European Association for Battery Electric Vehicles
www.going-electric.org

FINAL DRAFT

Energy consumption, CO_2 emissions and other considerations related to Battery Electric Vehicles

Abstract

1. **Electric vehicles consume less primary energy and substantially less final energy** than fossil fuel vehicles of same weight and performances (excluding driving range).

2. Taking account of the emissions generated by the production of electricity in the EU, the refining of oil and the distribution of energy, **electric vehicles generate less than half the CO_2** of fossil fuel vehicles of same weight and performances (excluding driving range).

3. In addition, because of their limited range, electric vehicles will mainly be used for daily commuting and urban traffic. They will therefore generally be smaller and lighter than fossil fuel vehicles and consequently **even cleaner and more fuel-efficient**. They will also contribute to **a reduction in traffic and car park congestion**.

4. Taking account of the production of electricity in the EU and the production and refining of oil, as well as of their distribution, it appears that, on average, **the four electric vehicles analysed in this study consume around 1.7 times less primary energy and generate less than half the CO_2 of a Toyota Prius**.

5. **Electric vehicles will not require significant increases in electrical infrastructure** until their number reaches 20-25%. However, they will provide electricity producers with financial incentives towards **improving the energy efficiency and CO2 emissions of electricity production**.

6. If electric vehicles were systematically used for city driving, the results worldwide would be:

   - To save around **20% of oil production**.
   - To significantly reduce **urban pollution**.
   - To eliminate almost all **traffic noise**.
   - To reduce **traffic and parking congestion**.

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Energy consumption and CO_2 emissions generated by Electric Vehicles

Comparison with fossil fuel vehicles

1. Summary and Conclusions

1.1 Electric vehicles consume less energy than fossil fuel vehicles.

If we calculate 'Tank-to-Wheel', that is to say only on the vehicle, an electric vehicle consumes around three times less final energy (= petrol, diesel or electricity) than a fossil fuel vehicle with the same weight and the same performance (excluding driving range).

However, energy is required to produce fossil fuel and electricity, as well as to distribute them. If we include this energy, then fossil fuel vehicles consume 'Well-to-Wheel' 20 to 80% more primary energy than electric vehicles of the same weight and performance, excluding driving range (20% = diesel-lead comparison, 80% = petrol-lithium comparison).

1.2 Electric vehicles generate significantly less CO_2 than fossil fuel vehicles.

Electric vehicles do not produce emissions and therefore, on a 'Tank-to-Wheel' basis, cause infinitely less pollution than fossil fuel vehicles.

If we compare 'Well-to-Wheel' CO_2 emissions generated from the source of the primary energy (oil well, mine…) to the vehicle, ***an electric vehicle generates*** on average, with the EU electricity mix, ***less than half the CO_2*** of a fossil fuel vehicle of the same weight and performance (excluding driving range).

1.3 Electric vehicles will generally be smaller and lighter and therefore even cleaner and more fuel-efficient.

In fact, because electric vehicles have a range limited by battery capacity, their use will essentially be limited to commuting and city-like trips, for daily distances of less than 50-100km. Such trips represent about 80% of the mileage covered by cars. For this usage, a small light vehicle is clearly preferable because it is more manoeuvrable in traffic and can be parked easier: it is only for longer trips that the comfort and luxury of a large car are really advantageous. Smaller and lighter vehicles are intrinsically less energy consuming and therefore **even cleaner and more fuel-efficient**.

In addition, the small size of electric cars will help ***reducing congestion on roads and in car parks***.

1.4 The electric cars in production or in the pipeline consume less energy and generate significantly less CO_2 emissions than the cleanest fossil fuel cars.

We compared the Toyota Prius hybrid (one of the cleanest petrol-engined cars on the market) with four electric cars: the Indian REVAi micro-car (the only electric car available to date in Belgium), the EV1 marketed by General Motors in 1999, the Dutch QUICC! mini-van (scheduled for end 2009) and the American Tesla Roadster sports car (in initial production phase).

Compared with the Prius, these electric cars consume on average almost 4 times less final energy (Tank-to-Wheel) and 1.7 times less primary energy (Well-to-Wheel). With the EU electricity mix, they generate 'Well-to-Wheel' less than half the CO_2.

1.5 Electric vehicles will have a positive impact overall on electricity production.

Since most users will recharge their electric vehicle at night during off-peak hours,

- Electric vehicles will essentially be recharged using the least energy-intensive and CO2-emitting fraction of the electricity production.
- Overall, BEVs will provide a financial incentive for electricity producers to improve the efficiency of electricity production and reduce its CO_2 emissions.
- Little expenditure on electricity infrastructure will be required until the number of BEVs exceeds 20-25% of the total number of cars.

1.6 The use of electric cars would yield to other major advantages.

Since city-like driving represents around 80% of all car journeys, worldwide use of electric cars for this type of driving would provide:

- A saving of around 20% in oil production.
- A significant reduction in urban pollution.
- The elimination of almost all traffic noise.
- A noticeable reduction of traffic and car park congestion.

2. Energy consumption

Electric vehicles consume less primary energy and significantly less final energy than fossil fuel vehicles of the same weight and performance (excluding driving range).

2.1 'Tank-to-Wheel' energy efficiency

For this purpose, let us compute the nominal Tank-to-Wheel energy efficiency for electric and fossil fuel vehicles, that is to say, the ratio of the energy transmitted to the wheels divided by the final energy (petrol, diesel or electricity) input into the car (via its fuel tank or electrical plug) in standard test conditions.

