A Pathway to Clean Energy – Clean *Fossil* Energy, that is*

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Abstract

Our energy industry is faced with two huge, undeniable problems: the warming of the planet and the costly and destabilizing excessive emphasis on traditional resources from the Middle East. Are these problems unsolvable or do they, together, in fact open an opportunity for a major, overdue, restructuring of this global industry in a way that also greatly enhances economic growth?

Most emissions are related to production of our heaviest hydrocarbons. Combustion chemistry reveals that burning of coal releases about twice as much CO_2 per unit energy as the burning of methane. Moreover, the energy use related to mining and transportation of coal further decreases its net energy contribution by another factor of 2 or 3 (depending on transport distance) relative to methane. So, shifting as much of the global hydrocarbon industry towards natural gas as possible is a huge shift in the right direction. The rapid growth in unconventional gas resources, such as 'tight' gas and shale gas is an important part of this shift. In-situ gasification of other hydrocarbons (such as coal) is another. It is an emerging technology that ultimately could bypass the need for carbon capture and sequestration by leaving the CO_2 in the subsurface to begin with - instead of sequestering it after it is released. Research is also underway for use of new metal catalysts to break down heavy hydrocarbon molecules into lighter ones. Real work on biological transformations of hydrocarbons and the many other pathways to decarbonize the hydrocarbon industry is just beginning.

A serious commitment to research on transforming the world's heaviest hydrocarbons to their lowest-emitting components (natural gas) clearly is good for the climate. It also opens up responsible exploitation of all hydrocarbon resources, which in aggregate are quite equitably distributed across all nations on earth, thus reducing pressures on politically vulnerable regions.

Add to this the rapid advances in renewable energy development. A 20 percent renewable portfolio standard has become the norm across the U.S. and similar (or higher) targets are in place in some countries overseas. Wind energy may be leading the charge in terms of development, but solar energy is leading the charge in science. Geothermal is the second largest energy resource on earth (after solar) and this is one industry sector where the AAPG community could play a huge role in its advancement.

References

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A Pathway to Clean Energy
Clean *Fossil* Energy, that is

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by

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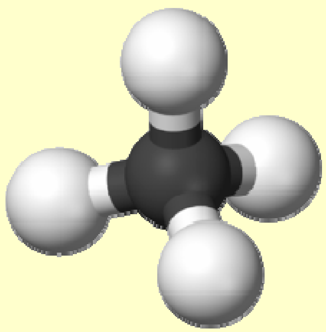
Purpose: The future of the oil and gas industry will go way beyond what you have probably learned in petroleum geology courses, let alone what politicians and other decision makers think is possible.

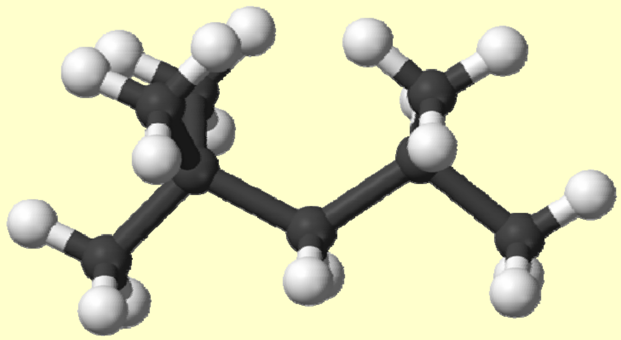
Promising RD&D Paths

- Fuel shift from coal to natural gas
- In-situ coal gasification: heat & microbes
- New approaches to coal-to-liquids
- Lessons from bio-geochemistry
- Why we are doing this? Will it ruin the economy – or provide a big boost?

Combustion Chemistry 101



Methane – CH_4
Primary constituent of natural gas



Iso-octane – C_8H_{18}
Typical molecule in gasoline

During combustion, energy is liberated as H is oxidized to H_2O and C is oxidized to CO_2

The more H relative to C the more energy is liberated per unit CO_2

In **methane H/C ratio is 4:1**. The CO_2 release per MJ = 1.2 mol

In **petroleum the H/C ratio is ~ 2:1**. In iso-octane the CO_2 release per MJ = 1.6 mol

In **coal the H/C ratio is ~ 1/1**
The CO_2 release per MJ = 2.0 mol

CO_2 Emissions Comparisons of Electricity Generation

Using Life Cycle Assessment

2004 World Energy Council[1]

Emissions include direct (stack emissions) and indirect (other stages - transport, production, parts manufacturing, etc.)

