Study of FLAs in the area of Secure, Clean and Efficient Energy

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Author: Klaus Kubeczko

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Content

1 Introduction

This Report has been prepared in response to the invitation for a study on **Secure, Clean and Efficient Energy**, in support of the work of the European Forum for Forward-Looking Activities. The aim of this Study is to develop mechanisms for ensuring that Horizon 2020 takes account of a wide range and fuller set of challenges for the area under review. The scope of the study was broadly defined by the societal challenge in this area as set out in the proposal for Horizon 2020, summarised by the objective:

> "The specific objective is to make the **transition to a reliable, sustainable and competitive energy system**, in the face of increasingly scarce resources, increasing energy needs and climate change." (DS 1293/12, p.93)

The key questions addressed in this report are:

- Will the implementation of the SET-Plan help to link research and innovation programmes?
- Identification of the main challenges and sub-challenges in respect of the transition of the energy system;
- Comparison of these challenges with the announced broad lines of activities under Horizon 2020;
- Assessment of the extent to which these challenges are disruptive for the assumptions or proposals of Horizon 2020;
- Identification of any adjustments to the themes in the light of this; and
- Whether any important challenges or issues are missing from the announced broad lines of activities.

Approach

Work focused on a review of key Forward-looking Activities with a view to identifying insights relevant to the questions set out above.

In practical terms the approach involved three main but overlapping steps:

a. Review of the SET Plan documents to identify links to research and innovation programmes;
b. Identification of FLAs relevant to the area;
c. Review of these FLAs to identify key insights emerging;
d. Comparison of these insights with the proposed Horizon 2020 actions in order to address the key study questions.

The search for relevant FLAs was done with the aim to select most recent ones with a time horizon beyond 2050. It was intended to focus on FLAs that are finalised post 2008, after energy prices went up above 100 USD. This would help to identify those exploratory, normative and participatory FLAs that take into account the potential turbulences as we see them now. Earlier FLAs were only taken into account very selectively.

The FLAs identified as relevant and reviewed in this section are listed in Box 1. Several other are available too

Box 1: The list of FLAs reviewed

a. FLAs by European and international agencies	
Stern	Stern Review: The Economics of Climate Change (2006)
GEA	IIASA Global Energy Assessment (2012)
ETP	IEA/OECD Energy Technology Perspectives (ETP) (2012)
E 2050	IEA/OECD ENERGY TO 2050 - Scenarios for a Sustainable Future (2003)
2052	2052: a global forecast for the next forty years. Report to the Club of Rome by Jorgen Randers (2012)
SREEN	IPCC Special Report - Renewable Energy Sources and Climate Change Mitigation, SREEN (2012)
WETO-T	DG R&I, EU, World and European Energy and Environment Transition Outlook, 2011
b. A review of selected national foresights of wider European relevance	
Finland	Government Foresight Report on Long-term Climate and Energy Policy: Towards a Low-carbon Finland (2009)
Germany	German Advisory Council on the Environment (SRU) - Wege zur 100% erneuerbaren Stromversorgung, Sondergutachten (Paths to 100% renewable electricity supply) (2011)
Austria	E-Trans 2050 Pathways to a sustainable energy future in Austria: Sociotechnical scenarios and structural challenges (2011)
UK	UKERC – Energy 2050 (2005-2010) UK Energy Research Council The UK Low Carbon Transition Plan (2009)
c. FLAs from private enterprises	
PWC	100% renewable electricity – A roadmap to 2050 for Europe and Africa (2010) Price Waterhouse Coopers
Shell	Shell energy scenarios to 2050 (2008)
d. A systematic examination of foresight and horizon scanning databases	
EU	Global Europe 2030-2050 - Inventory of Forward Looking Studies with a focus beyond 2030 EFP Briefs,
UK	Horizon Scans – Sigma Scan

2 Review of FLAs

2.1 Overview and Framework of Analysis

The review of FLAs provides a deliberately diverse range of activities, yet the outputs and content converge to provide a number of common insights. It is however important to highlight at the outset that the report is not comparing similar processes and/or products. Indeed, the FLAs vary in terms of:

1. *Scope*, with some activities having a focus on all energy technologies or on energy transition in a broad sense including socio-economic and governance issues, while in others there is a partial focus on electricity only.
2. *Content*, with a mix of forward-looking and strategy documents.
3. *End results,* with some activities developing scenarios, a set of recommendations or specific actions (or some mix of these).

The scenarios, visions and forward-looking strategies generally tend to reflect, as one would expect, the profile and remit of the organisation commissioning the FLA. For the activities under review, in some cases there was a stronger emphasis on a particular aspect(s) of concern, including global issues of energy supply and demand, national plans for an energy transition or climate change mitigation.

Approaches of Forward Looking Activities:

The purposes of the analysed FLAs are exploratory, looking for possible futures. Most of them are normative as well, starting from explicit or implicit normative assumptions how the future should look like. Increasingly possible scenarios are explored by coordinated efforts of experts to bring dispersed evidence coming from different sources. In most cases this is done through research projects bringing together research teams with dozens or hundreds of co-authors combining (e.g. GEA, IPCC). This exercises synthesising dispersed knowledge are big coordination effort. However, often normative assumptions or images of the future, taken as starting point for the assessment of exploratory scenarios, are relatively vague. Only few of the FLAs intentionally and explicitly include stakeholder participation into the forward-looking process, although this would help in matching evidence base with normative position of relevant stakeholders.

In the review of FLAs in the area of Secure, Clean and Efficient Energy looks into

- Rationale of the FLAs and the key challenges they address,
- Disruptions which are likely to affect the energy system and to have long run consequences for it, and wild cards which are unlikely to come true but would have substantial consequences on transition paths.
- Recommended actions of the analysed studies and processes that should be taken into account in the further development of Horizon 2020

2.2 Rationale and Key Challenges

Consensus on the need for a transition

The scientific and policy debates of the recent years (reflected in long term studies and foresights) converged towards a **consensus on the need for a transition** in the way the energy needs of our societies are met and that energy systems of the future will look quite different (e.g. Germany's Energiewende, UK's Low-carbon Transition Plan).

Europe wants to take a leading role in mitigation of climate change and has set challenging targets that shall help to keep global mean temperature rise until the end of the century below 2^{o}C. This policy aim is also linked to the innovation and growth strategy, and therefore transition will have to take place at all levels of supply and demand of energy system. These are normative assumptions that are the basis for all studies and nearly all foresights covered.

We know we are at a crossroads and the urgency of decision making is acknowledged, but there is still controversy about the pathway to take, and thus about the technological and research trajectories to prioritize.

