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The new world of exploration: innovation in conventional and unconventional plays. AAPG Annual Convention Long Beach, April 2012 – Selected highlights

Peter Burri[1]

Key words: AAPG, oil exploration, gas exploration, coal, unconventional gas, unconventional oil, shale gas, reach of oil and gas, CO_2 emissions, CO_2 sequestration, environment, renewable energy, power generation, electromagnetics

1. General impressions and highlights

The convention: *The convention was attended by some 6,000 participants. Attendance from Asian countries remains strong. Chinese companies and universities have an increasing presence, both actively participating in presentations as well as with large groups of attending delegates. European attendance, low in past previous years, is recovering. The AAPG Convention remains the best worldwide event in energy related geosciences for networking.*

As in previous years the best papers came from small- and medium-size companies, while Majors were often overcautious and trapped in their corporate-speak and legally-politically correct motherhood statements.

US E&P Industry: *The move «back home» to the US onshore amongst US companies continues. This is predominantly fuelled by the strongly rising number of exploration opportunities in North America but is also driven by the increasingly risk-averse attitude of many of the E&P companies. American companies remain deeply concerned with the very low gas price, caused by the increase in unconventional and – surprisingly – conventional gas production.*

The low gas prices cause severe problems for many of the smaller, gas-focussed companies. This is resulting in a rapid consolidation of the industry, with smaller companies being bought by large players who continue to invest in unconventional US gas and oil with billion dollar acquisitions.

While the US E&P industry suffers from the low gas prices, Bloomberg has recently published a study showing that with direct and indirect benefits of the low gas price the US economy has approximately a 100 billion USD cost advantage per year. Very low energy prices add significantly to the international competitiveness of the US economy and are one of the reasons for the recent stabilization and recovery.

It is expected that in the US gas will increasingly substitute coal for power generation (coal is still the main primary energy in the US for electricity). Natural gas, costing now about ¼ of gasoline in N America per energy equivalent, is also likely to gain an increasing share in transportation. Substitution by gas is already taking place: coal in power generation, at 50% in 2005, has dropped to 40% today and keeps falling. This has brought the US over the same period the biggest reduction of CO_2 emissions of any industrialized country.

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Comments and additions by the author in italics.

__Unconventional hydrocarbons__ remain a very important part of the topics of the convention and many of the lectures on unconventionals were packed with a standing crowd. In the light of the low gas prices, the exploration in N-America is increasingly shifting to wet gas and unconventional oil, with considerable success. On the basis of these recent exploration successes several speakers indicated the possibility that the US could regain self-sufficiency not only in gas but also in oil. The country has indeed reduced its share of imported oil since 2005 from 60 to 40% of consumption.

With increasing maturity of the unconventional plays it is realized that mature source rocks are not a uniform play but that content of total organic carbon (TOC), lithology, structural history and present day stress regime control the flow rates and thus the sweet spots. Many researchers complained that the exploration so far was operations-driven by drillers who had a target of a certain number of wells per month and who had little consideration for coring, sampling and logging which all are considered obstacles to reaching their drilling target. The head of Exxon's unconventional research team estimated that with proper prior studies and sampling the number of wells required could be reduced to half or one third.

The environmental concerns with fracturing are still a theme in the US, though much less virulent than in Europe. It is also clear that resistance against unconventional hydrocarbons is – with the exception of parts of California – strong only in states that so far had little oil production; in states with traditional oil and gas production this is not an issue. The US government is presently issuing a set of standards and regulations for unconventional operations. Generally this is welcomed by the industry, as it should greatly facilitate future permitting and create a solid legal base for the operational activities. The perception of risks is also gradually falling back into the right proportions: in North America, where so far about 1.5 million individual frac jobs have been carried out, there is not a single case where contamination of groundwater, or the surface environment, by hydraulic fracturing has been proven. Most contaminations were caused by poor well integrity (e. g. poor cement jobs) or by leaks of well fluids from the surface installations or poor operational handling and disposal of the fluids. In many cases biogenic gas from natural sources was present in the groundwater but was previously never analysed (the notoriously famous burning taps in the Film Gas Land proved to be biogenic gas from shallow sources).

