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Impact Assessment on Environment, Economy and Society

VDI / VDE
Innovation + Technik GmbH
Steinplatz 1
10623 Berlin

Contact Person:

Pietro Perlo
pietro.perlo@gmail.com

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WP 4 – Strategic Advice FEV

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Pietro Perlo[1]

1 Introduction

Electro-mobility is a very fast moving competing research and industrial context, the speed and dimensions of the actions taken in this area by the EU Parliament, Member States and industries will have large implications on European citizens and economy; earlier than initially forecasted in the EU electrification roadmap [2].

The motivations of this work-package are:

- Describe simple to use metrics with the purpose to provide a common background to evaluate the advantages of electro-mobility over conventional hydrocarbon based motorizations,
- Present an update of the current state-of-the-art technology developments,
- Provide recommendations for concerted actions,
- Support the commitment to move as fast as possible towards electro-mobility with European technologies and productions.

The report is structured in a first synthetic chapter that summarizes the main findings and five specific appendices:

- Electrical Vehicles: CO_2 emissions "In–use"
- Energy consume and GHG emissions in the production of cars
- Li-ion batteries
- Market evolution of road electro-mobility
- The environmental impact of Natural and shale gas

[1] Interactive Fully Electrical Vehicles
[2] http://www.green-cars-initiative.eu/public/documents/Roadmap%20Electrification.pdf

There is a need to emphasize and further disseminate the advantages related to electro-mobility, this will allow to quickly respond, and make the life more difficult, to the never ending opposing parties that, by acting thought non-technical publications, have a deleterious impact on citizens and decision makers when arguing on: Scarcity of resources (lithium, copper, cobalt..) – High cost of batteries - Safety aspects of batteries (explosion and fire) - High energy to produce batteries – Higher GHG emissions - Inadequacy of the electrical vehicle to satisfy people's need – Electromagnetic emissions – Generation of employment in other countries etc.

The study has been approached and assessed by interrelating technology achievements and roadmaps, environment, society and economy with facts before statements, aware that the interests in play and the complexity of the topic are such that, the findings and the conclusions, could be opposed well above the physiological background.

2 Benefits

2.1 Environment

Technologies related to electro-mobility evolve very fast and the challenge is to find representing data to consider a vehicle's whole life cycle, **in terms of the global carbon footprint as well as the energy mix needed to produce it (impacting on vehicle's production cost).**

The result of the life cycle assessment of a typical passenger vary depending on segment and lifetime mileage; even with peer review and sensitivity analysis, LCA results from different studies can still be significantly different depending on input data sets and assumptions.

Ideally, LCA of the vehicle end-of-life should consider the logistics, energy and processes required to dispose of the vehicle. The end-of-life vehicle directive [3] is encouraging re-use and recycling of automotive components, which should help to reduce the environmental impact of disposal.

An accurate analysis requires the definition of the energy mix of the nation where the production is made, hypothesis on the level of recyclability of materials, the exact composition of the battery cells

[3] The ISO 14040:2006 outlines the general principles while the 14044: 2006 is the guide for practitioners. Environmental product declarations (EPDs) are defined by ISO 14025. An EPD must be based on a product LCA, Use Product Category Rules (PCR) for the relevant product type, and be verified by a third party. An international standard for carbon footprint is currently under discussion ISO 14067.

and the availability of data regarding the energy needed to operate a modern manufacturing plants of batteries, however qualitative but useful simplified comparisons are possible.

With the current state-of-the-art technology a life cycle analysis should be made adopting specific criteria starting from the selection of **vehicle size** and **mission**.

Electro-mobility would benefit from the introduction of a directive that would establish a new metric based on the global GHG emissions calculated by a LCA over the overall end-of-life, and including the production of the fuel (liquid, gaseous or electricity) from the search of the well to the point of use.

The more detailed the LCA the more evident is the advantage of electro-mobility over combustion based technologies in terms of both the overall GHG emissions and primary energy use.

a) Primary Energy Savings

In the EU-27, 73% of all oil (and about 30% of all primary energy) is consumed by the transport sector [4], due to the EU's growing dependency on primary energy this parameter is particularly relevant.

Neither first generation bio-fuels, nor third generation ones (algae), have proven to have a Life Cycle positive energy balance and appear to be inadequate solutions to the challenges posed by oil. Whilst cellulosic bio ethanol (second generation bio-fuels), although having a rather positive energy return, needs to be further developed before it can meet cost parity with petroleum based fuels [5,6,7,8,9].

"*Infrastructure requirements of the individual alternative fuels are very different, with regard to technological challenges, cost, complexity, coordination requirements and administrative implications. Investments for the development of infrastructure take time, which is even more*

[4] J. Potočnik, Making the European transport industry "greener, safer and smarter" to boost our industrial competitiveness, Transport Research Arena Opening Ceremony, Ljubljana, 21 April 2008 (SPEECH/08/211).

[5] D.V.Spitzley, G.H.Keoleian Report N0 CSS04-05R 10, February 2005 , H.T Odun, Environment, power, and society, New York, Wiley interscience, 1971 and "Energy, Ecology, and Economic" AMBIO, Vol.2, pp.220-227, 1973.

[6] http://nextbigfuture.com/2007/08/comparison-energy-returned-on-energy.html

[7] http://en.wikipedia.org/wiki/EROEI, and Cutler J Cleveland "Ten fundamental principles of net energy",

[8] Gerd Klöck, Professor of Bioprocess Engineering, University of Applied Sciences, Bremen, Germany. It's the process, stupid. Biofuels from microalgae are not yet sustainable. In response to a request of the European Commission. January 6th, 2010.

[9] "Energy, Ecology, and Economic" AMBIO, Vol.2, pp.220-227,1973.

evident in the case of CNG and L-CNG stations where investments are at least five times higher than for conventional liquid fuels. More established NGV (Natural Gas Vehicle) countries needed more than 15 years to develop the infrastructure of today. In total there are around 3.000 refuelling points (public and private) in the EU and EFTA countries, of which 2.300 are public. Of these, 2.000 public refuelling stations are based in Austria, Germany, Italy, Sweden and Switzerland alone. So far there are 23 stations that are equipped with the LCNG technology, mainly in UK and Spain (as of June 2011)" [10].

Further improvements of Internal Combustion Engines ICEs are possible; considering the time needed to reach the current efficiency values and the theoretical limit imposed by the Carnot cycle, an average 5% improvement in the peak efficiency could be possible by 2020 (supposing the investment will proceed as in the past), but that will not meet the challenge posed by liquid fuels of which world demand is supposed to grow on average 1.3% per year until 2035 [11].

On the contrary, petroleum contributes less and less to the EU electricity generation mix with a rapidly decreasing share currently at around 3.0% [12]. Electrical mobility alleviates the ever increasing EU critical imports of petroleum as well as the use of biofuels whose production cost, until the net energy balance remains low, will for many years be strictly related to the price of oil.

The requirement to develop costly and time consuming new infrastructures for liquid or gaseous hydrocarbon fuels is motivated by the need to provide an alternative to the critical supply of oil. However, the most energy saving, cheapest and easiest to deploy method is moving towards technologies that do not require liquid or gaseous hydrocarbon fuels, that is, electro-mobility! The opposite would be to invest on conventional thermal motorisations, whose decline in Europe is signed, in fact all parameters indicate that EU sales of ICEVs will continue to diminish at a faster rate than that already registered in the last four years [13].

On the basis of the current state of-the-art, the comparison of the overall primary energy consumption of FEVs and ICEVs may lead to opposing conclusions in relation to the vehicle type and its mission (speed, range, use..). An appropriated comparison requires both a classification of the means per their mass and the definition of the mission.

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[10] Infrastructures for alternative fuels, Report of the European expert group on future transportation fuels, December 2011.

[11] EIA, International energy outlook , July 2010

[12] Eurostat 2010, and www.ewea.org

[13] Source ACEA, 2012

High speeds (>140kmh) and long range (>300km) in a single charge cannot be addressed with cost competitive electrical vehicles adopting the current technology. *Under these missions EVs are likely not to be able to be cost competitive with ICEVS for another decade.*

City cars (650-1000kg), small cars (1000-1300kg), mid-sized (1300-1500kg) and large ICEVs so far have been offered to satisfy high speeds, long range and the need of urban mobility. But ICEVs suffer the problems associated to liquid or gaseous hydrocarbons: dependency to foreign primary energy, noxious emissions, and high GHGs emissions. The population living in urban areas is continuously increasing, 80% of Europeans live in large cities, the great majority of people move less than 20km a day, and 80% of daily trips made by cars in Europe are less than 60km [14]. Most drivers experience high speeds and long range only occasionally and can accept one or even two fast recharges during the same trip the few days of the year they need to travel longer distances. The possible inconvenience they could experience in those days is largely justified by the great benefits obtained the rest of the year.

For most of the urban missions ICEVs cannot compete with FEVs [15].

The choice of a reference car with a mass of 1300kg, with batteries allowing a range of 150km with a single charge in a New European Driving Cycle NEDC (max speed 120km/h) is largely justified because it represents the majority of uses where ICEVs and FEVs will compete all along this decade. A comparison in a 5 to 15 years perspective can be made, with a good degree of confidence, depending on the applied rate of change on technological evolution, including the mix of energy sources and the specific energy of batteries.

For vehicles of this class, the operation of a Full Electric powertrain with the current state of-the-art of automotive battery packs close to 180Wh/kg, the primary energy savings is the order of 25% [16] reflected in a radical cut of the petroleum used.

Although the electrical powertrain is always referred for its efficiency, it is far less than a mature technology, for instance the forthcoming multi-ratio transmission gear boxes integrated in electrical

[14] Gonzalo Hennequet, Mass Production of EVs: The Technological Challenge of RENAULT, Auto e-motion conference, 27 September 2011, Graz, Austria

[15] Most large OEMs seem to be aware of the new demand proposing e-bikes, motorcycles and LEVs of various kind having no rivals amongst ICEVs. See the note on: *cars21.com.* Urban mobility: small, light and electric, the way to go! 2011-09-28

[16] http://www.green-cars-initiative.eu/public/documents/Roadmap%20Electrification.pdf

motors, when compared to single transmission ratios, can lead up to 20% energy savings in urban ECE15 cycles [17].

Extending the analysis to vehicle manufacturing, amongst the total 85-90 GigaJoules of primary energy needed to manufacture a mid-sized ICEV [18], about 35-38 GigaJoules are required to produce the powertrain system (engine-transmission-exhaust systems-fire protection and noise reduction systems).

Although the comparison, through a LCA analysis, could be only qualitative, for less than 1000kg vehicles with ranges up to 150km in the NEDC cycle, the production phases of gasoline and electrical powertrains require the same energy and have equivalent CO_2 emissions (**Appendix II**).

In this regard it should be noted that battery technology is evolving very rapidly, the energy needed to produce 1 kWh of battery capacity is halved every five to six years and since the commercial advent of the Li-ion battery the energy needed to produce 1kWh of capacity has been reduced to 1/10th [19,20,21,22].

By 2020, with battery cells expected to double the current specific energies, already above 280Wh/kg, the manufacturing of FEVs will lead to considerable energy savings. In a 15 year term, FEVs are expected to meet both ranges and speeds of larger size ICEVs, but their manufacturing requirements will use as much as 25-30% less energy than that required by equivalent Plug-in Hybrids.

b) Reduction of Greenhouse Gas (GHG) Emissions

[17] Stefano Bertolotto, Ian Morrish 2-Speed Electric Vehicle with Seamless Gearshift System, 9th International CTI Symposium Innovative Automotive Transmissions and Drive Trains, Berlin, 29 November – 2 December 2010

[18] Hidden cost of energy: unpriced consequences of energy production and use. WW.NAP.EDU/catalog/12794.html, pag 154-210.

[19] Dominic A. Notter, Marcel Gauch, Rolf Widmer, Patrick Wager, Anna Stamp, Rainer Zah, and Hans J.Orgalthaus: Contribution of Li-Ion Batteries to the Environmental Impact of Electric Vehicles *Environ. Sci. Technol June 16, 2010.* Paper and support information at http://pubs.acs.org/doi/suppl/10.1021/es903729a - data received directly from the principal author Dominic Notter: "*1 kg battery needs 104 MJeq while 1kg battery contains 114Wh (8.8 kg battery/kWh). This results in about 250 kWh of energy per kWh of battery capacity*".

[20] J. Matheys et al, Life-Cycle Assessment of Batteries in the Context of the EU Directive on end-of life Vehicle, International Journal of Vehicle Design, Vol. 46, No. 2, 2008

[21] C. Samaras, K. Meisterling, Life cycle Assessment of greenhouse Gas Emissions from Plug-In Hybrid Vehicles: Implications for Policy. Environmental Science Technology, 42 (9), 3170 (2008)

[22] C.J. Rydh, B.A. Sanden, Energy Analysis of Batteries in Photovoltaic Systems: Part I Performance and Energy Requirements, Energy Convert. Manage, 2005, 46 (11-12), 1957-1979

Clearly the convergence of renewable energies (RE) and electrical mobility is the most appealing. The EU-27 is paving the way for RE to achieve over **90%** of new power installations before 2020 [23]. In the EU, the transport sector causes 26% of all GHG emissions due to human activities [24], furthermore, it is the fastest growing source of greenhouse gases, and of the total from transport, over 85% are due to CO_2 emissions of road vehicles. Therefore, they are considered a major sector to target for a limitation of GHG emissions [25].

The fleet average tailpipe **CO_2** target [26] is encouraging to develop low carbon technology.

The introduction of battery packs, electric motors and power electronics into a car increases the embedded CO_2 emissions associated with the vehicle's production, while significantly reducing the tailpipe CO_2 emissions from the use phase. This leads to a shift in the life cycle balance between production and use phases.

The differences between conventional mobility based on internal combustion engines (ICE) and EV in terms of CO_2 emissions, reflects the EU mix of electricity generation. With fossils generating about 50% of the total electricity produced, renewable energy at 23.5% and nuclear at 26.5%, the European average CO_2 emission of electricity produced in 2010 is in the range of 340-360g/KWh [27]**.** As a consequence, considering detailed LCA analysis including production, in use and disposable, for the typical mid-size FEV vehicle of reference, the total CO_2 emission is just half of the equivalent ICEVs (**Appendix I**). In a 2020 perspective, with a likely EU share of renewable electricity at 40%, the total CO_2 emission of FEVs will continue to be half or less of the planned 2020 fleet target at 95g/km [28].

The current metric for comparing the GHG emissions of European passenger cars is based on measuring the tailpipe **CO_2** emissions over the New European Drive Cycle (NEDC) with that the analysis does not consider the impact on the environment during the fuel extraction and delivery before the tailpipe.

The example of natural gas motorizations is particularly evident; from the point of view restricted to the emission of the NG engine the expectation is "*CO_2 saving of about 3% versus diesel vehicles, and saving up to 8% of the next generation of NG heavy engines improved the with inlet valves'*

[23] www.ewea.org and www.epia.org
[24] Implementing the Recovery Act, www.epa.gov , 17 April 2009.
[25] Implementing the Recovery Act, www.epa.gov , 17 April 2009
[26] COM(2009) 593, 28.10.2009
[27] Eurostat 2010, and www.ewea.org
[28] COM(2009) 593, 28.10.2009

electronic control"[29]. **Very different is the result of the full Life Cycle Analyses of methane motorisations for which GHG global emissions are twice those emitted by gasoline and diesel motorizations (Appendix V).**

As one of the EU's key laws on climate change the European Commission has published a paper analyzing the impact on individual EU countries of a move to a 30% carbon cutting target by 2020. The paper concludes that lower income EU countries could benefit the most from moving to 30% mainly by increasing national revenue from the Emissions Trading System (ETS) – by as much as 80% [30].

c) Reduction of noxious emissions (raising public health)

Road transport remains the main source of many local noxious emissions including benzene, 1,3-butadiene, carbon monoxide (CO), nitrogen oxides (NO_x) and particulate matter (PM). There is a growing body of evidence linking vehicle pollutants to severe health problems such as respiratory and cardio-pulmonary diseases and lung cancer [31,32]. In general, according to the World Health Organisation, the emissions from car exhausts are responsible for more deaths than road accidents [33,34]. The problem is growing with an ever increasing cities with PM values exceeding several times the suggested limits many days of the year [35]. Radical solutions like the closure of city centres or the ban of old diesel cars, 4X4s and trucks are becoming more and more popular [36].

EVs can contribute to the elimination of the side effects which are due to the local hydrocarbon combustion in conventional vehicles. Furthermore the PM_{10}, SO_2 and NOx emissions occurring during power generation are being continuously reduced because of the increased share of both natural gas and the rapid growth of Renewable Energy with respect to coal.

[29] Infrastructures for alternative fuels, Report of the European expert group on future transportation fuels, December 2011.
[30] http://ec.europa.eu/clima/policies/package/docs/staff_working_doc_2012_en.pdf
[31] Air quality and health, Fact sheet N°313, Updated September 2011
[32] http://en.wikipedia.org/wiki/Air_pollution
[33] Health effects of transport-related air pollution, Michaĺ Krzyżanowski, Birgit Kuna-Dibbert, Jürgen Schneider WHO Regional Office Europe, 2005
[34] http://www.huffingtonpost.com/2008/11/13/california-air-pollution-_n_143521.html
[35] Polluted Cities: The Air Children Breathe, 11airpollution, WHO
[36] http://edition.presstv.ir/detail/156874.html

2.2 Economy, Society, employment

The numbers of the automotive sectors are impressive [37]:

- 2.3 million direct jobs and another 10.4 million in directly related manufacturing and other sectors,
- An output of over 17 million passenger cars, vans, trucks and buses per year (25% of worldwide vehicle production),
- Net auto exports of € 57 billion,
- An annual turnover of € 500 billion (Acea members only),
- The auto industry is the largest private investor in R&D in Europe.

