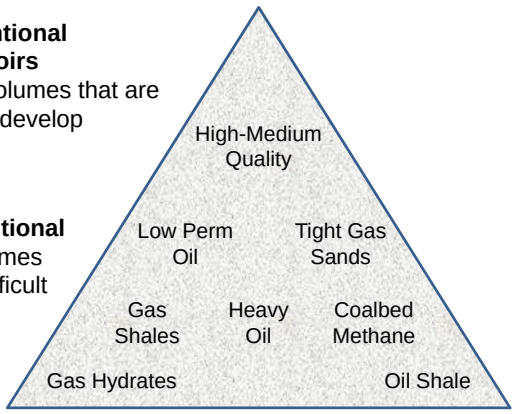
Unconventional Sources of Oil & Gas

- Oil Sands and Heavy Oil
- Shale Oil
- Shale Gas
- Oil Shale Gas
- Methane Clathrates

Unconventional Sources of Oil & Gas

Conventional Reservoirs
Small volumes that are easy to develop

Unconventional
Large volumes that are difficult to develop



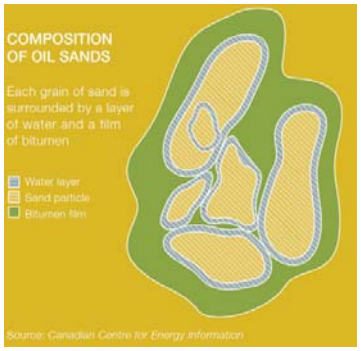
Oil Sands

Sand grains coated by water and clay, with bitumen, an especially heavy, viscous crude oil, filling the intervening pore spaces
API <10º

16 major deposits around the world.

Two biggest:

- Athabasca, in Alberta, Canada (Tar sands - bitumen)
- Orinoco Oil Belt, Venezuela (Extra-heavy oil)
- Others:
  - Kazakhstan 42 billion barrels
  - Russia 28.4 billion barrels

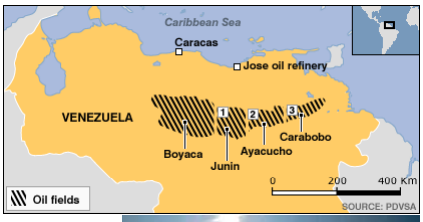


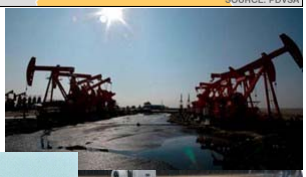
Athabasca Oil Sands

- Used by Cree Indians for waterproofing their canoes
- First “western” discovery in 1848
- Commercial production started 1967
- Athabasca + Peace River + Cold lake deposits
  - 1/3 known global oil reserves
  - 141,000 km^2 in extent
- Reserves of 1.7 to 2.5 trillion barrels of bitumen
  - 10 - 15% recoverable
- Only reserves suitable for large scale surface mining
- Most can be recovered using *in-situ* methods
- Alberta oil sands
  - 10 – 12% bitumen
  - 80 – 85% mineral material
  - 4 – 6% water

Orinoco Oil Belt, Venezuela

- Orinoco Oil Belt – Eastern Venezuelan basin
- Reserves of 1200 billion barrels
  - Of which 513 billion barrels recoverable
  - Number of projects involved
- Natural bitumen (7.5º – 8.5º API) extracted from reservoir
- Emulsified with water to give Orimulsion
  - 70% bitumen
  - 30% water
  - <1% surfactants
- Orimulsion used as fuel oil in boilers





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Other main sources

Trinidad and Tobago

- Pitch Lake at La Brea
- Semi-solid emulsion of soluble bitumen, mineral matter & water
- Used as road surfacing since 1815
- Reserves of 10 million tonnes

USA

- Distillation of tar sands started in California in 1870s
- Gilsonite (a naturally occurring solid hydrocarbon) found in eastern Utah – Green River Formation
- Used for printing inks, paints, protective coatings

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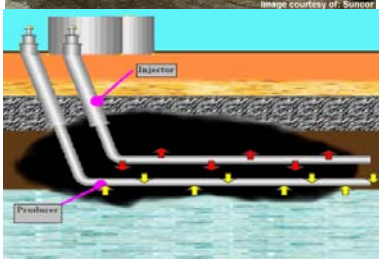
Oil sands - extraction