- **Fossil fuel vehicle**: The Tank-to-Wheel energy efficiency (from the fuel tank to the wheels) of the best internal combustion vehicles (excluding hybrids) is, in nominal operating conditions, generally less than **22% for diesel and 18% for petrol**.

  Note that the nominal figures are computed in rather ideal conditions. They vary a lot with driving style and traffic conditions and are generally lower in real life. They are notably quite lower in congested urban traffic, since then the engine operates often at low or high rotation speeds at which its efficiency is low, and because fuel vehicles consume energy when idling.

  In other words ***only 22% of the energy contained in diesel and 18% of that contained in petrol is transmitted to the wheels in ideal conditions*** – the rest is lost as heat!

- **Electric vehicle**: The Tank-to-Wheel energy efficiency (from the electrical plug to the wheels) is typically **60%** (55 to 65%) **with lead-acid batteries** and **72%** (65 to 80%) **with lithium batteries**: approximately 85-87% for the charger and 75-85% for the charging and discharging cycle with lead batteries; approximately 88-90% for the charger and 85-95% for the charging and discharging cycle with lithium batteries; 96-98% for the electronic engine management; and 90-95% for the electric motor.

  These numbers vary little with driving style and conditions, since electric motors have a reasonably constant efficiency at most rotation speeds and because electric vehicles consume no energy when idling.

  In other words, typically ***60-72% of the electrical energy consumed at the plug is transmitted to the wheels*** – and 40 to 28% is lost as heat! These figures are valid in all driving conditions.

The 'Tank-to-Wheel' energy efficiency of electric vehicles is therefore around three times better than that of the best fossil fuel vehicles (excluding hybrids) in ideal conditions. It is even better if computed in real-life conditions.

This means that an electric vehicle consumes at least three times less final energy than any fossil fuel vehicle (excluding hybrids) with the same weight and performance (excluding range).

2.2 'Well-to-Wheel' energy efficiency

The Well-to-Wheel energy efficiency of a vehicle is the ratio between the final energy transmitted to the wheels divided by the primary energy at the source (oil well, mine…). It is equal to the Tank-to-Wheel efficiency (as computed above in 2.1), multiplied by the Well-to-Tank efficiency, which is the efficiency from the source of final energy (oil well, mine…) to its introduction into the vehicle (fuel tank or electrical plug).

2.2.1 Fossil fuel vehicle

The Well-to-Wheel energy efficiency (from the primary energy source to the vehicle wheels) for the best performing conventional fossil fuel vehicles (excluding hybrids) is nominally **around 15% for petrol and 18% for diesel** (and lower in most real traffic conditions):

- The Well-to-Tank energy efficiency (from the primary energy source to the fuel tank), which takes into account the energy consumed by the production, refining and transport of the fuel, is **around 83%.**

  This means that the production, refining and distribution of a litre of fuel delivered to the vehicle and fuel tank consume the equivalent of a fifth litre of fuel.

- The nominal Well-to-Wheel energy efficiency of the best fossil fuel vehicles (excluding hybrids) is therefore around 15% (= 16% x 83%) for petrol and around 18% (= 22% x 83%) for diesel.

  This means that, in ideal driving conditions, only ***around 15% (petrol) or 18% (diesel) of the primary energy is transmitted to the wheels*** – the rest is lost as heat!

- These numbers can be significantly lower depending on traffic conditions and driving style, because engine's efficiency depends largely on rotation speed and since fuel vehicles consume energy when idling.

2.2.2 Electric vehicle

The 'Well-to-Wheel' energy efficiency (from the primary energy source to the car wheels) of an electric vehicle is **around 22%** with lead-acid batteries and **around 27%** with lithium batteries:

- The 'Well-to-Tank' energy efficiency (from the primary energy source to the electrical plug), taking into account the energy consumed by the production and distribution of the electricity, is estimated at **around 37%**:

  - The energy efficiency of electricity production is difficult to estimate, because it varies widely depending on the type of power plant: approximately 30-40% for conventional power plants, 50-55% for combined-cycle power plants with integrated gasification, 50-60% for combined-cycle gas power plants, up to around 90% for combined systems were all the steam is re-utilised. Furthermore, any comparison is difficult for power plants which do not use fossil fuels (wind turbines, hydroelectric, nuclear, etc).

    A figure of around 40% is however often considered a useful average for this type of calculation. In other words, only around 40% of the primary energy arriving at the power plant is converted into electricity – the rest is lost as heat!

  - The energy efficiency of electricity distribution is around 92.5% (90 to 95%). This means that approximately 92.5% of the electricity produced at the power plant arrives at the consumer – the rest is lost as heat!

  - The 'Well-to-Tank' energy efficiency is therefore estimated at around 37% (= 40% x 92.5%). This figure is close to the JRC figure of 35% quoted in annex 1.

- Given that the 'Tank-to-Wheel' efficiency averages 60 % for electric vehicles with lead-acid batteries and 72 % for those with lithium batteries (see 2.1), the average 'Well-to-Wheel' energy efficiency of electric vehicles is therefore:

    - around 22% (= 60% x 37%) with lead-acid batteries,
    - around 27% (= 72% x 37%) with lithium batteries.

This means that only ***around 22% (lead-acid) to 27% (lithium) of the primary energy is transmitted to the car wheels*** – the rest is lost as heat! These numbers depends only moderately on the driving style and traffic conditions, since electric motors have a reasonably constant efficiency over most rotation speeds and because electric vehicles consume no energy when idling.

2.2.3 Comparison

Nominally, the 'Well-to-Wheel' energy efficiency:

- of an electric vehicle with lead-acid batteries is on average:
    - 1.2 times better than that of the best diesel vehicles (excluding hybrids).
    - 1.5 times better than that of the best petrol vehicles (excluding hybrids).