This is reflected in the variety of scenarios that are explored. In varying combinations they tackle key challenges by proactive or reactive approaches, market based or regulatory based approaches, technology push or demand pull, hierarchical or self organised governance approaches, protected innovation or shared innovation, efficiency oriented or end-of pipe fixing approaches, and people or technology.

Environmental threats

Two major environmental considerations must be taken into account when assessing the fundamental alternatives of a future energy transition. First of all, the main issue about energy supply is that it generates negative externalities in terms of environmental impacts and CO2 emissions. The **climate change issue** (i.e. mitigation keeping mean temperature rise until 2100 below 2^{o}C and adaptation to climate exposure) **is the most pressing challenge for our future energy systems**. It is even more problematic than the often projected scarcity of fossil fuels.

In view of growing energy demand of emerging economies, it is even more pressing to switch trajectories.

Secondly, a**s there is too much fossil fuel on the planet and we must not use it all (Stern 2006)**.

With respect to global vulnerability to climate change, the transition to a low-carbon global economy will take place against the background of an abundant stock of fossil fuels to "to take the world to levels of greenhouse-gas concentrations well beyond 750ppm CO2e, with very dangerous consequences." (Stern 2006).

That is to say, the stocks of hydrocarbons that are profitable to extract (under current policies) are extending in a laissez-faire scenario the potential to increase the concentration of CO2 in the atmosphere (Stern 2006) to a level that hence causes a mean temperature rise way beyond 2^{o}C. The concentration could get even more critical as the decline of fossil fuel stocks is postponed by recent geological evidence of unconventional oil reserves (still the peak is expected to be reached within the next 20 years (GEA 2012)) and rebound effects of technological innovations might even lead to an acceleration of extraction without sustainable and substantial change in social and industrial practice.

Socio-technical transition

Two sides of a socio-technical transition (E-Trans 2050) have to be considered when looking into the energy debate. The first side refers to the debate about the direction of a future energy transition. This debate has not yet been settled, but it appears that current R&I policy prematurely focuses on some **technological pathways** that are hyped in the present, and discard others which – at first glance – seem to be less promising. Industrial and R&I policies are too much focused on extending dominant trajectories. Voices get louder asking for more experimenting and courage to take risks which correspond to the foreseeable uncertain framework conditions in the next two or three decades.

The other side is related to the demand for **energy services, social practice and societal needs**. When dealing with the human dimension of transition, studies are often focusing on macro- and micro economic dimension of supply and demand for efficient energy technologies. In recent studies a new focus is laid on accessibility and effectiveness of energy services (see e.g. GEA 2012). Hence lifestyles, the sustainable social and industrial practice and cultural and governance systems influencing energy use get more attention in analysis of long-term developments and in shaping transition paths.

Looking into social and technological innovation simultaneously could help to provide and **secure energy services for all** with a lower level of energy end-use and hence leading to less demand for energy resources in the upstream of energy supply. As a consequence, social practice of using (or not using) energy services triggers change in the whole energy systems technology and management wise. This, in turn, requires better coordination of-, and joining up with, other policy areas that are often outside of the focus of R&I policy. Better orchestration between policy levels is also required. E.g., energy related policy goals at urban levels will play an increasingly role in the future (GEA; 2052, IPCC).

2.3 Disruptions / Wild Cards

Turbulent times ahead

All of the foresights share the expectation that Europe is most likely going to face turbulent times with many uncertainties and big challenges (in terms of geopolitical situation, climate exposure, economic and financial stability ...) over the next decades ahead. Even very optimistic scenarios do not ignore the urgency for action with respect to grand challenges, particularly climate change mitigation and changing global framework conditions. The Shell Energy Scenarios to 2050 (Shell 2008) states that turbulences are expected to come up from 2015 onward to 2030, with a big question mark beyond that. The Finnish foresight Towards a Low Carbon Finland (2009) considers the worst case to be the shaking of the foundations of civilisation through climate change in the long term. The Austrian Foresight on Energy Transition 2050 – Socio-technical Scenarios (E-Trans 2050) assumes one “Break-down” scenario showing the cumulative causation of events in turbulent times.

Climate Exposure: The increase of CO2 concentration (and other Greenhouse gases) in the atmosphere, to a level that hence causes a mean temperature rise way beyond 2°C, will have a wide range of consequences. Threats related to climate exposure range from food, water, eco-system, extreme weather events to an irreversible large-scale shift in the oceanic and climate system. Sea level rise possibly will threaten densely populated areas worldwide, including coastal and near to coast cities in Europe (Stern 2006).

Uncertainty in financial markets about the indebtedness of key industrialized countries has made energy infrastructure a highly risky investment proposition (GEA). Increasing occurrence of extreme weather events might challenge insurance industry and energy utilities.

Risks of CO2 storage: 1) risks associated with the release of CO2 back into the atmosphere, and 2) health, safety, and environmental risks associated with the local impacts of the storage operations and potential leakage out of the storage reservoir. (GEA)

Lack of progress in clean energy according to the International Energy Agency (IEA/OECD) is alarming and the **window of opportunity** for low carbon solutions in the investment cycle of generation of electricity **is closing**

2.4 FLAs' Recommended Actions

The review of **recommended actions** in FLAs shows a wide variety and ranges from technology push actions to demand pull action and from market based policy instruments to regulations.

Actions either refer to the global level (e.g. asking for more coordination), to the EU-level (e.g. asking for joint research), the national level considering national interests or to the sub-national level (increasingly of urban regions), and are related to: Technology and infrastructure, Governance, Regulation, Finance, Knowledge and socio-cultural

The following summary tries to give an overview of the spectrum of actions recommended in the FLAs without the intention to be all-encompassing. It includes actions that are already addressed by Horizon 2020 research but also ones that are new and might require further support at EU-level.

- **Technology and infrastructure**
  On the one side efficiency gains are seen as important. Finding or applying technologies for more efficient upstream and downstream energy supply including a more efficient use of existing or future network infrastructures (e.g. smart grid). Improving efficiency of end-use technologies is another action field.
  On the other side enabling technologies allowing for a transition are recommended. Fostering technologies that open new pathways (e.g. e-mobility) or allow following old pathways with end-of pipe technologies (e.g. Carbon Capture and Storage CCS). Given that alternative energy sources such as solar and wind produce electricity independently of demand, storage of temporal overcapacities is one of the most essential topics for the next decades.

- **Governance**
  Recognising the need for more integrated and complex systems, new ways of reflexive governance have to be found taking into account the interaction of multiple levels and horizontal policy coordination.
  Energy saving policies are seen as key to climate change mitigation and as an effective way of reducing negative effects of potential price shocks and disruptions affecting infrastructures.
  Spatial aspects become more important when demands side aspects of energy systems get more attention. Hence, urban and regional planning is paramount to improving efficiency of energy services and infrastructures.
  Taking into account the potential of networks as coordination mechanism besides markets

and hierarchies, foresight processes can help bring stakeholders together. Adequate monitoring system are necessary at all territorial levels in order to allow for evidence based policy making using the right sets of criteria and indicators for ex post and ex ante assessments.

