The Timeline to Carbon Neutrality in Road Transport – a long-term effort, with different phases, multiple technologies and interdependences

The road to carbon neutrality is long and intertwined between vehicles, energy and infrastructure technologies. A brief overview of the potential milestones and changes along this way is given in this paper, decade by decade, from now until 2050. It is hoped that, by envisaging this route, this document is an aid to discussion, understanding and decision making.

Naturally, whilst the goal is given (net Zero Carbon Mobility by 2050, Well-to Wheel), full clarity of the route ahead is not yet available. What is clear, however, is that this route is complex, requires the contributions from many stakeholders and much investment. The negative impacts of making possibly wrong decisions, too early, are significant.

Therefore, it is worthwhile now, to suggest a possible timeline; as a basis to both test the scenarios it foresees but also for direct comparison with other viewpoints. Hence, through discussion and improved precision, the impacts of the milestones along the road to defossilised mobility be better understood by all, decisions made upon firmer foundations. Additionally, such a timeline can give now, with technical neutrality and a long-term perspective, insight into the open questions, the needs for research and innovation that thus arise.

This document should not be read in isolation: there is much work on-going to quantify the consequences of possible routes to and the results of different scenarios. Reference is given to several such studies at the end of this paper. Furthermore, this document should not be considered definitive nor set-in-stone: just as any journey might experience delays, diversions but also improved timetables, so this Timeline is open for adjustments to the routeplan, the milestones and their phasing, as more is learned during the journey.

Without a map, without a route, without signposts along the way, we are surely lost before we set-off for our destination. This Timeline is suggested as an aid to ensure the start is right, feedback is always welcome.

The decade 2020-2030:

Milestone 2030: Air quality limits related to road transport are achieved, as far as possible, all across Europe (even in hotspots). Alternative technologies for CO_2 reduction (Well to Wheel) are pushing strongly into the market. The climate relevant (CO_2 and equivalent) emissions from road transport are decreasing but slowly, due to the low rate of vehicle stock turnover yet growing road transport, and the levels of investment in the energy and infrastructure aspects needed.

Vehicles:

- **L-category vehicles (including two-wheelers):** for commuting these make a significant transition to battery electric powertrains. Internal combustion engine (ICE) vehicles remain for leisure activities.
- **Passenger cars (PC):** the electric vehicle (xEV) share of New Vehicle Registrations (NVR) is growing up to ~50%, but the share in the vehicle parc remains below 25%. For the first time, the fleet CO_2 reduction is being achieved mainly through electrification.
    - **Battery Electric Vehicles (BEV):** the majority of these have a short to medium range. The functionality and economy of BEV is attractive for urban use, less so for long distances.
    - **Plug-in Hybrid Electric Vehicles (PHEV):** the electric-only range increases up to 100km so that one is able to drive "emissions free" in urban areas.
    - **Internal combustion engines (ICE):** becomes "clean" under all conditions. Further efficiency improvements continue to reduce CO_2 emissions. These are still the attractive prime-mover for long distance road journeys.
    - **Fuel Cell Electric Vehicles (FCEV):** are a niche market application.
- **Commercial vehicles (CV):**
    - **Medium Duty Trucks (MDT) & Busses**: Local regulations increase the share of BEV for urban transport and logistics. For non-urban use-cases, the ICE is still relevant as a prime-mover.
    - **Heavy Duty Trucks (HDT) & Coaches:**
        - **ICE** remain the most prevalent prime-mover. Efficiency improvements continue and, coupled with mild-hybridisation, fleet CO_2 targets are achieved. Natural Gas is an alternative to conventional fuel in some corridors.
        - **FCEV:** First applications are available.
        - **ERS:** Electrified Road Systems (ERS) only on specifically selected routes (e.g. for evaluation or local operation).

Infrastructure:

- The charging infrastructure for PC is available (public & private, including some fast charging for long distances but is still the limiting factor for increasing the EV market share.
- The charging infrastructure for CV is not significant: there are only some options for urban logistics operators.
- Hydrogen: is available in the first corridors at specific filling stations.
- ERS: is present on publicly funded test routes or specific (private) local operations. The decisions for long-term investment have to be made.
- Cities: several large cities in Europe and the world have expanded "zero-emission-zones". Only vehicles with a ZEV-mode (BEV, FCEV, PHEV in e-mode (using geofencing)) are allowed to enter these zones.

