The Future of Transportation

PROJECT
BETTER PLACE

Shai Agassi
Founder and CEO, Project Better Place
Young Global Leader
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Projecting the future of energy, transportation, and environment

In 2005 the world entered the “post peak-oil” era, as predicted by many oil experts years before reaching this situation. The price of oil is dominated by two factors, new discoveries of oil fields and global demand for oil, falsely called production. As the R/P ratio (Reserves to Production) slides we begin to witness sharp price hikes in the futures market for oil immediately affecting the price of fuel at the pump. During the last 10 years, the price of oil shot up from $10 a barrel to well above $80 a barrel, with current predictions more certain of the price crossing $100 a barrel than ever coming back to $50. The oil market is tightly intertwined with the car market, as both products complement one another to produce the “complete product” consumers desire - the freedom of personal commute. With this document we try to project the most probable set of changes in the energy markets and the transformational technologies that exist today and how they will come together to address this emerging oil shortage. The paper will also try to illustrate the potential business, national and regional affects of such transformation to the energy and related industries. It is important to note that as these markets are so complex and inter-dependent; many other events may happen can accelerate or alter the course of events described here. The technologies that are described here are all present today, and no scientific breakthrough was assumed or needed.

Current State

The world depends on oil today as its fundamental transportation energy source. Half of oil production is used to drive consumer cars, commercial transportation (mostly trucks and boats) and air transportation. With the emergence of china as an outsourcing powerhouse, and the internet as the global e-shopping mall, we have significantly increased the distance our global materials and finished goods travel, requiring more transportation fuels. Even more critical, with the emergence of a consuming middle class in China and India, we have a sharp rise in demand for cars. Those cars in emerging countries drive on congested roads and use cheaper older engine technologies - creating an immense demand for fuel and tremendous amounts of car emissions.

Various solutions have been proposed in recent years, with varying degree of success. Most prominently, Ethanol as a short term fossil fuel replacement and Hydrogen infrastructure as a long-term solution, were touted as energy source and distribution mechanisms for our transportation needs. It is the authors’ belief that while Ethanol has a very important role to play in the short term it is not a long term solution at scale for the needs of driving a billion cars, which is the scale of our market within a few decades. Hydrogen on the other hand, is a fundamentally flawed approach due to the negative energy equation underlying the generation, storage and consumption of Hydrogen in cars.

To understand the energy flow of fuel we need to understand the following energy/time cycle. Fossil fuel is the result of solar energy mixed with water in plants as we discover it after millions of years. Over the millions of years, the earth's core energy and pressure concentrate the Carbon-Hydrogen bonds into high energy density molecules that humans extract, refine and burn (inefficiently) in small car engines.
Unlike most descriptors used, we as humanity do not produce oil; we merely discover and surface it. To understand the cycle, let's examine what happens to crude oil after we have it on the surface. Through the application of an energy intensive process of refining oil we attain its most valuable derivative hydro-carbon molecules - fuels and other petrochemical derivatives (Such as plastics). We deliver the fuel through pipes and trucks to gas stations, where cars fill fuel into the car and consume the fuel through a very wasteful internal combustion engine - losing roughly 80% of the chemical energy fuel carries to non-productive heat. In the process of releasing energy from fuel, we break carbon-hydrogen chemical bonds, creating CO_2 as an undesired by-product which is slowly altering our atmosphere, heating our planet in the process. At the surface level fuel produces many other derivative gasses, such as NO_x, that cause local pollution and deaths.

To solve our critical global shortage of oil, we must find solutions that do not require the millions of years earth takes to make oil out of plants. Ethanol can be made through direct conversion of plants (mostly sugar cane in Brazil, and corn in the US) into bio-fuel, cutting earth's heat and pressure out of the loop. The problem with Ethanol is the energy, water (not to mention the shortage of arable land) required to produce a unit of energy is so high today that scaling the solution affects our ability to feed our population. In a sense, we are entering a stage where oil has becomes tightly linked to food in a very dangerous zero-sum game. The manifestation of that link can be seen in sharp price hikes for basic food crops, such as corn, in the US over the last few years. Even worse, in countries like china we are running out of enough clean water for drinking and irrigation (which consumes 80% of our sweet water). The only way to produce more water is through desalination, in essence converting energy into water. As such, converting water into energy is the reversed process to the one desired by nations looking to solve our immediate water shortage. Other problems stemming from the inability to distribute of Ethanol through pipes (Ethanol is a corrosive material) had already reduced the appeal of this fuel and prices for Ethanol are dropping sharply in the US, despite rises in oil prices.

