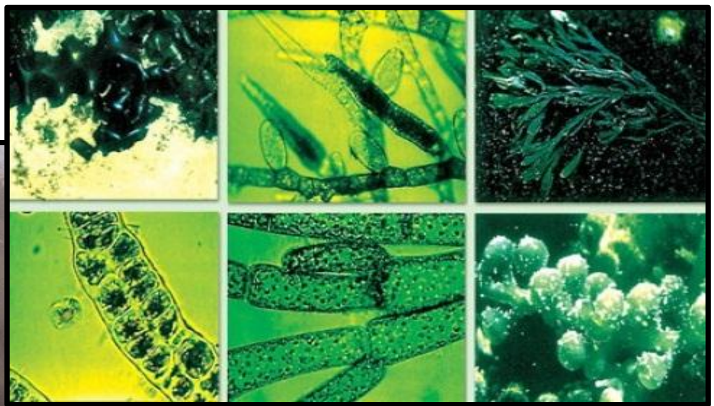
ENERGY Security



Nelson Mandela Metropolitan University

FIELD GUIDE

1 December 2014

2nd Global Change Conference

AEON

Contents of the field guide

1. Tour Timetable - 1 December

07h30 : Arrival for 08h30 departure

08h30 : Departure by bus from South Campus, Blunden Coach Parking – Aloe Road

09h00 : **WIND ENERGY**

- Visit to the site of Metrowind Van Stadens Wind Farm. This R550 million renewable energy project, one of the first in South Africa, provides around 80 million kWh/year to the Nelson Mandela Bay Municipality.

10h00 : **SUSTAINABLE LIVING**

- Guided tour of the Rhino House (which is totally off the grid) at Crossways Farm Village. Discussions about sustainable living and use of solar energy for domestic use will be carried out.

11h30 : Depart for Cape St Francis

12h30 : **NUCLEAR ENERGY**

- Overlook the Cape St Francis Bay Coastline towards Thyspunt, the potential site for the new nuclear power station. The geology and geophysics of this area will be discussed, insofar as it is a requirement to know precisely the depth to the hard bedrock on which a nuclear power plant must be built, as well as its stability with regards to rock fractures and faults.

Packed lunch is provided.

14h00 : Return to Port Elizabeth (NMMU)

14h30 : **BIO-FUELS and OCEAN ENERGY**

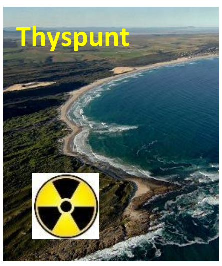
- Visit the Bio-fuel Laboratory at InnoVenton. Here algae-to-energy research is being conducted at Institute of Chemical Technology with an aim to provide bio-crude oil and other liquid fuels. The solution is also capable of expanding the life span of coal reserves with a greener coal product. The Director of InnoVentum, Prof Ben Zeelie will facilitate discussion.
- Presentation on Marine Energy (waves, tides, currents etc.) by Dr Eckart Schumann

Guides : Drs Viera Wagener, Bastien Linol, Maarten de Wit and Werner Illenberger

MetroWind
Metrowind Van Stadens Wind Farm

AFRI-COAST ENGINEERS

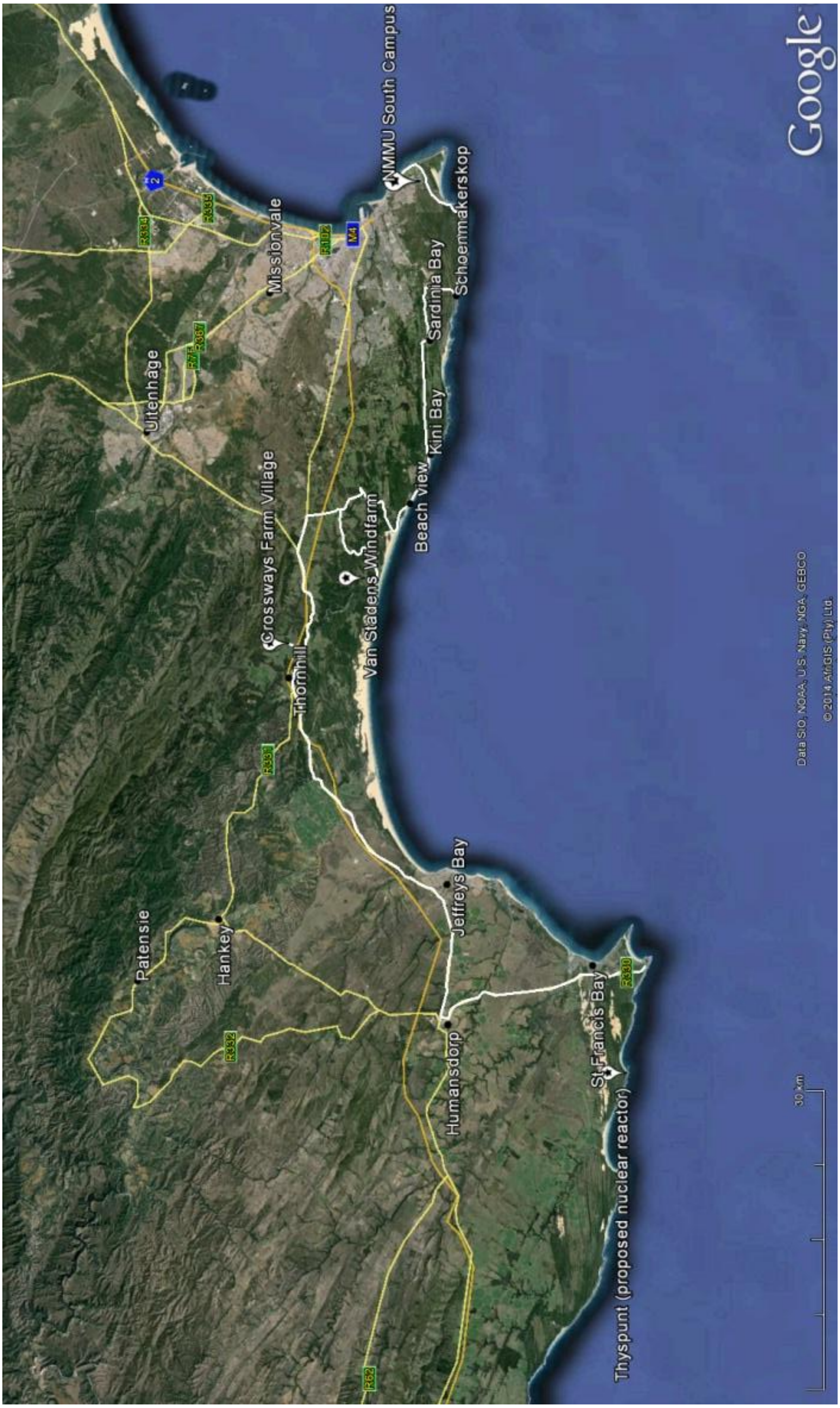
CROSSWAYS FARM VILLAGE



AEON
Earth Stewardship Science Research Institute

InnoVenton
Dream. Innovate. Create.

2. Map of Excursion



3. Energy in South Africa

'Hello Darkness, my Old Friend', wrote Sipho Kings in the Mail and Guardian last month (November 07-13, 2014), and asked what did South Africans use before candles? Electricity.

'In the beginning, god separated darkness and light and called it night and day. Eskom created lasting darkness and called it load-shedding'.

Load-shedding comes from poor managing and planning. Globally, electricity service providers have ca. 15% extra capacity so they can service and maintain their power stations and when they mall-function. Eskom supplies more than 42000 megawatts (MW) of power. It has a safety margin of just 2%, and is already way behind production from new (and apparently faulty) power stations that produce less than 5000 MW each. Moreover these power stations are almost all driven by burning coal, producing greenhouse gasses that will need to be seriously reduced within the next few years to avoid uncontrollable global warming and environmental pollution related to coal mining and associated acid mine water. New developments using conventional and unconventional gas may possibly help in this regard, but will likely also come at an environmental price.

Eskom says: load-shedding and less electricity is something the country will have to get used to until about 2020 – what a vision!

Should this be the moment for renewable energy to shine; and for capacity of homes to generate their own power?

Instead we see emergence of large mega projects costing billions to trillions of Rands: new nuclear power stations (the IRP 2010 stated that 23% of the country's energy mix would come from nuclear power by 2030), and investment by South Africa in hydropower from mega-dams to the north of South Africa (e.g. the total price tag for Inga III dam on the Congo River has been estimated between $50 billion and $80 billion, but these estimates are considered optimistic underestimates). So far the Inga project has spanned five decades to try and tap this massive energy potential, which, if realised, could supply up to 40,000 MW of electricity to half of Africa's 1 billion people. However, past experience has not been encouraging, and the environmental and social heritage costs may be incalculable. Can we afford all this?

Today the cost of going off the grid in South Africa is also prohibitive: a solar panel costs roughly R2500 to generate 200 Watts so that an average home would need about 20 panels. Batteries and other hidden costs may come to another R100 000. Moreover in South Africa Eskom refuses to buy electricity from homes that produce excess, as is the case in Germany for example.

