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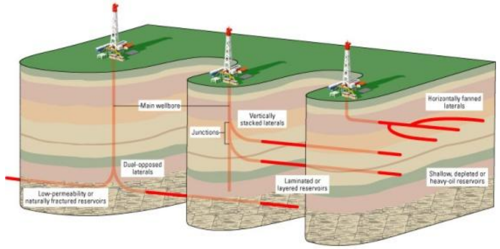

100 Years and Beyond: Future Petroleum Science and Technology Drivers

Some new paradigms for the future of non-conventional hydrocarbon production

A perspective by

Geoffrey Maitland
Professor of Energy Engineering
Department of Chemical Engineering

Imperial College London

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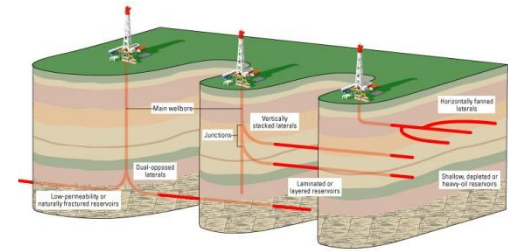


100 Years and Beyond: Future Petroleum Science and Technology Drivers

Towards a Low Carbon Fossil Fuel Future with Gas and CCS

A perspective by

Geoffrey Maitland

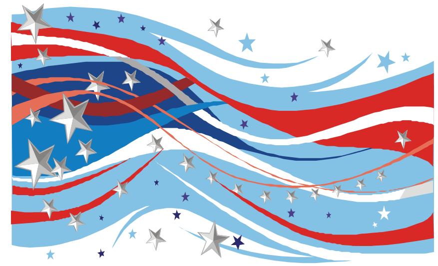
Professor of Energy Engineering

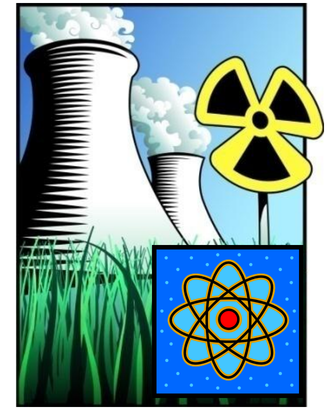
Department of Chemical Engineering

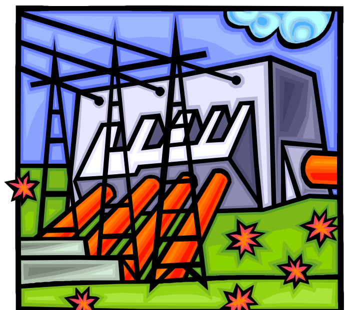
The Energy Landscape

Current world consumption 15 TW

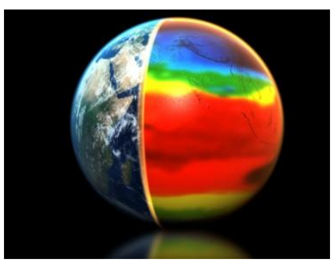
Hydroelectric: 4.6 TW gross, 1.6 TW feasible technically, 0.6 TW installed capacity



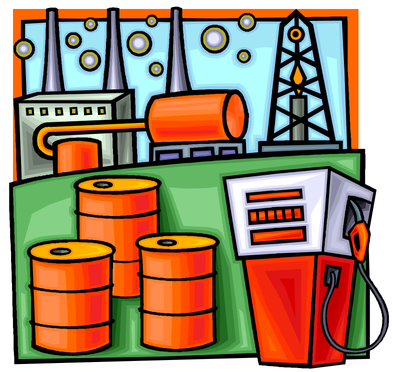




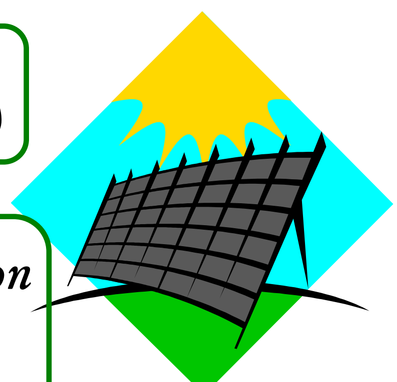
Tidal/Wave/Ocean Currents: 2 TW gross



Fossil Fuels: Current 12.5 TW Potential 25 TW



Geothermal: 9.7 TW gross (small % technically feasible)



Wind 2-4 TW extractable

Solar: 1.2 x 10^5 TW on earth's surface, 36,000 TW on land

Biomass/fuels: 5-7 TW, 0.3% efficiency for non-food cultivatable land

The Future of Fossil Fuels

- Continued use of Fossil Fuels for most of this century is essential/inevitable
  - To meet global energy demands
  - To address security of supply issues

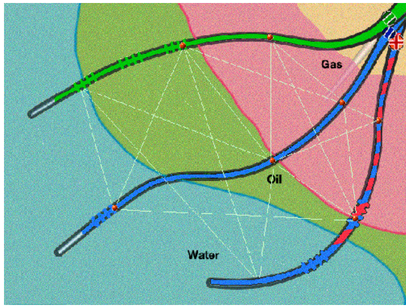
- So we need to give ourselves the option to continue to use Fossil Fuels for as long as we need for all energy-related and chemicals-materials uses…power, heat, transport, feedstocks…

- ...but at the same time reduce CO_2/GHG emissions to a minumum

How do we achieve this low carbon fossil fuels future?

- Use less energy
- Use more gas
  - A Future ‘Gas Economy’

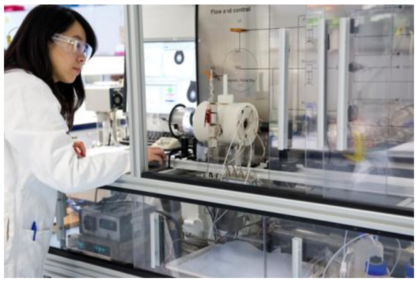
- Capture as much CO_2 as possible
- Decarbonise the fossil fuel



- Optimise Hydrocarbon Recovery
  - Manage the reservoir recovery efficiently
  - Improve conventional recovery: IOR/EOR
  - Discover and recover non-conventionals effectively

Qatar Carbonates and Carbon Storage Research Centre

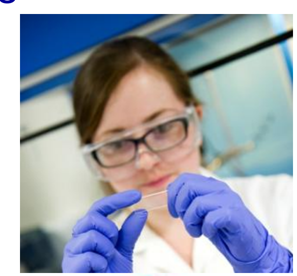
The Science and Engineering of Storing CO_2 in Carbonate Rocks




Currently there are
- 17 Academic Staff
- 3 QCCSRC Lecturers
- 10 Postdoctoral Researchers
- 34 PhD Students
- 5 Technical Support Staff

working within the Centre



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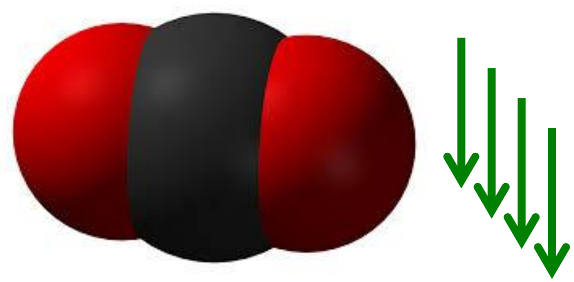
Qatar Petroleum

QATAR SCIENCE & TECHNOLOGY PARK
Member of Qatar Foundation

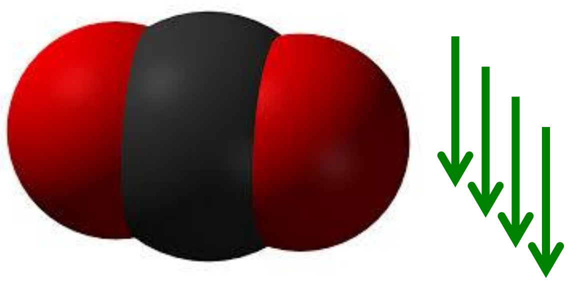
The Grand Challenge

Can we combine these targets of recovering and using more Gas together with minimal release of CO_2?



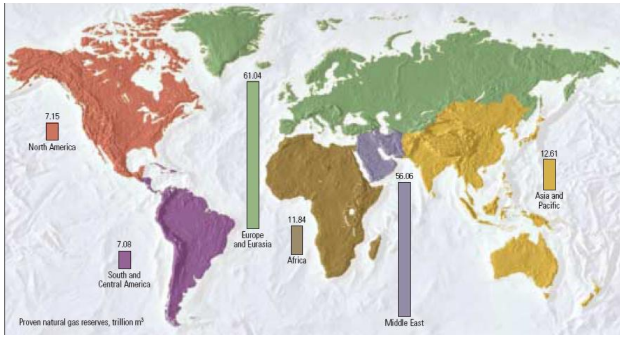
A Key Synergy...

CO_2 can enhance the recovery
of most gas sources,
in some cases it is critical
– can we exploit this?