- of an electric vehicle with lithium batteries is on average:
    - 1.5 times better than the best diesel vehicles (excluding hybrids).
    - 1.8 times better than the best petrol vehicles (excluding hybrids).

In real traffic conditions, these ratios can be much higher.

This means that over 20 to 80% more primary energy is required for a fossil fuel vehicle (excluding hybrids) than for an electric vehicle with the same weight and performance (excluding driving range).

3. CO_2 emissions

Electric vehicles generate significantly less CO_2 emissions than fossil fuel vehicles with the same weight, power and performance (excluding driving range).

3.1 Tank-to-Wheel emissions of CO_2

The manufacturers of fossil fuel vehicles only provide figures for the emissions generated directly by the operation of the car's engine, in other words of the 'Tank-to-Wheel' emissions (from the petrol tank to the wheels).

For electric vehicles, which emit nothing during their operation, the Tank-to-Wheel CO_2 emissions are zero: ***electric vehicles are therefore infinitely cleaner than fossil fuel vehicles.***

3.2 Well-to-Wheel emissions of CO_2

It is more appropriate to compute Well-to-Wheel CO_2 emissions in order to compare electric vehicles with fossil fuel vehicles, that is to say the CO_2 emissions generated not only by the vehicle, but also by the power plant or the oil refinery and by the distribution of the fuel or electricity.

3.2.1 Petrol-engined vehicle

- Nominally, for each kWh of energy transmitted to the wheels, around 5.6 kWh (= 1 kWh / 18%) of petrol in the tank is required Tank-to-Wheel (18% = efficiency – see 2.1). This number is higher in most real traffic conditions.

- According to appendix 2, the Joint Research Centre of the European Commission estimated in 2006 that in order to obtain the Well-to-Wheel value for CO_2 emissions from a petrol-engined vehicle, it is necessary to add 17% to the Tank-to-Wheel figures. Since:
  - the combustion energy from petrol is around 37 MJ/l and 1 kWh = 3.6 MJ,
  - the combustion of 1 litre of petrol produces around 2.35 kg of CO_2,
  Therefore Well-to-Wheel, each kWh of energy transmitted to the wheels emits nominally around **1490 g of CO_2** (= 5.6 kWh x 3.6 MJ/kWh / 37 MJ/l x 2.35 kg CO_2/l x (1+17%) x 1000 g/kg) – and generally more in real traffic conditions.

3.2.2 Diesel-engined vehicle

- Nominally, for each kWh of energy transmitted to the wheels, around 4.5 kWh (= 1 kWh / 22%) of fuel is required (22% = Tank-to-Wheel efficiency – see 2.1). This number is higher in most real traffic conditions.

- According to appendix 2, in order to obtain the Well-to-Wheel value for CO_2 emissions of a diesel-engined vehicle, it is necessary to add 19% to the Tank-to-Wheel figures. Since:
  - the combustion energy of the diesel engine is around 38 MJ/l and 1 kWh = 3.6 MJ,
  - the combustion of 1 litre of diesel fuel produces around 2.7 kg of CO_2,
  Therefore, each kWh of energy transmitted to the wheels emits, Well-to-Wheel, around **1380 g of CO_2** (= 4.5 kWh x 3.6 MJ/kWh / 38 MJ/l x 2.7 kg CO_2/l x (1+19%) x 1000 g/kg) – and generally more in real traffic conditions.

3.2.3 Electric vehicle with lead-acid batteries

- For each kWh of energy transmitted to the wheels, an average of 1.7 kWh of electrical energy is required Tank-to-Wheel (= 1 kWh / 60% – see calculation in 2.1), whatever the driving style and traffic conditions.

- According to the JRC, the production and distribution of one kWh of electricity generates, with the 2006 average European Union (EU) energy mix, around 443 g of CO_2 (see appendix 1). Therefore Well-to-Wheel, each kWh of energy transmitted to the wheels generates on average **738 g of CO_2** (= 1.7 kWh x 443 g CO_2/kWh).

3.2.4 Electric vehicle with lithium batteries

- For each kWh of energy transmitted to the wheels, an average of 1.4 kWh of electrical energy is required (= 1 kWh / 72% – seek calculation in 2.1), whatever the driving style and traffic conditions.

- Therefore, with the average EU energy mix, each kWh of energy transmitted to the wheels generates around **616 g of CO_2** Well-to-Wheel (= 1.4 kWh x 290 g CO_2/kWh).

3.2.5 Comparison of CO_2 emissions

With the average EU electricity mix, Well-to-Wheel CO_2 emissions of an electric vehicle are, on the average, nominally less than half the CO2 emissions of a fossil fuel vehicle with the same weight and performance (excluding driving range) in nominal traffic conditions – and even less in most real traffic conditions :

- CO_2 of a diesel powered car = 1.9 x CO_2 of an electric car with lead-acid batteries
- CO_2 of a petrol powered car = 2.0 x CO_2 of an electric car with lead-acid batteries
- CO_2 of a diesel powered car = 2.2 x CO_2 of an electric car with lithium batteries
- CO_2 of a petrol powered car = 2.4 x CO_2 of an electric car with lithium batteries

These ratios are generally higher in real traffic conditions.