Tons of carbon dioxide equivalent per GWh of electricity generated

Fuel type	Efficiency %	CO_2eq (T/gWh)
Lignite	31 – 37	1140 – 1370
Coal	33 – 44	820 – 1080
Heavy oil	37 – 40	650 – 840
Natural gas CC	47 – 55	363 – 485
Solar PV	5 – 38	43 – 104
Hydro	51 – 73	6 – 120
Wind	21 – 35	7 – 15
Nuclear	82 – 89	3 – 40
Geothermal		23 – 82

[1]London-based council (formed in 1924), running the tri-annual world energy congresses (members from R&D groups, industry, government agencies)

Similar data from: NREL; Univ. Wisconsin; International Atomic Energy Commission; IEA; INL; many others.

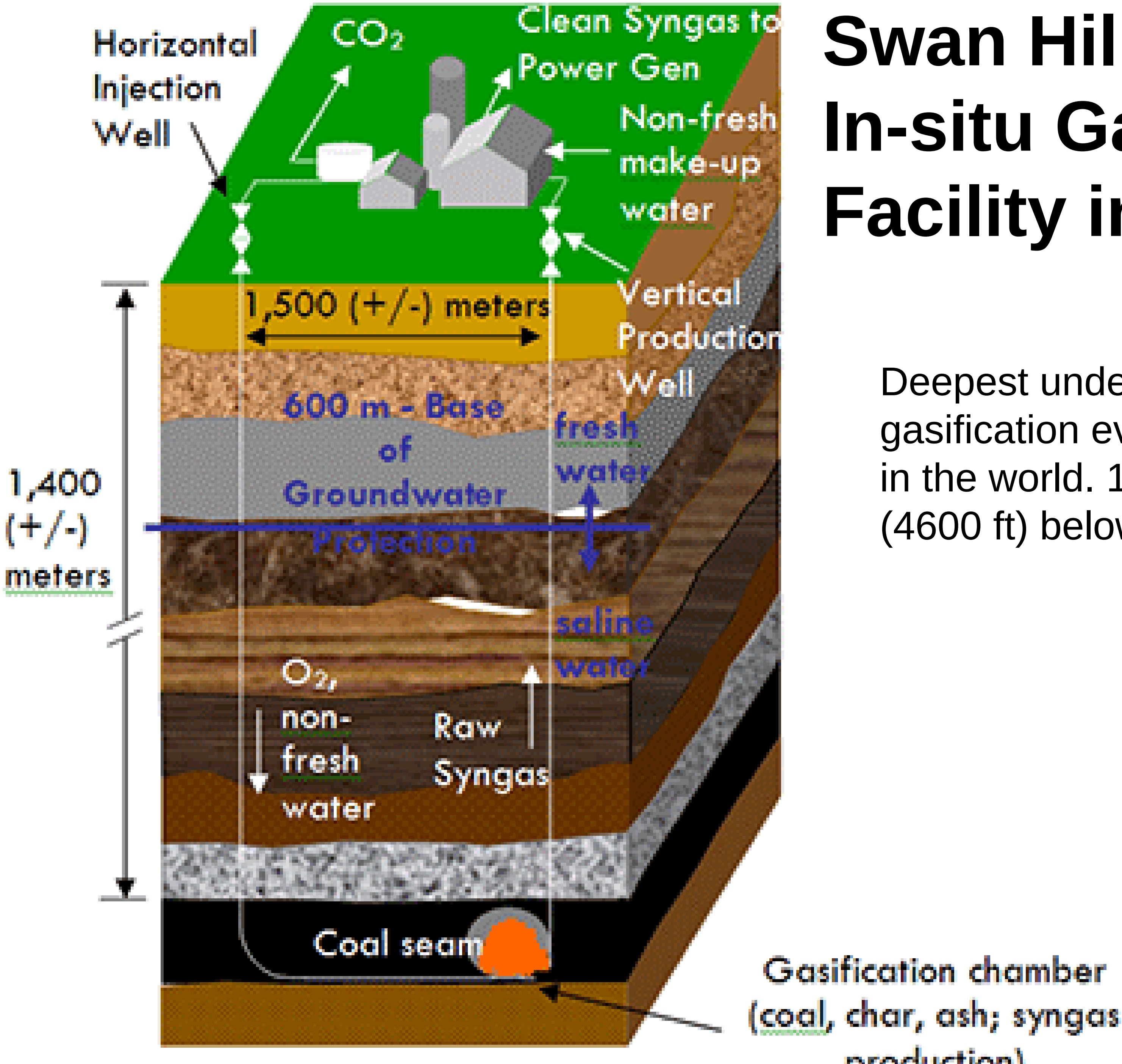
Additional Benefits of Gas Versus Coal

- Transportation losses (more for coal by 2:1 – 3:1)
- Mine safety (not getting better fast enough)
- Gas reserves in US growing rapidly with production of shale gas and tight SS gas
- Global energy security changes: reversal of gas flow in Europe?
- North America to be an LNG exporter versus importer

How Does In-Situ Coal Gasification Work?

- Deep ("unmineable") coal is exposed to high temperature and high pressure.
- In the presence of steam at such conditions coal is converted to syngas.
- Syngas: H_2, CH_4, CO_2, CO
- Use two wells:
  - 1) A horizontal injection well to introduce oxygen and water into the seam; the oxygen supports a limited and controlled amount of combustion, raising the temperature of the coal and boiling the water to generate steam.
  - 2) A vertical production well to conduct the raw syngas to the surface.
- Char, ash, which are remnants of the original coal, remain deep underground.

Swan Hills In-situ Gasification Facility in Alberta



Deepest underground coal gasification ever conducted in the world. 1400 meters (4600 ft) below the surface