Traditional surface mining

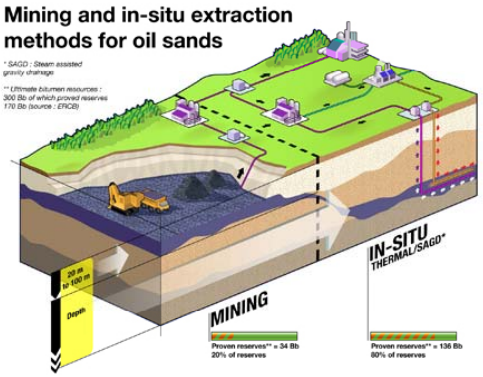
In-situ methods



Oil Sands

Traditional surface mining

- Giant shovels excavate bitumen to depth of around 75m
- Bitumen separated or “cracked” from its sedimentary matrix by the addition of hot water, mechanical agitation and skimming
- Uses process developed by Clark in 1920s
- 2 tonnes of oil sand gives 1 barrel of oil (0.125 t)



Oil Sands

Clark Hot Water Extraction (CHWE) process

- Ores mined using open-pit mining technology
- Ore crushed
- Hot water (50º – 80ºC) & NaOH added to give slurry
- Slurry transported to a primary separation vessel (PSV)
- Bitumen recovered by flotation as bitumen froth:
  - 60% bitumen
  - 30% water
  - 10% solids by weight

In-situ methods

Two main methods:

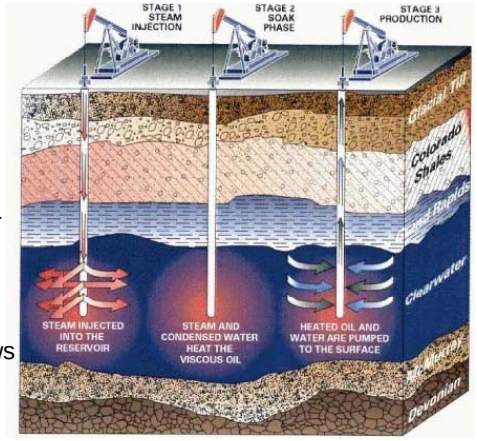
- Steam assisted gravity drainage (SAGD)
- Cyclic steam simulation

- Oil sands industry uses 4% of the Western Canada Sedimentary Basin's natural gas production
- 34 m^3 of natural gas required to extract one barrel of bitumen from *in-situ* projects

In-situ methods

Cyclic steam simulation – type of EOR

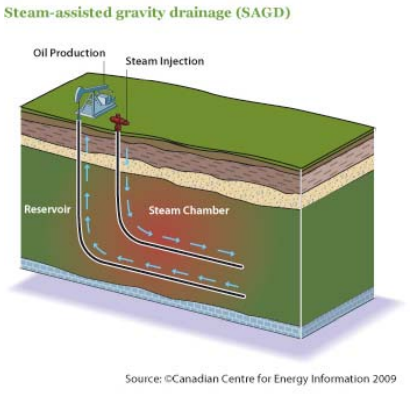
- Inject steam into deep deposits to heat the sands and reduce bitumen viscosity so can be pumped like conventional oil
- aka "huff and puff" recovery
- 3 stages:
  - Steam injection at 300-350ºC for months
  - Soaking for days/weeks
  - Oil pumped out until oil flow slows then start cycle again
- Recovery factor 20 – 25%



In-situ methods

Steam assisted gravity drainage (SAGD)

- Developed in 1980s in Alberta
- Pairs of horizontal wells drilled near base of deposit – 5m apart
- Steam injected into well ~5m above producer well
- Steam rises and heats bitumen & reduces its viscosity
- Bitumen flows down under gravity to lower producer well from which it is pumped to the surface
- Recovery rate 60 – 70%

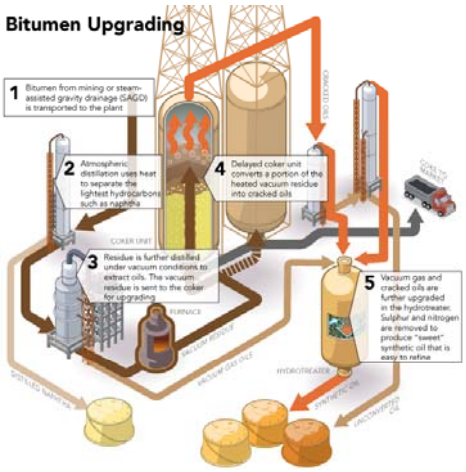


Upgrading

Heavy oils need to be upgraded before they can go to conventional refineries.