Hydrogen, on the other hand is not an energy source, rather an energy distribution mechanism. In a sense we need to produce Hydrogen, compress and distribute it, store it in the car without having it stream out of the container (a very complex problem), after which we can run it through a very expensive fuel-cell, where hydrogen atoms (the proton in the atom) combine with oxygen from the air, releasing an electron. It takes four electrons in production of Hydrogen atoms to produce a single electron within the fuel cell. In a sense we lose 75% of the energy we start with if we go through the Hydrogen route. Regardless of the technical and economic problems in producing a viable hydrogen infrastructure, it is simply an inefficient process that cannot help us at scale. To understand the fundamental problem of Hydrogen, we need to remember that what we want is the electron in the hydrogen atom, yet we seem to attach it to a proton which is 2000 times bigger to produce an inefficient distribution mechanism. The only question is why?

Our proposed solution improves the original solar energy concentration cycle by eliminating the role plants play routing photons from the sun (and their variants - wind and wave energy) into electrons within millions of cars. We do so by collecting solar energy (through large scale solar thermal installations), generating

electrons, sending the energy directly over the electric grid into an electric battery which powers an efficient electric motor. Motors, unlike engines, do not generate friction or heat, providing 90% + efficiency in converting electricity to motion. Past issues - such as battery cost, distance, speed and battery life have significantly improved over the last decade and the economics have now tipped in favor of electric transportation, as we will illustrate in the following paragraphs. A significant change required is the creating of new class of infrastructure replacing the role gas stations played with combustion engine based cars.
When we convert our transportation from combustion engines to electric motors, build renewable sources for the required electricity (a car needs an installation of approximately 1.2 kW of solar power, or 70% as much wind power) and connect the generation with the car through an intelligent Electric Recharge Grid (ERG) we will create a sustainable transportation energy solution which will go practically forever with no reliance on oil and no emissions.

Technology and the financial implications

Apart from crossing peak oil, another major event happened around 2005 - the emergence of a new generation of batteries - Lithium Iron Phosphate ($LiFePO_4$) - able to sustain more charge cycles and based on safe chemistry that can be put into a car. For the first time the total cost of energy for electric transportation has crossed under the cost of fuel when calculated on a per kilometer basis. The fundamental technology and economic drivers behind this these two events will continue to drive the price vectors for fuel and electricity further apart in favor of the electron and battery. Within a decade, the cost of energy for a single year of fuel supply for a combustion car should cost more than the cost of energy for an electric car's entire life, even when taking the cost of battery into consideration. The "cross-under point" had gone almost unnoticed in the world of automotive design which was focused on the hybrid-car race, yet its effect will change the industry in the most disruptive economic shift ever experienced in history.

Cars are not complete products, as they would not provide any function without fuel and variety of services (such as maintenance). As the price of crude oil increased, it drove the price of fuel at the pump higher to become a much larger component of the total cost of car ownership. To illustrate, an average European car costs 12,000 Euros to acquire, yet over its 12 years of life will require approximately 30,000 liters of fuel costing roughly 35,000 Euros (assuming fuel prices do not continue to increase even further). In other words, we now have a container for energy built into the car - the fuel tank - costing $100 to build; yet our energy costs three times the price of the car.

Contrast that with the electric vehicle where the container for energy, in this case a battery, costs roughly 7,000 Euros, yet the electricity to run the car costs 2,000 Euros for the entire life of the car. In the aggregate, energy to drive an electric vehicle now crossed under 10,000 Euros. Historic trend lines for battery over the last 25 years shows a 50% price per kWh improvement every 5 years, stemming from technological and process improvements. We have seen similar effects in the chip industry, where Moore's law predicted chip improvements amounting to 50% reduction every 18 months. Similarly, we see the price of renewable generation declining over the years, to the point where large solar installations cost today 2 Euros per Watt, shedding price roughly at the same rate of 50% every 5 years. Projecting forward to 2015, we should see the cost of the battery and solar generation sufficient for a car reaching combined cost of 5,000 Euro. By the end of the decade that price should drop to 3,000 Euro with the battery and solar generation both outlasting the car. At some point during the next ten years, the total cost of electric energy (with battery) for a car will equate the cost of fuel for a single year. We predict that at some point in time before that next cross-under point the entire car industry will tip to electric drive as the main design principle for new cars.

