretically possible, will provide the most insurance against CAFE legislation and allow the continued production of profitable cars more acceptable to the buying public.

There are a number of other improvements over existing vehicles. Maintenance intervals will be substantially increased as the engine is operated differently with less oil deterioration, the transmission is absent; there are no belts since all accessories are electrically powered, and brake pads usage is reduced by over 90% because of regenerative braking. In addition, there are possibilities for new conveniences, for example, ultra-rapid pre-heating and pre-cooling of the vehicle interior is now possible. Also enough stored power and generating capacity is available to provide emergency electrical power to the driver's home, as well as for a number of other electrical appliances and tools. The ability to provide emergency electrical power might be well appreciated in areas where power outages have been a problem. Hyperdrive powered vehicles can provide standby power with less pollution and lower operating costs than many other sources of standby power. There are also safety improvements. For example, the weight can be more evenly distributed in the vehicle, the center of gravity lowered, and road and load dependent electronic 4x4 control can be introduced.

COSTS

We have completed a first iteration of design of all major components. For cost analysis, we used the services of an automotive cost analyst as well as major suppliers' estimates. In the Table 3 below, we present a comparative summary of our findings. All costs are either inter-company transfer prices or purchase prices. These costs are in mature automotive volumes, which are in six digit quantities annually. These costs estimates must be viewed with caution in light of the introduction of any new technology. A supplier's lack of experience with the new technology encourages caution on the high side. Also these figures do not reflect any economies that could be achieved by the elimination of expensive substitute materials now being used solely to meet fuel economy standards with the old powertrain technologies.

Benchmark 24 MPG		**Hyperdrive 39 MPG**	
Engine	2,500	Engine	2,300
Transmission	800	Motor Module (MAM)	1,000
Transfer case, PS	600	Front Traction Motor	100
Alternator	60	Power electronics	900
Starter	60	Battery system	900
SLI Battery	40	Stand. Bat	30
A/C comp.	100	Elect. A/C comp. P/S & Vac.	150
P/S pump	60	Wiring & connectors	200
Belt drive	50	Eng. Cooling	100
Eng. Cooling	150	Catalytic con	100
Catalytic con.	150	Hyperdrive Controller	450
Total Drivetrain	**4,570**		**6,230**

Table 3: Rough Order of Magnitude estimated system cost for a benchmark drive and the Hyperdrive. Note: this represents $110 for each 1 MPG improvement.

The mechanical components are reduced in cost and weight: the engine is greatly simplified and downsized, the transmission is eliminated, and the transfer case and the half shafts are eliminated.

What is added to cost and weight are motors, power electronics or inverters (PEM), a large LABS and the drive controller. The expected direction of these additional costs is mainly downwards over time. The price of motors will hold, the price for LABS will go down, and especially inverters and controller costs will become materially lower with time.

SOFTWARE CONTROLS

It is obvious from all prior content of this paper that software control is pervasive. Without it, the Hyperdrive cannot function. This is an evolution from the conventional powertrain. At first powertrains could be made operational without software. Increasing demands for efficiency and emission control forced conventional powertrains into increasingly complex software control. It is the further evolution of this software control, which is the foundation of the Hyperdrive, which allows it to become a successor powertrain for automobiles

PRINCIPLE #2
USE OF RELATIVELY HIGH VOLTAGE

Economical DC voltage for this application is in the range of 600-800 V, substantially higher than in existing HEVs with voltages in 140-280 V range. The first advantage of higher voltage is that the inverter losses are much lower. In turn, these lower losses at high voltage increase overall vehicle fuel economy. In our earlier report (8), we have shown that due to higher voltage fuel economy for European light commercial vehicles increases 40% in comparison with a low voltage implementation. Other effects of higher voltage are substantial reduction in lead-acid battery system weight and cost, and overall decrease in electrical subsystem cost by 35% in comparison with a low voltage version. In summary, higher voltage has double impact on the value of the Hyperdrive, providing more value in terms of fuel economy and reducing system costs at the same time.

