statement

European Academies' Science Advisory Council

For further information

secretariat@easac.eu
www.easac.eu

European Academies
easac
Science Advisory Council

Shale gas extraction: issues of particular relevance to the European Union

Background and scope of this statement

Following the rapid increase over the past decade in the production of shale gas in the USA[1], political interest in Europe has grown on the local potential of gas obtained by hydraulic fracturing of shale ('fracking')[2]. Potential attractions are seen from the energy security, local economic competitiveness and (to a lesser extent) employment standpoints, while the overall environmental advantages and disadvantages remain a matter of debate. Public concern has been high, with significant local opposition to attempts in a number of European Union (EU) countries to conduct exploratory drilling, and in some countries (e.g. France) a vote in Parliament on forbidding hydraulic fracturing by law. A number of EASAC member academies have already completed reviews on the risks from shale gas extraction and their management (see Royal Society and Royal Academy of Engineering 2011; Académie des sciences 2012; acatech – German Academy of Science and Engineering 2014; Lithuanian Academy of Sciences 2014; Polish Academy of Sciences 2014; Swiss Academies of Arts and Sciences 2014).

On 22 January 2014, the European Commission adopted a non-binding Recommendation for '*Minimum principles for the exploration and production of hydrocarbons (such as shale gas) using high volume hydraulic fracturing*' (European Commission 2014). Member States have been invited to implement these recommendations within 6 months of publication and the Commission will review the Recommendation's effectiveness in July 2015. Recognising the public and political interest in the issues around fracking and the underlying science, EASAC set up an expert review group whose advice was discussed by EASAC Council in May 2014.

EASAC Council noted that scientific and engineering assessments are now available from a number of science and engineering academies, both within Europe (Royal Society and Royal Academy of Engineering 2011; Académie des sciences 2014; acatech – German Academy of Science and Engineering 2014; Lithuanian Academy of Sciences 2014; Polish Academy of Sciences 2014; Swiss Academies of Arts and Sciences 2014) and elsewhere (see, for example, International Energy Agency 2012; Australian Council of Learned Academies 2013; International Risk

1 Gas extracted from shale deposits through horizontal drilling and hydraulic fracture provides more than 40% of US natural gas supply and is projected by the US Energy Information Administration to be the dominant source of domestic gas for the foreseeable future (EIA 2014). Other unconventional gas production in the USA (including coal bed methane and tight sediments) requires similar stimulation methods so that total unconventional production requiring hydraulic fracturing is above 50% of total US gas demand.

2 Although media coverage often uses the term 'fracking', this is shorthand for the term 'unconventional gas extraction', which requires 'hydraulic fracturing' to inject fluids into geological formations to create and expand fissures, allowing the enclosed gas to be released and flow out of the formation into the well bore.

Governance Council 2013; Council of Canadian Academies 2014). The most recent of these incorporate data available up to the end of 2013. However, much of the data and assessments are based on experience and evaluations outside the EU area. This EASAC statement therefore focuses on three particular aspects that may require special attention from a European perspective in seeking to harvest the economic potential of shale gas reserves in the EU:

1. While some shale gas areas in the USA (e.g. Pennsylvania) have comparable population densities to Europe, most of the areas studied to date in the USA, Canada and Australia have much lower densities. Issues related to population density may therefore be more significant in EU countries.

2. Since the EU has the world's most comprehensive and legally binding greenhouse gas (GHG) reduction and climate change mitigation policies, potential effects of shale gas exploitation on meeting Europe's climate change targets are an important consideration, both for carbon dioxide (CO_2) and methane emissions.

3. The EU public has already shown considerable sensitivity to the issue of fracking, so effects on the public and on their communities are also critical issues.

This EASAC statement thus considers factors related to these three issues. It draws on the reviews and assessments cited above, peer-reviewed literature since late 2013 and consultation with experts from EASAC member academies (Annex 1).

Issue 1 Implications of Europe's high population density

The average population density of EU countries ranges from just below 100 to over 600 people per square kilometre, compared with just over 3 in Canada and Australia, and 32 people per square kilometre in the USA. It is thus inevitable that unconventional gas and oil operations can interact closely with other activities of society. Demands on, and values attached to, a given area of land are also likely to be greater where population densities are higher. Critical features include the areas required for hydraulic fracturing activities, the interactions (transport, noise, local emissions, etc.) with other land users, and longer-term impacts on the area, including post-closure reclamation. Since the zone reached by a single well is limited, large-scale fracturing requires many wells to be established, so potential impacts should be considered on a cumulative basis.

Europe is not, however, starting from the beginning in using hydraulic fracturing and horizontal drilling. These technologies have been practised in Europe since the 1950s and 1980s respectively. One European company (Elf, now merged with Total) was a pioneer in horizontal drilling. In the early 1990s, horizontal drilling and multiple hydraulic stimulations were successfully executed in northern Germany in 5000-metre deep wells to increase gas flows. Overall, in Europe more than 1000 horizontal wells and several thousand hydraulic fracturing jobs have been executed in recent decades. None of these operations are known to have resulted in safety or environmental problems.

Regulations intended to ensure safe and environmentally sensitive drilling activities are already in force in those European countries with their own oil and gas industry. In Germany, for example, no hydraulic fracturing is allowed without prior proof of the technical integrity of the well. International Energy Agency (2012) guidance describes the key environmental and social risks and how they can be addressed, and suggests 'Golden Rules' necessary to obtain the economic and energy security benefits while meeting public concerns. Academy analyses mentioned above also provide detailed guidance on environmental, seismicity and safety issues. In the UK review, the Royal Society and Royal Academy of Engineering (2011) concluded that the health, safety and environmental risks associated with hydraulic fracturing can be managed effectively as long as operational best practices are implemented and enforced through regulation. Similar conclusions emerge from other analyses (Académie des sciences 2012; International Energy Agency 2012; Australian Council of Learned Academies 2013; International Risk Governance Council 2013; acatech – German Academy of Science and Engineering 2014; Lithuanian Academy of Sciences 2014; Polish Academy of Sciences 2014; Swiss Academies of Arts and Sciences 2014). The priority is thus seen as to apply existing regulations adequately rather than produce new ones.

Nevertheless, studies such as that by the Council of Canadian Academies (2014) and those of EASAC experts draw attention to the limited information and number of peer-reviewed studies that are available, owing to the young age of the industry. Uncertainties thus exist in assessing potential impacts at individual sites that differ in their geology, hydrology, climate, access infrastructure and socio-economic conditions. Such uncertainties need to be taken into account when setting priorities for monitoring, research and regulation, as addressed later in this statement.