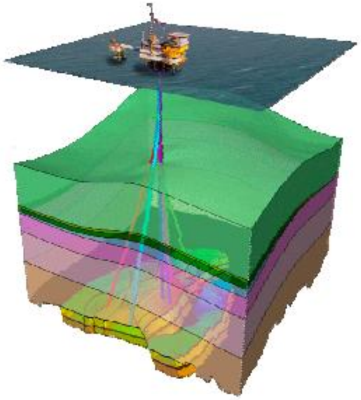


Conventional Gas

- Significant Global Reserves
  - >7000 Tcf or 200 x 10^{12} m^3



- But EGR will play a significant role
  - Gaseous and Supercritical CO_2 (> N_2)
    - Reservoir pressurisation
    - Gas-gas displacement
  - Depleted gas reservoirs good potential sink for CO_2 storage



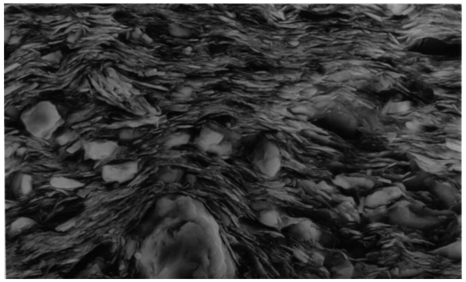
K12-B
N Sea Gas Field – CO_2 reinjection

- Tight gas (~7500 Tcf) and Deep, geo-pressurised gas (> 50,000 Tcf?) represent additional longer term prospects

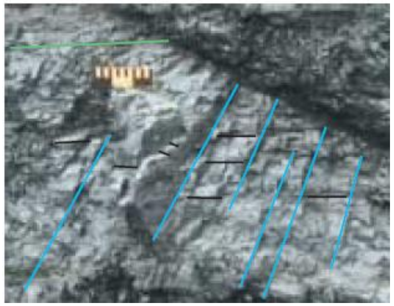
Global Annual Gas Consumption 2012: 3.2 Tm^3 or 110 Tcf

Potential Sources of Unconventional Gas

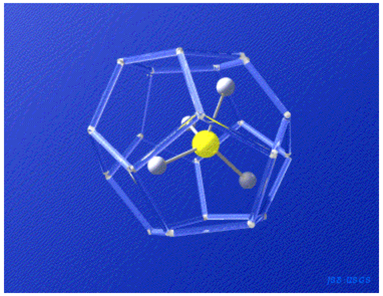
Shale Gas



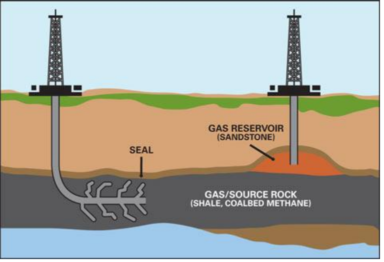
Coal-Bed Methane



Gas Hydrates



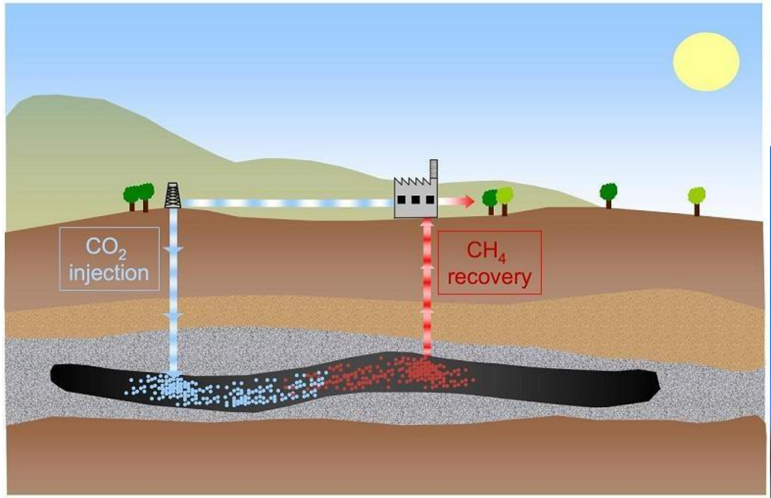
Heavy Oil Reservoirs

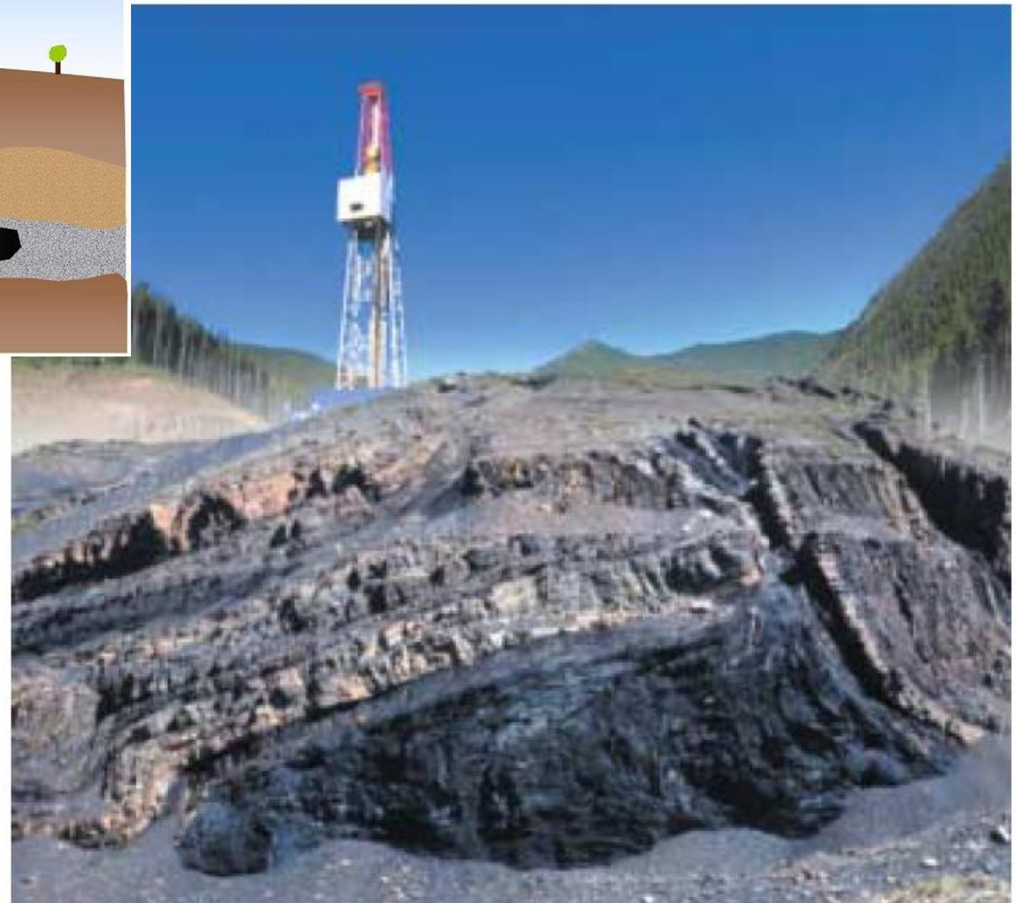


Shale Gas

- Large potential reserves, >16,000 Tcf ~ 450 x 10^{12} m^3
- Key to date: horizontal wells, hydraulic fracturing
  - Mechanisms far from fully understood, process far from optimised
  - Shale fracturing is a chemo-mechanical process
- Possible technology improvements
  - Alternative fracturing fluids: sc CO_2, liq C_3H_8
  - Chemically-induced osmotic swelling and softening of shale (water, CO_2), low pH (CO_2)
  - Chemically-enhanced fracturing
  - Alternative production conduits
    - wishbone sidetrack wells
    - radial jet drilling
- CO_2 can adsorb preferentially on clay surface and in shale nanopores → IGR + Sequestration of CO_2 within shale