With of about 500 (Italy 700) cars every 1000 inhabitants [38], the increase of the number of cars on EU roads is very unlikely, similarly, lifetime (8 years) and the replacement rate of cars, depending very much on the general economic wealth, confirm the tendency of the last four years towards lower registrations.

For the automotive companies the challenge is to face the evolution of road mobility of people considering: different forms of private and public transportation, implications on health, noise pollution, congestion and closure of city centres, availability of resources (primary energy and materials), climate change, technology evolution and competition.

The demand for new forms of mobility is spreading all over the world, reflecting peoples' awareness of the ever increasing problems of providing primary energy and raw materials, congestion, climate change and impact of noxious emissions on health. Rather than offering vehicles on ever increasing prices, the industry is asked to satisfying a rational demand of mobility. Clean, safe and low energy consumption vehicles requiring less energy to be produced, using recyclable and eventually self-disposable materials-systems.

The sales growth of e-bikes, e-scooters and new form of vehicles weighting less than 700kg, combined with traffic restrictions on large cities, will have a considerable impact on the overall volume of non-electrified vehicles[39] (**Appendix IV**). **Because the total km run by people will change only minimally, the 2020 share of the km run by vehicles adopting internal**

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[37] www.acea.be The automotive industry pocket guide 2011.

[38] http://en.wikipedia.org/wiki/Motor_vehicles

[39] Most large OEMs are aware of the new demand proposing e-bikes, e-scooters and LEVs of various kind having no rivals amongst ICEVs. Urban mobility: small, light and electric, the way to go! 2011-09-28. *cars21.com*

combustion engines is likely to decrease 30% (conservative) from the 2010 value. The consequences on employment and the EU general economy can only be mitigated by increasing the investments on electro-mobility.

3 Challenges

a) Range and Speed

Anywhere there has been a trial to test EVs, the response has been very positive, range anxiety disappears after few months of ownership [40,41]. With an EU demand far exceeding the offer, the challenge is to generate the conditions for adequate manufacturing volumes of vehicles and related enabling technologies in Europe.

For that it is suggested to keep the R&D focus on FEVs less than 1300kg for the following reasons:

- Speed up applications for the dominating and growing size of urban mobility by focusing on critical technologies,
- The 2020 perspective for much higher specific energy of battery cells is expected to assure affordable FEVs that in a single charge would be able to cover ranges up to 300km even at speeds of 120kmh,
- The ICT related R&D technological development made for FEVs will anyhow be beneficial for all kind of FEVs and Plug-in Hybrids.

b) Cost of Technology and Constraints on Raw Materials

Cost and supply constraints of battery packs are acknowledged to be the most limiting factors for a wide scale introduction of electric vehicles. All together, the available information confirm that **cost targets** for the installation of automotive battery packs **and technology evolution** can converge at 200€/kWh well before 2020 **(Appendix III).**

As soon as the OEMs will get used to the technology, there are no reasons why the overall installation into the vehicle would cost more than 200€/kWh. In few years, battery costs will not be any more the major issue; the driving factors for the OEMs will be the optimisation of the energy power supply at a systems integration level and as a structural element.

[40] http://www.treehugger.com/cars/range-anxiety-versus-reality-why-evs-havent-won-our-hearts-and-minds.html

[41] http://www.greencarreports.com/news/1070076_chevy-volt-electric-car-owners-most-satisfied-consumer-reports-says

Substantial reservations remain about the long-term performance of Li-ion, however, commercial EVs like the Nissan Leaf and the Plug-in Chevrolet Volt are both sold with **battery packs covered by an eight-year/160,000-km warranty**.

The launch of new production facilities announced from the beginning of 2010 to mid-2011 is going to change the relation between production and demand in short. The Nissan-Renault alliance has announced a global production capacity of 550,000 battery pack per year by 2013, of which 220,000 in Europe only [42]. The spread of production facilities is such to raise the first concerns on a possible over supply of battery packs starting from 2015 [43].

Public institutions, OEMs and suppliers are accelerating their efforts experimenting demonstration car-fleets in many large cities with the purpose to gather data, define best practices and justify the widespread commercialization of electro-mobility. This will further motivate the adoption of FEVs fleets and spread the awareness of the benefits of electro-mobility in cities. It is expected that before 2015 most OEMs will be selling electrical vehicles below 1000kg in weight, and in the hypothesis that 12-17% of this class of vehicle will be demanded to be electrical, by 2015 the European market will demand 1.1-1.3 million battery packs. However, the limited offer of the European OEMs due to: reduced engineering and specific design experience - reduced vehicles experimentation on the road - critical supply of battery packs consequence of the lack of initiatives to start large scale risk sharing manufacturing plants on batteries - speed to implement regulations, may delay the first large sales of European made FEVs. Starting from 2015 the EU production could reach 370,000-550,000 FEVs (3,0-4,5%) out of the 12-13 million total car EU sales [44] (it is here worthwhile noticing that in Europe 17% of the vehicles are sold to public institutions [45]).

The booming of Light Electrical vehicles (<500kg) and the growing integration of battery packs in both small and large renewable energy installations will be such that batteries will not be available in adequate volumes during the regulatory compliance 2012-2015 period. Even insufficiently proven Li-ion batteries will continue to be subject to daunting cost and supply constraints. In a nutshell, in the context of the current OEMs-TIER1s 2011 alliances, cost and supply constraints will leave the HEVs, Plug-in HEVs, EVs and LEVs markets in a critical state of flux until at least

[42] Gonzalo Hennequet, Mass Production of EVs: The Technological Challenge of RENAULT, Auto e-motion conference, 27 September 2011, Graz, Austria

[43] PRTM Analysis Finds Li-ion Battery Overcapacity Estimates Largely Unfounded, with Potential Shortfalls Looming; Total Market Demand in 2020 Will Require 4x Capacity Announced To Date, http://www.greencarcongress.com/2010/03/prtm-20100322.html, 22 March 2010. And Advanced battery technology: Region's capacity growing as fears of overcapacity mount , 19 December 2011 http://www.mibiz.com/news/energy/19140-advanced-battery-technology-regions-capacity-growing-as-fears-of-overcapacity-mount.html

[44] Gonzalo Hennequet, Mass Production of EVs: The Technological Challenge of RENAULT, Auto e-motion conference, 27 September 2011, Graz, Austria

[45] http://www.green-cars-initiative.eu/public/documents/Roadmap%20Electrification.pdf

2017. The expectation being that technology and cost evolutions could soon lead European OEMs and Governments to consider the start of plants capable to produce battery packs with a comparable output to those producing Internal Combustion Engines (~500,000 engines per year).

From the 130,000 tonnes estimated consumption of lithium in 2011 the forecast of the high case scenario is for 500,000 tonnes demand by 2020. Future growth is seen in a jump in demand from grid storage and in the solar power generation sector [46]. The proven reserves of Lithium are far above the future needs of the transportation industry [47].

The second large source of uncertainty is related to the availability of reliable and diversified supplies of metals, e.g. copper and permanent magnets that are necessary to assure high efficiency and high power density (compact) electrical motors. Per a fixed range, 1% increase in the efficiency of the electrical motor is reflected in a typical 1,5% decrease in weight of the battery pack. An increased cost for a more efficient motor is amply balanced by the reduction in weight and cost of the overall powertrain. While at a research level several solutions are pursued, it seems there will be no viable industrial alternative to NdFeB for at least another decade. The price of permanent magnets of all grades has grown exponentially from mid 2009 to mid 2011 (4 to 7 times in relation to the grade), but even more critical is that the production of PM motors is more and more constrained to be made in China. The move from scant and critical sources of oil to a likely even more critical single source of permanent magnets should urgently address the development of both new high efficiency motors using limited weight of permanent magnets and completely new motor designs. Like for the batteries, the production of low cost, efficient and compact motors using permanent magnet technology will not be available in adequate amounts and will be subjected to supply constraints for several years. China currently produces more than 95 per cent of the world's rare earth metals and has recently revealed its intention to limit exports, fearing depletion of its natural resources. Several manufacturers use rare earth magnets in their synchronous motors, but there are other options which work rather well. The induction motor does not require rare earth metals. It is also possible to use a variable switched reluctance motor that does not use rare earth metals. Although VSR motors do have problems, they can be resolved. Moreover, VSR motors do not have the temperature limitations that are caused by rare earth metals. Also, rare earth metals are

[46] Lithium Supply and Markets Conference Highlights, http://www.prnewswire.com/news-releases/new-america-energy-provides-summary-of-lithium-supply-and-markets-conference-highlights-138475584.html, Feb. 1, 2012.

[47] Jan Tytgat, Umicore, Report on Joint EC/EPoSS/ERTRAC Expert Workshop 2011 "Batteries and Storage Systems for the Fully Electric Vehicle" held in Brussels on 7 December 2011.

mechanically weak thereby limiting speed and power. So actually, by running them much faster, VSR motors could be made smaller and lighter than motors using rare earth metals.

China's hesitancy has forced hybrid manufacturers like Toyota into overdrive to find alternatives to rare materials [48], the production plans announced by Renault [49] and Volkswagen in Europe are in the same direction.

Whether using motors with or without permanents magnets, lots has still to be made to enhance the efficiency of the overall powertrain. When thinking and designing at a systems integration level, that is, battery-inverter-motor-transmission designed as a whole to optimise the figure of merit of the full electrical powertrain, the limitations set by the availability and cost of permanent magnets can be radical reduced.

Europe should consider its own way of focussing on the areas (ICT) that would allow its industry to compete without or with a minimum use of exotic critical materials.
The issues of batteries, motors, and the scarcity of crucial materials, threaten the large scale introduction of electrified vehicles as they are hampering the enormous and crucial economic and environmental benefits that EVs can provide. The industry is responding with appropriated solutions.

4 Recommendations

4.1 EU Targets by 2020 and 2025

EU met its 2010 Renewable electricity target – and is now aiming to establish what to achieve by 2030 [50]. Considering the advancement of the technology it is now evident that the move to electrical mobility is the most cost effective way to cut both GHG emissions and oil dependency.

Targets have to be ambitious and not necessarily agreed by all Member States (as it was for renewable energy), the suggestion is to set objectives per categories keeping in mind that from 2015

[48] http://www.caradvice.com.au/156331/toyota-finds-alternative-to-rare-earth-metals-for-hybrids-report/
[49] Electric Vehicles: EIB Lends EUR 180 Million To Renault Group. Source: European Investment Bank 16 January 2012 , http://www.egovmonitor.com/node/45391
[50] www-ewea.org, "A strategy for the deployment of renewable energy beyond 2020 will be developed to offer stability for the longer term." President of the European Commission **Barroso** promises a new strategy in 2012 in a letter to the European Parliament and "We want to establish what must be achieved by 2030" EU Energy Commissioner **Guenther Oettinger** on cutting carbon emissions .

new car models weighting less than 1000kg (>50% of the global sales) will be designed starting from the fully electrical option.

The more ambitious the targets the higher the manufacturing of EVs in Europe, and the lower the consequences due to the decline of conventional motorizations.

4.2 New directive for Life Cycle Analysis

Because there are no specific CO_2 targets for the production of the whole vehicle the possible recommendations–actions-scenario could be [51]**:**

- Priority funding for the main alternative fuels,
- CO_2: Internalise cost; cap on CO_2 intensity for fuel mix,
- Efficiency standards for all vehicles beyond 2020,
- Infrastructure: EU-wide build-up for the main fuels,
- Low emission requirements for urban traffic,
- Access privileges for clean and energy efficient vehicles,
- Revision of energy taxation Directive: introduce CO_2 tax,
- CO_2/energy efficiency Regulation for Heavy Duty Vehicles,
- Tighter CO_2/energy efficiency Regulations for passenger cars,
- Refuelling/recharging infrastructure: build-up, standards,
- Labelling of CO_2/energy efficiency in a revised Directive.

And

- Consider the introduction of a directive that establishes a new metric based on GHG emissions emitted during vehicle production,
- Consider targets aimed at reducing the life cycle $\mathbf{CO_2}$. For example:

[51] Franz Söldner European Commission Directorate General for Mobility and Transport "Towards a European alternative fuels strategy,15th AMAA Forum, Berlin, 29 June 2011"

- Cap on production **CO_2** dependent on vehicle segment,
- Reduction target for production of life cycle **CO_2**, compared to an appropriate baseline,
- Maximum payback period for trading increased embedded emissions against reductions in tailpipe/TWW **CO_2** emissions.

❑ Consider the fiscal and regulatory framework in which vehicles are sold, used and disposed (allocation of incentives).

Further work is required, engaging with OEMs, LCA practitioners and vehicle drivers, to close the gaps in life cycle understanding. Amongst the actions to address are:

❑ Open a new dialogue with other vehicle manufacturers aiming at a common LCI dataset to be used by the automotive industry and aiming at evaluating the impact of different in use assumptions, especially around drive cycles and use of ancillary functions,

❑ Establish new forms of collaborations-relations with suppliers,

❑ Intensify the contact with LCA networks and initiatives aiming at obtaining a better understanding and modelling of the environmental impact of vehicle end of life, especially for new technologies such as electric vehicles,

❑ Investigate the variability of vehicle use to understand the range between extremes,

❑ Research vehicle end of life to understand what really happens during vehicle disposal,

❑ Make LCA part of the process: Get life cycle thinking embedded within the design process; allow LCA results to drive reduction in both costs and CO_2 foot print.

4.3 Coordinate actions on power electronics and batteries

Europe produces 6% of the electronic manufactured worldwide against a 30% consume; with a share diminishing 1% a year, the perspective is to end the production of electronics by 2018 [52].
European semiconductor companies are growing in other regions of the world moving the plants closer to the production sites of their customers. Pilot plant initiatives, conjunctly coordinated by ARTEMIS, ENIAC, FP7 and the European Investment Bank, would assure the necessary critical mass and contribute to turn the tendency **to manufacturing back in Europe**.
In a quickly evolving technology context, the start of **risk sharing manufacturing plants** in power electronic and battery cells would represent a novelty. As per the targets set on renewable energy, there is a need for a proactive coordination of the Commission.

5 Vision, Milestones and Roadmap

The first version of the electrification roadmap, published September 2009 jointly by the ETPs ERTRAC, EPoSS and Smart Grid, addressed in quantitative terms the benefits associated to primary energy saving, reduction of noxious emissions and reduction of GHGs. Starting from the existing technologies and the running programmes known, the roadmap has forecasted technology evolutions and the impact on the market with a focus on mid-sized cars. The adoption of the roadmap as a reference of the PPP Green Car Initiative, national programmes all around Europe, Eniac and Artemis JTIs has led to large programmes with strict collaborations amongst OEMs, Tier1s, silicon foundries and public institutes. The results achieved in only few years **are impressive**, most technical milestones have been anticipated putting the European industry in a leading position to satisfy the first large demand for new forms of mobility spreading all over the world, reflecting peoples' awareness of the ever increasing problems of providing primary energy and raw materials, of climate change and of the impact of noxious emissions on health.

It is now evident that **electrical mobility is much more than the electrification of conventional cars**. Rather than offering forms of mobility based on ever increasing prices, the industry is now faced with satisfying a rational demand of mobility. Clean, safe and low energy consumption vehicles, requiring less energy to be produced, and using recyclable and eventually self-disposable materials-systems.

E-bikes are evolving to larger LEVs, micro-cars and city cars proving that the large scale deployment of electrical means is following a step-by-step approach starting with small vehicles,

[52] Source: Eniac office, www.eniac.com

covering at most urban mobility and offering new solutions to the difficulties encountered by thermal engines (clean ICEV requires costly and complex catalytic architectures and their radical downsizing implies a reduced overall efficiency. As a consequence it is difficult to design new clean, safe and low cost small ICE Vehicles).

European automotive companies are faced **to new and novel vertically organized supply chains** competing with large nations where regulations are made by fast acting Governmental Institutions. In the past regulation has sometimes been used to protect indigenous industry and hinder foreign competition. However if non-European companies are quicker and better at responding to new rules and regulations than European based companies then this could act against them.

This is having, and will have, an ever increasing impact on the relations amongst Tier1-2 suppliers and OEMs, leading to heavy industrial restructuring. **The introduction of these new forms of mobility is driven by new players acting much faster than what large OEMs are used to**. European institution and industries are asked to managing the effects caused by this radical change of the supply chain, adopting quickly and properly sized competing instruments that could avoid the move of European productions in other more appealing regions of the world.

The technology achievements obtained in few years only, suggest the setting of ambitious 2020-2025 targets and the planning of the necessary roadmaps to meet them.

Appendix I

Electrical Vehicles: CO_2 emissions "In –use" **

Principal findings

- A simple to adopt metrics to calculate the CO_2 emissions of the "In–use" phase is reported,
- In the EU-27 Member States the CO_2 emissions of the "In–use" phase of Electrical Vehicles **are currently half** of those emitted at the tailpipe of the best Internal Combustion Engine Vehicles,
- Anywhere in the world, independently of the energy mix, electrical cars produce less "in use" CO_2 emissions than equivalent ICEVs.

1 Description of the metrics adopted

The computation of the CO_2 emissions of an "in use" electrical vehicle is reported in this appendix thinking there is a need to adopt a simple common methodology to avoid misleading numbers and interpretations.

From the plug to the wheel, taking into account all blocks of the powertrain, quite extensive tests on real drive cycles, including highways and lights always on, have demonstrated the following consumes:

- Nissan Leaf of mass 1521 kg: **150Wh/km**,
- Mid-size converted electrical vehicle of mass 1300kg: **130Wh/km,**
- Delivery van converted electrical vehicles of mass 1600kg: **180Wh/km**,
- Born electrical vehicle of mass 650kg: 70Wh/km (limited test avoiding highways with light off).

At Bibendum 2011 Renault and Michelin have demonstrated that the consume of a mid-size vehicle could be in the range **125Wh/km**.

