STANFORD **ELECTRIC** VEHICLE **PROJECT**

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Project Overview

The Stanford Electric Vehicle Project is focused on three fundamental goals. We will design and build a revolutionary long-range electric vehicle. We will use this vehicle to increase public awareness of clean energy systems. We will provide education to students about high-efficiency vehicle technology.

Long range
This project aspires to create a versatile electric vehicle capable of driving five times further on a single charge than the best electric vehicles on earth, at any speed. Depending on the speed driven, the range per charge will be between 1,500 and 3,000 miles.

Awareness
This vehicle will dispel the public misunderstanding that electric cars are incapable of a range that equals (let alone far exceeds) the common internal combustion car. We will renew public interest and excitement in EVs with a graphic demonstration of the amazing advances in both cost and energy storage that have occurred in battery technology over the past 5 years. Electric vehicles are on the brink of surpassing gasoline-powered cars in nearly every figure of merit. We are seeking to demonstrate just *how* close they are by crushing the "range myth" – the last major barrier to full public acceptance.

Education
This project will educate and introduce a generation of Stanford students and engineers to ultra-efficient vehicle technology. By instilling the knowledge that clean energy is a viable option in the world energy economy, we are preparing a cleaner future for our planet. Students are already directly involved in every aspect of the project, and their involvement will continue through racing the car. Our industry and alumni partnerships will assure that the project is well guided and focused , while still allowing hands-on learning for new participants.

Who we are
The Stanford EV Project is comprised of an extraordinary team of individuals and organizations. We bring together a unique combination of new

student talent and enthusiasm with experienced alumni skills and knowledge. All of the students involved have already built and successfully raced a solar electric car from the ground up. Alumni have built and raced at least two and in some cases three or four solar-electric cars. There is a broad experience base with past leaders of the MIT, Yale, Michigan, Queens, and Stanford solar car teams all involved.

Many of the alumni involved have also worked for several years in industry designing equipment such as hybrid vehicles, motor control electronics, battery monitoring systems and other electric vehicle components. All of this experience will be focused on building the most successful vehicle possible and keeping the project on track.

How the car will work

To achieve the range goals that we have set, an amazing battery is required. Recent advances in lithium-ion batteries have provided sufficiently high performance to make 2000 miles a realizable range goal. In only the last few years have the prices and availability of these amazing batteries entered a range where such an application is possible.

In addition to an amazing battery, we also need an incredibly efficient vehicle. Low aerodynamic drag, low mass, and high electrical efficiency are all of extreme importance in meeting the benchmarks we have set for ourselves.

Where we're headed

There are several major events in which we plan to showcase our vehicle, to both demonstrate its performance and to generate public and media awareness.

Maximum Range (closed-course, 45 mph):

This will be the first event at the culmination of the final vehicle testing. It will set an "official" world record for EV range under closed-course conditions at an

The Stanford Back2Back Burner, completed summer of 2003, is a true testament to the abilities of the Stanford EV team.

average speed of 45 mph or greater. Our track results will serve as a benchmark to compare this vehicle with others under known conditions without the variability of traffic, stop lights, mountains, and weather.

Cross-Country Drive:

The second event will be a cross-country road trip – from one end of the United States to another – as a prominent public display of EV technology. With great media and public visibility, we will showcase the real-world performance of electric vehicles. Along the route, we will set up organized press stops, generating as much publicity as possible.

24 hour Maximum Distance Challenge:

This is an event that has been in existence for several years. Historically, the competition has been based on fast-charging technology with the cars driving, then charging as quickly as possible, then driving again. Since the challenge is only for the total distance traveled in 24 hours, our advantage will be a lower steady-state speed, since the car does not need to stop and charge.

Lithium Ion Battery Technology

It's all about energy density

The heart of any electric vehicle is the battery. It determines the instantaneous power available to the drive system (for acceleration) and the total energy available (for driving range). Historically, the battery is also the largest and heaviest component in the vehicle, since a large amount of battery mass is needed to store an acceptable amount of energy. This is a characteristic known as specific energy or energy density, and is generally expressed in Watt*hours per kg [Whr/kg].

It is the very low energy density of commercial batteries relative to other transportation fuels (such as gasoline) that has limited EVs since their inception. It became clear very early that combustion vehicles could travel much farther using only a small tank of gasoline instead of hundreds of pounds of lead acid batteries (the only viable EV battery at the time.)