Energy production:

- Fuels are mainly fossil based, with a drop-in proportion less than 20% "renewables".
- Electricity is becoming "greener", but is still not climate-neutral.
- Whilst the consumption of electricity by PC's is growing, the gross electricity production capacity is not a problem, but local distribution infrastructures face issues.

The decade 2030-2040:

Milestone 2040: Since the vehicle stock is renewed, air quality relevant emissions from road transport are no longer an issue. Whilst the mobility of people and goods continues to grow, climate change relevant emissions (CO_2 etc.) from road transport are decreasing rapidly within Europe, by tens to hundreds of millions of tonnes per year. Significant infrastructure and energy production changes, in particular related to renewable sources and chemical storage, have enabled this.

Vehicles:

- **L-category vehicles (including two-wheelers**): Applications for urban use are fully electrified. First applications for the on-road leisure market are available (but dependent upon the fast charging options available in the countryside).
- **Passenger cars (PC):** BEV & PHEV are the "new normal", dominating the vehicle parc (> 50%).
    - **Battery Electric Vehicles (BEV):** are becoming omnipresent in urban environments and more attractive for long-distance trips.
    - **Plug-in Hybrid Electric Vehicles (PHEV):** are the only applications with ICE, their efficiency continues to increase. They are still essential for long-distance trips.
    - **Internal combustion engines (ICE):** when not found in PHEV these will be for niche applications and non-EU markets. There may be some niche applications for direct H_2 combustion.
    - **Fuel Cell Electric Vehicles (FCEV):** are only a small share of private use vehicles but are a relevant share in commercial fleets (e.g. taxis).
- **Commercial vehicles (CV):** most of their powertrains are hybridized or electric.
    - **Medium Duty Trucks (MDT) & Busses**: BEV or PHEV are being used for all urban operations. Logistics operations are increasingly effective, such that ICE use is only needed for regional activities.
    - **Heavy Duty Trucks (HDT) & Coaches:** NVR see xEV dominating the fleet.
        - **ICE** are still a prime-mover yet in highly-electrified powertrains. Efficiency improvements continue, and the CO_2-footprint is improved by "drop-in renewable fuels".
        - **FCEV:** become an alternative to ICE engined vehicles in some areas (corridors) which have an H_2 refuelling infrastructure.
        - **ERS:** depending on previous investments in the infrastructure, ERS will expand in specific use-cases.

Infrastructure:

- The charging infrastructure for PC applications is established in urban and most other areas, it includes smart and fast charging facilities
- For commercial vehicle (as defined above) extra-urban applications, the charging infrastructure is still limited.
- Hydrogen: the main corridors are supplied with sufficient filling stations.
- ERS: depending on the roll out of investments some publicly funded corridors will be established.
- Cities: Zero emissions zones are the "new normal" also in smaller European cities.

Energy production:

- Production of "defossilised fuels" is increasing, but not yet mostly renewable (≤ 50% drop-in).
- Most hydrogen is produced in a renewable, carbon-free way.
- Electricity is predominantly renewably produced.
- The consumption of electricity by road transport is growing significantly. The gross generation capacity is not a problem on average, but peaks in energy demand may cause issues. Smart Charging is being established as business case and taxation issues are overcome.

The decade 2040-2050:

Milestone 2050: All of road transport, throughout Europe is climate-neutral (Well to Wheel) and air-quality is not affected by powertrain emissions anymore.

Vehicles:

- **L-category vehicles (including two-wheelers):** these are fully electrified or running on renewable fuels.
- **Passenger cars (PC):** the only NVR are xEV. In the vehicle parc, BEV & PHEV are accounting for over 90%.
    - **Battery Electric Vehicles (BEV):** are the dominant form of passenger car.
    - **Plug-in Hybrid Electric Vehicles (PHEV):** are a consumer choice.
    - **Fuel Cell Electric Vehicles (FCEV):** retain their small private yet large commercial fleet shares.
- **Commercial vehicles (CV):** the vehicle parc is highly electrified. If equipped with an ICE, climate-neutrality is assured by using renewable fuels.
    - **Medium Duty Trucks (MDT) & Busses**: the vehicle parc only contains BEV and FCEV.
    - **Heavy Duty Trucks (HDT) & Coaches:** NVR see xEV dominating the fleet.
        - **ICE** will continue as a defossilised prime-mover, using fully renewable hydro(carbon) fuel in a highly-electrified powertrain.
        - **FCEV:** constitute a major share of the main route, long distance operations.
        - **ERS:** depending on infrastructure investments, this is established on specific routes.