4 Main steps:

1. Thermal conversion or coking to crack the long hydrocarbon molecules
2. Catalytic conversion breaks down oil into smaller hydrocarbons using high pressure hydrogen
3. Semi-refined bitumen is distilled in a fractionating tower
4. Gas oils, kerosene & naptha hydrotreated with high temperature & pressure hydrogen to stabilise the hydrocarbons and remove impurities



Bitumen processing

Bitumen diluted and then hydrogenated to produce Syncrude

Shell's Scotford Upgrader

- 100,000 bbl/d (16,000 m^3/d)
- 25% of Canada's liquid fuel requirements
- Takes clean bitumen from Muskeg river mine
- Uses hydrogen, produced on site, to produce refinery-ready sweet, light crude oil called Syncrude

Syncrude upgrader plant

Oil Sands

Shale Oil

Shale Oil

Shale
A fine grained kerogen-rich sedimentary rock produced by the consolidation of clay, silt or mud, and composed roughly of:

- 33% Quartz
- 33% clay materials
- 33% other + organic matter

Oil Shale
A group of fine black to dark brown shales rich enough in bituminous material (kerogen) to yield oil upon heating in a retort

Shale gas
Natural gas produced from reservoirs predominantly composed of shale with lesser amounts of other fine grained rocks, rather than from more conventional sandstone or limestone reservoirs

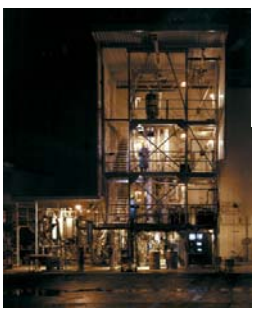
Shale Oil

Unconventional oil produced from oil shale by:

- Pyrolysis
- Hydrogenation
- Thermal dissolution

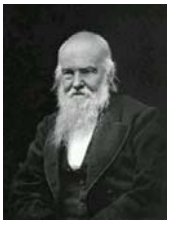
Converts organic matter (kerogen) in rock into synthetic oil & gas

Ratio of shale gas to shale oil depends on retorting temperature and increases with rise in temperature 300 – 480^{o}C



Shale Oil

- Used since ancient times as it burns without any processing
- Rock oil used for road construction and architectural adhesives
- Early 1300 in Austria shale oil produced by an early retorting method of heating crushed oil shale in crucibles
- 17th Century Modena used shale oil to light streets
- 1837 – first industrial scale use in France – used Salligue process
- 1847 – James "Paraffin" Young made "lighting oil" from cannel coal
- 1859 – Commercial scale shale oil extraction started by Robert Bell in Broxburn
- 19th Century focused on kerosene, lamp oil and paraffin
- 1916 Beginning of Estonian oil shale industry
- 1924 – Tallin Power Plant 1st power plant using oil shale as primary fuel
- 2005 China became world's largest shale oil producer



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Resources

- Deposits range from small presently non-economic to large commercially-extractable reserves
- Defining reserves difficult due to variation in:
  - Chemical composition
  - Kerogen content
  - Extraction technologies
- 2005 Global estimates 2.8 – 3.3 trillion barrels of recoverable oil
- 600 shale deposits known
- USA + Russia + Brazil have 86% of the reserves

EG5066 Energy Technologies: current issues & future directions

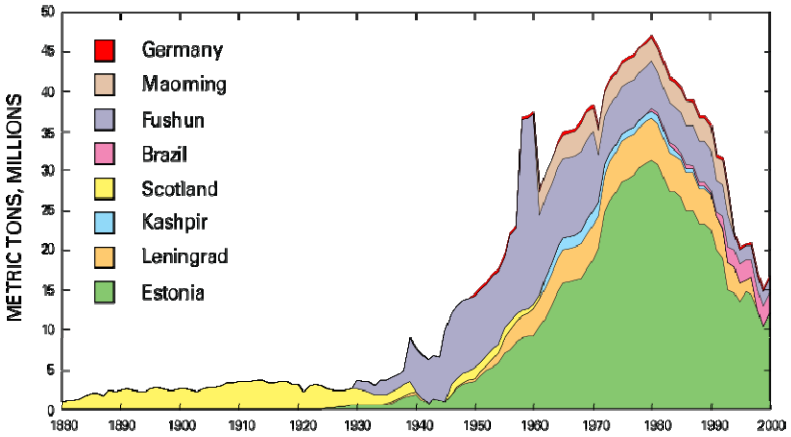
Resources (2006)

Deposit	Country	In place shale oil deposits (million barrels)	In place shale oil deposits (million tonnes)
Green River Formation	USA	1,466,000	213,000
Phosphoria Formation	USA	250,000	35,775
Olenyok Basin	Russia	167,715	24,000
Congo	DR Congo	100,000	14,310