Mass media (including social media) shall be firmly considered in the transition process as playing its generic role enabling societal reflexivity through informing people, interpreting what is going on, and through visioning.

- **Regulation**

  Climate change mitigation policies are recommended or assumed by all FLAs. This includes existing market like policy instruments but also fading out regulations for carbon intensive power plants.

  Standardisations and design of markets are asked for which are in line with recommended technological and infrastructure action

- **Financing Transition**

  It is recommended to provide stable condition for financing large scale infrastructure investments (PWC, IPCC, GEA). The short window of opportunity that opens through end of life replacement of infrastructures that were built 30 to 50 years before should be used to transform the structure of the energy sector. Replacement of old conversion technologies could take place with other technologies and re-configurated systems. Trans-national cooperation would help to reduce the investment costs (SRU) significantly, particularly when large electricity storage capacities are dislocated from production sites (e.g. offshore wind power to be stored in Norwegian reservoir power station).

- **Socio-cultural**

  Although little concrete measures are recommended by FLAs, the change in social and industrial practice in the use of energy services such as thermal comfort, cooking, information processing and mobility of passengers and loads need further thought (GEA). Energy saving as effective way of reducing energy end-use can be supported through metering that allow for household's energy saving strategies through adequate monitoring systems.

- **Knowledge**

  In order to deal with the complex challenges of climate change and energy transition, a movement towards transdisciplinarity is observed (Sigma Scan 282, E-Trans 2050). It envisages a future of increasing exchange between both, the natural and technical sciences and social sciences, art and the humanities.

  Assuming more intensive involvement of end-users (as well as prosumers), symmetric knowledge and information is important as foundations for energy saving and changes in social practice. Access to knowledge and information is also important with respect to democratic processes of societal change co-evolving with energy transition.

  Support through the primary, secondary and tertiary educational system is of paramount importance for a long-term transition process.

3 Relevance for Horizon 2020

In the next section of the Report, the key disruptions are extracted from the analysis and presented, together with themes in Horizon 2020 which require adjustment and/or elaboration as well as missing issues which require attention.

3.1 Key challenges for Horizon 2020

The review of forward-looking activities and strategy documents identified a number of challenges which could prove disruptive to the energy system part of Horizon 2020. A shortlist, starting with the challenges considered likely to have the highest impact, is presented below:

- **Turbulent times ahead**
  Even very optimistic scenarios do not ignore the urgency for action with respect to climate change and the potential of changing global framework conditions (Stern, GEA, 2052, Shell, SRU, PWC, Sigma Scan 472). Major efforts will have to be made in many areas as transitions will affect European energy systems in many ways but there are controversial debates about how to become flexible, adaptive, resilient ….

- **Climate Change is seen as the key driver for energy scenarios**
  Climate Change is more challenging than energy security (2052) Rather abundance of fossil fuels is the problem (Stern, Shell)
  Urbanisation (globally) is a key driver of next decades' development (2052, GEA)

- **There is too much fossil fuel on the planet – we must not use it all**
  We must not use up all existing fossil energy reserves on the planet to reach the 2 degree target
  "The shift to a low-carbon global economy will take place against the background of an abundant supply of fossil fuels. That is to say, the stocks of hydrocarbons that are profitable to extract (under current policies) are more than enough to take the world to levels of greenhouse-gas concentrations well beyond 750ppm CO2e, with very dangerous consequences." Stern Review (2006)

- **Short window of opportunity for modernising**
  Evidence about resources and energy system: Short window of opportunity for modernising low-carbon energy production and the energy system – (SRU, ETP)

- **Energy Poverty**
  Although energy poverty is considered to be a challenge for next decades, the energy policy goal of affordability explicitly for the poorer population is not yet addressed in Horizon 2020 (WETO-T, GEA).

- **Urgency and need for coordinated action**
  The urgency and need for coordinated action is highlighted (Stern, GEA, SRU ...) and speeding up the process is required taking into account the complexity of the task. Relying on market mechanisms only is not seen as a feasible option.
  Nevertheless, only few long-term FLAs can be found that explicitly explore on socio-economic and governance aspects (E-Trans 2050) in scenario building.

3.2 Adjustments to Horizon 2020 Themes

In comparing the Horizon 2020 themes with those identified in the Forward-looking activities, certain themes are mentioned in Horizon 2020 but are not framed in a comprehensive way and/or addressed in sufficient detail.

- **Conversion technologies, network infrastructures and energy resources**

The energy and climate change challenge as addressed in Horizon 2020 builds to a large extent on the SET-Plan (2007), and could thus not take into account more recent developments, such as the Fukushima event, or the recent increases in oil prices. In emphasizing technological research for the decarbonisation of energy supply, a number of implicit choices are made. It may stress the importance of financing issues as well as of fiscal policy for shaping future energy pathways, but it is conservative by focusing on large-scale technology options mainly. This is leading to an unbalanced approach to the portfolio of conversion technology in the broad lines of activities of Horizon 2020.

Although **gas fired power plants** are seen as an interim solution for flexible electricity production by many FLAs and strategic documents, they are not considered to play an important role for base load in the long run. They are also **not part of the SET core strategies**, nor is natural gas foreseen in the Roadmap for Low Carbon Economy 2050 (as incorrectly stated by the Horizon 2020 draft, DS 1293/12 p.93). CCS technologies as accompanying key element of a low-carbon path while fossil fired power plants fade out (GEA, PWC, UKERC ...). Countries like UK have even established an office dealing with the implementation of CCS technologies (UK Low Carbon Transition Plan). However, they are by no means considered as environmentally safe technologies; on the opposite, they are regarded as comparatively risky in terms of consequences for climate and local life (GEA). When CCS will fail to become the most effective end-of pipe technology, CO2 reduction goals can only be achieved with demand side measures (UKERC).

In Horizon 2020 **decentralised alternative conversion technology options are not mentioned** at all, although there might be innovative ways of large scale implementation in rather short time with moderate risks.

Extending **biomass use for energy** is considered to bear several risks and tensions by many of the recent studies (GEA, IPCC, Shell ....) for mobile as well as stationary use both from a socio-economic perspective (food versus energy) as well when considering all greenhouse gas emission for intensive agricultural land use. This, as well as the recommended focus on fuel cell and hydrogen, shows that hype cycles are part of the reality of innovation processes that might or might not be followed by successful market implementation. Horizon 2020 should follow a broader portfolio approach that does not prematurely embrace and subsequently lock us into some hype-driven technological trajectories. It should thus not only focus on up-scaling without clear indication from markets or long term commitments by both industry and policy that are rooted in a consensus across sectoral policy fields. Other developments like e-mobility that link across policy fields might also be considered as one of the options for mobile energy sources combined with the potential for energy storage.

