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ENVIRONMENTAL AND HEALTH IMPACTS OF HYDRAULIC FRACTURING

Abstract: Oil and gas shales have become important components of energy production, particularly shale gas, which rose from almost nothing in an early century to nearly 30% of natural gas production. As a result, world natural gas production is expected to increase by 43% from 2015 to 2040, mainly due to a sharp increase in gas production. With technological advances in progress, development of shale resources could be facilitated in many countries such as Algeria and Mexico, supplementing the production of the first four producing countries (Argentina, Canada, China, and USA) which already commercialize gas shale. By 2040, production should account not less than 70% of the total shale offer. Although the emergence of gas and oil shale has changed the landscape of energy supply and security opportunities, difficulties have arisen, such as evaluating the actual amount of world reserves of shale hydrocarbons and its peak which could be already exceeded and for how long this could last. In addition, the fear of possible severe environmental impacts has led some countries to not engage despite their large shale resources, because these impacts are often associated with hydraulic fracturing or "fracking" itself and for which evidence is increasingly denounced in places where the intense hydraulic fracturing and lack of regulation coexist. Indeed, the growing concern is how hydraulic fracturing affects public health, as it involves handling large volumes of fluid containing a variety of physical and chemical constituents, each for a specific purpose, which are injected under high pressure through wells in subsoil to release hydrocarbons from shale formations; ground and surface water pollution, degradation of local air quality, greenhouse gas (GHG) emissions, induced seismicity, etc. For these reasons, hydraulic fracturing is subject to international scrutiny with some countries defending it and the other preferring to focus on regulation than outright banning. These issues are discussed in this paper after a state of resources and an overview of the global geopolitical situation.

Key word: *Hydraulic fracturing; Fracking; • Hydrofracking; Water contamination; Environmental impact; health impact; fracturing fluid*

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I. INTRODUCTION

Among the key issues on the international agenda for sustainable development, energy future should remain as it is for the years to come in the light of the recently adopted Agenda for Sustainable Development 2030, especially for the Goal 7, which aims to ensure affordable, reliable, sustainable and modern energy for all by 2030. In addition, the recent Paris1[1] agreement under the United Nations Framework Convention on Climate Change had stiffened international mobilization to address the effects of climate change at a time when governments reaffirmed their intention to ensure access to energy for all by 2030. The combination of these international instruments raises the need to decide what strategy to adopt with regard to the issue of unconventional sources of energy [1].

In fact, even if judicious regulation and strategic use of unconventional energy sources such a shale gas within an energy mix can help bring down greenhouse gases emissions(GHG), uncontrolled development of this energy type is incompatible with climate change mitigation aspirations at the global scale [2]. Indeed, a 2°C Scenario (2DS)[2] global average warming threshold was agreed upon in the UNFCCC ‘s Copenhagen Accord of 2009 and while contested, it is the policy guideline for more than 100 countries. The IEA suggests that if we have to achieve the 2°C Warming Scenario at global scale, we would need to accelerate in the short term a natural gas baseload, generating capacity to replace coal, then reverse this trend and stat use the gas increasingly as we move to an energy system, where the baseload is dominated by nuclear and intermittent renewables and fossil fuels with carbon capture and storage (CCS) [3].

Although in 2016 more than 85% of global energy demand was met by fossil fuel use; natural gas ranked third with about 24% of the total, behind oil 33% and gasoline 28%, resource in depletion for the majority of producing countries, they should remain the main source of energy by 2040 [2], [3]

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[1] Convention-cadre des Nations Unies sur les changements climatiques. (2015). Historic Paris agreement on climate change: UN set path to keep temperature rise well below 2°C. http://newsroom.unfccc.int/unfccc-newsroom/finalecop21/.

[2] 2°C Scenario (2DS) is the focus of ETP 2012. The 2DS describes an energy system consistent with an emissions trajectory that recent climate science research indicates would give an 80% chance of limiting average global temperature increase to 2°C. It sets the target of cutting energy-related CO_2 emissions by more than half in 2050 (compared with 2009) and ensuring that they continue to fall thereafter. Importantly, the 2DS acknowledges that transforming the energy sector is vital, but not the unique solution: the goal can only be achieved provided that CO_2 and GHG emissions in non-energy sectors are also reduced. The 2DS is broadly consistent with the World Energy Outlook 450 Scenario through 2035.

within a diversified and more environmentally-friendly energy mix. According to current IEA policy scenarios, the share of these energies in the global energy mix is expected to be between 16.1% and 19.3% in 2040 and could reach 31% in the most optimistic scenario. However, even in this scenario, a longer period and higher levels of investment are needed for renewable energy to reach the current share of hydrocarbons in the global energy mix. By 2040, it is expected that the share of fossil fuel investments to reach 60% of total investment in energy supply projects compared to about 70% in the last 15 years, [3], [4]. In some cases, this transition away from baseload generation will need to occur before the natural lifespan of physical infrastructures (natural gas plants have more than a 25-year lifespan); under the 2°C scenario, the energy system as a whole would reach an average carbon intensity lower than the average of natural gas by 2025, at which time it will be a high carbon fuel relative to the desired average [3]. Even under the less ambitious 4°C Scenario (4DS),[3] gas will be considered high carbon by 2040, and the baseload gas must ultimately be curbed in favor of peaking power [3].