__The future of gas:__ In April 2012, just before the AAPG convention, gas price had fallen in the US to below 2 USD/MCF for the Henry Hub benchmark (the lowest price in over a decade), 4 - 5 times lower than gas prices in Europe and over 8 times lower than LNG prices in Japan, where prices post Fukushima have risen by 25 - 30%. The shortfall of the power production in Japan after the closure of the nuclear plants was almost exclusively replaced by coal and mainly gas, proving the high flexibility of gas power plants. The increased gas demand in Japan and China is responsible for the fact that – against all expectations – the oversupply in the US has not yet led to a worldwide slump in gas prices. The feared surplus of LNG, originally designated for the US market, has in the meantime been largely absorbed by Asia. Fukushima has «saved» the worldwide gas market.

Large new gas volumes, mostly conventional, are also being discovered in other parts of the world, in the Eastern Mediterranean and offshore East Africa, where, after the recent large finds of Anadarko, BG and ENI, in excess of 100 TCF (almost 3,000 BCM) may become available for LNG plants in the next decade (this is almost 1,000 × the annual gas consumption of Switzerland). With the vanishing US market for Canadian pipeline gas, LNG exports are expected from Canada possibly as early as 2016, US LNG exports may be operational as from 2015 but are less likely to reach large dimensions, given the potential gas market trough substitution and the political resistance against exporting domestic energy.

The CO_2 question: *CO_2 sequestration was discussed in special sessions. It does not appear, however, that sequestration will be the solution to the CO_2 problem for following reason: There is increasing resistance among the public and in pressure groups against sequestration on the grounds of safety (guarantees that CO_2 will not leak back to surface). Similar to other underground waste disposals the principle is «yes, but not in my own backyard». In addition there is a volume problem: most sequestration schemes can only handle tiny fractions of the actual CO_2 emissions in the country. The fastest way to a drastic reduction of the CO_2 output in the short to mid term would be to replace the world's coal power plants by gas (see particularly the most revealing/disturbing analysis of CO_2 stabilization measures at the end of the CO_2 chapter).*

Reserves and reach of fossil fuels: *Gas reserves worldwide grew every year since 1970, they are now 21% higher than in 2000 and some 400% higher than in 1970. World proven oil reserves are even 25% higher than in 2000. Surprisingly, new conventional gas worldwide, still adds considerably more to growth than unconventional gas.*

Though unconventional resources have transformed the world outlook for fossil fuels, there is a growing conviction that new technology, especially seismic resolution and drilling/ stimulation techniques will also result in much larger than anticipated conventional resources, especially in gas. The proof is North America, by far the world's most mature exploration area, where almost every stone had already been turned over by geologists, and where thus, little new reserves were expected. The reality is that US domestic oil production is now 10% higher than in 2006 and oil reserves have grown by some 3% in the past 10 years (plus 75% in Canada); also during these 10 years over 26 billion bbls of US production were replaced by new finds.

US gas reserves have grown 54% since 2000 (+ 12% in production). If this N-American experience is being extrapolated to the much less mature rest of the world, very large additional conventional hydrocarbon volumes must be expected on a global scale in addition to the unconventional potential. In line with this, the conference highlighted the large number of new exploration areas being opened up at present especially in Africa. Gas has more potential than oil since gas exploration has been neglected until recently in many of the classical petroleum basins.

Renewables: *Most of the larger US oil and gas companies are developing renewables but, with the exception of Chevron, investments are at best a few % of the total budget. Geothermal use of hot well fluids in oil and gas fields is making further progress and heat extraction pilot projects are running in several of the hydrocarbon production areas. Most of the use is for heating purpose but power production for consumption within the oil and gas installations is being tested as the next step with the aim of making the field's generator plants obsolete. Economics are still marginal but several states, e .g. Colorado, offer incentives.*

Given the large areas with shallow volcanic heat, deep geothermal projects, especially enhanced geothermal systems (EGS) are not a prime target and progress in the development of EGS is in the US much slower than in Europe. Many of the renewables activities appear to be alibi exercises for the oil and gas industry and this will not change as long as the very large profitability gap between hydrocarbon production and geothermal projects persists. With the present boom in discovering new domestic fossil fuel reserves it is highly questionable whether the US will reach the government target of 30% renewables in 2050. Forecast of the share of renewables by the Department of Energy (DOE) for 2035 is 14% (presently 9%) including hydropower.

