Are we running out of fossil fuels?

Sustainable Energy

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May 14, 2018

ULg - Applied Sciences
Introduction
What is a fossil fuel?

Fossil fuels are

• solid, liquid or gaseous substances
• that contain organic (or covalently bonded) carbon and
• are produced by chemical and physical transformations of plant and animal remains over geological time periods.

The chemical energy contained in fossil fuels is traditionally extracted by
1. a rapid reaction with an oxidant through a process called combustion
2. the electrochemical oxidation where the fuel produce electricity and heat in a fuel cell.

\[
\text{CH}_4 + 2\text{O}_2 \rightarrow \text{CO}_2 + 2\text{H}_2\text{O} + \text{heat}
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Conventional Fossil Fuels

Coal: coal (organic rock) originates from the arrested decay of the remains of plant life that flourished in humid areas many millions of years ago.
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**Natural Gas** : Found in underground reservoirs of porous rocks (sometimes mixed with petroleum), it consists primarily of methane (*CH₄*).
Non-Conventional Fossil Fuels

Shale Gas:
Natural gas from low shale permeability (makes the extraction of the gas more difficult).

Oil Shale:
A fine-grained sedimentary rock consisting mainly of carbon and hydrogen capable of producing petroleum-like liquids upon heating.

Tar Sands:
a sand impregnated of a viscous hydrocarbon substance (up to 18%) known as bitumen.

Shale gas rock
Shale rock in the UK is present at all depths, but gas only starts to be produced between 1500m-4000m and the rock can be up to 3000m thick in some areas.
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![Diagram of shale gas rock](image-url)

Shale gas rock
Shale rock in the UK is present at all depths, but gas only starts to be produced between 1500m-4200m and the rock can be up to 3000m thick in some areas.

![Diagram of hydraulic fracturing](image-url)

Table 1

Hydraulic Fracturing Required to Produce

<table>
<thead>
<tr>
<th>Reservoir Type</th>
<th>Unconventional</th>
<th>Tight Gas</th>
<th>Conventional</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shales</td>
<td>0.000001</td>
<td>0.0001</td>
<td>0.01</td>
</tr>
<tr>
<td>Granite</td>
<td>0.000001</td>
<td>0.001</td>
<td>0.1</td>
</tr>
<tr>
<td>Clay</td>
<td>0.0001</td>
<td>0.1</td>
<td>10</td>
</tr>
<tr>
<td>Concrete</td>
<td>0.01</td>
<td>100</td>
<td>1000</td>
</tr>
<tr>
<td>Brick</td>
<td>0.1</td>
<td>1000</td>
<td></td>
</tr>
<tr>
<td>Building Stone</td>
<td>10</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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Why fossil fuels are so attractive?

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While changing the energy sector from fossil fuel to something else is possible, the time needed to make the change makes it difficult to switch rapidly.
Fossil fuels: the resource
Estimating the reserve at constant consumption

- The world coal reserve is estimated at $Q = 290\,000\,000\,PJ$
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If the world switched all its energy consumption to coal the reserve would last:

$$\int_{2010}^{\infty} dt = \frac{Q}{-490 \times 10^3} \rightarrow \Delta t = \frac{290 \times 10^6}{490 \times 10^3} = 592 \text{ years}$$
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\[
\begin{align*}
  \Delta t &= -\int_{2010}^{\Delta t+2010} \frac{dQ}{dt} \, dt = \int_0^Q -\frac{dQ}{490 \times 10^3} \\
  &\rightarrow \Delta t = \frac{Q}{490 \times 10^3} = \frac{290 \times 10^6}{490 \times 10^3} = 592 \text{ years}
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at actual consumption.
Estimating the reserve with exponential growth

- Assuming exponential growth from year 2010 and after: \( \frac{dQ}{dt} = -ce^{m(t-2010)} \)
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\left. \frac{dQ}{dt} \right|_{t=2010} = ce^0 = c \quad \rightarrow \quad \left. \frac{dQ}{dt} \right|_{t=2010} = \left. \frac{dQ}{dt} \right|_{t=2010} e^{m(t-2010)}
\]