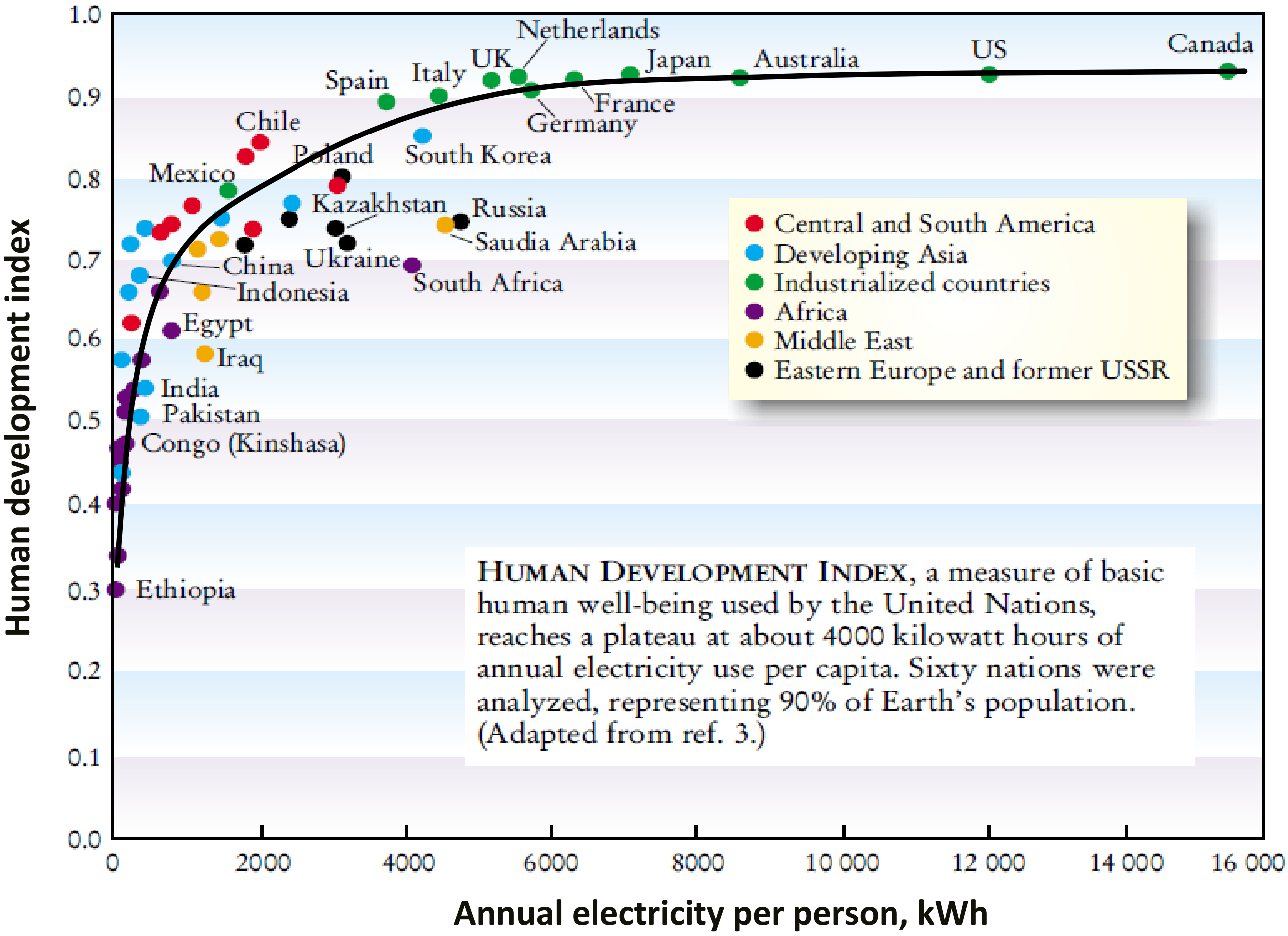
Going off the grid in small towns and villages, using solar, wind and biogas is growing elsewhere, but in South Africa this in very early development stages – less than 4000 MW has been tendered for (e.g. only 8% off the grid).

If we also factor into all this the clear relationship between the electricity use and the human development index (think poverty alleviation throughout Africa), then we are at a serious crossroad.

So what are the answers to a more sustainable energy solution in South Africa? This is a serious issue that needs robust solutions.

This Field Trip is designed to examine and discuss a number of issues that bear on these problems. We hope you will actively participate in discussions so we can all learn from each other to resolve some of these seemingly intractable problems facing you into the unforeseeable future.

Human development index and electricity consumption



- Non hydrocarbon resources: Shale gas

Rumours of Gas in the Karoo – Speculations about vast cheap energy wealth stacked away beneath the Karoo have reached fever pitch. But not all stakeholders agree, or are yet part of an on-going debate whether or not South Africa should even consider the potential value of this resource (for more information see: http://www.karooshalegas.org/).

Energy Security in South Africa (cont.)

Energy security is a complex and evolving concept. In South Africa's 2007 *Energy Security Masterplan*, energy security is defined as, "ensuring that diverse energy resources, in sustainable quantities and at affordable prices, are available to the South African economy in support of economic growth and poverty alleviation, taking into account environmental management requirements and interactions among economic sectors".

The challenges to energy security are disrupting supply of electricity, liquid fuels and energy resources to the economy and to the citizens of South Africa. Further, these challenges are undermining efforts to extend safe and reliable energy sources to those who do not have them and impairing the prospects for mitigating the prospective energy intensity of the economy. These challenges are not simply threats to energy security but indicate an energy security crisis, where the complex energy system is failing to maintain its functionality.

The electricity supply crisis is perhaps the most obvious of South Africa's current energy security crises, with emergencies in supply being declared in 2008 and once again in early 2014. While there have been recent successes, these are the exception and not substantial in the context of the challenges being faced.

South Africa's energy future still looks insecure despite Eskom's new build projects. Key sectors of the energy system are in crisis, evidenced by the protracted electricity generation capacity shortage, the South African Coal Roadmap alert of potential coal shortages by 2015 and the huge backlog in transport and re-distributor infrastructure investments and/or maintenance.

In March 2011, Department of Energy (DOE) published the 2010 Integrated Resource Plan for Electricity 2010-2030, which contained more than 18GW of renewable energy. With the Electricity Regulation Act (No. 4 of 2006) and the Electricity Regulations on new Generation Capacity to back it up, this was a watershed in electricity planning in South Africa. On the 3rd August 2011, DOE issued a Request for Proposals for the supply of 3,725 MW of renewable energy to the national grid, with a bid submission date set for November 2011. In December, 28 successful projects totalling 1,416 MW were selected. By the end of 2013, 64 projects for a total of 3,882 MW of renewable energy with foreign direct investment worth R150 billion had been secured. This includes 1,983 MW of Wind, 1,499 MW of PV and 400 MW of Concentrated Solar Power.

Multi-disciplinary research into South Africa's energy security situation is urgently needed to inform policy making going forward if the underlying causes of the crisis are to be addressed and the medium to long term risks mitigated.

[*Trollip, H., Butler, A., Burton, J., Caetano, T., Godinho, C (2014) Energy Security in South Africa. Cape Town, MAPS*]

4. Increased R&D Crucial for South Africa's Energy Future

Inadequate coordination, insufficient funding and skills shortages threaten South Africa's **energy future**.

ASSAf
ACADEMY OF SCIENCE OF SOUTH AFRICA
Applying scientific thinking in the service of society

These are among the findings of a consensus study entitled ***The State of Energy Research in South Africa*** released by the Academy of Science of South Africa.

The study is seen as an important baseline assessment that can inform future energy research investment in the country.

According to the study report, investments in coal research and development are inadequate despite the fact that coal will dominate South Africa's energy supply for the foreseeable future.

The study proposes that government departments with an energy budget establish a formal coordination mechanism, with a mandate to steer, plan and coordinate energy and energy-related R&D funded with public money, eliminate gaps and overlaps, taking into account national imperatives and priorities.

It is recommended that human capital development for energy areas aligned with the national energy agenda needs to be prioritised through the establishment of more research chairs, centres of competence and centres of excellence.

Other findings and recommendations of the study are:

- **GAS**: Significant R&D is needed in shale gas, which has the potential to provide a lower carbon medium-term energy future for South Africa. Research is needed on exploitation of the resource, techno-economic evaluations of exploitation pathways, environmental and other risks, risk abatement strategies and beneficiation strategies.
- **RENEWABLE ENERGY**: Significant R&D investment is needed to meet national targets and the penetration of renewable energy in South Africa should be increased through appropriate mechanisms.
- **NUCLEAR ENERGY**: The implications of delaying the nuclear decision in terms of the country's capability to support (any part of) the nuclear cycle, have to be evaluated and compared with alternative energy supply options.
- **ENERGY EFFICIENCY**: In spite of energy efficiency measures, the commitment to and adoption of energy efficient measures should be increased, *inter alia* by improving awareness and understanding of energy efficiency and effective incentives for participation in energy saving.
- **ENERGY ECONOMY and POLICY**: Comprehensive techno-economic feasibility studies are needed to inform the national energy R&D agenda, as well as the planning and legislative environment needed for effective implementation on a path to lower carbon and energy intensity.

[*www.assaf.org.za*]

- Example of health issues with coal in China, with relevance for Africa

"Evidence on the impact of sustained exposure to air pollution on life expectancy from China's Huai River policy". Yuyu Chen, 12936–12941, doi: 10.1073/pnas.1300018110.

This paper's findings suggest that an arbitrary Chinese policy that greatly increases total suspended particulates (TSPs) air pollution is causing the 500 million residents of northern China to lose more than 2.5 billion life years of life expectancy. The quasi-experimental empirical approach is based on China's Huai River policy, which provided free winter heating via the provision of coal for boilers in cities north of the Huai River but denied heat to the south. Using a regression discontinuity design based on distance from the Huai River, we find that ambient concentrations of TSPs are about 184 μg/m3 [95% confidence interval (CI): 61, 307] or 55% higher in the north. Further, the results indicate that life expectancies are about 5.5 y (95% CI: 0.8, 10.2) lower in the north owing to an increased incidence of cardiorespiratory mortality. More generally, the analysis suggests that long-term exposure to an additional 100 μg/m3 of TSPs is associated with a reduction in life expectancy at birth of about 3.0 y (95% CI: 0.4, 5.6).

Air quality in China is notoriously poor and recently has become an issue associated with increasing social unrest. Ambient concentrations of total suspended particulates (TSPs) between 1981–2001 were more than double China's National Annual Mean Ambient Air Quality Standard of 200 μg/m3 and five times the level that prevailed in the United States before the passage of the Clean Air Act in 1970. Furthermore, air quality is especially poor in Northern China, which is home to several of the world's most polluted cities. Following a career in the Southern China city of Shanghai, Premier Zhu Rongi reportedly quipped in 1999: "If I work in your Beijing [in Northern China], I would shorten my life at least five years".