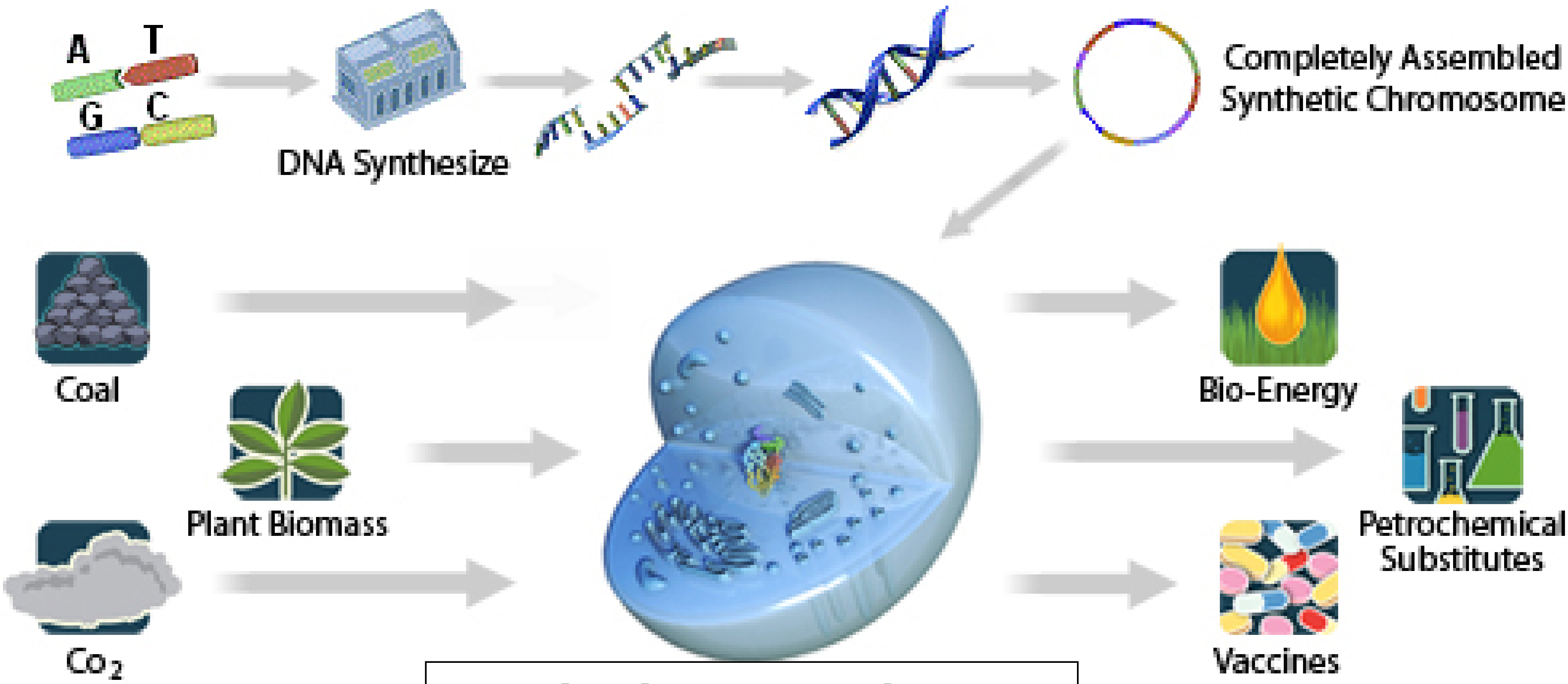
Microbial Conversion of Coal to Gas

- **Powder River basin** (Wyoming) microorganisms metabolize the large hydrocarbon molecules present in coal and oil into smaller hydrocarbons, principally methane.

- **LUCA Technologies**, a Golden-based company describes these naturally occurring methane factories as "Geobioreactors".
  - Laboratory experiments have shown that methane associated with coal can be increased by a factor of 5.
  - Example: if 1% of the coal in the Powder River Basin could be converted to methane, approximately 30 TCF of gas would be produced.
  - Current U.S. usage of natural gas: 23 Tcf/yr
  - Gas could be produced without dewatering the coals.

- **CSM project (RPSEA) - Junko Munakata-Marr**
  - Identify chemical constituents of coals that are bioconverted
  - Identify organisms involved
  - Characterize influence of environmental conditions on biogas generation

A “Pathway” to Microbial Conversion of Coal to Gas or Liquids



Synthetic Genomics, Inc

ExxonMobil and other co-investors

Other Approaches to Coal Conversion

- The Syngas Chemical Looping process (Ohio State University) converts coal and biomass into electricity, hydrogen, and/or liquid fuel with zero or negative net CO_2 emission. A biomass and coal blend will be converted with 100% CO_2 capture. OSU is working with the National Carbon Capture Center (NCCC) operated by Southern Company and many other companies.

- MS Technology, Inc., Oak Ridge National Laboratory, and PetroBeam, Inc. are developing a microwave susceptor technology to liquefy coal and electron beam processing to upgrade the liquids into desirable fuel fractions.

Heavy Oil Conversion

- **Chevron Technology** – patent on “deep catalytic cracking” to convert unconverted heavy oil into one or more light oil products.