Resources - 2008

Region	In place shale oil deposits (million barrels)	In place shale oil deposits (million tonnes)
Africa	159,243	23,317
Asia	45,894	6,562
Europe	368,156	52,845
Middle East	38,172	5,792
North America	2,100,469	383,758
Oceania	31,729	4,534
South America	82,421	11,794
World	**2,826,103**	**408,602**

Shale Oil



Shale oil extraction

Shale Oil Extraction

- Oil from shale cannot be obtained by drilling bore-holes
- Earliest description of process in 10th Century
- 1684 – GB granted first formal process patent
- Extraction industries widespread in 19th Century
- 2010 – major extraction industries running in Estonia, Brazil & China
- Two main methods:
  - *Ex-situ* Mining and processing
  - *In-situ* combustion

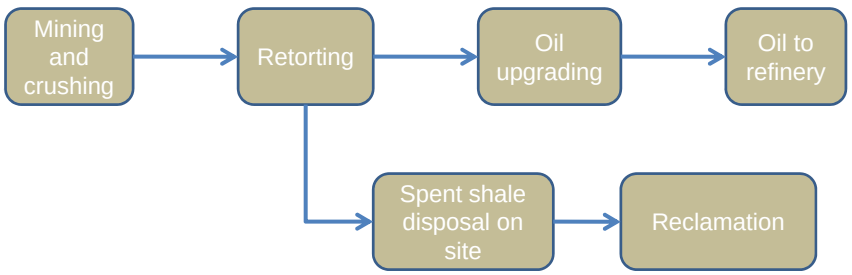
Shale Oil Extraction

Oil Shale Mining

Not usually open-cast mining – have to use sub-surface mining just as in the coal mining industry - e.g. room & pillar

- 100t crushed rock gives 90t waste
- Volume of waste 40% greater than that of original rock
- 1 barrel of oil/t rock requires 5X more mining than coal
- 3 barrels of water for each barrel of oil

Processes in Mining and Surface Retorting



Shale Oil Extraction

Steps in thermally conductive *in-situ* conversion

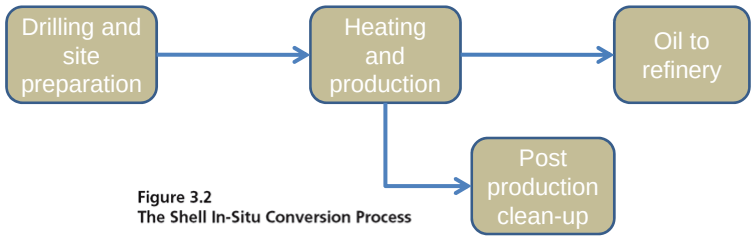
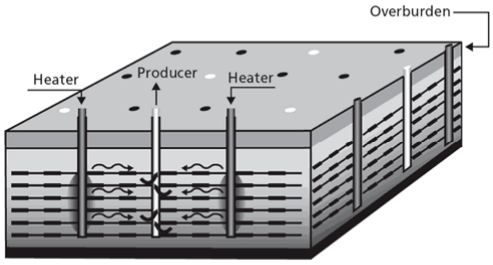
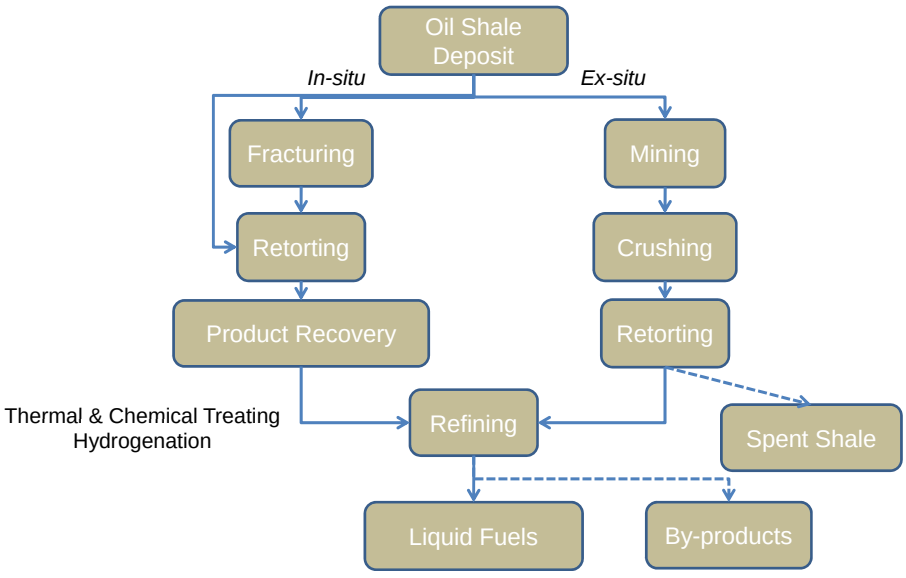