What is missing for this transformation to happen today? Infrastructure and scale. Consumers simply cannot buy products that are not available. Electric cars as well as all their critical components are produced in small runs, not on commercial scale. The car industry was caught by surprise with the sharp increase in oil prices as the US makers focused on ever larger SUVs and vans. Even Toyota was surprised with the success of its hybrid Prius line. While the entire industry scrambled to catch up to the hybrid wave, every one of the car majors assuming no new infrastructure will be in place for a pure EV decided not to produce an EV until the emergence of a battery that can last for 10 years and provide enough energy to safely drive a car for 500+ kilometers. Since such a battery is not in existence, and most likely will not be there for another 15-20 years all makers pushed their EV plans into niche solutions focused on fleets of cars that run predetermined routes and come back to home base after 100-150 km, such as postal delivery trucks.

It turns out that the solution does not stem from a more powerful battery. Rather we propose the creation of a ubiquitous infrastructure that can enable a car to automatically charge up its battery when parked, and on the exceptional long drive using an exchange station where an empty battery is replaced with a full on in automated lanes resembling car-wash devices positioned in gas stations across the country. We for the first time look at the car battery as part of the infrastructure system, not part of the car, much like the SIM card inside a cell phone is part of the network infrastructure which is residing inside the phone. Since the car owners do not own the battery they can freely exchange it as needed, not fearing the issue of receiving an “older battery” in exchange for a new one.

The collection of park and charge spots across a country or city, together with software that controls the timing for charging the cars, creates a smart grid - synchronized and extending the country’s existing electric grid, matching excess electricity on the grid with the need to charge batteries flattening the demand curve in the process. When we put together the charge points, the batteries, exchange stations, and the software that controls timing and routing we get a new class of infrastructure - the Electric Recharge Grid (ERG). A new category of companies will emerge in the next few years which will install, operate and service customers across this grid - called Electric Recharge Grid Operators (ERGOs). The business model for such operators will be similar to that of wireless phone operators, and so we can predict that a few years after the ERGOs, we will also see the emergence of virtual operators on top of the physical grid (or VGOs).

The economics of large infrastructure operators call for massive investments up front, which can be monetized over years through subscription based services to consumers. Similarly in this case, once a grid is installed to the degree of sufficient ubiquity in a contained region, car owners will be able to subscribe to a complete commute solution - car, energy and maintenance contained in a singe predictable monthly price. Not only is the price predictable (unlike the case of fluctuating oil prices), depending on the length of the subscription the ERGO can subsidize the cost of acquisition of the car. As the costs of battery and clean electricity will continue to decline over the next ten years, we can easily foresee enough subsidies in the contract to the point where electric vehicles will be given for free to long term subscribers. Assuming that subscribers will be happy to pay the same amount they pay for fuel and maintenance today, the economics require a contract lasting 6 years in order to get a free SUV. By 2015 that same monthly fee will require a contract lasting 4 years, and in 2020 that contract will already be reduced to 3 years - the average leasing contract today. Such radical process has happened before in the wireless phone industry, where it is almost expected today that a basic handset will be handed for free with any new subscription.

With infrastructure and economics in place the demand curve for such new transportation model will grow exponentially - taking a significant portion of the current global demand for cars, standing at 70 million new

cars a year. The supply curve for components and cars will need to scale similarly - scaling an entire set of industries, from batteries to motors and power electronics. To illustrate the rate of growth, today's Lithium based battery market (working mainly for laptops and cell phones) produces enough batteries to power roughly 100,000 electric vehicles. Reaching a market of 10 million cars (representing only 15% market share) would require a 100-fold increase of annual production capacity globally.
On the other hand, as electric drive trains have less moving parts than the combustion engine and its supporting components, the markets for today's mechanical auto parts (such as spark plugs and carburetors) will start to decline sharply, as will the market for car maintenance. We will also predict that used car prices will at some point decline sharply, as a result of the availability of cheaper all new clean cars, costing consumers less than the cost of fuel based used-cars.