2. Technical topics

2.1 Generation and Trapping

Percent Trap Fill and Its Implications (R.S. Bishop, Consultant Houston)

An excellent talk of a study based on many hundreds of case histories. The study confirms previous investigations (e. g. a worldwide Shell study in the 90's) that have concluded that «underfilled» traps do not exist (Shell could not prove any underfilled trap in the study of over 400 fields). Charge is virtually always sufficient to fill the existing traps.

- Evaluation of hundreds of fields in many different types of basin settings and different source rocks show that traps are full to either a leak point or spill point. The degree of fill is virtually impossible to determine in strat-traps or in very complex tectonic settings.
- Source rock expulsion capacity is in most cases one or two orders of magnitude larger than the trap capacity of the basin.
- Main implications:
  - Maximum field size is determined by maximum trap capacity, not source rock yield.
  - Different tectonic settings have different maximum field sizes.
  - If the large, simple traps are full, there is sufficient hydrocarbon generation to fill the complex ones with more difficult migration paths.
  - The occurrence of both free gas and oil in a single reservoir requires leakage or the gas would displace the oil.
  - The widespread occurrence of oils saturated with gas indicates selective leakage of gas from these traps.
  - Many widespread, thick top seals – with the exception of thick salt – may also leak. Often regional seals are gas saturated waste zones.

2.2 Geophysics

A Novel EM Driven Approach to Frontier Exploration in the Barents Sea (S. Fanavoll et al., EMGS ASA, Norway an EMGS America, Houston)

- Large parts of the west and north-east of the Barents Sea are still virtually unexplored. Electromagnetic data (EM) are a valuable first screening tool. Earlier this year, an agreement with Russia concerning the so-called «Grey Zone» (Fig. 1) has opened a totally new area for exploration, which among experts is regarded as very promising.

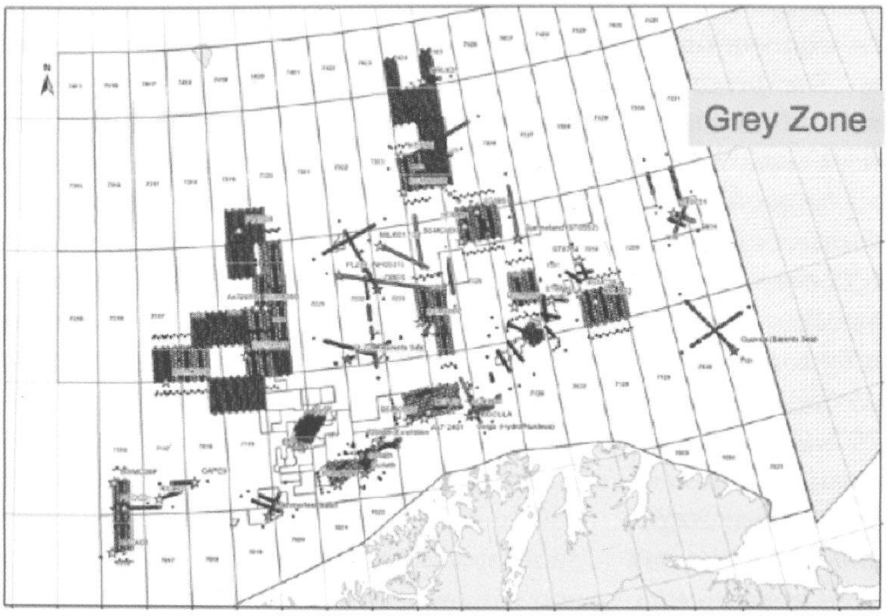

Fig. 1: Barents Sea EM surveys. «Grey Zone» (Joint development Norway/Russia), newly openend (source: S. Fanavoll et al., Abstracts AAPG Convention, 2012).

- EMGS acquired in 2008 - 2010 an EM coverage over 16,000 km^2 of the potentially prospective area. In 2011, two new major discoveries were made in 20th round licenses, both properly imaged/predicted by EM. Major hydrocarbon accumulations, such as Snohvit and Goliat, are seen on EM data, while minor, non-commercial discoveries do not exhibit any significant EM responses (5 large accumulations are clearly imaged by EM). CSEM (Controlled Source Electro Magnetics) data can provide a valuable addition to the exploration database, since EM is sensitive to saturation and volume, and therefore can indicate where the economic accumulations are (Figs. 2, 3).

