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Artikel: The global impact of unconventional hydrocarbons (hydraulic fracturing on the way to a clean and safe technology) : AAPG annual convention Houston, April 2014 : selected highlights

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The Global Impact of Unconventional Hydrocarbons (Hydraulic Fracturing on the way to a clean and safe technology). AAPG Annual Convention Houston, April 2014 – Selected highlights

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Comments and additions by the author in italics.

Key words: AAPG, natural gas, unconventional gas, unconventional oil, hydraulic fracturing, fracking, global energy, climate, CO_2, coal, US energy, gas reserves, peak oil, peak gas

1 General impressions and highlights

The convention: *The convention was held in Houston, the centre of the US oil and gas industry and drew, with over 8.000 attendees almost twice the crowd of the Pittsburgh meeting last year.*
The focus of the talks has been very much on domestic business: never in the past years have there been so few contributions by US companies on plays outside America. There were many very specialized technical talks (many by Chinese scientists) but disappointingly few overviews of large new international plays. Especially the independents are retreating to domestic activities. The other general observation is the still increasing importance of unconventional exploration and development, a topic that had an absolutely dominant role at this year's conference.

US E&P Industry: *Amongst US companies the move «back home» to the US onshore is still on-going. This may also be a matter of funding: unconventional domestic activities have attracted a very large part of the worldwide E&P investment and fewer companies can afford to dance on too many shows. In addition, banks and private capital are still reluctant to invest in exploration activities outside N-America. An additional reason may be the disappointment of many US companies with the progress of unconventional activities outside America, especially in Europe, even though high gas prices in Europe, and especially in Asia, are most attractive. US companies see Europe increasingly as a high-risk area with low legal security. This mood has been triggered by the moratoria on shale gas and the revoking of valid exploration licences (also in Switzerland) as well as short term changes in tax regimes and very slow and unpredictable approval processes.*
Gas in the US was in April 2014 valued around 4.0–4.5 \$/MCF, i.e. about half the prices in Europe and 3–4 times lower than in the Far East. Prices of 4–5 \$/MCF do allow breakeven production in most of the plays but the main profits are presently made on associated liquids. European Majors who had invested heavily in unconventional gas acreage in the US (e.g. BP, Shell, Statoil) have grown more cautious. Most of these companies have been latecomers to the game, have overpaid corporate acquisitions and acreage and often only managed to get second grade blocks. The most successful companies in the US unconventional business remain the smaller independents.
The low energy prices continue to have a strong positive effect on the US economy. Energy inten-

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sive industries and/or industries with a large demand for gas as a raw material are relocating back to the US. The US draws a major competitive advantage from the gas boom and the recovery of the US economy over the past years is at least partly driven by energy costs.

The Obama administration has called unconventional gas «America's answer to Fukushima». The switch to gas, mainly the substitution of coal in power generation, has led to a further decrease in CO_2 emissions in 2013 in strong contrast to Germany where CO_2 emissions are rising (Figs. 1, 2). Gas will also impact the transport sector: by 2030 over 10 million vehicles in the US, especially diesel trucks are expected to run on natural gas. This will have a major positive impact on the environment. In spite of not having signed the Kyoto Protocol the US may eventually be one of the few countries achieving the Kyoto target reductions (reducing greenhouse gases emissions until 2020 to 18% below 1990 levels).

Reserve and Production growth: *Gas reserves and oil reserves of the US continue to grow. The country added over 35 TCF in 2013 (production 24 TCF). Proven gas reserves are therefore about double of those 20 years ago. Oil reserves and -production grew even stronger. The country is approaching about 9 Mio BBL/D in total liquids production (including NGL) compared to 6.8 Mio BOPD in 2006 (Fig. 3).*

Energy self-sufficiency for the US is still a prominent topic. Though it is very questionable whether the US will reach self-sufficiency in oil, imports are steeply decreasing and the US do in principle not need any imports from the Middle East or N-Africa. The US will become a net exporter of gas in 2020 (Fig. 5).

Unconventional hydrocarbons

Unconventional oil in US: Unconventional oil exploration is today in the US as important as unconventional gas – and more profitable. Contrary to gas where the biggest plays have probably been identified, unconventional oil plays continue to emerge. The production of the Bakken oil shale in Montana has already changed the US energy landscape and has led to a situation where the domestic oil production now exceeds imports for the first time in 20 years (Fig. 3).

Unconventionals US: *There is a conspicuous move away from the «drilling the hell out of it» approach to a sweet spot exploration. The brainier part of the Industry has realized that 80% of the production came from only 20% of the wells and that many wells (possibly up to 50%) were not or only marginally commercial. The new approach gives much more weight to*

