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Bleischwitz, Raimund; Bader, Nikolas; Dannemand, Per and Nygaard, Anne
College of Europe

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Nikolas Bader*, Raimund Bleischwitz**
College of Europe, Belgium

Anne Nygaard Madsen, Per Dannemand Andersen
Technical University of Denmark

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[**] Raimund Bleischwitz is visiting professor in the economics department of the College of Europe (Bruges). He is also affiliated with the Wuppertal Institute and the Universities of Wuppertal and Kassel (all Germany). Nikolas Bader is research assistant at the College of Europe (Bruges).
Corresponding author: nbader@coleurop.be; tel.: +32 50477315; fax: +32 50477300.

Abstract

This study takes on the issue of political and socio-economic conditions for the hydrogen economy as part of a future low carbon society in Europe. It is subdivided into two parts. A first part reviews the current EU policy framework in view of its impact on hydrogen and fuel cell development. In the second part an analysis of the regional dynamics and possible hydrogen and fuel cell clusters is carried out.

The current EU policy framework does not hinder hydrogen development. Yet it does not constitute a strong push factor either. EU energy policies have the strongest impact on hydrogen and fuel cell development even though their potential is still underexploited. Regulatory policies have a weak but positive impact on hydrogen. EU spending policies show some inconsistencies.

Regions with a high activity level in HFC also are generally innovative regions. Moreover, the article points out certain industrial clusters that favours some regions' conditions for taking part in the HFC development. However, existing hydrogen infrastructure seems to play a minor role for region's engagement. An overall well-functioning regional innovation system is important in the formative phase of an HFC innovation system, but that further research is needed before qualified policy implications can be drawn.

Looking ahead the current policy framework at EU level does not set clear long term signals and lacks incentives that are strong enough to facilitate high investment in and deployment of sustainable energy technologies. The likely overall effect thus seems to be too weak to enable the EU hydrogen and fuel cell deployment strategy. According to our analysis an enhanced EU policy framework pushing for sustainability in general and the development of hydrogen and fuel cells in particular requires the following: 1) A strong EU energy policy with credible long term targets; 2) better coordination of EU policies: Europe needs a common understanding of key taxation concepts (green taxation, internalisation of externalities) and a common approach for the market introduction of new energy technologies; 3) an EU cluster policy as an attempt to better coordinate and support of European regions in their efforts to further develop HFC and to set up the respective infrastructure.

Keywords: hydrogen, energy policy, clusters, regions, innovation

JEL codes: O18, O52, Q48, R58

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1. Introduction

In its recently launched European Strategic Energy Technology Plan (EC, 2007c), the European Commission calls for the development of the technologies and for the creation of the conditions that enable industry to commercialise hydrogen fuel cell vehicles. Other applications and the challenges for large scale production and distribution of hydrogen with its high up-front investments are also clearly addressed. Other energy policies such as the commitments of the EU Spring Council 2007 to slash the EU's greenhouse gas emissions by 20% in 2020 compared with 1990 levels (EC, 2007) are in line with the enablement of hydrogen as an energy vector.

Looking at the climate issue in the long run (Stern, 2006), the European Union will need to radically innovate and to change energy supply systems. Assuming that all GHG emissions need to decrease by 50 – 80 % in the long run as the IPCC suggests, there has to be a massive restructuring of the energy supply system. Despite these requirements however, both energy and electricity production is likely to increase from 2,963 TWh to 3,666 TWh till 2020 according to current EU forecasts and the McKinsey European Power Model (McKinsey, 2006). The challenges therefore are enormous and aggravated by the global nature of the problem and rising emissions elsewhere (IEA 2005).

Having characteristics of a disruptive technology that is still in its early stage of market introduction, hydrogen cannot yet compete with incumbent technologies, in particular not if it is produced via renewable energies. The political and socio-economic framework, which comprises financing instruments and regulatory instruments, is important to bridge the gap between the three dimensions of (a) market requirements, (b) sustainability / climate requirements and (c) the current state of hydrogen technology development.

The following study takes on the issue of enabling political and socio-economic conditions for the hydrogen economy as part of a future low carbon society in Europe. It follows the well-established argument that in early phases of business development and market introduction hydrogen needs a technology specific support scheme. Without such specific support scheme, lock-in effects of prevailing technologies (Arthur 1989, David 1985) will lead to incremental innovation only and have an advantage over potentially disruptive technologies such as hydrogen.

Lock-in effects of prevailing technologies, the risk of being entrapped in carbon lock in (Unruh/Carillo-Hermosilla 2006) or other large technological system (Walker 2000), potential diseconomies of scale (Isoard/Soria 2001) and the necessity to reach at least a critical mass of production legitimize tailor-made support schemes for hydrogen alongside non technology specific support schemes for more near-term solutions.

However along with increasing maturity and cost-effectiveness of hydrogen technology over time, regulatory emphasis will need to shift from specific support schemes such as those offered by the recently established Joint Technology Initiative (JTI)[1] towards more competitive incentive systems (such as competitive dialogues and bidding processes, general taxation, market based instruments and so on).

The assessment of the State of the Art in hydrogen technology[2] suggests that hydrogen needs a more complex support scheme compared to other emerging solutions, because it combines a high degree of technical challenge in the application itself (for example storage technologies for hydrogen), and the nature of hydrogen as a new energy carrier or an energy vector that not only needs to be produced in a sustainable manner (Heiman/Solomon 2007) but also requires a distribution system, preferably at a European and international scale. This is different to e.g. biofuels that can be blended into conventional gasoline and diesel fuels with little or no modifications to the engines that use them as well as using the existing infrastructure of gasoline stations. It is also different to heat or electricity produced by solar energy and other renewables that can use the existing pipelines and the electric grid. For those reasons, it is unlikely that support systems that have proven to be successful for renewable energy can straightforwardly be applied to hydrogen. The conditions that enable industry to commercialise hydrogen fuel cell vehicles and other applications are not yet in place. They require regulatory reforms and incentive systems for production, distribution, and end-use application of hydrogen.

The conditions that enable industry to commercialise hydrogen fuel cell vehicles and other applications such as CHP systems are not yet in place. Some niche markets such as material handling vehicles (fork lifters), remote leisure facilities and portable educational toolkits may flourish without market introduction support. Mass market development and full deployment of hydrogen however will require substantive regulatory reforms and incentive systems for production, distribution, and end-use application of hydrogen, as well as pioneering action from regions. This will be a challenge for the European Union since the evolutionary pathways towards a low cabon society are far from being clear and will need decision-making on some crucial crossroads:

- The role of biomass: there is increasing but conflicting demand for biomass stemming from gasification processes aiming for hydrogen production, biofuels, direct heating, materials production, and food;

- Steam methane reformation offers relatively low-cost production pathways for hydrogen and some potential for CO_2 savings compared to EU-25 standard fuel mix (Wietschel / Hasenauer / de Groot 2006), however it may not be the best pathway in the long run;

- Carbon Capture Sequestration (CCS) may enable fossil fuels to produce hydrogen with little CO_2 emissions, however this s not yet a mature technology and it might not be considered part of a sustainable energy system (Fischedick et al. 2007);

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[1] See for example https://www.hfpeurope.org/hfp/jti

[2] See www.roads2hy.com for such an analysis

- Nuclear energy allows for the production of hydrogen, however it is highly controversial and some EU member states have decided to phase out nuclear energy.

There is a need for an analysis on a comprehensive policy support for the deployment of hydrogen which we call a „third approach“ that bridges the gap between specific support schemes and overall framework conditions to enable a low carbon society. It is necessary because

- Existing varieties in demo projects and quite different regional features throughout Europe call for de-centralised strategies along with coordinated deployment and implementation;

- Production of hydrogen will only become sustainable if it comes from low carbon (ideally: carbon free) sources with low risks and at affordable costs;

- There are requirements for distribution systems, which gives hydrogen a spatial and public good dimension comparable to the establishment of electricity grids in the late 19th / early 20th Century;

- Incumbent technologies “hinder” deployment of hydrogen unless the hydrogen-based alternative can be made more appealing;

- The upfront set up costs not only are enormous, they might also differ throughout the Member States (with larger Member States having a higher burden, some Member States being in a central distribution position while others are more remote);

- A disruptive technology such as hydrogen has many possible applications which need to be addressed;

- New applications are only attractive for customers if they offer significant additional functionality to justify the cost difference towards a reference technology (Jenninga/Ros/Godfroij 2006);

- There is a risk that some existing policies are inconsistent with the need to create the conditions for the enablement of hydrogen.

- At a global scale, the issue of energy and raw materials security as well as ongoing programmes to deploy hydrogen require a strong role of the European Union rather than industries and regions alone.

We call it a „third approach“ because, alternatively, either the specific support mechanism will have to be maintained for quite a long time, or the overall framework conditions will have to be adopted so that they can guide processes better than regulation usually attempts. This pledge for comprehensiveness and coherence is in line with the hydrogen implementation strategy (EC 2006) calling upon business and policy makers to prepare for mass market development beyond forerunners and early markets. Furthermore, such analysis responds to recent EU initiatives of establishing a Joint Technology Initiative (JTI) and a Hydrogen Regional and Municipal Platform (HyRaMP) in 2008. Both initiatives will bring additional push in the emerging hydrogen economy, which in turn calls for the development of more comprehensive policies to follow first support schemes.

Our study will develop some characteristics for a comprehensive policy for the deployment of hydrogen. It does so by

- Screening existing policies on energy and climate. The reason behind such analysis is that those policies may entail incentives that can be used for the hydrogen deployment without developing new and additional policies and, on the other hand, even like-minded policies may have unwanted side effects on the deployment of hydrogen that needs to be considered;

- Screening other policies of general importance (Lisbon process, regional policy) for the same reason;

- Assessing regional clusters and innovation systems that may serve as platforms for self-sustaining hydrogen uptake in the future[3];

- Drawing conclusions at each step and summarize findings in a concluding chapter.

Methodologically, the study has been conducted by using the extensive amount of information generated by other studies in the Roads2HyCom project, literature analysis in the area of EU policy analysis, quantitative analysis by using the GIS-software for cluster analysis, plus feedback and interviews made with representatives and stakeholders from hydrogen communities through the workshops and other forms of exchange. Our approach thus complements research on how policies shape technological change towards sustainable energy, which has been done as ex-post evaluation of US experiences (Norberg-Bohm, 2000), of renewable energy sources in Germany, Sweden and the Netherlands (Jacobsson/ Bergek, 2004) and of energy-efficiency technologies (Grubb/Ulph, 2002).

2. Relevant policies in the EU[4]

2.1 Introduction

Since the Treaty of Amsterdam sustainable development is supposed to be one of the main objectives of European policy making (article 2). In recent years the focus on sustainable development – and sustainable energy systems being part of it - has been strengthened: In 2001 the Council agreed on a European strategy for sustainable development. In 2006, this strategy was critically revised in the light of growing concerns over unsustainable trends in Europe. The new strategy comprises seven key priority areas, amongst them two areas with direct relevance for hydrogen and fuel cell development: climate change and clean energy, as well as sustainable transport (EC 2006).

However, the EC Treaty does not confer a direct legal basis to the European level in the field of energy policy. The Lisbon Treaty – if ratified - would change this situation. In article 176A, it states:

“1. In the context of the establishment and functioning of the internal market and with regard for the need to preserve and improve the environment, Union policy on energy shall aim, in a spirit of solidarity between Member States, to:

(a) ensure the functioning of the energy market;

(b) ensure security of energy supply in the Union; and

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[3] See also work done in WP 2, 3 and 4 of Roads2HyCom by Planet, JRC, and ECN, www.roads2hy.com

[4] See also Bleischwitz, R. / Bader, N. (2008), The Policy Framework for the Promotion of Hydrogen and Fuel Cells in Europe: a Critical Assessment, College of Europe, Bruges European Economic Policy Papers BEEP No. 19.

(c) promote energy efficiency and energy saving and the development of new and renewable forms of energy; and

(d) promote the interconnection of energy networks."

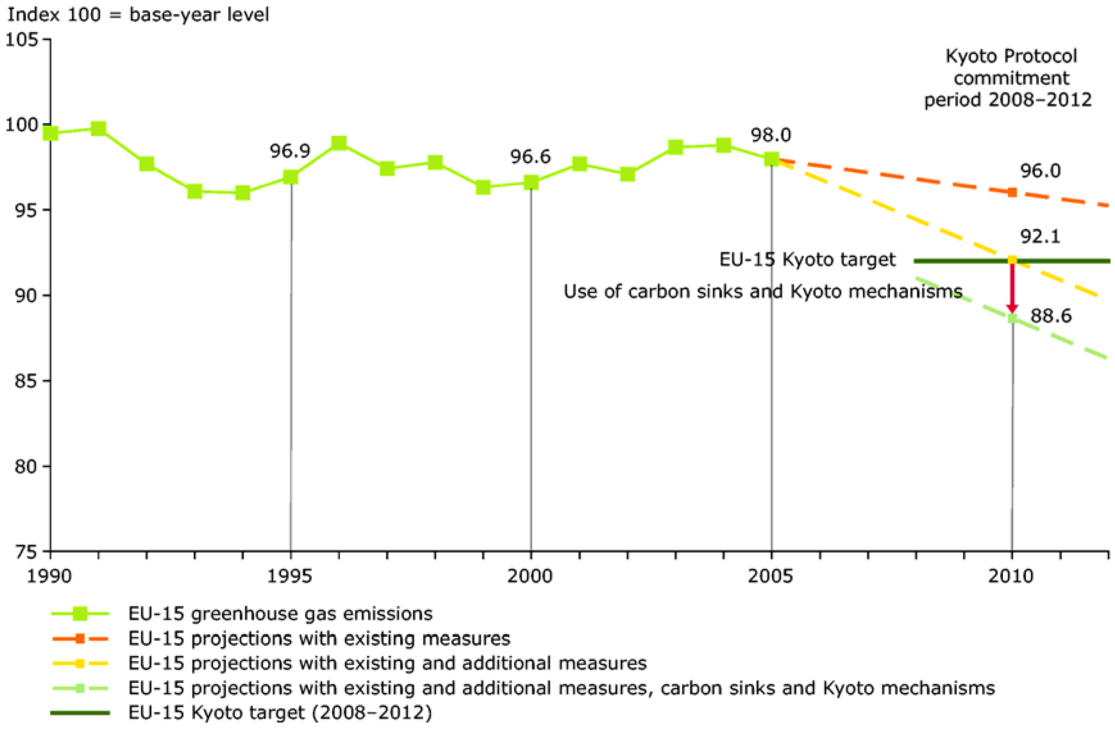
2.2 Commitments to reduce GHG

2.2.1 Analysis

The EU has committed itself to a drastic reduction of greenhouse gases (GHG). It was a key actor in the negotiation of the Kyoto agreement in 1997 and hereafter pushed towards its ratification by other states. In the framework of this protocol, the EU 15, and later on the new Member States, have agreed on a binding GHG reduction target of 8% by the period 2008-2012 compared to the emission levels of the year 1990. This collective objective of 8% was subdivided in different national reduction targets.

However, the EU is currently still lagging behind these objectives. Projections realized by the Commission and the European Environment Agency (EEA) show that unless new policies are implemented, the EU and most Member States will fail to reach their Kyoto targets.

Figure 1: Past and projected EU-15 GHG emissions compared with the Kyoto target for 2008-2012, source: EEA (2008)



However, some Member States have indeed succeeded in drastically reducing their emissions. This applies even to relatively big, industrialized states such as Germany or the United Kingdom and seems to demonstrate that with the right policy mix sensible reductions can be realized.

Table 1: GHG emission reductions EU-27, source: EC (2007 d)

			With existing policies and measures	**Use of Kyoto mechanisms (Govt.)**	**Use of carbon sinks**	**Additional policies and measures**	**With all measures, Kyoto mechanisms and carbon sinks**	
	Base Year (BY) emissions	**Kyoto targets**	**Projections for 2010**	**Effect in 2010**	**Effect in 2010**	**Effect in 2010**	**Projections for 2010**	**Gap between projections and target**
	MtCO2	% of BY	% of BY	% of BY	% of BY	% of BY	% of BY	% of BY
Austria	78.9	-13.0%	17.2%	-11.4%	-0.9%	-18.2%	-13.4%	-0.4%
Belgium	146.9	-7.5%	-3.6%	-4.8%			-8.4%	-0.9%
Bulgaria	138.3	-8.0%	-37.0%			-4.6%	-41.7%	-33.7%
Cyprus	6.0	na	101.6%			-13.7%	87.9%	na
Czech Rep.	196.3	-8.0%	-25.8%			-3.1%	-28.8%	-20.8%
Denm.	69.3	-21.0%	-9.7%	-6.1%	-3.3%		-19.0%	2.0%
Estonia	43.5	-8.0%	-56.6%			-3.3%	-59.9%	-51.9%
Finland	71.1	0.0%	19.6%	-3.4%	-0.8%	-17.4%	-2.0%	-2.0%
France	564.0	0.0%	0.9%			-4.3%	-3.4%	-3.4%
Germany	1231.5	-21.0%	-22.4%			-3.3%	-25.7%	-4.7%
Greece	111.7	25.0%	34.7%			-9.8%	24.9%	-0.1%
Hungary	122.2	-6.0%	-28.5%			-0.2%	-28.7%	-22.7%
Ireland	55.8	13.0%	22.6%	-6.5%	-3.7%	-0.2%	12.3%	-0.7%
Italy	519.5	-6.5%	13.1%	-3.7%	-3.2%	-12.2%	-6.0%	0.5%
Latvia	25.3	-8.0%	-46.2%			-2.4%	-48.6%	-40.6%
Lith.	48.0	-8.0%	-30.2%				-30.2%	-22.2%
Lux.	12.7	-28.0%	11.9%	-37.3%		-2.7%	-28.0%	0.0%
Malta	1.0	na	123.5%				123.5%	na
Netherl.	213.2	-6.0%	-0.6%	-9.4%	-0.1%		-10.1%	-4.1%
Poland	586.9	-6.0%	-28.4%				-28.4%	-22.4%
Portugal	60.9	27.0%	44.3%	-9.5%	-7.6%	-4.0%	23.1%	-3.9%
Rom.	282.5	-8.0%	-31.9%			-3.9%	-35.8%	-27.8%
Slovak.	73.0	-8.0%	-20.2%			-3.1%	-23.3%	-15.3%
Sloven.	20.2	-8.0%	6.8%	-3.0%	-8.3%	-8.2%	-12.7%	-4.7%
Spain	288.4	15.0%	42.3%	-11.0%	-2.0%		29.2%	14.2%
Sweden	72.3	4.0%	-3.4%		-2.9%		-6.4%	-10.4%
United Kingd.	775.2	-12.5%	-23.2%	0.0%	-0.5%		-23.7%	-11.2%
EU-15	**4271.4**	**-8.0%**	**-4.0%**	**-2.5%**	**-0.9%**	**-4.0%**	**-11.4%**	**-3.4%**

Through its Kyoto and its internal policy objectives, the EU has clearly shown its willingness to adopt stringent rules and laws to mitigate climate change. Following the launch of the recent IPCC assessment report and the so-called Stern-review and under the impression of a few extreme weather events, the European Council of March 2007 set more ambitious targets for the Post-Kyoto period. The EU has not adopted an objective of a 20% reduction in GHG by 2020 and a 60% to 80% reduction by 2050 compared with the level of 1990. It has furthermore endorsed the strategic objective “of limiting the global average temperature increase to not more than 2° C above industrial levels” (EC 2007e, p. 10).

