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260053 Modular energy for electric vehicles: a paradigm shifting innovation for the transport sector

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Abstract

Are electric vehicles capable of long distance trips? Yes, but with major sacrifice: either recharge several times en route, with a trip which takes about twice the time of an ICE vehicle, or make a significant capital investment in a large battery and vehicle. Not surprisingly both options are a major hindrance to wide EV dissemination.

Various technical solutions are emerging like enhanced batteries or plug-in hybrid (PHEV). But the public considers the marginal use versus the marginal cost: peak range usage is only 2% of the time, whereas on board energy storage for peak usage increases significantly the vehicle's cost, and reduces its payload. Long range EVs and PHEV are thus restricted to the premium car segment.

As a result, for EVs to gain significant market share against ICE vehicles, we need to align marginal cost to marginal use.

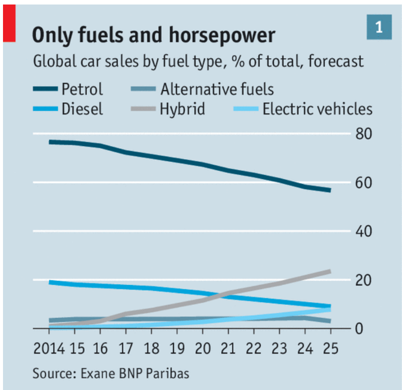
Two European startups have emerged independently to come up with an answer: mobile energy modules, attached occasionally to the EV, and providing the energy capacity required for peak usage.

Both EP Tender and Nomadic Power are proud to have been selected by H2020 SME for phase 2 projects [1] and [2], and have decided to jointly present their common vision at the EEVC conference.

Keywords: PHEV, Range extender, Battery, Fuel Cell, EV2G, Functional economy

1 Introduction: Unmet need

There is a legislative and environmental drive towards the implementation of EVs [3]. However, they remain a niche market primarily due to their cost/performance ratio. One of the main culprits is the cost of the EV's range. EVs that offer significant effective motorway range (*ca*. 350 km) are prohibitively expensive and remain a niche high end product (*e.g.* Tesla). On the other hand EVs with limited range (*ca*. 100 km, *e.g*. Leaf, Zoe, e-Golf) suffer from buyer's "range anxiety" and thus also belong to a niche market.



Economist.com 2015

It is noteworthy to point out a key difference between internal combustion engine (ICE) vehicles and EVs: for the former the fuel tank is one of the cheapest components (just a little more plastic); for the latter the batteries are the most expensive (retail cost is about 8k€ for 100 km effective range [4]).

In consumer electronics, cost has been optimized with batteries that provide power only for typical usage (a typical smart phone's battery lasts a single day). For extra power needs, external battery modules or chargers are used. Significantly, the consumer only pays for typical power use. In this way cost, weight and volume is optimized for common use. Who would purchase and carry a phone with a huge battery just for very occasional peak usage?

(1)

2 Disruptive innovation: modularity

EP Tender and Nomadic Power are proposing paradigm shifting innovation for the transport sector: design EV for typical use and provide a network of energy modules (Tenders, Nomads) mounted on small trailers available to rent at the point of use (*e.g.* motorway service stations and commercial centres) for longer trips (*ca*. 600km). By providing a modular approach the consumer gains affordability, convenience and peak range whilst not sacrificing environmental credentials.

98% of time (360 days)

2% of time (6 days) [5]

Energy storage technology is progressing at a faster rate than electric motors or other major vehicle component (cost/performance halves every 10 years [6]). As a result a key advantage to this approach is that the Tender/Nomad can take advantage of technology progress and offer it to the consumer without the need to replace their vehicles. EP Tender is based on an ICE, while Nomadic Power is based on a battery. They may evolve to be based on fuel cells or metal air batteries as technologies mature. A full EV thus gets omni-hybrid capability when having access to Tenders and Nomads!