This paper examines the health consequences of these extraordinary pollution levels by exploiting a seemingly arbitrary Chinese policy that produced dramatic differences in air quality within China. During the 1950–1980 period of central planning, the Chinese government established free winter heating of homes and offices via the provision of free coal for fuel boilers as a basic right. The combustion of coal in boilers is associated with the release of air pollutants, and in particular emission of particulate matter that can be extremely harmful to human health.

5. Information Notes

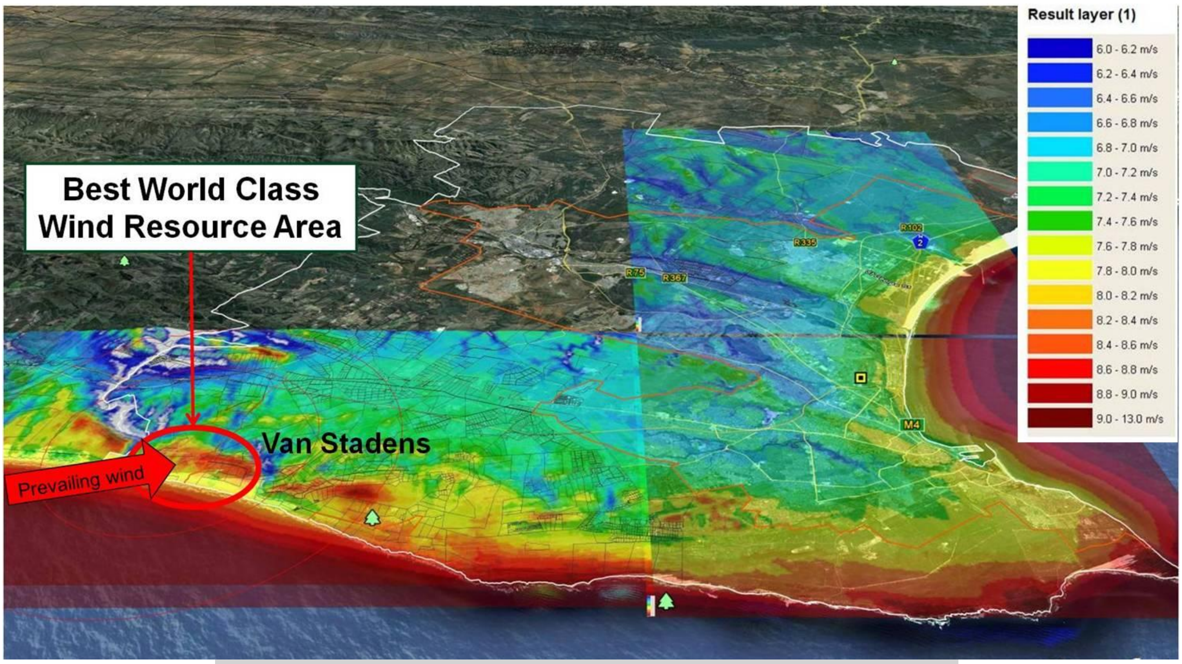
[More detailed brochures of the visited sites are attached to this guide.]

The tour begins by a drive along a picturesque and typical south-eastern Cape coastline. Folded and fractured quartzites and shales of the Cape Mountains form a series of headlands and bays. These hard rocks are cut at different elevations by marine terraces, and covered by pebbles and widespread aeolian dunes (about 100-300 m thick).

5.1 Wind Energy

The first stop of the tour is the **Metrowind Van Stadens** (MWVS) wind farm located some 30 kilometres west of Port Elizabeth, South Africa's renowned "windy city", in the remote south-western extremity of the Nelson Mandela Bay Municipality (NMBM). South Africa is richly endowed with some of the best renewable energy resources in the world because of its geographic location and geological formation, and the site of Van Stadens Wind Farm is no exception. Situated on the 34° south latitude and along the country's southern coast, the Van Stadens location receives an abundant supply of wind from across thousands of kilometres of Atlantic and Indian Ocean, making it a best-in-class wind site. Van Stadens is favourably and strategically situated in close proximity to the port of Coega and enjoys excellent road infrastructure.

On 2nd of February 2014 the 27MW wind farm has commenced commercial operations. The facility has been supplying electrical power to the regional grid since late November 2013. MWVS wind farm will sell renewable energy to ESKOM for the next twenty years.



Wind distribution along Nelson Mandela Metro Coastline

5.2 Sustainable Living

The next stop in the excursion is the Crossways Farm village and a tour of the **Rhino House**. After being initially conceptualised in 2011, the launch of the completed House Rhino is the culmination of vision, passion, dedication & great innovation, to deliver what is believed to be a first on the African continent – a pioneering green house, off-grid from energy, water & effluent perspectives, utilising the very latest in technologies, materials and capabilities. Built on an 1100m^2 stand, this 450m^2 home designed by CMAI Architects, has met with great acclaim from both local and international experts, thanks to the comprehensiveness of all that has been installed, covering both active and passive features.

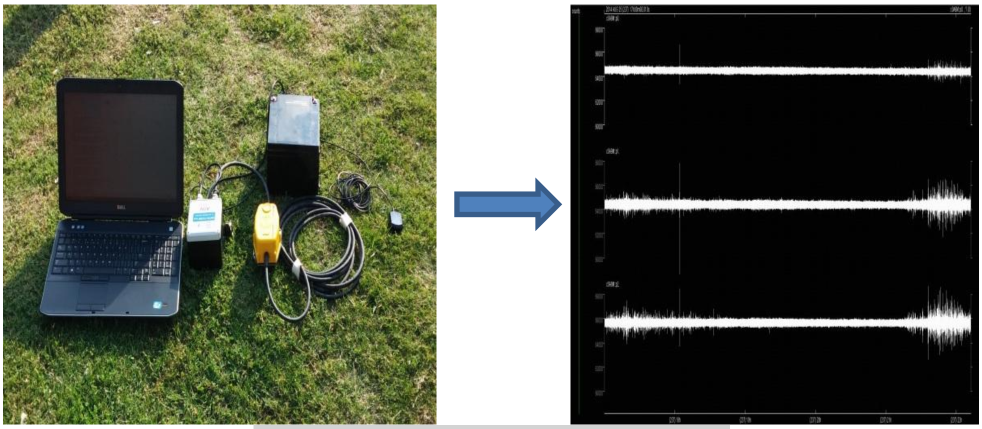
Layout of the Crossways Farm Village

5.3 Nuclear Energy

Continuing on, the journey of energy takes us to **Thyspunt** (Cape St Francis), the planned site of the new **nuclear** power station. The nuclear power stands on the border between humanity's greatest hopes and its deepest fears for the future. On one hand, atomic energy offers a clean energy alternative that frees us from the shackles of fossil fuel dependence. On the other, it summons images of disaster: quake-ruptured Japanese power plants belching radioactive steam, the dead zone surrounding Chernobyl's concrete sarcophagus. With the announcement of Eskom's plans to build the next Nuclear power station 70 km's South East from Port Elizabeth between Cape St Francis and Oyster Bay many discussions and debates have been provoked. The proposed 4000 MW station will cost in the region of R 300 Billion rand and could still be upgraded to produce up to 8000 MW of power. With the construction of these reactors the whole area will receive upgrades of existing roads and bridges over the Sand River that will have to be strengthened to accommodate the heavy vehicles transporting thousands of tons material procured by local suppliers. With the commitment of Eskom investing in the growth of the community many will benefit in the economic boom with a project of this magnitude. With the cost of electricity that rose almost 25% in the last two years projects like these are welcomed by the economy. Power outages and lack of supply of electricity cost businesses millions of Rands and puts more economic strain on economic growth in South Africa.

We will have a lunch and a discussion at Cape St Francis with emphasis on the geology of the area.

Table Mountain rocks have abundant joints and natural fractures, as well as some faults and inferred faults whose tectonic activity (or inactivity) must be determined before the implantation of the nuclear station. Also, this basement is eroded and covered by more recent marine and aeolian deposits. It is thus necessary to image the irregular surface of erosion and the thickness of overburden soft material. This can be done using passive seismic monitoring.



Seismic equipment and seismograph

5.4 Bio-fuel

In the afternoon, the excursion returns back to NMMU and a visit to **InnoVenton** (Institute of Chemical Technology). Here, innovative **algae-to-energy** project is focused on developing algae-based technologies for environmentally sustainable energy use and energy recycling. A custom-made algae biomass liquefaction reactor – the only one of its kind in the world – is successfully converting algae biomass into a bio-oil, not unlike crude oil, and other useful products.

InnoVenton director Prof. Ben Zeelie standing next to the photo-bioreactor

Micro-algae are used to convert harmful carbon dioxide from the atmosphere into crude oil, hydrogen gas and a water solution rich in sugars and proteins. The cultivation of micro-algae has the potential to play a significant role in the mitigation of carbon dioxide emissions. For every kilogram of algae biomass produced, about two kilograms of carbon dioxide have been taken out of the air.

