

**Further work on energy-return-on-energy-  
invested (EROEI).**

**J.C. Jones.**

**Background.**

**The paper follows:**

**Jones J.C. 'Energy-return-on-energy-invested (EROEI)  
for crude oil'**

**presented at last year's meeting in San Antonio and  
published in 'Journal of Petroleum and Environmental  
Biotechnology'.**

## **Structure of the talk:**

- **An examination of recently posted views on EROEI and a critique of them.**
- **An examination of a recently published article on EROEI and comparison of its contents with the San Antonio paper.**
- **An examination of some of the views expressed in a blog on the San Antonio paper.**

Statement posted in 2014 on:

<http://www.rsc.org/chemistryworld/2014/02/peak-oil-not-myth-fracking>



Royal Society of Chemistry, UK.

which contains the symbolic illustration reproduced below.



**‘As a rough comparison, conventional crude oil production has an EROEI in the range 10 to 20, while tight oil comes in at 4 to 5. Oil recovered from ultra deep water drilling gives 4 to 7, heavy oil 3 to 5.’**

**These data will be considered in turn.**

**Recall the expression given in the previous paper:**

$$\text{EROEI} = 5.5 \times 10^5 / 25h$$

**where h = well depth (m) or well + sea depth if subsea.**

**The EROEI range 10 to 20 given for 'conventional oil' corresponds to well depths in the range 1100m to 2200 m.**

**The statement that 'tight oil comes in at 4 to 5' will now be considered. If it is tight it has come from a rock formation of low permeability (mD or tens of  $\mu$ D).**

**The statement quoted makes no mention of depth of the oil, usually the most important factor in EROEI.**

**It is possible that what is meant is that the fracturing process itself has a significant energy requirement which 'mortgages' the oil field, requiring a large amount of oil for energy payback which could be expressed as a drop in EROEI. This will be examined.**

## Sequence of events in hydraulic fracture\* :

- The geological formation containing the oil is fractured open by admittance of fracture fluid, which is usually aqueous.
- The scene of the fracture is occupied by a proppant, often sand.
- Oil exits the formation and experiences the permeability of the proppant *in situ*, higher than that of the rock formation.

\* Hydraulic fracture is by no means restricted to tight oil and gas.

**Below is a jack-up rig recently used for fracking in the North Sea. Semi-submersible vessels are frequently so used. The operations are respectively *rig based* and *vessel based* fracturing.**



**Below: hydraulic fracturing truck for onshore oilfields.**



**The power requirements of devices such as those shown in the previous two slides have to be considered if energy requirements of fracking are to be determined.**

**Statement from a published case study\*:**

**‘In general, the process of hydraulic fracturing consists of injecting water, sand, and chemical additives into the well over a short period of time (typically less than one hour) at pressures sufficient to fracture the rocks to enhance fluid movement through the perforations and into the wellbore.’**

**[http://www.eenews.net/assets/2012/10/11/document\\_ew\\_01.pdf](http://www.eenews.net/assets/2012/10/11/document_ew_01.pdf)**

A mobile hydraulic fracturing truck such as that shown in a previous slide will typically deliver about 2000 horse power (1500 kW).

If it converts heat to work at 30% efficiency such heat has to be supplied at 5000 kW (5 MW). In one hour's operation the quantity of heat will be 18 GJ.

A barrel of oil when burnt releases about 6 GJ.



3 barrels of oil would suffice for one hour of fracking.

The numbers in the above are arbitrary. Even so the minuscule energy required according to the calculation justifies argument from the particular to the general: **the energy requirement of fracking is too small to affect an EROEI.** This would be true of a prolonged fracture operation involving multiple stages which required energy an order of magnitude or more in excess of that in the above calculation.

The conclusion is not affected if the fracking fluid is itself a petroleum product, in any case a declining practice.