3.2.6 Remark

The emissions generated by electric vehicles in a country depend on the electricity mix in that country. For instance:

- The Belgian electricity mix emitted, in 2003, 290 g CO2/kWh (according to IEA - annex 1). With this number, Well-to-Wheel CO_2 emissions of an electric car in Belgium are more than three times less than a fossil fuel vehicle with the same weight and performance:

    - CO_2 of a diesel powered car = 2.9 x CO_2 of an electric car with lead-acid batteries
    - CO_2 of a petrol powered car = 3.1 x CO_2 of an electric car with lead-acid batteries
    - CO_2 of a diesel powered car = 3.4 x CO_2 of an electric car with lithium batteries
    - CO_2 of a petrol powered car = 3.7 x CO_2 of an electric car with lithium batteries

- If an electric vehicle is recharged mainly with ***renewable or nuclear electricity***, which generate practically no CO_2 emission, its Well-to-Wheel CO_2 emission are ***close to zero***. This is the case in countries such as Norway, Sweden and France.

- If an electric vehicle is recharged mainly with ***coal power plants***, which generate over 1000 g CO_2/kWh, its Well-to-Wheel CO_2 emissions are ***equal to or higher*** than a fossil fuel vehicle with the same weight and performance. This is the case in countries such as Luxemburg and Poland.

4. Weight and power considerations

Given that electric cars have a limited range due to their battery capacity, their use will essentially be limited to commuting, town trips and other short trips which are often made in dense traffic conditions and with a single person on board. Also, it is generally accepted that about 80% of cars mileage are for trips of less than 50 km with a single person on board.

For this type of traffic, a small light car is clearly preferable because it is manoeuvrable in traffic and can be parked more easily. It is only for longer journeys that the comfort and luxury of a large powerful car are really advantageous.

Indeed, most electric cars currently in production or in the pipeline are small and light:

- Small manufacturers specialised in electric cars (such as REVA, Duracar and Lumeneo) generally opt for tubular chassis with plastic bodies, which are much lighter than steel bodies.

- Several major manufacturers are getting prepared to test the market by converting their smaller models to electric power (such as SMART, MINI and Mitsubishi iMiev). If successful, it is not unlikely that they will thereafter design models specifically for electric propulsion.

- It must be noted that, although batteries are much heavier than fuel tanks, electric cars can be made lighter than conventional cars while having a driving range sufficient the daily trips of most drivers:
    - An electric motor is several times lighter than an internal combustion engine with the same power.
    - An electric car does not require a gearbox.
    - An electric car does not require the heavy acoustic insulation and the steel body that are necessary to damp the sound produced by the engine.
    - It can be expected that batteries will become increasingly smaller and lighter in the future, which will further reduce electric vehicles' weight to range ratio.

It is therefore likely that electric vehicles will tend to become increasingly smaller and lighter. Obviously, for a same technology, small light cars are more energy-efficient and emit less CO_2 than large powerful ones.

Therefore, ***electric cars will be even more energy efficient and emit even less CO_2 than fossil fuel cars.***

Furthermore, their reduced size will also contribute to ***reducing traffic and parking congestion.***

5. Comparison between some vehicles

To illustrate these figures, let us compute the quantity of primary energy consumed by four electric vehicles and their Well-to-Wheel CO_2 emissions in nominal conditions.

- The **REVAi** is a heavy Indian electric micro-quadricycle with 2+2 seating, very manoeuvrable in town and with a top speed of 80 km/h. In production since 2001, it is currently the only electric car marketed in Belgium and in many European countries.

- The **EV1** is the two-seater electric coupe that General Motors marketed in the United States from 1996 to 1999.

- The **QUICC!** from Duracar is a small Dutch electric two-seater minivan. It is scheduled to go on sale in the second half of 2009.

- The **Tesla Roadster** is an American two-seater electric sports car based on the Lotus Elise with performance competing with the best petrol-engined sports cars. Pre-marketing began this year in the United States.

5.1 Fossil fuel reference vehicle

As a point of comparison, we have chosen the **2008 Toyota Prius**, one of the cleanest fossil fuel vehicles on the market whose nominal petrol consumption is 4.3 litres per 100 km and whose nominal Tank-to-Wheel emissions are 104 g CO_2/km. Therefore:

- The nominal **Tank-to-Wheel energy** of the Prius is around **44 kWh/100km** (= 4.3 l/100km x 37 MJ/l / 3.6 MJ/kWh).

This figure must be divided by the Well-to-Tank efficiency in order to obtain the Well-to-Wheel values (approximately 80% - see 2.2.1). So we have:

- **Nominal Well-to-Wheel consumption**: approximately **55 kWh/100km** (= 44 kWh/100km / 80%) of primary energy.

- **Nominal Well-to-Wheel emissions of CO_2**: approximately **122 g CO_2/km** (= 104 g CO_2/km x (1 + 17%) (see 3.2.1).

5.2 REVAi electric car

The Indian **REVAi** is a small electric car that has lead-acid batteries and uses technology developed ten years ago. The nominal figures provided by the constructor (www.revaindia.com) are:

- Electricity consumption for each full charge: approx. 9 kWh
- Range on a full charge: 80 km nominal

Therefore:

- **Nominal Tank-to-Wheel consumption**: approximately **11 kWh/100 km** of electricity (= 9 kWh/charge / 80 km/charge x 100), or almost *4 times less than the Prius*.

- As for all electric vehicles, **Tank-to-Wheel CO_2 emissions are zero.**

- **Nominal Well-to-Wheel consumption**: approximately **30 kWh/100 km** (= 11 kWh / 37%) of primary energy, or around *1.8 times less than the Prius*.

- **Nominal CO_2 emissions Well-to-Wheel**: approximately **50 g CO_2/km** (= 11 kWh/100 km / 100 x 443 g CO_2/kWh) with the average EU energy mix, or *almost 2.5 times less than the Prius*.