PRINCIPLE #3
USE OF EXISTING MATERIALS

The incremental cost of the Hyperdrive and its predicted downward direction over time are due to compliance with the principle of using materials that are inexpensive and readily available. We use existing technologies, a very simple ICE, induction motors made from steel, with aluminum cast rotor windings and copper stator windings, lead and sulfuric acid in LABS, silicon in the inverters and in the controller.

PROFITABILITY CONCERNS

Only profitable innovations replace existing paradigms. As we presented in Table 3, the Hyperdrive is at first projected to be more expensive than today’s powertrain, but what cost increase would be required to provide this much fuel economy gain in a conventional powertrain? Based on what is being spent today to provide hard-won fuel economy gains of tenths-of-mpg, Hyperdrive is orders of magnitude less expensive. As CAFE regulations tighten, the issue will not be expense as much as loss of market share, as many profitable vehicles could disappear from the marketplace without the Hyperdrive.

PRIOR TEST RESULTS USED FOR MODEL CALIBRATION

We had constructed the Hyperdrive with the following major components:
SI, I-4, 1.3 L normally aspirated engine, with 70 hp maximum power; 15 hp charger/starter; 100 hp peak traction motor; LABS to be operated at 6.5 Ah capacity in the string of 16 modules, 50 V each; inverters based on 1,400 V rated IGBTs.

A representative picture of this implementation of the Hyperdrive on the dynamometer is shown below:

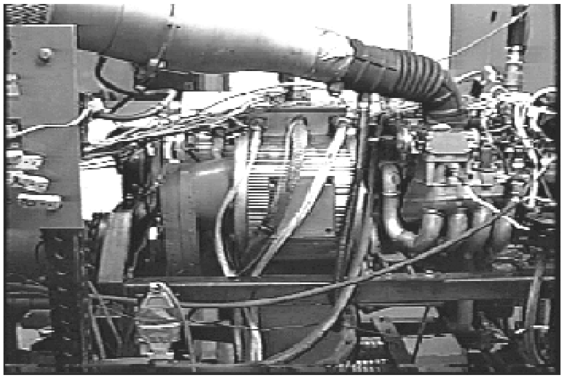


Fig. 7: The Hyperdrive on the dynamometer test stand.

We tested the Hyperdrive with a load representing a luxury sedan. The inertia load was 4,250 lb and the road load was programmed by using A,B,C coefficients of the polynomial approximating the load as a function of speed. EPA has provided these coefficients. We have measured the following fuel economies.

	Conventional	Hyperdrive
City (FUDS)	19 MPG	**38 MPG**
Highway (HWFET)	33 MPG	**54 MPG**
Combined	24 MPG	**44 MPG**

Table 6: Hyperdrive test stand results: fuel economy

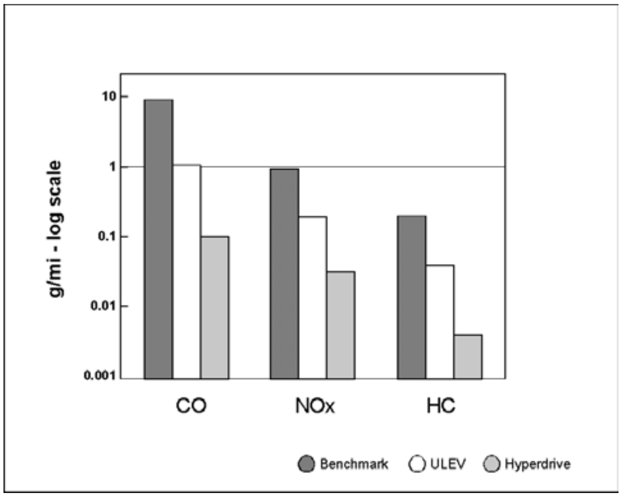


Fig 8: Hyperdrive test stand results: emissions as compared to ULEV and benchmark.