**‘Oil recovered from ultra deep water drilling gives  
[an EROEI value of] 4 to 7.’**

**Difficulties with the above:**

- **Drilling a well mortgages the well to a totally negligible degree.  
This is shown in:**

**Jones J.C. ‘Effects of exploratory drilling on the EROEI for crude oil’  
Fuel 88 2321 (2009).**

- **What is ‘ultra deep water drilling’?**

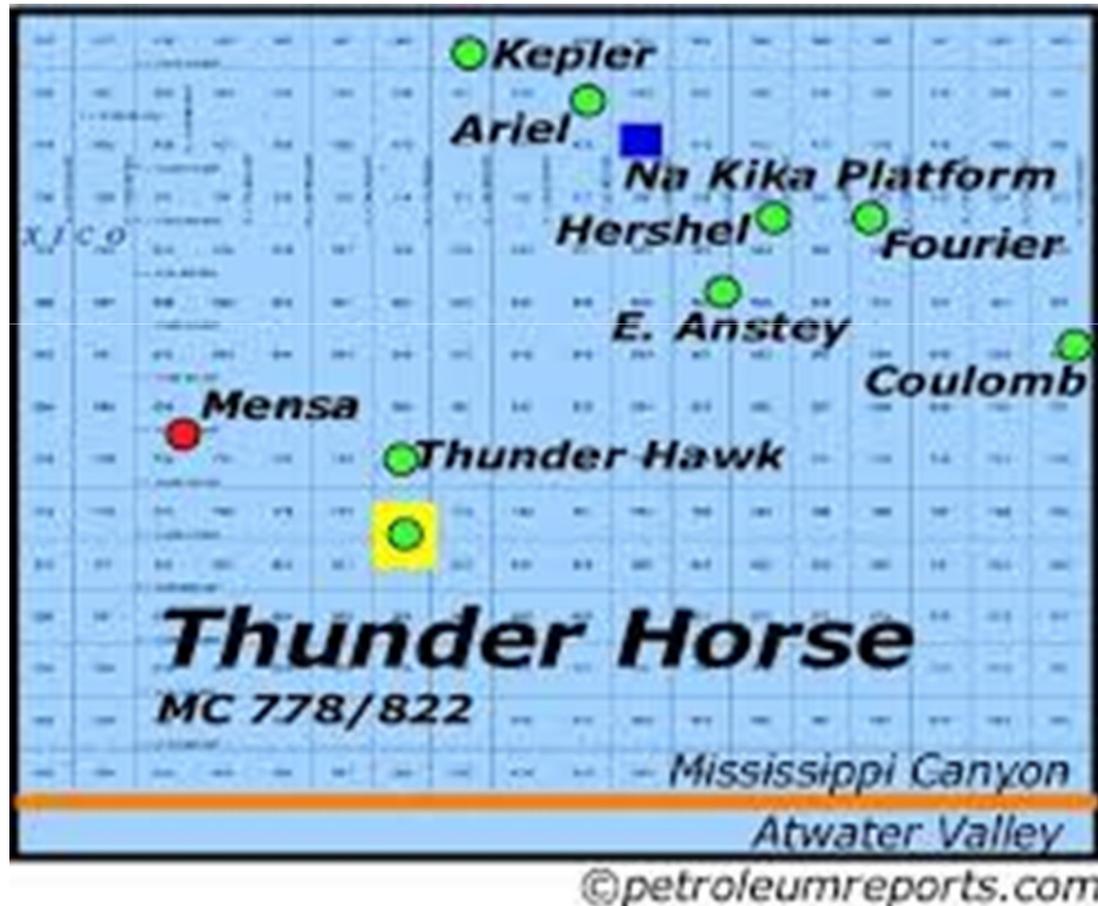
**Aside: From an article in Scientific American in 2013:**

**‘. . . . the output [energy returned] would be the energy in a gallon of gasoline, and the input would be all the energy required to make the gasoline [energy invested] including oil exploration, drilling and refining.’**

***It is not being asserted that the author of the piece in Scientific American ought to have cited the speaker’s work on EROEI with uncritical acceptance, simply that it might have added value to statements such as the above.***

Example of a deep water oil field: Thunder Horse field in the GoM.

Below: Map showing the Thunder Horse field. It is in the Mississippi Canyon, where the 2010 spill occurred.