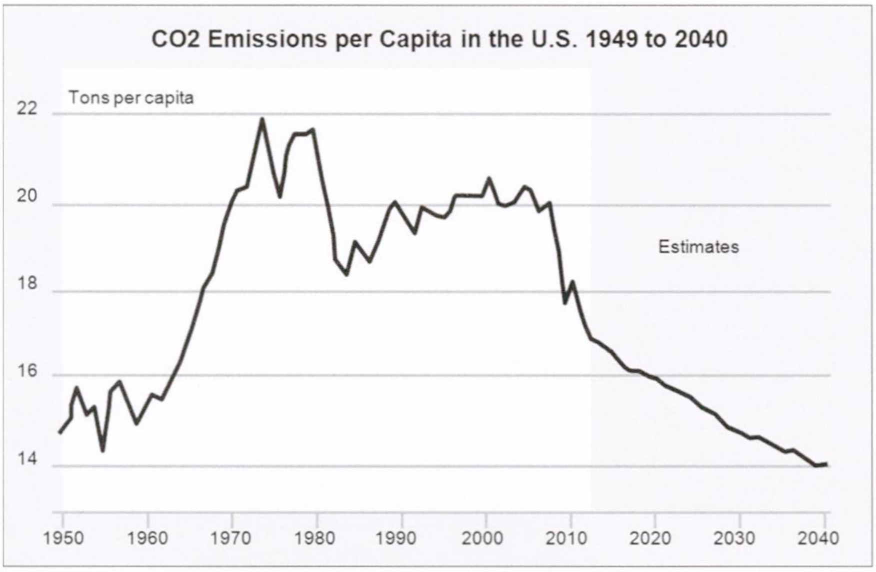

Fig. 1: CO_2 emissions in US per capita are at present back to levels of 1960s (contrary to Europe).

geological thinking, reservoir analysis, geochemistry and rock mechanics. Parallel to this, the drilling performance and well completion/stimulation technology are continuously improved. Thanks to these improvements one year drilling delivers today in the Marcellus 10 × more production than 6 years ago. Oil production in the Eagle Ford has risen 20 × in 5 years (see Fig. 4). The often heard statement that in general unconventional production per well is low, not sustainable and thus not commercial, is clearly incorrect. Production does drop steeply in the first year in most wells but it stabilizes thereafter and economic production can reach far over 10 years.

Unconventionals worldwide: *There is no doubt that the success of unconventionals will be repeated in many other parts of the world. There is, however, at present more caution in the forecasts as to how fast this will happen. Nowhere else are unconventional hydrocarbons tackled in the determined approach of the US and nowhere else will there be the same huge resources in money and technology dedicated to such exploration. In addition action by regulators in almost all countries and especially in Europe is slow and unpredictable. Unconventional gas and oil will be developed worldwide but it will most likely take decades rather than years.*

There are also some technical/geological concerns: e.g. China, seen after Argentina as probably the next major development area for unconventional gas, has geological settings that are very different from N-America. Most basins have a lacustrine source rock. Lacustrine shales are often rich source rocks but may provide lower quality shale gas plays since proximal intracratonic settings produce much more variable lithology and a more mineralogically immature clastic input. Lacustrine source rocks are also generally more shaly than marine ones and may thus be less brittle and less suited for hydraulic fracturing.

Environmental concerns *with hydraulic fracturing are still part of the public discussion, especially in the State of New York, the only state where a development of the Marcellus play is still banned, though interestingly New York is the biggest gas consumer of unconventional gas. In depth studies by the US Department of Environment show conclusively that the very large majority of water contamination by drilling fluids and gas is not related to hydraulic fracturing. Extensive water analyses in Pennsylvania identify methane as a very common constituent of drinking water from water wells (some 36% of wells in W Pennsylvania contain natural methane). Most methane stems from coal*

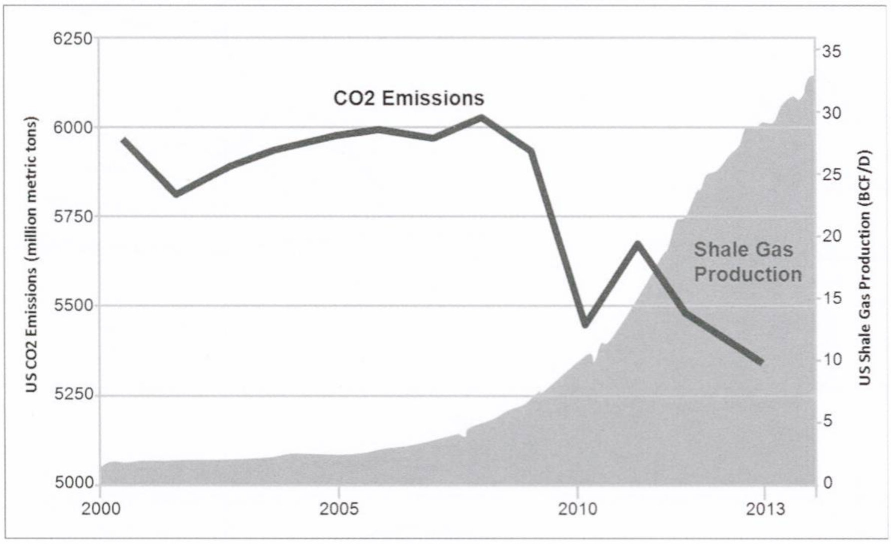

Fig. 2: US CO_2 emissions and shale gas production. Shale gas allows emission reductions that are not achieved in any other industrialized country. (Source US DOE).