2.2.2 Conclusions

The EU is strongly committed to drastic GHG reductions within the timeframe foreseen for the early deployment of hydrogen and fuel cells. On the international level, it is even one of the most important and dedicated actors in this field. Yet, the international commitment of the EU contrasts with the policy successes of European states. In fact, the EU is not lacking *commitment* to but *implementation* of climate change policy. Assuming that the EU will stick to its commitments, additional efforts to reduce GHG emissions can be expected.

In the following chapters, the EU instruments for the implementation of climate change and energy policy will therefore be analyzed.

The relevance of these commitments for an hydrogen economy is at hand: long term commitment will pave the way for more sustainable energy systems including carriers such as hydrogen (provided it contributes to GHG reduction). The current gap between commitments and implementation means that additional policies will need to be adopted which will constrain the use of prevailing carbon technologies (coal power stations in the electricity sector, use of gasoline in the transportation sector) und thus facilitate Hydrogen market introduction. The timeframe however is crucial: there might be a risk that while strongly focusing on the implementation of the Kyoto Protocol by the years 2008 – 2012, the EU and its member states might underestimate or even hinder the need to cope with long term solutions. The comprehensiveness of policies for the deployment of hydrogen thus is strongly related to inter-temporal consistency and dynamic efficiencies.

2.3 Energy taxation

2.3.1 Analysis

In its directive of 20 March 2003, the EU sets out minimum levels of taxation for energy products. The tax is paid by whoever purchases the energy product in question and not by the producer. The directive also exempts electricity consumed in the production of electricity, so-called on-site consumption. Member States have furthermore the option to offer companies tax incentives in return for specific undertakings to reduce emissions. The Commission also set up transitional arrangements for new Member States (EC 2003).

The final shape of the Directive which entered into force on 1 January 2004 is characterised by Hasselknippe/Christiansen (2003) as follows:

- New minimum rates are to be set at the latest by 1 January 2012 for a new period from 2013
- The minimum rates are set at a relatively low level (see below)
- Some Member States benefit from tailor made implementation agreements and long transitional periods
- Some energy-intensive industries can benefit from exemptions; the tax rates for business and industry are generally lower than those for other economic actors
- A return of revenue to companies/industries is possible if they enter into energy efficiency agreements (100% return to energy-intensive industries with agreement, 50% return to other industries)

Discussions on whether some exemptions from the Directive would qualify as illegal state aid were settled by the removal of these industrial sectors from the Directive.

In parallel, European stakeholders have been discussing a “green” tax reform in the light of the EU commitment to reduce its GHG emissions (Andersen/Sprenger 2000; Ecotec et al. 2001; EEA 2005, 2006). The more recent debate has been prompted by e.g. the Green Paper of the European Commission on the use of market-based incentives (March 2007), and the “Brussels Tax Forum on taxation for sustainable development” as well as by the “World Ecotax Conference”.

Table 2: Minimum rates applicable to motor fuels according to the EU energy taxation directive, source: EC (2007g)

-	Minimum excise rates before 2004	Minimum excise rates from 1.1.2004	Minimum excise rates from 1.1.2010
Petrol (/1000 l.)	337	421	421
Unleaded petrol (/1000 l.)	287	359	359
Diesel (/1000 l.)	245	302	330
Kerosene (/1000 l.)	245	302	330
LPG (/1000 l.)	100	125	125
Natural gas	100 (/1 000 kg)	2.6 (/gigajoule)	2.6 (/gigajoule)

Table 3: Minimum tax rates applicable to heating fuels and electricity, source: EC (2007g)

-	Minimum excise rates before 2004	Minimum excise rates from 1.1.2004 (business use)	Minimum excise rates from 1.1.2004 (non-business use)
Diesel (/1000 l.)	18	21	21
Heavy fuel oil (/1000 kg.)	13	15	15
Kerosene (/1000 l.)	0	0	0
LPG (/1000 kg.)	0	0	0
Natural gas (/gigajoule)	-	0.15	0.3
Coal and coke (/gigajoule)	-	0.15	0.3
Electricity (/MWh)	-	0.5	1.0

Currently, the EU's main tool to reduce emissions however is not tax policy but its carbon trading scheme (see below). Yet, the EU will need to find additional ways to discourage pollution if it is to reach its ambitious goals. Taxation could provide an answer as it can be used to move producers and consumers away from non-environmentally friendly goods. In its Green Paper on the use of market-based instruments to support energy and environment objectives of March 2007 the Commission therefore considers shifting taxes away from labour and increasing the tax burden on pollution or resource use. Such an “Environmental Tax Reform” could lead to an overall increase in social welfare (EC, 2007f, p. 5).

The EU has minimum fuel tax rates that are considerably higher than in the United States, making fuel at the pump more expensive and hence inducing car manufacturers in the EU to produce vehicles that are on average more fuel- efficient than in the US. Despite these incentives however, many Member States remain reluctant to give up their sovereignty in the field of taxation – and any move at EU level would require unanimity-backing from all 27 EU nations. The European Union has due to the unanimity rule in taxation issues very little influence on national taxation levels.

The Directive on the minimum taxation of energy products does not explicitly refer to hydrogen. Thus, in absence of any European minimum taxation level, Member States have the freedom to opt for the tax rate which they deem most appropriate at national level. According to a study led by Bocconi University, hydrogen is not taxed in a specific way in 13 Member States (Belgium, Denmark, Finland, France, Greece, Hungary, Ireland, Italy, Latvia, Luxembourg, Malta, Slovakia, Spain). Five Member States tax hydrogen when it is used as motor fuel (Austria, Czech Republic, Germany, the Netherlands, United Kingdom). Seven

Member States are not included in the study for they did not reply to the research enquiry (Cyprus, Estonia, Finland, Lithuania, Poland, Slovenia, Sweden).

An optimal tax in environmental terms aims at internalising negative externalities. In this respect, it is important to calculate not only the environmental costs of a given fuel at the end use stage but also at the production stage. Currently, hydrogen *production* (based on for example gas reforming) seems to cause in most cases higher external costs than the production of competing fuels. Hydrogen *use*, on the other hand, produces little or no external costs (GHG emissions) and may in fact substitute other more harmful fuels and energy carriers. From a systems perspective, there is no overall rationale for taxing hydrogen as long as it contributes to lowering overall environmental pressure of the energy system. However, this assessment depends upon the assumption that hydrogen is produced in a sustainable way, for instance electrolysis based on renewables or gas reforming combined with CCS (Chernyavs'ka, 2007).

European states which tax hydrogen impose only very low rates. Given that currently hydrogen is produced in a conventional way using fossil fuels, the tax level for hydrogen is estimated to lie below a level which would be needed to internalise its total external costs (Chernyavs'ka, 2007). The current European tax systems thus put hydrogen in a favourable position.

Looking ahead to the envisaged deployment however the question of hydrogen taxation must be addressed. When hydrogen applications pass the threshold from early markets to mass markets, a comprehensive framework which promotes sustainable hydrogen production will be needed. It is likely that there will be a trade off between cost-effective production of hydrogen at a large scale via gas reforming processes on the one hand and GHG reduction and the aim to promote clean energies on the other hand. Assuming that this situation occurs after 2010, the EU will be faced with the dilemma of having to implement its radical GHG commitments (20 % by the year 2020 based upon 1990 levels, more if other nations follow) and large scale production of hydrogen for which gas reforming is the most cost effective option (Ros et al 2007).

Two options for the inclusion of hydrogen in any energy taxation system can be envisaged:

1. Hydrogen taxation: hydrogen could for a certain period (= period needed to develop market pull) be exempted from any taxation. Accordingly, the incumbent carbon fuel technologies should be taxed when they are not part of an hydrogen production chain. Later on, when mass markets are forming, hydrogen from carbon intensive sources should progressively be taxed relatively higher than hydrogen produced via low GHG emitting processes. This implies that (national) taxes should serve as the major instrument to take external costs into account. Consequently the ETS would not apply to hydrogen production. An exemption of hydrogen from the ETS could set incentives for energy suppliers to increase hydrogen production.

2. Linking taxation with ETS: Given that hydrogen *utilization* typically causes only low or zero emissions, it is coherent with "green" taxation strategies to exempt it from any taxation. Consequently, the ETS would be the main instrument to internalise costs of hydrogen *production*. The ETS in turn should be expanded to any form of hydrogen production which causes GHG emissions. This option would be consistent with the ETS (see below) and have the advantage that it can be implemented at EU level. Member States would have to choose whether and how to tax hydrogen additionally. Using the Open Method of Coordination, Member States will be requested to coordinate their policies and refrain from any hydrogen taxation.

Such market based incentives can be enlarged to foster energy efficiency. For instance fuel cell applications in transportation offer energy efficiency advantages over internal combustion engines. However any such system will need careful discussion at EU level since taxation issues require unanimous agreement of Member States. With the internal market for energy being realized (see chapter 1.5) a closer cooperation in the field of taxation of fuel cell and hydrogen appliances may well be possible. The current debate on environmental tax reforms could be used as a forum by the Commission or other stakeholders to raise this question and pave the way for better understanding of mutual positions with regard to hydrogen taxation.

2.3.2 Conclusions

Since 2004, an EU directive has been setting minimum levels for the taxation of motor fuels, heating fuels and electricity. Hydrogen is not mentioned in this directive. On the national level, a few Member States tax hydrogen. Though, the tax level is relatively low, this is not entirely coherent with the hydrogen deployment strategy. Despite this burden, the overall fiscal environment for the promotion of hydrogen can be seen as relatively good and should be maintained for the coming years. One should also keep in mind that the world market prices for energy fuels (oil, gas and coal) have been soaring and strengthen the market introduction of hydrogen and fuel cells. Thus the conclusion is twofold:

1. In the short term, ecotaxes on carbon / energy should be maintained in order to give incentives for an alternative energy carrier such as hydrogen. Accordingly, any tax on hydrogen utilization should be removed.

2. In the mid to long run when mass markets for hydrogen are forming, it will become rational to include hydrogen in any minimum taxation Directive or to reform this system taking into account the total external costs of the life cycle of respective energy products.

2.4 Renewable Energy Directive

At the EU Summit in March 2007, the EU leaders agreed to meet 20% of their overall energy needs by the use of renewables by 2020. This objective also comprises a minimum target of a 10% share of biofuel use in transport, which is however, subject to sustainable production and expects second generation biofuels becoming commercially viable. The difficulties that are lying ahead are the fact that national targets need to be set that take into account specific circumstances and potentials in the different EU countries.

Up to date there is already a directive for the promotion of Renewable Energy Sources (RES) in place. Directive 2001/77/EC sets the target of a 21% renewables share of total electricity consumption by 2010. The current status of renewable electricity production shows the following figure, demonstrating implementation deficits in some member states (Slovakia, Spain, Portugal, Italy, France, Greece, Ireland, UK, Poland, Belgium, Estonia, Malta, Cyprus).

The directive covers five areas: setting national targets that take into account different potentials of Member States, evaluation of national support schemes for green electricity producers, measures to ensure transparent and fair rules for the connection to the national electricity grid, streamlining the procedure for new entrants, establishment of mutually recognised guarantees of origin for green electricity.

Figure 2: Share of renewable energies in gross electrical consumption in European Union countries in 2006 (in %), source: EurObserv'Er 2007

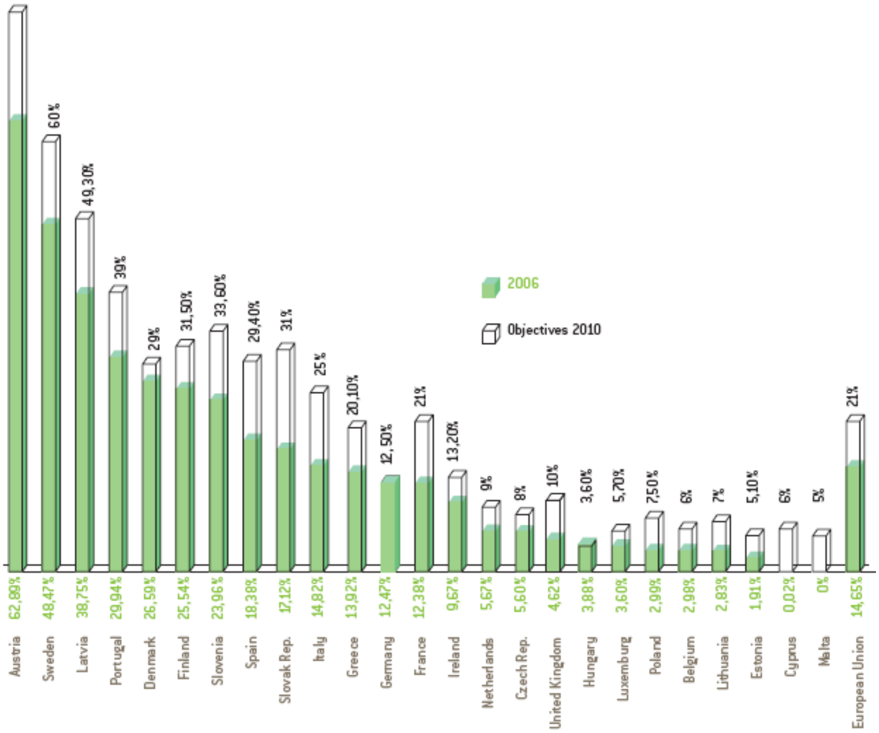
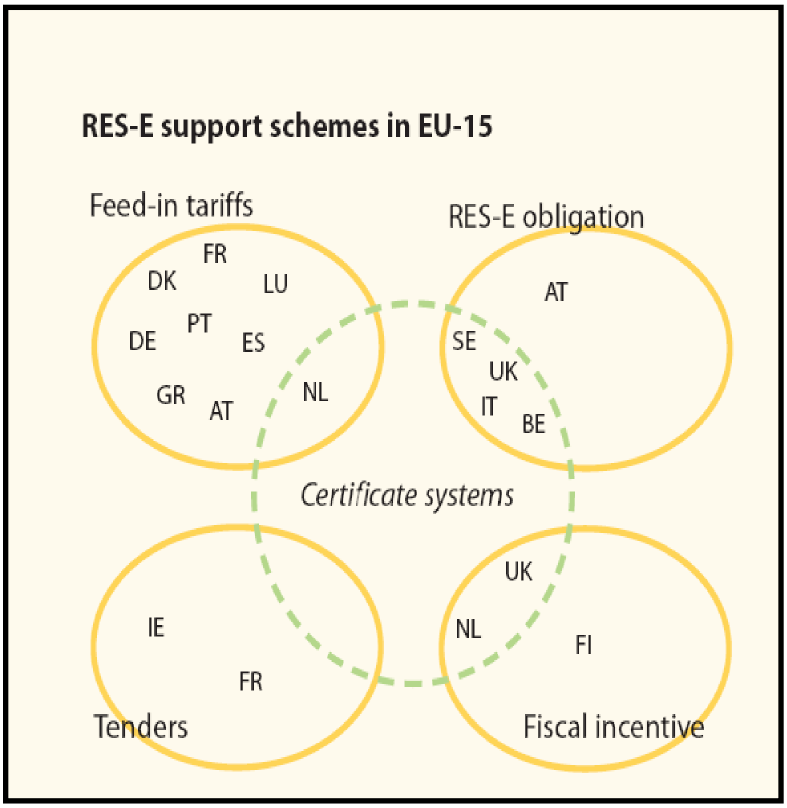


Figure 3 Existing Support Schemes in the European Union, source EC 2007h



One main characteristic of the directive is the recognition of all the different support schemes that Member States are operating with different objectives, such as security of supply, local employment or emissions reduction. The diversity of incentive system provides a rich information source and it should be recognised that renewable energy sources are different and might need different support at different stages. Often, national schemes are a combination of support schemes which are either supply side driven or demand side driven. The mainly used instruments are shown in Figure 3 on the previous page; feed-in tariffs can be seen as the preferred incentive which has been applied in many Member States.

As the 2001 directive has not yielded the expected results and in response to the EU objective of increasing the share of renewable energy sources by 2020 to at least 20%, the Commission published in January 2008 a proposal for a new directive on the use of renewable energy. This proposal explicitly allows for tradable certificates in renewable produced energy, an instrument which is not new in EU law but has barely been used so far. Furthermore, according to this proposal new or refurbished buildings would require the installation of renewable energy technologies to cover a minimum share of renewable energy use. The text also states that renewable energy is to be granted priority access to grid systems. Each Member State would have to reach a certain target of renewable energy production. These targets are calculated according to the GDP per capita of the Member States (EC 2008).