**At Thunder Horse:  
On the web site:**

[http://www.subseaig.com/data/PrintProject.aspx?project\\_id=129](http://www.subseaig.com/data/PrintProject.aspx?project_id=129)

**we are informed that at a position at Thunder Horse where the sea depth was 6300 feet (1920 m) an exploration well was drilled to a subsea depth of 22760 feet (6937 m). Returning to:**

$$\text{EROEI} = 5.5 \times 10^5 / 25h$$

**where h is the total depth (m)**

**at Thunder Horse the subsea depth makes a much bigger contribution to 'h' than the sea depth does.**

**So why should 'ultra deep water drilling' lower the EROEI?**

**' . . heavy oil [has an EROEI of ] 3 to 5.'**

**'Heavy oil' not the best term. 'Dense crude' would have been better.**

**Approximate range of densities of crude oil:**

**780 to 975 kg m<sup>-3</sup> (API gravity 50 to 14).**

**In the derivation of the expression for EROEI the density appears once to power 1. This is not sufficient to reduce the EROEI for a crude at the high end of the range by half an order of magnitude as is being suggested.**

**Other developments since last year's paper.**

**(i) A paper on EROEI originating in Australia:**

**Morgan J. Chemistry in Australia, August 2014 pp.22-24.**

**This article, which is concerned largely with electricity generation, draws on ideas by C. Hall which were reviewed in 'Scientific American' in 2013 (by the same author as the previously cited article in Scientific American). This is focused on oil production and is followed by an online discussion.**

**also**

**(ii) A blog in which the paper from the San Antonio conference is discussed:**

**<http://peakoil.com/geology/energy-return-on-energy-invested-eroei-for-crude-oil-and-other-sources-of-energy>**

**As a means of discussion of current views on EROEI the contents of each of the above will be examined in a comparative way against the San Antonio paper.**

<p style="text-align: center;"><b>Morgan/Hall</b> (With quotations from one or both.)</p>	<p style="text-align: center;"><b>San Antonio paper</b> (With quotations from the PP presentation. See also the journal article.)</p>
<p style="text-align: center;"><u><b>Terminology:</b></u></p> <p><b>Morgan: consistent use of the term EROI, energy-return-on-investment.</b></p> <p><b>Hall: EROI defined as being the same as EROEI in the SA paper.</b></p> <p style="text-align: center;"><b>Even so</b></p> <p style="text-align: center;">↓</p> <p><b>‘ . . . you can’t simply pay more and more and get enough energy to run society. At some EROI – I’m guessing at 6:1 to 5:1 – it doesn’t work anymore.’</b></p>	<p><b>‘An EROEI by definition should always be on an energy not a financial basis.’</b></p> <p><b>For this reason EROEI is probably the preferable expression.</b></p> <p style="text-align: center;">← <b>Finance and energy being confused here.</b></p>

- **Adventitious energy such as wind in a turbine does not feature in the calculation of 'energy invested' and also has no purchase price.**
- **This does not signify interchangeability of energy and cost in formulating an EROEI.**

Morgan/Hall	San Antonio paper
<p data-bbox="322 405 1055 504">'The concept of EROI was introduced .... in 1981'</p> <p data-bbox="618 520 770 619">↑ Not so!</p>	<p data-bbox="1167 520 1928 619">'100 barrels out per barrel in a rule of thumb as late as the mid 20<sup>th</sup> Century'</p>

Morgan/Hall	San Antonio paper
<p data-bbox="277 233 1301 472">'If you've got an EROI of 1.1 you can pump the oil out of the ground and look at it. If you've got 1.2 you can refine it . . .'</p> <p data-bbox="763 555 808 603">↑</p> <p data-bbox="264 619 1310 858">Disregard of non-isothermally supplied adventitious energy, obtained by burning natural gas otherwise destined for flaring or re-injecting into the well.</p> <p data-bbox="282 938 1292 1114">Measured EROEI values are from energy audits. Reliable distinction of 1.1 from 1.0 or of 1.2 from 1.1 very difficult.</p>	<p data-bbox="1368 555 1933 986">' . . . when natural gas is used as a heat source at a refinery the EROEI for a crude and that for a refined product from it cannot be distinguished numerically.'</p> <p data-bbox="1361 1007 1406 1054">←</p>