Electric vehicle history

The electric vehicle has always been superior to gasoline-powered cars in many ways. It requires minimal maintenance, delivers high torque at low speeds, is reliable, and is capable of acceleration equal to or better than gasoline cars. Thomas Edison himself spent several years and a small fortune seeking the ideal chemistry for a battery that could power an electric vehicle. He did improve upon the lead acid cell (inventing the nickel iron battery), but this was not a sufficient improvement to compete with the very low cost and long range that gasoline could provide.

Thomas Edison on an early-model EV. When internal combustion technology was still being optimized, electric drive was an attractive, reliable alternative.

The automotive industry has made several renewed attempts at manufacturing and selling electric vehicles in recent years. The most promising was General Motors' EV1. In the early 1990s, GM began a serious effort to create this modern electric vehicle that would have the range and power to compete with gasoline cars. However, the EV1 initially used lead acid batteries and suffered from the same low energy density as its predecessors nearly 90 years earlier. Heavy and lacking sufficient range, the lead-acid EV1 was not a great success.

In a second generation of the vehicle an upgraded nickel metal hydride (NiMH) battery was added. The NiMH chemistry has an energy density 2 to 3 times that of lead-acid yet the vehicle still had a maximum range of only 130 miles. This is less than half the range of nearly every gasoline vehicle sold today.

Furthermore, the NiMH battery was (and still is) extremely expensive since it was only made in very small volumes for a limited EV market. The lack of sufficient EV market pull (to reduce the battery cost) is a fundamental problem that, combined with low energy density and limited range, kept the EV1 and other EVs from reaching high-volume production. In fact, the EV1 project was permanently discontinued just last year and was seen by many as the "end of the EV era."

A new battery arrives

While the EV1 was failing to meet expectations throughout the 1990s, another battery-powered product was steadily gaining market share: the portable computer. As in the electric vehicle industry, the laptop market began using lead acid batteries and rapidly evolved to nickel cadmium, nickel metal hydride, and then to lithium ion batteries near the end of the 1990s.

The lithium-ion battery bas become ubiquitous in virtually all present-day portable electronic devices.

For the last 4 years, lithium ion batteries have been steadily improving, with rising energy density and falling costs. This is mainly a result of the huge market pull that laptop computers have exerted for high-performance batteries and the billions of dollars that have been spent on battery research for them. The latest generation lithium-ion laptop batteries are nothing short of spectacular with an energy density five times that of lead-acid batteries (200 Whr/kg versus 40 Whr/kg.)

The volume of batteries manufactured for laptop computers is enormous and has already created a mass production economy that was previously only thought possible with a full fleet of EVs. The “chicken and egg” problem of low cost batteries and a large EV fleet has been solved from an unexpected direction in a way that no one could predict only five years ago.

The dawn of a new EV era

The world record for electric vehicle range on a single charge (with rechargeable batteries) is only 375 miles. This record was set in 1996 by the *Sunrise*, a custom-built, lightweight EV designed by the Solectria Corporation. The *Sunrise* used NiMH batteries and was optimized for high efficiency and minimal weight. The farthest any EV has ever driven on a single charge is 1043 miles. But this distance was traveled using non-rechargeable zinc-air batteries in a golf-cart type vehicle at only 25 mph.

The new lithium ion batteries hold the potential of 200-400 mile range in almost any type of EV. The EV1 could travel over 350 miles with a new lithium ion battery pack, and AC Propulsion’s tzero EV has also demonstrated 300 mile range. For the first time in history, EVs are poised to deliver the range needed to be a successful and viable product.

The Stanford EV project battery

The battery that we are building is composed of approximately 10,000 individual lithium-ion 18650 cells (a standard laptop battery has 8 cells.) The packaged battery will weigh 490 kg and store over 80 kilowatt hours of energy. That is enough energy to run an average home for over four days! This is an unprecedented amount of energy storage for a vehicle and will deliver unprecedented vehicle range. The battery will be built using 150 modules that each have 68 cells in parallel. This basic 68-cell module design has already been built and rigorously tested by AC Propulsion. We will leverage their experience to create the largest collection of lithium-ion cells ever assembled.