5.3 EV1 electric car

The 1999 **EV1** model from General Motors used up-to-date technology and efficient NiMH batteries. According to the US Department of Energy (DOE) (source: http://www1.eere.energy.gov/vehiclesandfuels/avta/pdfs/fsev/eva_results/ev1_eva.pdf), its nominal **Tank-to-Wheel consumption** was around **11 kWh/100 km** of electricity (= 179 Wh/mile / 1.609 km/mile x 100 km/100km), or *the same as the REVA*.

Therefore, its nominal **Well-to-Wheel** characteristics are the same as the REVAi: **30 kWh/100 km** of primary energy (*approximately 1.8 times less than the Prius*) and **50 g CO_2/km** with the average EU energy mix (*almost 2.5 times less than the Prius*).

The EV1 weighed almost twice as much as the REVA and had a much better performance. It is therefore remarkable that its fuel consumption and CO_2 emissions were the same as those of the REVAi. This may perhaps be explained by greater efficiency of the EV1's batteries, electronics and/or motor, as well as by its advanced aerodynamics.

5.4 QUICC! electric mini van

The small Dutch QUICC! electric mini van will use different types of batteries. The manufacturer has announced an electricity consumption of 1 kWh per 7 km with lead-acid batteries (see appendix 2). Therefore:

- **Nominal Tank-to-Wheel consumption**: approximately **14 kWh/100 km** of electricity (= 1 kWh / 7 km x 100), or *about three times less than the Prius*.

- As for all electric vehicles, its **CO_2 emissions Tank-to-Wheel are zero.**

- **Nominal Well-to-Wheel consumption**: approximately **39 kWh/100 km** (= 14 kWh / 37%) of primary energy, or around *1.4 times less than the Prius*.

- **Nominal CO_2 emissions Well-to-Wheel**: approximately **63 g CO_2/km** (= 11 kWh/100 km / 100 x 443 g CO_2/kWh) with the average EU energy mix, or almost *half of the Prius*.

5.5 TESLA electric car

The American **Tesla Roadster** electric sports car uses lithium batteries with advanced technology.

The manufacturer announces a nominal Tank-to-Wheel efficiency of 2.18 km/MJ (source: www.teslamotors.com/efficiency/well_to_wheel.php). Based on this efficiency, we find:

- **Nominal Tank-to-Wheel consumption**: **12.7 kWh/100 km** of electricity (= 1 / 2.18 km/MJ / 3.6 MJ/kWh x 100), or *3.5 times less than the Prius*.
- As for all electric vehicles, its **CO_2 emissions Tank-to-Wheel are zero.**
- **Nominal Well-to-Wheel consumption**: **34.4 kWh/100 km** (= 12.7 kWh / 37%) of primary energy, or approximately *1.6 times less than the Prius*.
- **Nominal CO2 emissions Well-to-Wheel**: **56 g CO_2/km** (= 12.7 kWh/100 km / 100 x 443 g CO_2/kWh) with the average EU energy mix, i.e. *2.2 times less than the Prius*.

5.6 Summary

The summary table below shows that, compared to the Prius, electric cars available on the market or in the pipeline, consume on average 3.6 times less energy Tank-to-Wheel and 1.7 times less primary energy Well-to-Wheel, and that they generate Well-to-Wheel 2.3 times less CO_2 with the average EU electricity mix.

	Final energy	Primary energy	CO_2 Emissions
	(Tank-to-Wheel)	(Well-to-Wheel)	Well-to-Wheel
	kWh/100km	kWh/100km	g CO_2/km
Prius	44	55	122
REVAi	11	30	50
EV1 NiMH 1999	11	30	50
QUICC!	14	39	63
TESLA Roadster	13	34	56
Ratio Prius/electric cars	3.7	1.7	2.3

REMARKS:

- In this chapter, we have consistently used the nominal figures provided by manufacturers (for the Prius as well as for the electric cars). As we know, figures computed in real traffic conditions are generally quite worse and depend also largely on driver's style. However, assuming all manufacturers use similar nominal conditions, comparisons remain reasonably valid in real traffic conditions and with different drivers.

- CO2 emissions of electric cars are here computed using JRC's 2006 EU electricity mix number (443 g CO2/kWh – see annex 1). This number varies greatly from one member state to the other. For instance:

Country	gCO2/kWh	Average CO2 electric cars	Prius/electric CO2 ratio
Sweden	40	5	25.0
France	90	11	11.1
Belgium	290	35	3.5
EU15	443	54	2.3
Germany	600	73	1.7
Netherlands & UK	640	78	1.6
Denmark	840	102	1.2
Luxemburg	1080	131	0.9

6. Impact on electricity production

Electric vehicles will improve the efficiency and cleanliness of electricity production without requiring, in a first stage, any significant increase in infrastructure

Electric vehicle will consume a lot of electricity - approximately 2000 kWh/year for a car - whereas the average consumption of Belgian households is around 3500 kWh/year. In order to make savings, the majority of users will prefer to recharge their electric vehicle at night during off peak-hours, in order to benefit from the cheapest tariff. For electricity production this offers several advantages:

- For continuous electricity production, it is generally more profitable to operate high-efficiency power plants which cause less CO2 emissions and air pollution, since their marginal operating cost is lower and their higher investment expenditure can be depreciated over more operating hours.

  Conversely, in order to supply the additional electricity during short periods of high demand, it is generally more profitable to operate less capital-intensive power plants, which have a lower efficiency and generate more CO2 emissions and air pollution, because their lower investment expenditure can only be depreciated over a small number of operating hours.