With respect to network infrastructures Horizon 2020 focuses on the electricity grid. Smart grids are closely related to the need for increasing communication between supply and user of electricity as new renewable supplies require a transition of the ways how electricity can be stored temporarily and how the networks are managed and controlled by bringing in users as active players in keeping grids efficient, stable and safe (COM(2011) 202 final). Some FLAs (PWC, SRU) explicitly address **super grids** as requirements to increase the share of renewable energy in Europe. Different options are debated and media reports are hinting to the present situation of strategic positioning of the industry showing unstable ground for concrete activities within Horizon 2020.

- **Reducing energy consumption and market uptake of energy innovation**

Improving energy efficiency has a long-standing tradition in European energy policy. Reducing energy consumption has not been on the agenda for the last two decades but now receives some attention in Horizon 2020. It is quite clear that social practice in the use of energy will have to change quite significantly over the next decades. Innovation and transformative change towards less energy use ("negawatts" instead of megawatts) (GEA, WETO-T) will depend on it for any sustainable transition path of developed countries. It is paramount to better understand behavioural aspects on the demand side of energy in the context of technological options, skill as well as formal and informal rules and regulation. Stronger emphasis should also be laid on regulatory issues, pre-commercial procurement and adoption incentives at the intersection with other policy areas.

The market uptake of energy innovations emphasises the diffusion activities and standardisation. Attention should also be laid on the particularities and (favourable and unfavourable) consequences of transition processes, affordable energy avoiding energy poverty, and socially responsible as well as planned fade out of conventional power plants (SRU). The role of investment in making transitions happen might and socio-technical innovation should be better addressed.

As consumption reduction and sustainable use are addressed prominently, it should be more emphasised that inter- and trans-disciplinary research including practitioners' and stakeholders' involvement in the research process (e.g. Sigma Scan 282). Equally important are research processes including full scale living labs which can bridge between natural sciences and engineering sciences on the one side and social sciences and humanities on the other side. This is probably a generic challenge for the R&D system that needs to be addressed explicitly and with great care.

- **Reflexive governance and robust decision making and public engagement**

Several FLAs (E-Trans 2050, SRU, SREEN ...) highlight the need for new ways of governance that can deal with the complexity of decision making under conditions of dispersed power relations and environmental, economic and political uncertainties. Hence it can be concluded, that increasingly weight should be laid on non-technological research requirements as well as on improving the capacity for collective decision making.

The German Advisory Council on the Environment (SRU) states that a new balance between market, public planning and societal participation is needed for the transition of the energy systems like the one envisioned in Germany. The IPCC Report on Renewable Energy (SREEN) suggests involving civil society in open policy processes. Similar arguments come from the Austrian E-Trans 2050 process that considers reflexive governance as a key issue for sustainable transition of the energy system. Reflexivity is referred to the capacity to anticipate changes in the natural and societal environment and adapt to new situations that might occur rather abruptly and still need decision making processes that provide robust results. This includes deliberate participatory processes, involvement of civil society and role of media in societal reflexivity. It requires appropriate monitoring systems and strategic intelligence capacities. Not to forget the role of the education system in allowing the participation of population in democratic processes.

3.3 Important Issues Missing in Horizon 2020

In this final section, attention turns to major gaps/omissions in the Horizon 2020 design and approach, as currently formulated. The first set of concerns relate to **unknown territories and radical alternatives.** The second set of issues relate to the **adaptability and resilience of Europe's future energy system.** The third set of concerns relate to **new modes of governance.**

All three are considered important and require an appropriate investment of resources.

- **Unknown territories and radical alternatives**

The spectrum of technological options currently addressed by Horizon 2020 relies too much on the roadmaps developed in the context of the SET-Plan and ignores several recent developments that stress the need for **taking a broader spectrum on board in times of growing uncertainty.**

E.g. although both are considered as radical alternative bio-energy as well as CCS are related to high risks and seen critical in the meantime (GEA, SREEN, ETP, WETO-T).

More emphasis should be put on promising options with significant potential, even if they are still in a comparatively early stage of development. This concerns low-carbon options that are currently less favoured by industry, but also research on new forms of organising energy production and use in geographic space, and in particular the exploration of decentralised forms of organising energy supply. **Key enabling technologies** (KETs) may offer a major potential in energy-related applications, but to exploit their potential we must be prepared to learn and jump onto the bandwagon. If European research on societal challenges in energy is to make a difference, it must concentrate on identifying and fostering otherwise neglected options with high potential.

- **Adaptability and resilience of Europe's future energy system**

In line with the previous point, the adaptability and resilience of Europe's future energy system must feature prominently in Horizon 2020. Serious attention must be given to wildcards that may put into question the reliable operation of energy systems, as well as to disruptive developments from within or from outside of the energy system.

It should also be noted that concrete action, in particular at the demand side, is bound to the spatial reality of the rural and the urban (GEA, WETO-T, E-Trans). Hence capacity and resilience of the energy system will depend on all territorial levels from the EU to the national and to the sub-national.

- **New modes of governance**

In view of the growing conflict potential around energy supply including new forms of it, it is surprising to observe that this issue is not addressed seriously in Horizon 2020. At a first level, it refers to the **governance of conflicts of interest in society around energy matters** including **energy poverty**. Realizing large-scale projects of whatever kind is meeting with growing resistance and the inevitable transformation of energy supply systems will require certain choices to be made that will not please everybody. This issue concerns wind parks and high-voltage grids for transmission of renewable power as well as nuclear power plants. New modes of governing collective choices in energy supply need to be explored; **modes which are robust, democratic and ensure a serious participation of all stakeholders** concerned. Sound monitoring concepts and stakeholder involvement including civil society and population are absent when it comes to developing new governance modes (SREEN).

At a second level, new governance models are likely to affect the **balance between market mechanisms, public planning and societal participation** in the actual implementation of new energy solutions. This is about regulations and incentives in place, as well as mechanisms to ensure learning and adjustment. The complexity of horizontal and vertical policy coordination is hindering such efforts if not blocking them.

Conflict are foreseeable arising from policies that successfully help reducing energy use, as this will have consequences on business models of traditional and new players. On the supply side, sectoral structures might be threatened through such developments and industry might counteract new social practice. **Coordination between energy policies and consumer protection policies and activities** might help in this respect through complementary measures.

New governance models might also be investigated in order to **foster complementary action** between administrative levels, territorial structures, established and emerging networks at EU-level, the national level and the sub-national level (e.g. RTI policy with sectoral policies and urban policy).