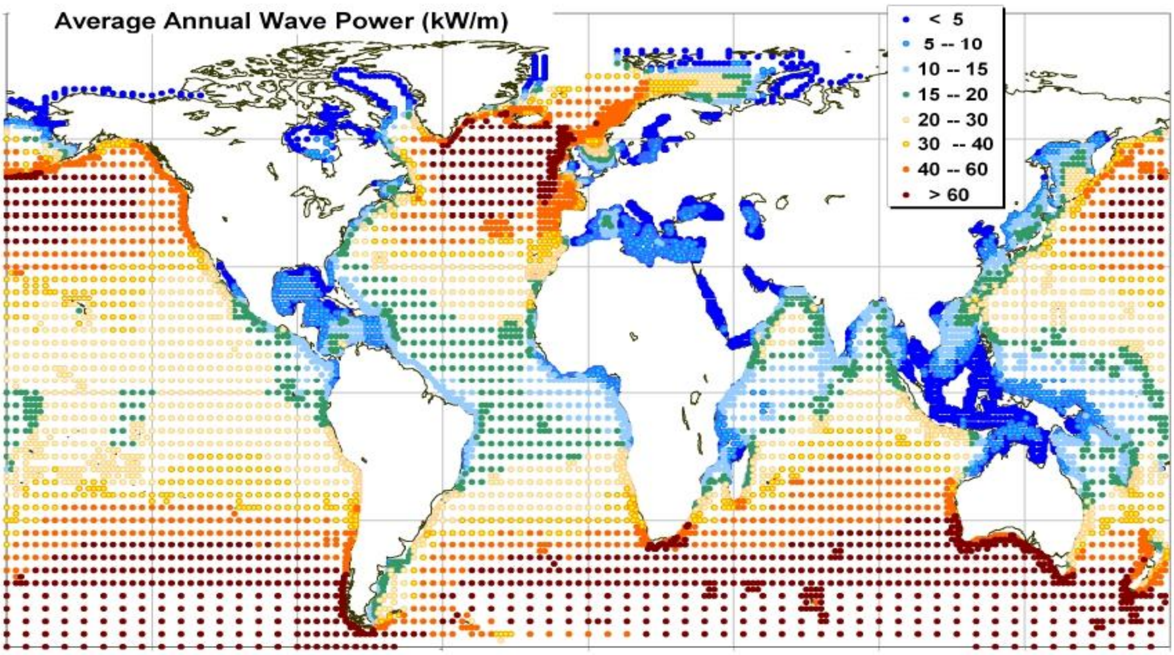
The algae can also be used to convert waste coal dust into a clean, high-quality coal which can readily be processed into biofuel. The **Coalgae** composites may be used as a substitute in applications that require coal, or may be further processed through a variety of additional technologies, such as pyrolysis (heating in the absence of oxygen). The result of the additional processing is a bio-fossil crude oil blend that may be processed into a variety of fuels, including gasoline, diesel, kerosene, aviation fuel, and heavy fuel oil.

5.5 Ocean Energy

The oceans of the world hold a large amount of energy and surely technology will advance to the point where this energy can be used to substitute other more harmful energy sources like oil, coal, and natural gas. Harnessing the energy from the ocean in an efficient and cost effective method would be a tremendous breakthrough in alternative energy research.

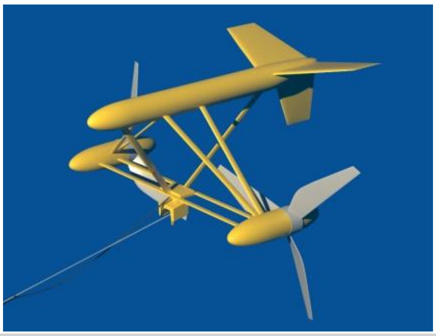
Eastern Cape Coastline

The problem with **current, tidal, and wave energies** is that they are not totally predictable. The demand for power is constant and these energy sources cannot supply continuous power as it is needed. That does not mean that these energy sources cannot be combined with other alternative renewable energy sources though, like biomass energy, wind energy, and solar energy. Eliminating dependence on fossil fuels may mean using a combination of different methods, one of which may be underwater energy sources.



Annual Average Wave Power

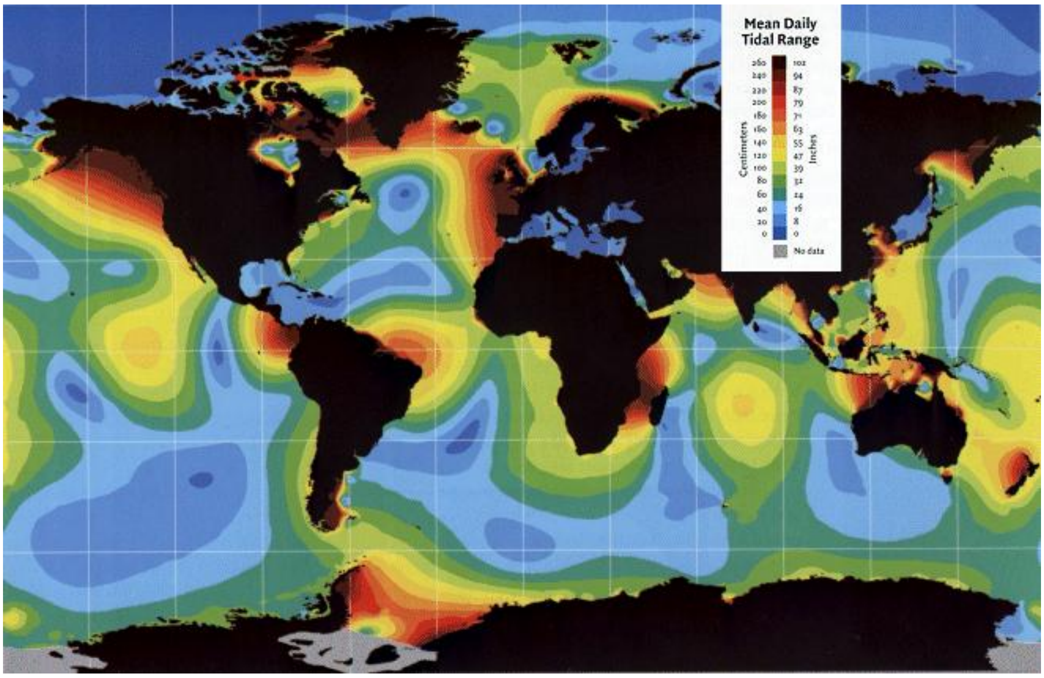
Underwater turbines are but one possible solution to capturing underwater energy from currents. These machines resemble wind turbines, only they are much stronger since they have to stand up to the force of the roughest currents where they are placed. The strength of ocean currents is strong enough to turn the underwater turbines and create electricity and other forms of energy.



Possible turbine for use in the Agulhas Current

Ocean thermal energy is another energy source available from the ocean. The surface of the ocean is warmed by the sun and a large temperature difference is seen between surface water and deeper water. This difference in temperature provides for thermal energy.

Mechanical energy is also available from the ocean. These energy sources include waves and tides. Tides are the result of the moon's gravitational pull and are found beneath the water's surface. Turbines can be used to capture this energy as well. These turbines must be placed carefully, concentrating on where tides are the strongest so that they can be most effective. Waves are also a source of energy, created by wind.



Mean daily tidal ranges

AFRI-COAST ENGINEERS SA

October 2014

SOUTH AFRICAN INSTITUTION OF CIVIL ENGINEERING

FINALIST FOR THE AWARD
FOR THE MOST OUTSTANDING CIVIL ENGINEERING ACHIEVEMENT

IN THE CATEGORY OF

TECHNICAL EXCELLENCE

METROWIND VAN STADENS WIND FARM PROJECT

MOTIVATION

The final implementation of this exceptional project is a product of in-depth investigation conducted over a number of years to identify a site with an excellent wind resource, through to successful submission of a bid to the Department of Energy, achieving financial close and conclusion of an EPC contract for the construction and commissioning of the wind farm within the extremely tight time frames.

Challenges included the finalisation of environmental authorisations amidst isolated public sceptics as well as the complex engineering design analysis to meet the diverse geotechnical in situ founding conditions experienced on site.

Environmental challenges were further compounded by sensitive protected plant species on site and the presence of localised areas being exposed during bulk earthworks, which were inhabited by the Khoisan tribe.

This project was the first wind farm construction project to commence from the first line bids advertised by the Department of Energy and also the first wind project to supply green energy into the national grid.

With a view to the diversity, complexity and engineering challenges presented by this project it warrants consideration for the award for Technical Excellence.

PROJECT DETAILS

The 27MW Metrowind van Stadens wind farm is located approximately 45km from Port Elizabeth and situated on a high-lying area adjacent to Van Stadens River Mouth.

The wind farm comprises 9 No 3 MW turbines, 7 km of gravel access roads, internal electrical reticulation, various substation buildings and a 10km overhead transmission line linking to the Fitches Corner substation.

The overall value of the project was approximately R590 million and was finally commissioned during February 2014.

With respect to the Civil, Structural and Building works, the following statistical information is applicable:

- Value of Works: R65 000 000
- Commencement date: November 2012
- Scheduled completion date: October 2013
- Actual Completion date: August 2013.
- Windfarm commercial operation date February 2014

The Project completed within budget and within the allocated time

DESIGN & IMPLEMENTATION

Project Design and Implementation was carried out under EPC Contractor, Basil Read Matomo. Afri-Coast Engineers were appointed to design and oversee the construction of all civil, structural & building works. The construction of the civil, building and structural works were carried out by locally-based Newport Construction

DESIGN

The design of the access roads on site required careful consideration of the extreme loads comprising turbine components transported onto the site and to each turbine position. Stringent vertical and horizontal geometric criteria had to be adhered to, as well as the design of the road layer works to cater for the abnormal wheel loads. Each turbine site was provided with an erection platform and turbine component laydown areas.

Turbine design criteria;

Overall mass of turbine (tower, nacelle, hub and blades)	440 t
Height to top of nacelle	95 m
Blade length (each)	55 m
Foundation volume of concrete	650 m^3
Foundation reinforcing steel mass	65 t

Extensive geotechnical investigations were undertaken prior to carrying out the design and included trial holes, DCP's and drilling at each of the turbine sites. Detailed recording of in situ materials encountered during the excavation and drilling process. Soil samples were taken for further laboratory analysis so as to make sufficient information available for design purposes.

Significant variations in the in situ material were encountered at the various turbine sites and it was concluded that additional precautionary measures would be required at three of the nine turbine sites whilst preparing the founding conditions.

Initially consideration was given to possibly introducing piled foundations at the three turbine positions referred to above. However, the costs of piling proved to be prohibitive and not necessarily ideal in these conditions.

The overall structural design was complex as the analysis of extreme wind conditions, dynamic loads and turbine-induced frequency considerations had to be factored into the design calculations.