This unprecedented global change brings risks and proportionate opportunities for mitigating climate change [2]. Critics note that in developing unconventional sources, we risk creating more fossil fuel infrastructures to maintain the supply of fossil fuels to a better return on energy investment and affect sensitive ecosystems that are already affected by climate change. However, the IEA, among others, suggests that shale gas could form part of a medium-term transition to clean energy sources by creating a cost competitive and lower carbon alternative to coal, the most carbon-intensive, abundant, and inexpensive of fossil fuels [5]. But shale gas development via high volume slickwater, horizontal hydraulic fracturing has recently emerged as a major controversial issue that permeates every day conversations globally [6]. Notable legislation governing this type of energy extraction has been promulgated in several countries; some European member states, Canada, United States and Algeria, ... It is expected that China, Russia, South Africa, Argentina, Algeria, Australia and other countries with extensive shale resources are considering large-scale development [7]. In the United States, natural gas

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[3]]4°C Scenario (4DS) takes into account recent pledges made by countries to limit emissions and step up efforts to improve energy efficiency. It serves as the primary benchmark in ETP 2012 when comparisons are made between scenarios. Projecting a long-term temperature rise of 4°C, the 4DS is broadly consistent with the World Energy Outlook New Policies Scenario through 2035 (IEA, 2011). In many respects, this is already an ambitious scenario that requires significant changes in policy and technologies. Moreover, capping the temperature increase at 4°C requires significant additional cuts in emissions in the period after 2050.

from shale formations could rise from 23% to 49% in 2035, due to substantial shale gas technology advances since 2007 and recent authorization to construct additional liquefied natural gas export capacity, which has led the United States to become a net exporter since 2017 [8]. These progresses could also offer interesting opportunities to improve national energy options and provide additional resources for many countries to increase their energy resources [9], [10], [11]. However, the use of hydrofracking technique continues to attract much controversy and media attention because of the potential economic benefits and risks associated with its use [12], [13], [14]. In Canada, hydraulic fracturing (HF) has been used primarily in the western provinces, while moratoria have been put in place in many eastern provinces. Despite this, there has been little social science research on how Canadians perceive the problem or the social impacts associated with its use, and even for other countries with the same type of resources. The share of unconventional gas in total gas output is projected to increase from 14% in 2012 to 32% in 2035 [15]. This development brings about promising economic perspectives—not only for the U. S, where a reference case of the U. S. (EIA) projects a growth for shale gas of 2.6% per year until 2040 [16]—but also in 41 other countries on different continents where shale gas has been found to reside in a total of 137 formations [7]. At the same time, opposition from homeowners and environmental interest groups is increasing. Reports of spills, accidents and potential harmful effects of chemicals released as a result of HF have emerged [17], [93], [19], [20]. Uncertainty about the potential impacts of HF have led to moratoria (Quebec, New Brunswick) or bans (Bulgaria, France, Tunisia, N. Y State, Vermont and recently the Maryland) [21] [22].

However, recent improvements in hydraulic fracturing (HF) and horizontal drilling have changed that view, drilling is now done kilometers underground and to horizontal distances of 2 km or more, fracking shale, sandstone, and other formations as narrow as 30 meters thick [23]. "After horizontal drilling, the well is hydraulically fractured with mixture (water, proppants such as sand, and chemicals), pumped underground at appropriate pressures to crack impermeable rock formations (10,000–20,000 psi)". The induced fractures by high-pressure, high volume hydraulic fracturing provide the required permeability to allow gas and oil to flow from the formation to the well and then up through the well to the surface. "In addition to outstanding questions related to the magnitude of any potential benefits of shale gas (or otherwise), the drilling and hydraulic fracturing technologies required, bring a number of" negative environmental impacts and risks [24]. In fact, unconventional oil and gas extraction is associated with a range of interrelated impacts, where possible adverse environmental effects include those on the quality and quantity of surface and groundwater resources, [25], [26], [27], [28], [29], [30] increased seismicity associated with wastewater injection into deep wells as well as fracturing operations [32]. The impacts on air quality can result from fugitive emissions and flares [35], [36], while extraction can also cause fragmentation of landscape and biodiversity [35]. The negative socio-economic impacts resulting from the extraction of UOGs may include: disruption of social cohesion, competition for water between oil and gas companies and existing legal users, potential risks to health, higher population density in ecologically sensitive areas, where water is scarce [35].

The concerns still growing about its health and environmental implications, whether due to the fracturing itself and its impacts or other aspects such as the natural gas shale-drilling lifecycle. Indeed, hydraulic fracturing companies inject into the ground solutions containing hundreds of chemical components, some of them are known carcinogens and other still unknown, because manufacturers consider their composition to be proprietary information or a trade secret. Some questions arise and merit to be investigated: What are the effects of injecting these chemicals into the earth? Are local aquifers endangered and drinking supplies? What is to be done with the astonishing amounts of polluted water and mud that result, requiring treatment and/or storage? The intense consumption of water resources is another big concern, especially in the arid regions. Clearly, the potential environmental benefits (reduction of GHG for example) (or not) from the development of shale gas are also associated with a number of environmental risks and costs that need to be addressed in a complex risk-cost-profit equation framework. In addition to the direct costs, risks and (potential) benefits of shale gas development, it is also possible that the indirect costs come from investment in shale and its development as a “transition fuel”. Here, there is the potential for shale development to deflect attention and investment from the renewable energy solutions that are at the base of a low-carbon economy. These issues are discussed after a state of resources and an overview of the global geopolitical situation.