After several decades with stable framework conditions for the development in Europe, turbulences become visible through erratic changes in framework conditions that make it hard to identify trends, drivers and consequences of change. **The capacity to adapt to new situations and to orchestrate collective action will be a matter of competitive advantages and the resilience of Europe.** Historically, transition pathways are closely related with disruptive change, avalanche change, specific shock that allow for specific development trajectories (Geels and Schot 2007)[1]. Governance models will have to be adapted with respect to agility, adaptability and the capacity to anticipate in order to find affordable, socially acceptable, economically viable and sustainable solutions.

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[1] Geels F.W. and Schot J. (2007), Typology of sociotechnical transition pathways, Research Policy 36 399–417

4 Concluding Remarks

This Report has tried to provide material that helps to reflect on the topic of Secure, Clean and Efficient Energy in Horizon 2020

The Review of Forward-looking Activities (FLAs) undertaken in recent years at national, European and international level in this area, indicates In order to better address the complexity and inter-relatedness of future challenges associated with energy supply, **Horizon 2020 needs to enable better coordination with other societal challenges and sectoral policies**. To this end, close links with key enabling technologies are as important as understanding energy as a cross-cutting issue affecting several domains of society and associated policy areas. In order to shape our energy future, we equally need to shape economic as well as spatial structures.

The energy challenge of Horizon 2020 builds in a straightforward manner on the perspectives and roadmaps drawn by the SET-plan, but neglects **exploring unknown territory and radical alternatives**, which – in times of high uncertainty – are needed to build a robust portfolio of future energy options. This includes in particular decentralised architectures and technologies, but also some "wildcard options" with a long-term potential.

In order to ensure a transformation of energy systems towards less energy and CO2-intensity, **more emphasis needs to be put on social practice and demand-pull aspects of innovation**. This is a very obvious connection with a range of sectoral policies to affect, not just about efficiency and technology standards, but also through deeper rooted causes for energy services in industry and private households. This kind of research requires looking beyond the horizon of scientific and engineering disciplines, by way of inter- and trans-disciplinary cooperation with social sciences and practitioners.

In the future, matters of governance and collective choices about large-scale energy infrastructures are likely to play a more prominent role than in the past. **Matters of social acceptability and participation, of balancing particular interests, and of managing long-term investments** will need to be taken into account in strategic energy choices. Forward-looking intelligence will need to be established to support appropriate decision processes and long-term strategies of public and private investors. Long-term processes of transformative change in energy systems need to be well-coordinated at the intersection of R&I, energy and sectoral policies, in order to provide clear incentives and framework conditions for both innovation and diffusion of novel solutions. At the same time, and recognizing the constraints imposed by uncertainty, experimentation, diversity and learning need to be fostered.

Finally, Horizon 2020 should explicitly take into account that the broad lines of activities as formulated now might need reformulation during the lifetime of the program when disruptive events change the landscape for energy systems. However, the underlying logic behind the headlines a to g, i.e. (a) demand side, (b) energy conversion, (c) energy resources, (d) network infrastructures, (e) knowledge processes, (f) governance processes, and (g) innovation processes. **Adaptations to the broad lines of activities should be allowed for and transparent processes should be foreseen that allow flexibility to be built-in explicitly into Horizon 2020.**

Annex 1: Short Reviews of the FLAs and Strategies

This section features relevant extracts from the select list of FLAs, focusing on rationale and key challenges, disruptions and/or wild cards and key results and/or recommended actions.

a. FLAs by European or international agencies and private strategic intelligence units

FLA	Rationale and Key Challenges	Disruptions / Wild Cards	Key Results/Recommended Actions
Stern Review (2006)	Abundance of supply of fossil fuels ... „… stocks of hydrocarbons that are profitable to extract (under current policies) are more than enough to take the world to levels of greenhouse-gas concentrations well beyond 750ppm CO_2."	Business as usual would bear the risk of irreversible impacts from climate change "Our action over the coming decades could create risks of major disruptions to economic and social activity .... on a scale similar those associated with the great wars and the economic depression of the first half of the 20th century."	The benefits of strong, early action considerably outweights the costs Manageable deep cut in GHG emissions by • Reducing demand for emission intensive goods/services • Increasing efficiency • Switching to lower-emission technologies Technology is at the core • Carbon capture and storage • Renewables • Nuclear • From coal to gas The report highlights urgency and need for coordinated action.
Global Energy Assessment **(GEA 2012)**	Global major challenges of the 21st Century: climate change, economic and social development, human well-being, sustainable development, and global security.	Examples taken from two chapters: Uncertainty in financial markets about the indebtedness of key industrialized countries have made energy infrastructure a highly risky proposition Risks of CO_2 storage 1) risks associated with the	1. Energy Systems can be transformed to support a sustainable future with (i) radical improvements in energy efficiency, especially in end use, and (ii) greater shares of renewable energies and advanced energy systems with carbon capture and storage (CCS) for both fossil fuels and biomass. 2. An Effective Transformation Requires Immediate Action: mayor focus on urban development 3. Energy Efficiency is an Immediate and Effective Option

		release of CO_2 back into the atmosphere, and 2) health, safety, and environmental risks associated with the local impacts of the storage operations and potential leakage out of the storage reservoir.	4. Renewable Energies are Abundant, Widely Available, and Increasingly Cost-effective 5. Major Changes in Fossil Energy Systems are Essential and Feasible 6. Universal Access to Modern Energy Carriers and Cleaner Cooking by 2030 is Possible 7. An Integrated Energy System Strategy is Essential 8. Energy Options for a Sustainable Future bring Substantial Multiple Benefits for Society 9. Socio-Cultural Changes as well as Stable Rules and Regulations will be Required 10. Policy, Regulations, and Stable Investment Regimes will be Essential
Global Energy Assessment **(GEA** Chapter 18 **2012)**	The world is already predominantly urban, with the urban environment housing more than 50% of global population and accounting for even larger shares in economic and energy activities. Almost all future population growth of some three billion people to 2050 will be absorbed by urban areas. With respect to Urban energy systems challenges are: Urban poverty, urban density and forms, urban transport, efficient cities, air pollution The systemic perspective applied in GEA, reveals a 'governance paradox.' in urban energy systems. Whereas the largest policy leverages are from systemic approaches and policy integration, these policies are also the most difficult to implement and require that	Without planning or intervention strategies there is a risk of maladaptation feedbacks, in which heat island countermeasures trigger increasing energy use, which amplify the heat island Liberalization of gas and electricity market pressures gives the lowest prices to consumers, but the effect is to incentivize producers to 'sweat' their existing assets (e.g., Drukker, 2000). It may then become necessary to introduce further complexity into tariffs to incentivize investment and reflect the value to the consumer of lost load. Undercapitalization of energy networks, many of which were built in the 1960s, remains a real risk over the next 20 years in developed world systems. Possibly the greatest vulnerability in an urban	The governance paradox of urban energy systems is compounded by weak institutional capacities, as well as by the legacies of market deregulation and privatization that have made integrated urban planning and energy, transport, and other infrastructural policy approaches more difficult to design and yet more difficult to implement. The promotion of local solar or wind renewables will, at best, have a marginal impact on the overall energy use of larger cities (typically <1%) 39 because of the significant energy-density mismatch between (high) urban energy use and (low) renewable energy flows per unit land area available in urban areas. Urban energy and climate policy should recognize that the most productive local decisions and policies influence the efficiency of urban energy use that is the demand side of the energy system, rather than its supply side. Systemic characteristics of urban energy use are generally more important determinants of the efficiency of urban energy use than those of individual consumers or of technological artifacts. For instance, the share of high occupancy public and/or non-motorized transport modes in