Enhanced CoalBed Methane, ECBM

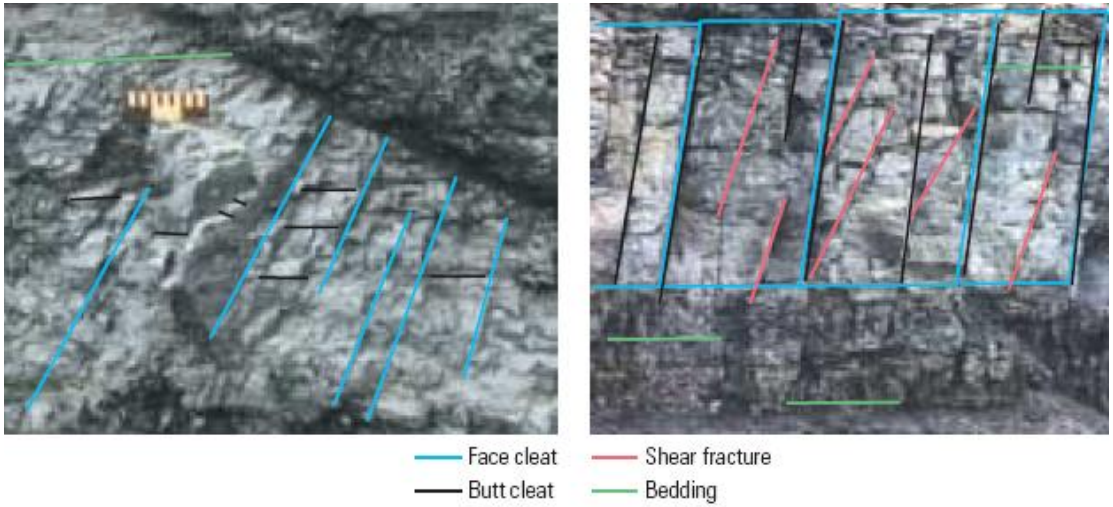




(Enhanced) Coalbed Methane

- Large potential reserves, >9,000 Tcf ~ 250 x 10^{12} m^3
- Process: horizontal wells, hydraulic fracturing + gas displacement of water and CH_4
  - Mechanisms reasonably understood
  - Surface chemistry and swelling as well as mechanical
- Possible technology improvements
  - Enhancement of fracture network and alternative production conduits
    - sidetrack wells
    - jet or percussion drilling
  - Chemical control of swelling
- Sequestration of CO_2 on large cleat surface and in matrix nanopores

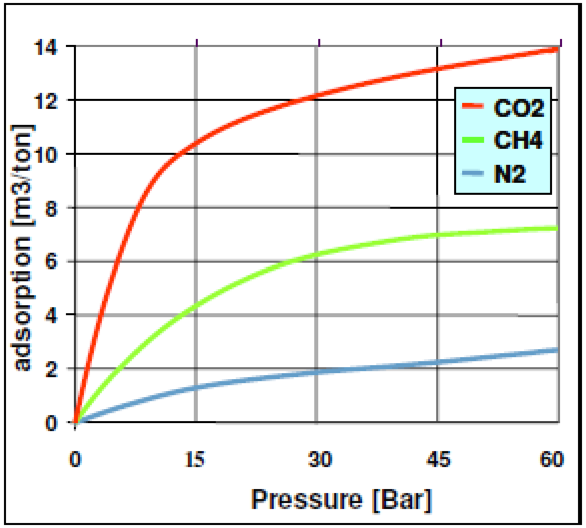
Methane adsorbed in coal



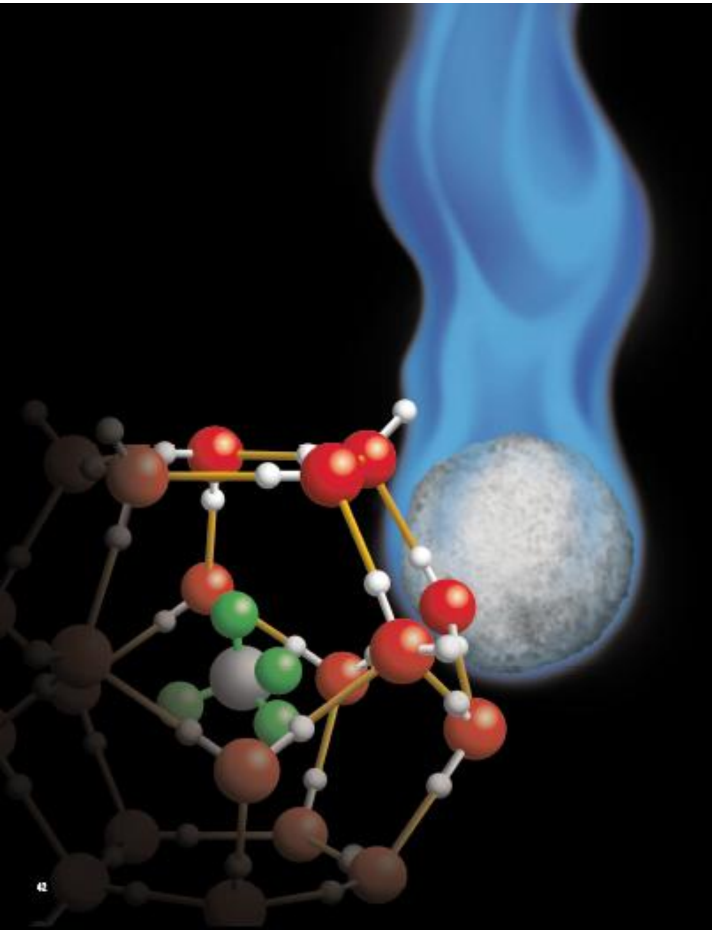
- Most gas (80%) in porous coal matrix (2-50 nm); cleats (2-25 mm) are a conduit for gas in and out
- ~ 20 m^3 CH_4 trapped per te coal on a pore surface area of ~ 20-200 m^2 te^{-1}
- Coal field may have 3-5 times gas content of typical oil/gas reservoir
- Water resides in cleats initially

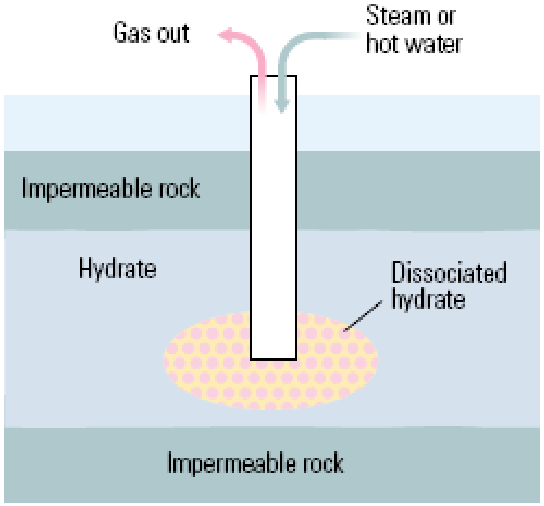
Gas Exchange Process

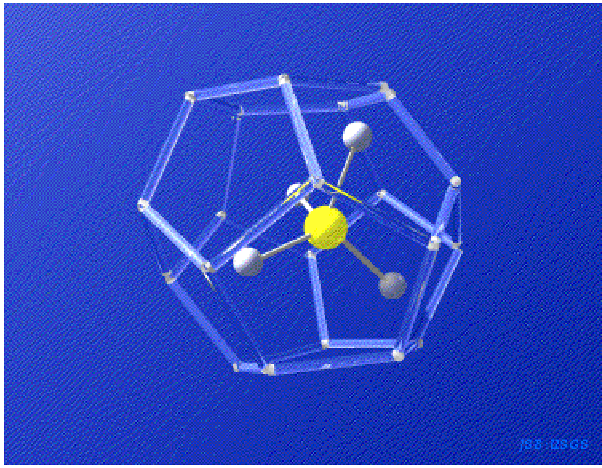
- N_2 initial injection → p_{CH4}(cleat) decreases, CH_4 desorbs
- CO_2 injection increases CH_4 release by competitive adsorption → CO_2 sequestration
- Fracturing and swelling of coal play an important role in controlling rate and extent of CH_4 recovery



Gas Hydrates





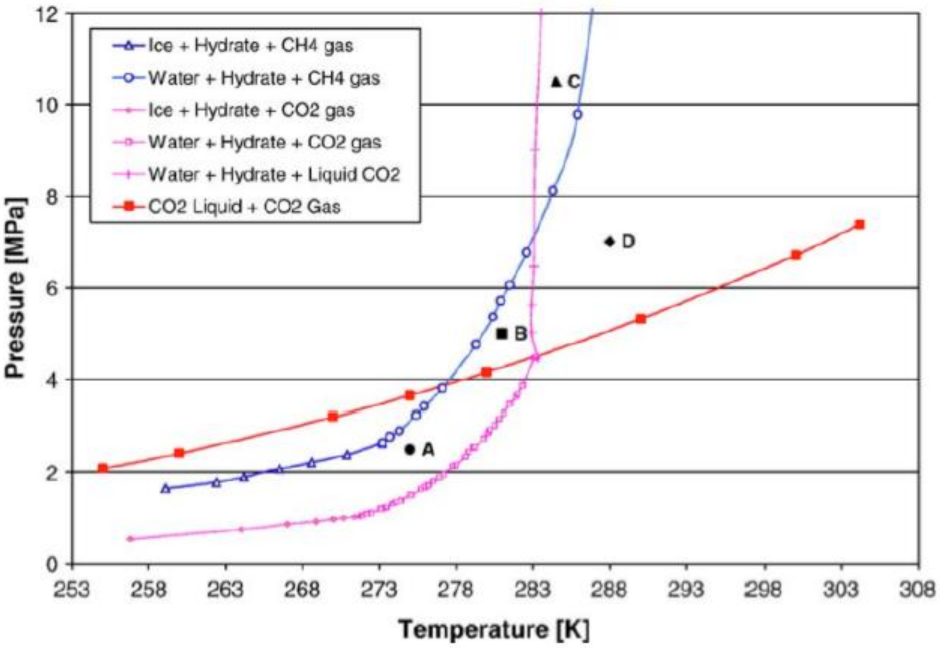


Known and inferred occurrences of gas hydrates.