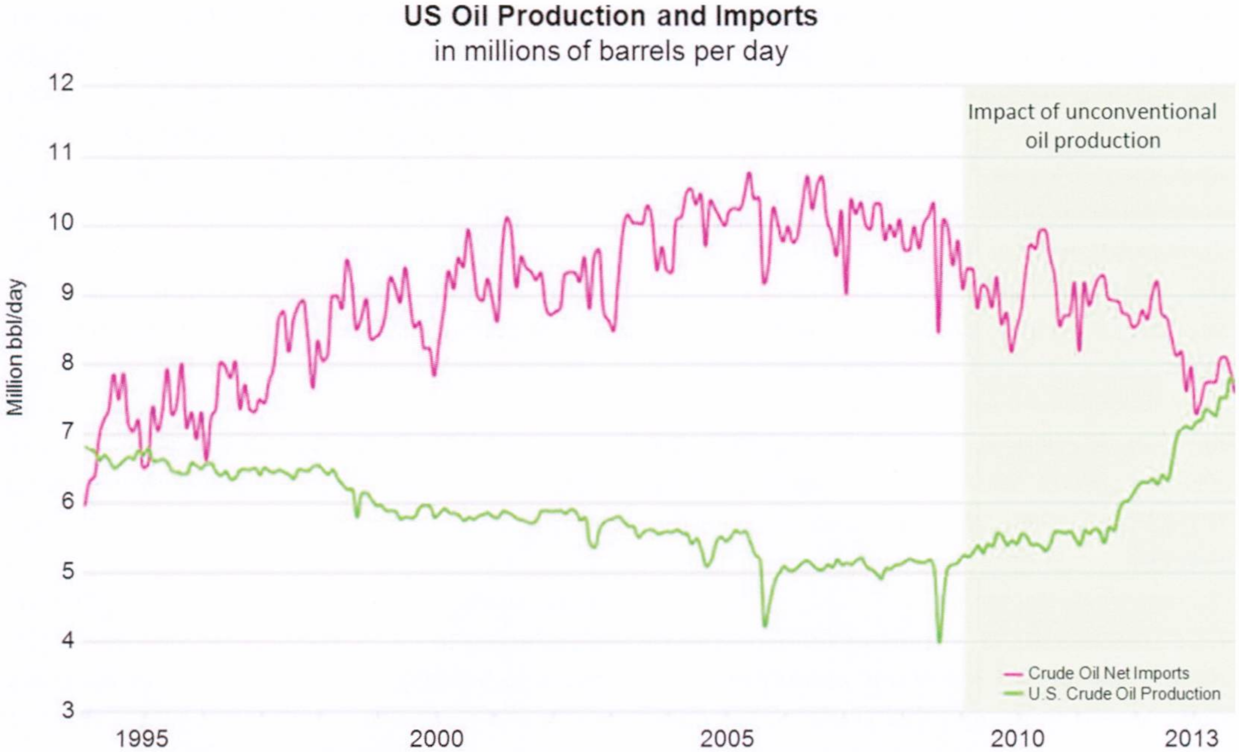

Fig. 3: US oil imports vs. exports 1994 to 2013 (source US DOE).

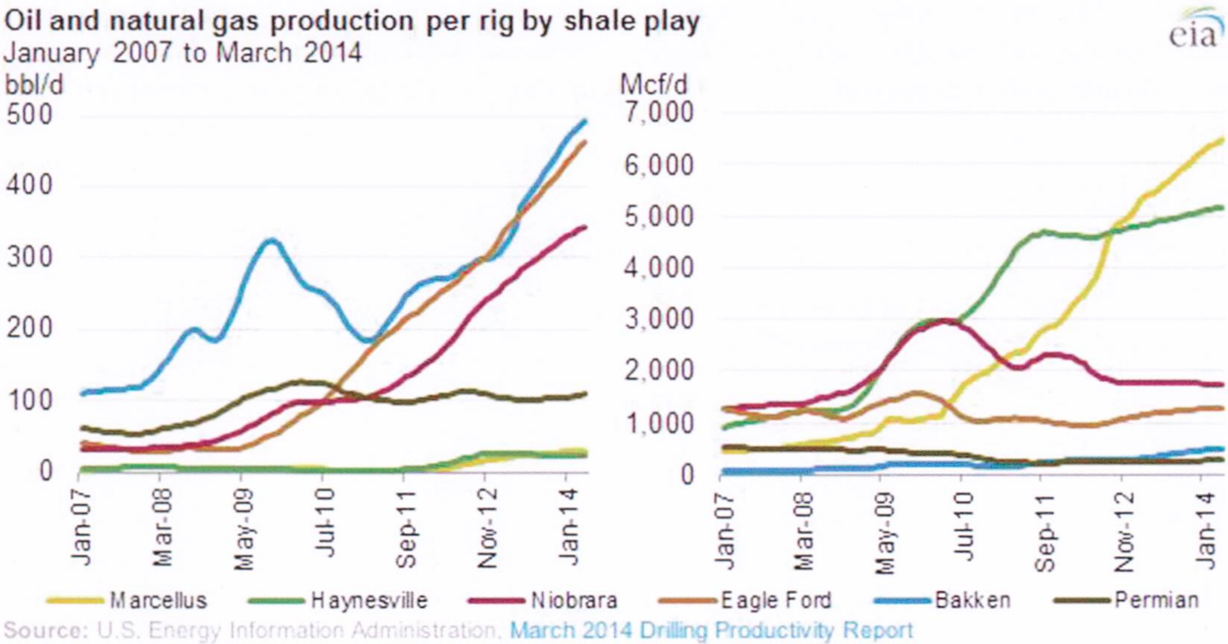

Fig. 4: Dramatically improved production per drilling rig (liquids left, gas right). The graph gives daily production added per rig active in the play. The growth reflects reduced drilling times as well as higher production per well as a result of sweet spot location and better completion/stimulation (Source US EIA).