Table 4 Renewables share EU 27, source: EC 2008

Member State	Share of Renewables in 2005	Share required by 2020
Austria	23.3%	34%
Belgium	2.2%	13%
Bulgaria	9.4%	16%
Cyprus	2.9%	13%
Czech Republic	6.1%	13%
Denmark	17%	30%
Estonia	18%	25%
Finland	28.5%	38%
France	10.3%	23%
Germany	5.8%	18%
Greece	6.9%	18%
Hungary	4.3%	13%
Ireland	3.1%	16%
Italy	5.2%	17%
Latvia	34.9%	42%
Lithuania	15%	23%
Luxembourg	0.9%	11%
Malta	0%	10%
The Netherlands	2.4%	14%
Poland	7.2%	15%
Portugal	20.5%	31%
Romania	17.8%	24%
Slovak Republic	6.7%	14%
Slovenia	16%	25%
Spain	8.7%	20%
Sweden	39.8%	49%
United Kingdom	1.3%	15%

In more general terms, renewable electricity production can be supported both at the level of the end user (e.g. tax exemptions, subsidies) or at the production level (e.g. stable returns, investment subsidies). The existing distribution system of the electricity grid can be utilized though some reforms need to be made (better load management, entry points etc.). In contrast, the introduction of hydrogen requires changes in the infrastructure (Jenniga/Ros/Godfroij 2006). Thus the difference to renewable energy sources is that in the case of hydrogen not only the cost differences on the production level must be minimized but also the distribution needs ought to be addressed.

Some of the RES support schemes could smoothly be extended to hydrogen. For instance, the instrument of feed-in tariffs can be differentiated across technologies. Hydrogen could thus be incorporated in feed-in support mechanisms. These mechanisms encourage private sector investment and, if combined with a guaranteed price over a longer period, lower the business risk. If well designed, feed-in tariffs can effectively promote renewable energies (EC 2007h) and also hydrogen. Given that one of the major barriers to renewable energy is their intermittent nature, hydrogen might be used to be fed-into the electricity grid, such as a storage system for over supply of wind production. Hydrogen production as a means of power storage thus fits well into a renewable energy system, and, moreover, can correct some of its shortcomings.

2.4.1 Conclusions

The Directive on RES is insofar very important for the development of hydrogen technologies in Europe as renewable and low GHG emitting technologies are the conditio sine qua non of sustainable hydrogen production. If, on the long run, hydrogen cannot be produced in a clean way, its market introduction makes no sense in environmental terms. Thus, the success of hydrogen hinges on the increase in renewable energy production (or any other alternative system). Furthermore, the RES Directive may be used as an instrument for hydrogen promotion. In its current form, it is not targeted on hydrogen. The EU therefore should consider the option to incorporate hydrogen in the RES Directive. This will complement and may even promote a renewable energy system as a means of power storage. Additionally, the system of remuneration fees could be considered for transportation too: providers for hydrogen busses and cars would receive a remuneration which is taken from gasoline revenues in the respective member states. This would not only boost the market but in particular support the market entry of new producers and thus support SMEs across Europe.

2.5 Emissions Trading Scheme

2.5.1 Analysis

The European Emissions Trading Scheme (EU ETS) started on 1st January 2005 after the Directive 2003/87/EC had been issued in 2003. The scheme specifies two periods, the first from 2005-2007 and the second corresponding to the first commitment period of the Kyoto Protocol from 2008-2012. It takes place on the level of installations, thus targeting the emitters themselves.

The EU ETS is based on six basic principles (EEA 2005b):

1. Cap and trade system
2. Initial focus only on CO_2
3. Implementation will take place in phases with reviews and possibilities for expansion of additional gases and sectors

4. Allocation plans for emission allowances are decided periodically (corresponding to the trading periods)

5. Compliance and penalty framework

6. EU wide system that taps reduction opportunities in the rest of the world through he other Kyoto Mechanisms - Joint Implementation and Clean Development Mechanism.

Annex 1 of the directive defines the activities that are obliged to participate among which combustion installations with a rated thermal input above 20MW, mineral oil refineries, coke ovens, iron and steel production, cement production and pulp and paper production. Even with the limited scope circa 12000 installations are taking part in the system, which covers about 45% of total EU CO_2 emissions.

From today's perspective it looks as if the system is working (late 2008). Prices do react to market developments and information given out to the public. However, there are still a lot of issues, such as complexity, transaction costs, liquidity, allocation rules, harmonisation and inclusion of other gases and sectors that need to be taken into account.

The question remains to what degree does the EU ETS spur investments towards more sustainable energy supply systems, such as hydrogen? Up to now the ETS is still at a more experimental stage, and the international agreements such as the Kyoto Protocol do not give a clear long term perspective, either. One could of course assume that the energy world will need to become less and less carbon intensive, but this is a normative assumption and there have been no intermediate and long term goals set. A promising energy carrier such as hydrogen, which is at the stage of demonstration projects but well below any deployment, needs long term forward looking policies with a system of clear time perspectives (Carraro/Egenhofer, 2003; Bleischwitz/Fuhrmann, 2006).

Analysing the Emissions Trading Scheme, it partly encourages the uptake of climate-friendly technologies by rewarding businesses investing in energy efficiency and some green technologies, thus turning their investments into quick, short term profits. But given the uncertainties about its future characteristics, it can hardly encourage investments into long term solutions. The risk of sunk costs is still too big and the coordination costs are too high for many investors. This is aggravated by the limited playing field for the ETS: the automobile industry and oil industry, both of whom have an interest in investing into mobility with alternative fuels are not covered by the EU ETS. Surrounded by many constraints, the EU ETS can only provide narrow incentives to discover new technical solutions. According to Endres/Ohl (2005: 29) the ETS will display the push generally expected from market forces only to a limited extent. The European Emissions Trading Scheme in itself thus neither gives the incentive to invest in such disruptive technologies nor is it its aim to start with.

A dynamic push towards sustainable energy systems would require both an improved ETS system and more targeted programs for business development and market entry of new energy sources and carriers. One could, for example, imagine that companies invest in emission reducing projects within the EU and get credits for it, comparable to JI or CDM projects. Yet, the European Commission does not favour this option as it merely shifts reduction efforts from one sector to the other.

In its communication "20 20 by 2020, Europe's climate change opportunity" of January 2008 the Commission proposes a major reform of the ETS (EC 2008b):

- GHGs other than CO_2 should be included in the ETS

- The ETS should apply to all important industrial emitters

- EU wide auctioning of allowances should replace the national allocation plans which are currently in place
- From 2013 onwards the whole power sector should be part of the ETS
- Member States should use at least 20% of their auctioning gain for investment in energy research, technology development and other GHG reducing measures
- The use of CDM credits should be limited

If a reformed ETS applied to all industrial emitters, hydrogen production would then most likely fall under it too. The ETS would thus hinder (GHG intensive) hydrogen production. Instead of ‘penalising’ hydrogen production, a reformed ETS should rather set incentives for it. Hydrogen production could for instance be exempted from the ETS whereas nearly all other industrial emitters may be included. Another possible option for hydrogen support may be to allow companies more emissions or grant them allowances to reduced prices if they produce hydrogen or develop potentially green technologies such as hydrogen and fuel cell applications. This supposes of course that the prices for CO_2 allowances rise, meet expectations to rise further and thus set incentives for long term investment in new energy solutions.

2.5.2 Conclusions

The EU ETS as it is today does not yet properly facilitate long term innovation dynamics like the transition towards hydrogen. This certainly does not come as a surprise, because the EU ETS has not been set up to do that in the first place. It encourages low cost emission reductions, but does not provide the support to bring about real structural change. Moreover, according to current proposals a reformed ETS might even hinder hydrogen deployment if it were extended to further sectors which are of great relevance for hydrogen production such as the chemical industry. However, if the reform considers the green potential of hydrogen and consequentially exempts its production from carbon trading, then a reformed ETS can indeed push towards hydrogen deployment since it may lead to more long term investment security. One may also note that the mechanism of tradable permits can also be applied to enforce market introduction (see e.g. the UK example of green permits).

2.6 Biofuels

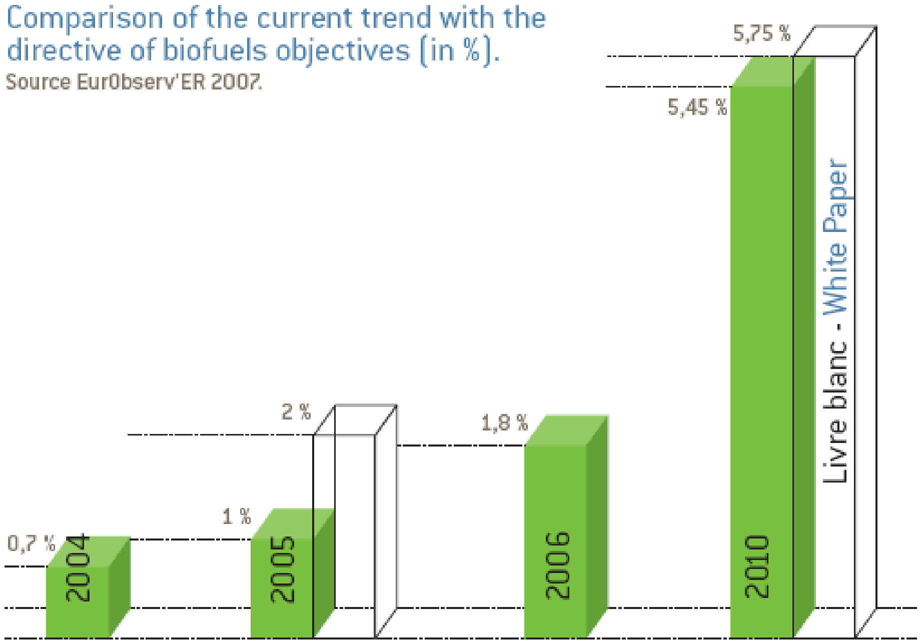
2.6.1 Analysis

In 2003, the EU set the indicative target to increase the share of biofuels in transport to at least 5,75% by 2010. The expectation is that CO_2 emissions in the transport sector might decrease given that biofuels are expected to substitute petrol and diesel (EC 2003b). According to the Green Paper “Towards a European strategy for the security of energy supply”, the Commission aims on the longer run to increase the share of alternative fuels in transport to 20% by 2020 (EC 2000). The term “alternative fuels” also includes gas and hydrogen but biofuels will have the main role to play if the Community is to reach this goal. In fact, at the EU summit of March 2007, the Council set the target of a 10% share of biofuels in transport to be reached by 2020.

However, the Community is still far away from reaching this objective. It is already unlikely that the goal of increasing the share of biofuels to 5,75% by 2010 will be reached. A progress report of 2007 shows that a share of 4,2% seems more likely for 2010. In fact, the EU 25 reached a biofuels share of only 1% in 2005.

Yet, other studies, notably the EurOberserv'ER Barometer 2007, estimate that the EU member states may come close to their targets (EC 2007i; EurOberserv'ER 2007).

Figure 4, source EurObserv'ER, 2007



The 2003 Directive on energy taxation allows Member States to apply reduced excise duty rates to biofuels when those are used in transport or as heating. Many Member States resort to this option to promote biofuels (Bringezu et al. 2007). A recent study estimates that the loss of revenues caused by the preferential taxation of biofuels mounts up to roughly 1,8 bill. € in 2005 (Bringezu et al. 2007: 146), notwithstanding the subsidies paid to farmers and negative price effects for other agricultural commodities.

In addition to the promotion of biofuels by the means of common targets and tax exemptions the EU also supports its production through the Common Agricultural Policy (CAP). The 1992 reform of the CAP has introduced the obligation for farmers to set aside a certain surface of their farm-land. Normally, this land must not be cultivated. Yet, if a farmer produces crops for non-food use he is allowed to resort to the set-aside area. Already in 2005, 0,85 million hectares of set-aside land served for growing oilseeds for biofuel production. Since 2005, also sugar beet for biofuel can be planted on set-aside land (EC 2006c). Moreover, the latter can benefit from specific EU aid for energy crops. Farmers who grow biofuel crops can benefit from a premium of up to 45 Euros per hectare. This incentive has worked so well that the area where energy crops eligible for this funding were grown increased from 0,31 million hectares in 2004 to 2,84 million hectares in 2007. The funding per hectare has since then been decreased because the budget ceiling for this instrument (90 million Euros per year) was reached (EC 2007p).The EU furthermore supports investment and training in biofuels via its Regional Development Fund and its Rural Development policy (EC 2006c).

Energy sources and carriers should be assessed not only against economic but also against environmental and political criteria. With regard to many criteria biofuels perform quite well: they lead to greater security of supply, they can relatively easily be commercialised, and they may furthermore foster regional development in rural areas and strengthen agriculture. However, there is a great controversy about whether biofuels meet one important criterion: environmental sustainability.

Compared to the use phase of conventional fuels, biofuels are "carbon neutral": when they are used, no more carbon dioxide is released than has been absorbed during the growth of the plants used to make these biofuels. Therefore replacing fossil fuels with biofuels for transport could help in the fight against climate change. However, this conclusion is controversial and other studies claim that biofuels might actually increase greenhouse gas emissions due to emissions from agriculture, production processes and transportation (exports) of biofuels. Furthermore, if forests are destroyed for the sake of biofuel production, high amounts of GHG are released in the atmosphere (Bringezu et al. 2007). Thus, the Energy Division of the United Nations (United Nations 2007) warns that the use of biofuels in transport might even increase CO_2 production and supports a use for combined heat and power production.

For various reasons scholars disagree on the energy balance of biofuel production. The energy balance is the amount of energy needed over the life-cycle to produce biofuels (input) versus the amount of energy produced (output). According to studies by Patzek, “production of ethanol from corn is 2-4 times less favourable than production of gasoline from petroleum” (Patzek 2007, p. 268) and has a very questionable energy balance. Other studies (eg. by the US Department of Agriculture) indicate that the energy balance is positive (Shapouri et al. 2004). In addition, economic analysis of biofuels seem to indicate that the abatement costs for CO_2 tons avoided is in the order of 200 €/t (Frondel et al. 2007: 1681) – certainly not a cost-effective option.

Some critiques argue that even if biofuels had a positive energy balance, they would still be environmentally harmful. As biofuels use large fields of arable land and may lead to monoculture farming, an increase in their production may destroy not only forests but also numerous species and increase global food prices. Growing demand for biofuels in Europe and North America can “export” these negative effects to developing countries by driving their biofuel production and reducing their food production. Some scholars as well as a growing number of politicians and environmental NGOs call therefore the US and EU to reconsider their biofuel strategies (Bringezu et al. 2007; House of Commons 2008).

However, second generation biofuels seem to be more promising than their current counterparts. Second generation biofuels can be produced from the whole plant and residues. For they do not use as much input as first generation biofuels and carry a higher yield they induce less environmental pressure and lead to greater GHG savings. Yet, the second generation is still in development and for the moment relatively costly.

Biofuels are more expensive than traditional fossil fuels when produced in the European Union and therefore tax exemptions are needed to make biofuels competitive with fossil fuels. At the moment there are discussions going on to fade out the tax exemptions for biofuels in some European countries. In some countries like Brazil, biofuels can be competitively produced.

2.6.2 Conclusions

Biofuels are a relatively rapid answer to the growing concern about security of supply. Unlike hydrogen, biofuels can be blended up to a certain degree with traditional fossil fuels, are easily to introduce (no special infrastructure needed) and might compensate for relative shortages of oil. Thus, biofuels can well be seen as rivals for hydrogen, at least in the short term. With regard to a long term solution, biofuels are however no answer to the global energy issues. First, they will not be able to substitute for fossil fuels since the global production capacities are limited by the land available and by shortages in other production factors. Second, it is questionable whether biofuels have such a good environmental footprint as its supporters claim – there is increasing evidence of negative environmental impacts. In this respect hydrogen performs clearly better, at least hydrogen produced from renewable energy sources. It thus does not seem to be advisable to recommend a more ambitious policy on biofuels than the prevailing EU policy.

In a transition period towards hydrogen and other sustainable energy systems, biofuels might nevertheless play a role. Cascading use of resources and the promotion of second generation biofuels may improve their environmental footprint. Thus, questions arise about which role biofuels are expected to play in the European future energy mix and the respective role of hydrogen in it. The EU strategy is not clear on this. Though biofuels do not rise to the challenges, they may broaden the energy supply and complement hydrogen. Due to its low energy density per unit volume, the latter cannot be used in planes or ships. This would be a field where biofuels may be of complementary use.

2.7 Energy Efficiency

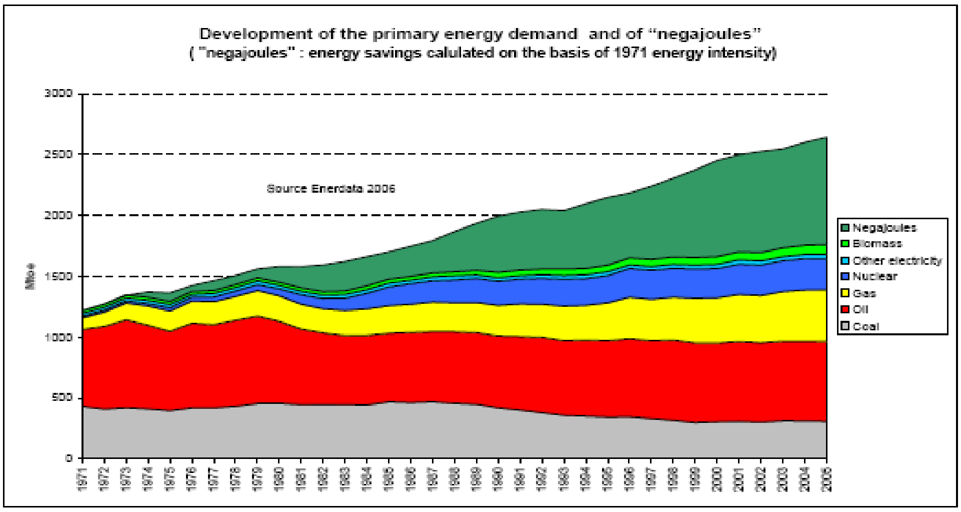
2.7.1 Analysis

At the EU summit of March 2007, the EU has agreed on the ambitious target to save "20% of its energy consumption compared to projections for 2020" (EC 2007e). This target is supposed to help the Commission to respond to three different challenges Europe is currently facing: the challenge of European competitiveness, the challenge of climate change and the challenge of security of supply (EC 2005).

According to the directive on energy end-use efficiency of 2006, the Council and the European Parliament define energy efficiency (EE) as "a ratio between an output of performance, service, goods or energy, and an input of energy" (EC 2006c). The scope of EE policy is rather encompassing as it concerns the whole value chain: the production of energy, its transmission and distribution as well as energy end-use. EE policies thus aim to alter the ratio between the output of a given process and the input of energy at every stage of this chain (Centre for European Policy Studies 1994).