CONSTRUCTION

Despite the extensive geotechnical investigations carried out initially the excavations undertaken for the foundations revealed localised pockets of poor founding material. This required the additional Continuous Surface Wave (CSW) testing to be conducted. This method of testing is effective up to and exceeding depths of 6 metres, dependent on the type of material being tested. The CSW testing was conducted after completion of the compaction of the in situ foundation material and proved to expose further areas of weakness in the foundation material.

The following supplementary precautionary measures were consequently decided upon:

- Carry out Dynamic Compaction at the base of each foundation after completion of the excavation, followed by compaction with a 16t vibratory roller
- In instances pockets of unstable material were removed and replaced with compacted rock-fill
- At two turbine positions drilling and grouting (to 6m depth) was carried out around the perimeter of turbine bases at 600mm centres and grout needles pumped into the drilled cavity.
- Introduction of a geotextile Triaxial Geogrid prior to construction of layer works
- Construction of 900mm of imported engineered layer works under foundations

Another critical feature was the design of a concrete mix which would be suitable for the construction of the turbine bases. It was required that the 650 cubic metre foundations be cast in a single pour. Heat of hydration in the concrete during the pour and initial curing period was a real concern, particularly during the hot summer months where the ambient temperature would play a significant role in high concrete temperatures.

Various mix designs were specified and a number of trial mixes prepared from which cubes were cast. The introduction of admixtures and various quantities of fly ash to these mix designs was specified. The focus was to optimise the amount of fly ash, for heat of hydration control, without retarding the curing period of the concrete. These cubes were crushed and tested at 7, 14 & 28 days and a suitable mix design selected. It was found that a 50/50 cement/fly ash ratio was suitable for the hot summer period and a 60/40 cement/fly ash ratio was better suited for the colder winter period.

Strict continuous monitoring of concrete temperatures were recorded via strategically located temperature probes inside the concrete foundations and maintained for a period of 7 days after each pour. All temperatures recorded at all foundations were found to be well within the allowable maximum temperatures.

The accuracy of the turbine embedment rings, which were cast into the foundations, required extreme accuracy where levels were checked prior to each pour and monitored on an ongoing basis for at least one month after each pour, to monitor for settlement of the concrete foundation and turbine. Laser levelling was used to ensure extreme accuracy.

Other challenges encountered during the early stages whilst constructing the site access roads arose when pockets of shells were exposed in the excavations. These were identified as having historical significance and were areas inhabited by the Khoisan tribe many years ago. These had to be exposed and areas demarcated as no-go areas. Roads were redesigned around these areas in an effort to protect these areas.

Transportation and erection of turbines posed its own challenges and specialised ships were required with their own cranes, as some of components exceeded the capacity of the cranes in the Nqura Port. The finger jetty also needed upgrading for temporary storage of the components before transportation to site.

The foundation embedment rings were shipped early so that they could be cast into the concrete foundations.

Afri-Coast Engineers undertook a detailed transport route assessment to site. This identified that the Nacelles required to be transported over a different route as certain bridges over the N2 were not high enough for the Nacelles to pass under the bridges.

Special snappel connector trucks were required to transport the tower sections and road radii required enlarging to accommodate the 55m long turbine blades.

A special 130t crane with extended boom capacity was required to lift the 120t Nacelle onto the tower section.

QUALITY CONTROL AND PROJECT REVIEW

Afri-Coast Engineers' designs for Civil and Structural works were reviewed by highly acclaimed international consultants, Sargent and Lundy, who have been involved with multiple wind farm designs internationally. The design reports and drawings were checked and all designs signed off for approval.

During construction very detailed Quality Control measures were implemented and all site records were reviewed and approved, also by Sargent and Lundy.

PHOTOGRAPHS

Turbine base excavation showing dynamic compaction imprints prior to being backfilled

Turbine foundations after placement of Triaxial Geogrid and commencement of engineered layer-works

Turbine foundation ready for concrete pour

Turbine concrete foundation being backfilled and compacted

Metrowind van Stadens Windfarm erection of turbines nearing completion

Welcome to House Rhino

After being initially conceptualised in 2011, the launch of the completed House Rhino is the culmination of vision, passion, dedication & great innovation, to deliver what is believed to be a first on the African continent – a pioneering green house, off-grid from energy, water & effluent perspectives, utilising the very latest in technologies, materials and capabilities.

Built on an 1100m2 stand, this 450m2 home designed by CMAI Architects, has met with great acclaim from both local and international experts, thanks to the comprehensiveness of all that has been installed, covering both active and passive features.

As such, House Rhino is a showcase for the carefully selected & diverse range of solutions offered by The Rhino Group of Companies. Whilst an architectural gem, it demonstrates options for all building types.

Let's take a brief wander through this extraordinary residence….and discover the future of green living……………

- ✓ The house is powered by roof-mounted solar photovoltaic panels, with a bank of zero-maintenance batteries charged by two inverters, giving the house autonomy. Further panels power the pool pump during daylight hours.
- ✓ Active & passive energy saving achieved through LED lighting; energy-saving taps & shower heads; flat-plate solar water heating & heat pumps; double glazed windows; polycarb sheeting for light harvesting, including through skylights; underfloor heating through solar heated & stored water, along with water heating from the fireplace; gas cooking from recycled organic waste; Envirotuff roofing insulation, etc. Cooling of the house achieved through a thermal tower that extracts warm air via the highest point, passively, as well as through piped underfloor water cooling. The wine cooler benefits similarly.
- ✓ Water sustainability achieved through significant rainwater harvesting, storage and recycling. 30,000l of storage tanks. Harvested & waste water treated using ozone and filters. Aquagardens, that form part of a complete loop along with reed bed systems, serve to naturally purify waste water. Such a loop includes the swimming pool. The driveway is made from the porous concrete product Hydromedia – all rainwater drains immediately and is collected underneath before flowing into the water recycling process.
- ✓ The house was built with Aruba blocks, which offer not only vastly accelerated construction time, but also a threefold improvement in insulation value versus traditional brick, due to its' own insulation properties and reduced need for heating/cooling in the house.
- ✓ Recycled materials have been used extensively, including the decking, natural rock features and with cupboards & counters made from shutterboard. Even the roof-garden veggie boxes are made from recycled plastic. Baths, basins, flooring and counter-tops are from concrete.

Rooftop veggie garden, solar in background.

Demonstration of porous Hydromedia concrete driveway for water harvesting

Aquagarden water purification

Recycled plastic decking, stone from site for pizza oven

NATURAL GAS IN THE EMERGING GLOBAL ENERGY LANDSCAPE

Patricia M. Dove

Energy was not on the mind of Heraclitus of Ephesus (circa 500 BCE) when he wrote "The only constant is change." However, his words ring true as you read this issue of *Elements*. Within a decade, the energy world has witnessed a tectonic shift that is roiling the international economic, political, and environmental landscapes. Technological advances, made largely by the Canadian and United States oil and gas industries, have converted North America from a gas-importing to a gas-exporting continent. Had the "shale boom" never happened, the US would currently be importing more than 280 million cubic meters of natural gas per day (*New York Times*, April 2014). Today, the US is poised to export an equal amount as liquefied natural gas (LNG).

This new abundance of "unconventional" energy, and the recent technologies that made it possible, are giving rise to a global energy market with a complex web of implications for regions, nations, and indeed, entire continents. The most obvious of these implications concerns energy pricing and the energy dependence of nations. Western Europe is the largest energy importer in the world with increasing needs as one travels eastward. While natural gas prices in the US are near unprecedented lows, recent tensions between Russia and Ukraine are threatening to further increase energy costs throughout the European Union. Incredibly, the price of electricity in Europe is already approximately triple that of the US. This has leaders of the EU pushing to restart the stalled negotiations regarding Russia-Ukraine gas pricing (*Moscow Times*, June 2014), redoubling their efforts to diversify the EU's energy portfolio (Reuters, May 2014), and in some cases, moving hydrocarbon-based chemical industries abroad (*Wall Street Journal*, May 2014).

Within a decade, the energy world has witnessed a tectonic shift that is roiling the international economic, political, and environmental landscapes.

For decades, energy security has been an important issue for Europe. Many favor developing local sources as a way to diversify their energy portfolios. Indeed, European efforts to increase the proportion of renewable energy sources are the envy of the world. But can renewable energy keep up with demand? For some, the potential for developing shale gas within Europe offers a local tap that is tempting. According to a 2013 US Energy Information Association report, there are significant resources in Poland (4 trillion cubic meters), France (3.8 trillion cubic meters), the UK (0.7 trillion cubic meters), and Germany (0.5 trillion cubic meters) (*Wall Street Journal*, March 2014). Those are impressive energy assets when one considers that the average yearly per capita consumption of natural gas in France and Germany is 758 and 1224 m^3, respectively (EIA, 2012).

But wait, not so fast! The circumstances that gave rise to the growth of natural gas production in North America are different from the situation in Europe. Europe lacks some of the natural advantages found in North America, with a higher population density that limits the space available for large gas-production facilities, geologic formations that are more costly to develop, and the fact that European landowners are not entitled to profit from gas extracted beneath their own property. Additional impediments include water availability and environmental concerns. These issues led France to ban hydraulic fracturing for gas and oil despite the belief by some analysts that France sits atop potentially highly productive natural gas fields (*Le Monde*, June 2013). There is similar widespread resistance to shale development in the UK.

Meaningful solutions to energy needs will take time. For example, the Canadian government desires new markets for shale gas exported as LNG. However, in recent bilateral discussions, German Chancellor Merkel and Canadian Prime Minister Harper reiterated that significant infrastructure will be required to make this a reality (Canadian Press, May 2014). New pipelines, gas conversion plants, and shipping terminals will be necessary to export from the Canadian east coast. Each of these facilities is a massive and costly project that typically requires 6–8 years to complete. Similar export challenges are unfolding in the US, Australia, Africa, and the Middle East. For example, the first LNG export terminal in the US will finally be fully functioning in 2015, and that gas is already spoken for. Half of that gas has been contracted by India and South Korea, while the rest will go to British and Spanish suppliers (*New York Times*, April 2014). This is another reminder that energy is transitioning to a globalized commodity and the demand is high.

