Mobility solutions for the energy transition

With

Researchers: Julien Brunet, Carolyn Fischer, Guy Meunier, Juan-Pablo Montero, Jean-Pierre Ponssard

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Based on an interview with Juan-Pablo Montero

How best to reduce the carbon footprint of motor vehicles in the United States?  
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missions from land transport are not only a major source of greenhouse gas emissions but also cause urban pollution (CO, NOx, SO2, fine particles, etc.) that are directly harmful to health, not to mention problems arising from congestion (loss of time and money, accidents, noise pollution, etc.).

To address these environmental and social challenges, various policy initiatives have already been introduced but more drastic measures are still to be implemented, both at national levels and at the level of the major metropolises. Analysis of these policies is a major research topic of the Chair Energy & Prosperity, founded in 2015. The aim is to assess the sectoral and macroeconomic impact of these policies and to identify the institutional regulatory framework most favorable to their funding by the public and private sectors. This issue of *Les Cahiers Louis Bachelier* provides an overview of the topics covered.

The article by Juan Pablo Montero focuses on short-term measures such as restrictions on the use of vehicles during peak pollution periods, that since 1989 have been in operation in Mexico City, one of the most polluted cities in Latin America, and more recently in Beijing, Berlin and Paris among others. Carolyn Fischer provides a critical assessment of various policies implemented in the United States, some of them since the late 1970s, either to reduce the carbon content of the fuels used or to improve the energy efficiency of vehicles. Julien Brunet’s article makes an evaluation of a pilot programme currently under way in support of the deployment of hybrid electric and hydrogen vehicles in the Normandy region. In the final piece, Guy Meunier revisits the concept of abatement cost, commonly used to define the optimal date for launching a clean technology, when the costs associated with the technology benefit from strong experience effects, with hydrogen vehicles serving as the empirical basis for illustrating the relevance of his conclusions.

These research papers have been presented in detail at annual workshops organized by the Chair on the topic of sustainable mobility. Supported also by the EDF-Ecole Polytechnique Sustainable Development Chair, these workshops provide an excellent opportunity to organize discussions between researchers and professionals, in particular with the financial partners of these two Chairs.

In this respect I would very much like to thank Pierre Etienne Franc (Air Liquide) and Grégoire Marlot (SNCF) for their participation in the present issue, and more generally their support for this research programme. Thanks also to the researchers, PhD students, Master’s students and the Institut Louis Bachelier for their invaluable contributions to the success and dissemination of our work.

Enjoy your reading!

*Jean-Pierre Ponssard*
Co-Director, with Gaël Giraud, of the Energy and Prosperity Chair
TO WHAT EXTENT DO DRIVING RESTRICTIONS AFFECT URBAN POLLUTION?

Over the past three decades, many cities around the world have adopted measures to limit car traffic, with the aim of reducing urban air pollution. The research paper presented below makes policy recommendations, based on the observed effects of legislation in Santiago de Chile.

The rapid growth of urbanization has caused urban pollution to soar. In fact, in 2016, 98% of cities with more than 100,000 inhabitants in low- and middle-income countries failed to meet World Health Organization (WHO) standards on air quality, and as much as 56% in high-income countries. This situation, which is particularly worrying for health, is due in particular to urban motor vehicle congestion, which by releasing fine particles, carbon monoxide and nitric oxide contributes greatly to local pollution. For example, urban pollution in the Île-de-France region is mainly due to road traffic.

MEASURES TO REDUCE CONGESTION

In order to limit urban pollution and encourage the use of public transport, various measures for reducing car traffic were introduced in the 1980s in a number of cities around the world, including Athens, Santiago and Mexico City. In the 2000s, other cities such Beijing, Berlin and more recently Paris adopted this approach. “There are two main ways of tackling the problem,” Juan-Pablo Montero explains. “The first is to limit automobile traffic, based on the last number on license plates. The second involves restrictions on traffic, based on the age or emission levels of vehicles. The latter policy was first introduced in Santiago in 1992.”

In addition to these two approaches, other policies may be used, such as scrappage schemes to encourage drivers to get rid of older, high-pollution vehicles and subsidies to buy new, more environmentally friendly vehicles. Urban tolls, introduced in London for example, are another option available to public authorities.