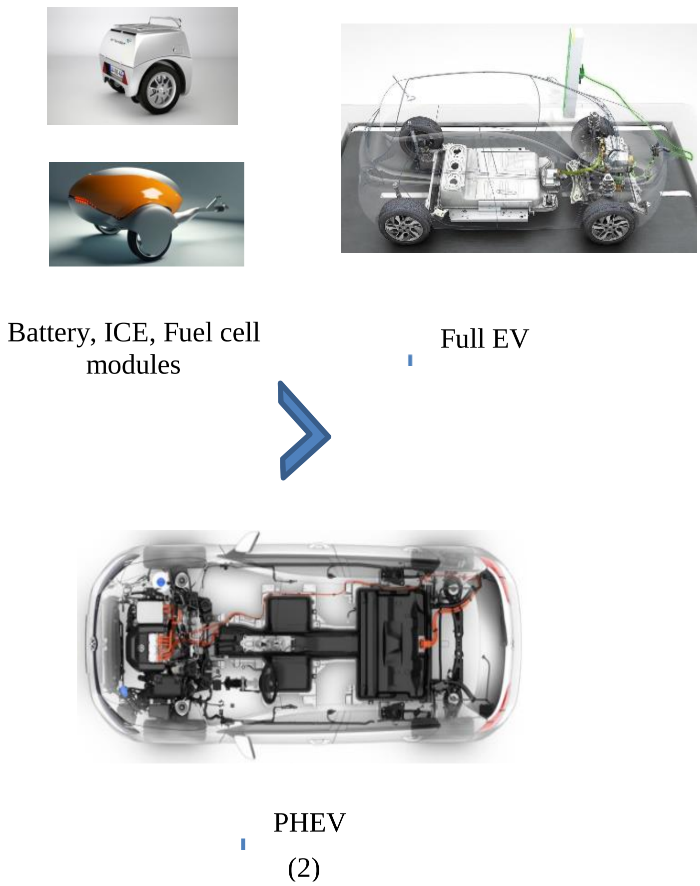
Revenue from electric vehicle charging services is expected to reach $2.9 billion annually by 2023 [7]. This is a major opportunity where EP Tender and Nomadic Power, by complementing for long distances the static charging services with more convenient on road charging, can play a meaningful role and develop a profitable industrial and commercial activity.

EVs can be run for many years and benefit from upgraded Tenders and Nomads carrying newer technology for energy storage (for example fuel cells), without having to replace the whole car, thus further reducing EV life cycle footprint and total cost of ownership (TCO)

The benefits are multiple:

- Car remains optimal for daily usage (5 passengers, trunk > 300 L, 150-200 km effective range, weight <1400 kg)
- Car is affordable, and will become high margin with volume
- Range can be increased on demand
- Marginal cost of range increase is affordable as the energy modules can be shared and rented only as needed, and Nomads can be used for home storage of energy
- Life cycle footprint is minimized as the add-on energy module used for long distance trips (ICE Rex, fuel cell or large battery) is shared by a number of cars, instead of being on board each car: these are the benefits of the functional economy concept, of which we are part.
- Full EVs may become omni-hybrid when they have a hitch
- The burden on the electricity grid remains mostly off peak on residential slow charging and office normal charging, and generates far less peak fast/superfast charging demand: see for example the EPRI initiative [8].
- Thanks to a wider and accelerated public adoption, EVs (an Nomads) can be used to smooth grid demand enhancing the sourcing of renewable but intermittent energy: (Nissan-Endesa initiative [9], San-Diego [10])

Milestones already achieved to date demonstrate the credibility of the mobile energy approach and the ability of the EP tender and Nomadic Power to attain objectives. Both companies are proud to have won H2020 SME support for their projects!



Splitting a complex issue into simpler ones is a classic problem solving method. And in principle we get here a very nice solution where both sub-problems can be very efficiently satisfied with existing technology, as is illustrated by “equations” (1) and (2) above !

Much stronger EV penetration:

Daily trip length distribution during the course of the year is the key determinant to EV adoption. Actual user data [11] demonstrates that an EV having a (real life) range 100 miles can satisfy all the needs of 9% of users.