II. CURRENT SITUATION OF UNCONVENTIONAL SOURCES ENERGY

II.1 RESERVES AND PRODUCTION OF UNCONVENTIONAL SHALE GAS

In response to the progressive depletion of global fossil fuel reserves accessible and affordable, interest in unconventional sources of oil and gas, particularly shale gas, continues to grow. Although the existence of these resources has been known for a long time, their exploitation was profitable only at the beginning of the 2000s with the systematization of the combined use of horizontal drilling and hydraulic fracturing (HF), allowing a production in large quantities of shale gas contained in the source rock and scattered all over the world (Figure 1 and Table 1). However, commercial exploitation remains limited in the United States and Canada. [4]. The recoverable shale gas resources are estimated at about 214.5 trillion m3 and represents about 61 years of global consumption of natural gas, considering 2016 as a reference year. According to the given data, the top 10 countries with the highest potential of technically recoverable resources are China, Argentina, Algeria, United States, Canada, Mexico, Australia, South Africa, Russia and Brazil. Together, they make up three quarters of the world's technically recoverable resources [1], [36]. Shale gas has created an energy boom that is already transforming energy systems in North America, with cascading effects worldwide. Shale gas production is now expanding to the United Kingdom, Poland, Australia, Qatar, South Africa, and China. Globally, shale gas could be a significant contributor to growing global energy needs, with gas consumption expected to increase by 44% between 2010 and 2035 [36], [39].

The African continent ranks third, considering the six regions of the world on a par with Latin America and the Caribbean (Table 1) [4]. Asia and Oceania are at the top of the list with 28% of the world's resources. Follows North America with 23%. The European Union and Eastern Europe close the ranking with 6% each. The 69% of technically recoverable shale

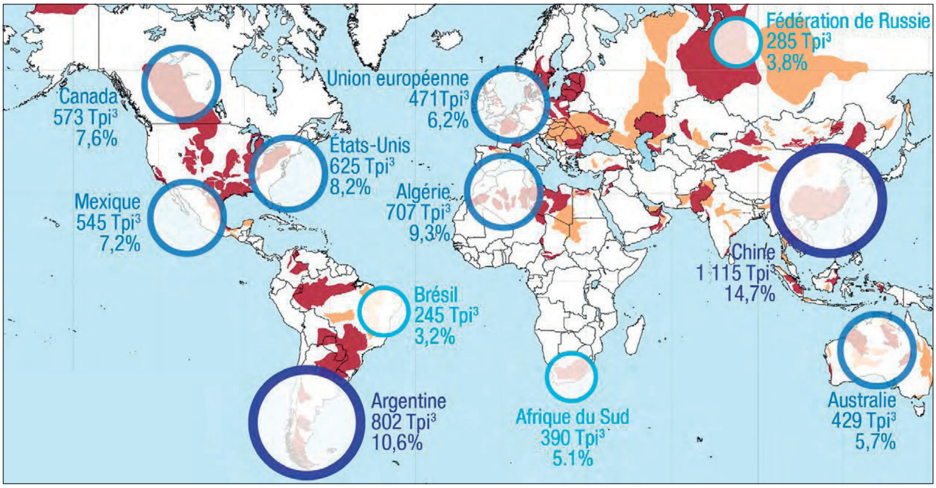

Figure 1: Source [4]. https: //www. eia. gov/analysis/studies/worldshalegas/. UNCTAD/SUC/2017/10 eISBN: 978–92–1-363266–6 ISSN: 2522–7866

Table 1: Regional distribution of technically recoverable resources (TRR) [4][2]

1 Asia and Oceania	2 North America
Share of world TRR: 28 % China and Australia, accounted for three quarters of TRR in the region.	Share of world TRR: 23 % Comment: The United States and Canada are commercial shale gas producing countries and respectively accounted for 36 and 33 % of regional TRR. Mexico represented 31 % of regional TRR, with nascent exploration activities.
3 Latin America and the Caribbean	4 Africa
Share of world TRR: 19 % Argentina is the main shale gas reservoir in the region, with 56 % of regional TRR, followed by Brazil (17 %) and the Bolivarian Republic of Venezuela (12 %).	Share of world TRR: 19 % 69 % of TRR in Africa, North Africa appears to hold the largest share of TRR on the continent. Algeria accounts for more than half of TRR in Africa. South Africa also holds large resources, with 28 %t of regional TRR. Countries in sub- Saharan Africa are almost excluded from the sample, with the exception of Chad, with 3.2 % of regional TRR.
5 European Union	6 Eastern Europe
Share of world TRR: 6 % France and Poland appear to hold most shares of regional TRR, with 30% each. Poland and the United Kingdom of Great Britain and Northern Ireland (5.5 %) have taken steps towards the future production of shale gas. France decided to ban hydraulic fracturing in July 2011 (law No. 2011–835).	Share of world TRR: 6 % The Russian Federation ranks first within the group, with a share of about two thirds of regional TRR, followed by Ukraine (29 %).

gas resources are located in North Africa with Algeria holding more than half of it. South Africa, meanwhile, has 28% of the continent's reserves, especially in the semi-desert region of Karoo [4], [31]. Hydraulic fracturing has had a huge impact on the history of energy in America, especially in recent times. The ability to produce more oil and natural gas from older wells and to develop new production previously deemed impossible has made the process valuable for domestic energy production in the United States. Without hydraulic fracturing (or fracking) up to 80 % of unconventional production of formations such as gas shale would be virtually impossible [38].