seams, some rise naturally from deep thermally mature Marcellus Shale. There is still no case in North America where a direct contamination of groundwater, or the surface environment, by the actual fracturing has been proven, this in spite of several hundred thousand stimulations/fracks every year. Proven contaminations were caused by poor well integrity (e.g. poor cement jobs) or by poor handling of completion fluids in the surface installations. Contaminations can also stem from old historical wells that were not properly abandoned. Best practice operations are being developed by several operators in the Marcellus Shale; they allow operations without excessive water use (thanks to total recycling) and without the use of toxic additives. Cluster drilling has reduced the land use by a factor 20–30.

Large water use is always mentioned as a main criticism for hydraulic fracturing. In this context it is important to know that burning gas produces CO_2 and water, an average Marcellus well produces therefore over its lifetime 15 × more water than all the water needed for drilling and fracturing of this well. Biofuels, praised as renewables, use one order of magnitude more water than HC production.

The only major environmental problem remaining is the flaring or venting of gas in unconventional oil production. Very large volumes of gas are being flared in the Bakken Shale of North Dakota or in the Eagle Ford in Texas since gas-gathering nets are lacking and flaring is more cost effective. This is an enormous waste of energy (about 10 BCM/y) and has a negative environmental impact. Flaring and venting have been largely eliminated in most oil fields worldwide and there is no technical reason to flare in unconventional production. This harmful practice can only be stopped with clear guidelines and laws by the regulator.

Application of unconventional technologies to mature conventional plays: *Through the unconventional boom the previous advanced technologies, like horizontal drilling, multilaterals and multifracs have become very affordable routine tools. These technologies are increasingly applied to mature areas that were previously deemed to be in tail-end production. Prime example is the highly mature Permian Basin where oil production from old fields has been rising by over 30% since 2007 and is expected to double to about 1.3 MMBOPD by 2018. Plenty of other similar revivals of old conventional plays exist in the US and the added volumes may even exceed those of the new unconventional liquids production.*

Worldwide Gas Market and LNG: *The world gas market continues to be bolstered by the rising imports in South Korea, China and the after-effects of Fukushima. Though almost half of the global LNG production goes still to Japan and Korea, China is soon likely to become the main importer and Europe may follow in a desire to diversify its energy sources.*

LNG exports will start from the US in 2015 and from Canada in 2016; considering also the still ongoing imports from Canada this will lead to the US becoming a net gas exporter before 2020. At present four LNG export projects have been approved by the DOE, others will follow. The American Petroleum Institute (API) has published an export forecast for the period 2015–2035, giving a cumulative total of 41 TCF or 1.15 BCM (Fig. 5). This amount is relatively small compared to the US domestic gas production (some 7%) but is significant for the world LNG market. On average the US LNG exports will add almost 60 BCM/y to the present LNG world market (18% of the 2012 global volume). Larger volumes would be possible but are unlikely in view of the strong political opposition against export of domestic energy. Similar LNG export volumes can be expected from Canada; in total N-America is thus likely to add some 120 BCM LNG per year to the world market (over 1/3 of the 2012 world LNG market). At present the world LNG market is still characterized by very large regional price differences, ranging from 3.15 to 16.40

USD/MMBTU. The new LNG volumes for N-America will, however, greatly add to the global availability and will have a moderating and equalizing effect on gas prices. With increasing global gas to gas competition the link of gas to oil prices will further weaken.

***Conventional gas** has in many parts of the world been neglected in exploration, especially where pipeline transport was not possible and where volumes were assumed to be too marginal for LNG. It is therefore not surprising that very large amounts of conventional gas continue to be found. The important new gas volumes discovered in the last 5-6 years in many parts of the world are being confirmed and keep growing, e.g. in the Eastern Mediterranean Levante Basin, where the proven reserves offshore Israel have now exceed 40 TCF (over 1.100 BCM). Israel is likely to export up to 23 BCM/year. The total potential of the Levante (incl. Lebanon and Cyprus) is estimated at > 100 TCF (about 1 year present world gas consumption). Additional upside will soon be tested offshore Cyprus. Offshore East Africa, the big discoveries in Mozambique, with reserves of > 100 TCF, are being repeated in neighbouring Kenya and Tanzania with similar volumes. By 2020 Mozambique is expected to become one of the world's largest LNG exporters after Australia and Qatar. The reserves offshore Mozambique could cover the demand of Switzerland for some 1.000 years.*