The scale of the potential for shale gas extraction in the EU is also uncertain because of limited geological data on the accessibility of gas (and oil) from the areas with geological potential shown in Figure 1. The US Energy Information Administration (EIA 2013) estimates unproven technically recoverable shale gas volumes in Europe to total 470 trillion cubic feet or 13.3 trillion cubic metres, of which the largest are in Poland and France (4.19 and 3.88 trillion cubic metres respectively). The next largest reserves are thought to be in Romania (1.44), Denmark (0.91), with the Netherlands and UK both estimated to have 0.74 trillion cubic metres. However, such estimates are based on limited data and are thus very approximate; as more studies are performed they will change—perhaps substantially. For instance, since the EIA report, UK estimates have been greatly increased in a British Geological Survey analysis (Andrews 2013). In western Lithuania, significant geological sources of unconventional oil and gas have been estimated (at a technical recovery rate of 1%) to potentially provide 14 trillion cubic metres of gas[3] from an area of 2,700 km^2. On the other hand, only a fraction of the EIA estimates are considered economically recoverable by the Polish Geological Institute (referred to in International Energy Agency

3 The Lithuanian analysis (Lithuanian Academy of Sciences 2014) also identified barriers to exploitation as the limited information from exploratory drilling; the high population density and lack of available land; past experience of low reclamation rates and the sensitivity of public opinion; and incomplete regulation on environmental, safety and health issues.

This document and any map included herein are without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries and to the name of any territory, city or area.

Figure 1 Unconventional gas resources in Europe (source: International Energy Agency 2012).

2012). The supposed presence of gas in the Paris basin has also been subsequently shown not to exist.

The geology of much of Western Europe is also more complicated than in parts of the USA. Older, more fractured formations are characteristic of many European countries and this has implications for the technical and economic viability of gas extraction. To determine the proportion of gas in place that can be extracted, flow rates must be analysed from test wells. Moreover, non-geological factors including costs, engineering, supply chain and access restrictions will determine the commercial scale of shale gas extraction. These uncertainties make it difficult to follow the EU Commission Recommendation that Member States ensure that '*the geological formation of a site is suitable for exploration of hydrocarbons using high-volume hydraulic fracturing*'. With no established criteria that can be used to verify 'suitable', the governing criteria will probably be the economic value of the site based on sales prices and estimates of total costs (including taxes), while recognising remaining uncertainties on the size of the gas resource and extraction (including regulatory compliance) costs. The main parameters can only be determined by a phased approach with exploratory drilling in combination with application of stimulation technologies in order to determine commercial viability.

The EIA estimates for shale gas in Europe can be compared with the USA's 567 trillion cubic feet (16 trillion cubic metres) estimated in the same study (EIA 2013) to suggest per capita reserves of around half those in the USA. The European Commission's Joint Research Centre (JRC) review of unconventional gas (JRC 2012) concluded that the potential significance of shale gas for the EU market would probably be much less than had been observed in the USA and that '*the best case scenario for shale gas development in Europe is one in which declining conventional production can be replaced and import dependence maintained at a level around 60 %.*' Nevertheless in the current heightened concerns over the geopolitical implications of reliance on imports from Russia, indigenous supplies of shale gas could make a valuable contribution to energy security by avoiding increased dependence on imports from such potentially disruptable sources. Import substitution is thus an important consideration when judging the merits of allowing shale gas exploration in Europe. Increasing local production of gas in Europe rather than importing more gas also has the benefits:

- the rules and standards for safe and clean operations and their enforcement are set within EU borders and controlled by EU Member States;

Figure 2 Innovation in well design and operation (source: Range Resources Ltd.). Left: old single well spacing (Texas); right: modern multi-well cluster configuration accessing gas from an area of up to 10 km^2 (Pennsylvania).

- the energy use and methane leakage associated with the transport of gas to Europe over long distances (up to 4000 km) from Siberia and Algeria is reduced.[4]

Rather than revisit the analysis of health, safety and environmental aspects already covered extensively in the documents cited above, this EASAC statement focuses on the spatial conflicts that may emerge when drilling and hydraulic fracturing are introduced into the more populous and high-land-utilisation countries of the EU. Shale gas development involves the same mix of construction and industrial activities as conventional gas development, but has historically been at a higher intensity because (1) the resource covers large geographical areas (see, for example, Figure 1), (2) production declines quickly requiring new horizontal wells to be drilled to keep production stable and (3) individual shale gas wells may need to be spaced closer together to drain the reservoir efficiently, owing to the rock's lower permeability.

In terms of land impacts, it is the well pad size and spacing that is significant. Areas of shale gas-well pads (1.5–3 hectares) tended to be larger than conventional gas pads. Moreover operations in some US gas fields initially had a well density of as high as one well per 0.8 km^2 after 13 years of development, and intensive development thus required significant displacement of land to shale gas activity. However, shale gas wells are no longer drilled as single wells but as part of a cluster with as many as 20 wells or more per cluster.

A comparison of old and current technologies is shown in Figure 2.

The reservoir volume accessed from a single site has increased substantially through such multi-well pads and longer horizontal laterals, offering a potential extraction area of 10 km^2 or more from one pad and reducing surface land use area accordingly. Unconventional gas fields thus no longer have significantly higher well pad densities than conventional fields. Technically, horizontal wells with a reach of up to 12 km are possible (although such wells would at present be uneconomic), but even with clusters of only 3 km radius, it becomes viable to produce unconventional gas in heavily populated areas[5]. This is a key contribution to reducing impacts in Europe, and investors and operators should be motivated to apply best practice to reduce concerns over land use demands. This reduction in land use burden also reduces the challenges of land reclamation after use and associated post-closure financial liability.

In addition to land for well pads and ancillary facilities, shale gas development also requires large amounts of water (95% of the fracking fluid), proppants for hydraulic fracturing (~5%) and chemicals constituting usually less than 1% of the fracking fluid. The most common proppant is sand, and hydraulic fracturing in oil and gas operations has led to a large increase in sand mining in the USA (some 28.7 million tons in 2011). The availability and location of the sand (high quartz content and round, 100–500 micrometre

[4] Such advantages were also emphasised in a recent UK Parliamentary Assessment of the potential for shale gas (House of Lords Economic Affairs Committee 2014).