Infrastructure:

- The smart and fast charging infrastructure for all road vehicles is available, with few limitations.
- Broadly, batteries in BEV are used as an element in the electricity grid.
- Hydrogen: the main corridors and local hot-spots are supplied with filling stations.
- ERS: some publicly funded corridors are maintained together with local routes that are commercially viable.

Energy production:

- Electricity generation is fully carbon-neutral.
- Hydrogen production is fully carbon-neutral.
- Drop-in Fuels: there is significant reduction of fuel demand in road transport due to electrification and hydrogen use. The remaining demand is fully covered by carbon-neutral, renewable fuels.

Further Information – the need for continued research & innovation

This Timeline for the decarbonisation of Road Transport can only be achieved through cooperation between the public and private sectors and, of course, with significant investment into new vehicle, energy production and infrastructure technologies. The relevant research and innovation needs are described, in detail, in the Strategic Research and Innovation Agenda (SRIA) for the "Towards Zero" Partnership and in the roadmap "Sustainable Energies and Powertrains" from the European Road Transport Research Advisory Council (ERTRAC).

Furthermore, it is important to understand how the scenarios through the decades, as show within this Timeline, relate to those given and implied in the sources above and within that from the ERTRAC CO_2 Working Group (which is trying to quantify the viability of possible "corner-point" scenarios specifically at 2050 in relation to the overall goal of net zero carbon mobility). For assistance, these aspects are visualised in the two diagrams below.

The first illustrates the positioning of the timeframes considered within the various documents. The 2Zero SRIA suggests the research and innovation needs within this decade, from a road transport system perspective, considering not only technologies but also impact assessment methods. The second, the ERTRAC Roadmap, considers a longer timeframe but with a specific focus on the research needed to improve the energy efficiency of vehicular mobility. The CO_2 Working Group considers the Well-to-Wheel (WTW) viewpoint, but specifically at the end-game position, that means to achieve the WTW carbon neutrality goal in 2050.