On the base of real measurements, we can assume, with a good degree of confidence, that from the plug to the wheel, a **mid-size born electric car** consumes 130Wh/km. Consequently, per every kWh of electricity produced in a power plant an EV runs:

1000 Wh **x 0.92** average EU-27grid efficiency x **0.97** efficiency from plug to battery x **0.9** efficiency of battery/(130Wh/km) = **6,2 km**

The real efficiency of the battery is typically close to 95% while the efficiency of the grids of the largest EU countries is higher than 92%, for instance the efficiency of the Italian grid is 93,6% (www.terna.it). That is, the hypothesis made on energy consumes, on efficiency of the grid and battery efficiency are all **conservative!**

Let's consider three countries of reference: Italy because having emissions very close to the EU-27 average [53], USA and China whose energy mix is very often put in relation with the GHG impact of electrical mobility.

1) **Italy 2010:** Terna 2011 data [54]

- Renewable 22,2% of the total (average emissions 40grCO_2 /kWh) [55]
- Natural gas 45,4% (400grCO_2 /kWh)[56]
- Other fossils: petrol 3,2%, coal and woods 10%, other fuels 5,1% (average emissions 700grCO_2/kWh)
- Imported mainly nuclear 13% (average emission 120grCO_2/kWh)[57]

Overall average in Italy 2010 (22,2x40+ 45,4x400 +18,3x700 +13x120)/100= 334grCO_2 per kWh produced.

With an average 334grCO_2/kWh and 6,2km per each kWh produced in the plants the emission of a mid size electrical vehicle is:

[53] EU met its 2010 Renewable electricity target at 21%: EU Share of renewable electricity to total electricity consumption 2008 (16.4%), 2009 (18.2%), 2010 (21.2%), *2011 (23,5%)*, 2020 (36.4%), 2030 (51.6%). Source European Wind Energy Association EWEA, www.ewea.org. The official data of Terna and Eurostat for the 2011 are still not available, the 23,5% is a conservative estimate on the base of the remarkable growth registered in Germany, Italy and several other EU countries.

[54] www.terna.it

[55] Most LCA studies demonstrate that the average emissions due to renewable is more likely 25gCO_2e/kWh. See for instance the publication: A guide to life-cycle greenhouse gas (GHG) emissions from electric supply Technologies Daniel Weisser PESS / IAEA. Revisions available directly from d.weisser@iaea.org

[56] The 400 gCO_2 /kWh value most often taken as a reference in LCA studies does not reflect the real values which are much higher. To be more correct it should be considered the GHG impact of gas leakage from the well to the plant.

[57] Total emissions from Nuclear plant are most often reported to be in between 25 - 30 gCO_2 /kWh. In this document we use 120 gCO_2 /kWh a value reported in the LCA study made by Storm–Leeuwen in 2008. That study is in our knowledge the most detailed and public. Storm van Leeuwen JW, Smith P. Nuclear power - the energy balance. Chaam, Netherlands, 2005 http://www.stormsmith.nl See also revisions Feb. 2008 JW. *Energy from Uranium* FactSheet4, http://www.oxfordresearchgroup.org.uk/publications/briefings/energyfactshee4_fullreport_2006.pdf.

Italy 2010: 334/6,2=**53,9gr CO_2/km**

The EU-27 average is 320grCO_2/kWh very closed to the Italian average, ranging from the 500gr$CO_{2\ eq}$/kWh in the UK (source: DECC 2010) to much lower values in France, Sweden, Spain. The average grid efficiency at EU-27 level is higher than 92%.

2) USA 2010: EIA annual energy outlook 2011

Electricity: nuclear 20%, renewable 10%, gas 23%, petrol 1%, coal 45%.

Overall average in the USA 2010: (10x40+ 23x400 +46x800 +20x120)/100= **492grCO_2 per kWh** produced.

With an average of 492grCO_2/kWh and 6,2km per each kWh produced in plants the emission of a mid size electrical vehicle is:

USA 2010: 492/6,2=**79gr CO_2/km**

3) CINA 2010: China Electricity Council 2011.

"Until 2010 two new nuclear plants per month and a new wind turbine being erected every hour".

China's power generation capacity reached 960 gigawatts at the end of 2010, including 700 gigawatts of thermal power capacity, 210 gigawatts of hydropower, 10.8 gigawatts of nuclear power and 31.07 gigawatts of windpower.

In 2010 China has produced 25% its own electricity with "clean sources".

China 2010: Renewable 23%, Nuclear 2%, Mix fossils 75% (most coal with natural gas growing fast)

Average China 2010: (23x40+2x120+75x800)/100= **612 grCO_2 per kWh** produced.

With an average of 612grCO_2/kWh and 6,2km per each kWh produced in plants the emission of a mid size electrical vehicle is:

China 2010: 612/6,2=**99gr CO_2/km**

By the end of 2011 renewable installations are expected to be >270GW. China's hydropower capacity may reach 220 GW, more than 14 GW of wind power and >500MW of photovoltaic capacity may be added in 2011 while nuclear power capacity may total 11.74 GW.

The earthquake in Japan will slow down the installation of nuclear power plants, likely to remain at 2% of the total. Natural gas and biomass plants are growing fast while the share of electricity produced by coal is diminishing rapidly.

2 Indirect impacts and on-board smart solar energy harvesting

- Electric vehicles are most times recharged at night using the least energy-intensive and CO_2 emitting fraction of the electricity production,
- FEVs stimulates users to generate renewable electricity; photovoltaic parking including fast recharge are becoming popular in many countries,
- On-board solar photovoltaic has been proved capable to provide the necessary energy for a small vehicle to run at 50kmh an average 20km a day in most southern EU regions.

3 Conclusions

In the EU-27 Member States the CO_2 emissions of the “In –use” phase of Electrical Vehicles are currently half of those emitted at the tailpipe of the best internal combustion engines vehicles [58].

In a 2020 perspective, the growth of renewable energies is expected to further increase the gap in CO_2 emission in between EVs and the ICEVS. Internal combustion engines are expected to improve and meet the 2020 average fleet target of 95gCO_2/km, however renewable energies are growing much faster than the improvement introduced in ICEs. Anywhere in the world, mid-seized electrical cars produce less “in use” CO_2 emissions than equivalent ICEVs.

[58] Similar findings are reported by: Chuck Shulock, Ed Pike, Alan Lloyd, Robert Rose, vehicle electrification policy study, task 1 report: technology status, Tab.13, pag.44. February 2011. www.theicct.org

Appendix II
Energy consume and GHG emissions
In the production of cars

Principal findings

- Generic comparisons of vehicles having different propulsions have little meaning if the mission and the class (mass) of vehicle are not specified,
- Technology related to electro-mobility evolves very fast: the energy needed to produce 1Wh of Li-ion battery cells is halved every five to six years, the contribute of renewable electricity at the overall EU electricity consume is increasing 2.5% year, advanced transmission multi-gear systems that allow up to 20% energy savings in the ECE15 cycle are going to be implemented only in next generation EVs,
- The result of a Life Cycle Analysis involving batteries requires a deep understanding of the process recyclability of Li-ion cells without which the comparison of different powertrain technologies would be very qualitative,
- When limiting the comparisons to vehicles satisfying most of the urban mobility needs (the largest market), and considering state-of-the-art technology, the energy needed to produce an electrical powertrain **is equivalent and most likely lower,** than that needed to produce the powertrain based on an internal combustion engine.

1 Metric to compare energy and GHG emissions in the production of cars[59]

The current metric for comparing the GHG emissions of European passenger cars is based on measuring the tailpipe $\mathbf{CO_2}$ emissions over the New European Drive Cycle (NEDC).

Legislative targets for reducing corporate fleet average $\mathbf{CO_2}$ are driving the development of low carbon technologies and alternative fuels.

The tailpipe $\mathbf{CO_2}$ metric is insufficient for comparing the environmental impact of zero and ultralow emission vehicles, such as electric (EV) and Plug-in Hybrids (PHEV), **since it does not consider**

[59] This document starts from the analysis published by Ricardo on 20 May 2011. Preparing for a Life Cycle CO2 measure. Report RD.11/124801.4 Jane Patterson, Marcus Alexander, Adam Gurr. Note: the report frames very well the topic of GHGs emission of road vehicles, we then follow the same structure and approach, however the conclusions on the total GHGs footprint of electrical vehicles and of vehicles fuelled by Natural Gas are based on misleading comparisons thus differing very much from those derived here.

CO_2 emissions resulting from the generation of the "fuel-electricity", or those embedded within the vehicle production.

There is a growing demand from consumers for information on the carbon footprint of the goods and services they purchase.

Life Cycle thinking is required to develop new measures for comparing the environmental impact of cars.

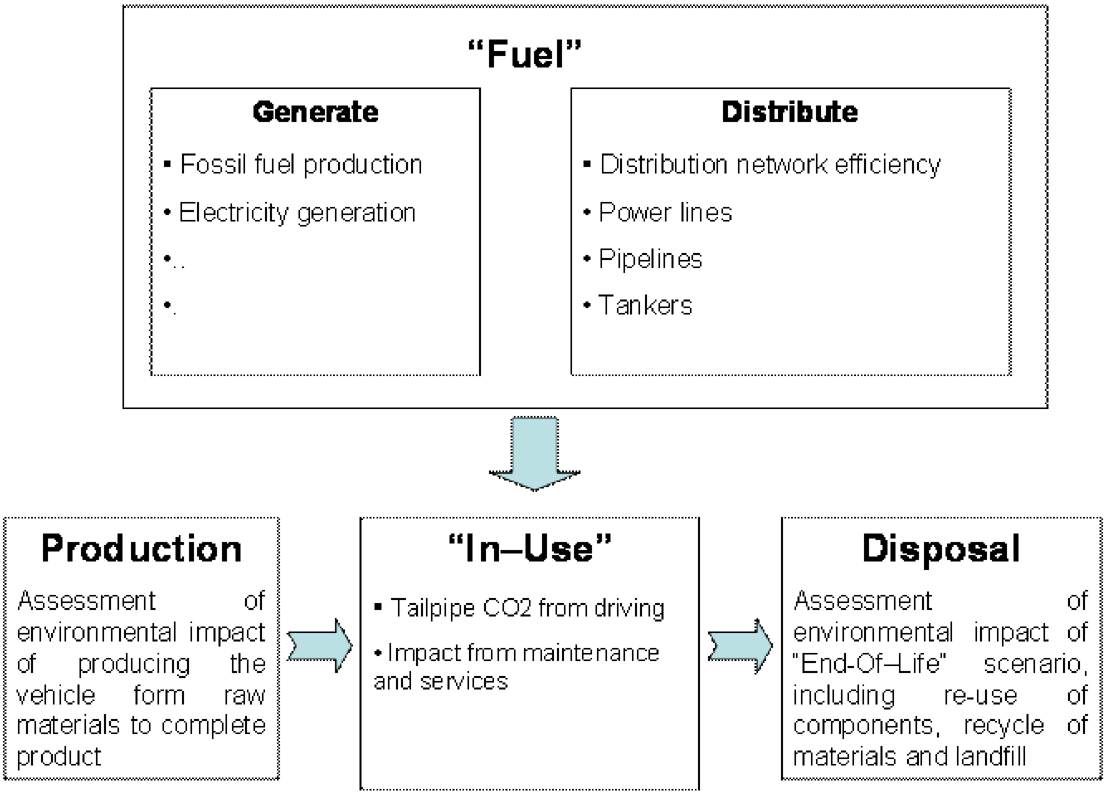
The challenges are:

- ❑ Find data representing the fast evolving enabling technologies of electrical vehicles,
- ❑ Consider a vehicle's whole life cycle, **in terms of the global carbon footprint as well as the energy mix needed to produce the vehicle (impacting on vehicle's production cost).**
- ❑ Conduct Life Cycle assessment studies as part of an Environmental Management strategy while preparing the introduction of new powertrain technologies on the base of reliable data and conforming the requirements of the ISO Standards 14040 and 14044.

The objectives to address are:

- ❑ **Strengths** (*fixed drive cycle, defined reference fuels, defined test procedures, Cold start emissions included, level playing field*) **and limitations** (*tailpipe only, constrained drive cycle, unrepresentative environment, no ancillaries, road load factors, powertrain*) **of the current gCO_2/km metric for comparing the GHG-emissions of passenger cars,**
- ❑ Consider all elements that contribute to a vehicle's life cycle **CO_2** emissions,
- ❑ Define appropriated boundary for the evaluation of a vehicle's life cycle **CO_2** emissions
- ❑ Define how evolving technologies, such as vehicle electrification, alter the balance of life cycle emissions between production, in use and disposal and more specifically define how the contributing elements could be assessed,
- ❑ Define the most appropriated forms for a new measure of **CO_2** emissions, and more specifically have a full control of possible new methodologies that could be introduced for assessing the elements contributing to a vehicle's life cycle emissions.

A vehicle's life cycle can be divided into four blocks: production of the vehicle, production of the fuel, in-use, and disposal [60].



Currently, there are no automotive targets specifically aimed at reducing CO_2 from production of the whole vehicle.

The renewable energy directive and fuel quality directive have set targets for increasing renewable energy in transport, and reducing GHG emissions form fuel.

The fleet average tailpipe $\mathbf{CO_2}$ target is encouraging to develop low carbon technology.

Ideally, LCA of the vehicle end-of-life should consider the logistics, energy and processes required to dispose of the vehicle. The end of life vehicle directive is encouraging re-use and recycling of automotive components, which should help to reduce the environmental impact of disposal.

A vehicle LCA study is likely to be conducted during the pre-production or launch phase of a new model. Clearly there are some uncertainties regarding how well these EoL elements can be quantified 10 years in advance.

[60]. Preparing for a Life Cycle CO2 measure. Report RD.11/124801.4 Jane Patterson, Marcus Alexander, Adam Gurr. 20 May 2011

Some legislation is directly designed to reduce a passenger car's environmental impact but have unintended consequences. On the contrary other legislation, not aimed at vehicle **CO_2**, has an indirect effect on vehicle life **CO_2** emissions.

2 Consequences of technology evolution on life cycle CO_2 emissions

International Standards already exist for defining the Life Cycle Assessment process. The ISO 14040:2006 outlines the general principles while the 14044: 2006 is the guide for practitioners.

Environmental product declarations (EPDs) are defined by ISO 14025. An EPD must be based on a product LCA, Use Product Category Rules (PCR) for the relevant product type, and be verified by a third party. An international standard for carbon footprint is currently under discussion ISO 14067.

LCA studies of OEMs vehicles are part of their Environmental Management Strategies. The purpose being the publication of the results to inform customers, shareholders and other stakeholders. The new need comes as a consequences of the technology evolution.

The detail of the methodology employed in the LCA study can have a significant impact on the life cycle results. It is possible to conduct two LCA studies of the same product which both comply with the ISO 14040 standards, but have very different results. This results from the LCA boundary chosen, the software used, the Life Cycle Inventory data set LCI, functional units…etc.

Even with peer review and sensitivity analysis LCA results from different studies can still be significantly different depending on input data sets and assumptions. Here the need to have a direct control of the LCA study for the evolving power-train technologies becomes evident.

The Life cycle assessment of a typical passenger car indicates that **the numbers vary depending on segment and lifetime mileage.**

Modern European mid-size cars for the "In-Use" phase have typical emissions of 120gCO_2/km reduced for several models to 100 gCO_2/km when provided with stop and start technologies (microhybrids).

The introduction of battery packs, electric motors and power electronics into a car increases the embedded CO_2 emissions associated with the vehicle's production, while significantly reducing the tailpipe CO_2 emissions from the use phase. This leads to a shift in the life cycle balance between production and use phases.

Vehicle hybridisation reduce the “in use” **CO_2** emissions, but there is an increase embedded emissions from both production and disposal.

3 Comparison between the overall CO_2 emissions of a mid-size full hybrid and a mid-size gasoline car

For the Toyota Prius various institutes and authors for the “In-Use” phase over the NEDC cycle report real measurements at 95-100gCO_2/km. Because 150kg have to be added to the ICE powertrain to transform it into a full hybrid, for an average 100MJ/kg, Prius like vehicles require from 13,000 MJ to 15,000 MJ more energy than equivalent ICE vehicles.

For an average EU mix of energy, 15,000MJ are equivalent to 850 litres of gasoline, the fuel needed for a conventional gasoline car to run 850 l x 20km /l = 17,000 km. We can state that ICEs gasoline and a full hybrids reach the parity of the overall CO_2 emission after 65,000km.

We can conclude that because of the higher CO_2 emission for both the production and the disposal phase, the full hybridization implemented in vehicles like the Toyota Prius does not lead to substantial improvement of the overall CO_2 emission.

4 Comparison between less than 1000kg gasoline and Fully Electrical Vehicles: range, weight and energy needed in the production phase

For full electrical vehicles, the situation is different because FEVs address mobility from a different perspective. With the current state-of-the-art technology the analysis should be made selecting the **vehicle size** and **the mission.**

Under high speeds and long range missions, EVs are likely not to be able to compete with ICEVS for another decade. While for most urban missions ICEVs cannot compete with FEVs.

For the comparison between a gasoline car and a FEV we will refer to vehicles weighing less than 1000kg, in that they are the most suited for urban mobility where electrical vehicles will find most of their applications.

Referring to a conventional 1000kg ICEV we demonstrate that a state-of-the-art technology EV having the same weight:

- has an acceptable range in the New European Driving Cycles NEDC (speed up to 120kmh).

- does not require more energy to be produced (same GHG footprint in the production phase)

Lets suppose that the two vehicles differ only in the typology of the powertrain. For a typical 1000kg car we have:

PWT ICE Gasoline

1) Total weight of the basic ICE powertrain engine-transmission-exhaust system-tank = 160-180kg
2) Weight of fuel: 0.7kg/20km

PWT FEV

1) Weight of motor with a total nominal power 16kW: 45 kg,

Weight of electronics cables: 10-12 kg, Weight of two complex two ratio transmission: 20-25 kg

Total weight of the basic electrical powertrain= 75-82kg

2) Total weight of battery pack is a linear function that depends on specific energy of the battery pack, on energy consume per km and on the covered range.