Restrictions based on vehicle age or emission level have so far been little examined. It was to fill this gap that Juan Pablo Montero and his co-authors developed their study.

AN EXTENSIVE BUT INCOMPLETE LITERATURE

Much research has been devoted to combatting air pollution in different types of urban area, variously in developing, emerging and developed countries. “The existing literature suggests that restrictions based on vehicle registrations are relatively ineffective because they act on demand and encourage people to purchase a second, more polluting, car. In the long term, this will lead to an increase in the car fleet and therefore a rise in urban pollution,” Juan-Pablo Montero points out. This unwanted effect has been very evident in Mexico City. In 1989, its alternate-day travel scheme, based on licence plate numbers, got off to a good start, but it soon led local drivers to buy cheaper, even more polluting, second vehicles. As a result, according to studies carried out in 2008, the size of the automotive fleet increased by 20% in Mexico City.

Restrictions based on vehicle age or emission level have so far been little examined. It was to fill this gap that Juan Pablo Montero and his co-authors developed their study, which is based on the observed effects of legislation in Santiago.
In 1986 the Chilean capital imposed restrictions, on the basis of registration plate numbers, during certain hours of the day between April and September. In a further measure, introduced in 1992, the authorities required that all new vehicles be equipped with a catalytic converter to reduce exhaust emissions. At the same time, vehicles manufactured prior to this reform continued to be subject to the driving restrictions in force in Santiago.

“We used Santiago as our case study for two reasons. First, the local automobile market is very well integrated, so purchasing decisions can only be explained by political measures or by the geographical location of households. And second, the 1992 measure has remained virtually unchanged, allowing us to identify its effects several years after it was introduced,” Juan Pablo Montero says.

**INNOVATIVE MODELLING TO IDENTIFY OPTIMAL MEASURES**

Using data from the Santiago conurbation, the researchers carried out an econometric study based on a model for vehicle demand. This dynamic model is innovative in that it is more comprehensive than the existing models in the literature, in three respects: it allows observation of changes in the car fleet over time; it introduces vertical differentiation that measures consumers’ willingness to buy less polluting vehicles; and it makes a distinction between high-pollution areas affected by the restrictions and other areas. This model, which is more comprehensive than those in the literature, is able, by means of numerical simulations, to test a variety of policies aimed at reducing urban air pollution.

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On the basis of their findings, the researchers were able to make concrete recommendations: “To reduce urban pollution, restrictions based on the age of the vehicle and emission rates are the best choice,” Juan-Pablo Montero says. In a word, this approach works much better than short-term schemes such as scrappage of old vehicles or subsidies for the purchase of new low-pollution vehicles. The model was also able to identify a further possibility for the public authorities: “A multi-tariff urban toll policy – in accordance with vehicle age or emission level – is another effective measure to reduce urban pollution, but its practical application is trickier than the first option mentioned above.” At a time when the city of Paris is implementing a new policy, this paper provides an analytical framework that is particularly relevant for its evaluation.
HOW BEST TO REDUCE THE CARBON FOOTPRINT OF MOTOR VEHICLES IN THE UNITED STATES?

The land transport sector is a major contributor to greenhouse gas emissions in the United States. Various federal and local policies have been introduced to reduce these emissions. This article offers an analysis for light vehicles (cars, SUVs, small commercial vehicles, etc.).

Although China is now the world’s biggest polluter of greenhouse gases, the United States is still the largest emitter of carbon per capita. In 2013, Americans emitted an average of 16 tonnes of CO₂ per head, compared to 7.3 tonnes per head in China, according to figures from the Global Carbon Project. This situation is mainly due to America’s high oil consumption, particularly in the automotive sector. In fact, last year, 26% of US greenhouse gas emissions came from transportation, of which 61% was attributable to light vehicles (cars, SUVs, small commercial vehicles, etc.), according to the Environmental Protection Agency. Despite the threat to the planet from climate change and a variety of policy interventions, car emissions have declined very little in recent years.