To verify the results, we measured heat losses in all components and compared them with the amount of fuel used. The results were in agreement. Moreover, these tests showed there is room for further improvements in city cycle fuel economy of at least 10%, but it was uneconomical to achieve it in this concept prototype.

Additionally, we measured the following improvements in exhaust emissions – Fig. 8. These emissions were measured on the FUDS cycle and not FTP75. The data represent the worst-case scenario for the Hyperdrive. The engine that we used was not an automotive engine, but a marine engine, so its engine-out emissions were about four times larger than an automotive variety. Nevertheless, we achieved quite low emissions, below not only ULEV, but also below SULEV. We used a computer-controlled, pre-heated, off-the–shelf catalyst. The engine was calibrated to operate with the Hyperdrive method of control. Some emissions like HC were so low (at background levels) that we needed much more sensitive and dynamic analysis equipment for further testing, so HC emissions results are preliminary (see also Honda's report in Ref.6). The bottom line is that Hyperdrive emissions are so low during ICE operation and zero during electric mode operation that it is difficult to expect that any further reductions would benefit the atmosphere. Compared to today's cars, the Hyperdrive car, without any further emissions development, is already 95 percent below today's emission standards, yet does not suffer the serious compromises which have doomed the market acceptance of other approaches to zero-emission cars

HYPERDRIVE IN OTHER VEHICLES

To provide a more complete picture of the improvement in fuel economy that could be expected in other classes of vehicles, we identified the relevant characteristics of the vehicle categories, defined in the Oak Ridge Transportation Energy Data Book (7), currently subject to CAFE regulation, and designed the Hyperdrive system for a *representative vehicle in each category*. A summary of our modeling results showing the original fuel economy of each representative vehicle, the fuel economy that results from incorporation of the Hyperdrive system, and the percentage improvement from such incorporation is provided in Table 7. With potential fuel economy improvements of the magnitude shown here, application of Hyperdrive to a large volume of production vehicles would significantly reduce total gasoline consumption and consequently, the requirements for oil imports.

All of the fuel economy improvements presented herein are based only on the use of the new Hyperdrive powertrain. Further small improvements are still possible, such as through ICE engine optimization, but such improvements will be subject to the law of diminishing returns as the Hyperdrive is operating the engine within 1-3% of its possible maximum thermodynamic efficiency.

Of course, any HEV can only reduce overall fuel consumption in a meaningful way if it is commercially mass-produced. As discussed above, we believe that the Hyperdrive system has the only cost effective configuration of HEV that is fully scalable and is not cost prohibitive to mass-produce. As a first step toward the mass production of a Hyperdrive vehicle, our projections for cost will have to be substantiated through a manufacturing cost analysis of actual components in an actual vehicle that exhibits the performance and fuel economy advantages described above. Once cost projections are verified in the prototype vehicle, we would expect that participating automakers will begin the process of preparing for large-scale production of vehicles with the Hyperdrive system. If a development program were to begin now, automobiles with the Hyperdrive could be commercially introduced into the U.S. market within five years.

Vehicles	Fuel Economy by Vehicle Type In CAFE Regulated Vehicles (mpg)		
	Conventional	**Hyperdrive**	**Improvement**
Automobiles			
Minicompact	26	44	**70%**
Subcompact	31	47	**51%**
Compact	30	48	**59%**
Midsize	27	43	**61%**
Large	25	39	**55%**
Two Seater	26	43	**65%**
SUVs/Light Trucks			
Small Pickup	22	30	**36%**
Large Pickup	19	28	**48%**
Small Van	23	31	**35%**
Large Van	18	28	**53%**
Small SUV	24	37	**57%**
Medium SUV	20	30	**45%**
Large SUV	18	25	**45%**