2.3 Unconventionals

General

Lower paleozoic shale gas and shale oil potential in eastern Canada (D. Lavoie, Geological Survey of Canada)

- The Upper Ordovician Utica Shale (50 to 300 m thick) and Macasty Shale (40 to 100 m thick) with TOC of 3 - 5% are widespread in southern Quebec and Anticosti Island.
- In place volumes of generated and not expelled HC in these source rocks amount to 120 - 140 TCF of gas and some 45 Billion bbl of oil.

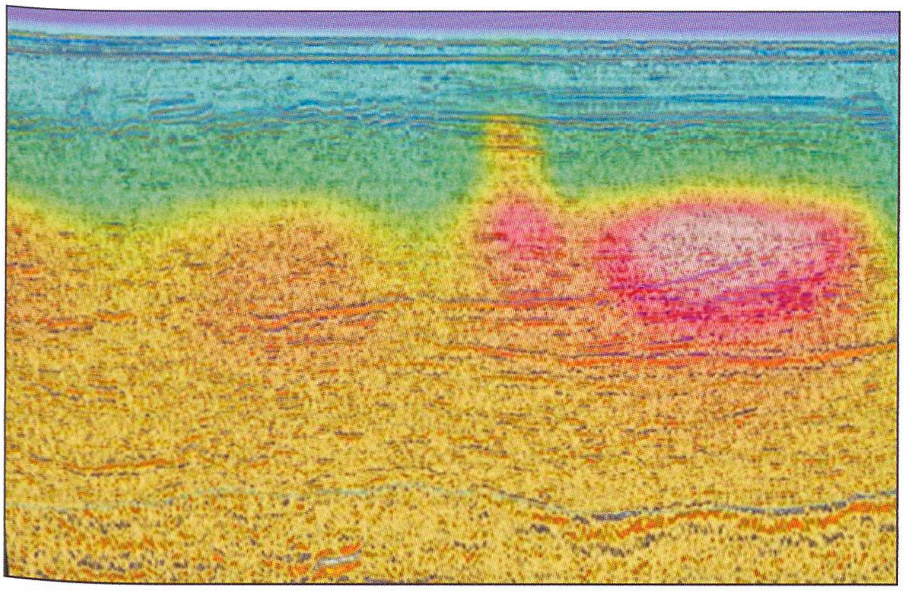

Fig. 2: EM anomaly in the Tertiary/Upper Cretaceous, Western Barents Sea (source: S. Fanavoll et al., Abstracts AAPG Convention, 2012).

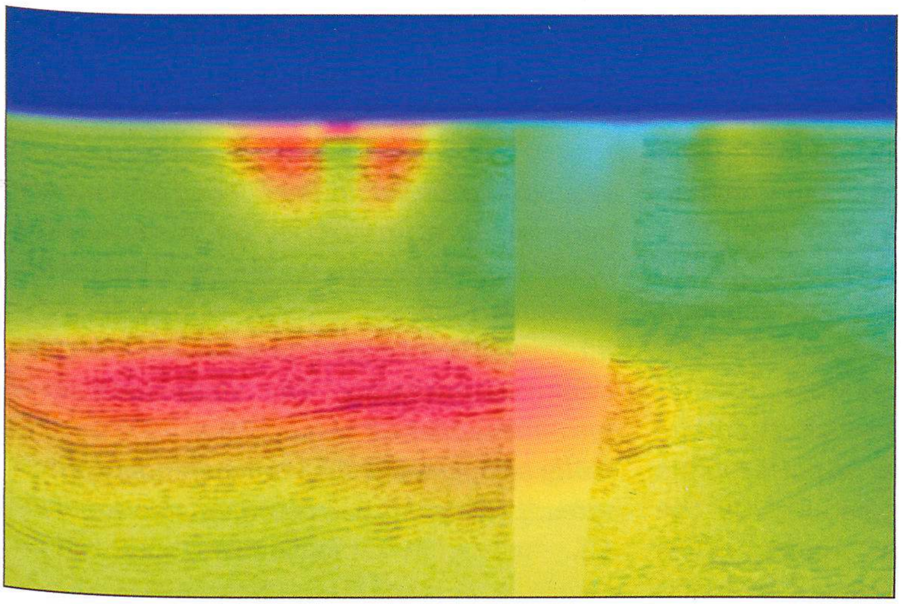

Fig. 3: EM anomaly in the Triassic; N-E Norwegian Barents Sea (source: S. Fanavoll et al., Abstracts AAPG Convention, 2012).