  Therefore, electric vehicles being essentially charged with off-peak electricity, ***BEVs will use the most efficient and less CO2 emitting fraction of the electricity production***: this will further improve BEVs Well-to-Wheel energy consumption and CO_2 emissions.

- The increase in electricity consumption during off-peak hours will contribute towards a levelling of the electricity demand. This will provide electricity producers with a financial incentive to profitably replace low-capital peak power plants, which are less efficient and emit more CO2, with capital-intensive power plants designed for continuous operation, which are more efficient and emit less CO2 and air pollutants. ***This will overall improve the efficiency and CO_2 emissions of the electricity production.***

- ***Electric vehicles will require little capital expenditure on electrical infrastructure*** (network and power plants) in the first stages of BEV commercialisation. Indeed, infrastructure is dimensioned to cope with the periods of high demand during which few electric vehicles will be on charge in order to benefit of off-peak tariffs. This will increasingly be the case with the generalisation of smart electricity metering which will provide strong incentives to charge off-peak.

  In appendix 3, we compute that ***at least 23% of the cars in France can be electric cars without requiring significant increase in the electrical infrastructure***, assuming that all BEVs are charged off peak hours. It is likely that this number can be roughly extrapolated to the whole of Europe.

7. Other factors to be taken into consideration

7.1 Electric vehicles reduce oil dependency

Only a small fraction of electrical energy is generated using petroleum products. Furthermore, urban-like traffic (trips of less than 50km) represents worldwide around 75 to 80% of cars mileage and consumes around 20% of the total petroleum production.

Hence, ***worldwide oil consumption would diminish by around 20%*** if all these trips were made in electric vehicles. This would significantly reduce our dependency on oil.

7.2 Electric vehicles reduce urban pollution

A large proportion of the pollutants emitted in town are produced by road traffic. For example, the MIRA-T report estimates that for Flanders, road traffic is responsible for 49% of NOx emissions, 32% of carbon monoxide (CO), 17% of hydrocarbons, and 25% of fine particles (PM10). Since electricity production only emits a fraction of these pollutants, ***the generalised use of electric vehicles in cities would significantly reduce urban pollution***.

7.3 Electric vehicles reduce urban noise

Road traffic is responsible for the majority of the noise in cities. Since electric vehicles are very silent, widespread use in town would eliminate the majority of the road noise, ***thus significantly reducing urban noise levels***.

NOTE: It is incorrect that the lack of noise is dangerous for pedestrians and other road users:

- Pedestrians look left and right before crossing – they do not close their eyes and listen to the sound!
- Bicycles are even more silent than BEVs and are not known to be a hazard to pedestrians (except of footpaths).
- Blind people generally have an excellent hearing and can hear the tire and wind noise produced by BEVs. Furthermore, they are usually precautious when crossing streets.

Anybody driving a BEV can confirm it. And statistics do not show that BEVs cause more accidents.

6.4 Electric cars reduce traffic and parking congestion

Being generally smaller that average fossil fuel cars, electric cars take less space in road traffic and will therefore somewhat reduce traffic congestion.

Also in some countries, smaller parking spaces are already reserved for ultra-small cars such as the SMART. With the multiplication of ultra-small electric cars, it is likely that more small parking places will be made available, providing more parking places per unit of surface. This will contribute to reduce car parks' congestion.

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Appendix 1:

National average values for CO_2 emissions per electrical kWh for various countries

Source 1: IEA

IEA 2003 report, retrieved from http://www.econologie.com/europe-emissions-de-co2-par-pays-et-par-kwh-electrique-articles-3722.html.

- Sweden: 0.04 kg CO_2 / kWh electricity
- France: 0.09 kg CO_2 / kWh electricity
- Austria: 0.20 kg CO_2 / kWh electricity
- Finland: 0.24 kg CO_2 / kWh electricity
- Belgium: 0.29 kg CO_2 / kWh electricity
- Spain: 0.48 kg CO_2 / kWh electricity
- Italy: 0.59 kg CO_2 / kWh electricity
- Germany: 0.60 kg CO2 / kWh electricity
- Netherlands: 0.64 kg CO_2 / kWh electricity
- Greece: 0.64 kg CO_2 / kWh electricity
- United Kingdom: 0.64 kg CO_2/ kWh electricity
- Portugal: 0.64 kg CO_2 / kWh electricity
- Ireland: 0.70 kg CO_2 / kWh electricity
- Denmark: 0.84 kg CO_2 / kWh electricity
- Luxembourg: 1.08 kg CO_2 / kWh electricity
- Average for EU15: 0.46 kg CO_2 / kWh electricity

Source 2: JRC

The 2006 "Well-to-Tank" report of the Joint Research Centre (JRC) of the European Commission quotes a EU WTT figure of 430 g CO2/kWh – see http://ies.jrc.ec.europa.eu/uploads/media/WTT_Report_010307.pdf page 51):

> "Including the distribution losses to the medium voltage level the overall energy efficiency is around 35 % and the corresponding GHG emissions 430 g CO_2eq/kWh$_e$ (119 g CO_2eq/MJ$_e$). A further correction is made for those cases where electricity is produced or used at low voltage. The detailed primary energy composition is given in *WTT Appendix 1, section 3.*"

Assuming a medium to low voltage loss of 3%, EU electricity's CO2 emissions are 443 g CO2/kWh.

Appendix 2: Proving EVs to be the most environmentally friendly!

Source: DuraCar Holding B.V.