We consider battery packs with specific energies of 100Wh/kg, 130Wh/kg, 170Wh/kg, 200Wh/kg, 300Wh/kg and 400Wh/kg. And suppose that from the battery the wheel the energy consume to cover the NEDC (max speed 120km/h) is on average 150Wh/km Figure 1.

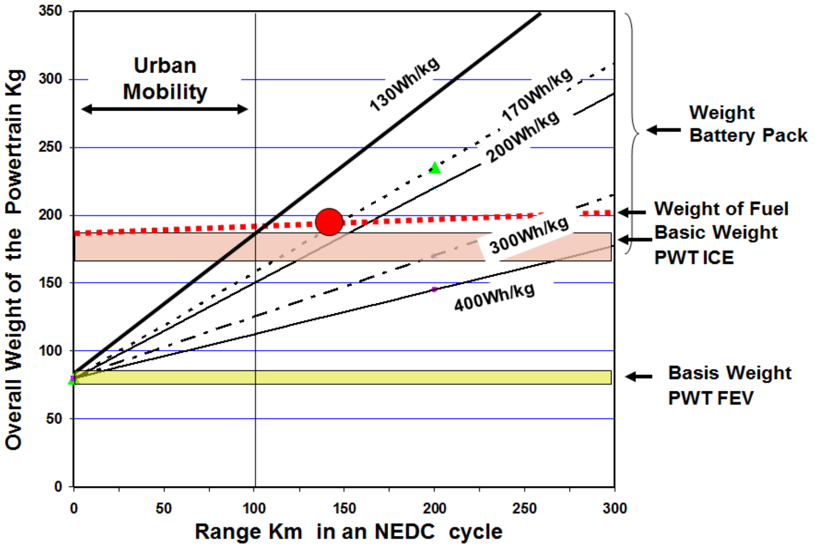


Figure 1: Powertrain of a 1000kg car: Comparison of an ICE gasoline having a consume of 1litre/20km and a FEV consuming an average 150Wh/km under the NEDC cycle.

A born electric vehicle capable to cover a range of 180-200km in the NEDC cycle, with a 170Wh/kg state-of-the-art battery pack, would have a similar weight of the ICEV.

If we compare the two systems on the NEDC mission, for all urban mobility needs, up to a range of 150km, the FEV can be made lighter than an ICEV.

The hypothesis made are in favour of the ICE powertrain for a least two reasons:

- a thermal engine requires protecting shields, noise dampers and fixtures whose weight can be as much as 5% of the total weight of the car,
- an efficient electrical powertrain of a 1000kg car in the NEDC has an average consume lower than 120Wh/km.

The second concern regards the comparison of the energy to produce the two powertrains.

An accurate analysis requires the definition of the energy mix of the nation where the production is made, hypothesis on the level of recyclability of materials, the exact composition of the battery cells and the availability of data regarding the energy needed to operate a modern manufacturing plants of batteries, however a qualitative but useful comparison can be made.

For the ICEV we have:

160-180 kg of powertrain requiring 170kg X 105MJ= **17850 MJ** of energy to be produced.

The global energy needed to produce 1kg of the ICE powertrain depends on the material used in the engine and in the transmission blocks. The complex manufacturing steps for the precise tooling of cast iron can be contained to 80-90 MJ/kg [61,62] while the aluminium blocks requires up to 220MJ/kg [63].

50kg of extra weight to damp the noise, shield and fix the engine require 50kg x 60MJ=**3000 MJ** of energy to be produced.

For the FEV we have:

[61] Metal production, Morten Simonsen, Vestlandsforsking, 5 April 2009.
[62] Life-Cycle Energy Savings Potential from Aluminum-Intensive Vehicles, F. Stodolsky, A. Vyas,R. Cuenca, and L. Gaines
[63] http://www.doitpoms.ac.uk/tlplib/recycling-metals/aluminium_production.php

120kg of a state-of-the-art battery pack (20.4kWh) requiring about 20.4kWh x 750 MJ/kWh [64] = **15300 MJ** of energy for its production.

80 kg for motor and transmission 80kg x 70MJ/kg= **5600MJ.**

Although the comparison is only qualitative, we can conclude that for ranges up to 150km in the NEDC cycle, the production phases of gasoline and electrical powertrains have equivalent CO_2 emissions.

It is worthwhile noticing that a small gasoline vehicle when converted to be operated by Natural Gas typically weights about 130kg more (tank of steel). In that case the energy needed to produce the NG ICE motorization would be 8500MJ - 9000MJ (20-25%) higher than that of the Gasoline one. Furthermore, when the NG ICE motorisation is compared with the electrical one, we can deduce that for the same weight the ranges of the two motorisations are equivalent.

5 Recommendations–actions-scenario

Because there are no specific CO_2 targets for the production of the whole vehicle the possible recommendations–actions-scenario could be [65]**:**

- ❑ Priority funding for the main alternative fuels
- ❑ CO_2: Internalise cost; cap on CO_2 intensity for fuel mix
- ❑ Efficiency standards for all vehicles beyond 2020
- ❑ Infrastructure: EU-wide build-up for the main fuels
- ❑ Low emission requirements for urban traffic
- ❑ Access privileges for clean and energy efficient vehicles
- ❑ Differentiated charging favouring alternative fuels

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[64] Dominic A. Notter, Marcel Gauch, Rolf Widmer, Patrick Wager, Anna Stamp, Rainer Zah, and Hans J.Orgalthaus: Contribution of Li-Ion Batteries to the Environmental Impact of Electric Vehicles *Environ. Sci. Technol June 16, 2010.* Paper and support information at http://pubs.acs.org/doi/suppl/10.1021/es903729a - data received directly from the principal author Dominic Notter: "*1 kg battery needs 104 MJeq while 1kg battery contains 114Wh (8.8 kg battery/kWh). This results in about 250 kWh of energy per kWh of battery capacity*". Note: the data available on the energy needed to produce a battery are very controversial thus actions are recommended to start specific LCA studies aiming at the evaluation of the energy needed to produce Li-ion battery packs by state of-the-art production facilities.

[65] Franz Söldner European Commission Directorate General for Mobility and Transport "Towards a European alternative fuels strategy,15th AMAA Forum, Berlin, 29 June 2011"

- ❑ Revision of energy taxation Directive: introduce CO_2 tax
- ❑ Business models for multi-energy filling stations
- ❑ CO_2/energy efficiency Regulation for Heavy Duty Vehicles
- ❑ Tighter CO_2/energy efficiency Regulations for others
- ❑ Refuelling/recharging infrastructure: build-up, standards
- ❑ Labelling of CO_2/energy efficiency in a revised Directive

And

- ❑ Consider the introduction of a directive that establishes a new metric based on GHG emissions emitted during vehicle production
- ❑ Consider targets aimed at reducing the life cycle $\mathbf{CO_2}$. For example:
  - o Cap on production $\mathbf{CO_2}$ dependent on vehicle segment
  - o Reduction target for production of life cycle $\mathbf{CO_2}$, compared to an appropriate baseline
  - o Maximum payback period for trading increased embedded emissions against reductions in tailpipe/TWW $\mathbf{CO_2}$ emissions.
- ❑ Consider the fiscal and regulatory framework in which vehicles are sold, used and disposed (allocation of incentives).

Further work is required, engaging with OEMs, LCA practitioners and vehicle drivers, to close the gaps in life cycle understanding. Amongst the actions to address are:

- ❑ Open a new dialogue with other vehicle manufacturers aiming at a common LCI dataset to be used by the automotive industry and aiming at evaluating the impact of different in use assumptions, especially around drive cycles and use of ancillary functions
- ❑ Establish new forms of collaborations-relations with suppliers
- ❑ Intensify the contact with LCA networks and initiatives aiming at obtaining a better understanding and modelling of the environmental impact of vehicle end of life, especially for new technologies such as electric vehicles

- Investigate the variability of vehicle use to understand the range between extremes
- Research vehicle end of life to understand what really happens during vehicle disposal
- Make LCA part of the process: Get life cycle thinking embedded within the design process, allow LCA results to drive reduction in both costs and CO_2 footprint.

Appendix III

Li ion Batteries

Principal findings

- The energy needed to produce 1Wh of Li-ion battery cells is halved every five to six years,
- Cost targets and technology evolution are converging at 200€/kWh before 2020,
- More limiting than the cost of the cells, seems to be the lack of experience that OEMs and Tier1s have when they are asked to design and manage Li-ion battery packs,
- In few years, battery costs will not be any more the major issue; the driving factors for the OEMs will be the optimisation of the energy-power supply at a systems integration level and as structural elements,
- A single facility capable to produce 200,000 automotive battery packs a year will be operative since 2013.

1 Rate of change in energy density and productivity of Li-ion batteries

There are several technologies coming to the market but it has taken from 1990 up until about 5-6 years ago for reliable large format lithium-ion cells. The recharge-ability of Li-air has still to be proved [66], Li-Sulfur Galvanic cells have been demonstrated at 350Wh/kg and have a promising high theoretical limit of the specific energy at 2500Wh/kg, but considerable research and investments will be needed before they could meet automotive standards [67]. New technologies are not going to arrive on the market in the next few years and Li-ion will continue to dominate until at least 2020.

Since 1993 the specific energy (Wh/kg) of Li-ion cells, either with an organic solvent electrolyte or with a solid polymer composite electrolyte (Li-ion polymer), have continued to grow with a remarkable Compound Annual Growth CAGR of about 7% [68], reaching in the 2012 a commercial state of-the-art of 280Wh/kg (Panasonic 18650 cells). Cathodes with layered mixed oxides (nickel, manganese, cobalt) and anode with graphite, graphene, silicon or their mixtures are currently receiving the highest industrial considerations while, at a laboratory level, cell architectures Li_2-

[66] www.polyplus.com
[67] www.sionpower.com
[68] Battery Association of Japan, http://www.baj.or.jp/

Sulphur cathodes and thin-carbon nanocomposite anode SnC/Li_2S have been demonstrated at 1200Wh/kg [69]. The intensive industrial and research efforts spent on the development of Li-ion chemistries and architectures are such that, until 2020, the commercial growth of specific energy is expected to continue with a CAGR of at least 5%, leading to 280 X $(1+ 0,05)^9$ = 434Wh/kg, a value still rather far away from the theoretical limits of several Li-ion cathode-anode architectures [70].

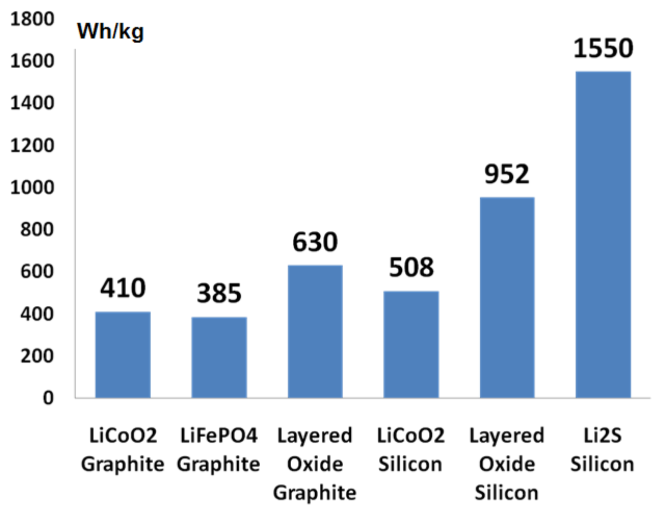

Figure 1: *Comparison of theoretical specific energy for different types of Li-ion* and Li-ion Polymer *batteries, calculated based on the theoretical capacities of the active materials in the electrodes and the average operating voltage of the battery. Source: Yuan Yang, Stanford.*

From the manufacturing point of view, the equipment to pack pouch cells has registered a considerable increased of productivity (**Wh/h**); more specifically in the period 2008-2011 [71]:

- the productivity of small cells for netbook /ipad /iphone (65mmx115mm) has increased 108%,
- the productivity of automotive cells (150mmx210mm) has increased 79%.

On the base of the machinery under development, with respect to 2008, the productivity of automotive cells is expected to increase 170% by 2013 (2.7 times).

[69] Jusef Hassoun, Yang-Kook Sun, Bruno Scrosati, Rechargeable lithium sulfide electrode for a polymer tin/sulfur lithium-ion battery, Journal of Power Sources (2011) , Volume: 196, Issue: 1, Publisher: Elsevier B.V., Pages: 343-348

[70] Yuan Yang, Matthew T. McDowell, Ariel Jackson, Judy J. Cha, Seung Sae Hong and Yi Cui (2010) New Nanostructured Li_2S/Silicon Rechargeable Battery with High Specific Energy. *Nano Lett.*, Article ASAP doi: 10.1021/nl100504q

[71] Data provided by Kemet-Bologna a major world-wide supplier of equipment for the production of battery cells.

Specific energy and productivity of pouch cells are approaching those of the more consolidated cylindrical cells and the two technologies will continue to compete for years on: internal resistance (lower for pouch cell), cost, specific energy, robustness and flexibility of design assembly (better with cylindrical cells).

With specific energy (Wh/kg) and productivity (Wh/h) increasing respectively 5-7% and 20-25% a year, **we can formulate a rule of thumb by which the energy needed to produce 1Wh of battery cells is halved every five to six years.** Since the commercial advent of the Li-ion battery the energy needed to produce 1kWh of capacity can be estimated to have been reduced to less than 1/10th [72,73,74].

2 Cost, price and supply

The cost and supply constraints of the battery pack are acknowledged to be the most limiting factors for the wide scale introduction of electric vehicles. The average cost of the raw materials used in the current state-of-the-art Li-ion cells is of the order of 15€/kg, depending on chemistry and cell architectures, today requiring less than 5 kg of raw materials per 1 kWh. The higher cost of the most expensive raw materials like cobalt, influence only 15% to 20% the average cost of the raw materials used. In fact the great majority of Li-ion cells chemistries have in common aluminium and copper electrodes substrates, graphite, binders, and lithium which determine the largest portion of the weight.

As starting point we can consider the following facts:

- Teslamotors in 2009 was selling spare packs with a capacity of 53kWh at 36000$, that is 679$/kWh [75],
- The range extended battery pack of the 2012 Tesla Model S, with a capacity of 45kWh is sold at 20000$, that is, 444$/kWh (33% decrease of the price with respect to 2009) [76].

72 Dominic A. Notter, Marcel Gauch, Rolf Widmer, Patrick Wager, Anna Stamp, Rainer Zah, and Hans J.Orgalthaus: Contribution of Li-Ion Batteries to the Environmental Impact of Electric Vehicles *Environ. Sci. Technol June 16, 2010.* Paper and support information at http://pubs.acs.org/doi/suppl/10.1021/es903729a - data received directly from the principal author Dominic Notter: "*1 kg battery needs 104 MJeq while 1kg battery contains 114Wh (8.8 kg battery/kWh). This results in about 250 kWh of energy per kWh of battery capacity*". Note: the data available on the energy needed to produce a battery are very controversial thus actions are recommended to start specific LCA studies aiming at the evaluation of the energy needed to produce Li-ion battery packs by both state of-the-art chemistries and production facilities.

73 C. Samaras, K. Meisterling, Life cycle Assessment of greenhouse Gas Emissions from Plug-In Hybrid Vehicles: Implications for Policy. Environmental Science Technology, 42 (9), 3170 (2008)

74 C.J. Rydh, B.A. Sanden, Energy Analysis of Batteries in Photovoltaic Systems: Part I Performance and Energy Requirements, Energy Convert. Manage, 2005, 46 (11-12), 1957-1979

75 http://blogs.edmunds.com/greencaradvisor/2009/02/tesla-battery-pack-replacement-would-be-36000-today-musk-says.html

76 www.teslamotors.com

- Currently lithium cobalt oxide cells for portable devices are sold for 240-280 per kWh [77]. The materials used in these battery cells have an overall average cost comparable with those used for automotive cells.
- The packaging of automotive battery cells including air cooling, connectors, cables and BMS can be easily contained to 800-1000€ even for medium-low production volumes. For a typical 20kWh pack that means 40-50€/kWh.
- The current trend in commercial FEVs is the adoption of air cooled battery packs integrating mixed oxides energy cells such as NMC Nickel Manganese Cobalt technology [78,79] with a tendency to combine energy and power cells (thinner layers of active materials) having the same chemistry.

For most mature technology based products, the ratio between selling price and cost of raw materials is in the range 1.5-2.2, the analysis made by several energy institutions confirm that the manufacturing of battery is expected to converge to the same ratio soon [80,81]. Learning effects due to large scale productions and further optimisation of the cell structure would very likely lead to more desirable price levels in a few years' time, nevertheless, the user of the automobile is asking for much more than just lower costs. Progress has been dynamic in terms of design of lightweight chassis, powerful and efficient drive trains, aerodynamic shapes, and sophisticated computer controllers, but the same statement cannot be made for battery technology.

In such rapidly evolving environment, more limiting than the cost of the cells, **seems to be the lack of experience that OEMs and Tier1s have** when they are asked to design and manage Li-ion battery packs responding to automotive criteria namely safety, reliability, manufacturability, and durability.

As seen from the EU automotive manufactures the field is still new, most of the attention is currently given to the engineering of the battery pack as a standalone system, while the design of the optimal energy-power system, when conceived at systems integration level (battery(ies)-inverter(s)-motor(s)-transmission), is still at its infancy. Similarly, very little has been made to the take-up of the potentiality of battery systems as structural elements.

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77 Lache, R., Galves, D., Nolan, P. (2010). *Vehicle electrification: More rapid growth; steeper price declines for batteries*.Frankfurt, Germany: Deutsche Bank Securities, Inc. Available at: http://gm-volt.com/files/DB_EV_Growth.pdf Lache, R., Galves, D., Nolan.

78 www.cars.21.com, Christian Mohrdieck, Daimler Battery Drive Development, 2011-05-30 and www.cars21.com Andrew Heiron, Head of Electric Vehicle Programme, Renault UK, 2012-01-05.