[5] For example, for a medium-sized city such as Zurich, virtually all of any gas under the city could be accessed from a single central location.

size grains are required) from quarries, near-shore or coastal sources are thus potential issues. Current trends to manufacture proppant grains artificially (e.g. via ceramics) are a potential means of reducing such demand.

The large quantities of water required make this a sensitive issue in areas where existing supplies are already highly utilised; there may be a particular problem in meeting water demands in dry countries (or regions, or periods) because of competition with agriculture, urban supply and other (e.g. industrial) uses. The water used is turned into a pressured fluid containing sand and chemicals, and will also release gas and other minerals when it returns to the surface. Migration to nearby aquifers needs to be avoided and any contaminated water that returns (flow-back water) appropriately treated. Detailed guidance on these aspects has been given in the academy reviews already cited and will not be repeated here. In general, part or all of the flow-back water can be recycled and net water consumption reduced. Moreover, in some areas, water can be extracted from non-potable resources to avoid competing with potable water resources. Nevertheless, in areas of limited water supply, water demand could limit where, when and how fast shale gas can be developed. In response to this, alternative techniques using non water-based hydraulic fracking fluid have been developed—for example propane-based fracking fluids[6].

With regard to water quality, public concerns over potential water contamination are high, so proposals for shale gas extraction should evaluate thoroughly the potential effects on local and regional hydrogeology, and potential long-term, long-range groundwater impacts. Fracturing of shale formations forms fissures which open new water transport routes, and can thus affect flows and chemical composition of surrounding waters. In particular, black shales are generally rich in trace metals and often in sulphides (notably pyrite) so a change in the chemical composition of the deeper waters in contact with the shale cannot be avoided (this may affect pH as well as concentrations of trace elements). At the usual depths of fracking, directly affected groundwater is not of drinking water quality; most are undrinkable brines with a higher specific gravity so that they would not normally mix with the shallow and lighter potable groundwater. However, there are conceivable situations in which hydraulic fracturing could affect potable waters. Firstly, fracturing operations at shallow depths have been suggested in which case direct impacts are possible. Secondly, though geologically unlikely, the possibility of vertical transport between different depths through overpressures or major pathways such as permeable faults should be considered, and a thorough geological characterisation performed of the reservoir and its overburden to map any geological faults that could provide connections between distant layers.

Up to now, effects on groundwater that have occurred have been caused by poor well integrity or cementation, or deficient handling at the surface. Thus, as emphasised later in this statement, securing a correct well design and regularly checking its integrity are critically important. Clearly, groundwater composition should be included as one of the baselines that should be monitored at the start, during operations and after they have concluded. Additional monitoring of deeper non-potable aquifers (located close to the shale but far from the potable water table) can allow early detection of any possible contamination source and provide time to respond.

In one location in Poland, fracking operations led to drinking water from a well becoming muddy, which led to fears of contamination by the chemicals used while fracturing. However, investigations showed that the origin was vibrations from water pumps which caused mud to suspend in the water. Such physical interference with local water supplies should thus also be considered. Guidance on these aspects has been published in the cited academy reviews.

With regard to potential interference with communities and their lifestyles, shale gas extraction requires energy to power the drill rigs and pumps, etc., and vehicles and infrastructure to access the sites. Transport of equipment, chemicals, water, construction materials, and workers, often in large vehicles, will be needed at various stages. Sources of noise include drilling and hydraulic fracturing equipment, natural gas compressors, traffic, and construction. Drilling and completing a well is a 24-hour operation, so lighting can also be an issue. Drilling a shale gas well typically takes 4–5 weeks and, as multiple horizontal wells may be drilled sequentially from the same pad, this may extend the period to several months. Because hydraulic fracturing requires more pressure and water, more pumps and other noise-producing equipment may be used than in a conventional well. Practices developed in low-population-density locations may need rethinking to redefine the work-flow to minimise overall disturbance and environmental impact—for example by starting with the building of shared infrastructures before deploying the drilling process.

[6] See, for example, http://www.gasfrac.com/.

Restoring a well site after the gas has been extracted is an important part of the overall process. It includes capping and sealing[7] the well, removing equipment, and performing necessary remediation and restoration to the subsequent land use (which may differ from the pre-drilling use). Historically in the USA (for all types of oil and gas extraction), the reclamation rate has been only 41% that of the abandonment rate, and there were over 50,000 uncertified abandoned wells at the end of 2012, although many of these were from earlier technologies that would not be used in Europe (see Figure 2, left), and abandonment and reclamation regulations in Europe should prevent similar problems. More modern multiple sites (Figure 2, right) are of much smaller total area and thus less of a logistical and economic challenge for restoration.

Finally, there is an important difference between the USA and Europe in land mineral rights. Owning private land in the USA includes ownership of any hydrocarbons underneath, which can thus create revenues from gas production to the landowner. In Europe, according to existing mining laws, ownership is with the state so that landowners and communities do not get the compensatory financial benefits found in the USA. Revision of mining law is, however, underway in some EU countries; for instance in France new fiscal regimes will be introduced with the twin objectives of dedicating part of the shale gas exploitation benefits to local communities, and introducing environmental protection aspects into the permitting process.

The US system has the advantage that financial interests of the landowner and shale gas extractor are aligned. The European model of state ownership of the underground has the advantage that horizontal drilling that crosses surface property boundaries is not affected. Such horizontal drilling has reached 6–10 km in some industry experiments, considerably increasing the area of the underground resource that can be reached from a single cluster pad to 30–100 km^2.

This present difference between the existing legislation in the USA and in Europe can lead to fundamentally different general public and individual attitudes to the inconvenience and potential risks of shale gas development. While this is a legal or political issue, the extensive literature on perception of risk shows the critical importance of the presence or absence of individual benefits in influencing an individual's perception, and acceptance, of risk.

In relation to issue 1, EASAC identifies a number of key points:

Applying existing best practice:

- maximise the horizontal wells drilled from the same pad (cluster drilling);
- establish strict well completion and land restoration rules with the necessary enforcement regimes and associated financial liability in the event of failure to meet restoration standards;
- establish standards for the long-term sealing of shale gas wells and the methods required to control sealing quality;
- apply low noise and disturbance technology and logistics;
- recycle flow-back fluids to reduce water use and trucking;
- disclose additives used.