A WIDE VARIETY OF POLICIES

The federal government and local authorities at individual state levels have put in place a whole series of interconnected measures. One is a federal fixed gasoline tax of $0.184 per gallon, though it has not increased since 1993! On top of this charge, state governments levy taxes of about $0.30 per gallon (2016 figures), based on the weighted average of gasoline sales. These levies are not designed for environmental improvement, but are mainly used to finance road infrastructure. In addition to fuel taxes, a Renewable Fuel Standard was introduced at the federal level in 2005. This programme requires transportation fuel sold in the United States to contain a minimum quantity of biofuels, made from maize, sugar cane or biomass, a figure that was intended to rise to 36 billion gallons a year by 2022 (although a series of waivers lessen the ambition of the target). Further incentives to promote biofuels, such as tax credits and subsidies, have been subsequently added to the original legislation. Alongside these measures, the Corporate Average Fuel Economy (CAFE) standards, introduced in the late 1970s, obliges manufacturers to improve the fuel economy of light-duty vehicles produced for sale, based on the number of miles per gallon. Initially uniform, distinguishing only between cars and light trucks, CAFE standards have evolved considerably, now also distinguishing fuel economy according to vehicle size. Manufacturers are thus subject to different constraints depending on the vehicles produced. CAFE has even resulted in a system of quota trading between car manufacturers, enabling manufacturers like Honda, Nissan, and Tesla Motors to profit from selling their quotas to more polluting competitors. Lastly, in 2007 California introduced a Low Carbon Fuel Standard, with a view to reducing CO₂ emissions by 10% by 2020. This policy implicitly taxes traditional high-emission fuels and subsidizes biofuels.

*To reduce carbon emissions from cars, the authorities have two main types of instruments. The first, fuel substitution, focuses on the carbon content of the fuels used, with the introduction...
Methodology
The researchers developed a long-term model in the personal transport sector, divided into two phases: 2015-2025 and 2025-2040. In each phase, the balance between fuel supply and gains in energy efficiency is determined, as well as the fuel demand associated with the utility of using a vehicle. The model also allows cost reductions to be introduced from one phase to the next, linked to experience effects in the production of advanced biofuels. Using numerical simulations, the model is able to evaluate policy combinations, together with each component taken individually, and to determine the optimal policy.

Carolyn Fischer is a Senior Fellow at Resources for the Future, the Marks Visiting Professor of Gothenburg University for 2017-2018, a fellow of the CESifo Research Network, and a recent Marie Skłodowska–Curie Fellow of the European Commission. She is currently a co-editor of Environmentand Resource Economics. She earned her Ph.D. in Economics from the University of Michigan-Ann Arbor in 1997. Her research focuses on policy instrument design applied to a variety of environmental and resource management issues, including climate and renewable energy policies, carbon leakage, technological innovation, eco-certification, and wildlife conservation.

Various policies have thus been put into place, but they still need to be evaluated. What specific impacts do they have on reducing carbon emissions from vehicles? How costly are they? What is the implied cost per tonne of CO\textsubscript{2} avoided? To answer these questions, Carolyn Fischer and her co-authors have developed a model that is new to the economic literature, adapting and extending previous work she conducted in 2008 and in 2013 related to the electricity sector. It involves modelling, on the one hand, fuel supply and improvements in energy efficiency and, on the other, the demand for fuel given the utility for users of owning and driving a vehicle in the segment concerned (cars, SUVs, small commercial vehicles, etc.). It should be emphasized that light-duty vehicles account for 90% of US gasoline consumption, according to the International Energy Agency's 2015 figures, and that 99% of these vehicles use fossil fuels. “Our model has a number of distinctive features. It covers a long time period, divided into two phases: 2015-2025 and 2025-2040. It introduces experience effects into the production of biofuels, which then lower their costs in phase two. It also incorporates the undervaluation of the benefits of fuel economy investments by motorists,” says Carolyn Fischer. Without going too deeply into the technicalities of the various parameters used in this work, the model makes it possible to determine the individual effectiveness of existing policies. After carrying out numerical simulations, the researchers found that the portfolio of current policies has been reducing carbon emissions by 9% at an implicit cost of $44/tCO\textsubscript{2}. The model also shows that much cheaper policies would achieve the same level of emission reductions.