Morgan/Hall	San Antonio paper
<p data-bbox="342 264 846 547">'EROI [= EROEI] is a fundamental thermodynamic metric . . . .'</p> <p data-bbox="495 879 689 1010">↑ It isn't!</p>	<p data-bbox="1025 264 1883 320">'EROEI is not an energy balance.'</p> <p data-bbox="949 419 1957 778">'Energy which could not in engineering practice have been put to any alternative use ('adventitious energy') need not feature in an EROEI calculation. . . .'</p> <p data-bbox="965 879 1957 1090">'Adventitious energy <u>would</u> obviously feature in formal thermodynamic analysis.'</p>

**Aside: Over the few years since the idea of adventitious energy in EROEI was introduced by the speaker the term has not filtered through to web discussions.**

**The Wikipedia entry for EROEI *does* have a paragraph (without a reference) on 'Non man made energy' which is 'not usually included in the calculation of energy invested'. This is consistent with the view that EROEI is not an energy balance.**

Morgan/Hall	San Antonio paper
<p data-bbox="277 268 1097 576">'Civilisation requires a substantial energy return on investment. You can't do it with some kind of crummy fuel like corn-based ethanol (with an EROI of around 1).'</p> <p data-bbox="327 655 1077 898">           ↑            Disregard of such interplay.            ←            Ethanol 'crummy'? Its RON is 108.         </p>	<p data-bbox="1160 268 1944 576">'Interplay of energy and financial considerations is inevitable if the concept of EROEI is applied to carbon-neutral fuels because of the carbon credits they engender.'</p> <p data-bbox="1144 655 1957 834">Equivalently, use of a fuel with a low EROEI might be viable because of the carbon credits it generates.</p>

**Comments from the blog and responses to them.**

**NOT intended to be a defence or promotion of the speaker's own conclusions.**

**An objective, scientifically based critique of the comments.**

**Statement from the blog:**

**'EROEI is an entropy balance.'**

**Entropy is not conserved like energy and mass are.**

**The term entropy balance is correct if taken to mean:**

$$S_{\text{final}} = S_{\text{initial}} + \Delta S$$

**How does that relate to oil production at a well??**

## Statement from the blog:

**'Lifting/production costs: there is no universal calculation that can be applied.'**

**Of course there isn't! But the San Antonio paper has nothing at all to say about such costs. It *does* deal with the energy required for lifting according to the principles of elementary Newtonian mechanics.**

**'[The paper] does not establish a fitness to use criteria [sic] for petroleum . . .'**

**This is taken to mean a cut-off value of the EROEI above which production is viable and below which it is non-viable.**

**Not that simple!**

**For example:**

- **A low EROEI might be acceptable for fuel produced at an isolated location for *in situ* use. The alternative would have been to transport fuel over a long distance.**
- **Operation at a low EROEI might be easier to justify for production of a light oil than from production of a dense one. One could say the same of low-sulphur and high-sulphur crudes.**
- **Even when the EROEI correctly expressed in energy terms is  $< 1$  electricity might be available at below-market prices making production viable, all the more so if carbon credits are yielded by the electricity generation.**

**Also from the blog, addressing the statement that a low EROEI values should not be identified with diminishing depletion.**

**‘ . . . There is a 0.96 correlation coefficient between production and EROEI.’**

**?**

**The contributor to the blog who made that statement was probably drawing on:**

**<http://www.theoil drum.com/node/9249>**

**where it is stated:**

**‘We have also plotted world crude prices vs EROEI and [we] came up with a correlation coefficient of 0.947 . . .’**

**and:**

**Our plots of actual \$/b [price in dollars per barrel] vs projected [price] for 1960-2009 came up with a correlation coefficient of 0.96 . . . .’**

**All of the work in the San Antonio paper had been  
peer-reviewed before presentation.**

**Some readers and commentators do not understanding of the  
work**