- **Georgia Tech Research Institute** – use of ionic liquids (liquid salts) as solvents for heavy oils. Properties can be switched on and off to facilitate separation of heavy and light fractions.
- **EnCana** patent to use methanogenic bacteria to convert heavy oils to lighter fractions.

Lessons From Biogeochemistry?

“Most of the world's oil was biodegraded under anaerobic conditions, with methane, a valuable commodity, often being a major by-product, which suggests alternative approaches to recovering the world's vast heavy oil resource that otherwise will remain largely unproduced”.

Nature **426**, 344-352 (20 November 2003)
Review article –
Biological activity in the deep subsurface and the origin of heavy oil
Ian M. Head, D. Martin Jones & Steve R. Larter

Summary - Why Are We Doing This? It's Very Costly, No?

- **Need to do this to reduce CO_2 emissions and increase domestic energy production.**
- **Fossil energy can play as big – bigger? – a role in this transition as can renewables.**

- **Nick Stern's report (2005):** transition will have a net cost but vastly less than the cost of flooding, displacement of agricultural zones, diseases…
- **McKinsey (2008):** Cost savings by new technologies are about balanced by CCS costs!

- **The Opportunity**: We can go way beyond CCS – that is just a small beginning. We should start down a path to decarbonize the fossil energy supply as much as possible, leaving everything in the ground but the energy, which we carry to the surface – and markets – by natural gas.

- **Historical evidence**
  - Switch from wood to coal in 1750… – costly, good or bad?
  - Switch from coal to petroleum in WWI
  - Investments in high tech – costly, or ?
  - Switch to new energy technologies – net cost or net gain?