In 2005 there were 790 million cars worldwide. At least 14% of worldwide greenhouse gas emissions are from transport. ***Looking at the calculations on the next page, it is important to distinguish between:*** **Well-to-Wheel = Well-to-Tank + Tank-to-Wheel.**

According to the ANWB , the Dutch equivalent of the 'RAC Patrol motoring organization', the two cars that are perceived as being most environmental friendly are 2 passenger cars, Toyota Prius and Honda Civic. Obviously this is not a coincidence.

The issue with published grams of CO_2 per km figures is that these are always tank-to-wheel numbers.

German electric mobility expert, Mr. Tomi Engel, conducted an extended research for DGS (Deutsche Gesellschaft für Sonnenenergie e.V. – www.dgs.de) and BSM (Bundesverband Solare Mobilität – www.solarmobil.net) and published results in a book (ISBN 978-3-89963-327-7). All the numbers below can also be found in his publication.

In order to include the CO_2 that originates from the production of petrol or diesel, the following factors have to be taken into account (source: EJRC-2006, European Commission Joint Research Centre):

Petrol	*17%*
Diesel	*19%*
Natural Gas	*15%*

Most EV producers or start-ups publish zero grams of CO_2 per km. However, this is tank-to-wheel as well. The German öko-institute GEMIS, published studies about the energy sector and amounts of CO_2 originating from different types of electricity production. These numbers provide the necessary Well-to-tank numbers in order to provide a complete overview.

EU 15 Gridmix	*439 g CO_2/kWh*	*439 / 7 = 63 g CO_2/km*
Solar Energy	*89-168 g CO_2/kWh*	*89-168 / 7 = 12 – 24 g CO_2/km*
Wind Energy	*19 g CO_2/kWh*	*19 / 7 = 3 g CO_2/km*

QUICC! uses 1kWh per 7 kilometers (tested and calculated together with Prof. Sauer, battery specialist, from the RWTH – technical university of Aachen, Germany).

This would result in the following results, proving in a complete Well-to-Wheel analysis that driving EVs is by far the most environmental option!

Car	Type of Energy	Published Tank-to-Wheel CO_2 g / km	Well-to-Tank CO_2 g/km	Total Well-to-Wheel CO_2 g / km
Most popular hybrid passenger car	**HEV**	**104 g/km**	**+17%**	**122 g/km**
2nd most popular hybrid passenger car	**HEV**	**109 g/km**	**+17%**	**128 g/km**
Most popular delivery van	**Diesel**	**161 g/km**	**+19%**	**192 g/km**
2nd most popular delivery van	**Diesel**	**147 g/km**	**+19%**	**175 g/km**
QUICC!	**Wind energy**	**0 g/km**	**3 g /km**	**3 g /km**
QUICC!	**Solar energy**	**0 g/km**	**12 – 24 g/km**	**12 – 24 g/km**
QUICC!	**EU15 grid-mix**	**0 g/km**	**63 g/km**	**63 g/km**

In this comparison the delivery vans chosen have engines of approx. 1.4 litres.

Appendix 3: Electrical infrastructure

In this annex, we provide a bold-part answer to the following question is: ***How many battery electric vehicles (BEVs) can be put on the road without requiring additional electrical infrastructure (grid and/or power plants)?***

Electricity demand varies greatly:

- During the day: it is lowest at night, higher in the day and generally peaks in the evening
- During the week: it is lowest during week-ends.
- During the year: in temperate European countries, it is higher in the winter

Thus electricity demand is highest during winter's weekday evenings (around 6-7pm). Electricity production and transport infrastructure is designed to cope with these peaks. BEVs will require additional infrastructure only if they cause an electrical consumption increase during peak hours.

Therefore, our question can be rephrased as: ***How many BEVs can be put on the road without increasing the electricity demand during winter's weekday evenings?***

In the graph below showing electricity demand in France over one winter day, it appears that:

- Peak demand (84 000 MW around 6pm) is 32% higher than the lowest demand (63 400 MW at 4 am).
- The highest demand during off-peak hours (between midnight and 6am – about 72 700 MW), is about 20% lower than the peak demand.
- The energy available between midnight and 6am (striped zone) is about 91 000 MWh (= (84 000 MW – 68 800 MW) x 6 h)