II.2 TRANSFORMATION OF GLOBAL MARKETS AND MODELS OF SECURITY RELATIONSHIPS AND GEOPOLITICS.

In 2015, commercial production of shale gas was essentially limited to two countries, namely the United States and Canada, accounting for 87 and 13 % of world production, respectively. However, large projects have been implemented in other countries such as Argentina and China, while other countries have banned its directly or ban its main technique of production, hydraulic fracturing. The division of countries into groups favorable or unfavorable to the exploration and production of unconventional natural gas from shale gas deposits has been a major feature of this sector for a decade [1], [39].

The concerns about energy dependence on imported energy have shaped geopolitics since First World War [40]. In fact, the industrialized countries have pursued greater energy self-sufficiency (the ratio between the energy produced and the energy consumed). For instance, while the United States was an energy importer in the second half of the 20th century, since 2013, it has been world leader in natural gas production. By surpassing Russia as the world's largest gas producer, the United States has asserted itself globally through energy [39], [41]. To evaluate unconventional energy resources, scientists have started to explore lessons learned from conventional fluid (oil and gas) studies [43], including concerns related to oil wars [43] and the resource curse (economic and political results) on oil and gas exports for state returns [44]. However, unconventional resource development models differ from conventional energy, in part because they have been positioned as a fuel for a low-carbon economy (since natural gas burns less CO_2 than coal and oil). But this development alone has reverberated around the world, causing changes in the trade patterns and management of other countries in Europe and Asia to explore their own shale gas potential. These changes put pressure on long-standing agreements, such as oil-related gas deals and the separation of the North American, European and Asian gas markets, and may result in strategic changes such as the weakening of Russian European gas market. The geopolitical impacts on shale boom seem to be complex and is amplified by other policy shifts such as sanctions and protectionist trade policies et. [39]. The pursuit for non-conventional energy resources is motivated by the increasing demand for oil and natural gas from fast-growing economies like China and India, as well as the geopolitical security objectives of Northern Countries These emerging players are changing production and consumption patterns and encouraging national exploration and production. However, some countries face significant domestic challenges, most recently the balancing of theirs budgets in light of relatively low oil and gas prices like in Algeria [45]. In addition, developing unconventional energy resources is a challenging attempt, as seen in countries as varied as Argentina, China and Poland, [46]. Although there is currently little reason to believe that a similar boom in the United States can be replicated elsewhere, it is clear that many countries will opt for hydraulic fracturing extraction of unconventional fluid.

In Africa, unconventional resources have been identified as a major future source of growth in energy production. In fact, shale gas in the Karoo Basin in southern Africa and coal bed methane in source rocks in Algeria and Libya have been identified as having an under-explored potential [47]. "Other unconventional potential resources include oil sands in the Congo Basin and Madagascar, and coal bed methane across southern Africa, particularly in Botswana and South Africa, but also" in Zimbabwe, Namibia and Mozambique [47]. However, market forces, particularly the uncertainty of the price of oil, have delayed their development. In addition, political volatility and domestic pressures shape resource extraction activities. For some countries, analytical frameworks familiar with conventional oil and gas resources seem to be suitable, Algeria, for example, has decades of heavy reliance on conventional oil and gas exports to finance its national budget, which motivates his search for unconventional resources. [45]. The predictions are significant, given the country's vast estimated resources [45], but are uncertain in light of the post-2014 price environment, security risks, infrastructure gaps, local protests, and questions about corporate partnerships with the national oil company Sonatrach [48]. The source curse literature aids lighten the connection of hydrocarbon development, resource returns distribution, and dissatisfaction with popular exclusion from government decision-making. However, for some countries, unconventional resources need particular analysis. Perhaps reflecting the limited development of these potential resources, there is little Social Science literature on African unconventional oil and gas, with the most extensive work focused on hydraulic fracturation (HF) is in South Africa. The later offers a case where the discourses on clean energy and environmental safety are important, with controversy over plans for the Medupi power plant, which would be the seventh largest coal-fired plant in the world [49]. The impulse to explore shale gas was engendered in part by the government's concerns regarding energy supply, [50], [51]. The need for climate solutions and new local energy supplies are and will be particularly important for Southern Countries for the coming years. In fact, debates about whether or not to develop unconventional resources remain politically and socially thorny. Developments in unconventional energy across Africa echo a general wave in Southern Countries, where continued investments in fossil fuels perpetuates [52] the "Petro-market civilization"; However, the challenge of reducing energy poverty requires the expansion of local access. In fact, in areas where hundreds of millions of people do not have reliable access to basic amounts of energy, governments have made it clear that they will not compromise development for other purposes [51].