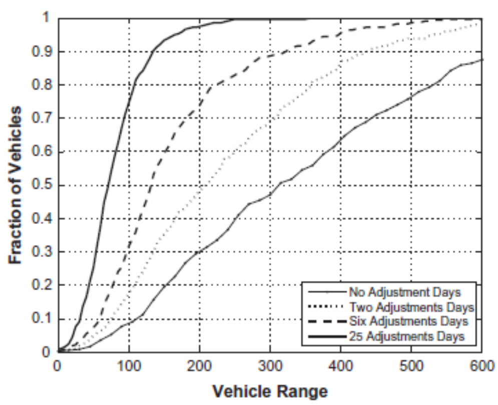


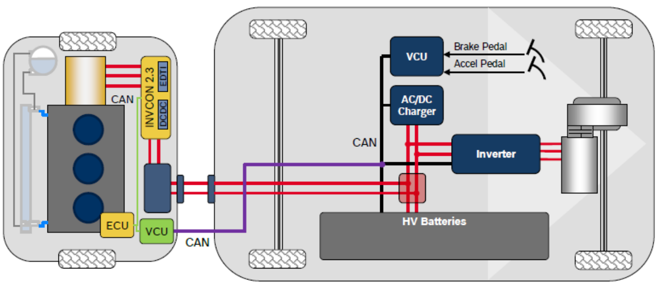
Figure1: [11] “Driving success surface by adaptation days. Fraction of the 363 vehicle fleet appropriate for varying vehicle range, with the four lines representing vehicles owners willing to make adaptions 0, 2, 6 and 25 days in the year”

By using an alternate solution on 2 days only (like range extending Tenders or Nomads), the same vehicle can satisfy 17% of users, 30% on 6 alternate solution days, and 75% on 25 days. With an EV range of 200 miles the same data is: 30% of users are fully satisfied, 49% with 2 energy modules days, 75% with 6 Tenders or Nomad days, and 97% with 25…

Although long distance trips are rare, they are made by the vast majority of users. The difficulty with batteries or on board REX is that they are a high marginal cost solution to a low marginal occurrence. EP Tender and Nomadic Power have the huge benefit to be both a convenient, and low marginal cost solution. It allows the EVs to be competitive in a global and open market, and provides a huge leverage to their prospective client base (from 9% to 30% assuming up to a mere 6 days annual usage, plus reassurance to the 9%...)

2 Technicalities of connecting to the EV

Both EP Tender and Nomadic power have chosen to power the EV with DC current and are connected in parallel to the EV's battery.
We are not using the on board charger of the EV. Through CAN communication we receive data from the Battery Management System (BMS), which at all times indicates the maximum power acceptable by the battery and the actual power it receives. The power produced by of our modules is continuously adjusted accordingly.
As a result we can provide energy while driving, without interfering in any way with the vehicle's systems: the vehicles are 100% standard and require no modifications, apart from adding a tow bar and connecting to the 400V line and to the CAN bus.
Below is an illustration of EP Tender's connections with an EV.



Vehicle diversity is managed by adding a "CAN Merger Box" along with the high voltage junction box in order to select and reformat the vehicle's CAN messages into a vehicle independent format.
When the energy module carries a battery, or a fuel cell, a DCDC power electronics module will provide the necessary voltage adjustments. When the energy module carries an ICE generator, the generator's output is equipotential with the vehicle's battery.
The energy module can provide a continuous power which equals the average energy consumption of the vehicle. Peak power will be provided by its battery, which acts as a buffer. As a result the energy module is optimised on the energy capacity parameter, with a moderate power requirement.

3 Specifics of each offering

Nomadic Power and EP Tender will compete against each other!
But we have a joint interest at promoting our common approach on a precompetitive basis. This article and our speech are a testimony to this.
We have taken slightly different routes for the initial implementation of modular energy for EVs. For example Nomadic Power has chosen to store energy in a battery, whereas EP Tender has chosen to use a classic combustion engine and a fuel tank.
It is quite possible that over time each of us will diversify energy sources and adjust to technology progress and infrastructure developments, giving users an optimal energy source at all times.
In both offerings the energy modules will be available for on demand rental (car-sharing concept), and will be picked by the users en route to their destination.
Purchasing will also be possible, but this is assumed to be rarer.

3.1 EP Tender (www.eptender.com)

EP Tender has focused on the compacity, and lightweight of the Tenders.

The energy is provided by gasoline. Electricity is generated by a small Internal Combustion Engine and an alternator. Peak power is 20 kW, with a fuel tank of 35 liters providing 85kWh, and the total weight is 250 kg. EP Tender allows the public to switch, with current technology, from 100% petrol to 98% electric, at a TCO and convenience which are equivalent to an ICE vehicle!

Attaching the Tender to an EV is achieved in one go, by punching the car with the hitch, and backing maneuvers are made easy thanks to the self-steering feature embedded into EP Tender's platform.

The QR codes below are linking to videos demonstrating both features.