79 www.cars.21.com, Joe LoGrasso, Manager, GM Global Battery Systems Engineering, 2012-01-19.

80 Paul A. Nelson, Danilo J. Santini and James Barnes, Factors Determining the Manufacturing Costs of Lithium Ion Batteries for PHEVs, EVS24 Stavanger, Norway, May 13-16, 2009.

81 Chuck Shulock, Ed Pike, Alan Lloyd, Robert Rose, vehicle electrification policy study, task 1 report: technology status. February 2011. www.theicct.org

According to Prof. Chu of the Obama Administration "*batteries suitable for plug-in hybrids four years ago cost about $12,000 to produce, we think we're on target by 2015 so that the cost of that same capacity battery will be reduced to $3,600. The goal, is to more than halve the cost by 2020*" [82].

All together, the available information confirm that **cost targets** for the installation of automotive battery packs **and technology evolution** can converge at 200€/kWh well before 2020**!**

As soon as the OEMs will get used to the technology, there are no reasons why the overall installation into the vehicle would cost more than 200€/kWh. In few years, battery costs will not be any more the major issue; the driving factors for the OEMs will be the optimisation of the energy power supply at a systems integration level and as structural elements.

Substantial reservations remain about the long-term performance of Li-ion batteries under the extreme heat, cold, humidity and vibration conditions that automobiles have to endure on a daily basis (if compensated for by appropriate protection measures). For instance the lifetime of a battery is halved for every 15 degree increase from temperature, which requires complex and costly temperature conditioning, including either expensive liquid or forced air cooling of the overall battery compartment. On the other side it has to be acknowledged that commercial EVs like the Nissan Leaf and the Chevrolet Volt are both sold with **battery packs covered by an eight-year/100,000-mile warranty**.

The launch of new production facilities, announced in 2010 and 2011, is going to change the relation between production and demand in short. The Nissan-Renault alliance has announced a global production capacity of 550,000 battery pack per year by 2013, of which 220,000 in Europe [83]. As part of the Renault-Nissan alliance, in 2013, a new plant opens in Tennessee with the ultimate capacity of 150,000 LEAFs per year plus **200,000 lithium battery packs per year** [84].

The spread of production facilities is such to raise the first concerns for a possible over supply of battery packs starting from 2015 [85,86,87]. However, the booming of Light Electrical Vehicles (e-

[82] http://www.cars21.com/article.flash.php?Id=2743, Electric vehicle battery costs coming down: Chu, US Government, 2012-01-13.

[83] Gonzalo Hennequet, Mass Production of EVs: The Technological Challenge of RENAULT, Auto e-motion conference, 27 September 2011, Graz, Austria

[84] *John Addison,* Race to Make 100,000 Vehicles with Lithium Batteries *11/22/11,* http://www.cleanfleetreport.com/hybrid-cars/automotive-lithium-batteries/

[85] www.Cars21.com, Price of electrical vehicles batteries to fall as manufacturing capacity outstrip demand. 19 Sept 2011.

[86] Battery Modules for Hybrid and Electric Vehicles Will Be a $47 Billion Market in 2020, Says ABI Research, Jan 23, 2012, http://www.marketwatch.com/story/battery-modules-for-hybrid-and-electric-vehicles-will-be-a-47-billion-market-in-2020-says-abi-research-2012-01-23

bikes, e-scooters, other two and three wheelers, light and heavy quadricycles <550kg) together with the growing integration of battery packs in both small and large renewable energy installations, will be such that batteries will not be available in adequate volumes during the regulatory compliance 2012-2015 period. While waiting that the majority of OEMs and TIER1s will consolidate their technology position, the selling price and supply constraints are likely to leave the HEVs, PEVs, EVs and LEVs markets in a critical state of flux until at least 2016.

The expectation being that technology and cost evolutions could soon lead European OEMs and Governments to consider risk sharing manufacturing plants capable to produce battery packs with a comparable output to those producing Internal Combustion Engines (~500,000 engines per year).

[87] IDC Energy Insights Forecasts *Global Demand for Li-Ion Batteries Expected to Grow 447%* , **01/24/12,** http://www.idc-ei.com

Appendix IV

Market Evolution of Road Electro-Mobility

Principal findings

- The decreasing EU sales of ICE cars of the last four years is very likely to continue and **never return** to the 2007 level,
- High customer acceptance of the EVs in commerce; customers get used with their EVs in few weeks and range anxiety disappears,
- Not only large cars, the demand is changing asking for a quick adaptation of the mobility offer, in Europe the request of EVs will largely exceed the offer for several years,
- Technology is evolving fast and by 2015 most new cars weighting below 1000kg is expected to be designed starting from their fully electrical option,
- The penetration of e-means is proceeding faster than forecasted in the first EU electrification roadmap. 2012 will be the first year of appreciable sales (35,000-40,000) in Europe but the general lack of road experimentation will set the first large sales at 2015,
- The current focus given to mid-size full hybrids cars (1300-1500kg), is hiding the real market potentiality of FEVs weighting below 1000kg. Since 2013, with the introduction of cars like Volkswagen UP, Toyota Scion IQ EV, and several other models of the same class, the approach to the design of EVs will experience a radical change,
- By 2020, up to 40% of the vehicles weighting less than 1000kg will very likely be sold fully electric. More than 30% of km of private road mobility of people is expected to be run by e-means (in China in 2010 that ratio was already at 50%),
- A figure of merit based on congested links, incentives, people's savings and dimension of the country indicate UK, and Italy to be potentially the first two largest EU markets of EVs,
- The simplicity of the EV architecture facilitates the appearance of new entries for which light and heavy Renault Twizy like vehicles will represent a new reference for personal mobility in large urban areas,
- **Until the demand is far superior to the offer the strongest Nations invest on industrial development, the weakest ones on incentives**.

1 Year on year registrations of conventional cars 2007-2011

In 2011 full year registrations of new passenger car in the EU decreased for the fourth consecutive year figure 1[88].

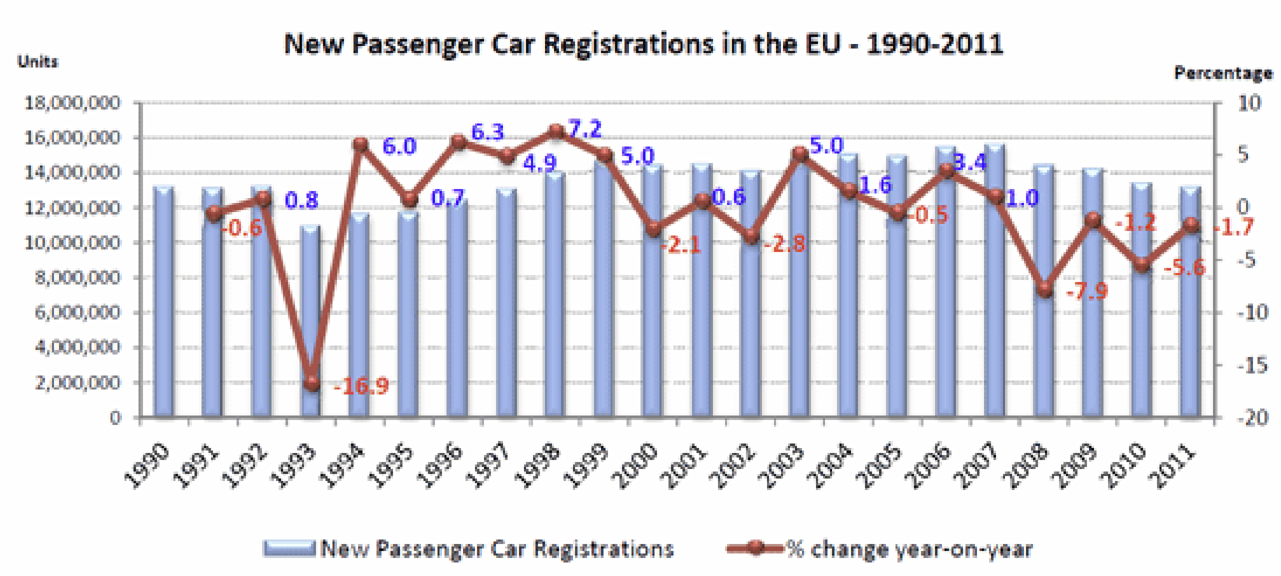

Figure 1: Demand for new cars in 2011 decreased by 1.7%, bringing the total number of units registered at 13,111,209. In 2011 most of the significant markets declined, from -2.1% in France to -4.4% in the UK, -10.9% in Italy and -17.7% in Spain. Germany was the exception as demand for new cars grew by 8.8% over twelve months. It remained the largest market with a total of 3,173,634 new registrations, followed by France (2,251,669 units) and the UK (1,941,253 units).

With of about 500 (Italy 700) cars every 1000 inhabitants [89], the increase of the number of cars on EU roads is very unlikely, similarly lifetime (8 years) and the replacement rate of cars, depending very much on the general economic wealth, will not change the perspective. The challenge is to face the evolution of road mobility of people considering: different forms of private and public transportation, implications on health, noise pollution, congestion and closure of city centres, availability of resources (primary energy and materials), climate change, technology evolution and competition.

88 www.ipmd.net
89 http://en.wikipedia.org/wiki/Motor_vehicles

2 Market evolution 2010-2020

Electro-mobility is a subject moving very fast, technology achievements and related industrial initiatives of the last three years are impressive.

There are many analogies with what has happened in the Photovoltaic industry in the period 2000-2010; after a difficult start the real market was always moving faster that the most optimist forecasts. The lesson has been that most of the PV modules production has gone to China through the implementation of large scale manufacturing aiming at the rich European market first.

The demand for new forms of mobility is spreading all over the world, reflecting peoples' awareness of the ever increasing problems of providing primary energy and raw materials, congestion, climate change and impact of noxious emissions on health. Rather than offering vehicles on ever increasing prices, the industry is now faced with satisfying a rational demand of mobility. Clean, safe and low energy consumption vehicles requiring less energy to be produced, using recyclable and eventually self-disposable materials-systems.

Electro-mobility is not just cars: a classification of the forms of mobility per their total mass and energy consume is necessary to better evaluate market's demand in relation to technology evolution and cost Table 1.

Type	Light EVs (e-Bike)	Light EVs (other)	Micro Cars Including light-heavy quadricycles	City Cars NEDC	Small Cars NEDC	Mid size Cars NEDC	Large Cars NEDC
Weight kg	15-50	50-350	350-650	650 -1000	1000-1300	1300-1500	1500-2000
Energy kWh/100km	1-2	2-4	4-8	9-12	12-15	15-18	18-25
kg/100km of Li-ion battery pack (180Wh/kg)	6 -11	11-17	23-50	50-67	67-85	85-100	100 -150

Table 1: Classification of e-means per weight, energy consume and battery pack needed for their typical missions.

2.1 E-Bike and Light Electrical Vehicles

China is the world leader with a 2010 production of over 30millions e-bikes and an accumulated fleet on the road of about 160 million and 50% of km of private road motor mobility already run electrically [90]. In 2010, China produced 216 million conventional bikes and pursues a vision that by 2030, LEVs will replace all traditional bikes and 60% of motorbikes [91]. **Electric Scooters will replace all forms** of gasoline scooters, mopeds and light motorcycles in the market today. Additionally, increasing affluence among consumers will result in many buyers of normal bicycles and today's electric bicycles upgrading to electric motor scooters. When we consider these factors, including the potentiality of India, **a world-wide market of about 130 million pieces per year is reasonable within 10 years, most likely 200millions/year.**

The bike is still a relatively cheap means of transport and will play an important role as the demand for affordable and sustainable mobility continues to increase. As well, the bicycle fits well with the growing interest in recreation, sports, fitness and health.

World-wide wealth is increasing and:

- People are enjoying more wealth, and this brings new choices.
- A consistent early choice by a human with more money, is better personal transport, with "better" being a matter of style, prestige, and utility.
- Most humans, world-wide, travel by foot, bicycle, bus, train, or metro. LEVs are an upgrade in personal mobility for most humans.

The move to e-bikes is very fast in Europe as well headed by the Netherlands where "*In a few years time the image of the e-bike changed from 'old people's' bicycle to a status symbol, e-bikes continued to show an upward trend as in turnover sales increased by 2.5% while the average retail price did not drop. Today 15% of all bicycles sold in the Netherlands are e-bikes and this number is*

[90] Tao WU, Tianjin Polytechnic University, The Infrastructure and Environment to Develop and Manufacture EVs in China, Presented at The future of Electrical Vehicles, 7-8 December, 2010, San Jose.
[91] Tao WU, Tianjin Polytechnic University, The Infrastructure and Environment to Develop and Manufacture EVs in China, Presented at The future of Electrical Vehicles, 7-8 December, 2010, San Jose.

expected to grow to 25%. The rising popularity of e-bikes is unprecedented" [92]. Electric bike sales broke the one million unit mark in 2010. Sales are forecast to grow to 3 million by 2015 [93].

The Electric Bike is far less than a mature product; sensors integration is often thought just as an addition to the system itself, to facilitate information gathering - The framework to makes sensible sense of the information is still basic - The connection between the sensors functionality and the psychology of the user at the design and usage stages is not really researched - Existing electric bikes are not smart and do not adapt themselves intuitively to the user's experience.

Most European OMEs are introducing in their portfolio either or both an e-bike and an e-scooter demonstrating a general understanding of a consumer change:

- Consumers are learning fast to adapt to electric vehicles,
- Consumers do like opportunities to be personally responsible –and are making purchases to do so,
- Consumers are learning that most transport events are short distances. A "Transportation Event" is one person going on one trip. Examples: Home to Metro station, home to work, home to bus stop, station to work, etc. Work, market trips, and child care trips usually short distance, most places have a 4-8 km transportation distances.

Daimler is now offering a family of electric Smarts (car, scooter and bike), on the same line are Pegeout, Volkswagen, Ford, Audi and BMW while Renault, in parallel with the e-bike exercise, has developed light and heavy quadricycles.

Europe in the e-bike world is playing a particularly important role with Bosch offering an eBike drive system with three sensors measuring speed, pedaling frequency, and torque, STMicroelectornics and Infineon with power MOSFETS and electronic kits are supplying the majority of Chinese players.

[92] E-bikes Stand Strong in Declining Dutch Economy, January 03, 2012, http://www.bike-eu.com/news/e-bikes-stand-strong-in-declining-dutch-economy-5543.html

[93] http://www.bike-eu.com/market-reports/beu-2010-b-e-bikes-rising-star-in-all-major-markets-5299.html

2.2 Electrification of four wheel vehicles

The race to be the 'world leader' of electric cars is often repeated. The Japanese Toyota, Nissan, Mitsubishi, Honda, starts the competition from several years of road testing and millions of full hybrids sold, in the same sector Ford and GM are acquiring experience.

Japanese and US automotive companies have started with full hybrids (Toyota, Honda, Ford..) and the replacement of NiMH batteries with Li-ion as well as the transformation of hybrids in plug-in versions is the straightforward consequence. Currently all full hybrids, plug-in hybrids (Chevrolet Volt) and Fully Electric (Nissan Leaf) per weight can be classified in the mid-size class, the smaller Mitisubishi i-Mev (1150 kg) in the small class.

Nissan will deliver 50,000 LEAFs in 2012. In 2013, a new plant opens in Tennessee with the ultimate capacity of 150,000 LEAFs per year. Nissan will be the first with 100,000 freeway speed FEVs [94].

General Motors leads with Plug-in Hybrids in the US, in 2012 it will deliver at least 60,000 Volts (1,529 units sold in 2011) and Amperas with LG Chem advanced lithium battery cells. From 2012 GM will introduce a pure electric Chevrolet spark (1350kg).

Toyota Motor Corp is bringing to market four vehicles with lithium batteries – the Prius PHEV, the RAV4 EV, the Scion IQ EV, and Camry Plug-in Hybrid. These give Toyota a selling of 100,000 vehicles with lithium batteries in 2013.

Ford has a 2020 goal of 10 to 25 percent of its vehicle sales including lithium batteries of which 70% hybrids, 20 to 25% plug-in hybrids, and 5 to 10% battery-electric (2% of their total).

All together, Gartner, the largest technology market research firm, is forecasting 100,000 electrified (FEVs and Hybrid Plug-ins) car sales in 2012 in the United States **close to one percent** of the 13.4 million U.S. vehicle sales.

The multi-billion investments made by GM, Nissan-Renault,Toyota, and their battery suppliers LG, Samsung, Panasonic and A123 have set the conditions for a rapid growth of both Plug-in and fully electrical vehicles.

According to the Electric Vehicle Market Forecasts (published 3Q 2011) report from Pike Research, cumulative sales of plug-in electric vehicles (PEVs), which includes both PHEVs and BEVs, will reach 5.2 million units by 2017, substantially up from just under 114,000 vehicles in 2011. Also by

94 http://www.cleanfleetreport.com/clean-fleet-articles/electric-car-forecast-us/

2017, cumulative sales of HEVs will represent an additional 8.7 million vehicles, for a combined total of 13.9 million electrified vehicles in all categories [[95]].

After a quick look at the investments and the supporting Govermental initiatives made in America and Asia, **Europe's Commitment to green transport may appear doubtfull** [96]**,** but making a deeper analysis we can notice that the advancements on the enabling technology made in the last four years are impressive. Luckely the focus given on electro-mobility in the JTIs (Eniac, Artemis), FP7 and national programs have allowed European industries to be able to compete.

2.3 On the move to satisfy the unbalanced demand and offer of EVs in Europe

The penetration of EVs is proceeding faster than forecasted in the first EU electrification roadmap. In 2011, the total sales of electrical vehicles reached 14,000 units of which 4,000 sold by Peugeot iOn and the Citroen C-ZERO [[97]]. A minimum of twelve European fully electrical vehicles will be on sale starting from 2012 [98], the first year of appreciable sales (35,000-40,000) in Europe [99]. Market demand is much higher in spite the price of the EVs in commerce is still rather high.