On the first sight, Europe's policy in the field of EE seems to be a success story. In fact, energy intensity, i.e. "the amount of energy used per unit GDP" (IEA 1987) has drastically decreased in the EU in the last 35 years. If one counted the energy consumption Europe has avoided by becoming more energy efficient ("negajoules"), EE would be the most important "energy source" in Europe (EC 2006d).

Figure 5: Development of primary energy demand and energy savings (EC 2006c)



However, huge potentials for energy savings can still be identified. Yet, companies, organisations and individuals do not always make the investments needed to realize these savings potentials even though they could herewith reduce their costs. Hence, there are severe barriers and market failures (Sorrel 2004) such as information deficits, split incentives, high implicit discounting rates, hidden costs, high transaction costs or market power. Public policies in the field of EE are designed to lessen the impact of these economic barriers (Ramesohl 2007).

Since 2000, the Community has adopted several measures in the field of EE. Many legal instruments concern specific sectors such as buildings and the labelling of precisely defined products (for instance household appliances or electric ovens). However, two relatively recent directives are already rather encompassing in their scope and set a framework for nearly all sectors. They are therefore referred to as "framework directives":

- One of these framework directives is the 2005 directive on energy end-use efficiency and energy services which sets the target of 9% EE improvement over 9 years. This means that every member state must on average improve by 1% its EE every year. These targets are indicative. The Member States are relatively free to choose the instruments by which they want to reach these goals (EC 2006c).

- In 2005, the EU also adopted a framework directive on the ecodesign of energy-using products. This directive applies in principle to any energy using product with the only exception of vehicles for transport. The text aims to improve EE in the whole life cycle of the product. This means that the directive envisages to provide for EE standards and requirements for every stage of the production beginning with the early design phase. The text itself does not set any binding targets (EC 2005b). In theory, this directive has an enormous energy saving potential. Yet the realisation of this potential depends largely on its future implementation

According to the Green Paper on EE, already half of the 20% energy savings target for 2020 could be reached if the existing legislation was well implemented and the promotional and dissemination activities reached out to a high number of energy consumers. To reach the remaining 10%, the Community would need to adopt and implement new legislation (EC 2005) such as the measures proposed in the 2006 EE action plan. After having agreed on the 20% target at the Council of March 2007, the Community will discuss the proposed measures in the coming months and years.

According to a more in-depth analysis the EU activity in the field of EE has certainly undergone a profound change during the last decade. Yet, the targets still are not very ambitious. Between 1973 and 1990, EE improvements in IEA countries were far higher (2% average annual change) than in the period 1990-2004 (0,9% annual change on average) (IEA 2007). This can be explained by the fact that the oil crises and the correspondingly high energy prices, constituted a major incentive for economies to reduce their energy consumption. After 1990, this incentive has been absent due to relatively low price levels. However, the 1973-1990 period shows that it is possible to improve EE at a much faster pace than it has been the case since the 1990s.

The 1% target of improvement in EE as fixed in the energy end-use directive almost corresponds to a "normal rate" of EE improvements in a situation where no binding targets exist. In fact, even without any legislation on EE, industrialised economies tend to reduce their energy intensity because of for instance technological improvements or cost cuts. This explains the EE improvement of 0,9% for the period 1990-2004. In a period of rising energy prices and rising concern about global warming, more ambitious targets would be needed. Many authors, such as Stefan Lechtenböhmer et al. from the Wuppertal Institute, propose an annual improvement of energy efficiency in the order of 3 – 5 % p.a., and have demonstrated the feasibility of such improvements in numerous analyses (Blok, 2005; Lechtenböhmer et al. 2005).

The EU has many instruments to improve EE. If the existing directives were well implemented and the measures proposed in the EE action plan led to a more ambitious policy, the Community's policy would be able to make a real difference and reduce energy intensity. Other countries have set a good example. The Japanese "Toprunner Program" for instance has yielded drastic EE improvements and has by no means harmed the competitiveness of the Japanese economy. The Japanese Ministry of Economy, Trade and Industry (METI) fixes thereby EE standards for several product groups according to the most energy efficient products on the market, in cooperation with the producers and experts. The less energy efficient producers are given a certain timeframe to improve their products. The EE improvements have so far been greater than expected by the ministry (Energy Conservation Centre 2006; Bahn-Walkowiak / Bleischwitz et al. 2008).).

With regard to hydrogen and fuel cell deployment, it is interesting to see that energy consumption has grown between 1990 and 2004 mainly in two sectors and is expected to continue to grow in future: electricity consumption (households and services demand more electricity) and transport (freight and passenger transport). In the latter, there have so far been relatively little EE improvements (IEA 2007). One way leading to more energy efficient vehicles is the use of fuel cells. Higher EE standards in the transport sector can therefore benefit to the deployment of hydrogen insofar as they promote the use of fuel cells.

However, not only the transport sector is of great importance in this context. Directives on the EE of appliances for non-transport use can also pave the way for greater use of fuel cells. Fuel cells are for instance mentioned as a cogeneration technology in the EU directive on combined heat and power (EC 2004c). Moreover, even when fuel cells are not directly mentioned in EU directives, the latter can still have great impact on their market deployment. The before mentioned directive on the "eco-design of energy using products" sets a framework for all energy-using products, except for vehicles for transport. As it covers also all energy sources it may advance the market introduction of fuel cells and hydrogen. Progress in fuel cell technology in some specific areas like small appliances has the potential to further the development of fuel cells in other areas too, such as transport. One should note, however, that these standards need to be set with a mid term perspective in order to go beyond incremental improvements and to attract financing for the fuel cell business (which is SME based).

The downside of energy savings is that it can lead to increasing consumption ('rebound effect', see e.g. Herring 2006 a + b) which may over compensate EE gains. Legislation on EE should therefore be complemented by other incentives to real energy savings such as effective price systems. Such a system (taxation, ETS) should lead to price increases parallel to efficiency increases, so that the final user still receives signals to use less energy. Thus, a rise in consumption may be avoided; consumption-oriented strategies can support such incentives (for further details see overall conclusions at the end of part I).

2.7.2 Conclusions

The current EU legislation in the field of EE is promising but not very ambitious. If the Community wants to reach its targets, not only effective implementation of existing directives is needed but also new policy initiatives and legislation. Given that energy efficiency offers many advantages, the targets to increase energy efficiency could also become more ambitious (e.g. 3 – 4 % p.a.). In view of the promotion of hydrogen and fuel cells in Europe, the introduction of EE standards in transport and further improvements in EE standards are generally advantageous. If designed with a mid term perspective and combined with information, economic incentives and deployment policy, they are likely to channel investment and research to innovative energy efficient technologies such as fuel cells and potentially also hydrogen.

2.8 Liberalisation and the internal market for energy

2.8.1 Analysis

The liberalisation of the European market for electricity and gas is supposed to strengthen the competitiveness of European firms and improve the efficiency of the energy market (Pelkmans 2006). It should allow consumers to choose among different energy suppliers and select the one they deem best after having compared their services and prices. All energy suppliers should furthermore have access to the market, irrespective their market power and the energy source. Thus, also small producers of renewable energy could better promote their products provided that the price mechanisms reflect the external costs too. According to the Commission the liberalisation of the energy markets could then also promote sustainability and lead to more security of supply.

However, in its conclusions of March 2007 the Presidency of the Council of the European Union states that “a truly competitive, interconnected and single Europe-wide internal energy market […] has not yet been achieved” (EC 2007e, p. 16). In view of reaching this goal, the Council sees the need to firstly fully implement existing directives. Secondly, further measures that go beyond existing legislation are to be discussed and implemented.

The implementation of existing legislation refers mainly to two 2003 directives, one on the internal market for natural gas, the other on the internal market for electricity:

- The directives stipulate that for non-household customers the markets for electricity and gas must be liberalised by 1 July 2004.
- The respective markets for the remaining customers, above all private households, must be liberalised by 1 July 2007 (EC 2007j, 2007k).

Notwithstanding these already elapsed deadlines, the internal markets for electricity and gas have not yet been fully liberalised and actors still complain about the persistence of entry barriers to the market. Thus, the Commission stated in a sector inquiry of early 2007 that several problems need to be addressed and respective policy responses to be implemented if the liberalisation is to advance (EC 2007l):

- Market concentration: in most national markets a relatively small number of market players is dominant
- Vertical foreclosure: energy networks and supply are often in the same hands which makes it difficult for small actors to enter the market
- Market integration: actors that compete on a given national market normally do not cross borders in order to act as competitors on other European markets
- Transparency: competitive markets would require timely and reliable information which is not yet the case on the European markets

- Price formation: as price formation is not transparent, users lack trust in the market mechanism; in some cases, firms supply energy below the market price to deter possible competitors from market entry

- Downstream markets: competition between suppliers at the retail level is in many cases limited; sometimes customers cannot opt for a new supplier since retail contracts have often a very long duration

- Balancing markets: the balancing zones are small; existing balancing markets often favour incumbents

- LNG markets: LNG markets still favour national incumbents; however, the diversification of upstream sources on LNG markets could favour downstream competition

These problems require new legislation which goes beyond the scope of existing directives. The Council conclusions of March 2007 enumerate some needs: unbundling, strengthening of national energy regulators, facilitating cross-border electricity trade, facilitating the market entry of new actors, improving the efficiency of transmission grids, rendering the market more transparent and protecting consumers (EC 2007e, see also Pelkmans 2006).

However, there is a great debate about how to exactly implement some of these points. In the centre of the debate has been the issue of unbundling which means separating the activity of energy supply and generation from the activity of managing transmission networks. The Commission and some Member States are favouring “ownership unbundling” which would prevent a company of being active in electricity generation and transmission activities at the same time. As this would mainly apply to big vertically integrated companies, some Member States whose firms would hereof be concerned are opposing such a solution and call for “Independent System Operators” (ISO). The latter would be independent actors that would operate the networks of vertically integrated companies.

From today’s perspective, it is difficult to see which option - ownership unbundling or the establishment of ISO’s - will lead to lower prices while at the same time the EU will seek to achieve an internalization of external costs. However, one can assume that both reform models may increase competition on European markets and thus lead on the medium term to lower prices (not in absolute terms but relative to a situation without policy change).

At the current price level, hydrogen is not competitive with most energy sources and energy carriers. Thus, one might be tempted to conclude that rising energy prices favour hydrogen development as long as only prices of competing energy vectors and sources increase and not that of hydrogen. Under this assumption, policy makers face a liberalisation trade-off:

- Policies like those proposed by the Commission that tend to relatively decrease energy prices may on the one hand hinder hydrogen development given that softly and continuously increasing prices would be best for it.

- On the other hand, open access supply policies will favour the market entry of new energy carriers and technologies such as hydrogen and fuel cells.

However, these assumptions are likely to have only limited value in today’s context. Energy prices are expected to either maintain at a high level or even follow an upward trend in the coming years (EC 2003c). The liberalization of the gas and electricity markets may have an influence on the level of the price curve, but not in a significant way. The overall price level will also depend on other factors such as impacts from climate policy. To conclude, liberalization needs twinning policies for the internalization of externalities and for the deployment of hydrogen and fuel cells.

Moreover, the described trade-off is based on the assumption that hydrogen will compete with electricity and gas. However, electricity and gas are two major inputs for hydrogen production. If gas and electricity prices rise, the price for hydrogen rises too. The price for hydrogen is thus dependent upon the gas and electricity price. In absolute terms, hydrogen will always be more expensive than gas and electricity as long as it is mainly produced via electrolysis and gas reforming. Yet, the price for gas and electricity may affect the hydrogen production processes. High prices for gas and electricity can be an incentive for further research of alternative ways of hydrogen production, such as biological production.

We are confronted with a different picture if we blank out hydrogen for stationary use and only analyse hydrogen for transport applications. From an end user perspective hydrogen for mobile applications competes mainly with oil. Thus, the price of hydrogen must be compared with the crude oil price. In a scenario where the medium term increase in crude oil prices is higher than the increase in prices for electricity and gas, hydrogen will become more competitive with regard to crude oil. Any policy change that renders electricity and gas relatively cheaper with regard to crude oil can therefore be seen as a policy change which benefits to hydrogen. The liberalisation of the electricity and gas markets may thus have positive effects on the promotion of hydrogen in transportation in Europe.

2.8.2 Conclusions

The effects of the liberalization of the gas and electricity markets may have two positive effects on hydrogen deployment:

- Market entry for producers of fuel cells and hydrogen will be facilitated,
- Hydrogen produced by gas reforming and electrolysis may become more competitive with oil in the transportation sector.

These effects differ with regard to stationary and mobile use of hydrogen. Hydrogen for stationary applications competes with electricity since both energy carriers can be used for similar applications. For some applications the use of hydrogen and fuel cells may bring big advantages that compensate for the relatively high price for hydrogen and enable its commercialization (material handling vehicles because of long operating times compared to batteries, leisure sector because of quietness compared to conventional engines, portable goods and some luxury goods)[5]. For other applications hydrogen will have to be almost as cheap as electricity or gas. Hydrogen will not be used for these applications as long as its production is based on these two inputs.

With regard to applications in automobile transportation the cost of hydrogen must be compared with crude oil. Given that gas and electricity are major inputs for hydrogen production, the liberalization of the energy markets will on the long term affect the price competitiveness of hydrogen with regard to crude oil.

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[5] See www.roads2hy.com for further information on early markets

2.9 Regional Policy

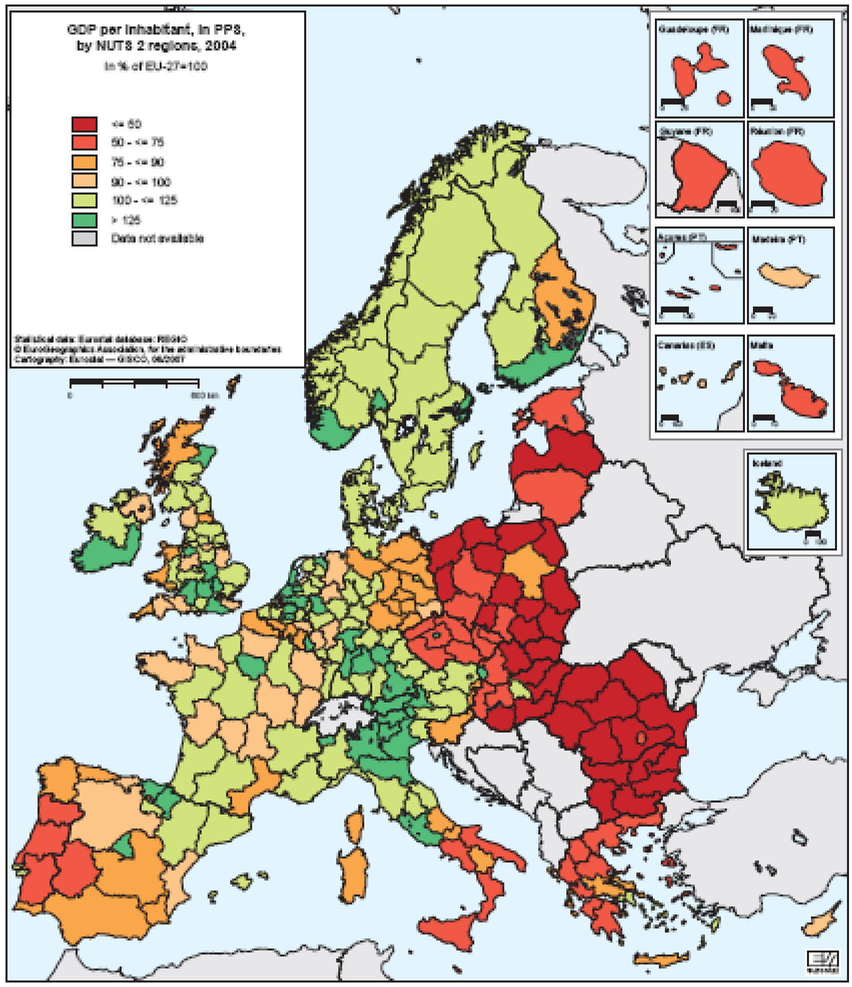
2.9.1 Analysis

The treaty stipulates that the Community should aim for economic and social cohesion. The main policy destined to respond to this challenge is the Community's regional policy. Enshrined in the EC treaty in Maastricht (articles 158-162) it mainly aims to lessen regional disparities. The latter have drastically increased since in 2004 the Union has opened its doors to new members whose regions sometimes represent only 50% of the average EU wealth (expressed in GDP per capita in PPP).

This development towards greater inter regional disparities is reflected by the EU budget: The share of regional spending will increase to 36% of total EU spending by 2013 and represent the amount of 308 billion € over the period 2007-2013. Furthermore, the major part of this amount goes to the poorest regions since only those regions that have a GDP per capita below 75% of the EU average are eligible for all of the three main objectives of regional funding (EC 7007m).

GDP per inhabitant in PPS, by NUTS 2 regions, 2004 (eligibility for the cohesion objective requires GDP per capita below 75% of EU average)

Figure 6: GDP per habitant in PPS, source: (EC 2007n)



The policy objectives and the funding allocated to them in the 2007-2013 period are as follows:

- Convergence: almost 82% of regional spending goes to the poorest members via the convergence objective. The funding is supposed to help to build infrastructure as well as human and economic resources.
- Regional competitiveness and employment: approximately 16% of regional spending is dedicated to this objective for which all Member States are eligible. Sustainable development, research and innovation should thereby be priority areas for investment.
- European territorial cooperation: 2,5% of the funds will be allocated to inter-regional cooperation and cross-border projects (EC 2007m).