Research and development needs to include the following:

- technologies that minimise the environmental impact of hydraulic fracturing;
- technologies for better characterising and assessing the resources, including their spatial heterogeneities;
- the acquisition of baselines for potable aquifers before any production starts[8];
- technologies for monitoring and detecting in advance any deviation from expected behaviour;
- advanced technologies (such as use of coiled tubing, smart completion systems) for reducing drilling and production environmental impacts both at the surface and down-hole;

[7] To ensure final sealing of the well, it may be necessary to remove at a selected depth the casing and cementation of the well over a limited length, and replace it with a plug of clay and cement which will provide a stable corrosion-resistant plug to ensure long-term tightness of the seal.
[8] Groundwater in many areas contains substantial levels of natural methane (for example, of 22 geothermal wells drilled in recent years in Holland, 20 have intercepted strata that contained groundwater with substantial natural amounts of methane, requiring the installation of gas separators).

- alternatives to high-volume (water) hydraulic fracturing using either alternative fluids or alternative processes (including increased recycling of flow-back fluids).

Issue 2 Climate change policies

The EU has legally binding GHG reduction policies[9] to address the threat of global warming. Shale gas is often cited in the public debate as offering the potential to reduce EU GHG emissions more efficiently (on the assumption that less coal or other high-carbon-energy sources would be used) and potentially providing economic leeway for more ambitious GHG reduction targets in the short to medium term. However, the volume of methane emissions from gas leakage at the wellhead and in the distribution system is a critical factor in view of methane's global warming potential[10] (GWP) being much higher than that of CO_2. In this context, the critical importance of timescale to methane's contribution to global warming may not be fully appreciated by policymakers. The commonly quoted GWP for methane is from the assessment of IPCC (2007), where the GWP is given as 25 (effect over 100 years). However, the assessment of IPCC (2013) increases methane's GWP to 34 (100 years), and calculates the GWP for the first 10 years after emission is 108, and 86 for the first 20 years after emission.

Which GWP value should be used is influenced by the international consensus that average global temperature should not rise to more than 2.0 °C above pre-industrial levels, because of the high risk of triggering 'runaway' warming from feedbacks such as release of natural GHGs (particularly methane) from stores in permafrost and deep oceans. With current warming already approaching approximately 1 °C, current trends have this 'dangerous climate change' state reached in a few decades, not a century (IPCC 2013). It is thus argued that the contribution of additional GHGs with a high GWP should be considered over short (10–20 year) periods rather than the 100 years used in earlier assessments (Shindell et al. 2012); in other words, the GWP of methane should be considered as 86–108 that of CO_2. When considering any 'trade-off' between methane and CO_2 therefore, short-term increases in methane can outweigh even a substantially larger reduction in CO_2.

While these re-evaluations of methane's GWP are not related to any particular source of methane, they do increase the significance of methane emissions from *any* source. In this respect, analyses from the USA reveal a consistently higher level of methane in the atmosphere (from direct measurements from aircraft, towers, etc.) than would be expected from bottom-up calculations based on presumed emissions from resource extraction and the gas and oil transportation and distribution network (see, for example, Brandt et al. 2014; Caulton et al. 2014). Research suggests that these 'extra' emissions include leaks from abandoned wells, a small number of large leaks at well sites (termed 'super-emitters'), the infrastructure of gas processing plants, storage and compressor facilities, as well as from the huge (and in many cases old) transportation and distribution system. Some authors (Barcella et al. 2011; Molovsky et al. 2011; Allen et al. 2013; Williams 2013) conclude that hydraulic fracturing is *not* a substantial emissions source relative to current national totals; nevertheless, such large differences between field measurements and emissions inventories can and should be better understood to allow efforts to reduce methane emissions to be properly prioritised.

At GWPs of 86–108, it is clear that the potential climate 'benefit' of natural gas relative to coal is highly sensitive to methane emissions. The US Environmental Protection Agency currently assumes a 1.5% leakage rate in natural gas extraction and production, but recent studies (Brandt et al. 2014; Caulton et al. 2014; Miller et al. 2014) suggest fugitive emissions in the USA may be considerably higher. This remains contested, however, with other studies (for example, Barcella et al. 2011) that suggest flaws in the EPA's methodology that fail to reflect current industry practice and *over*state emissions. One of the recent studies (Allen et al. 2013), based on direct measurements of methane emissions at 190 onshore natural gas sites in the USA, also found total methane emissions from natural gas production lower at approximately 0.42% of gas production. It should be noted that German upstream industry is reporting approximately 0.02% of methane emissions from natural gas production (Ziemkiewicz et al. 2014), indicating that significant methane emissions can be avoided with appropriate regulations[11].

Owing to current uncertainties over methane emissions, the simple claim that natural gas is always

[9] The EU is committed to transforming Europe into a highly energy-efficient, low-carbon economy. For 2020, the objective is to cut GHG emissions to 20% below 1990 levels; for 2050, the objective is to reduce by 80–95% compared with 1990 levels.
[10] Global warming potential expresses how much a greenhouse gas traps heat in the atmosphere relative to CO_2 (assumed to be 1).
[11] Methane is also released by coal mining (coal bed methane) and its handling varies between countries. In China, for example, methane is released to the atmosphere; in Germany it is collected and used for heating.

better than other fossil fuels, and of gas being a 'bridging fuel' to a low carbon economy, is under scrutiny in the USA (see, for example, Howarth et al. 2011; Trembath et al. 2013; Brandt et al. 2014; Howarth 2014; Newell and Raimi 2014), with competing claims about the contribution of shale gas extraction to reported methane emissions. A recent meta-analysis (Heath et al. 2014) of the scientific publications on this issue came to two conclusions: (1) that emissions from shale gas extraction are similar to those from conventional gas extraction and (2) that both when used in power generation would probably emit less than half the CO_2 emissions of coal. Nevertheless, the analysis also noted that higher assumptions on fugitive emissions '*may lead to emissions approaching best-performing coal units, with implications for climate change strategies*'.

Regarding potential sources of emissions from shale gas extraction, flaring and venting in conventional exploitation in Europe ceased during the 1990s (with the exception of initial flow tests in successful exploratory drilling); industry therefore possesses the necessary expertise to avoid this problem. 'Green' completion technologies are also widely used to capture and then sell (rather than vent or flare) methane and other gases emitted from flow-back water (they can be recovered at low cost by taking out the gas within a confined separator). This will be mandatory for hydraulic fracturing of all gas wells in the USA from 2015 onwards. Ensuring 'green completion' is fully applied in Europe is thus an essential prerequisite for maximising benefits from shale gas to climate change policies.