Anywhere there has been a trial to test EVs, the response has been very positive, an example is the project of the two-year Smart Move EV programme led by Cenex which targeted twelve major fleets in the United Kingdom including Indesit, Stagecoach, Asda or national car club Commonwheels. The objective of the trial was to test EVs in real world conditions, measure their technical, economic and emission performance [[100]]. On the economic side, the project findings estimate that the premium for EV ownership is decreasing and can result in cost reductions in the future. The project that used the Mitsubishi i-MiEV and smart fortwo electric drive resulted not only in increased awareness of fleet managers and users about the attributes of EV drive, but collected a number of other relevant conclusions:

- 63% of companies consider inclusion of EVs into their fleet by 2013 compared to 25% prior

[95] http://www.ev.com/knowledge-center/electric-vehicles-articles/14-million-evs-on-roads-by-2017.html
[96] EV Japan: cars21.com members reporting on site, 2012-01-26, www.cars21.com
[97] http://puregreencars.com/Green-Cars-News/markets-finance/psa-peugeot-citroen-delivered-4000-evs-in-2011.html
[98] Brussels Auto Salon: EVs in the spotlight, 2012-01-13. http://www.cars21.com/content/articles/73120120113.php, On sale 2012: Citroën C-Zero, Peugeot iOn, Renault Twizy, Mitsubishi iMieV, Mia Electric, Smart Fortwo Electric Drive, Renault Fluence ZE, Renault Kangoo ZE, Nissan Leaf, Fisker Karma, Tesla Roadster, Opel Ampera, Ford Focus Electric, Toyota Prius Plug-in, Toyota Prius +, Volvo C30. On sale 2013: BMW i3, Renault ZOE. On sale 2014: Volkswagen Blue e-motion, BMW i8,

[99] Interview with Andrew Heiron, Head of Electric Vehicle Programme, Renault UK, 2012-01-05 - cars21.com
[100] More than 60% of UK companies willing to adopt EVs in their fleets by 2013, 2011-11-16 - cars21.com see also Cetelem study gauges European interest in Evs, *January 11, 2012, AutomotiveWorld.com*

to the trial

- 75% of drivers would be willing to use an EV
- 100% of fleet managers recognised low running costs and environmental characteristics as the main EV advantages
- 75% of fleet managers admitted the trial improved their opinion on EVs
- Companies would be willing to spend up to 50% more to buy an EV
- 15% emission saving was achieved using the Cenex Fleet Carbon Reduction tool

Considering that in Europe 17% of the vehicles are sold to public institutions, there is a high demand of FEVs, strengthened by large incentives in many countries of high congestion (UK, Italy,…).

However, facing the reality, the offer of the European OEMs is limited by:

- reduced engineering and specific design experience,
- reduced vehicles experimentation on the road,
- critical supply of battery packs consequence of the lack of initiatives to start large scale risk sharing manufacturing plants on batteries,
- speed to implement regulations.

These factors will contribute to delay the first large sales of European made FEVs starting from 2015 with a production of 370,000-550,000 FEVs (3,0%-4,5%) out of the 12-13 million total car EU sales. That might appear a conservative estimate when compared with the anticipated plans of the major OEMs for instance the Nissan-Renault announced a global production capacity of 550,000 battery pack per year by 2013, of which 220,000 in Europe only [101] .

Within the **Renault-Nissan** alliance the goal of accumulated sales of 1.5 million EVs and an annual production capacity of 500.000 EVs, per year by 2016 is set [102] out of a total world production of about 8 million vehicles [103].

Nissan forecasts 10% of the global market share will be pure EV by 2020. Considering the

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[101] Gonzalo Hennequet, Mass Production of EVs: The Technological Challenge of RENAULT, Auto e-motion conference, 27 September 2011, Graz, Austria.

[102] Francisco Carranza-Sierra, Joint EC/European Green Cars Initiative Expert Workshop 2011 Europe's Strengths, Competencies and Job Opportunities in Electric Vehicle Battery Manufacturing, 7 December 2012, Brussels

[103] Renault-Nissan likely placed third in sales in 2011: Ghosn , Jan. 13, 2012 http://www.japantimes.co.jp/text/nb20120113a1.html

production capacity of all plants supposed to produce battery packs, the overall production of EVs would seem to be potentially higher (in one single plant in Tennessee US, Nissan has announced a capacity of 200,000 battery packs a year since 2013).

Since the 2010 Geneva motor show **VolksWagen** is aiming at 300,000 EVs and Plug-ins by 2018 (3% of their total) [104] the aim has been confirmed announcing the launch of ten amongst EVs and plug-in by 2015 [105]. The electrified version of the **UP** (<1000kg), on sale from 2013, is supposed to change the overall scenario well before 2018.

Daimler, with the Smart, seems to be particularly well positioned in that in the last two year has acquired considerable on-the-road experience. The vehicle per weight and functionality is the ideal convergence between state-of-the-art technology, market demands (urban and suburban drive) and potential target price.

The approach of the OMEs to the US market is the key to understand the Li-ion industrial context, in fact, most Li-ion batteries, in the next five-seven years, will be used in full hybrids and plug-in hybrids. **However, the analysis focussing on hybrid mid-size cars are misleading because the largest market is urban mobility for which fully electrical micro cars, city cars and small cars are more suited.**

2.4 The impact of Traffic Congestion in Europe

Congestion affects the economy through loss of productive time, it impairs quality of life, and it impacts badly on the environment thus reducing the benefits of car ownership. Congestion is studied in many reports, one of these, "Intelligent Mobility" [106], focuses on advanced Intelligent Transport Systems (ITS) as complement and alternative to public mass-transit systems such as buses, trams, light-rail, congestion pricing systems, infrastructure such as underpasses and covered walkways, that creates a safe and comfortable environment for pedestrians, car pooling, car sharing and education/outreach campaign.

[104] http://www.treehugger.com/cars/volkswagen-plans-to-sell-300000-electric-cars-a-year-by-2018.html, March,2,2010

[105] VW To Unveil at Least 10 EVs, Hybrids by 2015, Jan. 19, 2012, http://www.hispanicbusiness.com/2012/1/19

[106] Intelligent Mobility A National Need?, Publication of the Automotive Council ,UK, November 2011

ITS when deployed at national scale, including the possibility to connect all forms of transport, link the traveller both to his car and to the alternative mass transport systems (road, rail, sea, and air). ITS can help to improve travel reliability and reduce costs through systems such as:

- Online journey planners
- Dynamic route guidance and traffic alerts
- Traffic control measures, including urban traffic management control (UTMC), active traffic management (ATM) and parking availability systems
- Demand management measures (such as road user tolling).

Congestion can be chronically regular like rush hours and avoidable through specific plans, or randomly unpredictable making the general prediction of travelling times very difficult.

ITS are of help whatever are the means of transport, but cannot be intended the solution to continue using conventional cars in areas where they can be replaced by other forms of means.

Personal mobility without restriction is by most intended as the first expression of freedom. **In this direction the size of the mean of transport matters**! Bikes and micro-cars allow degrees of freedom impossible with a large car. The capacity to move goods or passengers around of small vehicle is far superior **(technical performance).**

In the lack of available space of most urban centres, small electrical vehicles equipped with advanced ITS contribute to simplify the problem. Cities and local authorities, public and private transport providers, logistics/freight companies, emergency services and traffic information service providers should be coordinated and committed in that direction.

Large cars designed with four or five seats when carrying a single person (1.6 is the EU average) [107] are the major cause of congestion in cities, it is a question of waist of resources and increased pollution as well as a limitation of the personal freedom.

A graphical representation of the percent of links congested in EU countries is shown in figure 2.

[107] J.L. Radtke, The Energetic Performance of Vehicles, *The Open Fuels & Energy Science Journal,* 2008, *1,* 11-18 see also Gavin Alford Jeremy Whiteman November 2008 ANZRSAI/ARCRNSIS National Conference.

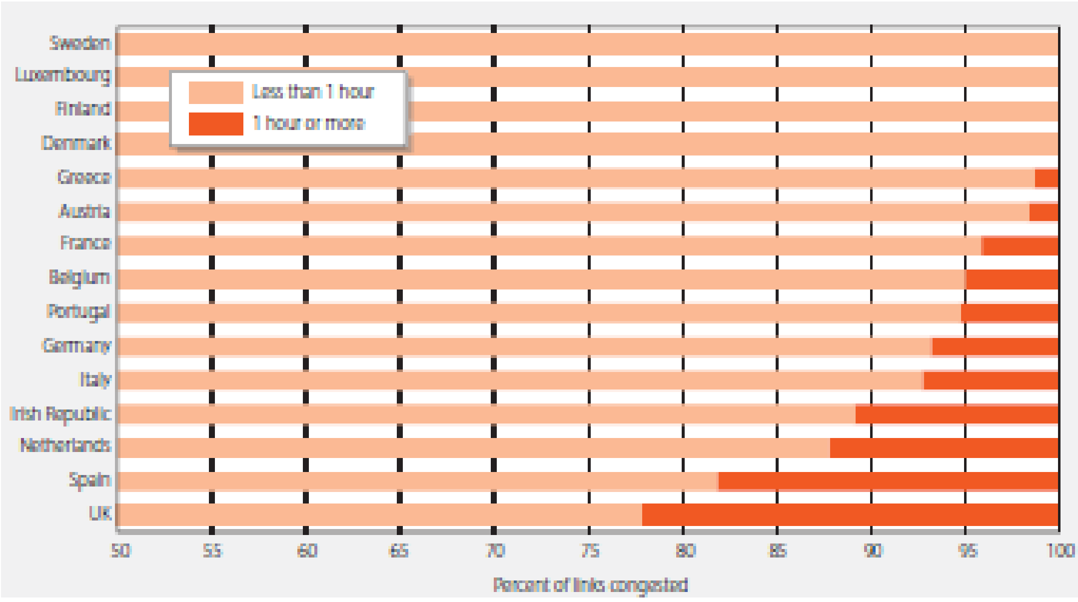

Figure 2: Congestion in EU countries (Publication of the Automotive Council, UK, November 2011).

A high congestion level of a nation can be seen as:

- Motivation for a Government to accelerate the change
- An opportunity for the sale of electrical vehicle

Countries, such as the UK, where the one-time prosperous auto-mobile factories have faltered, see EVs as a chance to revive the industry.

In the beginning of January 2012, a Frost and Sullivan report highlighted London as the future city likely to lead European EV-infrastructure.

A British ‘Electric Highway’, inaugurated on December 2011, with a network of 15 charging points will make it possible to drive from the North to the South of the UK without running out of power on the highway. The initiative aims to reduce range anxiety when travelling between cities, which seems to be a major disincentive for electric vehicle (EV) purchase, despite government incentives. Within 18 months, additional charging points will be placed in Wales, Scotland, on the M1 and at the Eurotunnel passenger terminal, extending the network to 27 stations [108].

The £5,000 Plug-In Car Grant followed by Government plans to strengthen the UK’s charging infrastructure and introduce 1,500 charging stations in the North East of England by the end of 2013 will push the EV sales to flourish.

[108] British ‘Electric Highway’ to be inaugurated this weekend 2011-12-20 - cars21.com

London could also become the ‘European capital of EVs’ after the Department of Transport was granted £9.3 million by the Office for Low Emission Vehicles to install 25,000 charging stations by 2015.

The launch of the Source London scheme is working towards getting 1,300 public charging stations by 2013. F&S research also predicts that Europe could boast around two million charging points by 2017, with 390,000 of these in the UK [109].

Generating a hypothetical figure of merit based on: size of country, degree of traffic congestion, incentives, savings of people in banks, attitude of people toward green economy and tendency toward novelty, **United Kingdom, and Italy are the two most attracting European markets of electro-mobility** followed by Spain and Germany (no incentives). The focus that Renault has given to the UK market is not by chance [110], Italy is far the largest market for the Smart.

The analogy with the photovoltaic industry is again worthwhile to consider; **until the demand was far superior to the offer the strongest Nations (China, USA) invested on industrial development, others (Germany, Italy, Spain) on incentives.** At the end of the incentives wave the largest markets will be in the nations that developed the technology.

2.5 The impact on the 2020 market of less than 1000 kg vehicles

The rationale behind this paragraph is that we cannot use the same criteria when comparing an electric Smart (730kg) and a Nissan Leaf (1521kg), a Plug-in Prius or a Plug-in Volt.

Private road mobility of people is a very rapidly evolving context with a multitude of parameters very often depending on unpredictable events. An analysis over a ten year timescale can only be qualitative, however, when at the snapshot made in the previous paragraphs, we add the principal findings reported in the technical appendices II and III, we can draw interesting considerations and predictions.

A qualitative representation of the kilometres run in Europe in 2010 by different private means in relation to their weight, such as the one shown in figure 3, is far less than exhaustive when taken alone, on the contrary, it becomes quite informative when compared with its likely evolution at 2020 as per what shown in figure 4.

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[109] http://www.thegreencarwebsite.co.uk/blog/index.php/2012/01/20/390k-uk-charging-points-by-2017-research-predicts/
[110] Interview with Andrew Heiron, Head of Electric Vehicle Programme, Renault UK, 2012-01-05 - cars21.com

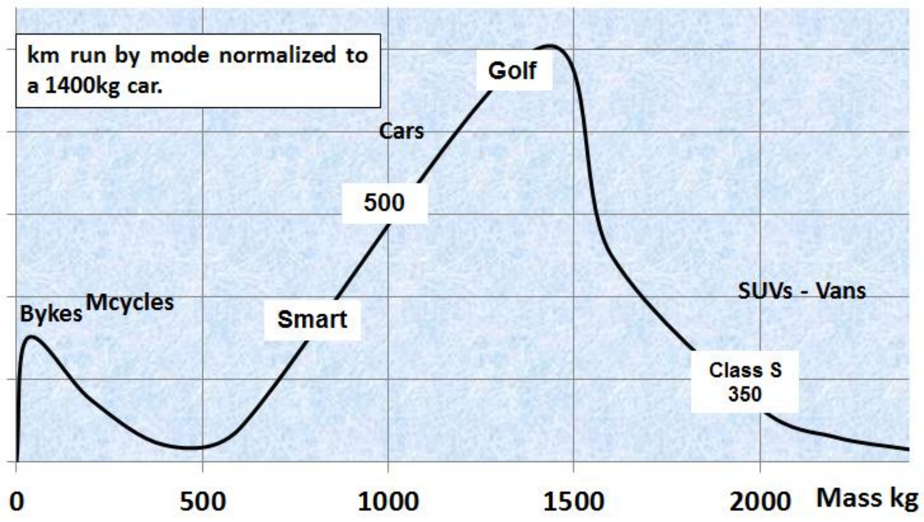

Figure 3: Road mobility of people by private means in EU in 2010: Qualitative representation of the distribution of the km run normalized to the conventional average ICEV weight of 1400 kg.

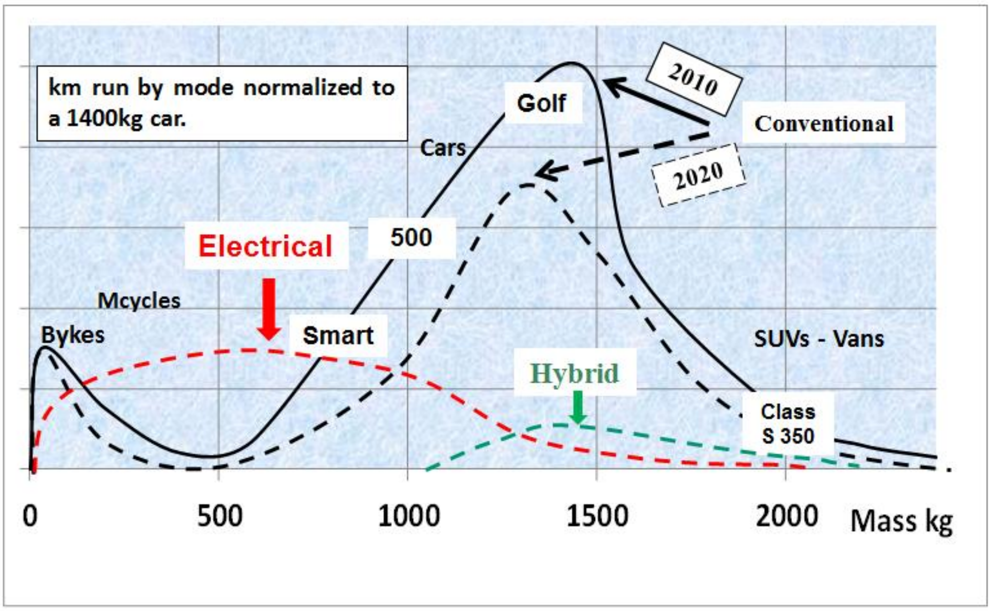

Figure 4: Representation of the evolution of private road mobility from 2010 to 2020.

The hypothesis behind the predicted evolution are the following:

- The polarisation of the markets towards small and large vehicles will continue with small and lower medium vehicles increasing from the current 63% of the overall market [111]. Average mass of conventional cars is likely to decrease from 1400kg to 1250kg,

[111] www.acea.com, pocket guide third edition pag. 53.

- High speeds (>140kmh) and long range (>300km) in a single charge cannot be addressed with cost competitive electrical vehicles adopting the current technology. **For these highways and sub-urban missions, EVs are likely not to be cost competitive with ICEVS before 2020**,
- The population living in urban areas is continuously increasing, 80% of Europeans live in large cities, the great majority of people move less than 20km a day, and 80% of daily trips made by cars in Europe are less than 60km [112], most drivers experience high speeds and long range only occasionally. **For most urban missions ICEVs cannot compete with FEVs,**
- Target costs and technology evolution are converging to the manufacturing of battery pack at 200€/kWh before 2020. From 2015, vehicles with a mass below 1000kg will be designed starting from a fully electrical option.
- Because of complexity and cost, full hybrids will find their best price/performance above 1300kg. Full Hybrids and Plug-in hybrids together are expected to represent 8-10% of the overall 2020 car market.
- In 2010, e-bikes, e-scooters and other forms of two/three e-wheelers were already covering 50% of the km run by private road motor means in China. E-bikes and e-scooters are growing fast in Europe as well.