Figure 3.2
The Shell In-Situ Conversion Process



SOURCE: Adapted from material provided by Shell Exploration and Production Company.
RAND MG414-3.2

Shale Oil



Shale Oil Extraction

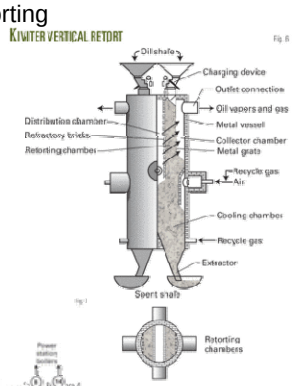
***Ex-situ* processing**

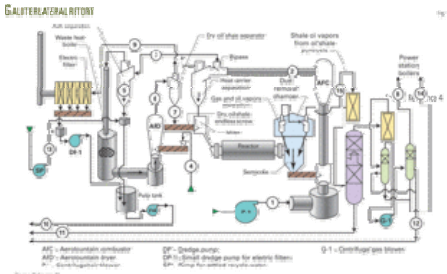
- Extracted oil-bearing shale crushed (12 – 75 mm) and heated to ~ 500ºC
- Kerogen condenses to viscous shale oil containing 80% of the original energy in the kerogen
- Contains nitrogen compounds and sulphur that need to be removed
- Combustion technologies burn the shale within a vertical retort to supply heat for pyrolysis.
- Raw shale fed into the top of the retort and heated by the rising hot gases
- Condensed shale oil is collected
- Non-condensable gas recycled and used as heat carrier
- In lower part of retort spent oil shale is heated to about 900ºC to burn off char

Shale oil retort in Somerset

Oil Shale Retorting Technologies

- There are hundreds of patents for oil shale retorting
- Only a few undergone thorough testing
- 4 main technologies in commercial use
  - Kiviter - used in Estonia
  - Galoter - used in Estonia
  - Fushun – used in China
  - Petrosix – used in Brazil





Shale Oil Extraction

***In-situ* technologies**

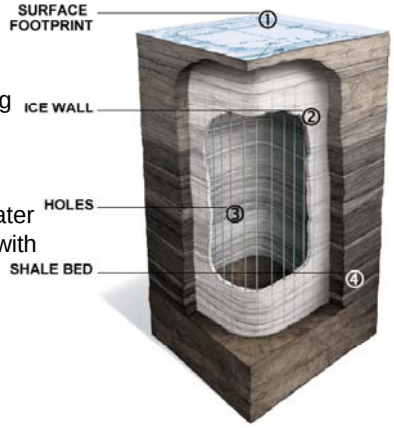
- Oil shale is heated underground by injection of hot fluids into the oil shale formation
- Shale oil recovered through vertical wells drilled into the oil shale formation
- Potentially able to extract more shale oil than conventional *ex-situ* processing technologies as wells can reach greater depths than surface mines
- Can be used with lower grade deposits

- One of the earliest *in-situ* technologies was the underground gasification by electrical energy (Ljungstrom method)
- Newest technologies utilise different heat sources and heat delivery systems

Shale Oil Extraction

Wall conduction

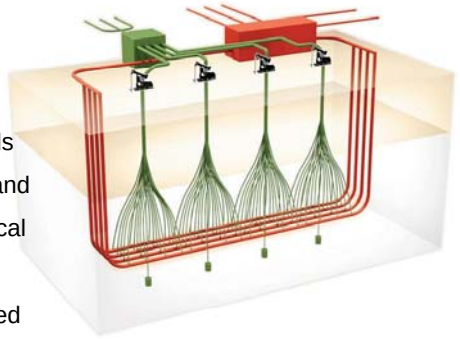
- Use heating elements or heating pipes placed in the oil shale formation
- Shell ICP process uses electrical heating elements to heat the shale layer to 650-700ºC over approx 4 years
- Processing area isolated from groundwater by a freeze wall consisting of well filled with a circulating super-chilled fluid
- Disadvantages:
- Costs of electricity, water use, risk of contaminating ground water
- Tested in Piceance Basin in 1980s – 270m3 oil extracted from 9 x 12 m test site