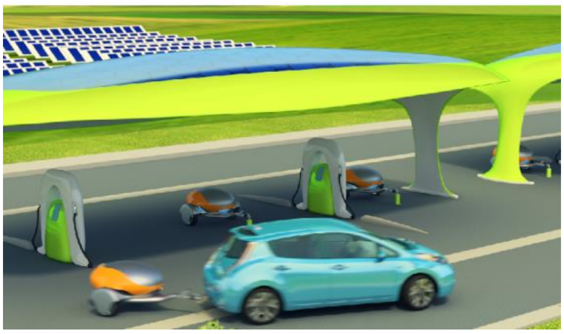
Hitching and backing [12]

Platform [13]

Future versions of EP Tender will include Fuel Cell, or batteries. Hitching to the EV will become fully automatic within a few years.

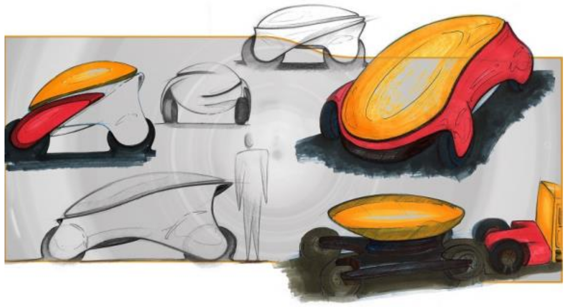
3.2 Nomadic Power (www.nomadic-power.com)

Nomadic Power has focused on a 100% ZE approach by mounting a high power density battery on its Nomads, with a capacity of 85kWh. The Nomads will be either rented or owned. They can be integrated in the Grid, and provide storage as well as backup power. Their battery is designed to provide both DC (electric mobility) and AC current (home power).



Future versions will be self-driving. Self-driving Nomads can be ordered automatically while driving on the highway. They will track the vehicle autonomously and transfer energy by induction. AutoNomad solutions will be developed for electric passenger vehicles and for autonomous driving electric trucks.

QR Code to Video [14]



4 Competitors and previous attempts

Tom Gage at AC Propulsion has developed an early demonstrator of the future Tesla Roadster and its powertrain, as well as a very interesting self-steering mobile range extender, from 1992 to 2001 [15].

http://www.tzev.com/1992_1995_2001_acp_rxt-g_.html

Better Place has failed due to over expensive infrastructure and high constraints on vehicle/battery integration. Sadly they have sunk 850 M USD [16]. But there was some truth in their understanding of the range and marginal cost requirements. This unfortunately has left some scars and added cautiousness on the side of car makers. **Tesla** has made a recent implementation, but it appears to be for California ZEV tax credit optimization, not for real business perspective [17]. This concept seems now abandoned by Tesla as well.

Plug-in Hybrid Electric Vehicles: quite a few new products (A3, Golf GTE, BMW i3, New Volt), and many high tech range extender prototypes with equipment makers (AVL, KSPG, Lotus-Fagor, Polaris-SwissAuto, Mahle, Obrist, etc.). The difficulty is to keep an acceptable level of cost, given the complexity involved. This is acceptable for large or premium cars, but not reasonable for smaller and affordable cars. The other significant downsides are that the full electric range tends to be lower than a full EV (Golf GTE = 40 km effective electric range [18]), or the gasoline range is less than a classic ICE (BMW i3 = 9l fuel tank), and the trunk gets smaller in order to accommodate for all the technology (only 270 l in the Golf GTE vs 370l in the e-Golf and 225 l in the BMW i3).

Chevrolet Volt

Very large batteries: Tesla Model S is probably the best car in the world, and loved by affluent enthusiasts. But such a large, heavy and expensive car is not ideal in towns, and is not a good cruiser, requiring to stop 35’ every 225 km (assuming driving at 130 km/h and 80% battery charge on Supercharger). Recent examples of cross continental trips in the US show that total trip duration is just above 30% higher than the same trip with an ICE. Recent academic work from Oak Ridge National Laboratory [19], confirms that most users are better-off with 100 miles range. Model S and the new Model X are anyhow a great symbol helping to enhance the credibility of EVs.

Tesla Model S and Model X

Fuel cells: this technology remains very expensive in itself, as well as requiring H_2 distribution infrastructure. There is also the debate on how to manufacture clean H_2 at acceptable efficiency. It will take years to emerge as a viable stand-alone business, as expensive and scarce infrastructure has to be used by expensive and scarce vehicles…

Toyota Mirai

Mobile energy modules, equipped with a fuel cell and rented on demand, might change that picture, by allowing a concentrated and progressive deployment of the infrastructure, used by numerous and affordable vehicles !