● Hydrate location

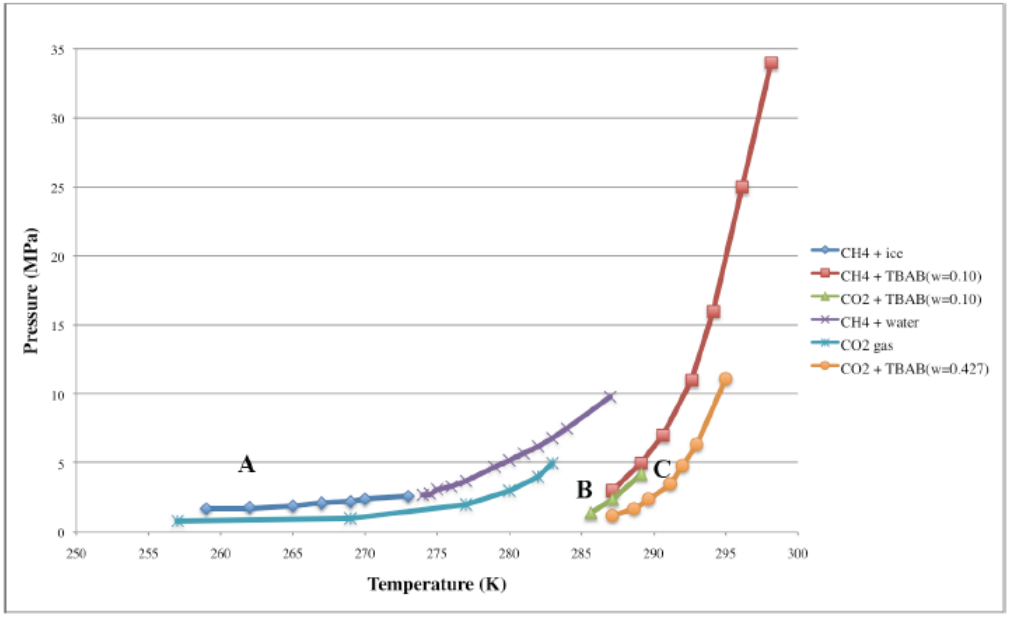
Gas Hydrates

- Enormous potential reserves: 70,000 Tcf = 20,000 x 10^{12} m^3 CH_4 = 10,000 years at current gas consumption
- Current methods: thermal, depressurisation, solvent – mechanical instability a major problem
  - A major chemomechanical problem
- CO_2 hydrates more stable – exchange drives CH_4 production and huge CO_2 storage capacity



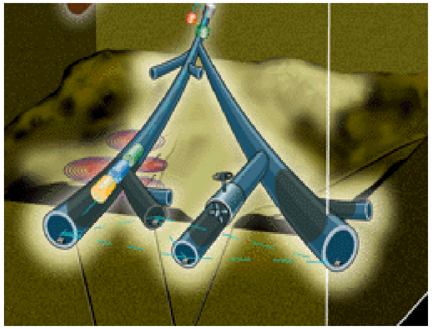
Gas Hydrates

- Possible technology improvements
  - Develop fracturing techniques for ‘soft’ hydrates
    - Improve gas mass transfer rates by surface area increases
  - Co-inject g/l CO_2 or use as fracturing fluid
    - Use exchange (rather than diffusion) to drive CH_4 production
  - Chemical mechanical stabilisation of hydrate matrix
  - Alternative production conduits e.g. thermal jet drilling

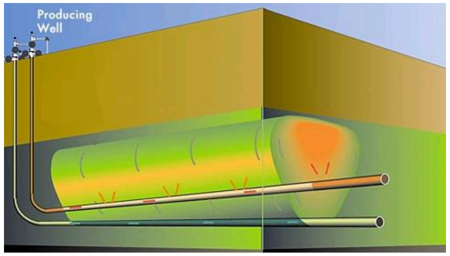


Optimising Future Oil Recovery

- Conventional hydrocarbons
  - Real-time reservoir monitoring and management
  - ‘The Illuminated Reservoir’
  - Mobile fluid – main aim is to improve reservoir sweep and fluid displacement
  - Coping better with reservoir heterogeneity
  - Reduce residual oil – porescale processes - EOR



- Non-conventional hydrocarbons (heavy oil, tar sands, bitumens, oil shales)
  - Oil is non-mobile – more like coal than conventional oil
  - Most current methods aim to reduce viscosity, increase mobility sufficiently to flow to surface and process like conventional hc
  - Very energy/CO_2 intensive
  - Recoveries low
  - New production paradigm ?
    - – gasification and conversion



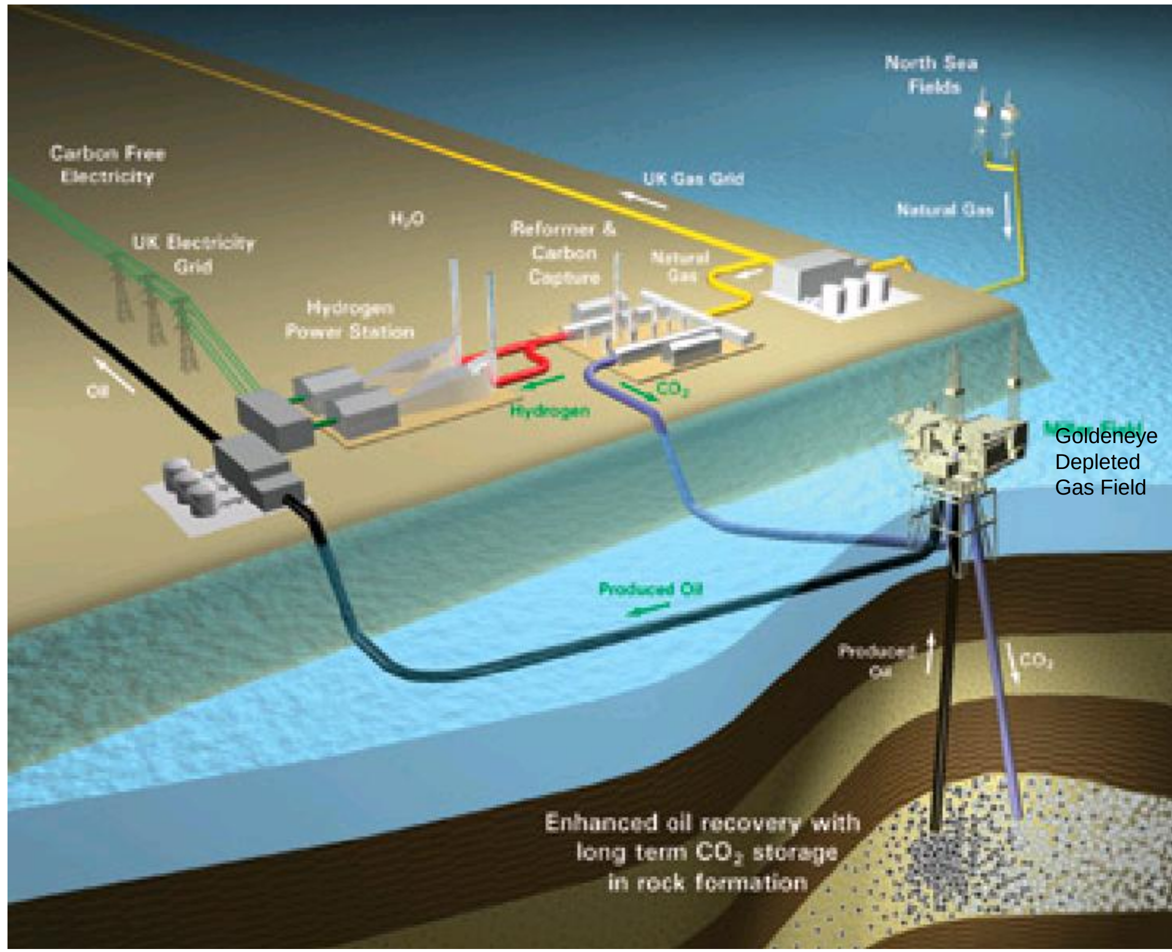
UKCCS Commercialisation Competition: Shell, SSE Peterhead Project