	policy fragmentation and uncoordinated, dispersed decision making be overcome.	context is the supply of transport fuels.	urban mobility is a more important determinant of urban transport energy use than the efficiency of the urban vehicle fleet (be it buses or hybrid automobiles).
Energy Technology Perspectives (IEA/OECD 2012)	Investment in clean energy technologies makes economic sense by saving energy in the future Stronger role for governments encouraging shift to efficient and low carbon technologies	Technologies with large potential show least progress • CCS, Problem of *integration into large scale projects* • *concentrated solar power* Lack of progress in clean energy is alarming • Window of opportunity for low carbon solutions is closing	Energy security and climate change mitigation are allies • Recognize need for more integrated and complex systems • Distributed and variable generation • Storage • Diversification of technologies
2052: a global forecast for the next forty years (Randers 2012)	Asks the question of the most likely global roadmap to 2052	Asks if we are facing a global future that makes it sensible to be concerned. Disruptions: destruction by climate change, resource depletion, biodiversity loss and growing inequalities will be visible and felt in 2052 Wild Cards: Abundant oil and gas, Financial meltdown, Nuclear war, Diseases, Collaps of ecological services, Counterrevolution in China, Revolution in US, A dedicated global effort to stop climate change	Temperature will rise over 2.8 degrees after 2052. Change in energy use will be slow Jobs will be available Climate problems will hurt us but not critically before 2040. Energy prices will rise but not enough to have an impact on global energy consumption per person declining only after 2040. Global Fossil fuel consumption will still be 60% in 2052. Intergenerational conflicts will rise. China will be world leader in 2052. Change in attitudes of decision makers towards longer term

IPCC **Renewable Energy Sources and Climate Change Mitigation** **Special Report (2012)**	Assessment and thorough analysis of renewable energy technologies and their current and potential role in the mitigation of greenhouse gas emissions	Extreme events, particularly weather related ones have an impact on the cost of extensive deployment of renewable energy technologies No wild card analysis available	Factors contributing to a successful RE governance regime • Integrating Policies (national/ supranational policies) • Reducing Financial and Investment Risk • Planning and emitting at the local level • Providing infrastructures networks and markets for RE technology • Technology Transfer and Capacity Building • Learning from actors beyond government Actors contributing to a successful RE governance regime: Policy making institutions, Politics, Civil society, Finance and business communities,
WETO-T **World and European Energy and Environment Transition Outlook (Chateau and Rosetti 2011)**	Such a demographic evolution, together with the considerable increases in education (and therefore labour productivity) and participation of women in the labour market that go along with the demographic transition, will drive a huge increase of “human capital” availability. As a consequence, the overall needs of energy services for the world might be multiplied by 3.2, between 2000 and 2100. T he energy needs per capita, which ranged globally from roughly 10 to 110 in 2000, would be multiplied by 2.4 over the century; with a drastic reduction in the gaps among world regions by 2100, between 35 and 140 times.	But, as shown by Fukushima, enormous progress is still required on security and waste management/destruction to make such a paradigm sustainable. Electricity goes along with higher end-use efficiency, but there is no reason why a nuclear paradigm would bring drastic changes in the end-uses technologies. If Carbon Capture and Storage (CCS) remains limited for technical or economic reasons or because of a lack of public acceptance, then nuclear electricity and hydrogen could become the core of a new paradigm. If both a CCS breakthrough and nuclear sustainability do not occur rapidly enough, renewables and energy thriftiness might be the only solution to avoid major environmental disasters (and then these would take the lead of a green paradigm).	Fossil fuels may continue to be the core of the system, even with the perspective for oil and gas peaking well before the end of the century, thanks to the huge coal resources worldwide. But then only limited progress can be expected in decoupling energy demand from the needs of energy services, and a continuation of the current energy technology paradigm. Renewables and energy thriftiness would induce a totally different way of supplying needs of energy services, contributing to decouple energy demand from needs of energy services. A transition to a low carbon society by 2050, based on renewables and energy thriftiness, implies changes in household behaviours towards thriftiness and a large-scale adoption of low energy technologies, in particular in buildings and transport. Renovation of existing buildings will form a large part of energy demand reduction in housing. For new constructions, concepts such as passive, zero-energy, and plus-energy buildings, will become common. Rethinking how we create our built environment is critical to the success of the deployment of innovations related to

			buildings and transport. In a green paradigm based on renewables and energy thriftiness, the energy system will have to be increasingly re-balanced between urban and rural areas. "Anticipatory experiences" of energy transition conducted throughout Europe are important to understand how the post-carbon transition as a whole may happen.

b. A review of selected national foresights of wider European relevance

FLA	Rationale and Key Challenges	Disruptions / Wild Cards	Key Results/Recommended Actions
Finland: **Government Foresight Report on Long-term Climate and Energy Policy: Towards a Low-carbon Finland** **2009**	The Report reviews the challenges of long-term climate and energy policy from global and national perspectives. It aims to map out a variety of possible futures and to support preparedness for them by weighing up a number of different lines of action. It includes quantitative targets and sets out concrete guidelines for measures to be taken. Climate change is a challenge to policy both because of its exceptional time span and its scope. Climate change is an issue with major economic, social, political and security dimensions. The severity of impacts is dependent on the adaptive capacity of societies. Building a low carbon society calls for strong and urgent measures at all levels and sectors. The climate perspective needs to be	In the worst of cases, climate change could even shake the foundations of civilisation. Increasingly subject to extreme and abrupt climate changes - feedback mechanisms in the climate system may accelerate or decelerate warming. There is still uncertainty over some of these feedbacks and they have not been factored into models. Climate policy decisions taken now will have impacts long into the future. There is a need to minimise the risk of extreme, irrevocable and possibly catastrophic changes.	Vision of Low Carbon Finland 2050 - as leader in climate protection it will enhance its international status. The Vision is implemented through targets which are revised based on new scientific information and as international cooperation progresses. A list of measures to promote international cooperation, including efforts to support Europe's leading role in climate policy and transfer of technologies to developing countries. Further work on assessment of the means for reducing green house emissions; scenarios for low carbon and carbon neutral Finland; cost-effectiveness of climate policy; how urban structure effects emissions; indirect impacts of climate change transmitted to Finland from rest of the world; a comprehensive estimate of the costs of adaptation; road user charges based on satellite positioning; the role of public procurement in the