Shale Oil Extraction

American Shale Oil CCR process

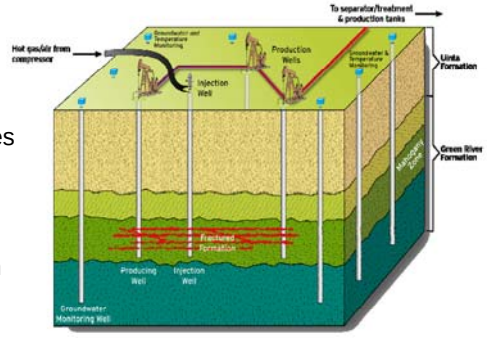
- Superheated steam circulated through a series of pipes placed below the oil shale layer to be extracted
- System combines horizontal wells through which steam is passed and vertical wells which provide vertical heat transfer and a means to collect the hydrocarbons produced
- Heat provided by combustion of natural gas initially and subsequently from oil shale gas



Shale Oil Extraction

Externally generated hot gas

- Hot gases produced above ground and then injected into the formation
- Chevron CRUSH process uses heated CO_2 injected into the well through drilled wells and then exposed to the formation through a series of horizontal fractures



Power Generation

Oil shale burnt like coal to drive steam turbines

Country	Capacity (2012)
Estonia	2,967MW
Israel	12.5MW
China	12MW
Germany	9.9MW

Narva Power Plant, Estonia

Shale Gas

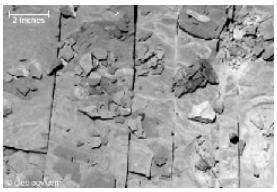
Shale Gas

- Natural gas from shale
- First commercial gas well drilled in Fredonia, USA in 1821
  - Shale gas well - 8.2m deep dug by hand
  - Fredonia, New York - first natural gas lights
  - Overshadowed by oil following Drake oil well in 1859
- Could supply up to 50% of natural gas produced in USA by 2020
- Shale gas is a *"potential game changer"* – Rune Bjornson of Statoil in 2009

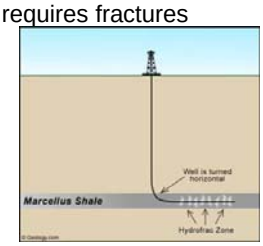
EG5066 Energy Technologies: current issues & future directions

Shale Gas

- Shales have insufficient permeability to allow significant fluid flow to a well bore
- Shale gas occurs:
  - Within pore spaces
  - Within vertical fractures
  - Adsorbed on mineral grains and organic matter



- Most shales are not commercial sources of natural gas
- Significant commercial gas production from shale requires fractures to be created to give permeability
- Shale oil boom due to development of:
  - Horizontal drilling
  - Hydraulic fracturing



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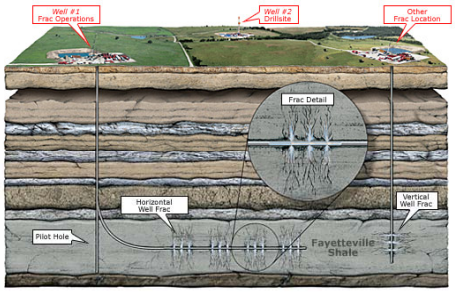
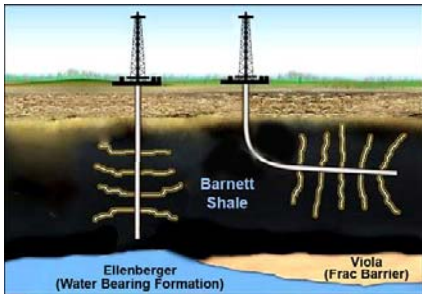
Shale Gas

- Horizontal wells – cost $3-5million *cf* $800,00 for a vertical well
- Hydraulic fracturing
  - Fluid pumped into well bore at sufficient pressure to create, propagate and maintain a fracture in the surrounding rock formation
  - Fluid is a slurry of water, proppants & chemical additives (0.5%)