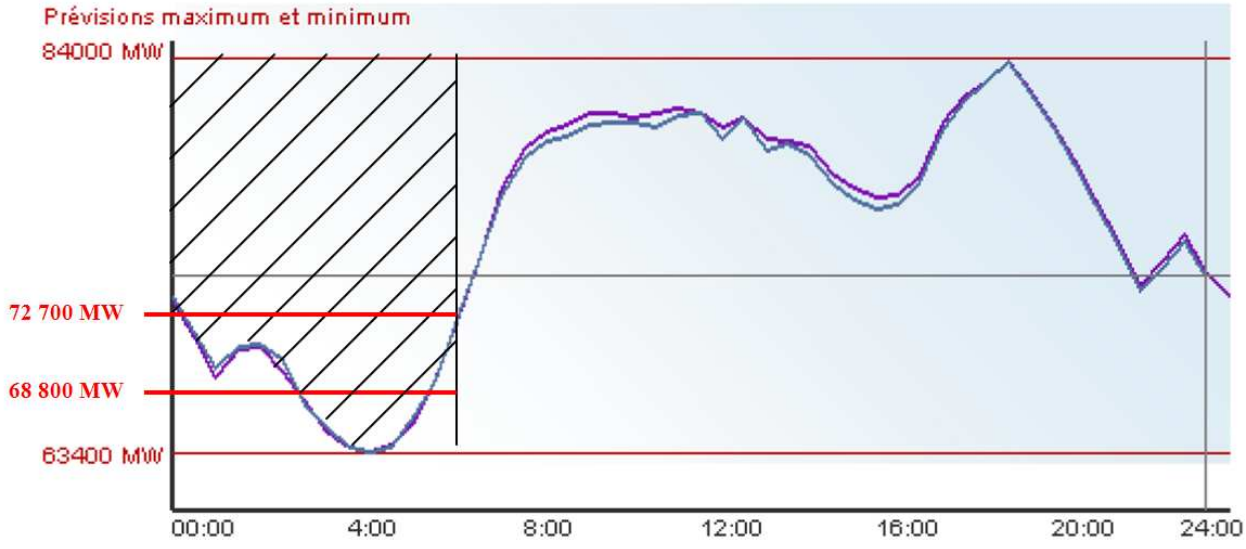

Figure 2
Evolution de la demande pendant une journée ouvrée d'hiver (17/12/2008)

Source: http://www.sauvonsleclimat.org/new/spip/IMG/pdf/Acket-Nucleaire_et_suivi_reseau.pdf

Assuming that 100% BEVs charge at night, starting at midnight (this can easily be done by installing a timer on the plug connected to the BEV), and knowing that BEV loading current is highest during the first hours of battery loading – and comparatively very low after 6 hours, then about 20% of the peak power is available for BEV charging at night (between midnight and 6 am) without exceeding the peak demand.

To simplify the computation, we assume that all BEVs will in the first stage be passenger cars, as well as very small trucks, which draw similar power to electric cars, and neglect:

- Electric bicycles, scooters and motorcycles, which draw comparatively little power.
- Heavy trucks and busses, which are only likely to reach significant numbers in 5 to 10 years if ultra-fast-charging batteries become available.

Assuming that:

- Car-like BEVs drive on the average 50 km per weekday (this is probably a maximum),
- BEVs consume on the average 20 kWh per 100 km (realistic figure in urban traffic),
- BEVs draw on the average 10 Amps or 1.56 kW (= 10 A x 220 / SQRT (2)) during the first 6 charging hours (realistic figure).

Then each EV will charge 10 kWh per day and draw 10 Amps (2.2 kW) between midnight and 6 am.

In France, according to the above graph, the instantaneous power available between midnight and 5am without exceeding peak power is at least 11 300 MW (= 84 000 MW – 72 700 MW), and the energy available during this time is about 91 000 MWh (see above). Considering:

- Instantaneous power: the maximum number of EVs that can charge without exceeding peak power is 7.3 million (= 11 300 000 kW / 1.56 kW).
- Energy: the maximum number of EVs that can charge without exceeding energy available between midnight and 6am is around 9.1 million (= 91 000 000 kWh / 10 kWh).

Taking the most conservative of these two figures, we conclude that, under our assumptions, ***the electrical power infrastructure will not have to be reinforced before the total number of BEVs in France reaches 7.3 million.***

NOTES:

- This computation assumes that all BEVs are electric cars (and ultra-small trucks). It ignores electrical bicycles and scooters whose numbers are growing fast. It also ignores electrical busses and trucks, which will need to charge in the daytime and are likely to reach significant numbers in 5 to 10 years assuming ultra-fast-charging batteries become available (which is likely). If we were to take these additional BEVs into account, our numbers would be slightly lower.

- All other assumptions are rather conservative. Notably we assume that all BEVs will charge at maximum power between and only between midnight and 6am. However it is also possible to charge many more BEVs at other hours (except the peak hour) without exceeding the peak hour's maximum.

- Smart electrical power metering will become compulsory between 2020 (80%) and 2022 (100%). This will offer consumers the possibility and price incentives to charge only off peak hours and will therefore increase the number of BEVs that can be put on the road without requiring additional electrical infrastructure.

- The 7.3 million number is high compared to the current number of BEVs in France, estimated to 11 000 in 2007 by IEA – mostly bicycles and scooters. There is a lot of room for development!

- Knowing that there are about 32 million cars in France (for a population of about 65 million) (source: http://www.statistiques-mondiales.com/ue_voitures.htm), it means that nearly one car out of four (23%) can be a BEV without requiring additional electrical infrastructure.

- Assuming that the French figures can be extrapolated to the whole of Europe, and considering that there are about 175 million cars in Europe, it would then be possible to put 40 million BEVs (= 175 million x 23%) on the European roads without requiring additional electrical infrastructure.

- Assuming that in France, 4 million cars belong to a two-car family (realistic estimate), all second cars could be BEVs without additional infrastructure. It would therefore be an excellent idea to provide strong incentives to promote BEVs as second car (such as an additional tax on the second fossil fuel car): the BEV would be small, light and low-power, and used for daily commuting and short trips, while the fuel car would be used for week-end trips and holidays, which represent only a small percentage of the mileage, and could therefore be a big and powerful family car without causing overall too much emissions.

Sources

Whenever possible, we have used reliable sources for the parameters used in this study and cited the sources for the parameters which originate from a single source.

However, in several cases, different authoritative sources give different values for the same parameter. In this case, we have consulted experts and/or used our own judgement to estimate an adequate value for these parameters. In order to simplify the text, we have then omitted to cite all these sources.

Status

This draft has been peer-reviewed by two experts. Their corrections and comments have been integrated in this final draft, which is currently proposed to the reviewer for final comments and/or acceptation.

Also, we intend to detail and further justify chapter 7's conclusions in a later release.
If you wish to receive subsequent releases, kindly consult http://www.going-electric.org/what/reports.htm where the latest version will systematically be posted, or let us know by email at 2008@going-electric.org.