The best policy would be to introduce a carbon tax
At the theoretical level, the existence of scale effects for the production of biofuels and negative externalities linked to the emission of greenhouse gases would militate for the introduction of at least two instruments: for example, ➔
a standard for the use of renewable fuel (fuel substitution) and a carbon tax on vehicle emissions (fuel conservation). On the basis of the data collected, the authors’ analysis shows that a carbon tax alone would achieve the same level of emissions reduction at an implicit cost of $15/tCO₂, without requiring any expensive advanced biofuels. “The optimal policy for this level of ambition would be the introduction of a carbon tax and the discontinuation of subsidies for ethanol producers,” Carolyn Fischer says. “The standards regarding fuel conservation are inefficient, especially when vehicle size-based quotas are introduced. The worst solution is the fuel substitution policy, because the costs of the least emissions-intensive biofuels are not falling enough.” She goes on, “These differences in effectiveness with respect to the optimal policy are all the stronger when the external effects linked to congestion and accidents are taken into account, which are exacerbated by fuel economy policies that make driving more miles and owning larger vehicles less expensive.”

**Key points**

- The researchers’ work allows the effectiveness or ineffectiveness of existing policies to be quantified and is able to identify alternative policies for reducing carbon emissions from light-duty vehicles (cars, SUVs, small commercial vehicles, etc.).
- The optimal policy would be to introduce a carbon tax and to discontinue other types of instruments, using uniform fuel economy standards just to target behavioural gaps in the valuation of fuel economy.
- The worst policy is one that encourages the substitution of biofuels for traditional fuels. Biofuels are currently more expensive than pump prices and the expected effects of a future reduction in production costs are not large enough.

**PUBLICATIONS**

The Institut Louis Bachelier collections for consultation and downloading:

The Opinions & Débats collection presents the most recent research and makes policy recommendations with a view to feeding public debate.

The Louis Bachelier Cahiers are accessible to a wide public and present the most relevant research for application in the professional sphere.
The workshop will promote exchanges between research scientists with public and private decision makers on the following topics:

✔ Economics of the new powertrains: evaluation and deployment strategies
✔ Learning-by-doing, spill-overs and coordination needs along the value chain
✔ Competition and/or complementarity in usage and infrastructures
✔ Implications of zero emission vehicles for electricity storage and supply/demand balance
✔ New trends in transportation modes (collaborative transportation modes, development of multimodal journeys, autonomous vehicles...)
✔ Evaluation of public policies at the national and local levels (carbon tax, subsidies, technical norms, driving restrictions, urban tolls...)

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HOW CAN HYDROGEN MOBILITY BE SUSTAINABLY DEVELOPED IN FRANCE?

Hydrogen is an effective technology for reducing the carbon footprint associated with terrestrial mobility, especially because of its flexibility of use. It is, however, costly and its deployment in France is still embryonic. This article analyses its impact in Normandy, where a specific programme has been launched.

Despite technological advances in improving the energy performance of fossil fuel vehicles, road transport is still a major emitter of carbon throughout the world. In the European Union, road transport emissions have actually increased by 20% since 1990, according to European Commission figures, and today account for about 20% of the EU's emissions.

Given this situation, governments need to take measures to limit road transport emissions and achieve sustainable mobility. To this end, the development of electric vehicles offers an appropriate alternative. Their main drawback, however, is their lack of range, which makes it difficult for them compete with conventional vehicles. And this is where hydrogen comes in. For hydrogen can augment the range of electric vehicles by as much as 180 to 300 kilometres, when they are equipped with a hydrogen extender, operating with the aid of a fuel cell. In addition, this clean fuel can give fuel-cell vehicles totally powered by hydrogen ranges comparable to those obtained for thermal vehicles (500-700 km).

While this technology has been developing for some years in various parts of the world (the United States, Germany, Japan and China), it is lagging behind in France because no government-backed national plan has been adopted. It is true that its costly deployment creates a chicken and egg dilemma that is difficult to resolve: charging stations become profitable only if there are sufficient number of vehicles near them and likewise production of green hydrogen is viable only if there is a significant level of consumption. It is therefore necessary to promote charging stations and vehicles at the same time in order to bring down prices, and this calls for the support of local and regional authorities.

France would certainly gain from this support, however, since the transport sector is the largest emitter of CO₂ with 27.6% of total emissions, 92% of which comes from road transport. With regard to health, road traffic accounts 15% of particle emissions and 56% of nitrogen oxides.