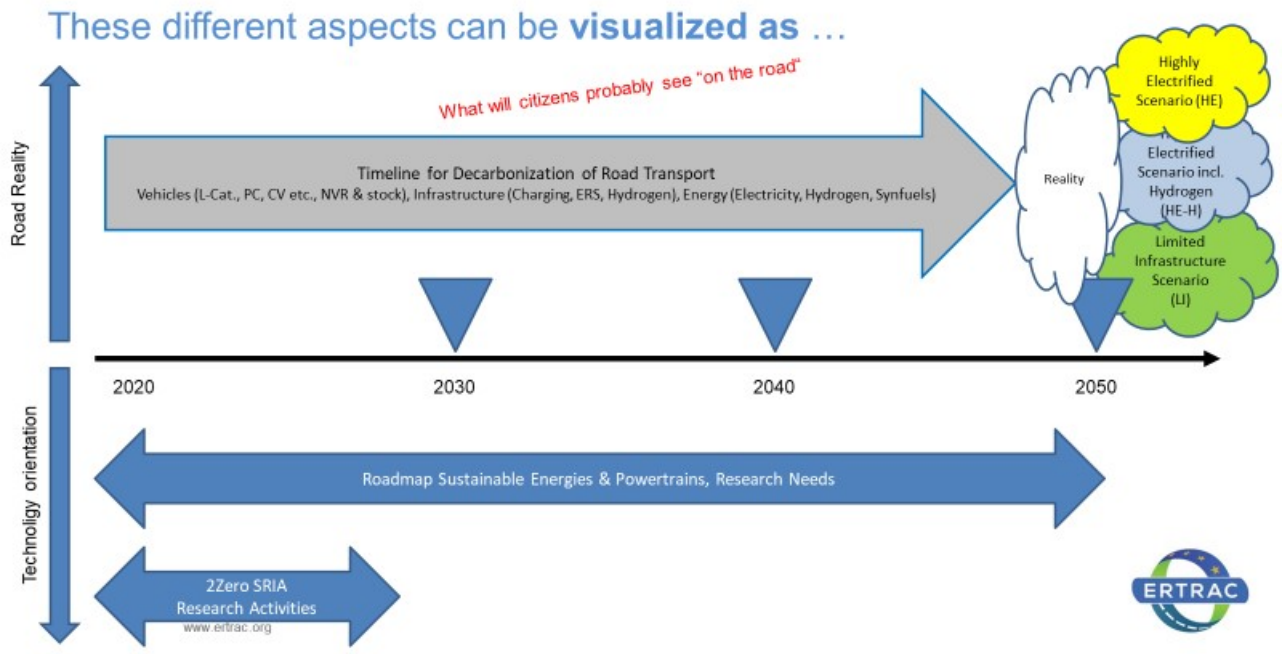

Figure 1 The Positioning of the Timeframes of various ERTRAC & 2Zero Documentation

Further, as illustrated in the second diagram, the scenarios considered by the CO_2 Working Group can be considered as corner-points, extreme market distributions of technical solutions, in an optimistic and pessimistic manner, to establish whether this end-game position is feasible at all and, if so, the consequences thereof.

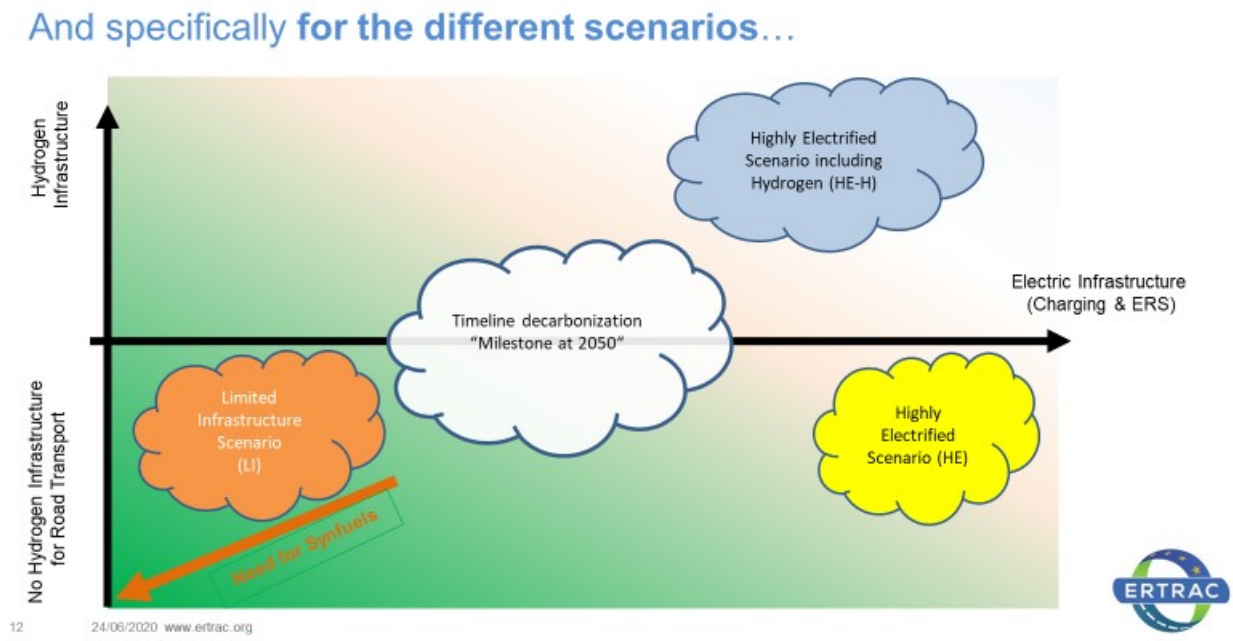

Figure 2 The Relationship between the CO_2 Evaluation Group Scenarios and what is presented in this Timeline

As such, this Timeline can be viewed, as shown in both of the diagrams, as a possible, perhaps potential "middle way", from today until 2050, with evolutionary market distributions. The hope is, of course, that at 2050 this "middle-way" will be as effective as those extreme scenarios established within the CO_2 Evaluation Group study. However, this has to be established: effort is now needed to work back from the 2050 scenarios, through the time period 2050-2030, ensuring consistency, to better quantify the milestones along the way and to phase into the desired outcome of the 2Zero R&I in the 2030 market (as measured by their key performance indicators).