Synthetic fuel: possibly the best of all solutions could be the production of synthetic fuel from solar energy, hydrogen and carbon capture. Energy density and ease of storage would no longer be an issue, but this still remains highly hypothetical.

EV as main car + ICE car rental: this solution is perfect in the context of multimodal trips. But costs are higher, and door to door trips are often more convenient than having to fetch a vehicle at the car rental (unless as a complement to plane or train). EP Tender’s research [21] shows that only 11.5% of EV owners prefer this solution.

The fundamental benefit of designing a car for optimal daily usage and adding on demand an energy module for occasional long distance will remain as long as the marginal cost and weight of a larger battery remains a multiple of a larger fuel tank [22], as well as the time for filling it.

5 Business model

A good technology and product is nothing without a good business model. Pricing power, distribution and growth potential are the key determinants.

Pricing power

The pricing power of energy modules is quite strong due to:

- High client value (unlimited range)
- Sticky clients and recurring revenues (once the EV is equipped with the hitch it will likely remain client for 10-15 years)
- Intellectual property safeguards key features and helps maintaining healthy margins

Distribution

Car dealers will play an essential role in the distribution and mounting of the tow bars on EVs and the promotion of energy modules to prospective EV clients, which will facilitate EV adoption as demonstrated above. The client acquisition cost will then reside mostly on the car maker's side.

Growth

- Our business models are very scalable once the basic structures are in place.
- Costs are mostly variable: building the Tenders or Nomads, and operating them.
- The market is global, and very large.
- Expected growth for EVs, Tenders and Nomads is well into double digits for many years to come.

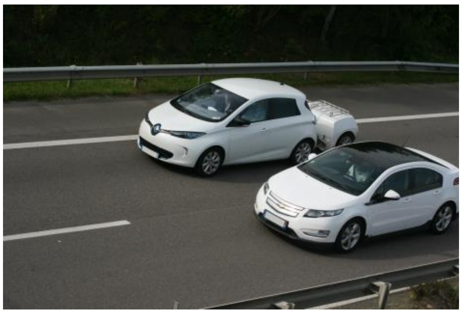
The combination of such positive features in a single business model is quite rare. We have chosen to aim high and take risks, but if our execution is right, both businesses could be highly successful.

6 Our vision for 2030

Cars are clean, connected, autonomous and lean. The functional economy represent a significant and growing percentage of GDP.

The typical range of a car satisfies 98% of its use cases with its on board energy storage (most often a battery).
The Tenders and Nomads are booked automatically by the EV's routing system, and join automatically the EV when it reaches the motorway for a long distance trip (virtual or mechanical link).

The energy modules are also part of the grid when not in use, and are providing energy storage or micro generation.
The cars are optimized for theirs daily usage, and are supplemented by the most suitable energy module given the infrastructure available on a long distance trip (grid charging, H2, inductive road [23], bio fuel)
The life cycle environmental impact of road transport is minimized thanks to the motorway commuting of energy modules, providing peak energy demands to EVs.



7 Conclusion

EP Tender and Nomadic Power are contributing to solving the range issue of EVs destined to the general public, in a convenient and affordable way, with great care put on safety. This innovation should significantly enhance the rate of growth of EV dissemination and prove fully disruptive.
Car makers and the stakeholders of soft mobility will benefit from supporting the joint and parallel initiatives of EP Tender and Nomadic Power.

EP Tender NOMADIC

Acknowledgments

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Authors

Jean-Baptiste Segard graduated from the Swiss Federal Institute of Technology in Lausanne (EPFL). He received the Maillefert award for research and creativity. He founded EP Tender in 2012 from his own frustration of willing to purchase an EV, but having to renounce due to rare occasional long distance trips (he now drives an EV!). He was previously a senior executive in the asset management industry.

Manfred Baumgärtner graduated with honors (summa cum laude) from the University of Konstanz and today's IMK of Karlsruhe Institute of Technology (KIT). He is the CEO of BVB INNOVATE GMBH: a leading innovation management firm in Germany - providing technical and financial engineering for disruptive technologies. Recently, he started Modular Power in order to build a category leader in energy storage - capitalizing from an innovative modular battery providing AC and DC without any AC/DC inverters.