NORMANDY, FORERUNNER OF HYDROGEN MOBILITY

In fact, after the Rhône-Alpes region in 2014 and a first charging station in Saint-Lô in early 2015, Normandy adopted a specific programme called EAS-HyMob (Easy Access to Hydrogen Mobility), which runs from 2016-2018. This pilot project involves a partnership between Normandy, the Serfim group and the equipment maker Symbio. The aim is to deploy 15 hydrogen recharging stations at a pressure of 350 bars and a fleet of 250 vehicles, mainly Kangoo ZEs with a range extender as well as 100% hydrogen electric vehicles. The programme has a budget of 4.8 million euros, half of which is funded by the EU. Consequently, a number of questions arise. Is the Normandy project economically and ecologically efficient? Will it give rise to the development of a hydrogen industry?


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COST-BENEFIT ANALYSIS OF THE NORMANDY PROJECT…

To evaluate the EAS-HyMob programme, the researchers first carried out extensive documentary and data collection work, then modelled the entire hydrogen value chain in order to compare its various costs with those of the diesel sector. “In our model we broke down three main activities: hydrogen production, assuming that it gradually moves from the current high-pollution method of steam reforming from natural gas to electrolysis, which does not emit carbon; the cost of transport, depending on whether production is centralized or decentralized at the recharging stations; and the costs of hydrogen distribution, depending on the size of the stations (small or large),” Julien Brunet explains. The model yielded three final results: “The cost of hydrogen fuel per 100 kilometres travelled, the difference in the total cost of ownership of the vehicle (Kangoo ZE H2 vs. Kangoo Diesel), and the abatement cost, obtained by comparing the price per tonne of CO₂ avoided with a carbon tax.” These three findings were then compared with those of the diesel sector, based on the figures for 2016 and projections for 2025.

… WHICH CALLS FOR A SECOND, MORE AMBITIOUS SCENARIO

The researchers evaluated the scenario used in the EAS-HyMob programme. “Our analysis reveals that the current project, as envisaged, will remain highly dependent on regional and national public support. Converting the car fleet to more hydrogen will be lengthy and costly,” Julien Brunet says. So as not to leave it at that, the researchers considered a second scenario that is more favourable to the development of a future Norman hydrogen industry. “This scenario could be achievable by 2030 or even before, but it requires a massive subsidy policy in the order of €80 million over ten years. The hydrogen value chain would then no longer need public funds,” he says. To make this a reality, two conditions have to be fulfilled. First, the cost of ownership of fuel-cell vehicles must be reduced by 40% by 2025, as a result of the experience gained by manufacturers, geographical expansion of these vehicles beyond Normandy (on the continent) and an extension of this technology to other types of vehicle (buses, trucks, saloon cars, etc.). Meeting this condition would be possible since the industrial chain is starting up. Secondly, the price of hydrogen needs to fall, through the increase in consumption generated by the development of these vehicles and through optimization of its production.

Methodology

The researchers conducted a cost-benefit analysis of the Normandy hydrogen mobility programme. To this end, they carried out extensive documentary work on existing studies, while gathering data on the programme among its main actors. They then modelled the hydrogen value chain (production, transport and distribution), and compared it with that of diesel. They were able to produce three results: the final fuel cost, the difference in vehicle ownership costs and the cost of carbon abatement for the two sectors. Finally, they assessed the current scenario, along with a more favourable scenario that could achieve sustainable mobility within ten years.

Key points

- The current scenario of the Normandy programme is very dependent on public subsidies and precludes extending a self-supporting hydrogen mobility sector to the whole of France by 2025.

- Implementation of the scenario favourable to the development of hydrogen mobility by 2025 requires a policy of massive subsidies at the outset (around 80 million euros over 10 years).

- The viability of the favourable scenario is subject to two conditions: reduced hydrogen prices, with optimization of its production and an increase in its consumption though other types of vehicle; and lower ownership cost of hydrogen-powered vehicles, through the experience acquired by manufacturers.
WHY HYDROGEN IS A Viable OPTION FOR SUSTAINABLE MOBILITY

Road transport makes massive use of fossil fuels and contributes significantly to the release of carbon into the atmosphere. However, hydrogen can play a role in decarbonising long-term mobility. This article explores the ways in which this emerging technology can be used.

Environmentally friendly and sustainable mobility is a crucial issue in limiting pollution-generating carbon emissions. In this area, road transport is a major culprit. In the European Union (EU), more than 95% of cars were running on fossil fuels in 2014, according to the specialist company Emisia.