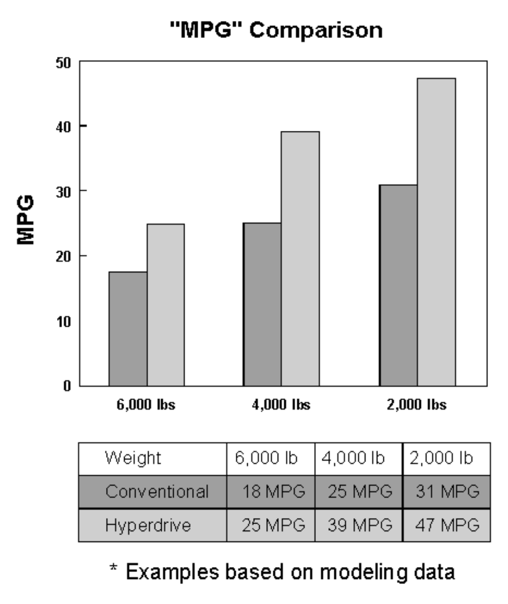
Table 7: Fuel economy in CAFE regulated vehicles (8,500 lbs. GVW and less) – selected conventional vehicles compared to comparable vehicles modeled with the Hyperdrive

FUTURE SOCIO-ECONOMIC IMPACT OF THE HYPERDRIVE

Every major change in the automobile industry was triggered by a noticeable improvement in performance and convenience – electric starter, automatic transmission, electronic engine control, air-conditioning, ABS, etc. Hyperdrive technology creates the opportunity for even larger changes than prior incremental changes. Existing major constraints on design imposed by regulations, weight control, aerodynamics, etc. can now be reexamined in the new light of a changed automotive architecture. For example, fuel tanks could now be substantially smaller.

Secondarily, for individual drivers but primarily for society, the Hyperdrive will create a major impact on fuel consumption.. We have presented the case of 62% improvement in CAFE for a popular American SUV. In the overall vehicle fleet, the Hyperdrive can improve fuel economy over 50%.

To expedite this substantial improvement, the current direction to automakers as dictated by CAFE becomes outdated and could productively be reexamined. It is not miles per gallon (MPG) that need improvement as much as Gallons Per 100 Miles (GPM), similar to L/100 km in Europe. This puts the emphasis on reducing fuel consumption in large cars. Current CAFE artificially favors small cars but the savings in fuel are much lower than in large cars. On the following Figs 9 and 10, we present the difference in the approaches.



Weight	6,000 lb	4,000 lb	2,000 lb
Conventional	18 MPG	25 MPG	31 MPG
Hyperdrive	25 MPG	39 MPG	47 MPG

* Examples based on modeling data

Fig 9: MPG comparison of 3 vehicle classes with expected improvement from using the Hyperdrive in each class.

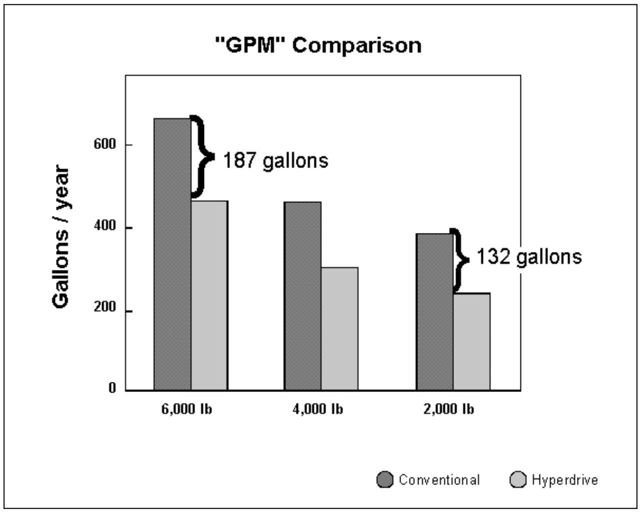


Fig 10: GPM (Gallons Per Mile) comparison of 3 vehicle classes with expected improvement from using the Hyperdrive in each class, and the total fuel saved over 12K miles.