Hydrogen and fuel cell related projects might respond to all the three objectives of EU regional policy. However, not every funding instrument may be suited to promote hydrogen and fuel cells. Three main instruments provide money to match the above mentioned objectives:

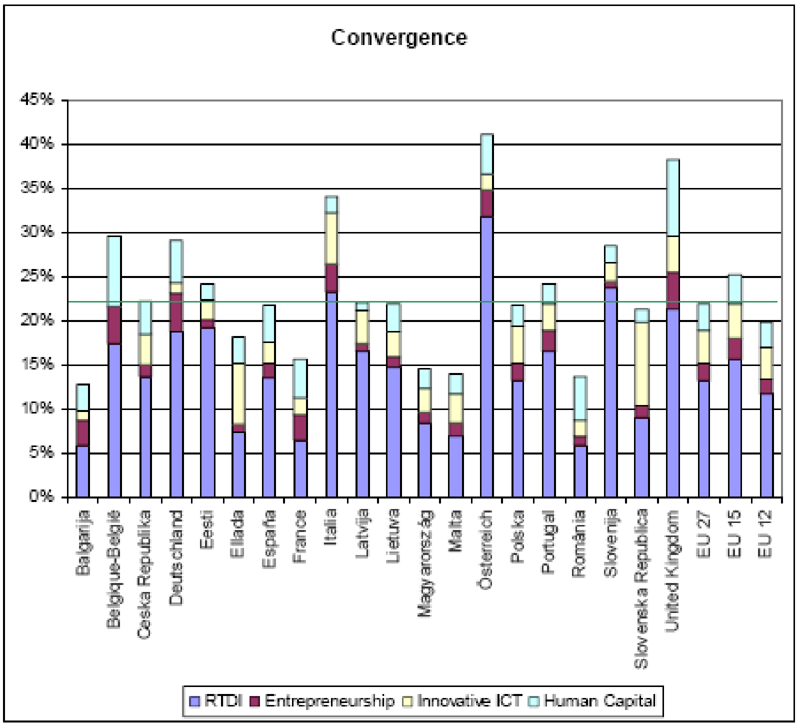
- The European Regional Development Fund (ERDF) prioritises investment in infrastructure and innovation; the poorest regions of all Member States are eligible for this fund (applies currently to regions in 19 Member States).
- The European Social Fund (ESF) invests in employment and training related projects; all Member States are eligible for this fund.
- The Cohesion Fund may insofar be relevant to hydrogen and fuel cell development as it is focused on transport, environment and renewable energy. However, only those Member States whose GDP lies below the threshold of 90% of the EU average are eligible for this fund (please note: the cohesion objective of 75% ≠ cohesion fund with 90% threshold); currently 84 regions in 17 Member States are eligible (EC 2007m).

In its aim to re-launch the Lisbon strategy and to mobilise all available resources, the Commission has announced to promote growth and employment also through regional policy instruments. Thus, EU regional funding should be concentrated on innovation, research, knowledge and entrepreneurship (EC 2007o) - fields which can potentially benefit to hydrogen and fuel cell development.

In the period 2000-2006, 11% of the cohesion spending was dedicated to innovation. In 2007-2013, 25% (85 billion €) of the envelope is planned to be channelled towards innovation. Given that national and private co-financing and additional investment are not yet included, the actual sum will be far greater (EC 2007o, p. 13). The role of innovation in the cohesion spending has thus clearly increased in the 2007-2013 financial framework compared with the previous one.

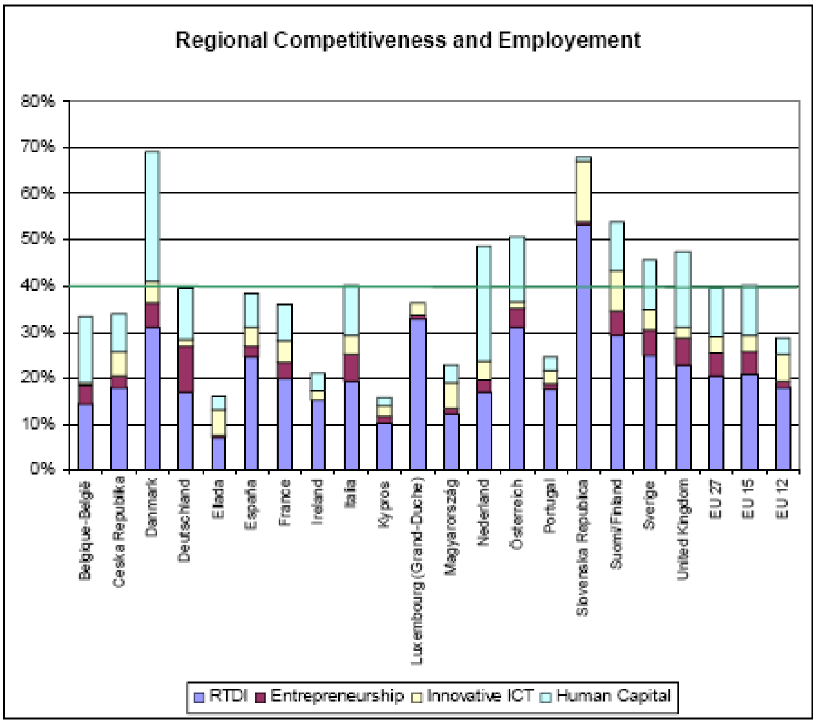
With regard to the before mentioned policy objectives, the Convergence objective is allocated by far the greatest financial resources: 282,8 billion € will be available under this heading for the period 2007-2013. Around 61 billion € out of these 282,8 billion € are planned to be spent for innovation which represents nearly 22% of the total allocation. However, only those regions which have a GDP below 75% of the EU average are eligible for Cohesion funding. The most prosperous regions which are in many cases also the most innovative regions are consequently not eligible. Currently 84 regions representing 154 million inhabitants can apply for Cohesion funds.

Figure 7: Planned investment in innovation 2007-2013 by country, source: (EC, 2007o)



The objective of regional competitiveness and employment may potentially apply to 168 regions which altogether count 314 million inhabitants. In the 2007-2013 period, 55 billion € are allocated to this objective of which 40% (22 billion €) is supposed to be spent for innovative measures.

Figure 8: Planned investment in innovation 2007-2013 by country, source: (EC, 2007o)



The third objective, territorial cooperation, applies to EU regions that are active in cross-border cooperation and is endowed with 8,7 billion €. Around 2 billion € or 27% of the funding is planned to be spent for innovation. “Regions for Economic Change” is one of the initiatives of the territorial cooperation objective directly linked to innovation. It covers themes such as the ‘low carbon economy’ or ‘bringing innovation quickly to the market’ which should be applicable to hydrogen and fuel cells. The yearly awarding of RegioStars for particularly innovative projects is deemed to disseminate best practices and reward innovative regions for their efforts (EC 2007o).

It is very difficult to assess the effects that the investments in innovation will have on the development of hydrogen and fuel cells. However, innovative regions are generally a pre-condition for the adoption of a new, potentially disruptive, technology. The Commission defines spending in innovation as spending that falls in one of the following four categories: research and technological development, entrepreneurship, innovative ICT and human capital. The spending for research and technological development (such as the promotion of “environmental-friendly products and processes”) is “referred to as innovation in the narrow sense” (2007o, p. 22). The investment in entrepreneurship (e.g. support for firms and start-ups), innovative ICT and human capital should establish an environment conducive for growth and help to reap the fruits of research activities.

The increased spending for innovative measures can definitely be seen as very positive with regard to hydrogen development. However, it is questionable whether the money is spent in the most effective way. In fact, hydrogen and fuel cells have so far been deployed in relatively innovative regions that dispose of the necessary capital, the political will and technical know-how. Yet, the Commission states itself that “Cohesion policy concentrates its financial support on the poorer regions that are usually included in the group of regions with lower levels of innovation” (2007o, p. 5). Regions that have already gained some experience with hydrogen and fuel cell and are well placed to pursue their development are often not eligible for the major part of the spending. Regional policy as it has been pursued in the past might be an effective tool to bridge the innovation gap in Europe. However, it is questionable whether the EU can bridge the innovation gap with the US and Japan if its most innovative regions are not eligible for major regional funding.

Moreover, scholars clash over the question whether regional policies are effective at all in strengthening economic growth. A study of Boldring and Canova argues that regional policies have only very little impact on economic growth. They should therefore mainly be seen as redistributional policies in the light of political bargaining (Boldrin/Canova 2001). New Economic Geography suggests that regional disparities between the core and the peripheries are relatively stable and cannot be lessened by the means of traditional redistributive regional policies which focus on peripheries (Brakman et al. 2005).

Other studies conclude that EU regional funds do strengthen economic growth. Based on an empirical analysis of the 1995-2001 period, Beugelsdijk and Eijffinger argue that regional funds have indeed helped poorer regions to catch up (Beugelsdijk/ Eijffinger 2005). The reforms in the 1980s and 1990s seem to have increased the effectiveness of the funds. Yet, there is evidence of regional funds being most effective in relatively developed environments (Cappelen et alii 2003). One may also note that the whole market integration in Europe leads to social advantages for all regions (Pelkmans 2007).

2.9.2 Conclusion

The regional policy of the EU represents 308 billion € over the period 2007-2013. Thus, it is potentially an important funding source for the development of hydrogen and fuel cells and may trigger private and national investment. Yet, the EU faces a dilemma:

- On the one side, hydrogen and fuel cells can best be promoted if innovative regions with considerable expertise and know how in this field of hydrogen receive funding;

- On the other side, the Union understands its regional policy as a means to bridge the gap between poor and wealthy regions and therefore channels the major part of the funds towards the poorest regions.

This trade-off is inherent to EU regional policy. In view of hydrogen promotion, the EU should continue its reform of regional funds towards greater investment in innovation and growth. Moreover, for the sake of transparency and efficiency the EU should pursue the two objectives of redistribution and growth with distinct instruments. According to the rules in place, the different funding instruments do not correspond each to only one distinct objective but may serve different objectives.

All Member States which have already good infrastructure for hydrogen and fuel cell development should receive greater funding, regardless their GDP, provided that conditions such as investing in hydrogen and fuel cells are met. Today, the size of the funds for which early adopting regions are eligible is too small to allow for significant advances in hydrogen and fuel cell development. Therefore, the amount of money dedicated to funds open for all Member States regardless their GDP per capita should be increased. Otherwise, the marginal product of capital invested in hydrogen and fuel cell technologies through regional funding risks to be low. The establishment of HyRaMP (Hydrogen Regional and Municipal Platform) may lead to formulating criteria for using the regional funds in that direction.

With regard to energy and research spending which is not directly related to hydrogen and fuel cells it is of crucial importance that the investments increase the sustainability of a national energy system. Given that hydrogen should on the long run be produced from low carbon energy sources its success hinges on the deployment of renewable energies. Thus, EU regional spending should be used to promote these technologies and relevant research in the Member States.

2.10 Conclusions on the EU Policy Framework and Recommendations

The screening of existing EU policies unfolds some inconsistencies in the macro-framework for hydrogen promotion. The EU is strongly committed to reduce GHG as shown by its role in the Kyoto Protocol framework and the Council conclusions. Hydrogen and fuel cells are conceived as an instrument to reduce GHG. The EU therefore strongly supports research and development in this field through its Framework Programs. However, the EU policy framework for the promotion of hydrogen is not as strong and coherent as its commitment to these technologies may suggest.

First, the EU lacks a clear mid to long term strategy explaining the desired role of different energy sources and carriers. In view of avoiding lock-in effects, this absence of technological preferences is understandable. Yet, biofuels which are unlikely to be a sustainable long term solution for the global energy challenge and may even be competing with hydrogen are promoted by EU policies too. It is not clear whether the EU conceives biofuels as an instrument for transition management or whether biofuels are understood as a potential long term solution. If the latter were the case, hydrogen technologies would directly compete with biofuels. Since this is under responsibility of member states, the EU should use the Lisbon method to develop a coherent strategy together with Member States which also embraces policy for the long term ramp-up of carbon-free energy sources from which to make hydrogen.

Second, changes in EU policies must closely be analyzed with regard to their effects on hydrogen and fuel cell development. A case in point is the current taxation of hydrogen utilization in some member states which could deter the uptake of hydrogen-based technologies, especially if the taxation level becomes unreasonable relative to the comparative environmental credentials of hydrogen as a fuel. Furthermore, in a communication of January 2008, the Commission proposes to extend the ETS to all major energy emitters. A reformed ETS should push towards more investment in low GHG emitting technologies. Yet, the current proposals may also deter from investment in hydrogen technologies given that transitional hydrogen production from gas would be part of such a new ETS (and perhaps also chemical production), and would therefore be required to pay the full cost of its carbon emissions. Exemption would assist a transitional phase, but needs to be linked to the ramp-up of zero carbon hydrogen production so that hydrogen production is not seen to enjoy “unfair advantage” beyond a managed transition period.

Third, the EU lacks competences necessary to reach its ambitious energy policy goals. The Treaty of Lisbon would confer the EU level stronger legal competences in the field of energy. However, other matters of relevance for energy and climate change policy will remain at national level such as taxation. Stronger coordination of national policies is therefore needed; stronger competences at the EU level e.g. on energy security and energy distribution is an option that ought to be considered.

Fourth, the overall policy framework must be aligned with the challenges ahead. Otherwise, different policies might neutralize each other. Improvements in EE and the liberalisation of the electricity and gas markets may for instance reduce the share of energy expenses in household or firm budgets. Such a development may lead to higher energy consumption which can over compensate for the initial gains in EE (‘rebound effect’). Hence, not only a coherent policy framework is needed but also a clear link between the energy objectives of GHG reduction targets, deployment and roadmaps on the one hand and instruments on the other. Coherency thus is not only a matter of today’s policy but a matter of long-term dynamic development in the EU.

Improvements in EE could be accompanied by higher energy prices so that the incentives to save energy remain stable. This might be done through the ETS or an ecological tax reform (tax escalator system) like the one proposed by Ernst Ulrich von Weizsäcker. A reliable system which ensures that increases in resource and energy efficiency are accompanied by increases in resource and energy prices would set incentives for investments in new technologies and new infrastructures. The payback times for those investments can stretch over several decades (Weizsäcker 2007). Without clear and reliable long term signals, the breakthrough of disruptive technologies such as hydrogen and fuel cell technologies is potentially jeopardised.

The following proposals are key elements for a policy framework for hydrogen and fuel cell promotion:

1. Develop long term GHG reduction targets in line with other EU energy objectives and the hydrogen deployment strategy at EU level.

2. Maintain taxation on energy with a view to internalize externalities while revising taxation on hydrogen.

3. Incentives to comply with the targets (proposal 1) should be market based. Instruments may be combined:

4. Feed-in systems for producers of hydrogen and fuel cells

5. Permits for early adopters / purchasers of hydrogen vehicles

6. Dynamic standard setting and visible label (and monitoring) of full life cycle carbon missions for energy-intensive products including vehicles

7. A Pan-European network of agencies for energy efficiency to coordinate efforts (analogy to European Energy Regulatory Agencies)

8. Financing SMEs in the hydrogen and fuel cell area via a European Risk and Trust Fund (see also Competitiveness and Innovation Programme (CIP) 2007-2013).

9. Regional funding: cluster policy (as described in the next section)

3. Regional Analysis and possible Cluster Policies

3.1 Clusters and Innovation Systems

Communities' decisions on engaging in hydrogen and fuel cell demonstration projects typically are guided by energy and environmental policy concerns but also by industrial and political-economical concerns. In particular, when the community is an administrative region (or: receives support from a region or has the intention to create spill-over for the region), it is usually the ambition not only to contribute to the energy supply and environmental achievements but also to the region's overall strategy for economic development – and especially stimulating industrial clusters based on these new technologies.

The following we focus on opportunities at the regional level to promote an emerging hydrogen and fuel cell innovation system. To do so we study the characteristics of European regions who are highly engaged in the HFC development today.

The regional level seems to have an increasing importance in providing good political and socio-economic framework conditions for innovation. Asheim and Gertler (2005) have emphasized that a regional level of governance of economic processes, between the national level and the level of clusters and firms, is important in supporting the institutional settings that can promote innovation. In a study of a global economy's impact on innovation policy Lundvall and Borrás (1997) find that "The region is increasingly the level at which innovation is produced through regional networks of innovators, local clusters and the cross-fertilising effects of research institutions."

This trend seems to be confirmed by studies and actions at the hydrogen and fuel cell area in Europe, where the regional level has been recognised as a significant driver on the pathway to a hydrogen economy. Examples on this are the work done in recent years to get the local and regional authorities represented in JTI and HFP which has culminated in the constitution of the Regions and Municipalities Partnership on Hydrogen and Fuel cells, HyRaMP on the 14th of April 2008. We seek to test the hypotheses that

- innovative regions are more likely to become engaged in hydrogen and fuel cell development and

- certain industrial clusters are favourable for the emergence of any full-scale hydrogen economy

If both hypotheses can be verified, it will constitute a case for individual regional support schemes complementary to hydrogen-specific support (as claimed e.g. by HyWays 2007).

Our last section will look at options for any such regional cluster policy for the promotion of hydrogen and fuel cells.

Several local and regional authorities in Europe are already highly engaged in the formative phases of hydrogen communities. Roads2HyCom data provides numerous examples of communities (remote islands, cities, municipalities, regions, etc.) that declare themselves as hydrogen communities or their network activities for hydrogen clusters. Authorities and stakeholders have in many cases developed strategy plans and allocated significant public financing in achieving the goals of such strategies (for strategy plans see for example the Western Isles Hydrogen Community Plans or the Fuel Cell and Hydrogen Network in North Rhine-Westphalia)

In view of learning more about how innovation policy should be designed at the regional level to promote HFC technology as well as the development of respective industrial clusters, we analyze regions where HFC activities have been carried out. The aim is to describe and characterise these regions and to provide insight into the challenges policy makers face in promoting an industry based on a new and disruptive technology at the regional level. Hence the analytical questions in focus are:

- What characterize European regions that are highly engaged in HFC development?
    - Do they have existing H2 infrastructure such as industrial pipelines and do they also have production sites?
    - Are they generally more innovative than regions that are not that engaged?
    - Is there any geographical match between regions highly engaged in HFC activities and existing industrial clusters in Europe?
    - Can one draw conclusions on which industrial cluster may be favourable for HFC development?
- Which policy measures can be recommended to facilitate the emergence of industrial clusters based on hydrogen and fuel cell technology?

3.2 Cluster and innovation policy for regional HFC promotion

As mentioned before regions are important stakeholders in all aspects of socio-economic development and may play the role of catalysts for the development of emerging technologies. Their smaller size and closeness to actors participating in economic development place them in an excellent position for promoting emerging technologies.

In the field of economic geography various approaches have studied the region’s role in promoting economic development. Most attention has been drawn to regional clusters and industrial districts (Asheim and Gertler 2005) and more recently to the concept of Regional Innovation Systems. In the following we will present some of the essential aspects of these approaches and their consequences for policy interventions.

3.2.1 The Cluster approach

Michael Porter defines a cluster as a “Geographic concentration of interconnected companies, specialized suppliers, service providers, firms in related industries, and associated institutions (for example universities, standard agencies, and trade associations) in particular fields that compete but also co-operate”.