High Efficiency Vehicle Platform

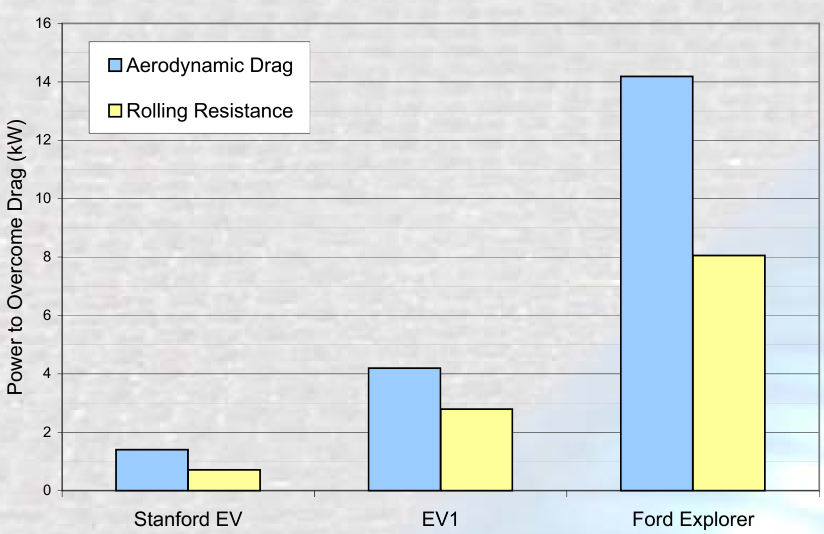
A revolutionary union of advanced technologies

To achieve our range goals, we will need to construct one of the most efficient passenger vehicles ever built. However, all of the required technologies are well developed, such as high-efficiency DC brushless motors and low rolling resistance tires. Competitive racing of solar powered, human powered, and small IC engine powered vehicles has generated a wealth of technical advancements, design innovations, and performance data in the arena of efficient lightweight vehicles. We will simply be the first to integrate into a single platform the technologies best suited for an ultra-long range electric vehicle.

Efficiency considerations

Three of the most important considerations in designing an efficient vehicle are minimizing drag, minimizing weight, and maximizing powertrain efficiency. The drag on the vehicle determines how much power is needed to maintain the vehicle at speed. The two most significant sources of drag are aerodynamic drag on the body and rolling drag of the tires. Minimizing the weight of the vehicle decreases energy losses associated with starts and stops as well as hill climbing. Tires also roll more efficiently when loaded with less weight, so decreasing weight also decreases drag. Maximizing the drivetrain efficiency means that the highest possible fraction of the electrical energy extracted from the batteries is converted to mechanical energy at the drive wheels.

Drag Comparison of Vehicles Traveling at 60 mph



Aerodynamic drag minimization

The Stanford EV will have approximately one third of the aerodynamic drag of production EV's or hybrids (e.g. GM EV1 or Honda Insight). This level of aerodynamic performance is comparable to what has been achieved with other highly streamlined vehicles

Aerodynamic Drag Coefficient Comparison

Drag Force (Newtons) = $CdA\rho V^2/2$

p is air density (1.21 kg/m^2 at sea level), V is vehicle speed in m/s (1 mph = 0.45 m/s)

Vehicle	Coefficient of Drag, Cd	Frontal Area, A (m^2)	Drag Area, Cd*A (m^2)
MIT '97 Manta GT (Solar Car)	0.09	1	0.09
Stanford EV	**0.1**	**1.2**	**0.12**
GM EV1	0.19	1.89	0.3591
Honda Insight	0.25	1.9	0.475
Ford Explorer	0.42	2.89	1.2138

(e.g. solar racing vehicles). A mix of computational aerodynamics, empirical data, and practical constraints will be used to design the vehicle body. The generated shape will then be constructed from advanced composite materials, resulting in a strong yet lightweight (under 50 lbs.) body that slips effortlessly through the air.

Minimal rolling resistance

Overcoming rolling resistance of the tires typically consumes ¼ to ½ the power used to propel a vehicle at practical speeds (30-60 mph). To minimize this drag component we will use high efficiency tires developed for solar car racing by Michelin. These are high-pressure tires (90 psi) and use a thin layer of low-hysteresis rubber reinforced by Kevlar cords to achieve a rolling resistance that is only ¼ to ½ that of typical automobile tires. Combining low rolling resistance tires with a lightweight vehicle gives multiplicative performance gains, as the rolling drag force decreases linearly with decreasing vehicle weight.