Such reduction of fuel consumption will make a major impact on import demand. On Fig. 11 below we present a summary of reduction of oil consumption in the United States. The Hyperdrive will be able to contain oil demand over 30-40 years.

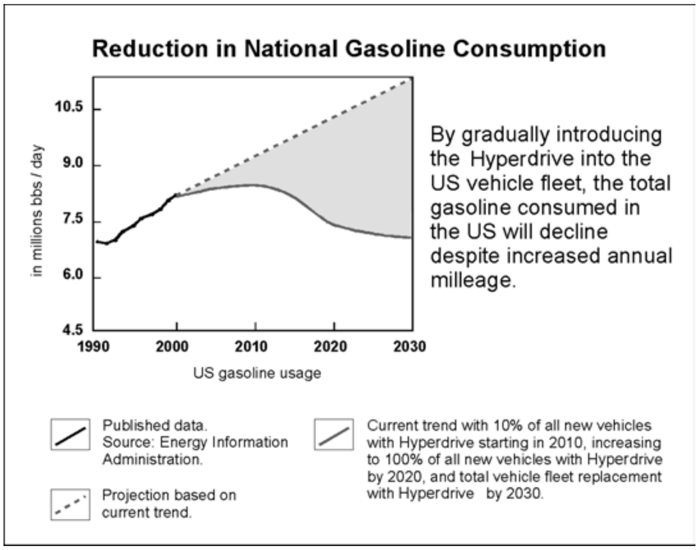


Fig 11: Potential reduction in national gasoline use.

Corresponding effect is on CO2 reduction.

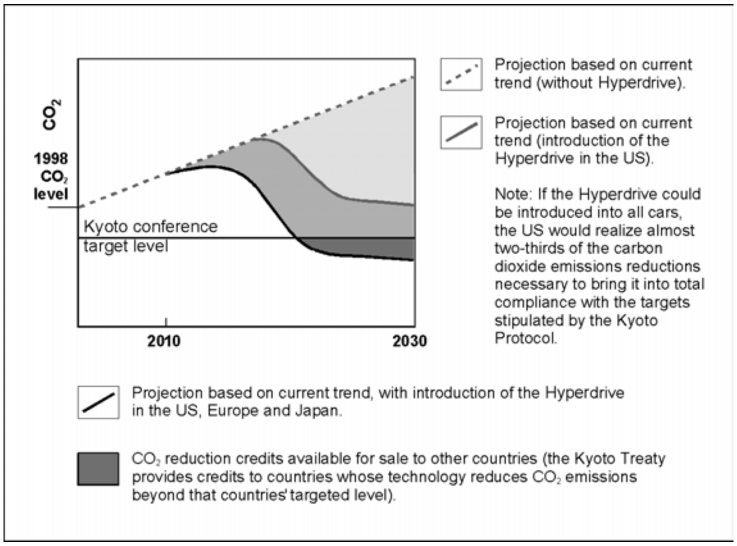


Fig 12: CO_2 projections with and without the Hyperdrive.

While American automobiles produce only 16% of US carbon dioxide, with the Hyperdrive alone, total CO_2 emissions will be lower than in 1998 with the gradual introduction of the Hyperdrive and total fleet replacement by 2030.

With the Hyperdrive and the reduction of fuel consumption by a third, pollution from gasoline transport and distribution can be reduced also by a third as well, to 0.14 g/mi. With the Hyperdrive, there will be no need for “boutique” gasoline, and those with low RVP can be utilized. The Hyperdrive, because of its high cranking speed and no need for cold start performance does not require high RVP fuel.

Everything that has been presented so far is not as exciting as the Hyperdrive’s potential effect on automobile design. Firstly, the powertrain can become more evenly distributed in the automobile. This creates room for dramatic style changes, becoming a virtual "dream-world" for car designers. Secondly, with such meaningful reduction of fuel consumption, the designers can reexamine existing aerodynamic constraints and have more design freedom.