In Europe road mobility with private means, by 2020, is expected to evolve considerably:

- E-bikes and e-scooter up to 50% of the market,
- Electro-mobility on four wheels is peaked for vehicles around 650-700kg (Smart like) with the great majority of vehicles weighting below 700kg being electric,
- 35% to 40% of vehicles weighting 900-1000kg will be sold fully electric,
- Fully electrical vehicles weighting more than 1500kg will be only a very small portion of the sales,
- Plug-in hybrids and hybrids at 8-10% of the market for vehicles above 1300kg.
- Four wheels vehicles weighting in between 650-800kg are on the ideal convergence in between robust state-of-the-art technology, high market demands (small dimension, urban and suburban drive) and a potentially low target price.

[112] Gonzalo Hennequet, Mass Production of EVs: The Technological Challenge of RENAULT, Auto e-motion conference, 27 September 2011, Graz, Austria.

Although these conclusions might appear over-optimist they reflect a conservative evolution of the technology already available in 2012. They match as well the average vision of most OEMs, analysts and specialized agencies whose analysis are used to address conventionally mid-sized vehicles (cumulative sales of plug-in electric vehicles (PEVs), which includes both PHEVs and BEVs, will reach 5.2 million units by 2017, and also by 2017, cumulative sales of HEVs will represent an additional 8.7 million vehicles, for a combined total of 13.9 million electrified vehicles in all categories [[113]]).

What makes a great difference in this report is the focus given to vehicles weighting less than 1000kg.

Traffic restrictions on large cities, combined with the introduction of Fully Electrical means will have a considerable impact on the overall volume of non-electrified vehicles. **Because the total km run by people will change only minimally, the 2020 share of vehicles adopting ICEs only is likely to decrease more than 30% from the 2010 values.** The consequences on employment and the EU general economy can only be mitigated by increasing the investments on electro-mobility.

[113] http://www.ev.com/knowledge-center/electric-vehicles-articles/14-million-evs-on-roads-by-2017.html

APPENDIX V

The environmental impact of Natural and shale gas

Author: Pietro Perlo

Principal findings

- European industries have a technology leadership in all areas of the Natural Gas "NG" supply chain, whether in Europe, Usa, India, Pakistan, Iran, Russia or Brazil, Internal Combustion Engines operating with NG "NGICEs" adopt 100% EU technologies.

- Major industries and governments, because of the general energy context, tend to present the advantages emphasizing the lower CO_2 emissions of the NGICEs than the gasoline ones. **However detailed analysis demonstrate this is absolutely wrong [2,3,4,5,6]**. In a 20 years' timescale GHG emissions of NGICEs can be **more than twice** that of gasoline engines.
- NG is the cleanest HC fuel in terms of noxious emissions, but **the finding of this reports is that NG is not at all the bridge to a low-carbon future of road transportation. Shale gas is much worse** in that recent studies demonstrate that it is at least 30% more than and perhaps more than twice as great as those from conventional gas **[2,3].**
- The growing EU dependency from the import of Natural Gas **[8]** cancels the economic benefits derived from the technology superiority of the EU industries. The global impact on Green House Gases "GHG" emissions (caused by leakages of methane) together with the economic constraints due to the importation of NG, pose questions on which area of road transportation Europe should continue to set the priorities and in which timescale.
- **Natural and Shale gas cannot be considered the bridge towards FEVs.**

1 The context: decarbonisation of road transport

The impact of GHGs on the environment has now convinced even the most sceptical people. The detailed measurements and the continuous refinements of the models make it clear that climate change and related disasters can be attributed to GHG emissions due to human activities **[9]**. Actions are taken everywhere and in all sectors aiming at keeping the global temperature increase below 2^{o}C **[9]**.The cost to limit GHGs emissions are impressive touching all industrial and more in general all human activities, but necessary to avoid uncontrollable consequences. Recent simulations made at NASA **[10]** emphasize the urgency of taking much more radical choices. Industrial activities and the transport of both people and goods are expected to continue with an unprecedented rate of change for at least three more decades **[11]**. The awareness of the problematic is now such that there is a growing demand from consumers for information on the carbon footprint of the goods and services they purchase.

Road transport is directly contributing to the overall anthropogenic GHGs emissions some 24% **[9]** while continuing to be the fastest growing emission sector **[9],** the decarbonisation of road transport it then in the agenda of all major Governments. The problematic related to liquid fuels, whose global demand is forecasted to growth some 1.3% a year until 2035 **[1],** poses the question whether gas fuels could be considered a viable HCs alternative.

Under a scenario with 50% CO_2 reductions to 2050, legislative targets for reducing corporate fleet average CO_2 are driving the development of low carbon technologies and alternative fuels. In both OECD and EU, gas will be the fastest growing conventional energy source **[1]**. When dealing with NG we are essentially considering the impact of delivering and burning methane. The question raised in this report is the relevance to be given to the data published by the International Panel for Climate Change "IPCC". More specifically, if the control of the GHGs emission is an urgency, should we better consider the IPCC values in a 20 years' timescale or the more "convenient" ones referring to the 100 years' timescale? **But whatever timescale considered it must be taken into consideration that, even from the most conservative view, NGICEs lead to higher GHGs emissions than gasoline engines.**

2 Composition of Natural Gas and Global Warming Potential of Methane

The composition of NG as it is extracted for the well, is very much varying on the location, the average Component Percentage is **[12,13,14,15,16]**:

Methane 85, Ethane 8, Butane 1, Propane 0.5, Heavier HCs 0.1, Nitrogen 1, Carbon dioxide 2, Hydrogen 0.1, Oxygen 0.1, Hydrogen sulfide 0.5, Water Vapor 1.2, Other gases 0.5.

NG comes from both ad hoc gas wells, but also as a boil-off from crude oil (bubbling, much like the gas in soda water), the latter with more heavier HCs.

Commercial NG is usually 95 to 99 per cent methane, averaging about 98 percent, the other 2 per cent being mostly ethane with traces of all the other gases. **This implies that the NG must be purified before it is distributed.**

A large percentage of natural gas supply of the EU comes from the gas fields in the north-west of Siberia, about 4000 km away from western Europe, the NG extracted there is 97% methane and requires a minimal treatment of purification **[13,15,16]**.

Methane (CH4) plays a significant role in the dynamics of global warming due to the following factors:

- Methane is a relatively potent greenhouse gas with a high Global Warming Potential "GWP index" of **72** (averaged over 20 years) **or 25** (averaged over 100 years). A unit of methane, that when completely combusted produces a minimal quantity of CO_2, if emitted in the atmosphere has an equivalent GHG impact of 72 units of CO_2 in a timescale of 20 years. To better account for the interaction of methane with aerosols, recent models for the global warming potential of methane compared to CO_2 suggest even more stringent values at **105** and **33** on a mass-to-mass basis for 20 and 100 years, respectively, with an uncertainty of plus or minus 23% **[2,3]**. **"***Some web sites authored by vested interests in NG cite the figure of 21, a figure which would be typical of a hot, very humid climate such as in a tropical rain forest. This low figure is not realistic in real life, except in a few relatively minor producing countries, such as Malaysia, Indonesia and Brunei"* **[13,15]**.
- CH_4 concentrations have more than tripled over the last 150 years **[17],**
- According to calculations reported in 2005, methane emissions may account for a third of the climate warming from greenhouse gases between the 1750s and the present, twice the level of previous estimates **[17],**
- An average molecule of CH_4 lasts around eight to nine years before it gets oxidized into carbon dioxide (CO_2) and water (H_2O). As a result, methane in the atmosphere has a half-

life of seven years (if no methane was added, then every seven years, the amount of methane would halve). The oxidation of methane in CO_2 and Water vapor is a process depending on location "*specifically depending on what are called the free hydroxyl radicals that are present in the atmosphere, which are very variable (low concentrations of OH radicals decompose methane more slowly than high concentrations*)"**[15,16,17],**

3 The supply chain of Natural Gas [31,52]

Purification-processing

The actual practice of processing natural gas to pipeline dry gas quality levels can be quite complex, but usually involves four main processes to remove the various impurities **[15,16]:**

- Oil and Condensate Removal by cooling and settling. Some of these may be further purified for commercial purposes,

- Water Removal by absorption in diethylene glycol in a tower followed by adsorption in zeolites,

- Separation of Natural Gas Liquids: 1) removal of propane and butane by absorption and fractional distillation. These are of commercial value as bottled LPG. 2) removal of ethane by cryogenic techniques. After distillation, this is useful in the petrochemical industry,

- Sulfur and Carbon Dioxide Removal by absorption in monoethanolamine. In cases where the sulfur content is high, it may be economically viable to separate it.

In addition to the four processes above, heaters and scrubbers are installed, usually at or near the wellhead. The scrubbers serve primarily to remove sand and other large-particle impurities. The heaters ensure that the temperature of the gas does not drop too low. With natural gas that contains even low quantities of water, natural gas hydrates have a tendency to form when temperatures drop. These hydrates are solid or semi-solid compounds, resembling ice like crystals. Should these hydrates accumulate, they can impede the passage of natural gas through valves and gathering systems. To reduce the occurrence of hydrates, small natural gas-fired heating units are typically installed along the gathering pipe wherever it is likely that hydrates may form.

At each of these stages, there is a small concomitant methane loss, mainly due to recycling the diethylene glycol and monoethanolamine and reactivating the absorbants and adsorbants. During the phase of purification the higher the content of non methane gas the higher is the leakage of methane in the atmosphere. The unpurified gas may be very corrosive, especially from "sour" gas wells with high water vapor and sulfur content. This means the lifetime of the pipework to the purification plant is limited and it must be regularly inspected for leaks.

A purification plant is an important and expensive infrastructure and one plant may serve many wells over a considerable area, with a spider's web of small bore pipework. This is often cast iron pipes with flanged joints, notable for leaks. At the wellhead, there is a "tree" for initial separation of gross impurities, including sand, by purging them out with the gas.

Distribution of NG [15,16,18,19,52]

Once purified, the gas has to be distributed to the end user. This is done by either liquefaction (LNG) or compressed by pipeline (CNG). The liquefied gas is eventually returned to gaseous state and compressed.

Liquefaction [15,16]

LNG is produced by refrigeration down to -163 °C at atmospheric pressure. It is then stored in large, double walled, well-insulated, spherical or cylindrical tanks in high-nickel steel, rather like enormous Thermos flasks. These tanks are not pressure vessels and have to be vented by pressure relief valves at, typically, 300 hPa, so that there is no risk of damage as the contents heat up, no matter how good the insulation.

The liquefaction process itself is done in two stages, initially a pre-cooling in a propane refrigeration circuit and then in a mixed gas one. It is quite a complex process requiring a great deal of energy. This is often supplied by gas turbines using the gas vented from the storage tanks at the liquefaction plant and raw methane. The resultant liquid-phase methane has a volumetric ratio of 1:593 compared to gas-phase methane. Unfortunately, I have not been able to obtain figures for the emissions or gas consumption (energy) at liquefaction plants but they are far from negligible.

Compression [15,16,18,19] Methane gas is easily converted to CNG. Three kinds of energy source for compressors are used: gas turbines running on NG, reciprocating engines running on NG and electric motors. Pressures up to 240 bars are sometimes used for bottled methane, but most pipelines run at 15 to 100 bars. Some leakage is almost inevitable with compressors, especially as they age. Much maintenance is required to keep emissions to a minimum. **Every 100 - 150 km a compressor station** is installed, where the gas is compressed and cooled in order to keep this pressure. The compressors burn a small fraction of the natural gas and release carbon dioxide. The compressor stations include thousands of flanges, valves and connections so that there is a high risk of leakage. A pipeline consists of 3 to 5 pipes installed in parallel, with **gate isolating valves (called valve nodes) located every 10-30 km**. Leakages may happen at valve nodes and the pipes have corroded. If the latter is the case, the escaping gas is self-ignited. Besides these, there are also planned and technological emissions. There are emissions from compressor drive engines and/or electrical power plants. Some emissions relate to pneumatically driven valves releasing some CH_4 in the atmosphere upon their operation.

Pipelines [15,16,18,19]

Once a well is completed and connected to a pipeline, the same technologies are used for both conventional and shale gas; it can be assumed that post-completion fugitive emissions are the same for shale and conventional gas. Most major pipelines are constructed of rolled sheet pipes with a welded seam and with sections welded together. When new, these are almost perfectly leak-free. However, they are generally buried at depths of typically 1.5 - 3 meters and the steel can corrode either from within or without. Corrosion is minimized by treatment with a coal tar coating, but this does not last forever and leaks do develop over time.

Pipelines need to regularly checked and maintained. Leaks are detected by portable gas detectors along the ground over the pipes. However, the greatest emissions are made when "pigging" a pipeline. A section of pipeline is isolated by closing the valves at each end and unscrewing the flanges. A very high-tech robot, nicknamed a "pig" is introduced into the pipe and sent from one end of the section to the other, examining the internal surface for weld problems, corrosion or leaks and transmitting the information back to an analytical computer. Obviously, this vents the gas in the section. After "pigging", the section has to be purged of air, before it can be put back in service and this, too, also involves considerable emissions. It is rare to either collect or flare the gas in the sections.

Small pipelines, particularly distribution pipelines in cities, are often relatively small bore flanged cast iron pipes, especially in older quarters. The leaks at the flanges are often aggravated by vibration from heavy traffic. Newer ones may be extruded steel from a punched blank, with welded joints, but street stop cocks are inevitably flanged. Some household distribution systems use welded plastic pipes, which are inevitably slightly porous.

4 Unconventional and Shale gas

The term “Shale Gas” refers to unconventional, continuous-type, self-sourced resources contained in fine grained (ranging from clay to very fine sandstone), organic-rich, low permeability reservoirs in which thermogenicor biogenic methane is stored as free gas in the matrix or fracture porosity, or as adsorbed/dissolved gas on the organics and/or clays **[20].**

Assessments of the recoverable volumes of shale gas all over the world have increased dramatically over the last five years. Globally, there are abundant supplies of natural and shale gas, much of which can be developed at relatively low cost [**21,22**].

Some EU regions like Poland, that have not traditionally been gas producers, do have significant shale gas resources **[24]** and the development of these resources could change patterns of production and distribution of gas in Europe.

No two shales are alike and gas composition variability complicates processing plans requiring different chemicals and technologies **[20].** Because a purification plant is an expensive infrastructure the tendency of gas industries is to limit the expense in relation to the “strength” of the well which usually diminishes to less than half after two years **[22,21]**. The consequence is that the control of leakages is not always optimal.

Presently, the natural gas industry does not have to disclose the chemicals used, but volatile organic compounds (VOCs) such as benzene, toluene, ethylbenzene and xylene have been identified **[25]**. The general lack of regulations makes the studies on emissions from shale wells rather difficult.

In terms of GHG the environmental impact of shale development are particularly challenging and, in spite of the technology improvements, **solutions that could lead to a lower carbon footprint are not in the horizon [2,3].** Other challenges lie in the area of water management, particularly the effective disposal of fracture fluids **[20,21,22].**

When evaluating the overall impact of NG combustion systems in terms of GHGs emitted, we should then consider the direct emissions from the vehicle and the indirect ones due to: the search of the well, extraction, purification, transformations and transportation to the location of use.

5 Biogas [26]

Because of the closed carbon cycle, biomass and organic residues when converted into biogas would appear a viable route to follow. However several challenges have to be overcome before this option could reach an appreciable share of the ICEs context. It appears more a local aspect rather than a mass market perspective. The composition of the bio-digested gas needs a pre-treatment before it is clean combusted, at the same time robust an effective catalysts have still to be properly refined. When deciding what conversion route to select an industry would more conveniently convert biomass into bioethanol rather than biogas and for this reason it is difficult to forecast an appreciable increase of the biogas option.

6 Natural Gas / Hydrogen blends

Even in the long term this solution will represent a very minor percentage of the total ICEs motorisation. The concerns on the available infrastructures and first of all on the overall GHGs impact will not help to spread the technology and the fuel mixture for at least another decade.

7 Indirect Emissions-Leakages: NG and Shale gas

The GHG footprint of both NG and shale gas consists of the direct emissions of CO_2 from endues consumption, indirect emissions of CO_2 from fossil fuels used to extract, develop, and transport the gas, and methane fugitive emissions and venting. Despite the high level of industrial activity involved in developing shale gas, the indirect emissions of CO_2 are relatively small compared to those from the direct combustion of the fuel. Thus, for both conventional and shale gas, the GHG footprint is dominated by the direct CO_2 end use emissions and fugitive methane emissions.

It is difficult to obtain precise figures of emissions because of the general lack of regulations. From the production to the final distribution there are no specific regulations obliging the operators, all over the supply chain, to measure and report on their data. In any case in the regions where regulations are in place they are insufficient to obtain reliable data **[2,3,25,52,54].**The emissions can be divided into those:

- produced during drilling a well, up to the moment of capping,
- fugitive emissions due to equipment leaks,
- fugitive emissions due to pipeline leaks,
- vented leaks from pressure relief,
- vented leaks for maintenance,

- vented leaks from diethylene glycol, monoethanolamine and adsorber regeneration, due to incomplete combustion of distributed NG.

The biggest studies of emissions have been carried out in the USA, representing about 1.4 - 2 percent of NG consumption. However, this figure excludes unburnt gas emissions at the users' premises, drilling emissions and those due to gas produced and transported outside the USA but consumed in the country. It is therefore expected that the holistic figure of emissions due to all gas consumed in the USA will be as high as 4 to 5 percent. In many other countries, especially those with poor equipment and antiquated pipelines, the percentage of emissions would be worse.

A study in Britain has estimated 5.3 to 10.8 percent of the gas flowing through Britain's natural gas pipes are leaking each year **[26].** Over 20 years a leakage of 2.8 percent would cancel any greenhouse advantage of gas over fossil fuels like oil and coal.