Nevertheless, the energy industry is currently unconvinced there is sufficient economic incentive to justify such large new investments. How is that possible, you ask? Well, it is important to remember that the government of Nation X doesn't ship gas to the government of Nation Y. Private companies sell gas to private companies that buy gas. This economic reality check also raises the issue that shipping LNG to Europe is a two-point problem. That is, receiving LNG requires similarly enormous investments in regasification terminals and distribution systems. While two European terminals are scheduled for completion within a few months and six more are currently under construction, many more will be needed to significantly reduce natural gas costs and satisfy regional demands.

Current events suggest that more transformations in the energy market are on the horizon. The energy conversation, traditionally focused on the distribution of resources from the Middle East, is

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THIS ISSUE

We now have the capacity to exploit economically gas and oil shale, oil sands, and heavy oil in spite of additional technology, energy, and cost requirements. Guest editors David Cole and Michael Arthur and the authors of this issue address the geological and geochemical nature of these resources and their impact on global socioeconomics and the environment. Rounding out the issue are two Perspective articles, on shale gas exploitation and the need for geoscientists to become involved, and Patricia Dove's editorial, which reflects on the global political context.

While working on this issue, I received the following e-mail: "Your next issue, 'Unconventional Hydrocarbons,' sounds terrifying. The environmental devastation caused by 'fracking,' 'tar sands,' and other processes is off the scale. We should be moving away from hydrocarbons and looking towards a carbon-free future…it is entirely possible." This comment illustrates well one side of the polarized debate surrounding unconventional oil and gas. In Quebec, legislation was tabled in 2013 to put a moratorium on exploration and exploitation for shale gas, but the bill died when the government called an election. But even exploration for conventional resources is controversial in some areas. Recently, aboriginal groups in Canada made an official request for a moratorium on oil and gas exploration in the Gulf of St. Lawrence "until a comprehensive environmental assessment is done." The St. Lawrence coalition, made up of environmental groups, First Nations, and fishery representatives from five provinces, is also pushing for a moratorium on exploration for oil and gas in this area because "too little is known about the possible effects of oil and gas projects on the gulf's fragile ecosystem to proceed with them in its waters." Exploration for any resource can no longer be made in isolation. Companies need to earn a "social license" to operate, and that can only be done by informing and involving the local populations and working closely with regulatory agencies.

EDITORIAL MEETING

We welcomed Jodi Rosso, incoming executive editor, and Bernie Wood, incoming principal editor, to our day-long annual meeting, held prior to the Goldschmidt Conference. We reviewed thematic issues currently in preparation, proposals received for potential inclusion in the 2016 lineup, and various editorial questions. Founding Editor Rod Ewing and Dan Frost, member of the Executive Committee standing in for Chair Barb Dutrow, joined us for a brainstorming session during which we discussed open access, how to make *Elements* even more relevant, and online and social media presence.

At Goldschmidt, we celebrated *Elements*' first ten years with the union session "Elements: 10 Years Old (see page 313), and a dinner with past and principal editors and members of the Executive Committee was held at Cafeteria 15L.

PETER ROEDER

Many of us mourn the passing of Peter Roeder (see obituary, page 298). Peter was my MSc supervisor. He was a great scientist, but he will be remembered even more for his kindness and gentle ways. He and his wife Claire welcomed countless students to their home. I remember well some of the grad parties at their house, with Claire's wonderful cooking. After we left Queen's, my husband and I would stop by every few years to show off our growing children, and we were always welcomed like family. Peter also had a great influence on my career: In 1994 while he was president of the Mineralogical Association of Canada, he asked me the join its outreach committee. This invitation was the beginning of my long involvement with MAC, which eventually brought me to *Elements*.

Pierrette Tremblay, Executive Editor

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pausing to hear the tummy rumble of energy-hungry China. Eager to wean its economy from energy imports and coal, Beijing has set an ambitious target of producing 60–100 billion cubic meters of gas per year by 2020 (*Wall Street Journal*, March 2014). It is quite possible that China will become an energy producer, with early estimates projecting that the Sichuan and Tarim basins contain massive gas reserves on the same order as those of the Marcellus Shale (US EIA report). Because water supply will be a major challenge, Chinese national companies are partnering with Royal Dutch Shell and US firms to adopt new low-water-use technologies. These events suggest the possibility of another tectonic shift, with the emergence of new Far East energy giants.

With the prospect of a truly globalized energy economy comes the reminder that we must consider environmental impacts. History seems to repeat itself, with the drive to frantically mine Earth resources and then leave behind environmental legacies with tremendous societal and ecological costs. Can it be different this time? As we rush forward to develop unconventional energy sources, can new technologies evolve in the "right" ways? We have an opportunity to write a new energy legacy that includes more environmental wisdom and foresight than before. In the bigger picture, such a change in mindset could also guide us toward solving other complex issues, with far-reaching benefits for humankind.

Patricia M. Dove
Principal Editor in charge of this issue

GEOSCIENTISTS MUST GET INVOLVED IN DEFINING CURRENT AND FUTURE DIRECTIONS IN ENERGY PRODUCTION AND IMPACT EVALUATION

John Chermak*

1811-5209/13/0010-250$2.50 DOI: 10.2113/gselements.10.4.250

As the human population continues to grow, global demand for energy is certain to increase. The consequences of this increase in parallel with expectations for a higher standard of living pose many critical questions about the future of our planet. How much energy will be needed by more than 7 billion people in 2020? 2040? Where will this energy come from? How are we going to manage the impacts of resource extraction? Is there such a thing as sustainable, nonrenewable energy? What can be done to encourage energy conservation and increase efficiency?

To answer these questions and understand the impact of humans on Earth, the expertise of geoscientists will be critical. Our understanding of the geosphere, atmosphere, biosphere, and hydrosphere and the associated processes is needed to guide the public and other stakeholders in the myriad of challenges that we face. Geoscientists must take more active roles in leading energy-related conversations with decision makers in government and industry.

A déjà vu is emerging with the current increase in the production of unconventional hydrocarbons in North America. Senior geoscientists recall the past boom and bust cycles associated with hydrocarbons and have witnessed the environmental and social consequences that follow depletion of a local resource or a substantial drop in price. It will be interesting to see how our choices unfold in the coming years and whether the shale gas boom will lead to another boom/bust cycle.

This issue of *Elements* evaluates many of these broad, energy-related questions in regards to unconventional hydrocarbon extraction. The articles describe cutting-edge thinking and discuss challenges in the area of resource extraction and impact mitigation for both petroleum and natural gas extraction. They point to a number of areas where we can expect this type of resource extraction to potentially impact water, land, air, biota, and humans. While the specifics of these articles are largely focused on North America, many of the current and forthcoming lessons are certain to have global applications.

Over the years of my career in resource recovery and impact analysis, and more recently with unconventional hydrocarbons, I have made a number of observations related to extraction (for example, Chermak and Schreiber 2014). Resource-extraction projects always begin by defining economic, environmental, health, and social impacts, both positive and negative. There is a formal process in the US for evaluating impacts and mitigation strategies during resource-extraction activities, with the development of an Environmental Impact Assessment, a Social Impact Assessment, and a Health Impact Assessment (Vanclay 1999; NYS DEC 2009). The process promotes communications between industry, regulators, and stakeholders during planning for the extraction of a resource. Negative impacts can be thought of as project risks, and this concept is discussed in the following Perspective by Zoback and Arent. Their figure 2 highlights some of the potential risks posed by unconventional hydrocarbon extraction to water, land, the atmosphere, and the community.

In North America, each well needs to have a project plan that is communicated to all groups. The plan should include information such as the number and type of workers to be used, equipment, costs, recovery estimates, efficiency, schedule, and economics. Exploration, construction, operation, and closure activities should all be considered. Once the plan is defined and finalized, the project is then analyzed for impacts. If the plan is modified, the evaluation of the project needs to be updated. Pre- and postproduction monitoring requirements must also be determined (i.e. groundwater sampling) so that impacts can be assessed, mitigation proposed, and communication pathways identified. Geoscientists assume many roles in developing these plans, and critical areas such as resource recovery-percentage estimates and optimization are critical to accurately determining the economics of a project.

Economic impacts from the current North American unconventional hydrocarbon boom are substantial, and many are summarized by Blumsack (2014 this issue). The big winners in North America are currently the consumers, due to increased supplies, cheap natural gas prices, and new jobs, and the US economy, with increasing petroleum/gas production (EIA 2014).

Environmental impact analysis from a project plan is a well-developed process. Mitigation methods are chosen based on a cost/benefit/risk analysis of the project. These mitigation decisions can impact the economics of the project. As an example, a cost/benefit/risk analysis can be applied to wastewater disposal by comparing injection with treatment and discharge. Subsurface wastewater injection is significantly cheaper than treatment and discharge but carries higher risks.

An example of an atmospheric impact reduction in the US that was primarily caused by the switching from coal to natural gas in electricity generation can be seen in CO_2 emissions data. In 2012, CO_2 emissions were more than 12 percent below 2007 peak emissions (EIA 2014). The atmospheric emission data on methane release from unconventional gas extraction and use as compared to coal are still being collected and interpreted, but if unconventional hydrocarbon extraction and use can be conducted with minor methane release, this would be a positive change in the current US greenhouse gas emission situation.

Data on the social impacts to individuals and communities associated with unconventional hydrocarbon extraction are also being collected and assessed. Social impacts can be significant during the transformation of a rural environment into a temporary industrial setting. Decisions about the mitigation of impacts are being made by industry from the analyses of consultants and others, but these internal documents are often not publicly available or communicated to the public. This lack of communication prevents further evaluation and critical discussions with stakeholders to promote community engagement and understanding, and to manage expectations. There currently is little or no public/academic viewing of these documents, when they exist; thus there is little or no opportunity for lessons learned to be developed, and operators may be spending money on social impact mitigation without being very effective.