Critical to eliminating methane emissions during well construction and production is to ensure '**wellbore integrity**'. This is accomplished by placing casing and tubing into boreholes, which are sealed towards the rock by cement[12]. Figure 3 shows the main elements of a properly designed and constructed well (Royal Society and Royal Academy of Engineering 2012). General industry practice in *conventional* wells (which typically have higher pressures and gas flow rates and longer lifetimes than shale gas wells) has solved the problems of gas migration. By pressure testing, the tightness of the well can be verified. Hydraulic fracturing also uses external casing packers to separate individual fracked zones from each other, creating mechanical barriers in the lowermost part of the well against gas migration outside of the casing. Regulations have to make

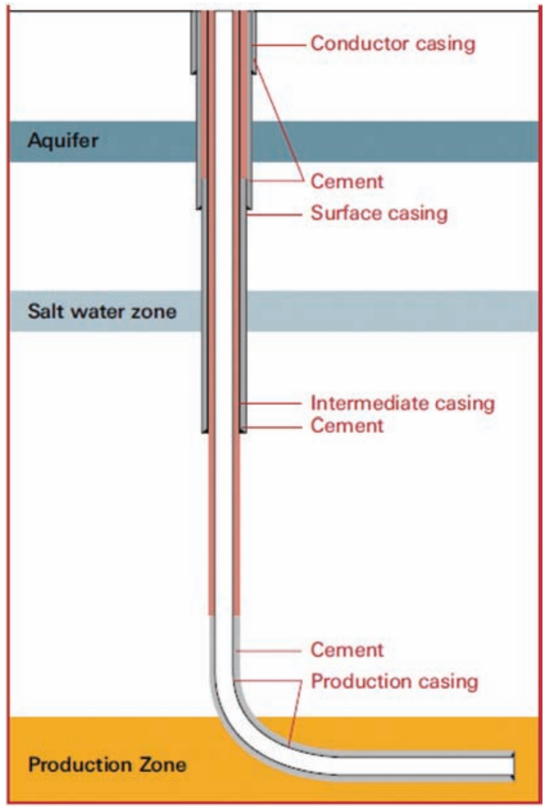

Figure 3 Cementing and wellbore integrity (source: Royal Society and Royal Academy of Engineering (2012)).

sure that proper monitoring systems[13] (during well construction, stimulation, production phase and after abandonment) are performed.

Poor well design has been the (most likely) reason for methane emissions in the vicinity of gas wells in Pennsylvania, which have been assigned by some to shale gas wells and fracking (Ingraffea et al. 2014). Further analysis (Molovsky et al. 2011; Williams 2013) has shown that even before drilling for shale gas, methane emissions had been observed in deeper water wells. Shale gas wells penetrated and bypassed these shallow gas zones, but were not designed for proper isolation of these intermediate gas zones. This appears to have allowed gas originating from uncemented layers to migrate upwards outside of the casing and reach the surface.

When no longer economical, the well is 'abandoned' using procedures long established in the industry.

[12] Well integrity is also an issue for groundwater protection since while the fracking itself generally takes place below the groundwater reservoir, well casing failure closer to the surface can result in groundwater pollution.
[13] Monitoring the tightness of the annulus (the space between casing–casing or casing–rock) can be achieved through several (mostly indirect) indicators: e.g. cement bond logging after cementing, pressure testing before fracking or production starts, monitoring annulus pressure and temperature, gas sampling for gas quality and source.

The well is plugged with cement to shut off previous producing zones, prevent emissions and protect groundwater. As with the construction and production phases, it is critical that these steps be implemented effectively and that cement does not degrade over time. The long-term integrity of well sealing still needs further technological development. Firstly, in respect of the method to be used—one option being the removal of casing and cement over a specific length of the well bore (at a depth selected below any aquifer) by drilling out the casing, and sealing with clay and cement in contact with a tight geological formation. Secondly, further research is also desirable on cement deterioration and on improved cementing materials to increase further effectiveness and durability of sealing on abandonment.

The importance of minimising methane emissions has been recognised in the evaluations by the science academies already cited. These emphasise that appropriate regulations and standards should be applied and well integrity secured by proper well design and drilling/completion procedures, including down-hole logging to detect whether cementing of the casing is effective. Monitoring arrangements should be applied to detect any well failure as early as possible and continue after closure. Europe should ensure a high degree of elimination and minimisation of emissions in its shale gas policies and regulations.

Socio-political factors related to interaction with other energy sources are also relevant to climate change policy. For example, the financial resources invested in shale gas will have to be retrieved, which could reduce the capacity (or willingness) of the financial community to invest in renewable energies such as solar or wind. One (not peer-reviewed) assessment (Tyndall Centre 2011) calculated that investment in shale gas could displace both offshore and onshore wind investment in the UK through such competition for investment resources. This led the UK House of Commons Energy and Climate Change Committee (2011) to conclude that lower gas prices driven by shale gas development could extend the economy's dependence on fossil fuels, thus '*contributing to locking in to high carbon infrastructure*'.

Such concerns may not apply to all EU countries since some, including France and Germany, use very little gas to generate electricity. In such cases, shale gas would just replace conventional gas imported for use in heating, with no interference with decisions related to electricity generation. Moreover, estimates of likely shale gas prices do not suggest that European supplies will significantly affect market prices (JRC 2012). EASAC experts thus comment that increasing supplies of shale gas may just displace imports and have limited impact on the energy balance. Furthermore, benefits from shale gas exploitation could be partly reinvested in improving renewable energy efficiencies: the option thus exists for governments to offer reassurance that shale gas exploitation would not weaken their renewable energy priorities, or even reserve shale gas taxation income to adhere to road maps towards low carbon energy.

EASAC thus concludes that the accuracy of claims that shale gas will mitigate global warming depends on factors ranging from the nature and quality of the extraction process to wider interactions with the energy system. The following issues are relevant:

- 'green' completions should be standard operating procedure; in particular, operational requirements should avoid open-air water disposal and require confined separation devices which recover hydrocarbon gases in flow-back operations;
- regulation needs to have a routine focus on 'well integrity' based on thorough planning and execution of the well, the completion phase (including hydraulic fracturing) and during later production and abandonment;
- monitoring arrangements should be applied to detect possible well failure and emissions from surface processes as soon as possible;
- in response to concerns over possible effects on renewable energy policies, governments should clarify the interaction of their shale gas policies and their plans related to research, development and implementation of low carbon renewable energy.

Issue 3 Public acceptance of shale gas development

Whether in academy studies or parliamentary enquiries, public acceptance is seen as a fundamental precondition for large-scale shale gas development. This will not be gained through industry claims of technological prowess or through government assurances that environmental effects are acceptable. It requires trust to be built in the industry and the regulatory system under which it operates, as well as transparent and credible monitoring of environmental impacts. Critical factors include issues related to the industry's 'social license', the environmental and other risk management systems applied, and transparency and access to relevant information.