Handling common complaints by private water well owners related to coal bed methane, shale gas and other unconventional development programs (John Fontana, Vista-GeoScience, Golden Colorado)

- 42 Million US Americans get their drinking water from wells. In Colorado some 40,000 oil and gas wells were plugged and abandoned, 27,000 are still active. These wells can pose a threat to new E&P activities since old wells can be conduits. Private water wells do not have to comply with federal standards, many are dirty. Most contaminations come from animals and septic tanks.
- The current public fear about hydrofracturing practices is unwarranted and should be easily dispelled. While a few complaints can be linked to real issues such as poor cement jobs, leaky pits, the vast majority turn out to be due to poor quality water well design, poor construction and lack of maintenance.
- Methane in a water well occurs naturally from bacteria, natural gas seeps, or the result of coals or shales present in some aquifers. Since methane occurs naturally and is not toxic, it's excluded from routine water quality tests in private wells, until oil or gas development occurs.
- Baseline studies before fracturing operations are a must. Typing of contaminations and tying them back to source can mostly be done with great accuracy.

Hydraulic fracturing: separating myth from reality (Steve Leifer, Division of Environmental Geoscience)

- The reality on accusations against Hydraulic Fracturing (HF):
  - There are no confirmed instances of Hydraulic Fracturing (HF) causing contamination of drinking water supplies. This has been confirmed repeatedly by the Environmental Protection Agency (EPA) and state regulators. References by NGOs to «thousands» of instances of contamination relate almost exclusively to routine reporting of surface spills.
  - All national studies so far show that there is little or no risk to drinking water. Drinking water is much more under threat from other sources (e. g. dumps, waste disposal by public, agriculture).
  - 30% of drinking water in the US contains some Methane.
  - Noticeable induced seismicity is not linked to HF but to reinjection of fluids. No damage case by induced seismicity from fracs is known.
  - 90% of the HF water is recovered in flowback and most of this is recycled. The industry is moving towards 100% recycling and zero discharge.
  - Shale development represents a very small portion of regional water use.
  - Additives to fracturing fluids have now to be disclosed and toxic additives are being replaced by non-toxic substances.
- A nationwide study by EPA will produce first results/recommendations by 2012 with a final report by 2014. The Obama administration is carrying out a 45 MM USD additional study and will propose regulations in 2012.
- The future: disclosure of additives, recycling of fluids, extensive ground water base lines, development of low- or no hazard substances for HF. Surface methane recapture and flaring restrictions.

Unconventional oil

The surplus in gas in the US and the ensuing very low gas prices have led companies to place more attention on unconventional oil, especially shale oil, where their experience in unconventional gas production can be deployed profitably. The understanding of unconventional oil plays is improving dramatically to the extent that some companies talk already about a future oil independence of the US.

The new Bakken oil shale play in Eastern Montana (S. Sonnenberg, Colorado School of Mines)

- The new play area is an exciting new development for the Bakken Petroleum System of the Williston Basin. This is the most prolific unconventional oil play with initial well production ranging from 370 to 3,000 BOPD and recoverable reserves possibly in the billions of barrels.
- The high flowrates are partly linked to high formation temperatures of over 100°C that guarantee a high degree of generation within the source rocks and light oil.

Improving hydrocarbon resource and fluid property prediction with a coupled generation/expulsion model (X. Xia et al., GeoIso Chem Corp. and Peer Institute California)

- The extent of expulsion processes is based on the evaluation of maximum amount of water, oil, free gas and adsorbed gas in the pore system and on the matrix surfaces of source rock.
  Main findings:
  - There is a large amount of oil and condensates retained in source rocks even at high maturity of vitrinite reflectance of >1.5%, which contribute to the formation of shale gas at high maturity.
  - The retained and expelled gas content is not only a function of organic matter properties, but also remarkably influenced by burial history, temperature and paleopressure profiles.
  - There is obvious compositional fractionation between retained and expelled hydrocarbon; this fractionation needs to be taken into account for fluid property prediction of both conventional reservoirs and shale gas.