III. HYDRAULIC FRACTURATION (OR FRACKING)

The flexibility and importance of hydraulic fracturing is easily shown in the range of its applications, is applied in the estimation of in- situ stress [38], [54], the exploitation of geothermal energy, enhanced oil and gas recovery (EOR) operations, enhanced coal bed methane (ECBM) operations, shale gas production and the control of the structure and deformation of rock roof during coal mining [69]. Hydraulic fracturing is not new. "The first commercial application of the hydraulic fracturation as a well treatment technology designed to stimulate the production of oil or gas probably occurred in either the "Hugoton field of Kansas in 1946 or near Duncan Oklahoma in 1949" [38]. In the last decades, the use of hydraulic fracturing has developed into a repetitive technology that is frequently used in the completion of gas wells, particularly those involved in what's called "unconventional production," such as production from so-called "tight shale" reservoirs. The process [56] has been used on over 1 million producing wells. As the technology remains to progress and advance, operators now fracture as many as 35,000 wells of all types each year.

III.1 HYDROCARBONS RESULTING FROM SHALE AND OTHER TIGHT GAS DRILLINGS

Shale gas zones are generally divided into "dry" and "wet" gas [56], depending on the hydrocarbon content. Dry gas is almost totally methane with relatively little higher molecular weight product. Wet gas is also predominantly methane but contains a larger percentage of higher molecular weight compounds (crude oil or condensate), including benzene, toluene, ethylbenzene and xylene (BTEX). Under current market conditions, wet gas is more valuable as it provides raw materials for plastics and other products of the chemical industry. Methane itself is relatively non-toxic to humans and ecosystems, but it is flammable and explosive. It is also a major contributor to global climate change. Of the higher molecular weight wet gas components, benzene is of particular concern because it is a known cause of human leukemia (carcinogen group A) and may be a contaminant of air and water [56] and xylene is a central nervous system depressant.

III.2 WHAT IS HYDRAULIC FRACTURING TECHNIQUE?

Hydraulic fracturing is a technique used to enable or improve hydrocarbon production from underground rock formations, increasing the volumes of fluids that can be recovered. Wells can be drilled vertically between hundreds and thousands of feet below the earth's surface and can include horizontal or directional sections also extending over thousands of feet [57]. It involves the injection of hydraulic fracturing fluids, typically a mixture of water, proppant (sand, ceramic granules or other small incompressible particles) and chemical additives under sufficiently high pressures to fracture the targeted hydrocarbon formations [58], [59]. After the injection pressure is released, fluids flow through the well fractures, leaving behind proppants that keep open the newly-created fractures. So, these fractures allow oil and gas to flow from the formation's pores to the production well. After the pressure applied during hydraulic fracturing is released, fluid flows back from the well, the initial fluid that returns to the surface is often named "flowback" and "produced water".

Fluid that flows from the well with oil and gas during the production step is often referred to as "produced water." The volume and chemical composition of fluids [60] that return to the surface after the rock is fractured can vary widely. Between 10 and 70 % of injected fluid comes back-up the well as flowback [61], [62]. General compositions and on-site volumes of flowback fluids vary among targeted formation types [66]and within formations of the same type [64]. Flowback fluids are, but not always, characterized as very briny [65] and often contain metals, major anions and cations, and naturally occurring radionuclides [66], [67]. Flowback fluids may also contain organic chemicals from injected fluids, formation waters, and formation solids [68], [69], [60]. Hydraulic fracturing is performed at depths between 5,000 and 10,000 feet and requires 2,500,000–4,200,000 gallons of water per well [70]. Fracturing operations inject highly pressurized fluids, that is, between 2,000 and 12,000 psi, at an average flow rate of 2000 gpm [71]. The water is mixed with chemical additives (0.5–2.0% by vol.)) to increase water flow and improve deposition efficiency. Nearly 1,000 chemicals are known to be used in the HF process [71].

III.3 THE MATERIALS USED IN HYDRAULIC FRACTURING SHALE

The most commonly used mixtures for fracturing shale [56] to produce gas are nearly 90% water and 9% proppant (typically sand) and the remainder consists of chemical additives comprising 0.5–2% by volume [72]. Chemical additives are used for a wide range of purposes including those classified as biocides, breakers, buffers, clay stabilizers, corrosion inhibitors, crosslinkers, foaming agents, friction reducers, gelling agents, iron control agents, pH adjusters, scale inhibitors, solvents, and surfactants [73]. Some chemicals are used for several purposes and not all purposes are disclosed for each chemical [74]. Not all chemical functions are needed for every fracturing operation and, although there are more than 1000 chemicals that have been used, only a limited number are routinely used. Depending upon state law and company practice, information about the hydraulic fracturing agents used in an individual well is often but not always obtainable. Then, the make-up of fracturing fluids, or "slickwater," varies from one geologic basin to another, but in general, it consists of about 99 % water and the remainder sand and chemical additives, some of which are potentially toxic if mishandled. The proper management and use of fracturing fluids is one key to environmental protection in regard to shale production, is enforced by laws and regulations, and is taken seriously by operators. Disclosure of fluid additives is an important issue which some states have addressed through legislation; FracFocus is an online registry for companies to disclose the chemicals they use in hydraulic fracturing. [38]