	mainstreamed throughout all decision-making and current policies and measures need to be strengthened as well as development of new ones.		commercialisation of sustainable technology; development of indicators of sustainable well-being; assessment of climate policy from perspective of sustainable development; assessment of economic and employment impacts of climate policy; legislative impacts.
Germany: **Paths to 100% renewable electricity supply (SRU – Sachverständigenrat für Umweltfragen)**	The assessment study asks the question: how to design Germany's "Energiewende" (Energy Transition) for a sustainable and climate compatible? The study assumes a zero carbon electricity supply by 2050 The main energy policy goals assumed are: supply security and affordability, besides environmental goals. The German constitution applies sustainability and precautionary principle to energy related issue including intergenerational aspects.	Risk and treat of terroristic action and nuclear disasters	Current window off opportunity to invest in known renewable technologies (without nuclear option) should be used to reconfigure the German energy system in the European context Energy saving and Efficiency policy are recommended for robustness of the energy system and to speed up the transition process Storage of temporal overcapacities is key to the zero carbon scenario and cost estimates conclude that • Coordinating with Denmark and Norway reduces costs by app. 30% • Investing in powergrid-infrastructure pays off
Austria: **Energy Transition 2050 – Socio-technical Scenarios (IFZ et al. 2011)**	Exploring critical socio-technical issues in the transformation of the energy system Assuming that many technological FLA with a time horizon of 2050 have been done recently but rather few particularly focus on the socio-economic, socio political dimension of energy transition.	A break-down scenario assumes cumulative causations of demographic, economic, geopolitical : Potential of industrial decline due to lack of inexpensive energy resources Regional conflicts for energy resources Economic crisis fuelled by strong fluctuation in energy prices and unpredictable price	Three key action fields were identified Spatial organization of energy production and use: • Intelligent use of local energy resources, • Coordination of planning activities for energy and urban and regional planning, • Models and concepts of sustainable settlement and regional structures including developers and investors Reflexive governance: • Knowledge and information as

	Three key challenges and fields for action were identified: • Spatial organization of energy production and use, • Reflexive governance, • Stronger role for civil society emphasising the potential of networks	developments Inflationary currencies weaken the global financial system and foster protectionism Developing countries (like China) are vulnerable to global economic and energy crises. Chaotic and uncertain economic and political developments foster migration flows.	foundations of societal change co-evolving with energy transition. • Support through the primary, secondary and tertiary educational system • Strategic Foresight and adequate monitoring systems that allow for transition, • Complementarity of policies • Taking into account the potential of networks as coordination mechanism besides markets and hierarchies. • Considering the role of media in societal reflexivity, informing people and in visioning Stronger role for civil society emphasising the potential of networks: • Increasing pressure for change in policies • Providing impulses for discourses, collective expectations and public opinion • Active role as system builders and change agents locally as well as globally • Active role on knowledge production and diffusion • Contributing to market and sectoral development
UKERC Energy Report (2009)	how can the UK move to a resilient ('secure') and low-carbon energy system over the period to 2050 Achieving a resilient low-carbon energy system is technically and economically feasible at an affordable cost	Should there be any delay in commercialising key technologies such as CCS, demand side measures may be necessary to keep us on the path to an 80% emissions reduction. Disruptions: energy price shocks and major disruptions to infrastructure are more likely without reducing energy demand If public concern about specific technologies prevents their deployment, the cost of meeting CO2 targets will significantly increase, and a greater burden will be imposed on demand side responses.	Extensive modelling and analysis of the UK energy system through to 2050 shows that the UK's target of reducing CO2 emissions by 80% below 1990 levels by 2050 is achievable and that the aggregate costs are small in relation to GDP. By 2050, the electricity system must be effectively de-carbonised whatever pathway is followed. Nuclear, renewables and fossil fuels with carbon capture and storage (CCS) are all likely to have an important role to play. Reducing demand in the residential sector and, later, in the transport sector will also be required. Early action and a readiness to invest in infrastructure and more capital intensive solutions could lead to lower costs in the long-term. A resilient energy system which provides adequate energy security is also achievable and can be realised on a much faster timescale.

			Changes will be needed to market design and regulation to facilitate the move to a resilient low-carbon energy system A resilient energy system needs a range of measures, but reducing energy demand is key.

c. FLAs from private enterprises

Shell energy scenarios to 2050 (Shell 2008)	Challenge: • More Energy, Less Carbon • There are no easy solutions Three hard truth: • Surging energy demand • Supplies will struggle to keep up • Stresses on our environment are increasing	Turbulences are expected to come up from 2015 onward to 2030, with a big question mark beyond that Geopolitical chaos is considered a wild card in both scenarios	Two alternative Futures: BLUEPRINTS “In this scenario, difficult decisions are taken sooner rather than later, leading to revolutionary changes and a better balance of economic and environmental needs.” SCRAMBLE “A more reactive approach, first focusing on increasing energy supply and then facing the consequences later.” It would require a tripling of biomass for primary energy. Shell recommends the BLUEPRINT-scenario which is based on more oil, gas and less coal and renewables. It needs 13% less primary energy in 2050 than SCRAMBLE and energy consumption in US and EU is 1/3 less in 2055 than today. Nuclear power is foreseen in both scenarios to rise by more than 50%.
100% renewable electricity - A roadmap to 2050 for Europe and North Africa (PWC 2010)	The study starts from a vision of • A regional power system based on a SuperSmart Grid • rapid scaling up of all forms of renewable power • unified European power market that is	• Considering terrorist attacks but assuming that decentralisation reduces the risk • greater perceived and real technology risks when compared with traditional power plants. • Cooling of CSP requires water	Policy: Free trade agreement 2015, Directive on Grid regulation in 2020, decommissioning plans for European Fossil fuel power plants Market: real time pricing models in 2015, single EU regional electricity market in 2020, Full connection between EU market and North African Market in 2040. One unified

	united with the North African one • Affordable electricity for each European Union and North African country Study examines whether a vision of Europe, in combination with countries in North Africa, developing an integrated power grid with 100% of electricity generation coming from renewable sources by 2050 is possible	• Geopolitical risk for transnational infrastructure project was investigated and seen as manageable as experiences from pipeline projects show	power market for EU and NA Investment: Phase out of FF subsidies in 2020. Funding plans for 2015, 2020 2030 Infrastructure: Construction of first generation capacities in North Africa in 2015. Large scale construction of renewable energy generation in 2020. Decommissioning of Fossil Fuel Power Plants by 2040.