***CO_2 Sequestration and Climate** (see also Figs. 1, 2): CO_2 sequestration was only a few years ago a prominent topic at the AAPG and was seen by many as the final solution to the CO_2 emission problem. Few talks were dedicated to this theme now. Not only in the US but worldwide the hope pinned on sequestration appears to be waning. This is partly due to the very high unit costs of sequestration: they would kill the economics of any coal powerplant (which might actually be a positive thing). Reasons for skepticism come also from the very modest volumes handled so far in pilot plants and the fact that public opposition and NIMBY («not in my backyard») attitude*

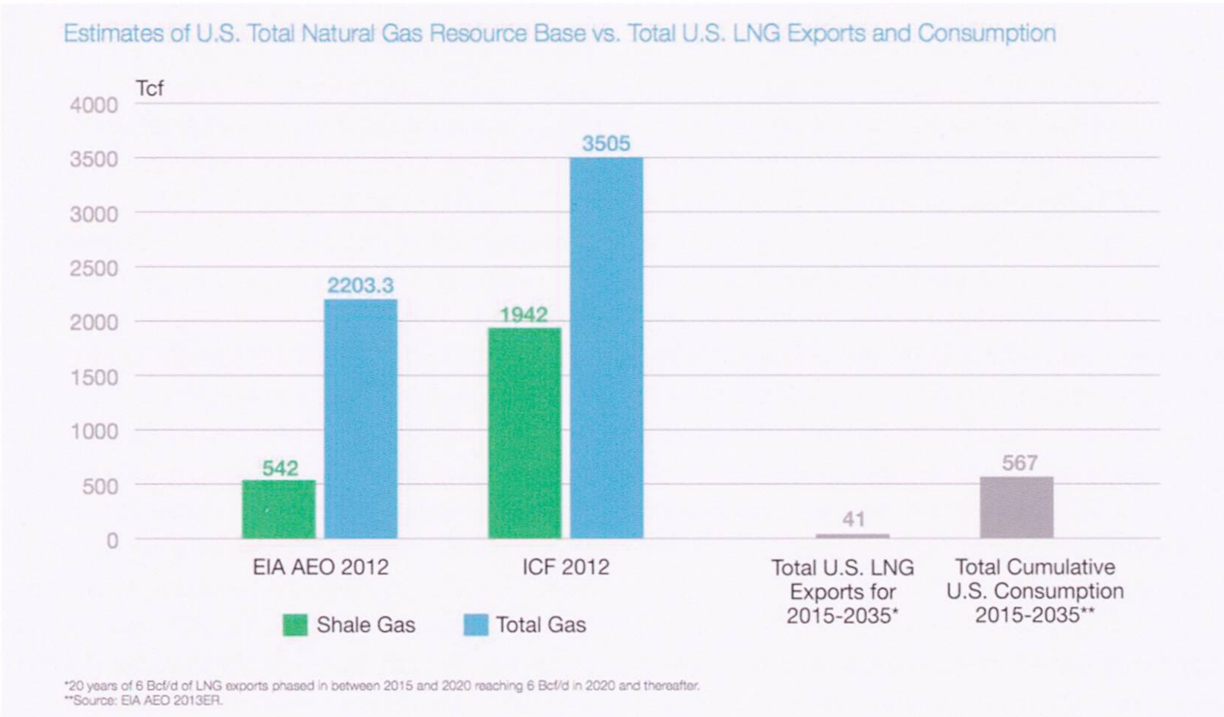

Fig. 5: US natural gas resources (left side) and domestic consumption and LNG Exports 2015–2035 (right side). All in TCF (1 TCF = 28 BCM). Total US LNG exports 2015–2035: 1.15 BCM (Source EIA).

are increasingly affecting the support for new projects. Energy projects of any kind, also renewables are in today's society more and more difficult to realize. This is unlikely to change as long as people have access to ample and cheap energy supply.
One of the best ways to sequestrate CO_2 is still in the enhanced oil recovery. With aging fields this is a growing opportunity, especially in the US where CO_2 pipelines from e.g. coal power-plants to oil fields already exist. Pumping CO_2 into depleted oil and gas fields will also meet with less public resistance since the existence of the old fields is proof that the system is sealing. Leakage of CO_2 back into the atmosphere is one of the main concerns in the public.

Renewables: *As last year, the US E&P industry is so focused on the technical and financial challenge of the unconventional revolution that renewables were not really a theme at the conference. The much higher profitability in hydrocarbons has led to a drain of financial and technical resources away from geothermal, wind and – to a lesser degree solar.*
Geothermal use of well fluids in oil and gas fields is still being pursued. New technologies that would allow a much more efficient heat extraction, especially at lower temperatures, would give a much needed boost to these efforts. Deep geothermal activities are concentrated in volcanic areas with little investment or research going into true enhanced geothermal systems (EGS), designed to artificially create deep heat exchangers. Given the large areas with shallow volcanic heat in the US, the more complex and less proven artificial stimulation methods are not a prime target and development is much slower than in Europe.

