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Enhancing the evaluation of Energy Investments by supplementing traditional discounted cash flow with Energy Return on Investment analysis

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ABSTRACT

Energy companies, like companies more generally, routinely have to make investment decisions by comparing alternative investment projects. In the face of the uncertainty of the current energy transition, traditional economic tools, such as discounted cash flow (DCF) analysis, that depend on long term cash forecasting, offer limited, deterministic and potentially misleading insights. Additionally there are many pressures on companies to expand decision making criteria to “ESG” (Environmental, Social and Governance) considerations. But these are often qualitative with no clear standards, leaving investors often forced to make significant investments based on poorly understood, at times misleading and even self-defeating considerations. We explore the application of Biophysical Economics (BPE), an approach to economics based on the natural sciences, as an alternative to provide an additional lens that cuts through the uncertainty and political pressures to help companies navigate this uncertainty and make more robust long term investment decisions. The most immediately useful tool within BPE is the concept of Energy Return on Energy Invested (EROI). Specifically we compare an investment case for oil companies, one in oil sands vs. one in microbial-enhanced oil recovery, applying the two methodologies in parallel. Results from a traditional economic perspective weakly favor the oil sands, whereas biophysical economics strongly favors the microbial case due to is significantly lower energy requirement to produce the energy that it yields. A close examination indicates that EROI can be used effectively and practically next to DCF to provide better insights and identify cases that are fundamentally less sustainable for society.

1. Introduction

Physical actions of companies in the world are generally the result of investment decisions that companies make. Whether it is building a new factory, hiring more people or constructing an oil platform, such a decision generally follows an investment analysis. The financial environment for investments by and inside companies has been changing rapidly as increasingly investors have started to consider a broader set of criteria. Traditionally financial decisions, both within companies and by investors of stock in companies, were based mostly on DCF (discounted cash flows) analyses, essentially estimating and comparing how much net profit can be returned from one vs another investment. Since the costs and returns on investments often span years or decades, corrections are made for money used or made now (which is considered more desirable) vs. progressively into the future. The standard tool for doing this is discounting, i.e. assigning future dollars a lower value than a dollar today on the basis that there are alternative opportunities to invest a given dollar now at equivalent or less risk (e.g. treasury bonds).

More recently there has been increasing anti-corporation sentiment given the large role that many companies are perceived as playing in climate change, deforestation, poor working conditions in sweat shops and other issues not directly related to the financial bottom line. This sentiment also has increasingly started to impact investment behavior, as investors assess investments in companies by more criteria than only financial return, and apply a much broader set of criteria including environmental and sustainability impacts of projects, its exposure to climate risks, its impact on communities and other reputational aspects. The general name for such considerations is ESG (Environmental, Social and Governance) which has grown from a consideration for a small segment of investors to an investment pool that accounts for close to 1/3 of total investment flows or 12 trillion $ (Kell, 2018; Marketwatch, 2019). ESG is currently being projected by Deloitte, a financial advisory firm, to become the key governing factor for as much as 50% of assets under management in the US by 2025. The outgoing CFO of BP, Brian Gilvary, mentioned that he spent 50-100% of his time with investors talking about these issues (S&P Global Platts, 2020).

A range of organizations, including the Global Reporting Initiative and the Sustainability Accounting Standards Board, have moved to trigger disclosure by corporations on a host of sustainability criteria such as CO_2 and other greenhouse gases, recycled materials, and energy

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efficiency, and many companies are now actively disclosing this information. Disclosure of more ESG-related data, however, does not equate to an investor assessment of performance on those criteria. Assessing ESG performance is notoriously difficult given the inherently qualitative nature of much of it, as evidenced by the wide divergence of ESG scores for the same companies by different ESG rating agencies on presumably the same information. A current shortcoming of the ESG assessments (or "ratings") of companies, therefore, is their largely qualitative nature and the absence of explicit criteria or standards, where the same company might be rated wildly differently in ESG terms depending on the rating agency, with evidence of rater bias (Berg and Kölbel, 2020). This makes it harder for investors to assess companies consistently and for companies to respond to legitimate investor concerns, and has triggered multiple calls for ESG investors to "up their game" (e.g. Financial Times editorial, 2021). In the absence of explicit ESG guidelines many companies choose to try to reduce CO_2 emissions.

1.1. *Example: energy companies*

In no sector of the economy are the previous topics playing out in a more pronounced way and are tensions more apparent than in the energy sector. We live in a world where energy needs have been increasing, and are likely to continue to increase significantly, on the back of population growth and desires for increase in standards of living in developing countries. Oil and gas still provide about two thirds of the world's energy and are almost irreplaceable in agriculture, much of transport and chemicals. At the same time there is a global drive for a transition away from fossil fuels to combat climate change, which in itself would require very large investments (Heun and Brockway, 2019; Capellan Perez et al., 2019). This implies that the energy sector will need to grapple with making major long-term investments in an inherently uncertain future.