- After some algebraic steps, we obtain \( \Delta t = \ln \left[ \frac{mQ_{\infty} - Q_{2010}}{dQ/dt|_{t=2010}} + 1 \right] \) \( m \).
  Taking \( m = 2\% \) leads to \( \Delta t = 192 \) years.
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- Integrating between the current time and the depletion time yields:

\[ \int_{Q}^{0} dQ = \left. \frac{dQ}{dt} \right|_{t=2010} \int_{2010}^{2010+\Delta t} e^{m(t-2010)} dt = \left. \frac{dQ}{dt} \right|_{t=2010} \frac{1}{m} \left[ e^{m\Delta t} - 1 \right] \]
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Conventional approach to fossil fuel depletion

One possible approach is to consider that, as fossil fuels are exhaustible, they exist in the Earth in a fixed stock.

- When this stock is used up, it becomes harder to recover whatever fuel from the resource.
- The recovery cost and the resulting price to consumers will increase.

The conclusions of that reasoning is that the time of cheap oil is finished as oil production has already peaked or will be very soon peaked.

Conventional depletion arguments express the temporal history of mineral-fuel production in terms of Hubbert curves.

**Figure 1** – The Hubbert curve for US crude oil production. The actual production is well above the one predicted by the Hubbert curve.
Figure 2 – Two production curves estimated from production data.
However, nobody knows when the world will run out of oil or any other fossil fuel.

Indeed, for a single reservoir, geologists can assess the amount of petroleum available but the petroleum reserves exist in many dispersed regions differing widely in size, quality and production costs.

The classical view of depletion theory does not account for advances in technology that will enable the profitable exploitation of stocks of fuels that previously were unknown or judged unattractive to develop. The history of our knowledge of fossil resources to date favors the latter thinking.

- the last 75 years, the recorded world’s petroleum reserves are growing, not declining and the prices (corrected for inflation and taxes) are stable or declining.
- Energy price fluctuation are better explained by political and economic crises than available resources.
How long will fossil fuels last?

If the incremental cost of production from a given source exceeds the cost of other wells or mines producing fossil fuels the production of that source is suspended.

So far, the technology has won the battle for fossil fuel production...

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td><strong>OPEC</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cumulative production</td>
<td>–</td>
<td>26</td>
<td>55</td>
<td>103</td>
<td>100</td>
<td>284</td>
<td>34.3</td>
</tr>
<tr>
<td>Gross reserve additions</td>
<td>–</td>
<td>219</td>
<td>251</td>
<td>128</td>
<td>434</td>
<td>1,032</td>
<td>0</td>
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<tr>
<td>Reserves at end</td>
<td>22</td>
<td>215</td>
<td>412</td>
<td>436</td>
<td>770</td>
<td>770</td>
<td>1,068</td>
</tr>
<tr>
<td><strong>Non-OPEC</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cumulative production</td>
<td>–</td>
<td>51</td>
<td>64</td>
<td>102</td>
<td>190</td>
<td>407</td>
<td>34.3</td>
</tr>
<tr>
<td>Gross reserve additions</td>
<td>–</td>
<td>98</td>
<td>187</td>
<td>114</td>
<td>207</td>
<td>607</td>
<td>6.1</td>
</tr>
<tr>
<td>Reserves at end</td>
<td>29</td>
<td>76</td>
<td>200</td>
<td>212</td>
<td>229</td>
<td>229</td>
<td>188.7</td>
</tr>
<tr>
<td><strong>Total World</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>–</td>
<td>77</td>
<td>119</td>
<td>205</td>
<td>289</td>
<td>690</td>
<td>82.1</td>
</tr>
<tr>
<td>Gross reserve additions</td>
<td>–</td>
<td>318</td>
<td>439</td>
<td>242</td>
<td>640</td>
<td>1,639</td>
<td>7.7</td>
</tr>
<tr>
<td>Reserves at end</td>
<td>51</td>
<td>291</td>
<td>611</td>
<td>648</td>
<td>999</td>
<td>999</td>
<td>1,382</td>
</tr>
</tbody>
</table>