Shale Gas

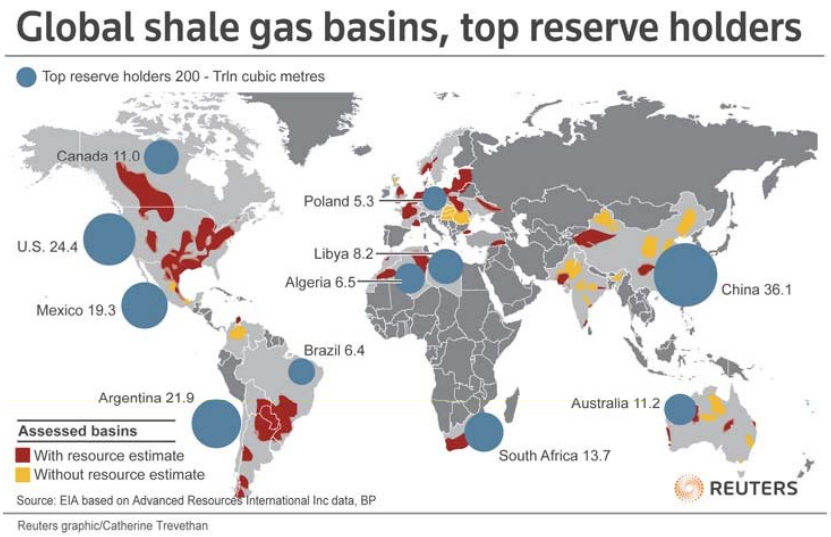
Reserves

- Significant reserves in USA – up to 100 years supply – 482tcf
  - Barnett Shale – 1.11 trillion cubic feet
  - Fayetteville shale
  - Marcellus Shale in the Appalachian region – a potential super giant field with 263 TCF reserves
  - Has 16% ethane so promoting new ethylene plants

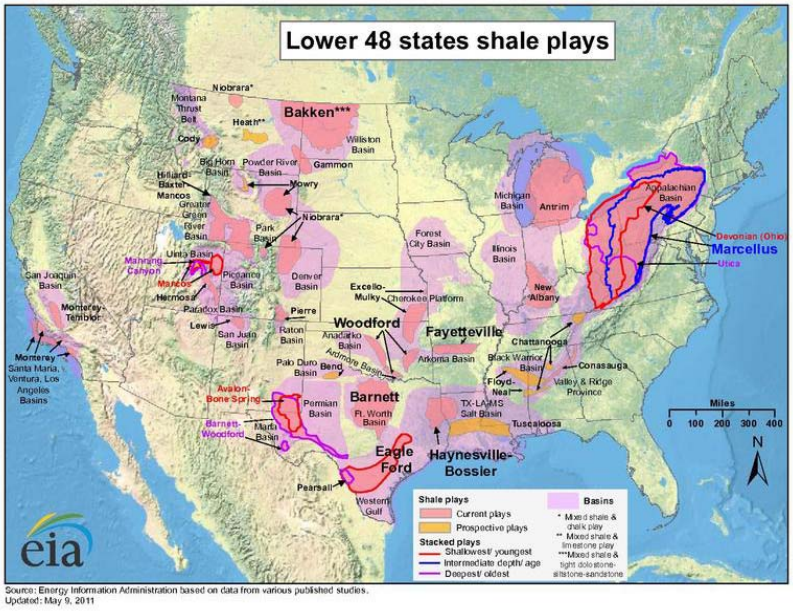
Significant reserves in:

- Canada
- Europe
- Estonia
- Germany – Lower Saxony Basin
- Hungary – Mako Trough
- Sweden
- UK – Weald Basin

Shale Gas Resources



Shale Gas Resources



Oil Shale Gas

- Synthetic gas mixture produced by pyrolysis of oil shale
- Different from shale gas which is natural gas
- Composition depends on technology and source of oil shale
- Typically: CH_4, H_2, CO, CO_2, N_2, H_2S, ethylene
- Substitute for natural gas – used as "town gas" in Tallin, Estonia
- Used in a power plant in Kohtle-Jarve until 1987

Methane clathrate

Methane clathrate aka:
- Methane hydrate
- Methane ice

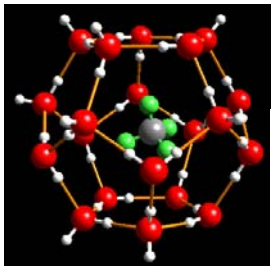
- *A solid clathrate hydrate in which a large amount of methane is trapped within the crystal structure of water ice*

- Common constituents of the shallow marine geosphere:
- In deep sedimentary structures
- Outcrops on the ocean floor

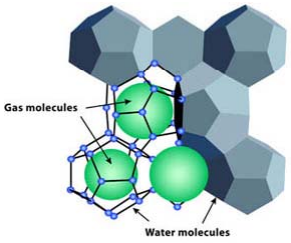
- Believed to form by:
  - migration of gas from depth along geological faults – precipitation or crystallisation on contact with cold sea water
  - Products of methanogenic bacteria on ocean floor crystallising with water

Methane clathrate

Methane forms a structure I hydrate with two dodecahedral (20 vertices, thus 20 water molecules) and six tetradechedral (24 water molecules) water cages per unit cell