The studies are another confirmation that very large amounts of HC are retained in the source rock after maturation. This is the very source of the unconventional HC potential.

Unconventional gas

After the operations-driven phase of the unconventional exploration there is clearly a move to more science. Production rates of shale gas wells have strongly improved but the number of wells with non-commercial production has hardly diminished. The low gas prices may eventually force some companies to focus on the search for sweet spots, rather than having drilling targets as the only parameter. The geological reasons for shale gas sweet spots and many of the physical processes that control stimulation and production are beginning to be understood but there is still a long way to go. It is time that unconventional exploration and productions evolves from an operational business into a science.

Predicting TOC, organic porosity and gas retention distribution in a shale-gas system using petroleum basin modelling (A. Huc, IFP, France)

- Three stages of source rock maturity:
  - Mature Kerogen: produces liquids and some early gas;
  - Pyrobitumen: produces liquids and gas;
  - Dead Kerogen: late gas.
- The volumetrically very important nano porosity in the source rock is almost exclusively generated in the maturation process. Organic matter cracking is at the origin of over half of the shale porosity.
- The Barnett shale creates most of its gas late by secondary cracking and most of this gas is retained in the high maturity shale.
- In the 5 - 8% TOC Barnett shale one m^3 of rock produces about 3 kg (sic!) of gas, of which about 1.8 kg are adsorbed.
- On a map scale most retained gas in the Barnett Shale is concentrated in mature areas with richness ranging from 40 to 100 kg gas/m^2 surface.

2.4 The CO_2 question

Migration rates and formation injectivity to determine containment timescales of sequestered CO_2 (L. Burke, US Geological Survey)

- Supercritical carbon dioxide exhibits highly variable behaviour over a range of reservoir pressure and temperature conditions. Because geologic sequestration of supercritical carbon dioxide is targeted for subsurface injection and containment at depths ranging from approximately 3,000 ft to 13,000 ft, investigation into the physical properties of this fluid can be restricted to the pressure and temperature conditions at these levels. On this basis the USGS has carried out modelling of the leakage/diffusion that can be expected at different rock permeabilities.
- Diffusion time calculated for diffusion in uniform rock over one km at different permeabilities (note CO_2 injection at economic rates is only possible in rocks of > 100 mD):
  Permeability and diffusion time for 1 km:
  - 1 D → 6 months;
  - 1 mD → several 100 years;
  - 1 micro D → several 1,000 years;
  - 1 nano D → several Mio years.

Containment of CO_2 in CCS: Role of Caprocks and Faults (John Kaldi, CO2CRC, Adelaide)

- The most significant aspect of containment is the seal potential of the caprock, defined as the seal capacity, geometry and integrity. The sealing capacity refers to the CO_2 column height that the caprock can retain before capillary forces allow the migration of the CO_2 through the caprock.
- For storage in depleted fields, assessments of seal capacity can be made from empirical observations of actual hydrocarbon column heights and converting these to CO_2 physical properties. CO_2 column heights will always be smaller than gas columns.
- **Nearly all seals leak over time.** The Sleipner field in the North Sea that is used as CO_2 storage has a clear CO_2 gas plume, indicating leaking. Caprock thickness has no influence on leaking entry pressure but reduces rates of diffusion.
- Faults are a risk, especially since the stress modification due to CO_2 injection can reactivate fault movements. The greatest likelihood of fluid migration up faults is during or immediately after reactivation. However, the mere existence of faults should not automatically prohibit geological storage of carbon dioxide. On the contrary, sealing faults are much more common than faults as conduits and commonly trap hydrocarbons and compartmentalize oil and gas reservoirs (however compartmentalization is a major handicap in injection).
- Sealing in pilot plants is tested by filling the reservoir with N_2; only if leakage is acceptable, CO_2 is injected. Leaking is tested in shallow observation wells. Sealing is defined by Australian regulations as a maximum loss of 1% of the gas in 1,000 years.
- Australia's first and only CO_2 pilot project has injected 60,000 t of CO_2 (note Australia's annual CO_2 emissions are over 400 Mio t). A very large project is planned in the longterm in the Melbourne area for sequestrating CO_2 from coal-fired power plants. Planned capacity is 50 MM t/a over 40 years. For comparison: the US have since 2005 reduced CO_2 output by 450 MM t/a through coal substitution by natural gas.