Two matters are important to notice in Porter's definition of a cluster. The first is the notion of geographical concentration. Physical proximity is seen as extremely important for the innovation process because it eases the sharing of tacit knowledge. Another important matter in the definition of a cluster is how companies are interconnected. In a cluster, companies, suppliers and service providers compete and cooperate both horizontally and vertically in the value chain. In fact the interaction between companies and the physical proximity is two sides of the same coin. They are mutually related and that is what creates the spill-over in form of a specialized workforce, specialized regional suppliers, information, and training facilities. And that is considered to increase the productivity with which companies can compete, nationally and globally.

Although some studies find that for high-tech sectors physical proximity is of less importance (Mans et al. 2008). In some high-tech sectors external relationships to companies located worldwide can be of just as great importance – or maybe greater – as relationships to companies located in their own region. In relation to hydrogen and fuel cell technology this fact should not be neglected and it might suggest that regions in formulating their policy strategies pay a special attention to how these ties can be strengthened as well.

From a regional policy perspective the most commonly used policy instrument in promoting clusters has been to support network activities (The Cluster Initiative Greenbook, 2003). Within the hydrogen and fuel cell area this has often been in form of Public Private Partnerships (PPP). Other policy objectives have been to promote innovation through RD&D (research, development and demonstration) funding, create a special brand for the region, attract new firms and talent to the region, provide assistance to businesses, diffuse technology within the cluster, study and analyse the cluster and its needs, etc.

In the hydrogen and fuel cell area, industrial clusters in Porter's version do not exist yet. Furthermore, it seems uncertain if it is an appropriate strategy to start creating HFC clusters from scratch. Instead the most reasonable way for regions to promote the creation of HFC clusters seems to be support of other (relevant) clusters in the direction of a stronger uptake of hydrogen and fuel cell technologies. In this way a region will be able to build their HFC engagement upon competences and strengths already present in the region.

However, in order to create the right conditions to fulfil the vision of a hydrogen economy the cluster approach seems to be too partial to stand alone. Its focus on segregated single clusters seems to be inadequate to address the system character of a future hydrogen based energy system. Furthermore, directing policy towards a single cluster is in jeopardy of favouring certain technology options ("picking the winner"). Hence, regional innovation policy needs to create framework conditions for HFC innovation that are broader based than the single cluster focus. To this purpose a broader analytical perspective, such as the regional innovation system approach, might be appropriate.

The Regional Innovation System approach provides greater insight into strengths and competences at the regional level. As an analytical tool it can reveal functions of the system that need support in order to improve the overall innovation environment in the region. In the next section we introduce this approach and suggest how it best can supplement the cluster approach.

3.2.2 The Regional Innovation System approach

The regional innovation system approach (Cooke 2001, Storper, Asheim and Gertler 2004, Asheim and Gertler 2005) is often used as an analytical tool to direct regional innovation policy. It takes a more holistic view on a region's production structure than the cluster approach. The administrative borders of a region define what to include in the analysis and the focus is on strengthening the regional innovation system's ability to innovate. Partly by improving the institutional set-up in the region and partly by improving the linkages to actors located outside the region. Hence the regional innovation system approach allows studying the technological development in a holistic perspective paying attention to a region's strengths and weaknesses to overcome lock-in from the incumbent technology.

Common for the various innovation system approaches (National Innovation System, Sectoral Innovation Systems (Breschi and Malerba 1997, Malerba 2000) and Technological Innovation Systems (Jacobsson and Bergek 2004, Hekkert et al. 2006, Carlsson and Stankiewicz 1991) is the perspective on a non-linear innovation process. As a consequence, the innovation system approaches emphasise that new technologies that try to gain foothold on the market need more than technology specific support schemes. It is not enough to focus solely on R&D investments in order to promote new technology's emergence. Alternatively, innovation policy has been suggested to strengthen innovation by improving the innovation systems ability to serve seven primary functions (Johnson and Jacobsson 2001, Bergek et al. 2008):

- to create and diffuse new knowledge,
- to guide the direction of the search process among users and suppliers of technology (i.e. to influence the direction in which actors employ their resources),
- to supply resources, including capital, competencies and other resources
- to create positive external effects through the exchange of information, knowledge and vision, and
- to facilitate the formation of markets, e.g. through public procurement
- to form legitimacy among relevant actors and stakeholders (social acceptance)
- entrepreneurial experimentation to increase the social learning process

The seven functions presented above are mutually related. For instance a stronger legitimacy may influence the mobilisation of resources positively and guide the search more easily. A well-functioning innovation system improves the region's ability to adjust and adapt to new development paths such as the hydrogen and fuel cell technology.

From this perspective, the rationale behind innovation policy moves beyond that of merely correcting market failures to correcting system failures. System failures are a relatively new concept in the innovation system approach (Bergek et al. 2008). They are defined as circumstances that hinder the seven functions of the innovation system. The overall aim of innovation policy is thus to ensure that agents and institutions in the innovation system work effectively as a whole, and remove blockages that hinder the effective networking of its components (Foxon et al. 2004) and the functions of the system (Bergek et al. 2008).

However, the regional innovation system literature does not point out a single policy scheme to overcome these system failures. Policy makers should design incentives and support schemes in accordance to the functionality of the system as well as on the phase of development (formative or growth phase). Examples of such policy recommendations could be to support advocacy coalitions in order to overcome a weak legitimacy; to create visions and strategies in order to guide the directions of search; and to support experiments and demonstration projects of new types of applications in order to create and diffuse new knowledge and to reduce the risk of entrepreneurial experimentation.

Another reason complicating the task of giving general policy recommendations is the fact that regions and their ability to direct innovation policy widely differ. Some regions may have all the necessary elements for governance of innovation policy whereas other regions may have to build stronger upon external linkages, in particularly to get access to knowledge.

The advantage of the regional innovation system approach is to serve as an analytical tool that can guide a region's innovation policy in order to induce the technological development by reducing uncertainties.

3.3 Data

Following the recent decades' interest in innovation studies and policy analyses solid statistical data has been provided by different authorities. However, for this study, it has been an analytical challenge that it is dealing with both geographical units (NUTS level) and distinct technologies (hydrogen and fuel cell technologies). Hydrogen and fuel cell technology is a new technology area and data to describe and analyse its characteristics is rather limited. There are neither time series established nor do the technology data necessarily match with regional data. We therefore rely on data collected in various European projects during the last decade, mainly from the Roads2HyCom project.

Geographical units

The main analytical focus in this study is concerned with the geographical distribution of hydrogen and fuel cell activities in EU-27, Iceland, Norway, Liechtenstein and Switzerland. We have mapped the various data at NUTS level 2 by the means of a geographical information system tool (GIS). NUTS (Nomenclature d'Unités Territoriales Statistiques) are created by Eurostat as hierarchical classification of geographical units used for statistical production across the European Union. NUTS level 1 corresponds to a territory with a population of 3-7 million inhabitants. NUTS level 1 thus often reflects high administrative levels such as the German Länder. The analyses of this study is carried out on NUTS-level 2 (NUTSII) defined by Eurostat as 'basic regions' and comprise 268 regions in Europe. Some countries are too small in terms of population to comply with Eurostat's definition of regional geographical entities or are characterised as NUTSII regions even though they represent nations with national policy authorities (Luxembourg, Denmark). A recent study of self-declared hydrogen clusters in the Netherlands utilise a much more detailed geographical level; the so-called COROP which divides the Netherlands in 40 COROP-areas (Mans, et al. 2008). These are identical with Eurostat's NUTSIII level. Such detailed analysis cannot be done here.

The problem of data

Regional innovation and cluster analysts usually draw on the vast statistical geographical oriented material provided by institutions such as national statistical offices and Eurostat. In Europe comprehensive statistical data are typically available as two entries.

- First entry is the geographical or regional levels of NUTS.
- The other entry is at the industry level based on the NACE (nomenclature statistique des activités économiques dans la communauté européenne) codes. NACE is a European industry standard classification system consisting of a 6 digit code and data is provided by national statistical offices based on questionnaires filled in by individual firms (for example NACE code DJ.28.22 is "Manufacture of central heating radiators and boilers".

The challenge is that no codes are available for neither hydrogen nor fuel cells, and the dispersed field of energy technologies is spread over many different NACE codes.

Table 5 shows examples of NACE codes with relevance for hydrogen and fuel cell technology. The NACE codes are very general and cover a lot more than industries involved in hydrogen and fuel cell development. The list is not complete but shows how diverse the range of industries that might be relevant for the development of hydrogen and fuel cell products are.

Table 5: Examples of NACE codes relevant for HFC technology

NACE CODES		
2-digit	**4-digit**	**Description**
DG.24		Manufacture of chemicals and chemical products
	DG.24.11	*Manufacture of industrial gases*
DK.29		Manufacture of machinery and equipment
DK.30		Manufacture of office machinery and computers
DK.31		Manufacture of electrical machinery and apparatus n.e.c.
DK.34		Manufacture of motor vehicles, trailers and semi-trailers
DK.35		Manufacture of other transport equipment
E. 40		Electricity, gas, steam and hot water supply
I. 60		Land transport; transport via pipelines
I. 63		Supporting and auxiliary transport activities, activities of travel agencies

Technology specific innovation system analysts usually draw on other types of statistical data than geographical oriented ones. Bergek, Hekkert and Jacobsson (2007) have proposed a number of indicators and data to map the functions of technological innovations systems (TIS). Examples on indicators of the development and diffusion of knowledge are patents, bibliometrics (publications, citations), and governmental expenditures on R&D. Examples on indicators on market formation are size of the market (e.g. for fuel cells) and support schemes (e.g. public investments subsidies). In the context of the European Environmental Technologies Action Plan (EU ETAP) a variety of investigations have been carried out on the concept of “eco-innovation” and indicators for this (Andersen, 2006; Kemp, 2008).

Much of such statistical information is available for energy technologies such as hydrogen and fuel cells. Patent statistics can be obtained using databases like Derwent, and bibliometrics can be obtained from Web of Science. The International Energy Agency (IEA) provides statistics on governmental expenditures on energy related R&D. But this statistical data is only available on national level and not on regional levels. In the following sections we will therefore analyse data made available from the Roads2Hycom project (see description of data and the use of data below). Besides these data we have included data from two major studies of the spatial economy of Europe – The Regional Innovation Scoreboard and The European Cluster Observatory.

3.4 Active regions within Hydrogen and Fuel Cells

Hydrogen and fuel cell technologies are emerging technologies and the markets for these technologies are still in the formative phases. Therefore it is yet impossible to analyse existing industrial clusters based on these technologies. However, hints can be drawn on analysing available information provided by other work packages in the R2H project and other similar projects.

As a first task in this analysis we have mapped the distribution of HFC activities across Europe. Available information provided by WP1, WP2 and WP3 comprise the following data at NUTS2 level:

- Hydrogen and fuel cell demonstration projects
- Hydrogen fuelling stations
- Registration of Interest (RoI) for communities undertaking large-scale hydrogen and fuel cell projects and innovative applications

Comparing these data indicates which European regions (at NUTSII level) are involved in hydrogen and fuel cell activities. Although the data may not give a complete picture of all hydrogen and fuel cell activities in Europe it seems to be the best available and can give us a broad idea of where hydrogen activities are located.

Classification

It is always important to consider the method to be used in classifying (geographical) data. The most appropriate method of classifying data depends on the context for interpretation and the quality of the data available. We have first classified the data (for each indicator) into four intervals based on natural breaks in the data, i.e. the biggest gaps in the dataset were used to classify the data into groups (Nelson, R. 1999). We used this classification method to ensure that similar observations were grouped together in the same interval. In order to be able to sum the three indicators into one total score for hydrogen and fuel cells activities, we then ranked the intervals with a score from 1-4. For example for the dataset on demonstration sites we first classified the data in four groups: 1, 2-3, 4-5 and 5<.

Table 6: Distribution of HFC activities in the 16 most active regions in Europe within HFC

NUTSII region		**Demonstration Sites**		**Fuelling stations**		**Registration of Interest**		**HFC-SCORE**
Code	Name	count	point	count	point	count	point	Total
DE11	**Stuttgart**	3	2	5	3	0	0	**5**
DE21	**Oberbayern**	1	1	5	3	1	1	**5**
DE30	**Berlin**	5	3	3	2	1	1	**6**
DE60	**Hamburg**	4	3	1	1	1	1	**5**
DEA1	**Düsseldorf**	3	2	1	1	2	2	**5**
DEA2	**Köln**	3	2	1	1	1	1	**4**
DK00	**Denmark**	17	4	9	4	3	3	**11**
ES30	**Comunidad de Madrid**	4	3	1	1	0	0	**4**
FR30	**Nord - Pas-de-Calais**	4	3	1	1	1	1	**5**
IS	**Iceland**	5	3	1	1	1	1	**5**
ITC1	**Piemonte**	3	2	1	1	2	2	**5**
ITC4	**Lombardia**	2	2	3	2	1	1	**5**
ITE1	**Toscana**	1	1	4	3	2	2	**6**
NO04	**Agder and Rogaland**	2	2	3	2	1	1	**5**
SE0A	**Västsverige**	3	2	0	0	2	2	**4**
UKL	**Wales**	4	4	0	0	1	1	**5**

Next we ranked the intervals with the values from 1 to 4. The total score for each region was calculated by summarising the score for the three indicators: demonstration sites, fuelling stations and registration of interests. All NUTSII regions with a total score higher than three (15 regions) have been included in the further studies. Additionally we have included one NUTSI region (Wales, NUTS-code: UKL) because the data on the Regional Innovation Scoreboard (that we compare the regions with later) only exists for the English regions at this level. An adding up of activities from NUTSII to NUTS level I for the UK regions ranked Wales among the most active regions within HFC.

The result for the 16 most active NUTSII regions in Europe within hydrogen and fuel cell activities is illustrated in Table 6. The three indicators and the characteristics of the data are explained further on the following pages.

3.5 Hydrogen and fuel cell demonstration projects

Based on existing and regularly maintained databases the European project Roads2Hycom has identified and analysed over 130 hydrogen demonstration projects within the European Union and the associated countries Norway and Iceland (Steinberger-Wilckens and Trümper, 2007). The demonstration projects were mostly related to transport, stationary use, and combinations hereof. Only 2 of the projects comprised portable use of hydrogen and fuel cell technology.

The mapping exercise by Steinberger-Wilckens and Trümper distinguished between four types of demonstration projects: In planning, in operation, finished and interrupted. For our purpose we have chosen to map an aggregated count for all demonstration projects without any distinction of the state they are in.

The NUTS2 regions were ranked based on data for demonstration projects using the following score: 0: no demonstration projects, 1: 1 demonstration project, 2: 2 to 3 demonstration projects, 3: 4 to 5 demonstration projects, 4: more than 5 demonstration projects.

Demonstration projects were located in 15 countries. Most in Germany (24%), but also France, Denmark and Italy hosted each more than 10 percent of the total. Steinberger-Wilckens and Trümper (2007) conclude that an early clustering of demonstration projects seems to appear in the German Rhein-Ruhr/Rhein-Main area and in the cross-boarder region of Denmark and southern Sweden.

3.6 Hydrogen fuelling stations

Hydrogen fuelling stations are a prerequisite for developing the use of hydrogen in the transport sector. Based on a study by German consulting firm Ludwig-Bölkow-Systemtechnik the Roads2Hycom project has analysed the existing and planned hydrogen fuelling stations for vehicles (cars and busses) in Europe. The analysis included stations in operation, expired stations and planned stations (Perrin, Steinberger-Wilckens, Trümper, 2007).

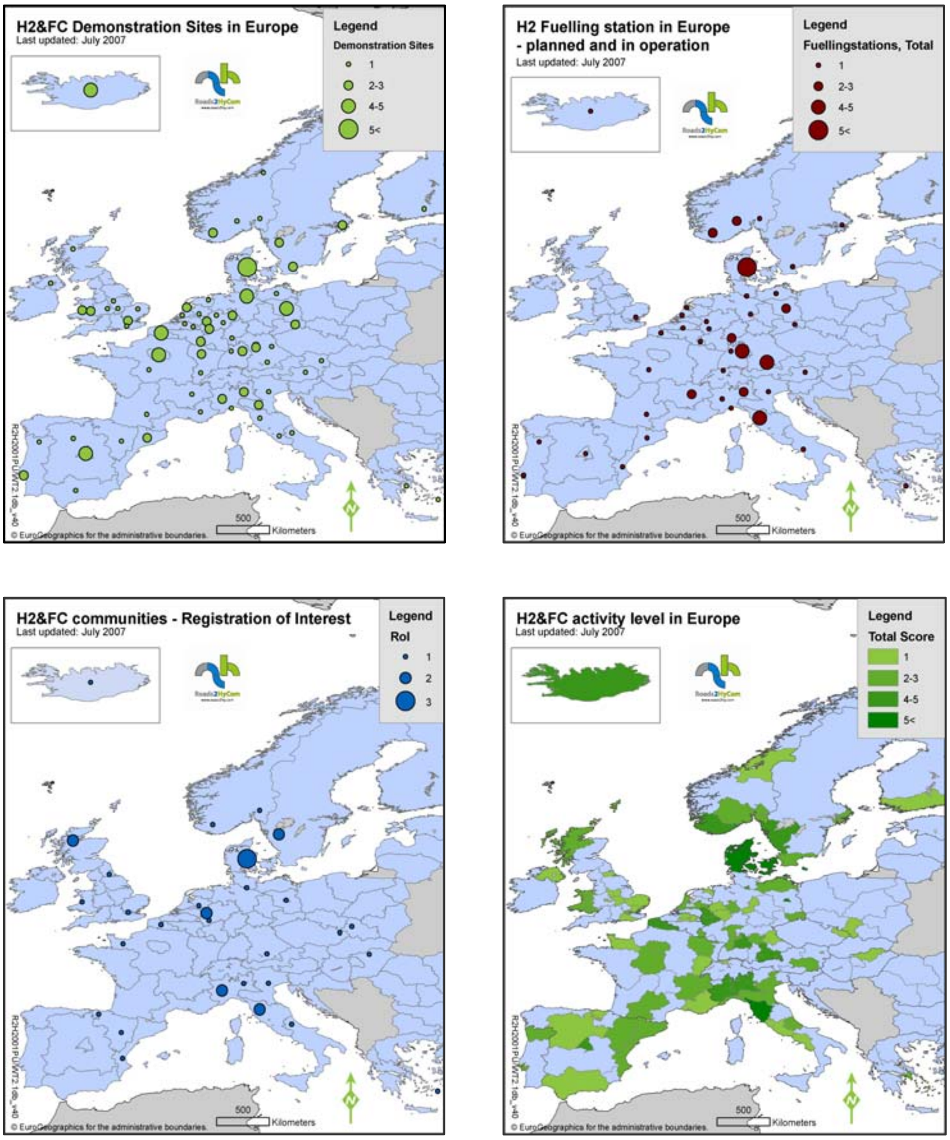
35 hydrogen fuelling stations are currently (end of 2007) in operation in Europe, and most of these in Germany. Furthermore, a large number of fuelling stations are planned especially in Scandinavia. In total, 72 operational or planned hydrogen fuelling stations were analysed with geographical data on NUTS3 level. Data for the analysis of this study was aggregated at NUTS2 level and ranked by following the natural breaks (see above) of the data set: 0: no H2 fuelling stations, 1: 1 H2 fuelling stations, 2: 2-3 H2 fuelling stations, 3: 4-5 fuelling stations, 4: more than five H2 fuelling stations.