Rolling Resistance Comparison			
(A Simplified First Order Model, Neglects Velocity Dependence of Crr)			
Tire Type	**Rolling Resistance Coefficient (Crr)**	**Car Weight, W (lbs)**	**Rolling Drag Force in lbs. (F=W*Crr)**
Michelin Solar Car Radial	0.004	1600	6.4
High Efficiency Production Tires (ie: used on GM EV1)	0.008	2922	23.4
Typical SUV Tires (ie: Ford Explorer)	0.015	4500	67.5

The Michelin Solar Car Radial is world-renowned for its low rolling resistance.

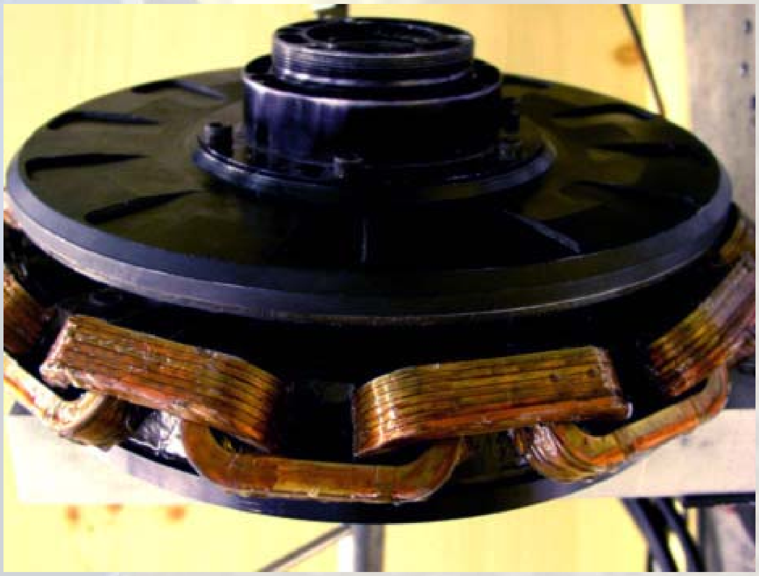
Lightweight space-frame design

Tucked inside the carbon fiber body, a structural network of TIG-welded chromoly tubes will provide the structure needed to support the driver and batteries while bearing the suspension loads. This proven construction method lends itself to rapid completion yet remains versatile and extremely lightweight. The finished chassis will weigh under 100 lbs. while supporting a 1600 lb. vehicle.

DC brushless motor technology

High performance electric vehicles can be realized with drivetrains of minimal complexity. As in most other electric vehicles, there is no need for a transmission in the Stanford EV. The wheels will be driven by the motor through a single stage of fixed gear reduction, a configuration made possible by the high torque characteristic of electric motors at low speeds.

Of the many types of motors available, DC brushless configurations excel at providing high efficiency over wide operating ranges. A number of DC brushless motors and controllers have been developed for small electric and solar vehicle applications. The efficiency of these systems ranges from 80 to 95% depending on parameters such as battery voltage, speed and torque.



A candidate DC induction motor, manufactured by New Generation Motors. Peak electrical efficiency is 98%.