The magnitude of this disruption is discussed towards the end of this document, it will take time, but we believe it is almost unavoidable at this stage. Since we ran out of cheap oil, and all new discoveries are in deep oceans or troubled locations in the world, we have now a floor price to the production and refining of oil. That floor price together with climate related tax policy will make sure that even as demand for fuel subsides in following years as the predicted events unfold, the price of fuel will not be able to go back below the 1 euro per liter at the European pump.

Climate Change

While we focused on the short term micro-economic questions surrounding the conversion from fossil fuel based transportation to renewable electronic transport systems, the real value of such change is the massive reduction in greenhouse gas (GHG) emissions and the long term implication on our planet. An average car produces 4 tonnes of CO_2 every year, with certain fleets (such as taxis or delivery vehicles) producing 20 - 40 tonnes a year per taxi. European car fleets are reducing their consumption of fuel and with it their emissions per km driven through the use of new catalytic converters and other advances in engine technology. On the other hand, the emerging China and India's middle class consumer is racing towards the ability to buy his or her first car. Those cheaper cars are not using the latest engine improvements, while being driven on heavily congested roads; as a result they produce tremendous amounts of emissions raising the average CO_2 per car in the world as well as NOx levels in major Asian metropolitan centers. We are in a race for providing a fundamental solution that India and China can adopt at scale before the local consumers flood the market with cheap emitting cars that will pollute the market for the next 20 years.

Accounting for the 700 million cars currently on the world's road, the current tailpipe emission level reached 2.8 Billion tonnes of CO_2 a year, projected to grow to 4 Billion tonnes within the next 20 years. This amount represents roughly 20% of the world's CO_2 emissions, staying in the earth's atmosphere for 45 years after it leaves the car's tailpipe. To understand the value of this framework, one has to understand that eliminating all car emissions through our proposed framework will reduce the entire projected growth of CO_2 emissions in the developed world over the next 25 years. If we apply other emission reduction policies aimed at homes and power plants, we could achieve the very ambitious GG reduction goals Europe and the world is hoping to attain within 25 years. Putting the emissions back into financial terms, using the projected price per tonne of CO_2 (estimated to range between 35-70 Euros[1]), the value of carbon credits from all cars stands at 150 Billion Euros a year. If we believe that the markets reflect the true cost of such externality, then the price of car emissions stands at roughly 10% of the price of fuel at the pump and depending on the

[1] Lehman brothers report

location and car anywhere between 20% and 100% of the price of the car over its life. While the true cost of emissions will always be hard to determine, we believe that most countries will end up adding such generally accepted carbon tax as a cost within the price of fuel, an emissions tax on cars or both.

Furthermore, electric cars with their distributed bank of batteries represent a great opportunity to store current electricity generation reserves from fossil-based power plants. Every grid system generates excess power capacity of roughly 3% called “active reserve”, which is used to guarantee immediate availability of power regardless of unpredictable demand spikes. The active reserve is usually wasted, as power stations have no ability to store such massive amounts of energy over time. The active reserve alone could power roughly a third to half the entire country’s fleet in developed countries, and even higher proportion of developing countries’ fleets, as they have a lower motorization rate. The smart recharge grid provides a distributed storage facility across all connected and reserve batteries creating grid storage for excess electricity. Those batteries and cars will stop charging automatically as other electricity demand surges. Taking the concept one step further, the cars and batteries can even feed back electricity to the grid (in a process called V2G - vehicle to grid) used in cases of emergency thus flattening the demand curve without the need to build new generation capacity used for the rare 30 hour of peak demand witnessed by utilities every year.

On top of the costs associated with GHG emissions and their adverse effect on global climate, combustion engines emit a variety of toxic pollutants - which are known carcinogens. The local impact of car pollution can be seen in sprawling metropolitans such as Los Angeles or even worse in Mumbai and Beijing. Even in environmental conscious countries, such as Denmark where a significant part of the urban commuters use bicycle, current studies estimate that car pollution contributes to the deaths of 1,000 people a year, more than 2.5 times the number of people who die in car accidents in the country. While there is never a price you can associate with the value of life, it is obvious that the cost of tailpipe emissions is much higher than the value of carbon credits associated with CO_2 emissions alone.