Now let’s focus on the expected changes in the automobile industry. With the adoption of this technology, there will be a major shift from commoditized automotive components toward high value-added electrical, electronic, and software based components. On Fig. 13 below, we present in a graphical form our assessment of this growth.

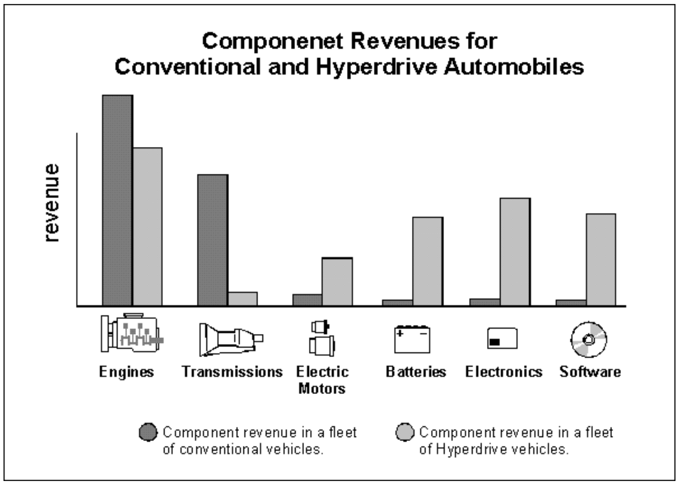


Fig 13: Changes in revenue for power train components for the Hyperdrive as compared to existing automobiles.

CONCLUSION

The Hyperdrive brings unique features of electrical, electronic, and software components to automobile powertrains. Because of high voltage power semiconductors, the Hyperdrive allows, for the first time, affordable fuel economy improvements of over 50%, reduces emissions to negligible levels, and materially improves performance of automobiles, with no compromise of safety or convenience, yet allows more design freedom for new automotive architectures. Its uniqueness is in the new method of ICE control, not allowing the ICE to operate outside its most fuel-efficient region of operation. This method became economical with the introduction of commercial high voltage power semiconductors. All technologies of the Hyperdrive are available today to bring powertrains to a new level of performance, environmental compatibility, and automobile profitability.

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ABOUT THE AUTHORS

Dr. Alex J. Severinsky is the inventor of the Hyperdrive. He received his Ph.D. in 1975 in the former Soviet Union. After his successful exit in 1978, he started working on the Hyperdrive in 1979. His American experience is in high voltage power electronics, inverters, lead-acid battery control, DSP based embedded control, and low cost production. Dr. Severinsky is CEO of Paice Corporation.

Ted Louckes has more than 40 years of automobile industry experience, mostly with General Motors where he retired as Chief Engineer of Oldsmobile. He is responsible for the development of the first overhead cam , 4-valve engine for American passenger cars and the introduction of the world's first air bag system. He serves as the Chief Operating Officer at Paice Corporation.

Robert Templin has also over 40 years of automotive experience, all with General Motors where among other assignments he was Chief Engineer of Cadillac and Director of Research Laboratories. Among his many achievements, he conceived and implemented the first automotive pollution control device ever put into production. He is best known for pioneering digital electronic fuel injection. He serves as a Director of Paice Corporation.

David Polletta has over 30 years of automotive experience, among them 12 years at Ford Motor Company as a supervisor of heavy truck engines and powertrain engineering. Mr. Polletta has 15 years experience in design, engineering and building of high performance alternate fuel, electric, and hybrid vehicles.

He serves as Vice President of Engineering at Paice Corporation.

Nat Adamson is the Executive Vice President of Paice Corporation. His career has included 32 years at Ford Motor Company in product planning, advanced engineering, marketing, and business management in the passenger car and truck activities. He has also had numerous consulting assignments in the auto industry.

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