We have not distinguished between planned and operational hydrogen fuelling stations in our mapping exercise in this study. We found that an aggregated count of fuelling stations ‘in planning’ and ‘in operation’ is adequate to indicate the level of activity. However, there is a risk that the planned fuelling stations never will be realised, but at present stage they indicate regions intention and can therefore very well illustrate the activity level.

3.7 Registration of Interest (RoI) for communities undertaking hydrogen and fuel cell projects

During 2006 the European project Road2Hycom launched a call for “Registration of Interest” for potential hydrogen communities in Europe (in this case: EU27, EEA and acceding and candidate countries).

Figure 9: Maps showing H2&FC activity level.



Top left: Total numbers of demonstration projects in planning, in operation, finished and interrupted. Top right: Total H2 fuelling stations in planning and in operation. Bottom left: Registration of Interest. Bottom right: Total H2&FC activity level.

In an overall database 96 potential hydrogen communities were listed. Not surprisingly the largest number of potential hydrogen communities was registered in Germany with almost a quarter of the total. Also Italy, and the UK had each more than 10% of the total number of communities. Collectively the five Nordic countries accounted for 17% of all projects (Shaw and Mazzucchelli, 2007). From the overall database a sample of 36 projects is included in this analysis. Those are the communities that responded to the Call for RoI for potential hydrogen communities. The call was launched in May 2006 and is regularly updated as new information becomes available.

Figure 9 illustrates the distribution of the three indicators together with the total HFC score. The map showing the total HFC score (bottom right corner) illustrates where activities are located. In many cases the clustering of activities in neighbouring regions matches the location of partnerships or corporative HFC initiatives. The high score in the Scandinavian regions matches the location of ‘The Scandinavian hydrogen highway partnership’ (SHHP) that focuses their collaboration on South/South-eastern Norway, the Swedish west coast and Denmark (see Figure 10).

SHHP is a collaboration between three national bodies: The HyNor (Norway), The Hydrogen Link (Denmark) and Hydrogen Sweden. The score in the regions of the federal state North-Rhine-Westphalia in Western Germany illustrates the many activities carried out by the ‘Fuel Cell and Hydrogen Network NRW’. One may note that the NUTSII level is well below the political entity of North-Rhine-Westphalia; looking at NRW requires an adding up of these activities.

Figure 10: Illustration of the focus area of the Scandinavian Hydrogen Highway Partnership, source www.scandinavianhydrogen.org

In Northeast Spain it is the Aragon hydrogen initiative initiated by the Spanish Ministry of Industry in 2002. The high score in Northern Italy illustrates the many diverse Italian projects that have been carried out during the last decade. For example, In Lombardy: the Zero Regio project in Mantova, the Bicocca Project in Milan, and the Arese project in Arese; in Tuscany: the HBUS project in Florence and the Arezzo project. And in Piedmonte: the Hydrogen system laboratory in Turin.

Additionally, the German cities Hamburg and Berlin also score within the highest ranked regions as well as North East England, Iceland and Nord-Pas-de-Calais in France.

3.8 High-level HFC regions and existing infrastructure and production capacities

The first enquiry we have made to describe the 16 high level HFC regions is whether existing infrastructure such as pipelines and production sites are located in these active high level regions. It is interesting to see whether there is any correlation between the location of current hydrogen activities and the location of existing capacities. Thus we could learn more about whether it is characteristic for regions to build upon experiences already present in the region. Furthermore, we could thereby identify regions that have strengths in both hydrogen activities and in existing infrastructure and therefore are potential communities for carrying out lighthouse projects.

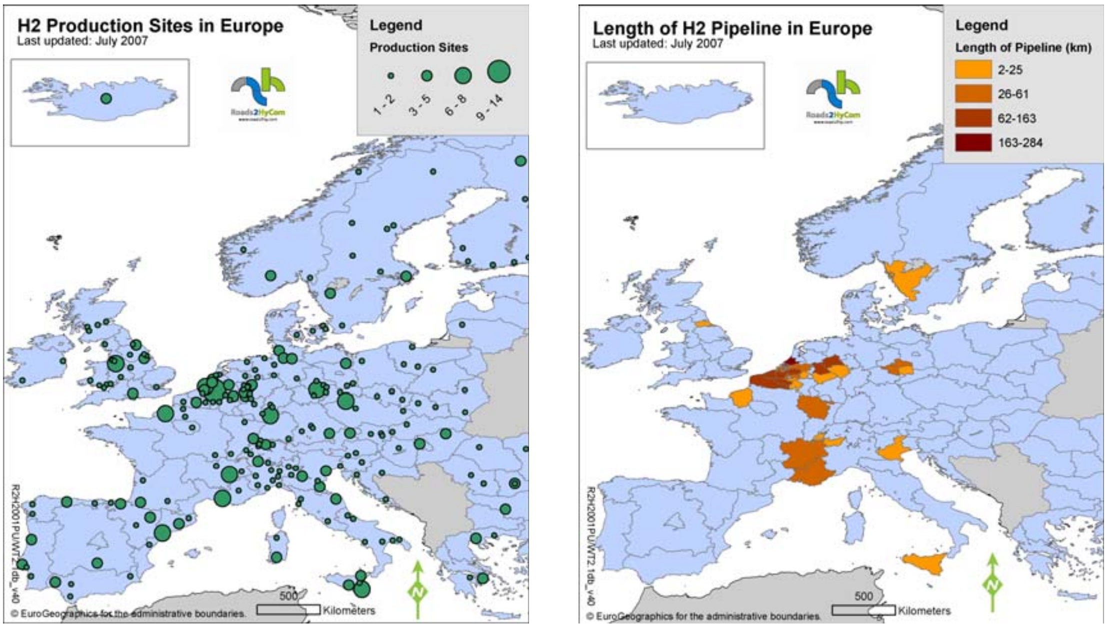
3.9 Existing hydrogen production capacity

Hydrogen is used as an industrial gas in many process industries throughout Europe. The total industrial hydrogen consumption in Europe is estimated to be about 61billion m^3 (in 2003). The most of this hydrogen was consumed by two industries: in oil refineries (ca. 50%) and for production of ammonia (ca. 32%). The total production of hydrogen in the European Union amounts to 80 billion m^3 (Steinberger-Wilckens, Trümper, 2007) – which means that some overcapacity exists.

For this study we have chosen to map the number of hydrogen production sites for each NUTS2 regions. A ranking of the regions is based on the following score: 1: 1-2 production sites, 2: 3-5 production sites, 3: 6-8 production sites, 4: 9-14 production sites. It was not possible to look at the specific production processes of these facilities within the scope of this study.

Important clusters of hydrogen production are mainly in the Benelux-countries, the Rhine-Main area, the Midlands in the UK, Southern France and in North Italy, but also regions in the periphery of the European Union such as Ireland, Finland Lithuania, North East Spain, and Romania have hydrogen production (see Figure 11).

Figure 11: Left: Total H2 Production Sites in Europe, Right: H2 Pipeline in Europe



Moreover it is interesting to note that the new member states in total have many H2 production sites.

3.10 Existing hydrogen pipeline infrastructure

The Roads2Hycom project has identified 15 larger hydrogen pipeline networks in different parts of Europe with a total length of nearly 1600 km. These pipeline networks are operated by firms like Air Liquide, Linde Gas and Air Products (Perrin, Steinberger-Wilckens, Trümper, 2007). Pipelines are located in Western Belgium, the Southern and Western Netherlands, the German regions North-Rhine Westphalia, Sachsen and Sachsen-Anhalt and in the three regions in eastern France (incl. South-East France). The length of the pipeline is measured in km and mapped at NUTSII level. A ranking of the areas is based on the following score: 1: 2-25 km, 2: 26-61 km, 3: 62-163 km, and 4: 164-284 km.

A total score on existing infrastructure and production capacity was calculated by summarising the score for respectively production sites and the length of H2 pipelines. Then we grouped the NUTSII regions based on their score on existing infrastructure into 3 groups: High score: 4-8 points, Medium score: 2-3 points and Low score: 0-1 points. The distribution of the 16 high level HFC regions between the three groups can be seen in Table . Only 4 of the high level HFC regions score high on existing infrastructure and production capacity (Düsseldorf (DEA1) and Köln (DEA2) in North-Rhine-Westphalia, Nord-Pas-de-Calais (FR30) and Lombardy (ITC4) in Northern Italy). Half of the high level regions score 2-3 points (Medium) on existing infrastructure and four regions score in the very low end, 0-1 point.

Table 7: Relationship between high-level HFC regions and existing infrastructure

Total existing infrastructure and production capacity score	Count of high level HFC regions
High score on existing infrastructure (>3 points)	4 (25%)
Medium score on existing infrastructure (2-3 points)	8 (50%)
Low score on existing infrastructure (0-1 points)	4 (25%)

There is no correlation between H2 production capacity/ H2 pipelines and the decision of regions to engage in HFC activities. However, the analysis highlights that four regions in Europe have a high activity level and a high level of H2 capacity: Düsseldorf and Köln in North-Rhine-Westphalia, Nord-Pas-de-Calais in France and Lombardy in Northern Italy. Provided that existing H2 infrastructure (production capacities and pipelines) is rewarding for HFC development these four regions seem to have a comparative advantage for carrying out larger lighthouse projects.

3.11 Match between regions' level of HFC activities and their score in the Regional Innovation Scoreboard

The Regional Innovation Scoreboard 2006 of the Maastricht Economic and social Research and training centre on Innovation and Technology (MERIT) measures seven innovation indicators: human resources in science and technology, participation in life long learning, public and private R&D, patent applications, employment in medium-high and high-tech manufacturing. It indicates the general innovation climate based on quantitative data within a region. The scores of the scoreboard data lie within an interval of 0 to 1 whereby the region with the highest ranking scores 0.90 (Stockholm, Sweden).

For the purpose of this study the Regional Innovation Score can be split into three categories; the bottom third, the middle third and the highest third. Of the 16 highest placed HFC regions (see Table 8) 10 (or 62,5 %) are also among the top third most innovative regions.

This clearly indicates that hydrogen and fuel cell activities take place in regions that are generally innovative. This connection can confirm the thesis that greater spill-over will happen where knowledge concentration is high on beforehand (so-called endogenous growth theory).

Table 8: Distribution of the 16 high level HFC regions over the 358 NUTSII regions' score in the European Regional Innovation Scoreboard

Score in the Regional Innovation Scoreboard	Number of high level HFC regions (top 16 in Table)
Highest third	10
Medium third	5
Bottom third	1

Provided that these regions also perform better (which has not been analysed here) the result suggests that innovative regions have been faster in their attempts to promote HFC activities. It also suggests that innovative regions find it easier to jump on new technology paths or at least are keener to take chances on new and uncertain technologies.

The high level HFC regions that lands in the medium third are the Italian regions – Toscana, Piedmont and Lombardy, the UK region Wales, and the German region Düsseldorf. The only high level HFC region in the bottom third is Nord- Pas-de-Calais a major centre for heavy industry in the 19th century (coal mines and steel mills). After a heavy recession in 1970's and 1980's the region focuses today on tourism.

This result also raises the question about the extent to which HFC demonstration activities can be used in a political agenda on improving regional innovative capabilities in general.

3.12 Assessing the presence of clusters in HFC-regions

The following section compares the presence of likely H2 related clusters in regions with the findings on high-level hydrogen and fuel cell regions. The aim is to investigate whether certain existing clusters are represented more frequently in high level HFC regions than in the rest of Europe.

The analysis is based on the cluster mapping carried out by the European Cluster Observatory. The European Cluster Observatory has carried out cluster analyses in 32 countries (EU 27, Iceland, Norway, Israel, Switzerland, Turkey) with NUTS2 regions as geographical unit (258 regions). They build their definition of a cluster sector on Michael Porter's analysis of employment distribution in North America (Porter 2003). The American study analysed the geographical distribution of employment in different industries and found different patterns depending on the type of industry. The industries were grouped into three different categories showing their diverse geographical profiles:

Local industries are present in all regions as they serve local markets. They are not exposed to direct competition across regions and are characterised by lower wages, productivity and rates of innovation. According to the European Cluster Observatory, local industries account for around 57 % of all employment in Europe.

Traded cluster industries experience advantages in choosing their location and serve markets across regions. They have a tendency to 'cluster together' and are characterised by wages above average and higher productivity and level of innovation. The cluster sector accounts for about 37 % of European employment.

Natural resource-based industries are located close to the deposits of the natural resources they exploit and are therefore also geographically concentrated but for other reasons. Around 5 % of the European employment is employed in the natural resource based industry.

From the perspective of creating a hydrogen economy in all parts of society all three industry groups will be affected. Local Industries will be affected either as users of new hydrogen products or as retailers. The Natural Resource-Based Industries will be affected as hydrogen is not an energy source in itself, but needs to be produced using fossil energy sources, bio resources or similar. But in the development phase of a new technological trajectory the most important industry actors should be found within the Traded Cluster Industries.

The European Cluster Observatory has divided the ‘Traded cluster industries’ into 38 cluster categories (see www.clusterobservatory.eu). They have categorised a cluster’s strength in accordance to size, specialisation and focus in order to measure sufficient critical mass to develop the type of spill-over and linkages that creates positive economic effects. According to the Cluster Observatory’s evaluation a cluster present in a given region receives between 1 and 3 stars depending on the strength of the cluster. However, in our study we do not distinguish between the amounts of stars but only focus on whether or not a cluster is present in the given region.

We have calculated a Cluster Quotient (CQ) for each of the 38 clusters. The CQ is a measure for co-location of HFC activities and clusters. The CQ compares the proportion of clusters (within the same cluster category) located in the 16 high level HFC regions to the proportion of the total amount of clusters (within that same cluster category) in all the 258 regions (see equation).

The Cluster Quotient is thus calculated as

$CQ_i = (A_i/B)/(C_i/D)$;

Where

$_i$ is a cluster according to the Cluster Observatory, e.g. Automotive

A_i is the number for $_i$ Clusters in all high level HFC regions

B is the number of all high level HFC regions (=16)

C_i is the number of all $_i$ type clusters (e.g. automotive) in all regions analysed by the Cluster Observatory

D is the number of all regions analysed by the Cluster Observatory (=258)

A CQ>2 shows that the cluster are more frequently located in the high-level HFC regions than in the rest of Europe. Table 9 shows the calculated CQ for the 38 clusters in Europe.

First and foremost it is important to keep in mind that the table reveals a statistical measure for co-location of HFC activities and clusters. The CQ is not measuring whether or not a relationship between certain clusters and hydrogen and fuel cell technology exists. Furthermore, clusters are analysed by studying concentration of employment within industrial sectors. Employment with relevance for hydrogen and fuel cell is most likely employed in companies' R&D departments and comprises a small part of the total employment. R&D departments are often located where companies have there headquarters or where there is a critical mass of skilled workers. Therefore we presume that this co-location measure can give us some information on which clusters that play a role in the hydrogen and fuel cell development.

Table 9: **Cluster Quotient**

Cluster Category	CQ
Medical Devices	4,7
Publishing	4,4
Distribution service	4,3
Analytical Instruments	3,9
IT	3,9
Biopharmaceuticals	3,1
Power generation and transmission	3,1
Chemicals	3,1
Sporting	2,9
Production Tech.	2,9
Aerospace	2,9
Communications equipment	2,9
Forest products	2,8
Lighting	2,8
Plastics	2,7
Entertainment	2,4
Jewelry	2,4
Oil and Gas	2,4
Automotive	2,4
Business Services	2,1
Building Fixtures	2,0
Constr. Materials	2,0
Tobacco	1,9
Education	1,6
Leather	1,5
Heavy Machinery	1,4
Finance	1,4
Agricultural	1,4
Textiles	1,3
Transportation	1,3
Fishing	1,3
Hospitality	1,2
Metal manufact.	1,1
Footwear	0,9
Apparel	0,8
Furniture	0,7
Food	0,7
Construction	0,7

Generally seen Table 9 reflects the result from the analysis above of the correlation between high active HFC regions and the regional innovation scoreboard. Clusters with a high CQ (>2) generally score higher in the indicators that form the innovation scoreboard (Human resources in science and technology, participation in life long learning, public and private R&D, patent applications, employment in medium-high and high-tech manufacturing) than clusters with a CQ<2. Table 9 therefore confirms that an overall well-functioning innovation environment is important for regions' engagement in HFC activities.

Hydrogen and fuel cell technology is yet at a stage where the relevance for many of the established clusters is limited. We have identified nine cluster categories that most likely play a role in the development of the technology and in improving the state-of-the-art of the technology. The nine clusters are highlighted in Table 9 and presented in detail in Table 10: Traded cluster industries with interest to HFC development. This table presents the nine cluster categories, examples of industries and some examples of companies involved in HFC development.

Of the nine clusters with high relevance for HFC technology seven have a CQ higher than 2. Only transportation and heavy machinery have a CQ less than 2.

Transportation covers inventories and logistics and distinguishes itself from the other clusters by being a service sector providing transport and not the technology for transportation. The transportations sector will be among the large end-user groups of HFC based transportation technology. Heavy Machinery clusters are located in 4 out of the 16 HFC clusters so the result indicates, not surprisingly, that this cluster does not play a leading role in the regional HFC activities.