To reduce carbon emissions from road transport in the EU – which have in fact increased by 20% since 1990 – alternative fuels, particularly hydrogen, are attractive but still costly options. Indeed, the abatement cost of a hydrogen fuel cell car – that is, the cost per tonne of CO₂ avoided – is in excess of 2,000 euros.

The cost is therefore currently too high to allow large-scale expansion of this technology. “This indicator is commonly used in public policy to compare technical options and to evaluate when to introduce them,” says Guy Meunier.

A YOUNG TECHNOLOGY THAT CALLS FOR A NEW PERSPECTIVE

However, calculation of the marginal abatement cost of different vehicles (hydrogen versus diesel, for example) is often carried out in a static manner, taking into account the parameters at time T, such as vehicle cost, CO₂ emission per unit of fuel, fuel consumption per 100 kilometres and the lifetime of the vehicle. This static approach does not really evaluate the benefits of an emerging technology such as hydrogen. “The marginal abatement cost used does not generally take into account the experience gained by manufacturers over time,” Guy Meunier points out.

Although experience effects are recognized in economic theory, they are difficult to operationalize in assessing technical options. “In practice, the benefits of the learning curve are not taken into account, because the calculations are complex and depend on a large number of operational parameters,” Guy Meunier adds.

AN EXTENDED MODEL INCLUDING EXPERIENCE EFFECTS

In order to provide more relevant answers to the public authorities and the sector’s manufacturers, the researchers studied the optimal trajectory that would allow the progressive replacement of polluting vehicles by hydrogen vehicles. They developed a partial equilibrium model of the automotive sector, containing two types of vehicle: high-carbon petrol driven vehicles and zero-carbon hydrogen vehicles. The dynamic aspects of this model lie in the learning effects acquired by manufacturers in producing hydrogen vehicles. Thanks to these experience effects, the production cost of hydrogen vehicles is assumed to be convex and degressive over time. On the other hand, the total cost of the researchers studied the optimal trajectory that would allow the progressive replacement of polluting vehicles by hydrogen vehicles.
vehicles to the public authorities comprises the private cost of production and the social cost of carbon (negative externalities). The latter is exogenous and grows at the social discount rate of 4% applied by researchers. The model is able to study the properties of optimal deployment of clean vehicles, which will gradually replace polluting vehicles. Alongside this deployment, the analysis shows that the price of CO$_2$ must be matched by a dynamic abatement cost that integrates the learning benefits. But calculation of this cost is difficult to operationalize, in particular because of the numerous technical constraints. To take their reasoning further and overcome this problem, the researchers decided to take a given deployment trajectory, in principle sub-optimal, and calculate the optimal launch date of the programme. This change of perspective, shifting from choosing the quantity of vehicles to be manufactured at each moment to choosing when a given deployment trajectory is launched, provides an indicator of the abatement cost associated with a deployment trajectory, not solely with the production of an isolated vehicle along a trajectory. Following this analytical stage, the researchers moved on to the applied stage, based on the German hydrogen trajectory plan (H2 Mobility Deutschland), with the help of a 2010 McKinsey & Company study. “Our objective was to minimize the cost of replacing 7.5 million vehicles in the German car fleet. We calculated the total cost of hydrogen and petrol-driven cars per year by adding in the external effects of CO$_2$. We then added up the years, to which we applied a 4% discount rate, thereby allowing us to compare the costs at different dates,” Guy Meunier explains.

HYDROGEN BECOMES ECONOMICALLY VIABLE WITH THE EXPERIENCE EFFECTS

In this exercise, the researchers considered three scenarios (high, intermediate and low), which differed according to the value of three parameters: the market share of hydrogen vehicles in 2050, the rate of growth of petrol prices, and the learning rate allowing production costs to be reduced. Since these numerical simulations did not call for much computational power, they could be carried out on Excel. “Vehicle deployment should begin when the social cost of carbon reaches the discounted abatement cost,” says Guy Meunier. In the intermediate scenario, the cost of replacing 7.5 million vehicles is estimated to be 21.6 billion euros at the end of the transition. The dynamic CO$_2$ abatement cost of the corresponding hydrogen car is 205 euros per tonne. The price of CO$_2$ required to initiate the transition is 52 euros per tonne, which is comparable with the estimates of the social cost of carbon. As for carbon emissions, they decrease annually by 2.18 tonnes of CO$_2$ per vehicle. “With sufficient learning effects taken into account, hydrogen vehicles would cost no more than gasoline vehicle at the end of their deployment, thus contributing to a significant reduction in negative externalities.”