A philosophical thought *by the director of the Smithsonian's National Museum of Natural History: The 21st century is unique in the 200.000 years of humans on earth. In the last 200 years the population of our planet has increased 700% to 7.1 Billion. Since the birth of our grandfathers the increase has been 3-4 ×. This explosive growth is the effect of the industrial revolution, which, in turn, has been triggered by the availability of abundant cheap fossil energy.*
Oil and gas people have shaped the last 100 years of the earth's development, they have a responsibility for the next 100 years.

2 Presentations of special interest for the topic hydraulic fracturing and unconventional production

2.1 Unconventional gas and oil, general aspects

The Future of US Shale (Scott Tinker, Bureau of Economic Geology, Texas University)

- The energy need grows with people: world population will grow by 1 Billion every 13 years.
- Over 50% of world population live in China, India, SE Asia. 85% of their energy needs are covered by fossil fuel.
- Wrong perceptions distort public discussion:
  - High water use: Hydraulic fracturing and unconventional drilling consume < 1% of Texas water needs.
  - Fracs contaminate drinking water: fracs are 5-6 Eiffel Towers below ground water. Heavy frac waters do not rise (gravity!).
  - Land use: 15.000 wells of Barnett shale would be only 800 locations if clustered. The productivity of wells is rising every year (fewer and fewer wells are needed).
  - Unconventionals are not economic: Most presently produced plays are economic or break even at 4$/MCF.
  - The recovery factor is negligible: Average RF is 10% but some areas achieve 50%, the RF is rising in all plays.
- Global aspects:
  - Peak Oil and Peak Gas: Oil peak estimate 2060, coal 2070, gas next century?
  - Unconventional gas could eventually reach 4 × the conventional volume (Fig. 6).
  - Shale gas will require 2.000 Billion $ investment globally until 2040.
  - The world will produce 40-50 TCF/y of

shale gas by 2050 (equivalent to 33-42% of present world production).
- Worldwide do-ability of unconventional gas developments:
  - Russia and Middle East: negative (not yet, too much cheaper gas).
  - Europe: mixed to negative.
  - Rest of world: positive.

Assessment of Technically Recoverable Resources (John Browning, Bureau of Economic Geology [BEG], Texas University)

- The statement that unconventional gas production levels are not sustainable is incorrect. There is generally a rapid decline of production in the first year but production stabilizes thereafter in most wells with low further decline rates. Most Barnett Shale wells produce over 5 years, Haynesville wells produce 5-10 years and for Fayetteville up to 20 years appears to be possible.
- The Barnett shale will require some additional 90.000 wells for complete drainage.
- Reserve estimates and remaining Ultimate Recovery in TCF (GIIP / Recoverable):
  - Barnett → 440 / 86
  - Fayetteville → 80 / 38
  - Haynesville → 487 / 138

  Recoverable volumes have kept increasing, driven by technological and geological (e.g. sweet spot) improvements; recovery factors are likely to increase further.

Shale Gas sparks Innovation (Vikram Rao, Research Triangle Energy Consortium)

- Almost anything that can be produced by oil can be produced by gas.
- 5 TCF/y are flared worldwide, a tremendous waste and pollution that must stop. All venting and flaring should be abandoned. Flexible, temporary pipelines will help to do this. The co-produced gas can be processed/used in the field.
- Mini LNG plants (producing about 200 m^3 LNG/day) exist and could be deployed in fields.
- Diesel must be eliminated from operations: field installations can all be driven by gas.
- Fresh water should no longer be used. There is plenty of saline, brackish water available, including oilfield waters.

Panel on shale gas

- US lessons for overcoming resistance in other countries:
  - Education and communication. Demonstration of positive economic impact.
  - Positive involvement of government representatives.
  - Local people must benefit.
  - Industry must realize that regulations are positive.
  - Show best practice cases and especially that land use has been dramatically reduced.
  - Show consequences of saying NO: Saying NO to gas is saying YES to something else: e.g. more coal and more CO_2.
- Transport can be the main bottleneck: trains should be used for LNG or CNG (trains are more flexible than pipelines).
- One well in the Marcellus produces over its lifetime out of the gas 15 × more water than what it uses for drilling and fracturing (burning gas produces water and CO_2).
- Decline rates: The Marcellus production can keep building capacity for another 10-20 years.
- The drilling effort decreases since wells deliver continuously higher flow rates and ultimate recoveries (The Industry has been too successful, resulting in a gas bubble and low prices). But unconventional production uses still in average 10 × more wells than conventional production for equivalent ultimate volumes.
- Economy: Cheap gas due to unconventional production has so far triggered > 100 Billion USD investments in new industry plants. Repatriation of industry back to the US is continuing. Without shale gas the gas price in the US would be at 10-12 USD/MCF (actual is 4-5 USD/MCF). Shale gas has given stability to gas prices.