The heavy direct and indirect CO_2 footprint of the oil and gas sector results in a generally blanket downgrade by investors of the sector relative to other sectors in ESG terms, as well as a focus on CO_2 above any other ESG criteria for performance of companies active in this sector. Aside from the real and serious challenge posed to climate by man-made CO_2, it is clear that there are already many serious tensions between the planet's finite resources and the continuous growth in energy use, with symptoms including degraded natural environments and wild populations, soil erosion, depletion of high-quality fuels, water scarcity and other pressures on natural resources. Ironically many of these issues are countered in large part by using more fossil fuels, albeit this is not always obvious to non-specialists (e.g. Sekera and Lichtenberger, 2020).

Large quantities of high-quality energy underlie society's wellbeing and development (Cleveland et al., 1984; Smil, 2018; Lambert et al., 2014). But for society to be wealthy globally, as ours aspires to be today, it is necessary to have relatively large surplus energy. In other words, society must generate significantly more energy than it takes to get that energy. England from 1300 to 1750 required about 50% of all its economic activity to produce the energy (i.e. food, fodder and wood) necessary to run that 50% plus the other half (King et al., 2015). Starting in 1750 and with the coal-based industrial revolution that ratio went to 25% and 75%, and today with petroleum to 10% and 90%. The consequence is that society can expend that excess energy to engage in other pursuits – which we perceive as wealth.

One would expect that good economic decisions are probably mostly synonymous with increasing the net energy returned to society, which in turn generates social welfare through its wise use. Thus, it is necessary to be deliberate and thoughtful in where we invest the planet's scarce remaining resources for meeting its energy needs. This is likely to be increasingly important if and as society makes a substantial shift away from traditional fossil fuels to "new renewables", usually meaning solar photovoltaic, wind turbines, biofuels, and possibly more nuclear.

The decision tools traditionally employed by industry are typically finance–based, and more specifically based on Neo-Classical Economics (NCE) philosophy. Approaches related to discounted cash flow (DCF) include "break-even price", "pay-back time", "unit technical cost" and other methods that rely on projecting future cash flows relative to investments today. Increasingly, under ESG pressures, oil and gas companies enhance these cash flow projections for investment decisions with CO_2 price assumptions significantly above currently prevailing levels as an attempt to anticipate future increases in CO_2 pricing. This also signals to the public and stockholders a desire to discourage projects with high CO_2 intensity.

Conventional economic analysis, despite its wide level of adoption, comes with some serious deficiencies. These include the assumption of indefinite growth, narrow financial boundaries, a poor track record of predicting future cash flows and a disconnect with the biophysical reality that is becoming increasingly clear (Krugman, 2009; Stiglitz, 2009). These deficiencies are particularly problematic when it comes to predicting long term future cash flows in the inherently uncertain energy transition.

Thus the use of methods beyond DCF and related methods becomes increasingly important in the new investment environment where ESG considerations have become increasingly relevant to investors. One can argue that their ascent is in part a reaction to shortcomings of DCF as an exclusive indicator of value because they identify practices that, while not costed in monetary terms, are genuine costs of production and may lead eventually to unsustainability for the firm or eventual loss of a license to operate - not to mention genuine serious cost to society or nature. DCF generally does not factor these real issues in explicitly.

2. BioPhysical economics

A fairly well developed alternative to conventional economics is BioPhysical Economics (BPE), the study, using the natural as well as social sciences, of the ways and means by which human societies procure and use energy and other biological and physical resources to produce, distribute, consume and exchange goods and services, while generating various types of waste and environmental impacts (Hall and Klitgaard, 2017a). This paper explores what we believe could be the great utility of BPE, by adding scientific logic, rigor, repeatability, and credibility to key aspects of ESG analysis. We give an example where we use BPE in conjunction with traditional DCF analysis to compare two oil and gas investment projects that might be considered as conventional resources are increasingly depleted. Our hypothesis is that the use of the two approaches, and a comparison of their results, enables the user to navigate limitations inherent in each one, enabling the selection of more robust and sustainable investments. In addition to comparing their effectiveness as a decision tool, this paper also attempts to explore ways of incorporating EROI in a fit-for-purpose way in day-to-day investment analysis. This initial and limited approach, while very useful for understanding BPE, does not, in our opinion, come close to understanding or appreciating the long term potential of BPE for greatly enhancing our understanding of real economic systems and their future. Additionally EROI is an important step in applying "hard" scientific criteria to the often "softer" ESG criteria used now.