The deployment of hydrogen vehicles and refuelling stations should begin when the social cost of carbon equals the discounted abatement cost.

**Methodology**

The researchers analysed the optimal trajectory (minimizing costs), which would allow the progressive replacement of fossil fuel vehicles by hydrogen-powered vehicles. Accordingly, they developed a partial equilibrium model of the automotive sector, into which they introduce dynamic aspects, especially learning effects. They then applied it to real data from the German national hydrogen plan. Lastly, they carried out numerical simulations, using Excel, to come up with an economically viable CO$_2$ abatement cost.

**Key points**

In practice, learning effects have been used very little in operational modelling. But taking into account dynamic aspects of this kind would make an initially costly decarbonisation option affordable.

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The deployment of hydrogen vehicles and refuelling stations should begin when the social cost of carbon equals the discounted abatement cost.

**Guy Meunier** is a researcher in the ALISS unit at INRA and a professor at the Ecole Polytechnique. His doctoral thesis, produced at CIRED, was concerned with investment incentives in electricity markets. Since then, he has worked on climate policies, focussing on the design of emissions allowances markets and the dynamics of transitions.
“HYDROGEN IS A SYSTEMIC SOLUTION TO THE ENERGY TRANSITION”

Pierre-Étienne Franc is Vice-President Air Liquide advanced Business & Technologies. As such, he is concerned in particular with the development of hydrogen as a source of zero-carbon energy. In this interview with ILB, he gives his views on the emergence of this technology in the context of green mobility and the energy transition.

ILB: What are the advantages of hydrogen as a fuel?

Pierre-Étienne Franc: To make a success of the energy transition, hydrogen needs to be used in association with electric batteries. Hydrogen allows us to overcome the problem of intermittence, storage and distribution on the grid and in the sectors downstream from renewable energy.

As regards mobility, the advantage of hydrogen stems from the fact that it is a dense molecule, making it four to five times more storable than electricity per unit mass and twice as storable by volume. This gives hydrogen vehicles a greater range. If you add in the reduced recharge time compared to electric vehicles, you have a solution to electric mobility that cannot be ignored. Moreover, hydrogen fuel has huge market potential, higher than Air Liquide’s annual turnover. Converting 10% of the billion vehicles in operation worldwide to hydrogen would generate a market of more than 100 billion euros.

Lastly, the future growth of this fuel offers a sustainable solution to today’s societal and energy challenges.

What are the main obstacles to the large-scale development of hydrogen?

P.-É.F.: First, the chicken and egg problem means that the deployment of charging infrastructure cannot be done without the prior introduction of hydrogen vehicles, and vice versa. Second, the technology now needs to be mass produced to make it competitive in terms of cost.

Third, this energy faces massive competition from the electric battery, which is simpler and less expensive to develop in the first stage. However, the battery sector continues to suffer from problems in achieving profitability; its overall environmental balance is still being debated; and the impact of its massive deployment on production and distribution infrastructure upstream has been greatly underestimated. In view of these issues, electric batteries can contribute only part of the solution to our energy transformation.

What possible levers are there for the sustainable development of hydrogen?

P.-É.F.: Firstly, innovative financing mechanisms and methodologies are needed to solve the chicken and egg dilemma. With regard to this, the Chair Energy and Prosperity has been very helpful. Then, as with any innovation, the “valley of death” has to be traversed. And lastly, bringing together actors from the different sectors affected by the transition is very important, showing that hydrogen is an energy vector that extends to various sectors – storage, transport, industry, residential. Hydrogen is a systemic solution to the energy transition. It was for this reason that the Hydrogen Council was launched last January in Davos, bringing together 15 CEOs of global leaders in their sectors – oil, energy, equipment, automotive, industrial gases, commodities.

How about the time horizon for the development of hydrogen?

P.-É.F.: In transportation, hydrogen has already emerged with the manufacturers Toyota, Honda and Hyundai, which have brought out specific vehicles. Daimler will be embarking on it next year, while Audi, BMW and General Motors are considering entering the market from 2020 onwards. The year 2020 is likely to be the take-off point. Overall, the increase in vehicle production volumes will reduce costs.