d. A systematic examination of foresight and horizon scanning databases

FLA	Rationale and Key Challenges	Disruptions / Wild Cards	Key Results/Recommended Actions
The Advent of Global Peak Oil (2012) **UK Horizon Scans – Sigma Scan Paper ID: 472**	Global oil discoveries peaked in 1965 at approximately 55b barrels/year; they have since declined to less than 10b barrels/year. Since 1980, annual discoveries have been less than annual consumption. US oil production peaked in 1970. The UK peaked in 1999. Much of the rest of the world has also peaked. Diversification by oil companies into alternative liquid fuel and broader energy technologies.	The likelihood that global oil production will peak within the medium term (including the possibility that it is already peaking), combined with the possibility of a steep decline thereafter, makes for an important policy challenge, especially since the ensuing 'gap' between global liquid fuel supply and demand will be exacerbated by rising demand due to the emergence of China and India.	Global oil production is set to peak between now and 2030, and may already be peaking. Unless emerging technologies are developed in time, this will be likely to result in a global economic downturn. Government intervention may be needed to ensure the necessary technological progress. Implications of a peak in global oil production include: • Rising oil prices as global oil production peaks and begins to decline. Associated rises in other commodity prices (including gas, as an alternative liquid fuel) and in goods prices. • Initial wealth transfer from net oil-importers to net oil-exporters. • Inevitable transfer to a post-crude oil economy.

			• An imperative for governments to intervene to hasten the development of emerging technologies. Efforts should be allied to existing cooperation on climate change, as different options for surviving peak oil involve vastly different greenhouse gas emissions.
Hydrogen Fuel Cells: Niche Technology or Backbone of Tomorrow's 'Hydrogen Economy'? (2011) **UK Horizon Scans – Sigma Scan Paper ID: 558**	Interest in hydrogen fuel cells stems from their potential to reduce carbon dioxide emissions by replacing oil-based automotive fuels: they may one day form the backbone of an emerging 'hydrogen economy' Drivers: Oil-security concerns. The imperative to reduce atmospheric carbon dioxide. The shift away from fossil fuels to renewable sources of electricity. Demand for clean, reliable remote/backup power generation. Demand for small, portable power sources. Government investments in the green economy.	First, there remain significant technical hurdles to cost-effective hydrogen fuel cells. ... Second, there are significant cost-barriers to a large-scale adoption. These include the cost of producing hydrogen fuel cell vehicles, the cost of producing hydrogen and the cost of establishing refuelling infrastructure. Third, current methods of producing hydrogen raise doubts about the 'green' credentials of hydrogen fuel cells. Hydrogen can either be stripped out of hydrocarbons (typically natural gas) or produced by electrolysis (i.e. using electricity to break water down into hydrogen and oxygen). Inhibitors: Cost of generating 'green' hydrogen. Cost of producing hydrogen fuel cell vehicles. Cost of refuelling infrastructure. Technology competition (biofuels, HyICE, battery-electric vehicles).	For all of these reasons, it is not obvious that today's oil economy will give way to a hydrogen economy or, if it does, that the hydrogen fuel cell (as opposed to HyICE) will form its backbone. • Hydrogen fuel cells may play a role in reducing global carbon dioxide emissions. The size of this contribution will depend on uptake within the transportation sector, as well as the means by which hydrogen is sourced. • In the medium-term, hydrogen economies are likely only in regions with abundant access to renewable energy (such as Iceland, with its abundant geothermal power), or in countries which 'go nuclear' [see Sigma Scan #437]. It is difficult to predict whether (and over what time period) hydrogen economies may emerge in other countries. Much will depend upon emerging technologies aimed at reducing the carbon footprint of fossil fuel usage [see Sigma Scan issue paper 440]. • If the vision of a hydrogen economy fades in leading economies, R&D funding for fuel cell technology is likely to fall. A slower rate of technological progress may then spill over into the uptake of fuel cells in other niche applications (which also experience technology-competition). The exceptions to this are applications in air-independent environments (for example, space, submarines.) .

Intensified Research into Fusion Power (2012) **UK Horizon Scans – Sigma Scan Paper ID: 481**	Enablers/drivers: Increased scientific evidence for global warming and public awareness, places increased importance on environmental attractiveness of alternative energy concepts and not just the economic cost of the energy produced. Increased diversification of fusion funding to stimulate development of more cost effective variants.	The complexity of either approach will probably make the cost of electricity production high by comparison with fossil fuels. The timescale over which fusion energy production can be realised is therefore likely to be elongated if it is assessed in purely economic terms.	Fusion ... has an advantage over most renewable energy sources in that it can be concentrated in a Giga-watt power station, without the additional economic and environmental costs associated with widely distributed sources. The difficulties associated with initiating fusion reactions, however, mean that despite 60 years of research, it will be at least another 20 years before energy production from fusion is realised. Both magnetic and inertial confinement fusion approaches will require decades more research before their effectiveness as an energy source can be completely assessed. It is essential therefore that the substantial environmental benefits offered by fusion are given equal measure when considering a future energy strategy.
Transdisciplinarity (2012) **UK Horizon Scans – Sigma Scan Paper ID: 282**	In the past two centuries, new "sciences" from meteorology to biochemistry were invented in response to intellectual and professional opportunities, philanthropic priorities, and economic and state needs. During the 20th century, the growth of the sciences, and academic and career pressures, encouraged ever-greater specialisation. More recently however, complex challenges such as developing our knowledge of the brain, or understanding climate change, have required scientists from different backgrounds to work together.	Transdisciplinarity poses a challenge to the existing subject-based structure of research funding agencies, universities and schools. Some commentators, such as Helga Nowotny (Chair of the European Research Advisory Board), suggest that the way universities function today could become obsolete. It also means a further challenge to existing patterns of academic publishing, which are already under stress because of open-source competition. Learned societies and academies might also need to be restructured, again at a time when their existing business model, based on profits from publishing, is threatened.	The movement towards transdisciplinarity is not isolated to the traditional sciences and envisages a future of increasing exchange between both the natural and technical sciences and art and the humanities There could also be extensive changes to the career patterns of researchers, and effects for employers. Good multi-subject teamwork and brilliant research skill may not always exist in the same person. If they are successful however, transdisciplinary approaches could mean the ability to solve problems that would elude the efforts of a single-subject, e.g. understanding how the mind-brain works and how to maintain its function. Fresh thinking might emerge about existing big problems..