A 2005 Russian study indicates that from the purification infrastructure the leakage within the Russian border all over the pipeline is in the order of 1.4% **[27,18,14]**. Because the last segments of the distribution are the most critical ones a higher value is very likely from the east German border to the heart of Europe. Direct leakages from the well all over its lifetime and the impact of purification not included.

The most recent studies (papers of reference) on emissions from both NG and shale gas have been made by The Environmental Protection Agency **[5]** and by the General Accountability Office **[6]**. From these data R. W. Howarth, R. Santoro and A. Ingraffea **[2,3]** have summed all estimated losses and calculated that during the life cycle of a **conservative** average **shale-gas well, 3.6 to 7.9%** of the total production of the well is emitted to the atmosphere as methane. This is at least 30% more and perhaps more than twice as great as the life-cycle methane emissions estimate for **conventional gas, 1.7 to 6%.** The consequence of this study is that methane dominates the GHG footprint for shale gas on the 20-year time horizon, contributing 1.4- to 3-times more than does direct CO_2 emission. At this time scale, the GHG footprint for shale gas is 22% to 43% greater than that for conventional gas. When viewed at a time 100 years after the emissions, methane emissions still contribute significantly to the GHG footprints, but the effect is diminished by the relatively short residence time of methane in the atmosphere. On this time frame, the GHG footprint for shale gas is 14% to 19% greater than that for conventional gas, see also **[38-50].**

8 CNG via Pipeline and LNG via Vessel

Energy usage and greenhouse gas emissions are perhaps the most significant areas where pipeline gas can have an advantage over LNG. However, this advantage is also highly dependent on various design factors. According to a recent study commissioned by the European Union, the typical energy "penalty" for gas delivery via pipelines is 10-15 percent (efficiency of 85-90 percent), whereas for LNG it is approximately 25 percent (efficiency of about 75 percent) **[8,14,28,52,55]**.

The efficiency for pipelines begins to decrease as the length of the project increases. This is also true for greenhouse gas emissions.

The energy used for the cooling process and subsequent decompression can be harnessed to some degree for various purposes. For example in Japan LNG users have found that the use of cryogenic power production for deep freeze food storage units can be a derivative benefit of LNG.

When comparing GHG emissions pipelines come out far 'greener' than LNG. For example, in Europe, pipeline transmission has a seven-fold lower carbon footprint than LNG **[8]**. However, the GHG contributions of pipelines increase considerably over distance due to fugitive emissions of methane that are often inevitable along large pipeline tracks and these grow much faster than the transportation emissions from the tankers traveling over large distances.

The crossover point in between pipelines and LNG depends from many factors such as location, technology, and carbon emission taxes. Therefore the analysis may differ a lot in relation to the boundaries, according to a report originated by the EC, pipeline GHG emissions equalize emissions from LNG transport when transport distance is around 7,500 kilometers, or 4,660 miles **[8]**. In another analysis made in Australia cross-ocean liquid natural gas (LNG) transport is considered more economical for natural gas when distances are greater than ~2,000 kilometers. But compressing natural gas into LNG consumes nearly 30% of the underlying natural gas energy. Assuming 25% project savings through labor and 10-20% carbon emission cost reductions from avoiding LNG, the crossover point between pipeline and LNG lies at around 2,200 miles (3,666) kilometers **[14,28]**.

9 Comparison of NGICEs and gasoline ICE on direct CO_2 emissions (tailpipe emissions)

Following the criteria of the **Tank To Wheel** "TTW" analysis the ideal NGICE emits as much as 25% lower CO_2 than those of an equivalent gasoline ICE **[32,54]**. "*On a burned BTU basis, the gas burns cleaner, gas produces 29% less carbon dioxide than oil, and 44% less than coal. When it comes to sulfur dioxide, gas is 1,122 times cleaner than oil and 2,591 times cleaner than coal.*" **[15]**.

During combustion methane reacts with oxygen in the air to form carbon dioxide and water vapor:

$$\mathbf{CH_4 + 2O_2 > CO_2 + 2H_2O}$$

Assuming complete combustion, per every kg of methane there is a production of 2,74kg of CO_2.

The current metric (regulation) for comparing the GHG emissions of European passenger cars is based on measuring the tailpipe CO_2 emissions over the New European Drive Cycle (NEDC). The tailpipe CO_2 metric is insufficient for comparing the environmental impact of zero and ultralow emission vehicles, such as electric (EV) and Hybrids (HEV), since it does not consider CO_2 emissions resulting from the generation of the "fuel-electricity", or those embedded within the vehicle production. **But it is first of all insufficient to evaluate the overall real impact of NG motorizations.**

The NG powertrain of a midsize car weights on average 130kg more than that of the gasoline one. The production and transformation of the steel used to construct the tank requires an energy of about 50MJ/kg.

The necessary energy to transform the gasoline PWT into a methane one is 130kg x 50MJ/kg= 6500MJ.

6500MJ are equivalent to the energetic content of 160 l of gasoline that at 20km/l would allow a range of 3200km. In the hypothesis that the ideal NGICE would produce some 25% lower CO_2 emissions we have: $125*X = 100*3200+ 100*X$ resulting in X=12800km, that is, for the first 12800 km the global direct CO_2 emission of the gasoline engine is lower than that of the NGICE one. From that moment on, assuming an ideal maintenance and an ideal catalytic conversion for the abatement of the un-combusted methane, the direct emissions of NGICEs will be lower.

10 Comparison of NGICEs and gasoline ICE on total CO_2 emissions (Well To Wheel including gas leakage)

Gasoline ICEs: let's consider an ICE gasoline having direct emissions of 125gCO_2/km.

The OEMs and all major automotive agencies are used to the ratio 80/20. That is 80% of the CO_2 emissions due to direct combustion and 20% due to indirect emissions. A ratio confirmed by several Well To Wheel studies **[33]**. A more detailed LCA would include the energy needed to search the well, the energy necessary to extract oil and to build the infrastructures such as oil-pipelines, transformation plants, ships or ports.

Within that limit, the transformation of crude oil into gasoline consumes 8-12% of the energy contained in the oil. While to transport the fuel to the point of use the needed energy is another 3-5% **[33]**.

Indirect emissions vary in time and with the location of extraction. With the rapid diminishing of the average "EROEI" ratio Energy Return On the Energy Invested **[35],** the indirect emissions due to the search of the well and extraction of the crude oil are continuing to grow. At the same time the efficiency of modern engines have very much improved. Because of these two concurrent factors we consider that a ratio 70/30 in many cases is currently more realistic that the 80/20 one.

With indirect emissions at 20% we have a total of:

125+ 0,2x125= 150 grCO_2/km

With indirect emissions at 30% we have a total of:

125+ 0,3x125= 162,5 grCO_2/km

Natural Gas ICEs: let's consider the same engine with NG injection with direct emissions of: 100 CO_2/km, that is, an NG motorization working optimally with a 25% less CO_2 emission than the gasoline one.

Again we limit the discussion avoiding an LCA including the energy needed to search the well, the energy necessary to extract gas and to build the infrastructures such as: gas-pipelines, transformation plants, ships or ports.

The energy needed to transport the NG to the point of use is of the order of 10-15% per gas-pipelines **(**1.5-2.0% /1000km**) [14,8]** and 25-30% for LNG **[8,14].** We suppose that this energy is spent without gas leakage and with a combustion process (electricity generation for compressors, liquefiers…) having 50% efficiency.

Before considering gas leakage we have a total of:

100+ 0.07x100= 107 grCO_2/km for NG pipeline

100+ 0.20x100= 120 grCO_2/km for LNG Vessel

Clearly WTW analysis that do not include gas leakages lead to favorable conclusions [34].

The impact of methane leakages on every km run depends on the GWP index selected, that is on the urgency given to the problem:

- 3% overall leakage of methane:

(GWP 25): (3x25)/2.74 = 27,4 gr$CO_{2\ eq}$/km calculated over the 100 years' timescale,

Note: the coefficient 2.74 accounts for the difference in weight between CO_2 and CH_4.

(GWP 72): (3x72)/2.74= 78,8 gr$CO_{2\ eq}$/km calculated over the 20 years' timescale.

- 5% overall leakage of methane:

(GWP 25): (5x25)/2.74=125/2.74 = 45,6grCO_2 eq/km calculated over the 100 years' timescale,

(GWP 72): (5x72)/2.74=360/2.74=131,4grCO_2 eq/km calculated over the 20 years' timescale.

- 7% overall leakage of methane:

(GWP 25): (7x25)/2.74=175/2.74 = 63,9 grCO_2 eq/km calculated over the 100 years' timescale,

(GWP 72): (7x72)/2.74=504/2.74 = 184grCO_2 eq/km calculated over the 20 years' timescale.

- 10% overall leakage of methane:

(GWP 25): (10x25)/2.74=250/2.74 = 91,2 grCO_2 eq/km calculated over the 100 years' timescale,

Note: the coefficient 2.74 accounts for the difference in weight between CO_2 and CH_4.

(GWP 72): (10x72)/2.74=720/2.74 = 262,8 grCO_2 eq/km calculated over the 20 years' timescale.

The overall total depends on the adopted criteria and in particular to the degree of urgency attributed to the control of climate change. Certainly, even by rather conservative hypothesis on methane leakage, there is no real evidence that NG motorizations could lead to whatever lower carbon footprint than the gasoline one. In view of the urgency of the actions to be taken towards climate change mitigation, the most realistic statement would be **“the NGICEs emits as much as twice GHGs than the equivalent gasoline”.**

11 Conclusions

We have reported **WTW** comparison between NG and gasoline motorizations pointing out the advantages of NG in terms of noxious emissions while demonstrating that NG motorizations are **not at all the bridge to a low-carbon future of road transportation, i.e, FEVs.**

For ICEs gasoline we have chosen more severe boundaries than for NGICEs. That is for NG and shale gas we have chosen conservative data.

We have chosen conservative GWP values of 25 and 72 rather than more stringent values, and most likely more accurate, at **105** and **33** on a mass-to-mass basis for 20 and 100 years, respectively.

A detailed LCA study including the energy needed to construct a gas-pipelines (1 Ton/m of steel over several thousand kilometers) would further emphasize the critical GHGs position of NG and shale gas motorizations with respect to ICE gasoline (and coal when discussing the production of electricity).

The current gCO_2/km metric for comparing the GHG-emissions of passenger cars considers fixed drive cycle, defined reference fuels, and cold start emissions at the tailpipe only. Because the NG motorisation weight some 130 kg more than the equivalent gasoline one there is a clear advantage given to the NG motorisation. Another big advantage is that un-combusted methane is not added in the calculation. When over the years the engine or the catalysts get old the combustion of both gasoline and methane is far less than ideal, again in the comparison the gasoline is penalized.

Table 1 summarizes the findings.

Motorization	Total GHGs: gCO_2eq/km		Note
ICE gasoline direct	125		Regulation: tailpipe or TTW, cold start, NEDC
ICE gasoline indirect 20%	150		Classical WTW analysis adopted by OEMs and auto agencies.
ICE gasoline indirect 30%	162,5		Considers the continuous EROEI diminishing of oil.
Natural gas direct emissions Tailpipe or conventional TTW	100		1) Hypothesis of ideal 100% NG combustion emitting 25% less CO_2 than the equivalent gasoline engine. 2) NG motorizations with a tank on steel weights about 130kg more than the gasoline one. For the first 12800km the total direct CO_2 emissions of the gasoline engine are lower. 3) In a real driving cycles the increased weight of the NG motorization is such that the difference on emissions of the two ideal motorizations is less than 25%.
Natural Gas indirect emissions without leakages	107 NG Pipeline 120 LNG Vessel		Conventional WTW analysis.
Natural Gas indirect emissions with global 3% leakages of methane	**GWP 25** 107+27,4=134,4 120+27,4=147,4	**GWP 72** 107+78,8=185,8 120+78,8=198,8	Average leakage without distinction between NG and shale gas.
Natural Gas indirect with global 5% leakages of	**GWP 25** 107+45,6=152,6 120+45,6=165,6	**GWP 72** 107+131,4=238,4 120+131,4=251,4	Average leakage without distinction between NG and shale gas.

methane			
Natural Gas indirect emissions with global 7% leakages of methane	**GWP 25** 107+63,9=170,9 120+63,9=183,9	**GWP 72** 107+184=291 120+184=304	Average leakage without distinction between NG and shale gas.
Natural Gas indirect emissions with global 10% leakages of methane	**GWP 25** 107+91,2=198,2 120+91,2=210,2	**GWP 72** 107+262,8=369,8 120+262,8=**382,8**	10% overall leakage is the most likely value in view of: the growing percentage of shale gas - leakage at the pump and on the vehicle when ageing - 100% combustion with aging of catalysts-engine is not real.

Table1: Comparison between gasoline and NG motorization including various hypothesis on gas leakages.

In view of the very likely improvement of the efficiency of ICEs and of the associated catalysts, aiming at a fleet average emission of 95 CO_2 gr/km by 2020, the NG motorizations will be even more penalized, in that the percent of gas leakage on the overall total carbon footprint will increase simply because the percent of shale gas is increasing over the NG one.

The findings demonstrate the opposite of what most Energy and Transportation agencies have stated so far. Certainly the debate of NG and shale gas should consider their impact on GHGs. More stringent regulations on leakage control are urgent, but that will not change the perspective so much **[2].**

To state that gas pipelines will spread and be in place independently from the degree of NG motorization is a typical reaction of the organizations promoting the introduction of NGICEs, but the position is un-defendable.

Incentives to stimulate a larger adoption of NG and shale gas are not justified if the purpose if climate control via a low carbon economy.

On the positive side, natural gas emits virtually no particulates into the atmosphere: in fact, emissions of particulates from natural gas combustion are 90 percent lower than from the combustion of oil, and 99 percent lower than burning coal **[53]** .

Natural Gas can be used in the transportation sector to cut down on these high levels of pollution from gasoline and diesel powered cars, trucks, and buses. In fact, according to the EPA, compared to traditional vehicles, vehicles operating on compressed natural gas have reductions in carbon monoxide CO emissions of 90 to 97 percent. Nitrogen oxide NOx emissions can be reduced by 35 to 60 percent, and other non-methane hydrocarbon emissions could be reduced by as much as 50 to 75 percent. In addition, because of the relatively simple makeup of natural gas in comparison to traditional vehicle fuels, there are fewer toxic and carcinogenic emissions from natural gas vehicles, and virtually no particulate emissions **[53].** According to the Department of Energy (DOE), about half of all air pollution and more than 80 percent of air pollution in cities are produced by cars and trucks in the United States. A study by the Union of Concerned Scientists in 1998, entitled 'Cars and Trucks and Air Pollution', showed that the risk of premature death for residents in areas with high airborne particulate matter was 26 percent greater than for those in areas with low particulate levels **[53]**, similar studies have been made by the World Health Organization **[54].**

Acid rain is another environmental problem damaging crops, forests, wildlife populations, and causing respiratory and other illnesses in humans. Acid rain is formed when sulfur dioxide SO_2 and nitrogen oxides react with water vapor and other chemicals in the presence of sunlight to form various acidic compounds in the air. The principle source of acid rain causing pollutants, sulfur dioxide and nitrogen oxides, are coal fired power plants. Since natural gas emits virtually no sulfur dioxide, and up to 80 percent less nitrogen oxides than the combustion of coal, increased use of natural gas could provide for fewer acid rain causing emissions **[53].**

European industries have a technology leadership in all areas of the Natural Gas “NG” supply chain, whether in Europe, Usa, India, Pakistan, Iran, Russia or Brazil, Internal Combustion Engines operating with NG “NGICEs” adopt 100% EU technologies. EU OEMs and TIERs 1 foresee a rapid growth of the propulsion based on NGICEs as the only realistic alternative to mitigate the problematic related to liquid fuels **[1]**. Several Governments promote a shift toward NGICEs with motivations converging to what it is said “energy and national security”. NG reserves and the daily discovery of new shale gas sites are such that for more than 160 years gas fuels can meet the critical demands of all hydrocarbons HCs (petroleum or biofuels) for road transportation **[1]**.

Major industries and governments, because of the general energy context, tend to present the advantages emphasizing the lower CO_2 emissions of the NGICEs than the gasoline ones. **However detailed analysis demonstrate this is absolutely wrong [2,3,4,5,6]**. A Life Cycle Analysis including gas leakages leaves no doubts that the promotion of NGICEs is far less than a panacea for the environment. In a 20 years' timescale GHG emissions of NGICEs can be **more than twice** that of gasoline engines (it is worthwhile noticing that LCA analysis demonstrate that the global carbon footprint of small FEVs can be less than half than those of equivalent cars running on gasoline **[7]**). Motorisations based on biogas (closed cycle of carbon) represents a very minor share of the current total nor are expected to grow to an appreciable percentage.

NG is the cleanest HC fuel in terms of noxious emissions, but **the finding of this reports is that NG is not at all the bridge to a low-carbon future of road transportation. Shale gas is much worse** in that recent studies demonstrate that methane emissions are at least 30% more than and perhaps more than twice as great as those from conventional gas **[2,3].**

Energy policy is shaped by concerns about energy security, the adequacy of supplies at reasonable and stable prices, and environmental impacts of energy production and use. From a practical point of view, the diversification of gas imports is constrained by the fact that the lion's share of imports (≈85%) comes via pipelines, which ties up both the supply and the demand side for years in advance **[8]**, but the question here is not on securing or diversifying the supply, in that Russia (pipelines) and newer sources such as Liquefied Natural Gas (LNG) by sea, using specialized ships, will continue to be reliable in the decades. The growing EU dependency from the import of Natural Gas **[8]** cancels the economic benefits derived from the technology superiority of the EU industries. The global impact on Green House Gases "GHG" emissions (caused by leakages of methane) together with the economic constraints due to the importation of NG, pose questions on which area of road transportation Europe should continue to set the priorities and in which timescale.

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