2.2 Expulsion efficiencies in source rocks

Determining Oil-Expulsion Efficiencies of Source Rocks by Hydrous Pyrolysis (Lewan, Michael, US Geological Survey, Denver)

- Expulsion processes have in the past probably not adequately been understood and expulsion efficiency was therefore generally overestimated. RockEval can e.g. not handle a mixed system of oil and gas. For the determination of expulsion efficiency RockEval should therefore be replaced by a process called hydrous pyrolysis.
- The initial porosity of a source rock and to a lesser degree clay mineralogy have the biggest effect on expulsion efficiencies. Higher TOC values (greater than 4 wt%) have no clear effect on expulsion efficiencies. High clay-mineral content can reduce expulsion efficiencies by 88%.
- Oil expulsion needs a continuous bitumen network in the SR. A 1-2% TOC SR never expels.
- Increasing porosity in the SR decreases (*sic*) the expulsion efficiency (organic porosity soakes up the oil)! The effect of porosity is best observed in carbonate-rich source rocks where chalky marlstones with porosities of > 30% can reduce expulsion efficiencies by 35%.
- Expulsion Efficiency increases with overburden. Without overburden a SR would grow 33% in volume during maturation due to creation of porosity in Kerogen during maturation.

The talk of Lewan confirmed again that the expulsion efficiency of most SR has in the past been grossly overestimated. The higher percentage of non-expelled HC creates the large opportunity of unconventional oil and gas.

2.3 Water use and potential groundwater contamination

The Prevalence of Methane and Solutes in Shallow Ground Water (Siegel, Donald et al., Syracuse University, NY.; Groundwater & Environmental Services, Altoona, PA).

- A geochemical synthesis of ~20.000 samples of shallow ground water from northeastern and western parts of the Appalachian Basin were collected 3-6 months prior to drilling for Marcellus Shale gas. In addition detailed temporal studies on the variability of methane and other parameters in ground water of 11 water wells in different hydrogeological settings was carried out in northeastern Pennsylvania.
- Mineral content: The results of the study show that the natural mineral content of drinking water is generally much higher than previously assumed. The spatial and temporal variability in concentrations of constituents (e.g. Na, CH_4, Fe, Mn, Sr, and Ba) span factors of an order of magnitude or more. Concentrations of these elements commonly exceed regulatory maximum levels because of natural geochemical processes.
- Methane: Tap water contained methane in 24% of analyzed samples in N-Pennsylvania and in 36% of samples in W-Pennsylvania. Traces of heavy metal are very common.
- In the absence of clear baselines, an observation of higher solute and gas concentrations in domestic well water after gas drilling cannot be considered as compelling evidence for contamination by shale gas development. Additional independent isotopic data and other forensic geochemical tools are needed.
- Best practice:
  - Sample 3-6 months prior to drilling.
  - Have analysis done by State certified labs.
  - Measure not only chemical composition but also temperature, turbidity, pH.

- Collect water samples in houses after flushing lines and taps (naturally occurring high mineral content turbidity and methane accumulations occurs when water wells are not used continuously.
- Take unfiltered samples.

The study confirms previous findings by the Department of Environment that water from domestic wells in many cases do not correspond to official standards for drinking water quality. Only in very rare exceptions a possible link to gas drilling can be established. Cases with clear proof of contamination by unconventional gas wells are still lacking.

2.4 Economics of unconventional plays

Scott Tinker Bureau for Economic Geology (Texas University)

- On a global scale unconventional gas resources (tight gas, shale gas, coalbed methane) have a volume potential that could be 4 × the volume of all so far produced and remaining conventional resources (Fig. 6).
- Unconventional gas is becoming more competitive with technical progress and experience. Production costs for unconventional gas will in future be less than double the average production costs of conventional gas. Unit production costs have been steadily decreasing.
- Between 1/3 and 1/2 of the known unconventional gas plays can today be produced at prices of 6 USD/MCF or lower. At least 25% can be produced below 5 USD/MCF. These figures are for dry gas, wet gas improves commerciality substantially (Fig. 7).

Economic Evaluation of Unconventional Plays (Clarke, Robert, Wood Mackenzie, Houston)

- It is unlikely that there are big unconventional gas plays in the US that have not yet been identified. The remaining plays are mainly for niche players but can still be very attractive.
- In the US the economics for unconventional gas are still marginal. The profits achieved in unconventional gas are only about 1/10th of profits in conventional gas plays. Better well placement and better stimulation may improve this. The main profit comes from associated liquids.
- Internationally the development of unconventional resources is a very slow progress. The road to unconventional suc-