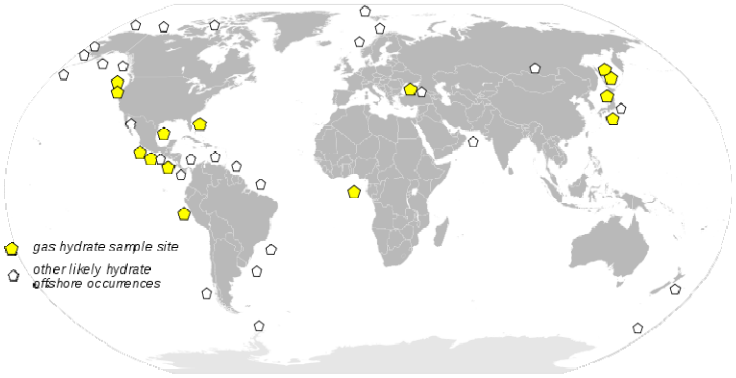


- Average composition is 1 mole of methane for every 5.75 moles of water
- Density is around 0.9g/cm^3
- One litre of methane clathrate solid contains 168 litres of methane gas (at STP)



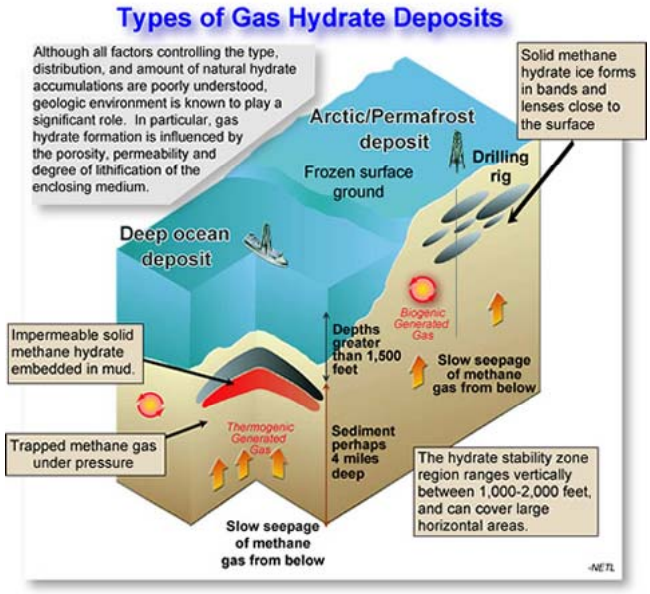
Methane clathrate

Deposits



- Restricted to shallow lithosphere (<2000m)
- Polar continental sedimentary rocks where surface temperatures <0^{o}C
- Oceanic sediment in water depths >300m where water temperature ~2^{o}C
- Deep lakes – eg Baikal in Siberia
- Size of deposits difficult to determine

Methane clathrate

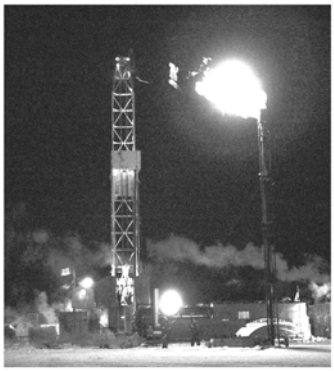


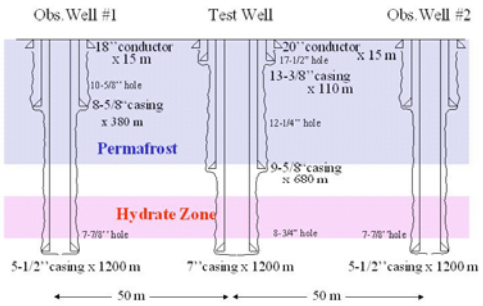
Methane clathrate

- Sedimentary methane hydrate reservoirs contain some 2-10 x known reserves of natural gas
- Potentially important source of hydrocarbon fuel
- Majority of deposits too dispersed for economic extraction
- Large potential exploitable deposit in Gulf of Mexico 10^{10} m^3 of gas
- Need development of extraction technology in order to exploit reserves
- Messoyakkha Gas Field near Norilsk in West Siberian Basin believed to be exploiting methane clathrates – it operates in a permafrost region
- Large R&D programmes in Japan and China

Methane clathrate

- Test project in 2008 at the Mallik gas hydrate field in the Mackenzie River delta – gas extracted by lowering the pressure rather than using heat
- Mallik gas hydrate field first discovered by Imperial Oil in 1971-72.





Methane clathrate