The Princeton wedges study creates a broad framework for 15 macro sources of GHG emissions. Stopping climate change will require us as global planet to solve at least 8 of the 15 wedges. The “tailpipe wedge” has always been considered the toughest one to address, due to the distributed and mobile nature of the problem. In demonstrating a commercially sound and sane policy approach to solving this most complex wedge we hope to demonstrate that technological solutions, applied through capitalistic frameworks at scale can lead to solutions, in a manner that can be applied replicated to other wedges as well.

Finally, much had been said about the emergence of the hydrogen economy, as the way out of our global oil addiction. This new electricity based framework demonstrates that the next step away from oil molecules leads us to electrons, not hydrogen atoms. The way to generate these electrons must be done through sustainable clean ways that can scale. At the same time, we have a unique opportunity to install clean electricity as a replacement to very expensive fuel which is economically easier to compete against than replacing dirty installed electricity generation. By replacing oil we set an easier bar for comparison, one that will lead to immense demand for clean electricity in the order of 1 Terra-watt of clean solar or wind installed capacity at the end of our framework deployment across the entire world. While such energy scale seems immense, the sun shines 800 Trillion Watts on the surface of the earth, we merely need to capture 0.1% of that energy and route it through our grid into cars’ batteries. We have 15 to 20 years to complete such a complex technological effort, but the science is well known, available and proven - with clear rewards, and en economic framework that is already in place.

The Future of Transportation

Macro Economics and Geo-Political implications

At the country level we will shift the transportation energy market from dependency on discovery of fossil energy reserves which are only present in certain locations around the world, into the manufacturing of energy that can be done in any location on the planet. Doing so shifts fundamentally the trade balance across countries and regions. While we call countries where reserves are found today - oil producing countries - in reality they do not produce the oil, merely dig it out of their ground or seas. These countries enjoy windfall profits of immense proportions. Most of the fields and the profits they produce have been shifting over the last decade away from global oil companies and into nationalized oil companies. In some cases the profits are used to drive positive social causes and country wide economic improvements, in other cases the money is used to affect negative change in the country and abroad.

Non-producing countries have seen their oil-driven deficit increase an average of 10-fold over the last decade, driven by consumption growth leading to crude oil price hikes. While the short term effects on country budgets are not immediately obvious, since fuel related taxes actually increase budgetary income, long term affects on local economies are devastating to other social causes. In particular, one has to pay attention to countries which have had cheap oil sources in the past, resulting in subsidized fuel price to consumers. Those countries can no longer afford such subsidy - passing immense price hikes for consumers. we have already seen strong fuel protest in various countries around the world, most recently in Myanmar.

One cannot debate the fact that not spending money on oil and driving that money back into the local economy can only affect it positively. Similarly, leaving more available money in the hands of consumers (by reducing fuel related spend) always leads to more local consumption, trickling more money into the local economy, and driving positive growth cycles. In a sense, such change has a similar affect as a the removal of a significant tax out of the economy.

Some oil producing countries began to realize that the recent price increase is not simply another cycle in the oil boom and bust historical economic cycle. This is most likely, the last boom the industry will witness in a very long time. While it may take quite some time for the market to tip and the transition to clean electron economy to happen (in the order of 10-15 years), smart leaders have already started to invest the current windfall into a diversified portfolio of economic growth drivers in their country and abroad. The best example can be found in the United Arab Emirates, where oil is still abundant, but all of its profits are invested back into such industries as tourism, financial services, media, education and recently alternative energy.

At the same time, these new industries require local markets for their success, unlike oil. Media outlets do not generate profits without media consumers; financial services thrive only in a trading economy; education modernizes society, and tourism leads to acceptance of foreign traditions. All of these are great drivers for modernization and in turn drive moderation of the local society as a strategic driver of continuous stability and sustained economic growth. These are all good news for the world, even before we shift our economy. The developed world has security interest in such outcome and should continue to work together with oil producing countries to clarify how this post-oil world shapes positively. In particular, it is of immense importance not to make the transition to one where oil-producing countries are necessarily on the “losing side” of a zero-side game. We should devise an economic development framework that allows those countries to continue to participate positively in the clean electron economy.