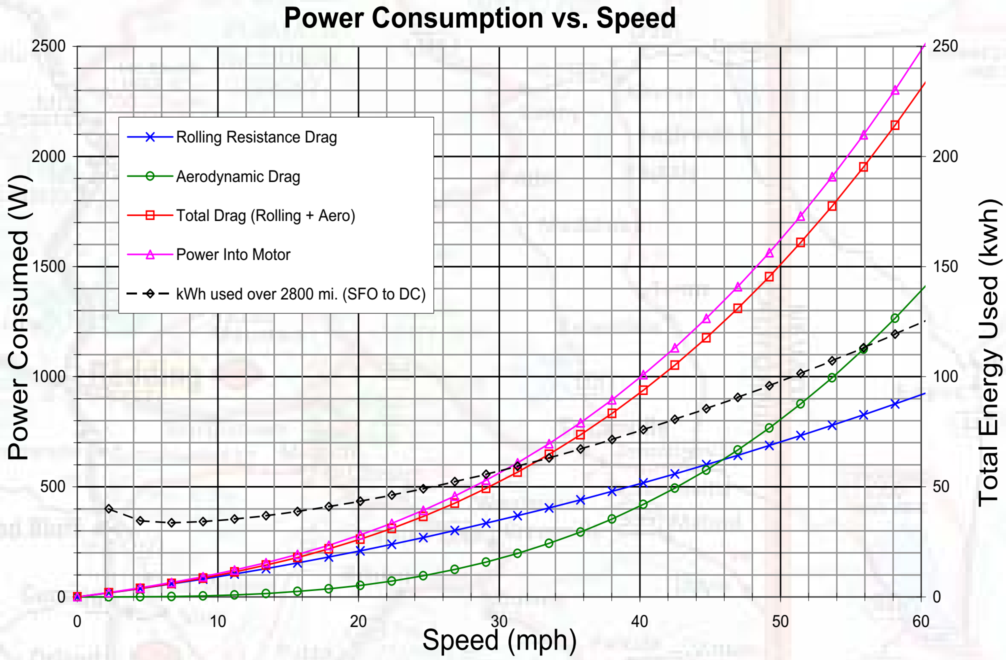
Testing platform

The success of this project hinges on our ability to efficiently integrate a collection of subsystems into a single vehicle. Consequently, we need to start assembling and testing subsystems immediately. In fact, work is already complete on a rolling test chassis that is compatible with many of the components and systems to be used on the final vehicle. This allows us to move forward on evaluating motor performance, drivetrain ratio tuning, and power systems integration before a vehicle design is finalized.

Performance Model

Overview

To prove the feasibility of this project, we've created a mathematical model that predicts the performance of the vehicle over a wide range of operating conditions. This is extremely valuable for setting goals, guiding design, and determining where to focus our efforts in order to get the largest improvements.



Battery pack

The starting point for the model is the battery pack. We begin with the maximum possible battery weight that will still result in a safe and versatile vehicle. This is how we arrived at using a 1080 pound (490 kg) battery pack. The main limiting factors to adding more battery mass are the weight capacity of the tires and the maximum power output of the motor. With a 1600 pound car (including driver), the weight fraction of the batteries is an impressive 67.5 %, and stored within these batteries is a over 80 kilowatt-hours of energy.

Power consumption

The next step in getting a range estimate is to calculate how much power the vehicle uses at different speeds. This requires tallying the best estimates of aerodynamic drag, rolling resistance drag, and drivetrain inefficiencies. Data for these various quantities are given in a number of references on aerodynamics and solar vehicle technology. Since the data is given for scenarios very similar to the operating conditions of the Stanford EV, these estimates are accurate to within 15%.

Implications for vehicle range

When this project was first conceived, our initial aspiration was to cross the United States on a single charge. Subsequent testing and modeling showed that this was indeed possible, and could be done at approximately 40 mph. This result is seen on the graph above as the speed required to cross the country using 80 kilowatt hours of energy.

Another exciting possibility is to cross the country at 60 or 65 mph, demonstrating that highway speeds are well within the capabilities of even such an efficient electric vehicle. This high-speed crossing would be done with a single recharge in the middle of the country, using green electricity generated by wind or solar power.

The model above is based on a versatile configuration designed for highway driving conditions. Further optimizations will be made to set an official distance record while driving around a track at 45 mph.

The fact that a single vehicle is capable of shattering multiple records with the same basic configuration is perhaps only a glimmer of the potential greatness of the Stanford EV.

Timeline

November 2003

11/15	Prototype rear swingarm completed
11/17	Prototype instrumentation, electrical system

December 2003

12/13	Prototype front suspension completed
12/15	3 refined aero bodies examined

January 2004

1/19	Prototype drive train completed
1/15	Final battery and wheel configuration designed
1/24	Prototype chassis completed
	Preliminary rolling resistance and power tests around campus
1/29	Final aero body chosen
1/31	Begin aero body mold construction
	Extended prototype mechanical testing

February 2004

2/7	Preliminary suspension geometry and battery pack design
2/21	Final space frame chassis design completed, construction begins

April 2004

4/1	Chassis completed
	Final mechanical systems design completed
	Final instrumentation/telemetry design completed
4/17-18	Aero body layup