Oil spills, ethics and society (Rusty Riese, AAPG distinguished Ethics Lecturer 2011 - 2013), CO_2 part of R. Riese talk

A very interesting, and provoking talk. Riese showed what it implies to reach the climatic goals that the politicians propose. His conclusion: stabilization of CO_2 at present levels for this century may be possible but at very high investment costs (ten-thousands of billions USD) and only if gas production can be

increased massively to substitute for coal.
I have ranked the 8 measures required in the order of technical and political/social difficulty (my own subjective view). The bottom three measures appear very difficult to reach: a] Increasing natural carbon sinks, i. e. massive growth of the surface of forests is incompatible with a rapidly growing world population, b] growing the present number of nuclear plants by a factor 2.5 × is politically very difficult to achieve even in Asia, c] Carbon capture and storage at a large scale looks increasingly impossible since no project so far provides remotely the storage volumes required, costs are astronomical and public resistance is increasing. A default on these three measures requires almost a doubling of requirements for the first four steps.

- Keeping world CO_2 emissions in 50 years at 2010 levels would require the following 8 «improvement wedges», ranked in order of do-ability (Fig 4):

- Car fuel efficiency: Doubling the fuel efficiency of cars (600 MM cars today, estimated 2 billion cars in 50 years).
- Coal to gas fuel switching (biggest contribution – two «wedges»): Replace coal fired power plants with gas plants (implying doubling of world gas consumption
- Replace 700 coal power plants with LNG (50 large LNG tankers/day);
- Replace 700 coal power plants with additional pipeline gas.
- Wind: Increase of wind power capacity by 50 × to two million large windmills (requires an additional wind park surface of 960 km^2).
- Solar: Add 40,000 km^2 of solar panels (surface of Switzerland).
- Capture and storage of CO_2: CCS from 800 coal fired power plants. Implies 3,500