**Figure 3** – World production and cumulative reserves of fossil fuels in bbl (1944-2010).
## Oil resource per category

![Table showing oil resources per category]

**Figure 4** – Oil resources and reserves in 2013 (source IEA) expressed in bbl.
## Gas resource per category

<table>
<thead>
<tr>
<th></th>
<th>Conventional</th>
<th>Unconventional</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Tight gas</td>
<td>Shale gas</td>
</tr>
<tr>
<td>E. Europe/Eurasia</td>
<td>143</td>
<td>11</td>
<td>15</td>
</tr>
<tr>
<td>Middle East</td>
<td>124</td>
<td>9</td>
<td>4</td>
</tr>
<tr>
<td>Asia-Pacific</td>
<td>43</td>
<td>21</td>
<td>53</td>
</tr>
<tr>
<td>OECD Americas</td>
<td>46</td>
<td>11</td>
<td>48</td>
</tr>
<tr>
<td>Africa</td>
<td>52</td>
<td>10</td>
<td>39</td>
</tr>
<tr>
<td>Latin America</td>
<td>31</td>
<td>15</td>
<td>40</td>
</tr>
<tr>
<td>OECD Europe</td>
<td>25</td>
<td>4</td>
<td>13</td>
</tr>
<tr>
<td><strong>World</strong></td>
<td><strong>465</strong></td>
<td><strong>81</strong></td>
<td><strong>211</strong></td>
</tr>
</tbody>
</table>

**Figure 5** – Gas resources and reserve in 2013 (source IEA) expressed in tcm (1 tcm ≈ 6 bbl).
Available resource duration

- **Uranium**: Cumulative production to date, Proven reserves, Total remaining recoverable resources
- **Oil**: Cumulative production to date, Proven reserves
- **Natural gas**: Cumulative production to date, Proven reserves
- **Coal**: Cumulative production to date, Proven reserves, Total remaining recoverable resources

Years: -100 to 3000
Sustainability aspects
Figure 6 – Energy prices evolution from 1900 to 1996 (without taxes).
The role of non-conventional fossil fuels
Gas is a relatively clean (high hydrogen content) and flexible fuel (used in gas turbines) that make it an ideal complement to renewable energies BUT:

- Half of the gas consumed in Europe comes from Russia and is still sold on prices indexed on oil price (makes gas more expensive).
- The gas is losing shares with respect to coal (cheaper).
- In countries with high renewable share, the average utilization of gas-fired plant has dropped significantly.

In order for the EU to develop policies some questions need to be addressed:

1. Will fracking be environmentally unsafe and environmentally disruptive?
2. Will shale gas be as cheap as in the US?
Shale gas well operation stages

**Stage 1: Exploration**

Exploratory drilling to identify if oil or gas can be produced profitably. The operator may do seismic surveys, samples of the shale rock, one or more tracks and flow testing.

A “pad” is built and a 30m tall drilling rig is installed. The operator may need to transport equipment, water and chemicals to and from the site.

£100,000 in community benefits provided per well-site where fracking takes place.

**Stage 2: Moving into production**

If the site is suitable for production more wells will be drilled and fracked. Water, chemicals, equipment and material will be brought on and off site and waste water carried away for treatment and disposal.

**Stage 3: Production**

Maintenance activity will take place from time to time and further wells may be drilled, but the overall level of activity is likely to decline.

1% of revenues at production stage will be paid out to communities.

**Stage 4: Decommissioning & restoration**

Restoring the site to its original condition. It includes making wells safe for abandonment and the removal of surface installations. Decommissioning and restoration could happen at any stage if the site doesn’t develop into the next one.

At each stage:

The industry has committed to early engagement – local communities can expect a continued point of contact and an opportunity for comment and feedback on initial plans. As part of planning permission the planning authority will advertise the planning application package in local media and consult statutory consultees. Local engagement with communities will formally be undertaken at this stage.