III.3.1 WATER AND CHEMICAL ADDITIVE REQUIREMENTS

The first use for the water is for the actual drilling of the well [24], a relatively small amount of water as compared to the rest of the fracturing process. The drilling process uses a water-based fluid called drilling mud. Drilling mud serves several functions, it acts as a lubricant and a coolant for the drill bit. It also suspends the drill cuttings and carries them to the surface as it circulates through the well. The mud also acts as a barrier along the bore walls until the casing is put in place [75]. All hydraulic fracturing operations require a carrier medium which must be of necessarily low friction to convey a high hydraulic pressure into the target formation so that fissures are generated. In the process it must further acquire sufficient viscosity to prevent loss of the base fluid into the formation, and to transport proppants to keep the fissures open. Then, it must become of sufficiently low viscosity to flow back so that the gas is released through the fissures and can be recovered at the surface. In addition, the well must not be plugged, and the well surface must be protected against corrosion during the operation. Each stage in a multi-stage fracturing operation requires around 1,100–2,200 m^3 of water, so that the entire multi-stage fracturing operation for a single well requires around 9,000–29,000 m^3 of water and, with chemical additives of up to 2% by volume, around 180–580 m^3 of chemical additives (or 180–580 tonnes based on relative density of one). Water and additives are blended on site and the blended fracturing solution is mixed with proppant and pumped into the wellbore.

III.3.2 FLOWBACK AND PRODUCED WATER (FLUID RETURN)

Following initial injection into the well to generate fractures, a portion of the injected water returns to the surface immediately and is termed "flowback" [24], [76]. The remaining fluids either permeate into the formation or return to the surface over the life of the producing well and are termed "produced water." Both types of wastewater may contain HF fluids, naturally occurring salts, radioactive materials, heavy metals, and other compounds from the formation such as polycyclic aromatic hydrocarbons, alkenes, alkanes, and other volatile and semivolatile organics [77–82]. The composition of both the flowback and produced waters varies due to the differences in the amounts and types of chemical additives used in the hydraulic. fracturing fluids, the location and the geological characteristics of sites the fluids are injected, as well as the chemical characteristics of the supplied water [85], [64].

III.3.3 CHEMICALS AND THEIRS FUNCTIONS IN THE HYDRAULIC FRACTURING

The most commonly used chemical additives are gelling agents, crosslinking agents, clay control agents, corrosion inhibitors, biocides, and the various impurities and stabilizers used in commercial mixtures [74] (Table 2). In addition to the common naturally occurring substances found in formations containing Oil and Gas |56] (Table 3), other additives such as hydrochloric and hydrofluoric acids used for acidification of the matrix and other purposes are rarely used [86], [87]. However, a large number and a mass of solvents and surfactants are used, including quaternary ammonium compounds and nonionic surfactants.

More and more data on HF chemicals used in the United States are disclosed by operators |61], [87], [88], but theirs reports are not necessarily complete (substances contributing less than 0.1% of chemicals not required to be declared). However, the information can be retrieved from FracFocus 2.0, in the US since 2011 [89]. Scientific contributions are beginning to exploit the information disclosed by operators and to analyze compounds to assess environmental and health impacts. This includes the review of HF chemicals such as; their lifespan {90], [92] and their environmental exposure [90], [92], [95], toxicity assessments [93], [94], reactivity studies in water treatment [95], [80] and the search for indicators of potential compounds, choice of adequate analytical method and the search for potential indicator compounds. [95], [96]. Some of them include in addition a ranking by disclosure, However, to understand the environmental chemistry of HF chemicals it is not the name or the function in the HF process that is most informative, instead, the *chemical structure* lends substances the characteristics that make them attractive as HF chemicals, and which determine the physicochemical properties that govern environmental behavior and the choice of adequate analytical methods [56]. In fact, since companies invest time and

Table 2: Fracturing Fluid Additives, theirs functions and main compounds [74]

Additive Type	Main Compound	Use in Hydraulic Fracturing Fluids	Common Use of Main Compound
Acid	Hydrochloric acid or muriatic acid	For the fracturing of shale formations, acids are used to clean cement from casing perforations and drilling mud clogging natural formation porosity, if any prior to fracturing fluid injection (dilute acids concentrations are typically about 15% acid)	Swimming pool chemical and cleaner
Biocide	Glutaraldehyde	Fracture fluids typically contain gels which are organic and can therefore provide a medium for bacterial growth. Bacteria can break down the gelling agent reducing its viscosity and ability to carry proppant. Biocides are added to the mixing tanks with the gelling agents to kill these bacteria.	Cold sterilant in health care industry
Breaker	Sodium Chloride	Chemicals that are typically introduced toward the later sequences of a frac job to “break down” the viscosity of the gelling agent to better release the proppant from the fluid as well as enhance the recovery or “flowback” of the fracturing fluid,	Sodium chloride is also used as a food preservative.
Corrosion inhibitor	N, n-dimethyl formamide	Used in fracture fluids that contain acids; inhibits the corrosion of steel tubing, well casings, tools, and tanks.	Used as a crystallization medium in Pharmaceutical Industry
Crosslinker	Borate Salts	There are two basic types of gels that are used in fracturing fluids; linear and cross-linked gels. Cross-linked gels have the advantage of higher viscosities that do not break down quickly.	Non-CCA wood preservatives and fungicides
Friction Reducer	Petroleum distillate or Mineral oil	Minimizes friction allowing fracture fluids to be injected at optimum rates and pressures	Cosmetics including hair, make-up, nail and skin products
Gel	Guar gum or hydroxyethyl cellulose	Gels are used in fracturing fluids to increase fluid viscosity allowing it to carry more proppant than a straight water solution. In general, gelling agents are biodegradable.	Guar gum is a food-grade product used to increase the viscosity and elasticity of foods such as ice cream etc.