Chemicals (3.1), Power generation and transmission (3.1), and Oil and gas (2.4) are three clusters that are in particular relevant in producing and distributing hydrogen.

Automotive (2.4), communications equipment (2.9), aerospace (2.9), and production technology (2.9) are clusters with an interest in the various application options HFC offer. The CQs show a high level of co-location between HFC activities and these clusters.

Table 10: Traded cluster industries with interest to HFC development

Cluster categories	**Industry examples**	Examples from European H2 and Fuel Cell Technology Platform's NEW-IG members
Oil & Gas Products and Services	Refineries	Statoil Hydro ASA, Gaz de France, Shell Hydrogen BV, Total France, Intelligent Energy, ILT Technology
Automotive	motor vehicles and components	Daimler, Adam Opel GmbH, Volkswagen, Cento Ricerche Fiat, AVL List GmbH, Volvo, Rolls Royce Fuel cell system, RiverSimple LLP, Intelligent Energy,
Power Generation and Transmission	Generators	Siemens, E.ON Sweden AB, EWE AG, GAMESA Corporacion Tecnologica, Intelligent Energy, Ceres Power Ltd.
Heavy Machinery	tractors, locomotives	Wärtsilä Finland, Gruppo Sapio, Ansaldo Fuel Cells, Nucellsys
Chemical Products	chemicals, industrial gases	Linde Gas, BASF Fuel Cells GmbH, ILT Technology, BP International
Production Technology	Tanks	Topsoe Fuel Cells, Nucellsys,
Transportation and Logistics	freight, air transport	Rail Safety and Standard Boards
Aerospace	APU on aircraft	Intelligent Energy, EADS Deutschland
Communications Equipment	portable applications, mobile, computers	

This result can be explained by taking the market maturity of HFC technologies into account. Firms interested in developing and demonstrating HFC technologies are in this early phase firms seeking business opportunities in producing these technologies and providing the hydrogen. Whereas, firms that potentially could become end-users of such technologies (such as transportation) are likely to become involved in a later state of the technologies market development.

To sum up, a positive correlation is found between the presences of clusters assessed to be hydrogen and fuel cell friendly and the high level HFC regions. This indicates that specific clusters may play a role in driving the development of hydrogen and fuel cell technology. However, the most important result of the study of Cluster Quotients seems to be a confirmation of the correlation between innovative regions (hosting innovative clusters) and HFC technology development. An institutional set-up with favourable conditions for innovation is therefore seen as extremely important in promoting innovation activities within HFC.

The above study of regions' role in HFC development has a preliminary character and has to be followed up by more in-depth studies. In particular studies of the relationship between certain clusters and HFC technology will be interesting. A study of the institutional set-up at the regional governance level and how to improve this through innovation policies would also be very interesting and would be fruitful for the regional engagement in HFC development in the future.

3.13 Conclusions

A methodology of Cluster Quotients has been employed to study the relationship between current geographical clustering of Fuel Cell and Hydrogen activity, and that of other areas of commercial activity. Along with a geographically based review of other data from the project, this analysis has been used to develop conclusions for policy relating to the development of clusters. Any support scheme will have to assess the feasibility of proposals as well as the viability of projects and industrial undertakings. In this respect our study has highlighted some important correlations that can help to better orientate EU funding for regional HFC development:

- Regions which are very active in pursuing HFC deployment are typically also very innovative regions. This finding is consistent with endogenous growth theories and thus confirms the hypothesis that innovative regions can more easily engage with and advance HFC technologies.

- The most active regions in the field of HFC are characterized by the location of clusters that are closely linked to HFC. This correlation is particularly strong for clusters in chemical products, power generation and production technology. The over-average importance of these industries in early adopting regions reflects the early stage of HFC market development. The relative importance of industries that provide end-use applications (such as transportation) is likely to increase in a later stage of the technologies market development. The decision of local authorities and/or the European level on whether to support a regional initiative should therefore take the specific regional cluster structure and the general stage of market development into account.

- The correlation between early adopting HFC regions and existing hydrogen production capacities as well as pipeline infrastructure is weak. Small projects can indeed be done with on-site hydrogen production and do not require existing production or pipeline infrastructure. The latter should therefore not be seen as preconditions for the engagement with HFC. However, the existence of production capacities and infrastructure is without a doubt a positive factor for the implementation of large scale projects and the development of HFC clusters. Currently it seems that not all regions have assessed their existing production capacity towards a hydrogen economy (for more detailed information on hydrogen infrastructure see Steinberger-Wilckens and Trümper, 2007, project deliverables D2.1/D2.1a).

4. Overall conclusions

4.1 The EU Level

The analysis of EU policy impacts on the development of hydrogen and fuel cells has yielded different results.

1. EU energy policies have developed strong push factors towards more sustainable technologies. The ETS, energy efficiency or renewables promotion – all these policy instruments also have some positive impact on hydrogen and fuel cells since they constitute a framework for sustainable energy production and use. However, these push factors are too weak to lead to the deployment of hydrogen and fuel cells because of, firstly, lacking incentives towards long term investments in sustainable technologies and, secondly, inconsistencies and negative side-effects within existing instruments that lead to distortions in hydrogen and fuel cell markets across Europe.

2. Current regulatory policies tend to have a weak but positive impact on hydrogen. In most EU member states hydrogen is exempted from any taxation or taxed at relatively low rates. Thus taxation currently favours hydrogen over competing technologies. Yet, the EU cannot be credited with this situation since hydrogen is not explicitly mentioned in the directive on minimum taxation nor has the EU strong competence in the field of taxation. The effects of the liberalization of the market for gas and electricity seem to be relatively weak. Nonetheless, they are positive and may in general favour the market entry of hydrogen and fuel cells and in particular the use of hydrogen in transport.

3. EU spending policies are a potentially powerful policy instrument for the regional promotion of sustainable technologies and infrastructure since they can channel funds towards them. However, this potential is currently not fully exploited. The analysis of regional policy yields a mixed result. On the one hand more regional funding has recently been directed towards innovation, a field closely related to hydrogen and fuel cells. On the other hand, cohesion funding normally does not apply to those regions which are the most innovative and the most advanced in the field of hydrogen and fuel cells. The CAP as the second big EU spending policy does not favour hydrogen or fuel cells. On the contrary it promotes biofuels which may on the long term compete with hydrogen and thus indirectly hinder its development.

Looking ahead the current policy framework at EU level does not set clear long term signals and lacks incentives that are strong enough to facilitate high investment in and deployment of sustainable energy technologies. The likely overall effect thus seems to be too weak to enable the EU hydrogen and fuel cell deployment strategy.

4.2 The Regional Level

The regional analysis has yielded four main conclusions:

First of all one can conclude that geography and cluster aspects seem to matter in establishing a European HFC technology innovation system. It is obvious that some regions are more active in the formative phase of HFC innovation systems. Regions with the highest level of HFC activities are found at different places in Europe and in many cases the clustering of activities in neighbouring regions matches the location of partnerships or corporative HFC initiatives. These geographical patterns of HFC activities indicate that some European regions are building up critical-mass within HFC.

Second, the relationship between early adopting HFC regions and existing hydrogen production capacities as well as pipeline infrastructure is weak. Small projects can indeed be done with on-site hydrogen production and do not require existing production or pipeline infrastructure. The latter should therefore not be seen as preconditions for the engagement with HFC. However, the existence of production capacities and infrastructure is a positive factor for the implementation of large scale projects and the development of HFC clusters.

Third, it can be concluded, that regions which are very active in pursuing HFC deployment are generally innovative regions. This finding is consistent with endogenous growth theories and thus confirms the hypothesis that innovative regions can more easily engage with and advance in HFC technologies. Less innovative regions may therefore need specific support schemes to help them engage with HFC.

Fourth, the most active regions in the field of HFC are characterized by the location of innovative clusters which confirms the importance of an overall well-functioning innovation system for the development of emerging technologies. Some of the industrial clusters located in the highly active HFC regions can furthermore be characterised as favourable for the development of HFC. This relation is particularly strong for clusters in chemical products, power generation, production technology, oil and gas, automotive and aerospace, which reflects the early stage of HFC market development. The relative importance of industries that provide end-use applications (such as transportation) is likely to increase in a later stage of the technologies market development. The decision of local authorities and/or the European level on whether to support a regional initiative should therefore take the specific regional cluster structure and the general stage of market development into account.

These findings might help to develop a comparative assessment scheme and support ensuing policies across European regions. This study has only provided a preliminary insight into the economic geography of HFC development. Additional studies of the character of regional innovation systems and how they can facilitate the HFC development through innovation and cluster policy is necessary in order to pave the way for a hydrogen economy. Another interesting issue this article has revealed is the benefits and synergies the clustering of activities in neighbouring regions seem to have for the HFC development. Also this relationship needs further study before qualified policy implications can be drawn.

4.3 Towards an integrated European Cluster Policy

Chapter three has shown that less innovative regions may need tailor-made support schemes to help them engage with HFC. However, such support should be subject to the condition that the less innovative region in question disposes of some other success factors (e.g. hydrogen production infrastructure) which promise to make the investment a rewarding one. In any case it is important to be aware of the extent of the hydrogen chain and that efforts are needed at all steps. It is yet too early to tell where the breakthrough will happen that can make hydrogen competitive with incumbent technologies. Less innovative regions might be engaged in development paths which can lead to breakthroughs in niche markets that can improve the overall state-of-the art of the technology. It is therefore not recommendable to cut-off less innovative regions from funding sources.

These points can help to develop a comparative assessment scheme and support ensuing policies. The Regions and Municipalities Partnership (HyRaMP) will be in a good position for coordinating efforts and developing tools for benchmarking across regions and across differing technologies. With growing development of HFC activities and clusters, these tools should be refined and causal relations for success should be investigated as soon as data for time series analyses are available.

Policies for promoting regional industrial clusters have, in recent years, been adopted by many regional authorities in Europe, as well as by Member States and the European Commission (see e.g. the Europe Innova activity). Successful policies for the promotion of clusters should be based on measures tailored to the specific needs of a particular region. In mapping the specific needs of a particular region, especially in promoting a stronger uptake of hydrogen and fuel cell technology, the regional innovation system approach can be useful. It can point out where the system's functionality is blocking the technological development and come up with some recommendations that can reduce uncertainties in the formative phase of a hydrogen and fuel cell innovation system.

Modern cluster policy research emphasizes the need for a good coordination of policies at both EU, national and regional levels (Europe Innova 2008), since they foster joint action between different stakeholders. Furthermore, both cluster analysis and policy analysis suggests not to favour certain technology choices ("picking out the winners") based on the limited number of applications that early adopting hydrogen communities could test. As shown above, the range of feasible applications and attractive technologies will become wider the more the technology advances. In fact, variety should be seen as desirable since it increases competition as well as technological and business options.

Based on the information and feedback received in the project Roads2HyCom it is very likely that there will be a variety of different regional strategies in Europe. Each region disposes of a distinct cluster structure and thus specific business opportunities. Exploiting these opportunities of cluster development at regional scale is in the interest of both the regions and the EU since such a strategy is likely to sustain economic performance and increase the performance of the technology.

The European level should hereby play a coordinating and enabling role:

- The EU should ensure the guidance of the innovation process by setting goals and developing visions that can legitimize and empower coalitions strong enough to threaten incumbent technologies. Such guidance should be developed in cooperation with a range of public, private and non governmental organizations to ensure consensus and create visibility and acceptance of the course.

- The EU should use its coordinating role to try to ensure that the different technological options are fully and at large scale covered in one or more regions. Given the unpredictability of future technological and market developments world wide, Europe has an interest in being well positioned in different emerging HFC markets.

- In order to facilitate HFC development and its market introduction the EU should harmonize standards and certification processes not only for production and product-related applications but also for infrastructure and distribution (e.g. fuelling stations). This is also required towards similar attempts made by the USA and Japan. Furthermore, it should ensure that Member States apply the mutual recognition principle. This principle "guarantees free movement of goods and services without the need to harmonise Member States' national legislation. Goods which are lawfully produced in one Member State cannot be banned from sale on the territory of another Member State, even if they are produced to technical or quality specifications different from those applied to its own products" (EC 2007q).

- Pioneering regional clusters should exchange information, best practices and group together for certain activities such as joint procurement. The EU is well placed for coordinating such an exchange given that it is involved in the JTI, has established HyRaMP and expertise in cluster policy. As a result transaction costs would decrease for the European regional actors.

The grouping and cooperation of regions at EU level is inasmuch of great importance as once regions have grouped together they can gradually become more and more interconnected. Thus common action can yield manifold benefits:

- Joint procurement: a group of regions can purchase certain products together. The supplier may thus realize economies of scale whereas the regional purchasers will get a lower price for the demanded product. This approach can also be aligned with public purchasing activities for products at a pre-commercial stage.

- Producer-user networks: If a producer supplies a relatively great number of regions with the same HFC product s/he will benefit from the feedback of users in different communities and geographical settings. As a result he can improve the product and better respond to market demands. The regional users of the product can also benefit from such a network for they can exchange information on how to best deal with technical problems or combine the product with other applications.

- Cooperation among regions can lead to a valuable exchange on how to scale up production and/or applications. A platform of regions such as HyRaMP may lead to a better understanding of the size of niche markets in Europe and enable actors to take well informed investment decisions.

- Interconnected infrastructure: regions and emerging hydrogen communities will have an interest in connecting their hydrogen infrastructure with those of other regions nearby. As the number of hydrogen fuelling station and the length of pipelines grows, the geographic range of HFC vehicles will increase and the supply of hydrogen will be diversified. The more hydrogen communities become interconnected the more HFC applications as such will become attractive.

Besides on research on the EU’s role as coordinator, research should also be conducted on the European Union as a financial facilitator. It certainly cannot cover the full funding of HFC development. However, in the early stage of market development, funding sources are scarce and EU instruments could therefore be of great importance (Mönter and Doran 2007, T7.2).

- Beyond any specific support scheme, the EU may also devote a share of funding to HFC in regionally focussed support schemes on intelligent energy and eco-innovation (CIP) as well as on CO2 reduction in buildings via CHP/HFC. Such focus is proposed to fit into existing programmes; it is not based on a technology assessment.

- It will be of great importance to geographically enlarge the HFC infrastructure in Europe, in particular in view of facilitating the uptake of HFC in road transport. The EU may therefore set up a program designed as private public partnership to connect regional networks such as the emerging Scandinavian one in the post 2013 period. The EU funding for the partnership could for example partly be covered by the Trans-European-Transport-Networks (TEN-T) budget as well as by structural funds.

EU support should be seen as an important condition for the development of HFC clusters in Europe. However, the support of national and regional authorities is necessary too. Because of the sustainability dimension, public policy is legitimate to foster such cluster development and to stimulate lead markets. In considering this dimension, linkage needs to be made to the long-term "greening" of the hydrogen supply (because current manufacture of hydrogen, like electricity, gives rise to GHG and other emissions at the point of production).

It can be concluded that hydrogen and fuel cells will require a special support scheme as well as an alignment of other policies which we refer to as a 'third approach'. This approach should go beyond traditional support schemes which are either general support or technology specific schemes. In addition to a favourable policy framework and technology specific support, our study underlines it must rely on a strong regional dimension. After 2010-2015 when demonstration projects and JTI funding will be running out, the regions will have to find their own ways towards commercialisation. In this respect regional infrastructure and cluster policy will be of paramount importance. Further research is, however, needed to learn more about the regional dimension and to better prepare and support European regions on their way towards a hydrogen inclusive economy.

4.4 Proposals for an enhanced policy framework

According to our analysis an enhanced EU policy framework pushing for sustainability in general and the development of hydrogen and fuel cells in particular should meet the following key requirements:

1. A strong EU energy policy with credible long term targets: The European governments have given their commitments for a strong reduction in GHG. However, the implementation must be improved and requires additional action. This implies for example higher carbon prices that set clear investment signals, higher energy efficiency requirements and a more ambitious implementation of renewable energy targets at national level. In addition, targets for the years 2030-2040-2050 need to be formulated and aligned with the hydrogen and fuel cell deployment strategy (see also Jacobssen/Bergek, 2004, p. 840 on the importance of long time scales to transform the energy sector). Research will have to do impact analysis on a variety of such targets as well as on their function for deployment processes.

2. Analysis on better coordination of EU policies: Europe needs a common understanding of key taxation concepts (green taxation, internalization of externalities) and a common approach towards the market introduction of new energy technologies. This requires more harmonisation of tax systems, codes and standards. Hydrogen could for a certain period be exempted from any taxation to promote its development. In the mid to long run when mass markets for hydrogen are forming, it will however become rational to include hydrogen in any minimum taxation Directive or to reform this system taking into account the total external costs of the life cycle of respective energy products. However, policy consistency is of great importance in this respect. If hydrogen utilisation is exempted from any taxation then its production should be part of the ETS. Liberalization of the gas and electricity markets should be pursued in order to relatively decrease prices and guarantee market access also to small producers of renewable energy sources. Entrepreneurs and SMEs in hydrogen and fuel cell sector should get better access to financing, for example through a European trust fund. The sustainability impact of spending policies furthermore needs to be increased: Setting up a distribution infrastructure for hydrogen and fuel cells will be facilitated if active regions in the field of hydrogen and fuel cells become eligible for the main regional funds.

3. Infrastructure development analysis: Regions that dispose of strong clusters in hydrogen and fuel cell related areas can further advance the market introduction and establish a first hydrogen infrastructure. Later on the first emerging hydrogen

communities could be interconnected to create a wider hydrogen infrastructure in Europe. The EU can support these efforts and play a coordinating role (see chapter 4.3); however this needs to be prepared by research.

Long term policies need to be adaptive and open to technological change. Alternative developments e.g. battery technology are crucial for the patterns of a hydrogen inclusive economy (Larsen and Höjer, 2007; Macario, 2007). In the short and medium term other technologies may well be more promising than hydrogen and fuel cells. Plug-in hybrid cars are for instance already commercialized in Europe and North America and are expected to highly increase their market share in the coming decade (Wyman, 2008) – it is far from being clear how hydrogen and fuel cells will perform in comparison to these technologies. In the end, this clearly points out the need for a more in depth-research on a comprehensive long term policy framework that induces and enables sustainable energy systems and other eco-innovations.

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