Also White Rose Project

- Alstom
- Drax Power
- BOC
- National Grid

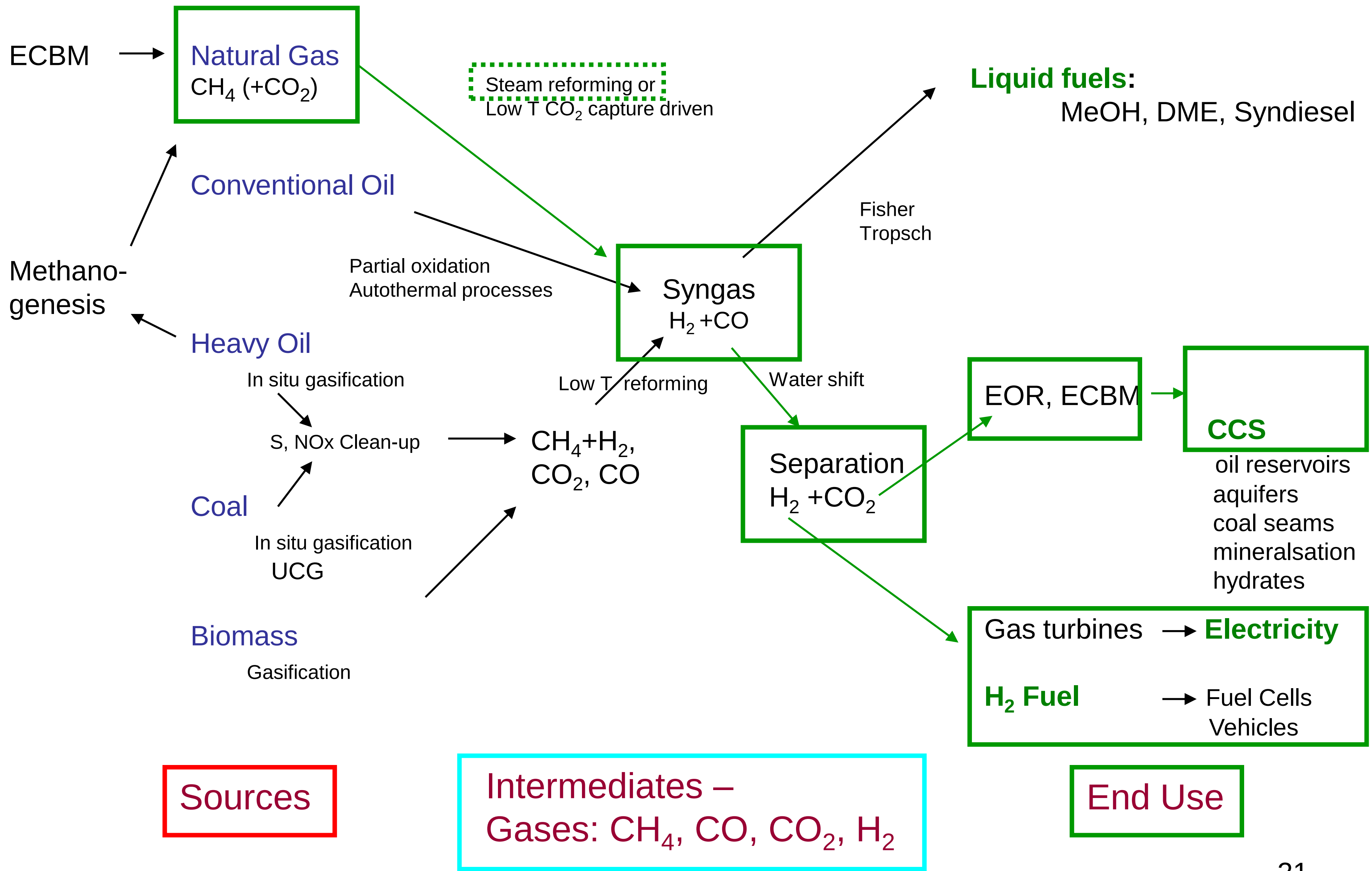
• Coal-fired power station

• Storage in saline aquifer in southern North Sea

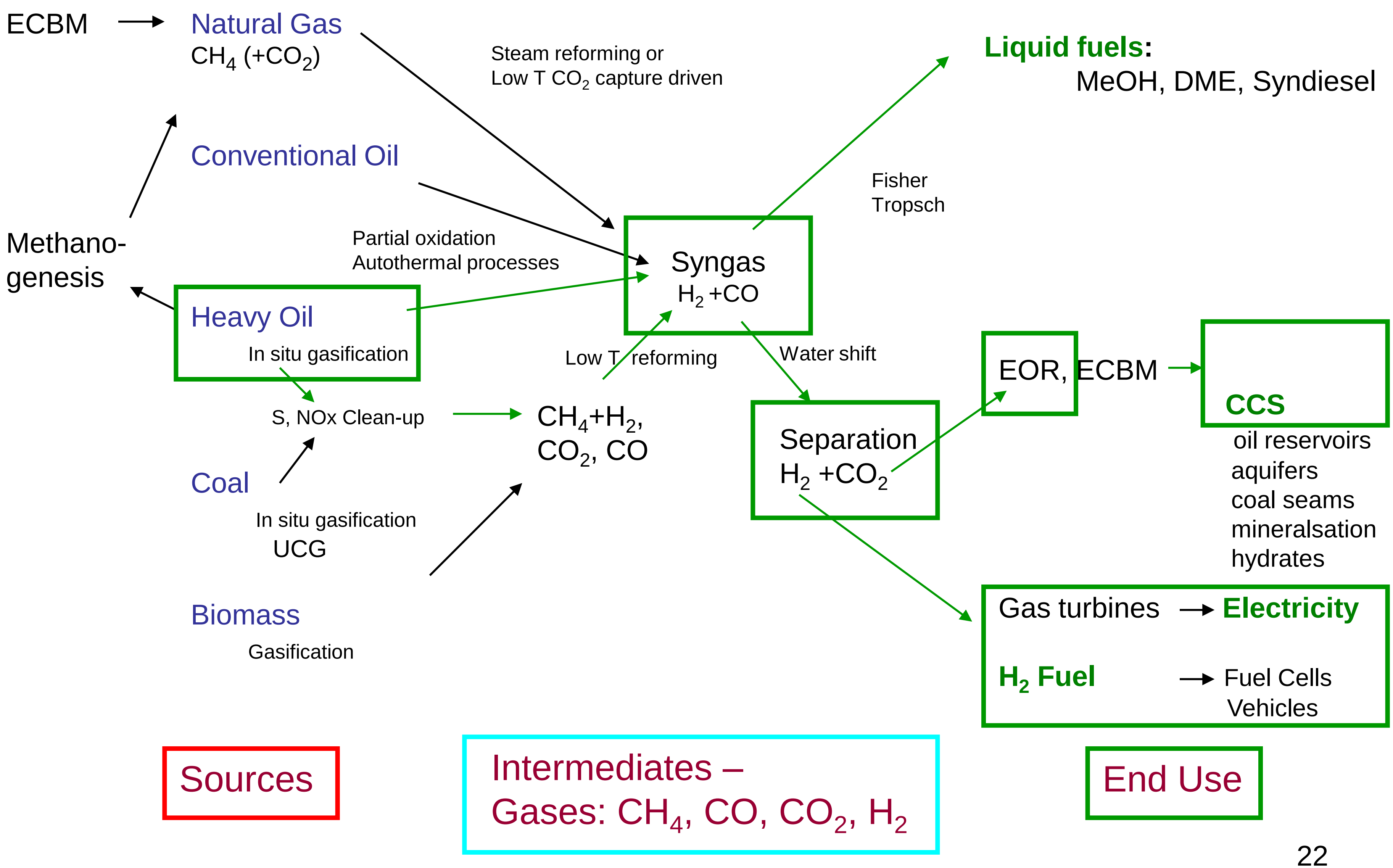


…move this process to the rigsite or downhole or subsea?