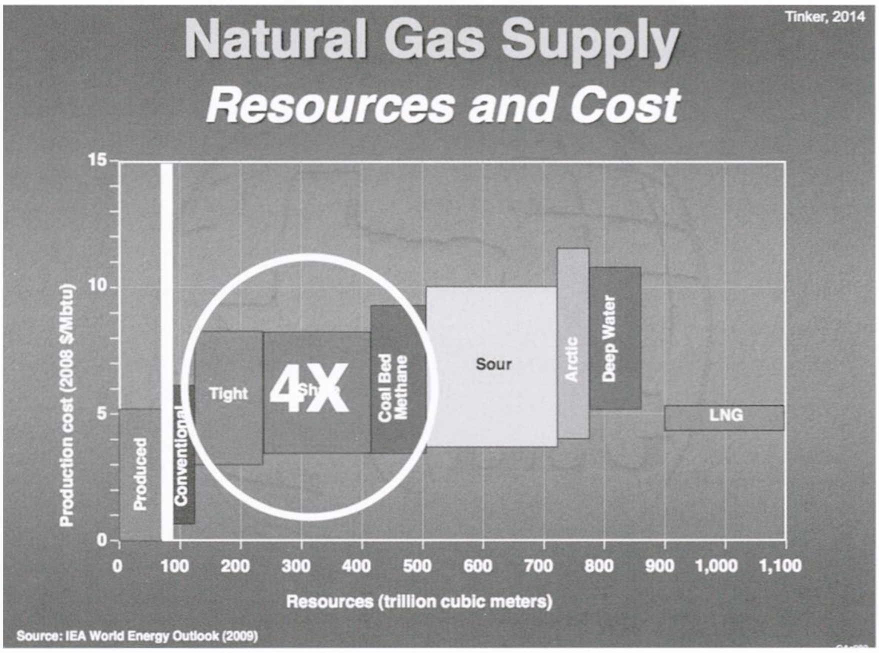

Fig. 6: Estimated production costs and resource volumes of unconventional and conventional gas supplies. Unconventional gas resources may be 4x larger than the produced and remaining conventional reserves. (Source IEA and Scott Tinker 2014).

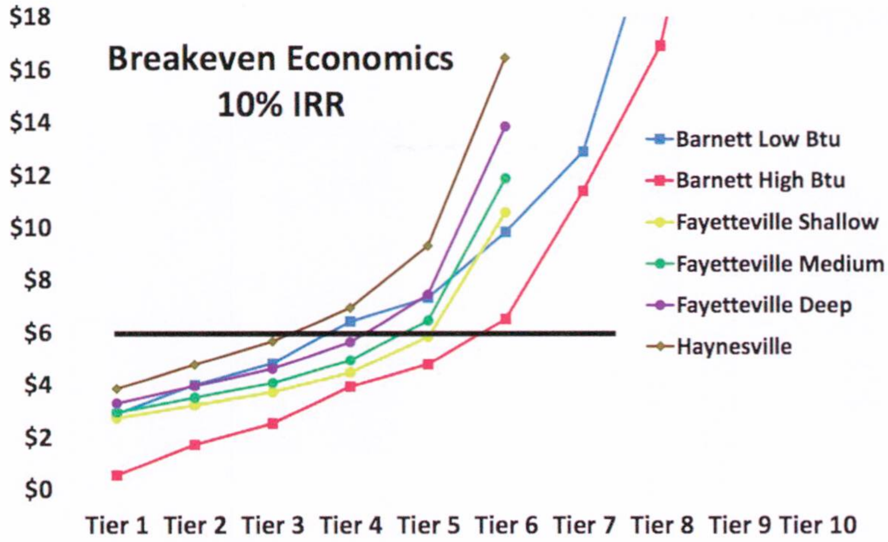

Fig. 7: Breakeven economics for different US shale gas plays. Reading example: some 2/3 of the wet gas (high BTU) Barnett Play can be produced at prices below 6 USD/MCF, at least half can be produced at gas prices ← 5 USD/MCF. (Source: Bureau of Economic Geology, Texas University).

cess will be much longer, more risky and more expensive by up to a factor 2 than in the US. Regulators do often not understand the business and the progress of regulation is very slow, especially in Europe.

- Number of shale gas or shale oil exploration wells drilled outside US by end 2013:
  - Europe 25
  - Russia 20
  - Australia 25
  - Asia (mainly China) 165
  - Argentina 250

  Argentina is likely to be the first country outside the US to have a substantial unconventional oil and gas production, followed by China.
- Role of Majors: Majors will be the dominant players in international unconventional activities. This contrasts with the US where the Majors came late, were often overpaying for the acquisition of acreage or companies and frequently ended up with second-rate acreage. Plays like the Vaca Muerta of Argentina, the Bazhanov source rock of Siberia or the Cooper Basin are too big to be tackled by independents. Majors are already well placed in e.g. the UK or China.

Acronyms and terms

B: Billion (10^9); BBO: Billion Barrels Oil; BOE: Barrel Oil Equivalent; BOPD: Barrel Oil per day; BBL: Barrel; BCF: Billion Cubic Feet (10^9); BCFD: Billion Cubic Feet per Day; BCM: Billion Cubic Metres; BTU: British Thermal Units (mostly as Million Btu – MMBtu); CBM: Coal Bed Methane; CF: Cubic Foot; CNG: Compressed Natural Gas; DHI: Direct Hydrocarbon Indications (from seismic); DOE: Department of Energy (US); E&P: Exploration and Production; EIA: Energy Information Administration (US); GIIP: Gas initially in place; IEA: International Energy Agency; Industry: here always meant as the Oil and Gas Industry; M: Thousand; MCF: Thousand cubic feet; MM: Million; Majors: the category of the largest multinational private oil and gas companies; mD: Millidarcy (permeability measure); Nm: Nano metre; RF: Recovery Factor; SR: source rocks; TCF: Trillion Cubic Feet (10^{12}); TCM: Trillion Cubic Metres (10^{12}); TOC: Total Organic Carbon; USD: US Dollar; USGS: US Geological Survey; 3D: three dimensional seismic.


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