The state of Pennsylvania has recognized that some of the social impacts associated with unconventional hydrocarbon extraction were not being mitigated appropriately. A good example is road and infrastructure upkeep and maintenance. In response, the state implemented Act 13 in 2013. This oil and gas law essentially charges an "impact fee" to operators for drilling, and the fee is distributed back to the local government (http://stateimpact.npr.org/pennsylvania/tag/impact-fee/). The concept of sustainable development is still not very prevalent in North American unconventional hydrocarbon extraction but is fairly well developed in international resource-extraction activities. Investments in this approach are proving to be worth considering, for example, in areas such as schools, training, etc., to help obtain/maintain a social license to operate (Vanclay 2006).

Another important social aspect to unconventional energy extraction is the education of stakeholders. To value resources, the public needs to know more about the project plan and impacts. This communication is essential to building a better appreciation of what goes into supplying fuels for transportation or producing electricity. An understanding that impacts and impact mitigation are part of the resource development

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faults or into formations immediately above crystalline basement, in which case pressure changes in the injection zone might affect potentially active faults in basement.

Fundamentally, whether one is addressing the potential risks associated with earthquake triggering, contamination due to poor well construction, or methane leakage, the solutions come down to all of the stakeholders—oil and gas operators, regulatory authorities, utilities, and the public—being proactive about dealing with the associated environmental impacts. As we noted at the outset, switching from coal to natural gas for electrical power generation could have profound and far-reaching benefits; however, to realize these benefits, shale gas resources must be developed in an environmentally responsible manner.

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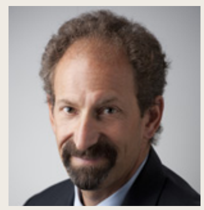

Douglas J. Arent is the executive director of the Joint Institute for Strategic Energy Analysis at the National Renewable Energy Laboratory and the acting director of the Strategic Energy Analysis Center. His research interests are centered on energy and sustainability. Arent was a coordinating lead author for the 5th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). He was a member of the Policy Subcommittee of the National Petroleum Council study entitled "Prudent Development of North America Natural Gas and Oil Resources".

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process needs to be communicated. In these discussions, it is critical that stakeholders learn how they can obtain credible information.

What will the future of energy look like? This is a difficult question to answer. The growth in consumption is projected to be primarily in developing countries / emerging economies such as China and India. This is a critical point because significant steps toward reducing CO_2 emissions in the short term will require more conservation and increased efficiency as well as a faster transition from coal to natural gas in China and India. Ultimately, the high-growth energy consumers will have to transition rapidly to renewables for the largest potential reductions in greenhouse gas emissions and for a sustainable energy future. But it is difficult to say if this is a realistic expectation. As one looks to other energy opportunities, the role the nuclear option will have in supplying global energy is debatable.

From a global energy perspective, scientists and engineers generally agree that a technological breakthrough in renewable energy is necessary. The long-term goal is to reduce cost and increase efficiency such that a global-scale transformation from nonrenewable to renewable energy could occur. Such a breakthrough would give a truly sustainable energy future to us all. Still, impacts from renewable energy sources must be understood and managed.

It is poignant to consider a visionary statement by Thomas Edison that refers to nonrenewable versus renewable energy. During a discussion with Henry Ford and Harvey Firestone in 1931, Mr. Edison said, *"We are like tenant farmers chopping down the fence around our house for fuel when we should be using Nature's inexhaustible sources of energy—sun, wind and tide. I'd put my money on the sun and solar energy. What a source of power! I hope we don't have to wait until oil and coal run out before we tackle that."* At the present time, we are unfortunately nowhere close to attaining this vision. In 2013, the United States used approximately 91% nonrenewable energy and 9% renewable energy, while world use was estimated at 89% nonrenewable and 11% renewable energy (EIA 2014).

The expansion of natural gas production is upon us. Geoscientists are uniquely positioned to lead the effort to create a balance between extracting this resource and managing impacts. As a college professor to hundreds of undergraduates each year and as a parent, I cannot overemphasize how important it is for the geoscience community to engage in the discussion about how to balance global energy needs with environmental and societal needs. To transform the black box of energy extraction into an informed process, stakeholders, politicians, and the public need geoscientists to communicate their interdisciplinary insights. If we don't initiate these discussions, who will?

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THE OPPORTUNITIES AND CHALLENGES OF SUSTAINABLE SHALE GAS DEVELOPMENT[1]

Mark D. Zoback[2] and Douglas J. Arent[3]

1811-5209/13/0010-251$2.50 DOI: 10.2113/gselements.10.4.251

Horizontal drilling and multistage hydraulic fracturing technologies have enabled the rapid expansion of natural gas production from organic-rich shale formations around the world. Abundant new supplies of natural gas have made possible large-scale fuel switching—from coal to natural gas—in electrical power generation in the United States. This fuel substitution has had beneficial effects on air pollution and greenhouse gas emissions, along with significant economic impacts as a fuel for consumers and industry. But fuel switching to natural gas will not be sufficient by itself to combat long-term climate change; further decarbonization by eventually switching to noncarbon energy sources will also be required. In this context, global shale gas resources represent a critically important transition fuel on the path to a decarbonized energy future.

For the benefits of natural gas to be realized, however, it is imperative that the resources are developed with effective environmental safeguards to reduce the impacts of development on water resources, air quality, ecosystems, and nearby communities. It is equally important that countries around the world implement energy policies that encourage the environmentally responsible development of shale gas resources while continuing to develop and deploy renewable energy sources.

Geologists have long known that large amounts of organic matter and natural gas are trapped (usually by clay and other fine-grained minerals) in low-permeability, organic-rich shale formations. Because of the shale's extremely low permeability (on average about 6 orders of magnitude lower than in conventional gas reservoirs), it is only through the use of horizontal drilling and multistage hydraulic fracturing that commercial quantities of natural gas can be produced.

As reviewed by King (2012), typical shale gas development operations proceed as follows: First, the operator drills a vertical wellbore to near the depth of the shale (Fig. 1), typically about 2–3 km. After drilling, steel casing is cemented into the well to stabilize the rocks surrounding the wellbore and prevent well fluids from contaminating the geologic formations drilled through. It is particularly important to protect shallow aquifers from contamination. Then, when the vertical well almost reaches the depth of the shale, the well is progressively deviated until its trajectory is near horizontal and lies within the layer of shale that contains the natural gas. The length of this horizontal section averages about 1.5 km, although this varies by region. After drilling, the horizontal section of the well is usually fully cased and cemented. Small explosive devices are used to sequentially shoot holes through the casing and cement to enable the well to be hydraulically fractured in stages, starting at the toe of the well (the most distant part) and working back toward the heel (closest to the vertical section). A wellbore that extends 1.5 km laterally may be hydraulically fractured in 10 to 20 stages, spaced more-or-less evenly along its length. During hydraulic fracturing, the formation is pressurized to extend fractures through the shale. Fracturing fluids used for shale gas formations are commonly 99 percent water and sand (the latter is used as a proppant to hold open the hydraulic fractures after the well goes into production.) The website Frac Focus (www.fracfocus.org) lists many of the commonly used hydraulic fracturing fluids and chemical additives.

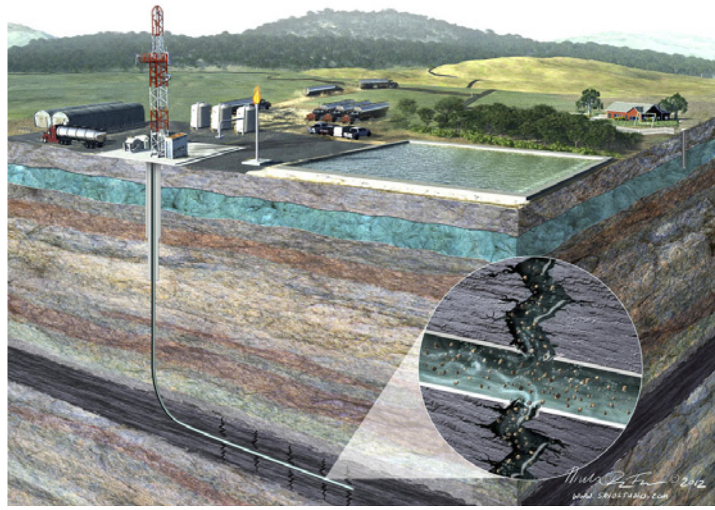

Figure 1 Artist's rendering of a horizontal well drilled for shale gas production (courtesy N. Fuller, SayoStudio.com). Typically, the vertical section of the well is drilled, cased, and cemented to a depth of 2–3 km and then the well is drilled horizontally through the shale for about 1.5 km.

Pad drilling is a common practice in which multiple wells (commonly 4 to 12, but as many as 75) are drilled at the same site to optimize the efficiency of drilling and hydraulic fracturing operations. At a given pad, the wells are drilled, cased, and cemented in sequence. After the drilling is completed and the drill rig and drilling equipment removed from the site, hydraulic fracturing equipment is brought to the site and operations commence. This type of operation, which is usually completed at a given site over a few months, dramatically reduces the amount of land needed for drilling, new road and pipeline construction, etc., and thus the overall impact of shale gas development on communities and ecosystems.

OPPORTUNITIES

A number of gains are already apparent from the widespread development of North American shale gas resources. These include the direct economic benefits of jobs created, taxes paid, the overall stimulus associated with development activities, and the royalty payments to the mineral interest owners. According to IHS (2014), unconventional gas development in the United States in 2015 is expected to be responsible for approximately 1.5 million jobs, $50 billion in federal, state, and local taxes, and an overall contribution to the US economy of $200 billion. Both the number of jobs and the economic benefits are expected to roughly double by 2020.