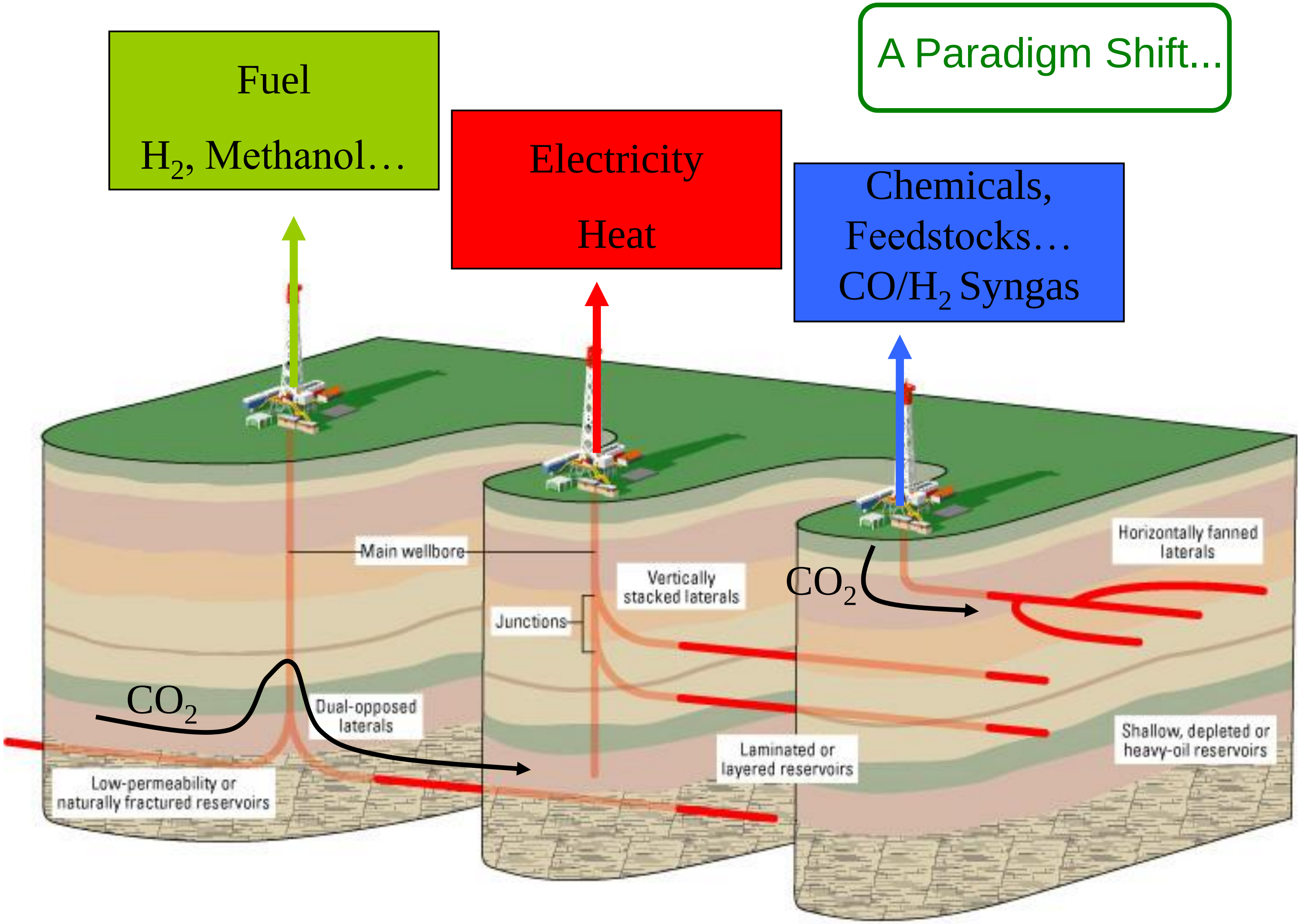
Clean Fossil Fuels - Roadmap



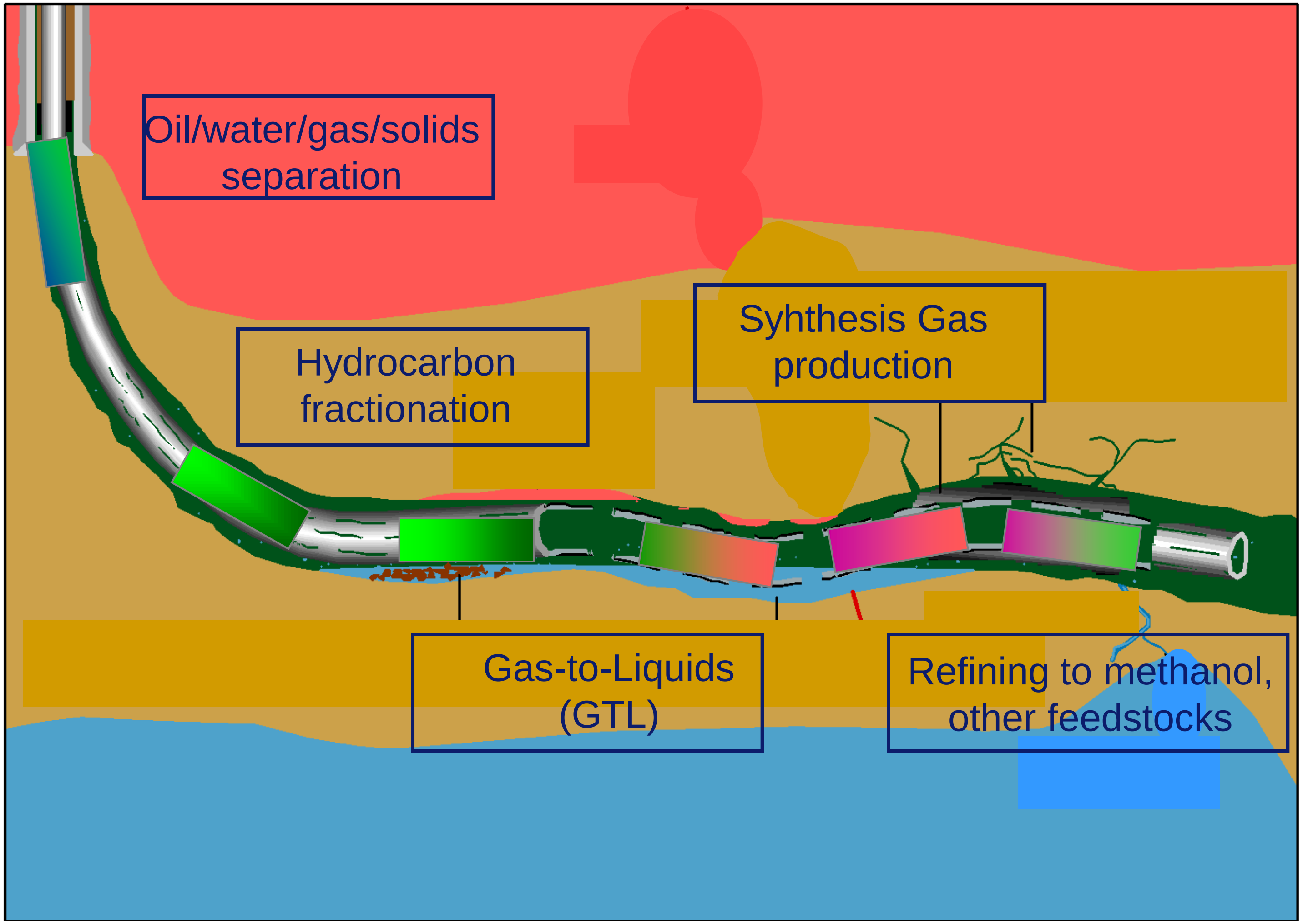
Clean Fossil Fuels - Roadmap



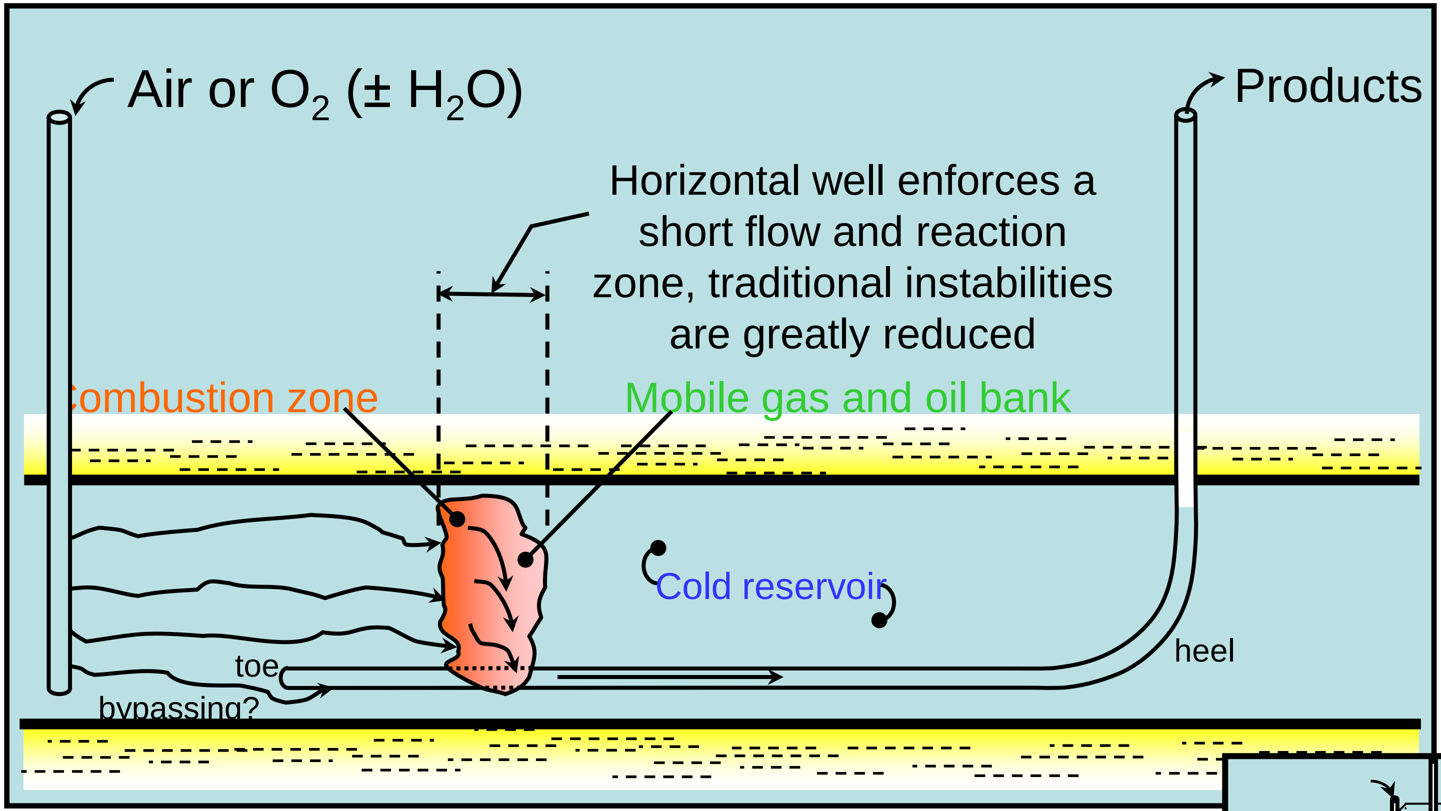
Integrated Subsurface Production of Clean Energy, Fuels and Feedstocks from Hydrocarbons and Coal