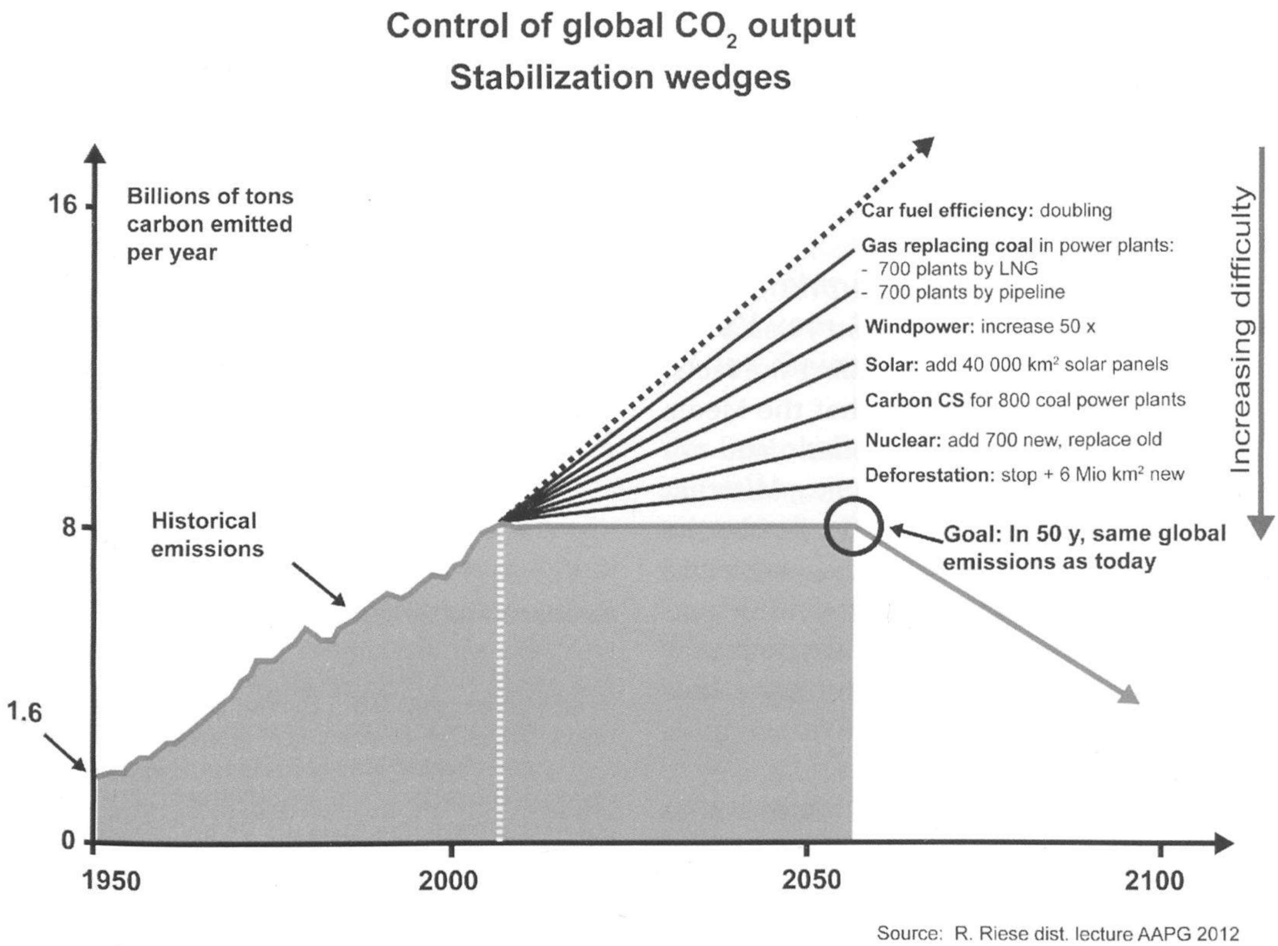

Fig. 4: World carbon emissions per year and measures to be taken to stabilise at present level by 2060 (action-wedges, see text above). Modified from R. Riese, Rice University, AAPG Distinguished Lecturer 2012.

developments equal to the In Salah CO_2 sequestration project of BP in Algeria (designed to store approx. 1 MM t of CO_2/y, investment costs to BP 130 MM USD).
- Nuclear: Adding 700 new nuclear plants and replacement of old ones (today 440 plants worldwide).
- Natural carbon sinks: Eliminate tropical deforestation and add 6 million km^2 of new forest plantations (150 × surface of Switzerland).

All these measures need to be fulfilled in parallel to stabilise present day CO_2 levels.

3. E&P industry and the public

Oil spills, ethics and society (Rusty Riese, AAPG distinguished Ethics Lecturer 2011 - 2013), Oil industry and public perception

- Oil and gas industry makes big profits due to very large volumes (investment, production) not due to high margins. Worldwide average returns on capital employed:
  - E&P industry → 6.5;
  - Computer Industry → 22%;
  - Pharmaceutical Industry → 24%.
- Media: The oil and gas industry has a bad reputation and is poor in selling the facts. This is helped by the fact that the Media focus on the worst case scenario and not on the most likely outcome. Mistrust towards the industry is also fuelled by the poor knowledge that the media, politicians and the public have about scientific matters. Recent polls in the US indicate that:
  - 47% of the Americans do not know how long it takes the earth to travel once around the sun.
  - 41% of the Americans believe that dinosaurs and humans lived together.
  - Some 30% of Americans do not believe in evolution.
  - Polls amongst non-scientists on university campuses showed only marginally better results. Only 25% of the non-science college students are scientifically literate, i. e. they can read and understand a scientific/technical article in the N.Y Times.

  The majority of journalists, judges and politicians are non-technical people who do not understand science. The problem is that it is these people who decide and judge when something in the technical world, e. g. in E&P goes wrong.

Acronyms and terms

B: Billion (10^9); BOE: Barrel Oil Equivalent; BOPD: Barrel Oil per day; BBL: Barrel; BCF: Billion Cubic Feet (10^9); BCM: Billion Cubic Metres; E&P: Exploration and Production; EM: Electro Magnetic surveying of the subsurface; HC: Hydrocarbons; Industry: here always meant as the Oil and Gas Industry; M: Thousand; MM: Million; Majors: the category of the largest multinational private oil and gas companies; mD: Millidarcy (permeability measure); TCF: Trillion Cubic Feet (10^{12}); TCM: Trillion Cubic Metres; TOC: Total Organic Carbon; USD: US Dollar; 3D: three dimensional seismic.