Table 3: Common Naturally Occurring Substances Found in Formations Containing Oil and Gas [56]

Type of contaminant	Examples
Inorganics	(or common ions) Brine (e. g, sodium chloride, bromide)
Gases	Natural gas (e. g, methane, ethane), carbon dioxide, hydrogen sulfide, nitrogen, and helium
Trace elements Mercury, lead, and arsenic	Mercury, lead, and arsenic
Naturally occurring radioactive material (NORM)	Radium, thorium, and uranium

resources into perfecting their fracking fluids, industry views chemical recipes as proprietary information that should be protected as trade secrets; thus, many of the chemicals used remain unknown.

IV. POTENTIAL HEALTH AND ENVIRONMENTAL HAZARDS FROM SHALE GAS FRACTURING

The key risks and impacts [24], [97], [98] shale gas processes and development can be divided as follows: related

a) Contamination of groundwater by fracturing fluids/mobilized contaminants arising from: wellbore/casing, failure; and/or subsurface migration;
b) Pollution of land and surface water (and potentially groundwater via surface route) arising from: spillage of fracturing additives; and spillage/tank rupture/storm water overflow from liquid waste storage, lagoons/pits containing cuttings/drilling mud or flowback water;
c) Water consumption/abstraction; waste water treatment; land and landscape impacts; impacts arising during construction: noise/light pollution during well drilling/completion; flaring/venting; and local traffic impacts;
d) Air pollution resulting from the release of volatile organic compounds, hazardous air pollutants, and greenhouse gases.

IV.1 ENVIRONMENTAL CONSIDERATIONS AND HUMAN HEALTH

Potential health risks in the current literature describe the links between sources of pollutants and health effects through emissions, pollutant concentrations, routes of exposure to pollutants (mouth, nose, ears, eyes, skin) and doses ingested daily [99], [100]. These potential sources of environmental pollution are present in many phases of shale oil and gas development and include: production and processing activities (drilling, hydraulic fracturing, hydrocarbon processing and production, and sewage disposal); transportation and distribution to the market (transport lines and distribution pipes); and the transportation of water, sand, chemicals and wastewater before, during and after hydraulic fracturing.

In fact, the use of many poorly characterized chemicals continues to raise public concern about their impacts on the environment and human health [85]; Some chemicals of concern based on occurrence of use, quantities used, and toxicological properties were identified. Indeed, for biocides, corrosion inhibitors and Quaternary ammonium compounds (CAQs), chemicals of concern deserve to be studied in more detail and more regulated than other chemicals because of their toxicity, particularly in the context of water treatment and reuse101]. The corrosion inhibitors, are known to have poor environmental profiles [102], [131]. CAQs as a class should be investigated further because of their widespread and recurrent use, potential aquatic toxicity and low characterization for transport and environmental persistence properties. Many other chemical additives used are nitrogen compounds (CAQ, amines, amides, ammonium salts, etc.), 24% of the compounds reported contain nitrogen. The prevalence of nitrogen compounds suggests that at high levels, it may be present in environmental waters that are affected by hydraulic fracturing waste streams. The question is whether the chemicals injected during the stimulation of the well return to the surface with water produced, if they are bound to the subsoil or if they are degraded [106}; Since techniques for analyzing these chemicals in water are still under development [107], [108], [98], there is very little information on the presence of chemicals or their degradation products in fluids returning to the surface. Most studies examining organic chemicals in water produced from hydraulically fractured wells found naturally occurring hydrocarbons in oil and gas formations [104], [105], [106], [95] and some studies have found ethoxylated surfactants or their residues [95] [109].

Hydraulic fracturing components may pose a threat to public health and the environment as some are known to be acutely toxic, some are carcinogenic, and others are believed to be endocrine-disruptors. Other chemicals remain proprietary information, whose effects on public health and the environment are unavailable. Understanding the fate of these materials in the subsoil and in the produced water is essential to understand the environmental impact of the use of chemicals during oil and gas development.

IV.2 EXPOSURE TO HYDRAULIC FRACTURING FLUIDS AND THEIR IMPACTS

IV.2.1 POLLUTION IMPACTS

Particular concern surrounds the chemicals that may return to the surface as a result of hydraulic fracturing. Both "fracking chemicals"—substances together with the HF fluid to optimize the fracturing performance—and geogenic substances are of relevance [24]. These compounds can emerge in the flowback, in the produced water or in a mixture of both [110], [111], [66]. The concentrations of additives typically make up between 0.5% and 3% of an injected gel-based fluid [62], [92] [112]. Given that a typical fracturing operation requires a huge amount of water, this translates into kilograms to tens of tons of the respective compounds. In 2005, underground injections of these substances for HF operations related to oil and gas were exempted from all U. S. federal regulations aiming to protect the environment;[4] in Germany, HF operations have been regulated by the Federal Law of Mining which currently does not require Environmental Impact Assessments including public disclosure of these chemicals [114].