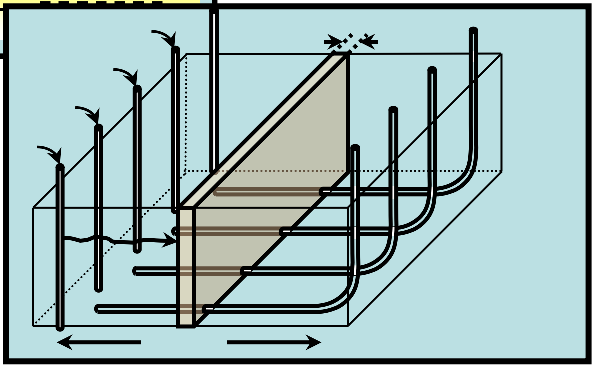


Sub-surface Separation and Conversion



The THAI™ In Situ Combustion Process





Heavy Hydrocarbons Recovery… a paradigm shift

- Recovery of Heavy Oil may benefit from the development of ***radical new recovery/production processes***

- Key elements:
  - Sub-surface gasification of solid-like hydrocarbons
  - Use *in situ* hydrocarbon as gasification/conversion fuel (or other heating source powered by renewables)
  - Also exploit the *in situ* HTHP energy within the reservoir
  - Integrate *in situ* capture and storage with production
  - Extract carbon in the subsurface with minimal release of GHGs (CO_2,CH_4...)
  - Release to the surface only what we want…clean fuel, power, heat, chemical building blocks
  - Could lead to significant increases in recovery factors for non-conventionals

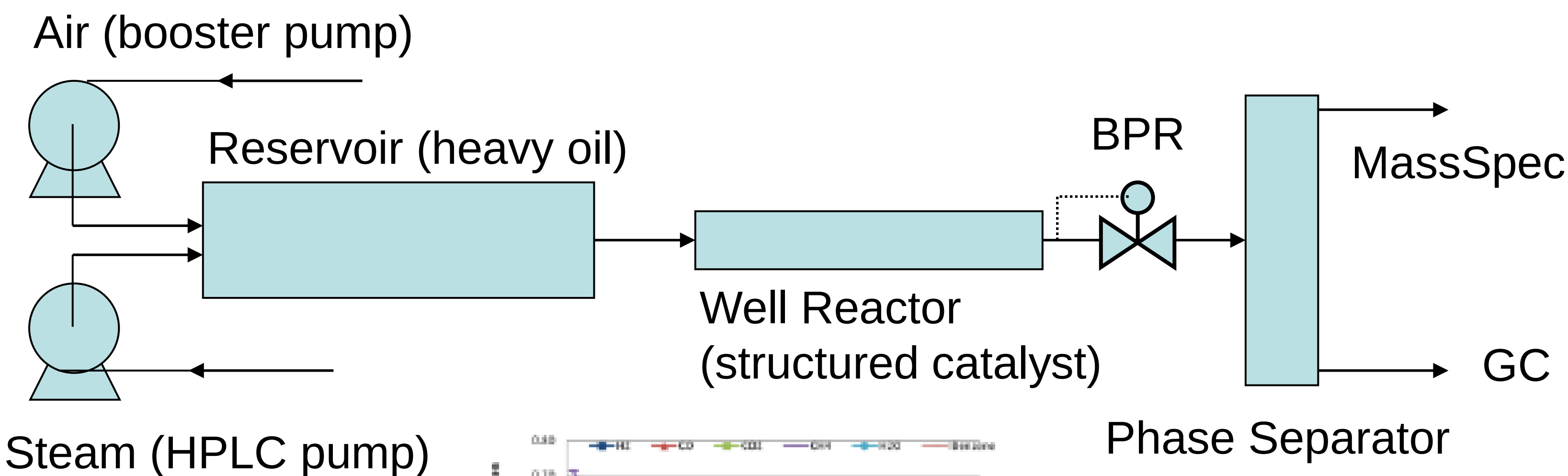
- Basis of Processes: Gasification to Syngas intermediates

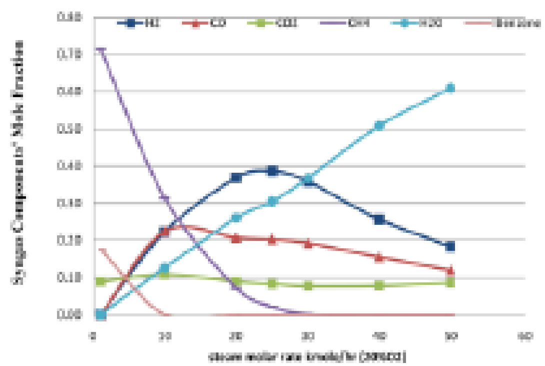
Hydra-Pro

Hydrothermal Processing of Hydrocarbon Reservoirs

Klaus Hellgardt and Yousef Alshammari

Aim: Demonstrate feasibility of hydroconversion of heavy oil into syngas and/or hydrogen under subsurface conditions

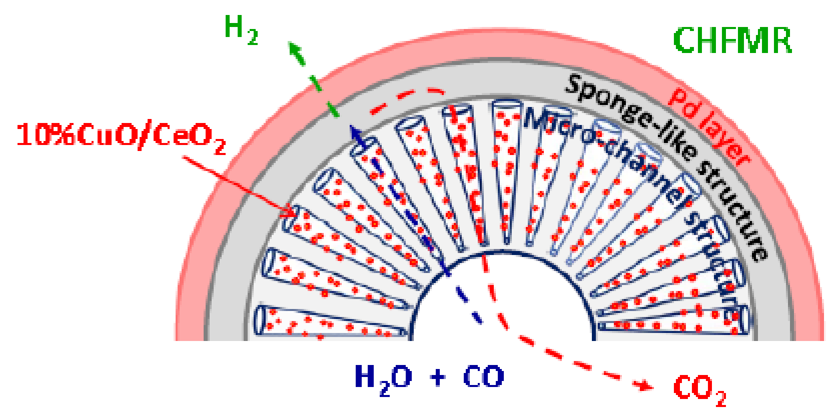




Yields of syngas components at varying steam injection flowrates

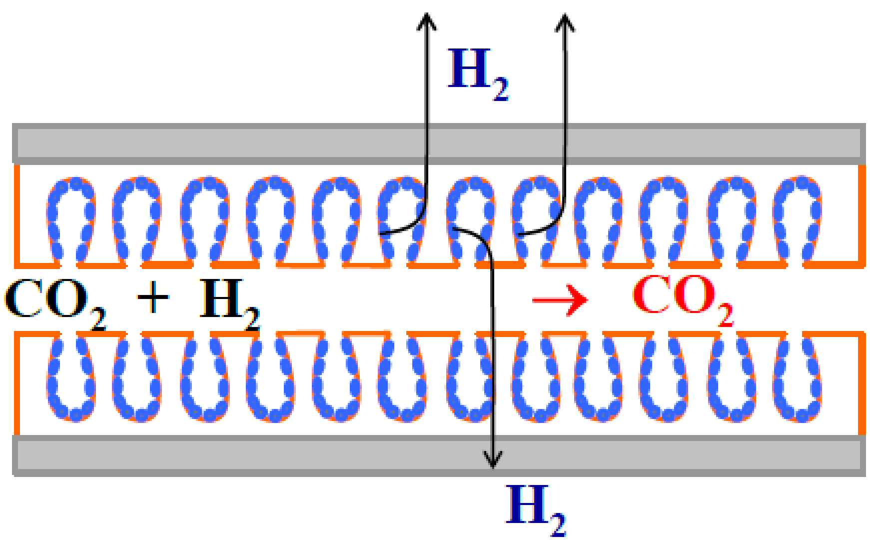
Example: Downhole Membrane Reactors

Water Gas Shift reaction



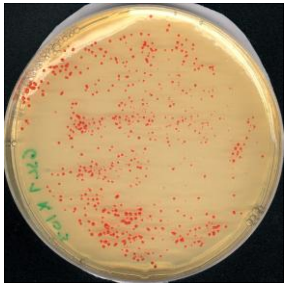
Membrane Catalytic Reactor:

$$CO + H_2O \rightarrow CO_2 + H_2$$



Alternative approach for Heavy Hydrocarbons: Low-energy *in situ* upgrading

- Possible solution:
  - Selective stimulation of *in situ* reservoir microorganisms…extremophiles
  - Methanolysis
    - Partial conversion of heavy oil to methane
    - In situ gas solution mobilisation-upgrading
  - Selective production of low carbon fuels?
    - Alcohols, DME
  - Issues
    - Anaerobic vs aerobic processes
    - Long timescales…years-decades…new production paradigm