The Future of Transportation

We see the car industry going through a very important transition, similar in nature to the change that happened to the telco industry upon the emergence of cellular wireless technology. The process will resemble the way certain emerging countries leaped over older land-line infrastructure and got directly into wireless infrastructure. In the case of electric transportation the main question revolve around (1) what path would China and to a degree India will take, and (2) would the current 7 car giants accept and lead the change or try to delay through lobbying, only to follow once the market has been proven.

If china decides to take on the challenge of leading the new clean electron economy on a global scale it will inevitably create massive production capacity for all critical elements of the solution: electric drive trains, batteries, electric cars, infrastructure installation and solar generation. Locally China will benefit from its ability to centrally direct its economy to and its need to drive for change at scale due to the urgency of a country running out of fuel and cities running out of breathing air. The most likely scenario we foresee is one where China starts by focusing on supplying the needs of its immense local market needs, but will immediately leverage its market size and scale to create multiple massive export industries.

Car makers in the US will need to choose how to address a problem in the local market where fuel prices are compressed (due to years of lobbying by the same car makers) distances are immense, and a new- and used-car market that is saturated and heavily financed (again due to marketing and financing plans driven by the big 3). The only way for the US auto industry to adapt rapidly to this massive market disruption is through government intervention and focused policy change. The US government will need to deploy federal funding to set the right conditions for the creation of a massive ERG across the country, through financial safety net and various tax incentives. To fund the program, the federal government will need to increase taxes on cars, based on carbon emissions, and tax fuel - bringing the price up to roughly $4.5 per gallon, not too far from where market conditions are today. If the government wants to accelerate the process it might need to guarantee that fuel price will not fall below that price point for the next decade, creating a floor price for consumers to compare. The odds for such policy within the next 18 months are very low, yet in the mid to long term there is very strong possibility that with an understanding of the potential stakes, and successful demonstration projects in other countries, such as Israel or Denmark, the US government will spring to action.

European countries will face a tough decision that stem from the lack of homogeneity of policy and needs across country members of the Union. The German economy is to a high degree dependent on its automotive industry, one with a strong lobby and union, leading it to be very adverse to fundamental changes in the tightly linked automotive supply chain that extends well into Germany's all important mid-sized companies' foundation of the country's economy. The UK and Scandinavian economies have very strong oil companies, yet with the exception of very few small carmakers, their economies do not rely on the car industry for growth. The environmental awareness and high fuel prices across the continent will create a strong popular bottom-up push to do the right thing, while saving money for consumers. As we can see all scenarios are open as to how the car makers, economies and governments (both local and European central government) will connect all these conflicting interests into a single unified policy. What is almost assured, the decision process will be a very complicated one, and governments will take local action well ahead of the central European Union.

The first mover advantage in this market for early adopting car makers, component manufacturers, ERG operators, and countries may be as big a prize as ever in the history of economic development. The first car maker to field a solid electric vehicle at scale will enjoy benefits that will dwarf the success of the Prius for Toyota. Countries that will develop local expertise will see new companies emerge which positively affect their economy for ages, in a manner similar to Nokia's effect on Finland.

Finally, looking at the entire picture, we attempt to estimate the total size of all markets affected. The total economic dislocation seems almost incomprehensible.

- Fuel at the pump represents a market of $1.5 Trillion every year.
- Cars and components size roughly to the same size of market, $1.5T a year.
- Financing for new cars, gaining acceptance worldwide is estimated at $0.5T a year
- Clean electricity generation for cars is a market that will reach $0.15T a year
- ERG infrastructure construction will reach levels of $0.5T a year
- Battery manufacturing will reach similar levels of $0.5T a year, accounting for reduction in battery cost as the market size will continue to increase.
- In-car services, such as GPS, media, phone as well as related services such as insurance and maintenance collectively worth more than $1.5T a year will be affected
- Carbon credits alone will be worth roughly $0.3T when all cars are driven on clean electricity

In the aggregate, we are looking at an annual dislocation reaching roughly $6T a year - some of it shifting industries, some moving from one country to another and some simply changing roles within the current automotive value chain.

Regardless of who wins or loses economically, there is one sure winner - the sustainability of our planet and humanity. If we desire to sustain the planet and our current way of living, we stand in front of a decision that has no alternative, since risking the one planet we have in an uncontrolled experiment is simply not a viable option. The time is now, and the change is already in motion. In the words of Lee Iacoca "It's time to lead, follow or get out of the way."