May 2004

5/12	Mechanical systems completed, rolling chassis
5/25	Battery monitoring system completed
5/31	Battery pack assembled, electrical system completed

July 2004

7/1	Test drive on campus
7/4	Test drive on Sand Hill Road
7/7-10	Extended test drive in California central valley
	Testing and tuning continues through August

Autumn 2004

9/1	Closed-course, official record breaking track drive
10/1	Single charge cross-country trip

Sponsorship Information

Financial support
This project is leveraging many donations, hundreds of hours of volunteered engineering expertise, and countless resources from Stanford University. However, there is still a minimum level of cash support that we must raise to make our vision a reality. If you or your organization can help, we will be thrilled to have you as a partner on the project.

We have several tiers of support available. The level of representation will be commensurate with the level of support as described below:

Namesake Sponsor: ($75,000 and over)
This will essentially allow an organization to adopt the project and have their name first on every media publication and on the vehicle itself. (Stanford University's name must also appear on the vehicles per university rules)

Platinum Level: ($30,000-75,000)
This will give the sponsor representation on:
The EV itself (large graphic)
The chase van (large graphic)
The trailer (large graphic)

Gold Level: ($10,000-30,000)
This will give the sponsor representation on:
The EV itself (medium graphic)
The chase van (medium graphic)
The trailer (medium graphic)

Silver Level: ($5,000-10,000)
This will give the sponsor representation on:
The EV itself (small graphic)
The chase van (small graphic)
The trailer (small graphic)

EV Friends: ($1,000-5,000)
This will give the sponsor representation on:
The chase van (small graphic)

Sponsor-A-Battery: ($8 and up)
After packaging, each battery in the vehicle's pack will cost the project approximately $8. Our Sponsor-A-Battery program allows anyone to show their support in a tangible manner by paying for one or more batteries in the car's pack. Contributors' names will appear on our website and in a listing in our media guide.

For direct monetary donations to the project, checks should be made payable to the Stanford Solar Car Project. Donations should be mailed to the mailing address listed on the back cover of this brochure.

In-kind support
In addition to cash contributions we rely heavily on donations of equipment, services, and materials from many different organizations. Without this support we could never accomplish our goal.

Regardless of how you choose to participate, putting your name on our vehicle makes a powerful statement. Your support shows that you are committed to a cleaner environment, to education of tomorrow's engineers and business leaders, and to pushing the very boundaries of technology.

Spread the word
Even if you are not able to directly contribute to our project, you can help us by spreading the word about what we are doing. The more people who hear about our effort, the greater an impact we will have. Our success ultimately rests on public awareness.

Project Budget

Prototype		
	Fabrication to date	$4,000
	Prototype instrumentation	$1,000
	Prototype testing	$5,000
	Total	**$10,000**
Vehicle		
	Aeroshell design	$5,000
	Aeroshell construction	$35,000
	New optimized race chassis	$5,000
	Vehicle mechanical asystems	$15,000
	Motor and controller	$15,000
	Batteries and end plates (race pack)	$80,000
	Pack assembly (AC Propulsion, Inc.)	$20,000
	Vehicle instrumentation and telemetry	$5,000
	Test drives and iterations	$10,000
	Sponsorship budget	$2,000
	Trailer	$8,000
	Total	**$200,000**
Project Total		**$210,000**
+10% contingency		**$221,000**

Vehicle Specifications

Performance Specifications

Range:	2800 miles at 40 mph 1600 miles at 60 mph
Top speed:	90 mph
Curb weight:	1600 lbs
Passengers:	1

Electrical Specifications

Capacity:	80 kWh
Battery type:	18650 Li-ion cell (there are 8 in a typical Laptop Battery)
Number of cells:	10,000
Weight:	1080 lbs
Bus voltage:	120 nominal
Recharge Time:	1 hr
Motor:	DC brushless rare earth permanent magnet (10kW peak)

Regenerative braking integrated into motor controller

Mechanical Specifications

Frame:	Chromoly steel tubular space frame
Tires:	Michelin solar car radial
Brakes:	Disc brakes on all wheels
Shocks:	Coil over damper, custom
Transmission:	Fixed gear reduction chain drive
Steering:	Rack and pinion
Suspension:	Double wishbone
Body:	Carbon fiber composite

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