These activities can only take place if planning permission is granted by the planning authority, and if other consents or clearances are obtained from the environmental regulator, the Health and Safety Executive and Department of Energy and Climate change.
Methane contamination in fresh water wells

Natural source of methane are

- decaying or digesting vegetation that can come in contact with groundwater and
- methane gas adsorbed onto the organic shallow coal surface that can access ground water.

If water is withdrawn from the well at a rate above the recharge rate, the methane will be absorbed by the well.

The later cause of contamination could be a default in the cement isolation or channel leakage (as for the frac fluid).
### Resource of shale gas

<table>
<thead>
<tr>
<th>Country</th>
<th>Technically Recoverable Shale Gas Resources</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>$36.1 \times 10^{12} \text{ m}^3$</td>
</tr>
<tr>
<td>United States</td>
<td>$24.4 \times 10^{12} \text{ m}^3$</td>
</tr>
<tr>
<td>Argentina</td>
<td>$21.9 \times 10^{12} \text{ m}^3$</td>
</tr>
<tr>
<td>Mexico</td>
<td>$19.3 \times 10^{12} \text{ m}^3$</td>
</tr>
<tr>
<td>South Africa</td>
<td>$13.7 \times 10^{12} \text{ m}^3$</td>
</tr>
<tr>
<td>Australia</td>
<td>$11.2 \times 10^{12} \text{ m}^3$</td>
</tr>
<tr>
<td>Canada</td>
<td>$11.0 \times 10^{12} \text{ m}^3$</td>
</tr>
<tr>
<td>Libya</td>
<td>$8.2 \times 10^{12} \text{ m}^3$</td>
</tr>
<tr>
<td>Algeria</td>
<td>$6.5 \times 10^{12} \text{ m}^3$</td>
</tr>
<tr>
<td>Brazil</td>
<td>$6.4 \times 10^{12} \text{ m}^3$</td>
</tr>
<tr>
<td>Poland</td>
<td>$5.3 \times 10^{12} \text{ m}^3$</td>
</tr>
<tr>
<td>France</td>
<td>$5.1 \times 10^{12} \text{ m}^3$</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>$158 \times 10^{12} \text{ m}^3$</td>
</tr>
</tbody>
</table>

Source: Wood Mackenzie, Deutsche Bank

[Diagram showing data points for different countries and their shale gas resource values.]
Oil and natural gas major net importers

Figure 7 – The new geography of demand and supply means a re-ordering of global energy trade towards Asia
Influence of shale gas on energy prices

Figure 8 – Ratio of industrial energy prices relative to the United States
Could Europe simply import the cost advantage of cheaper US gas?

Figure 9 – Indicative economics of LNG export from the US Gulf Coast (at current prices). High costs of transport between regions mean no single global gas price.
Figure 10 – Share of energy in total production costs for selected industries.
Energy prices and economic growth

Figure 11 – Share of global export market for energy-intensive goods.
Energy policies critical for Europe’s future!

- Stronger action to improve energy efficiency must be central to reconciling energy security, competitiveness and climate goals
- Supporting indigenous sources of energy supply, including renewables, nuclear power and unconventional gas can also help
- Renegotiation of long-term gas import contracts involving a shift away from oil indexation to hub-based pricing could also cut costs
Fossil resource and sustainability

As it is mentioned above, the driving force for sustainability is not that the world is running out of fossil fuels and needs to seek for alternative energy sources. The energy supply from fossil fuels seems guaranteed for the several decades to come.

**However**, alternatives energy sources do need to be developed for any of the following reasons:

- In case higher levels of global warming predicted from a doubling of current atmospheric concentrations of $CO_2$ prove to be correct.
- As a way to diversify our energy sources and avoid over reliance on any one source (would it become unavailable for political, environmental, regulatory or technological factors).

In this frame, fossil fuels are able to supply energy as a transition to non fossil alternatives at a pace that will prevent economic disaster.