The concept of 'social license to operate' is relevant to the resources industry. Central to the concept of social license to operate is the proposition that, even if fully compliant with laws and regulations, activities that are particularly intrusive or perceived to carry significant risks can be vetoed by a hostile public through campaigns, legal actions, demonstrations or other democratic pressures. Such industries must negotiate a 'social license' with their community to conduct their business. In the case of shale gas this requires that (Council of Canadian Academies 2014):

1. Communities and other stakeholders have an *informed understanding* of the technologies of shale gas production and the associated risks, impacts and potential benefits; they are also informed about the management and regulatory processes that are used to manage these risks.

2. Proponents and regulators of these technologies have an informed understanding of, and *demonstrate respect for*, the concerns and perspectives of various stakeholders.

3. Different parties are able to engage in *constructive dialogue* with each other and work towards agreed outcomes, or at least an accommodation of differences.

It is also important that communities see how they can benefit directly from production activities (as mentioned in issue 1).

A critical factor is that stakeholders understand and regard as acceptable the philosophical basis on which regulations are based. In the case of the EU Recommendation, a number of terms are used. For instance, the concept '*best available technique (BAT)*' is used (e.g. '*The risk assessment should be based on the best available technique*'). 'BAT' is also applied in the context '*anticipate the changing behaviour of the target formation, geologic layers … etc*', or establish '*a minimum vertical separation*'. However, 'BAT', while including valuable flexibility to adapt to improving technology, is vague in terms of the precision with which such effects can be determined. Alternatives used in some Member States include ALARP (as low as reasonably practicable), which leaves much of the detail to agreement between the industry and regulators. Such approaches leave uncertainties in the minds of stakeholders; trust in the regulatory process is thus very important.

Other requirements in the EU Commission's Recommendation (e.g. '*A site should only be selected if the risk assessment … shows that the high-volume hydraulic fracturing will not result in direct discharge of pollutants into the groundwater*') may also be difficult to fulfil owing to inherent data limitations. The concept of 'risk assessment' is used widely in the EU Recommendations in preference to the alternative method of 'environmental impact assessment'. Risk assessment is based on estimates of risk, which includes uncertainties, statistics and probabilities, etc., whereas environmental assessment can be seen as assessing the consequences and results following certain actions or events (and what measures can be taken to avoid any harmful effects). Environmental assessment may also need to capture the social and environmental context of fracking (e.g. issues of landscape quality, impact on tourism and water resource management). The concept of 'environmental risk assessment' to define any consequences and environmental effects is recommended by some academies. To boost trust in the process, such assessments should allow stakeholders to participate in the framing of environmental problems; identifying and assessing risks; and evaluating different means of managing them (Royal Society and Royal Academy of Engineering 2012).

Objective assessment of the environmental impacts of shale gas development has also been hampered by a lack, up to now, of adequate characterisation, monitoring, and study. To understand better the risks to surface water and groundwater resources at the watershed scale, it will be necessary to develop and apply effective baseline and operational monitoring. In the face of development with incomplete knowledge, an adaptive monitoring and management philosophy emphasising transparency would identify any unanticipated impacts as soon as possible (Rahm and Riha 2014).

Establishing a 'comprehensive baseline' is of utmost importance. Such baseline studies are essential, not least to enable the sources of any contamination to be properly attributed. In Pennsylvania and Switzerland, for example, studies (see, for example, Molovsky et al. 2011; Ziemkiewicz et al. 2014) revealed that methane very commonly occurs as a natural substance in groundwater. Such studies should also characterise the shale to identify other components (e.g. trace metals) that may be released and affect the near-field as well as far-field environment. As emphasised in issue 2, to detect potential leakages of gas, operators should monitor potential leakages of methane or other emissions to the atmosphere before, during and after shale gas operations, and such data should be submitted to the appropriate regulator.

EASAC recommends that detailed and precise information on water consumption and chemicals used and discharged to the environment should be available to regulators, so that they are in a position to provide correct information to the public and recognised interest groups[14]. Independent oversight is of great importance, especially in the area of water quality and quantity. A public monitoring network (available via the Internet) could be used to provide **independent** information on the impact of the shale gas industry. Establishing methods to monitor the environment and the creation of a monitoring network should involve the public. Companies should also engage with local communities to mitigate the impact of their work.

Public reaction may also be influenced by the degree of formal liability related to activities and actors. The low historical reclamation rate in the USA mentioned above supports Europe's general approach that operators provide a financial guarantee to cover post-closure costs.

A final comment

Current concerns over heavy reliance on imports of gas from Russia have increased further the attraction of indigenous supplies of shale gas to limit import dependence and contribute to energy security. This EASAC analysis provides no basis for a ban on shale gas exploration or extraction using hydraulic fracturing on scientific and technical grounds, although EASAC supports calls for effective regulations in the health, safety and environment fields highlighted by other science and engineering academies and in this statement. In particular, EASAC notes that many of the conflicts with communities and land use encountered in earlier drilling and hydraulic fracturing operations based on many single-hole wells have been substantially reduced by more modern technologies based on multiple well pads, which can drain up to 10 km^2 or more of gas-bearing shale from a single pad. Other best practices, such as recycling of flow-back fluid and replacement of potentially harmful additives, have greatly reduced the environmental footprint of 'fracking'. Europe's regulatory systems and experience of conventional gas extraction already provide an appropriate framework for minimising disturbance and impacts on health, safety and the environment.

This analysis, however, also shows that while shale gas may have significant global potential, it is no simple 'silver bullet' to address energy security and climate change. Indeed, the scale of the resource itself and the economic viability of its extractions in different Member States remain uncertain. Without exploratory drilling, this uncertainty will continue.

Claims that shale gas exploitation would contribute to a net reduction in the warming from GHGs are largely based on the possibility of replacing coal in power generation by gas or of expanding gas use in transport. Such environmental benefits can, however, only be achieved through avoidance (or, where not possible, minimisation) of methane emissions at all stages—from the initial drilling, through the production phase and into the future after the well is closed and abandoned.

To receive public acceptance, trust is critically important. Trust will in the end only be built by real projects, which prove the soundness of the technology and the reliability of the operations and operators. Through such projects, innovation based on empirical evidence and expertise can adapt and improve processes for the EU environment. Pilot projects need to be performed in Europe to demonstrate and test best practice methods and allow careful monitoring by the authorities.