When natural gas is used for electrical power generation in place of coal, it has the potential to reduce postcombustion CO_2 emissions by about 50 percent. In the United States, the switch from coal to natural gas over the past six years, along with other factors such as the cumulative impacts of energy-efficiency measures and the increased use of renewable electricity, has resulted in a marked decrease in CO_2 emissions. A substantial shift from coal to natural gas, particularly given the enormous reserves in China, Australia, South Africa, Argentina, and countries in Europe, could result in a significant reduction in global CO_2 emissions. In China, coal-generated electricity currently produces about 7 billion tonnes of CO_2 each year (over 3 times the emissions in the United States). The anticipated growth in energy consumption in China over the next ~25 years could double these emissions without abatement action. Because using natural gas to generate electricity produces negligible NO_x, SO_x, Hg, and particulates, switching from

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1 A longer version of this perspective originally appeared in the Spring 2014 edition of *The Bridge*, published by the National Academy of Engineering.

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coal to natural gas would lead to significant and immediate health and quality-of-life improvements, especially in large urban centers in countries like China and India.

LIMITING THE ENVIRONMENTAL IMPACTS OF SHALE GAS DEVELOPMENT

Production of large amounts of shale gas resources is a large-scale industrial process that, over time, will involve drilling tens of thousands of wells, carrying out hundreds of thousands of hydraulic fracturing operations, and building numerous roads and pipelines. Environmental issues generally fall into four main categories—air, land, water, and community (Fig. 2)—and shale gas development may affect them all. We briefly address three issues about which there has been widespread concern: potential contamination of groundwater by drilling and hydraulic fracturing operations, methane leakage, and earthquakes triggered by injection of wastewater following flowback of hydraulic fracturing fluids.

Numerous studies have addressed water issues surrounding shale gas development; these issues include the availability, quantity, transport, and treatment of produced water as well as the contamination of local aquifers via underground methane leakage (see recent review by Jackson et al. 2014). Detailed studies where groundwater contamination has occurred in areas of shale gas development have consistently shown that hydraulic fracturing itself is not the source of the contamination. Rather, the contamination appears to result from poor well construction or poor drilling practice. King (2012) and SEAB (2011) discuss the importance of preventing contamination of aquifers and/or methane leakage and identify many operational issues that require close attention to achieve proper construction. In a survey of experts from industry, academia, NGOs, and government regulators, Krupnick et al. (2013) also found well-construction issues to be of most importance.

Another water issue associated with shale gas development involves the disposal of wastewater flowing back from the shale formation after hydraulic fracturing. Flowback water typically contains large amounts of salt, various quantities of selenium, arsenic, and iron, and small amounts of naturally occurring radioactive materials, all of which come from the gas-producing shale formation. Practices related to water usage and treatment are rapidly evolving and improving. In Pennsylvania, for example, nearly all of the flowback water is reused for hydraulic fracturing in subsequent wells, thus returning the contaminants to the shale formations from which they originated. This reduces both the need for new sources of water and concerns associated with truck traffic and wastewater disposal. In other areas, brackish or saline water can be used for drilling and hydraulic fracturing, thus minimizing the use of freshwater.

Another environmental issue of appreciable concern (and debate) is the importance of methane emissions that occur during drilling, hydraulic fracturing, well production, and natural gas transmission and distribution (which, of course, are not unique to shale development). Because methane is a more potent greenhouse gas (GHG) than CO_2, if methane leakage, or so-called *fugitive* methane emissions, at well sites is appreciable, it could offset the inherent advantage of using natural gas over coal for producing electricity.

The scientific community must carry out comprehensive studies of the many issues surrounding methane leakage through detailed data collection and analysis. However, two recently published comprehensive studies indicate that methane leakage is not of sufficient magnitude to offset the appreciable advantages of switching from coal to natural gas for electrical power generation. First, a standardized comparison by Heath et al. (2014) shows through a life cycle assessment that the GHG intensity of natural gas–derived power is on average about 50 percent of that of coal-derived power, for natural gas produced from both conventional reservoirs and shale gas formations, but the authors caution that

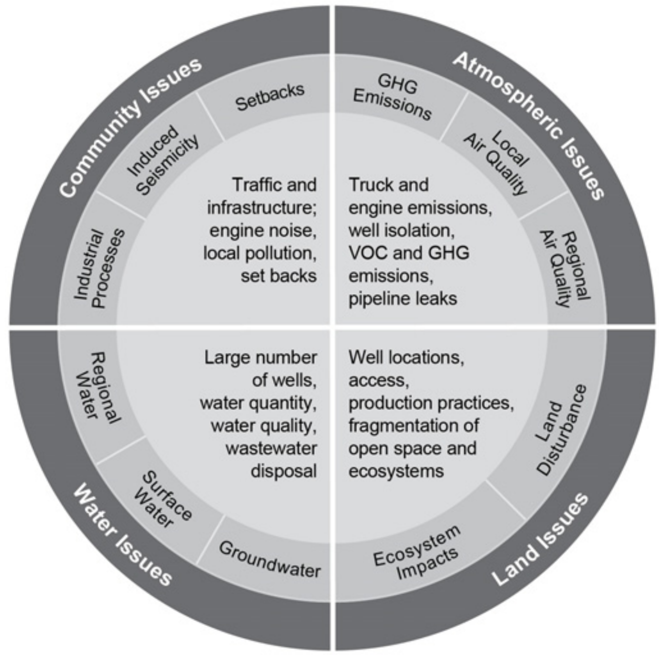

Figure 2 Risk factors associated with large-scale shale gas development. GHG = greenhouse gas; VOC = volatile organic compound.

much fundamental data are still needed to reduce uncertainties. In the second study, Brandt et al. (2014) point out that while the current level of atmospheric methane is generally higher than previously estimated, it is impossible to attribute this difference to shale gas development, and regardless of the sources of this additional methane, it does not offset the intrinsic advantage of fuel switching from coal to natural gas for electrical power generation. Another important finding of this study is that the majority of methane leakage results from relatively few, but large, leaks in the pipeline and distribution system—not from poorly constructed wells or the drilling and hydraulic fracturing process.

Finally, there is an apparent association between shale gas development and the marked increase in seismicity observed in recent years in the central and eastern United States. It has been known since the 1960s that the increase in pore pressure that results from fluid injection may cause seismicity by decreasing the normal stress on potentially active, preexisting faults. As the pore pressure changes at depth are usually quite small compared to the ambient stress, the pore pressure can be thought of as triggering the release of stored elastic strain energy resulting from natural geologic processes over time. In effect, the pore pressure increase from fluid injection advances the timing of an earthquake that would someday have occurred as a natural geologic process.

Hydraulic fracturing operations very rarely trigger earthquakes large enough to be felt by humans, principally because pressurization affects a relatively small volume of rock for a short period of time (a few hours) (NRC 2012). However, wastewater injection wells operate for years, sometimes injecting large volumes of wastewater that could affect large volumes of rock over large areas. Some straightforward steps can reduce the probability of triggering seismicity associated with wastewater disposal (Zoback 2012). Flowback water can be recycled by injecting it back into the shale during subsequent hydraulic fracturing operations. In addition, it is important to establish adequate seismic networks to detect and locate triggered seismicity, to improve the frequency and thoroughness of injection rates and pressures, and to establish protocols that define how operations might be modified in the event of triggered seismicity. Most important is to avoid injection near potentially active

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faults or into formations immediately above crystalline basement, in which case pressure changes in the injection zone might affect potentially active faults in basement.

Fundamentally, whether one is addressing the potential risks associated with earthquake triggering, contamination due to poor well construction, or methane leakage, the solutions come down to all of the stakeholders—oil and gas operators, regulatory authorities, utilities, and the public—being proactive about dealing with the associated environmental impacts. As we noted at the outset, switching from coal to natural gas for electrical power generation could have profound and far-reaching benefits; however, to realize these benefits, shale gas resources must be developed in an environmentally responsible manner.

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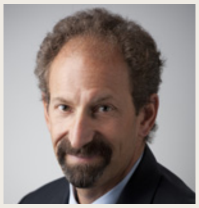

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process needs to be communicated. In these discussions, it is critical that stakeholders learn how they can obtain credible information.

What will the future of energy look like? This is a difficult question to answer. The growth in consumption is projected to be primarily in developing countries / emerging economies such as China and India. This is a critical point because significant steps toward reducing CO_2 emissions in the short term will require more conservation and increased efficiency as well as a faster transition from coal to natural gas in China and India. Ultimately, the high-growth energy consumers will have to transition rapidly to renewables for the largest potential reductions in greenhouse gas emissions and for a sustainable energy future. But it is difficult to say if this is a realistic expectation. As one looks to other energy opportunities, the role the nuclear option will have in supplying global energy is debatable.

From a global energy perspective, scientists and engineers generally agree that a technological breakthrough in renewable energy is necessary. The long-term goal is to reduce cost and increase efficiency such that a global-scale transformation from nonrenewable to renewable energy could occur. Such a breakthrough would give a truly sustainable energy future to us all. Still, impacts from renewable energy sources must be understood and managed.

It is poignant to consider a visionary statement by Thomas Edison that refers to nonrenewable versus renewable energy. During a discussion with Henry Ford and Harvey Firestone in 1931, Mr. Edison said, *"We are like tenant farmers chopping down the fence around our house for fuel when we should be using Nature's inexhaustible sources of energy—sun, wind and tide. I'd put my money on the sun and solar energy. What a source of power! I hope we don't have to wait until oil and coal run out before we tackle that."* At the present time, we are unfortunately nowhere close to attaining this vision. In 2013, the United States used approximately 91% nonrenewable energy and 9% renewable energy, while world use was estimated at 89% nonrenewable and 11% renewable energy (EIA 2014).

The expansion of natural gas production is upon us. Geoscientists are uniquely positioned to lead the effort to create a balance between extracting this resource and managing impacts. As a college professor to hundreds of undergraduates each year and as a parent, I cannot overemphasize how important it is for the geoscience community to engage in the discussion about how to balance global energy needs with environmental and societal needs. To transform the black box of energy extraction into an informed process, stakeholders, politicians, and the public need geoscientists to communicate their interdisciplinary insights. If we don't initiate these discussions, who will?

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