In the residential sector, 200,000 fuel cells have been installed in Japan, and these supply buildings with water, heating and electricity. And other countries could eventually be attracted by this source of energy.

In industry, power-to-gas will enable renewable energies to be stored by transforming them into hydrogen. At present, there are about twenty projects, but the more intermittent energies develop, the greater will be the need for storage and consequently hydrogen.

France appears to be lagging behind with regard to hydrogen fuel.

Why is that?

P.-É.F.: Precisely. The political will exists in France and the authorities are helping the sector, but not enough. French car manufacturers are still too focused on electric batteries, to the detriment of hydrogen and fuel cells.

To develop hydrogen mobility, the emphasis should be on the growth of the captive vehicle fleet, which offers a good demonstration of the advantages of hydrogen, such as our deployment of hydrogen-electric taxis in Paris, with the Hype project. There also needs to be a progressive shift towards corporate fleets, particularly in the distribution sector, so as to democratize the use of hydrogen fuel. 🌍
“STRONG REGULATION WILL BE NEEDED TO REAP THE FULL BENEFITS OF INNOVATION IN MOBILITY”

With the emergence of new actors and innovative solutions in the mobility market, competition is increasing for rail transport. In this context, Grégoire Marlot, SNCF’s director of strategy, talks to the ILB about the issues faced by the group.

ILB: As the historical actor in French railways, where does your group stand today?
Grégoire Marlot: We have become an international organization. We transport 13.5 million passengers every day, only 5 million of which in France. We are among the world’s top 10 freight transport and logistics companies. In total, a third of our turnover is generated abroad. Our ambition is to become the world leader in shared mobility in all forms of transportation – train, bus, shared taxi, car sharing, and so on. We are contributing to sustainable development with the provision of efficient, energy-saving, non-polluting mobility. We aim above all to be competitive with other forms of transport, both for the final customer and for the organizing authorities, whose budgets are constrained.

How do you see the future opening up of the rail sector to competition?
Grégoire Marlot: The French passenger rail market will open up to competition in 2020 for the TGV high-speed rail system and by 2023 at the latest for the TER regional express service. But we have always faced competition – from cars, which account for 80% of motorized journeys, from airlines, and now from new players such as coaches and car-sharing. In the freight sector, the rail market was opened up to competition in 2006, but again the main competitor is road transport. Our markets will be drastically changed by digital technology. This has already begun, with the BlaBlaCar and Uber platforms, real-time information, one-click purchasing, and so on. Mobility is becoming a service. The challenge for us is to be a mobility “integrator”, offering “door to door” services. Voyages-sncf.com is the leading online travel agency in France.

In what ways might autonomous cars affect your market?
Grégoire Marlot: The autonomous car is the next step in the digital transformation of transportation. Today, the driver accounts for about half the operating cost of a taxi or bus, so prices will fall sharply within the 10 to 15 year time frame. In addition, artificial intelligence systems will optimize the journeys of these vehicles. We’ll be able to share a taxi with two other people without wasting time. The same goes for bus services, in city centres or the suburbs. With digital technology and autonomous vehicles, the mobility business models change: they will increasingly offer mobility services that are non-subsidized and accessible to everyone.

What possible scenarios are there for the mobility market?
Grégoire Marlot: There are three major drivers of change: technological innovation, user aspirations, and transport policies. As travellers’ aspirations change, we see the emergence of the economy of sharing. The risk, however, is that the majority of users still prefer to travel by car unaccompanied, which is inefficient. The role of the regulatory authorities will therefore be crucial, and it will change. There will possibly be less need for public subsidies for mobility services, and greater need for incentives in the form of pricing, infrastructure tolls, and traffic restrictions for polluting and/or non-shared vehicles. The stakes are very high: with the appropriate policies, we can expect greater mobility that is less expensive and minimizes environmental pollution... but without regulation, there could be more congestion and greater energy consumption. In short, strong regulation will be needed to reap the full benefits of innovation in mobility.

To conclude, what contributions does research make to your business?
Grégoire Marlot: As a former researcher, I place great emphasis on academic partnerships. These are essential, not only in the field of technological innovation, but also to provide a better understanding of trends, to improve our economic analysis tools, and to engage in dialogue with the regulator (ARAFER) and other stakeholders. ●