References

Académie des sciences (2012). *La recherche scientifique face aux défis de l'énergie; Rapport du Comité de prospective en énergie de l'Académie des sciences Ed. EDP Sciences – December, 2012*. (see also Institut de France Académie des Sciences (2013). *Elements to clarify the shale gas debate - Avis de l'Académie sciences, 15 November 2013.* http://www.academie-sciences.fr/activite/rapport/avis151113gb.pdf. Also IFPEN-INERIS-BRGM (2011). *Maîtrise des impacts et risques liés à l'exploitation des hydrocarbures de roche-mère: enjeux, verrous et pistes de recherche.*

Allen DT, et al. (2013). *Measurements of methane emissions at natural gas production sites in the United States.* Proceedings of the National Academy of Sciences of the United States of America **110**, 17768–17773. http://www.pnas.org/content/early/2013/09/10/1304880110.full.pdf+html

Andrews IJ (2013). *The Carboniferous Bowland Shale gas study: geology and resource estimation.* British Geological Survey for Department of Energy and Climate Change, London, UK. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/226874/BGS_DECC_BowlandShaleGasReport_MAIN_REPORT.pdf

Australian Council of Learned Academies (2013). *Engineering energy – a study of shale gas in*

[14] Companies using best practice already give open access to all substances used and have found ways to eliminate potentially toxic additives.

Australia. http://mei.insights4.net.au/files/site1/docs/41/Peter%20Cook_Unconventional%20Gas_02.07.13_0.pdf

Barcella ML, Gross S, Rajan S (2011). *Mismeasuring methane – estimating greenhouse gas emissions from upstream natural gas development*. IHS-CERA private report

Brandt A, et al. (2014). *Methane leaks from North American natural gas systems.* Science **343**, 733–735

Caulton, D. et al. (2014). *Toward a better understanding and quantification of methane emissions from shale gas development.* Proceedings of the National Academy of Sciences of the United States of America **111**, 6237–6242

Council of Canadian Academies (2014). *Harnessing science and technology to understand the environmental impacts of shale gas extraction.* http://www.scienceadvice.ca/uploads/eng/assessments%20and%20publications%20and%20news%20releases/shale%20gas/shalegas_fullreporten.pdf

EIA (2013). *Technically re-coverable shale oil and shale gas resources: an assessment of 137 Shale formations in 41 countries outside the United States.* http://www.eia.gov/analysis/studies/worldshalegas/pdf/fullreport.pdf

EIA (2014). *Annual energy outlook, 2014.* http://www.eia.gov/forecasts/aeo/pdf/0383(2014).pdf

European Commission (2014). *European Commission Recommendation of 22 January 2014 on minimum principles for the exploration and production of hydrocarbons (such as shale gas) using high-volume hydraulic fracturing*. http://ec.europa.eu/environment/integration/energy/unconventional_en.htm

German Academy of Science and Engineering (acatech) (2014). *Hydraulic Fracturing - a technology under discussion.* http://shalegas-europe.eu/hydraulic-fracturing-eine-technologie-der-diskussion/ *(see also 'Hydrofracking Risk Assessment' by C. Ewen, D. Borchardt, S. Richter, R. Hammerbacher (2012)).* http://dialog-erdgasundfrac.de/sites/dialog-erdgasundfrac.de/files/Ex_HydrofrackingRiskAssessment_120611.pdf.

Heath A, et al. (2014). *Harmonization of initial estimates of shale gas life cycle greenhouse gas emissions for electric power generation.* Proceedings of the National Academy of Sciences of the United States of America **111**, E3167–E3176; doi: 10.1073/pnas.1309334111

House of Commons Energy and Climate Change Committee (2011). *Shale gas.* http://www.publications.parliament.uk/pa/cm201012/cmselect/cmenergy/795/79502.htm

House of Lords Economic Affairs Committee (2014). *The economic impact on UK energy policy of shale gas and oil.* http://www.publications.parliament.uk/pa/ld201314/ldselect/ldeconaf/172/17202.htm

Howarth R (2014). *A bridge to nowhere: methane emissions and the greenhouse gas footprint of natural gas.* Energy Science and Engineering **2** (2), 47–60

Howarth R, Santoro R, Ingraffea A (2011). *Methane and the greenhouse gas footprint of natural gas from shale formations.* Climatic Change **106**, 679–690

Ingraffea A. et al. (2014). *Assessment and risk analysis of casing and cement impairment in oil and gas wells in Pennsylvania, 2000–2012.* Proceedings of the National Academy of Sciences of the United States of America **111**, 10955–10960

International Energy Agency (2012). *Golden rules for a golden age of gas*. http://www.worldenergyoutlook.org/media/weowebsite/2012/goldenrules/WEO2012_GoldenRulesReport.pdf

International Risk Governance Council (2013). *Risk governance guidelines for unconventional gas development.* http://www.irgc.org/wp-content/uploads/2013/12/IRGC-Report-Unconventional-Gas-Development-2013.pdf

IPCC (2007). *IPCC Fourth Assessment Report (AR4), Working Group 1, the physical science basis.* http://www.ipcc.ch/publications_and_data/ar4/wg1/en/contents.htm

IPCC (2013). *Climate change 2013: the physical science basis.* Intergovernmental Panel on Climate Change. https://www.ipcc.ch/report/ar5/wg1/

JRC (2012). *Unconventional gas: potential energy market impacts in the European Union.* http://ec.europa.eu/dgs/jrc/downloads/jrc_report_2012_09_unconventional_gas.pdf

Lithuanian Academy of Sciences (2014). *Genesis of shale geological formations and hydrocarbon extraction: impact on environment and human health*. Compiler Algimantas Grigelis.