The knowledge of fracturing chemicals and geogenic substance, is necessary for several reasons [115]: Concerns have been raised about potential human health and environmental impacts associated with surface spills of fluids managed on oil and gas production well pads [162], [163]. In particular, spilled fluids associated with hydraulic fracturing may flow into nearby surface waters or infiltrate into ground water and alter water quality [91], [116]. Various cases are cited in the literature, including the distress and death of Blackside Dace fish in Kentucky [120] at lowering of the pH and increasing the conductivity of the current stream, where fracturing fluid has been spilled. Additionally, data from post-spill sampling reports in Colorado, [118], show the presence of benzene, toluene, ethylbenzene and xylene in groundwater samples, which were attributes to numerous hydraulic fracturing-related spills.

Because of the differences and the potential for the chemical additives to be toxic or contribute to the formation of toxic byproducts, a careful and systematic investigation of the chemicals is necessary for processing and managing the hydraulic fracturing fluids to avoid ecological damage [91]. Severe toxicity has been assessed and many low-risk chemicals for mammals have been identified as potentially hazardous to aquatic environments. Based on

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[4] (Clean Water Act, Save Drinking Water Act, Clean Air Act, Super Fund Law, Resource Recovery and Conservation Act, Toxic Release Inventory)

an analysis of the quantities used, the toxicity and the lack of an adequate risk assessment, ACQs, biocides and corrosion inhibitors have been identified as priority chemicals of concern that merit further depth study [119].

Another concern, is the effects of petroleum hydrocarbons on intrinsic microbes and microbial diversity. Generally, microbes possess a cellular metabolic mechanism to use petroleum hydrocarbons (PH) as source of carbon and energy. In addition, they hold various cellular, physiological and biochemical adaptations under the presence of PH. In fact, microbe exposed to hydrocarbons adapts their genetic mechanisms such that the gene(s) involved in the metabolism of PH are amplified. The impact of this adaptation on the exposure and biodegradation of PH and microbial behavior and physiological responses to PH are less explored [26].

IV.2.2 HEALTH EFFECTS

Several studies have identified health impacts associated with unconventional oil and gas development, such as a high incidence of premature births near oil and gas development, but these studies face data and measurement challenges. Some health impacts, such as cancers, are difficult to study because they have long latency periods, which means that the impacts may not be known for many years [132]. Many of them, look at the potential for health effects or human exposure, through a qualitative analysis that identifies and characterizes the chemicals used in the production process fracturing or air pollutants associated with certain operations. In addition, some surveys sample air or water and deduce the potential for health impacts by characterizing chemicals and reported pollutants. Other studies of public perceptions of the health effects of unconventional oil and gas development may be indicative of community concerns that other research and policy should address. Such studies are beneficial in that they are able to generate hypotheses and guide future research, but they do not measure actual emissions, chemical levels, exposure, or health effects.

V. CONCLUSION

The process is very controversial because of some issues as: [136], {137], [138]

— Contamination of Water Resources — Of the 20,000 m3 of water that can be pumped into a fracturing well, about 15% escapes from the well and can cause a spill if not handled properly. If drilling is not strong enough, the fracturing fluid can be injected into the aquifer and contaminate the water resources. This can be particularly the case when the well has poor structural integrity. Then these issues include the climate impacts of methane leaks during fracking operations and of CO_2 released when methane is combusted are still relatively unknown, as well as the risks of contamination and depletion of water resources.

— Methane Emissions — Methane is more powerful than carbon dioxide and has great potential to escape to the atmosphere during fracking. This damaging greenhouse gas has been detected in groundwater reserves near extraction wells. These gases can degrade the quality of the local air.

— Induced Seismicity — Several studies have linked destructive seismic activity — earthquakes — to the subsurface stresses induced by fracking in the vicinity of ground faults.

— Water Consumption — A considerable amount of freshwater is used for fracking a single well.

Then these issues include the climate impacts of methane leaks during fracking operations and of CO_2 released when methane is combusted are still relatively unknown, as well as the risks of contamination and depletion of water resources.

Given the potential for accidental human exposure due to spills, industrial accidents, improper wastewater treatment and handling, and potential seepage, it is important to understand the known and potential hazards posed by the diversity of chemicals used during hydraulic fracturing. The identification of inherent chemical properties will facilitate the development of models to predict environmental fate, transport, and the toxicological properties of chemicals. Through this level of understanding, scientists can design or identify more sustainable alternative chemicals that diminish or even avoid many fate, transport, and toxicity issues, while maintaining or improving commercial use. To understand exposure pathways in order to predict the effects on humans and the ecosystem, all activities, including the trucking of materials to and from the site, must be assessed. site and disposal of produced water. Exposure assessments should be coupled with toxicological studies of potential impacts using recognized toxicological methodologies as well as new approaches to computational modeling. Special attention should be given to mixtures of agents for which exposure is identified or likely.

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