Aerobic degradation of Crude Oil

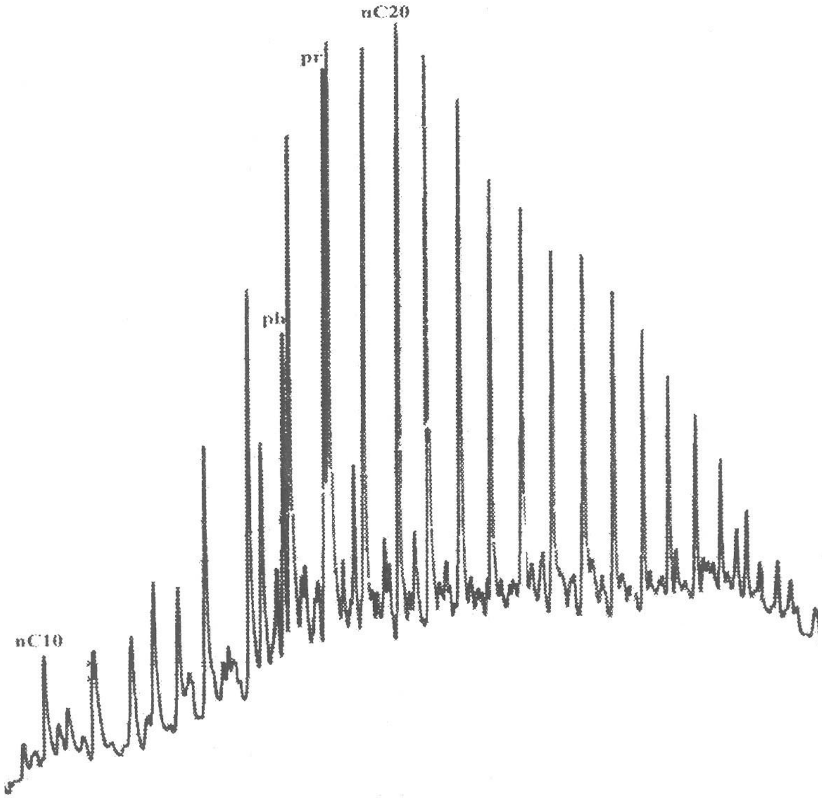


Fig. 1. GC analysis of the saturate fraction of the crude oil

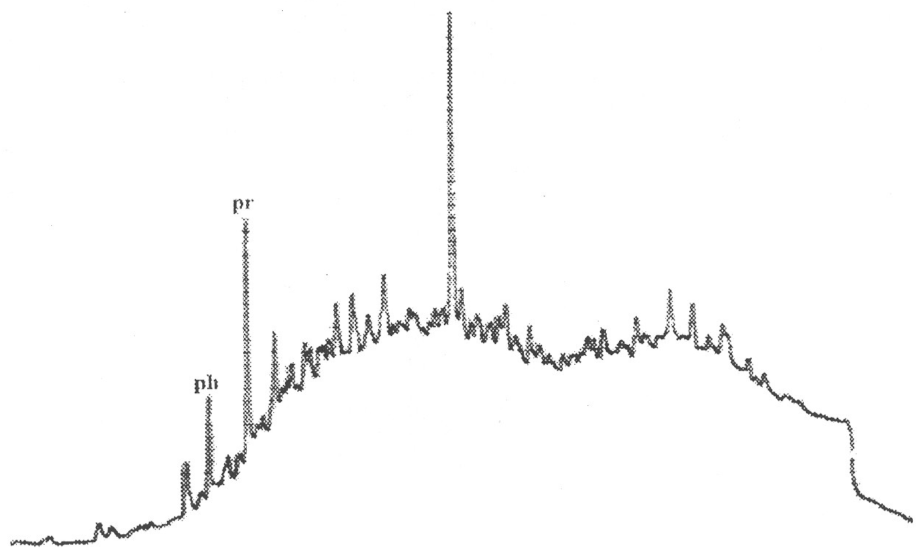


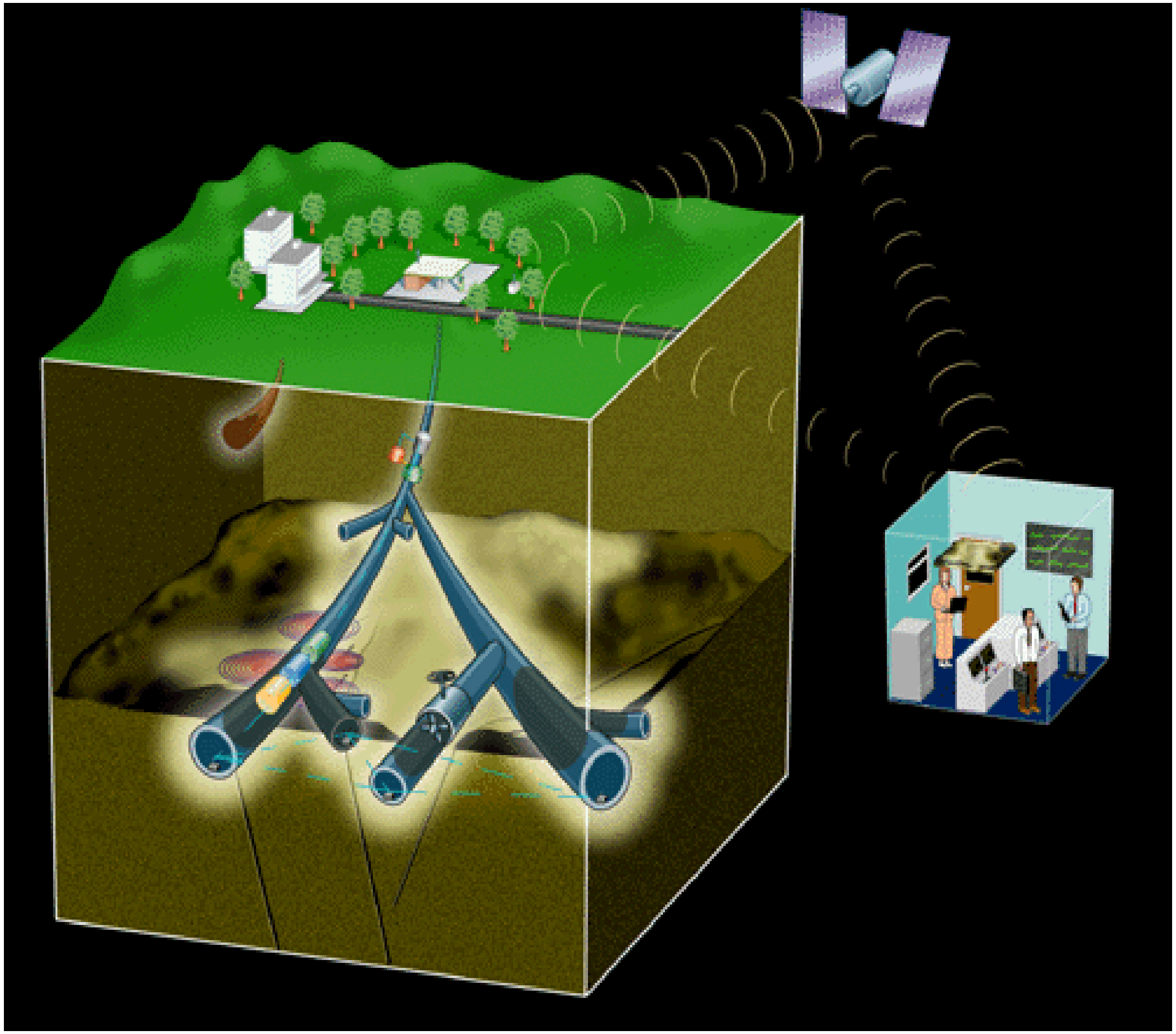
Fig. 2. GC analysis of the saturate fraction of the crude oil after incubation of strain 34[T]

S. Belyaev and T. Nazina, Russian Academy of Sciences, Moscow, (Institute of Microbiology)

Transforming the reservoir through microbiology

- Challenges
  - Representative, uncontaminated, preserved reservoir samples
  - Identification and selective stimulation of microorganisms with the appropriate metabolic functions
  - Acceleration of anaerobic processes and feasibility of reservoir aerobic processes
  - Optimising mass transport of hydrocarbons, nutrients and micro-organisms
  - Gene to reservoir understanding for cost-effective processes for transforming value and production capability of reservoirs on acceptable timescales

Gas Production Integrated with CCS
- a new meaning for Greenfield Production?



Subsurface processing and refining for integrated production of clean energy, fuels and chemical feedstocks