Miller S, et al. (2014). *Anthropogenic emissions of methane in the United States*. Proceedings of the National Academy of Sciences of the United States of America, **110,** 20018–20022

Molovsky L, et al. (2011). *Methane in Pennsylvania water wells unrelated to Marcellus shale fracturing.* Oil & Gas Journal **109** (49), 5 December

Newell R, Raimi D (2014). *Implications of shale gas development for climate change.* Environmental Science and Technology **48**, 8360–8368

Polish Academy of Sciences (2014). *Description of the shale gas formations: reserves and characteristics of problems related to its exploitation.* The Presidium of Polish Academy of Sciences, March 11, 2014

Rahm B, Riha S (2014). *Evolving shale gas management: water resource risks, impacts and lessons learned.* Environmental Science: Processes & Impacts **16**, 1400

Royal Society and Royal Academy of Engineering (2012). *Shale gas extraction*. https://royalsociety.org/~/media/policy/projects/shale-gas-extraction/2012-06-28-shale-gas.pdf

Shindell D, et al. (2012). *Simultaneously mitigating near-term climate change and improving human health and food security.* Science **335**, 183–189

Swiss Academies of Arts and Sciences (2014). *Fracking factsheet*. http://proclimweb.scnat.ch/portal/ressources/3060.pdf

Trembath A, et al. (2013). *Coal killer – how natural gas fuels the clean energy revolution.* Breakthrough Institute

Tyndall Centre (2011). *Shale gas: an updated assessment of climate change and environmental impacts*

Williams JH (2013). *Shale gas development and water resources in the United States with a focus on the Marcellus Play*. Presentation at BGR-GFZ-UFZ conference, Hannover, 24 June

Ziemkiewicz P, Quaranta J, McCawley M (2014). *Practical measures for reducing the risk of environmental contamination in shale energy production.* Environmental Science: Processes & Impacts **16**, 1692

Annex 1 EASAC academy-nominated experts for this study

Professor Bert Allard, School of Science and Technology, Örebro University, Sweden

Professor Dietrich Borchardt, Department Aquatic Ecosystem Analysis and Management, Technical University Dresden; Helmholtz Centre for Environmental Research, Germany

Dr Peter Burri, Swiss Association of Energy Geoscientists, Basel, Switzerland

Professor Algimantas Grigelis, Branch of Biology, Medicine and Geosciences, Lithuanian Academy of Sciences, Vilnius, Lithuania

Professor Christian Growitsch, Hamburg Institute of International Economics, Germany

Dr Francois Kalaydjian, IFP Energie nouvelles, Rueil-Malmaison, France

Professor Robert Mair, Department of Engineering, University of Cambridge, United Kingdom

Guy Maisonnier, IFP Energie nouvelles, Rueil-Malmaison, France

Professor Lucjan Pawłowski, Division Four of Engineering Sciences, Polish Academy of Sciences, Warsaw, Poland

Professor Peter Reichetseder, Institute of Petroleum Engineering, Clausthal University of Technology, Germany

Professor Rudy Swennen, Division of Geology, Catholic University of Leuven, Belgium

Professor Mike Norton, EASAC Environment Programme Secretary

EASAC

EASAC – the European Academies' Science Advisory Council – is formed by the national science academies of the EU Member States to enable them to collaborate with each other in providing advice to European policy-makers. It thus provides a means for the collective voice of European science to be heard. EASAC was founded in 2001 at the Royal Swedish Academy of Sciences.

Its mission reflects the view of academies that science is central to many aspects of modern life and that an appreciation of the scientific dimension is a pre-requisite to wise policy-making. This view already underpins the work of many academies at national level. With the growing importance of the European Union as an arena for policy, academies recognise that the scope of their advisory functions needs to extend beyond the national to cover also the European level. Here it is often the case that a trans-European grouping can be more effective than a body from a single country. The academies of Europe have therefore formed EASAC so that they can speak with a common voice with the goal of building science into policy at EU level.

Through EASAC, the academies work together to provide independent, expert, evidence-based advice about the scientific aspects of public policy to those who make or influence policy within the European institutions. Drawing on the memberships and networks of the academies, EASAC accesses the best of European science in carrying out its work. Its views are vigorously independent of commercial or political bias, and it is open and transparent in its processes. EASAC aims to deliver advice that is comprehensible, relevant and timely.

EASAC covers all scientific and technical disciplines, and its experts are drawn from all the countries of the European Union. It is funded by the member academies and by contracts with interested bodies. The expert members of EASAC's working groups give their time free of charge. EASAC has no commercial or business sponsors.

EASAC's activities include substantive studies of the scientific aspects of policy issues, reviews and advice about specific policy documents, workshops aimed at identifying current scientific thinking about major policy issues or at briefing policy-makers, and short, timely statements on topical subjects.

The EASAC Council has 29 individual members – highly experienced scientists nominated one each by the national science academies of EU Member States, by the Academia Europaea and by ALLEA. The national science academies of Norway and Switzerland are also represented. The Council is supported by a professional Secretariat based at the Leopoldina, the German National Academy of Sciences, in Halle (Saale) and by a Brussels Office at the Royal Academies for Science and the Arts of Belgium. The Council agrees the initiation of projects, appoints members of working groups, reviews drafts and approves reports for publication.

For more information about EASAC and for copies of all our previous publications, please visit our website www.easac.eu.

EASAC, the European Academies' Science Advisory Council, consists of representatives of the following European national academies and academic bodies who have issued this statement:

Academia Europaea
All European Academies (ALLEA)
The Austrian Academy of Sciences
The Royal Academies for Science and the Arts of Belgium
The Bulgarian Academy of Sciences
The Croatian Academy of Sciences and Arts
The Academy of Sciences of the Czech Republic
The Royal Danish Academy of Sciences and Letters
The Estonian Academy of Sciences
The Council of Finnish Academies
The Académie des sciences
The German National Academy of Sciences Leopoldina
The Academy of Athens
The Hungarian Academy of Sciences
The Royal Irish Academy
The Accademia Nazionale dei Lincei
The Latvian Academy of Sciences
The Lithuanian Academy of Sciences
The Royal Netherlands Academy of Arts and Sciences
The Polish Academy of Sciences
The Academy of Sciences of Lisbon
The Romanian Academy
The Slovakian Academy of Sciences
The Slovenian Academy of Arts and Science
The Spanish Royal Academy of Sciences
The Royal Swedish Academy of Sciences
The Royal Society

The Norwegian Academy of Science and Letters
The Swiss Academies of Arts and Sciences

The affiliated network for Europe of
iap
the global network of science academies

EASAC Secretariat
Deutsche Akademie der Naturforscher Leopoldina
German National Academy of Sciences
Jägerberg 1, 06108 Halle (Saale), Germany
Tel: +49 (0)345 4723 9833; fax: +49 (0)345 4723 9839
Email: secretariat@easac.eu

EASAC Brussels Office
Royal Academies for Science and the Arts of Belgium (RASAB)
Hertogsstraat 1 Rue Ducale, 1000 Brussels, Belgium
Tel: +32 (2) 550 23 32; fax: +32 (2) 550 23 78
Email: brusselsoffice@easac.eu
web: www.easac.eu

Printed on 100% recycled paper.