This issue is of particular importance now to energy companies (and to society more generally) because of the enormous recent historic and present dependence of our economic activities on fossil energy, and oil in particular, and the recent appearance of limitations to that (Cleveland et al., 1984; King et al., 2015; Smil, 2018). Fig. 1 implies that most of the

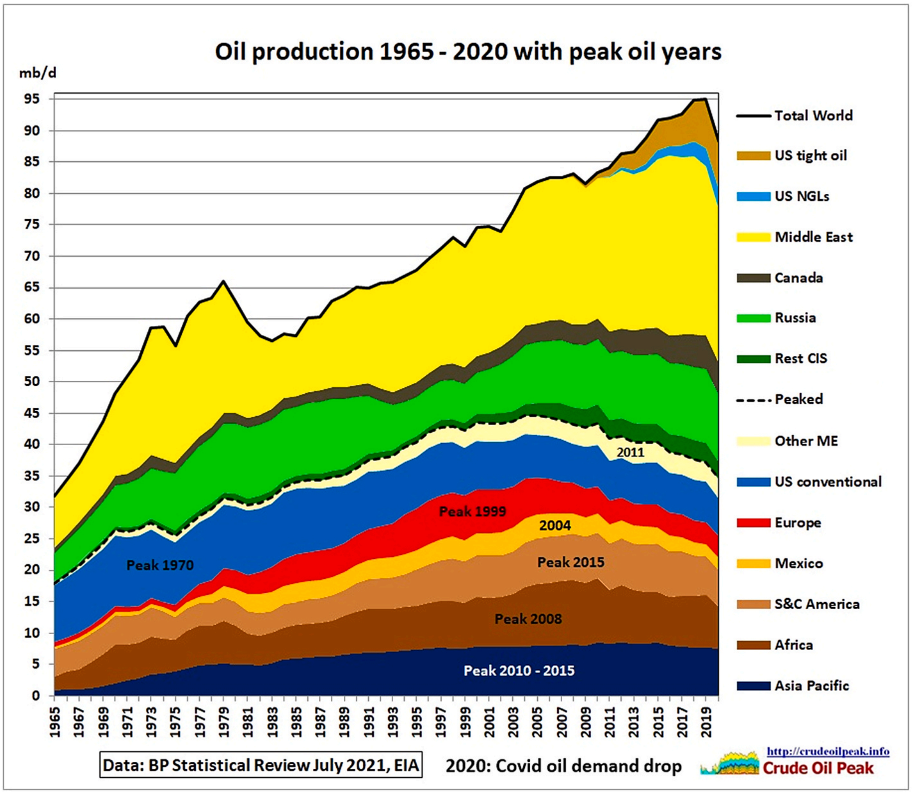


Fig. 1. Oil production by region. The data show that peak oil has occurred for some 6 of 8 continents. (From Mushalak, Matt. Newsletter. 2021).

world's continents and probably the world as a whole are at or past the "Hubbert Peak" of maximum physical extraction of oil (see also Deffeyes, 2005; Brandt, 2007; Nashawi et al., 2010; Hallock et al., 2014). Oil companies (and society) cannot afford to make investments into energy projects that appear green but are poor energy returners.

By contrasting these two investment cases, this paper also explores whether BPE can ultimately offer a theoretical yet practical basis for part of the critical "E" of ESG considerations, enhancing their consistency and allowing the considerations to become applied and cascaded to below the corporate strategy level to the day to day investment decision level where ultimately the bulk of decisions are made in companies.

By contrasting these two investment cases, this paper also explores whether BPE can ultimately offer a theoretical yet practical basis for ESG considerations, by adding a critical component to ESG that may be more important and at least more explicit than what has been used to date. EROI estimates the efficiency by which an activity delivers real social welfare to the rest of society. It makes no sense to develop a low or zero EROI which would only generate environmental destruction while delivering little or no net benefit to society.

2.1. Biophysical economics in more detail

Biophysical economics uses as its conceptual base and fundamental model the natural science associated with the structures and processes of real economic systems. It acknowledges that the basis for nearly all wealth starts with nature, and views most human economic activity as a means to increase (directly or indirectly) the exploitation of nature to generate more wealth. It often considers the relation of this biophysical structure and function to human welfare and to the money (i.e. dollar) flows that tend to go in the opposite direction to energy. From a biophysical perspective, one's job is viewed as trading one's time at work (the monetary value of which is related to the energy flows of society controlled by the individual) for access through wages to the energy flows of the general economy. One dollar is a lien on an average 5 MegaJoules (half a coffee cup of oil's) worth of energy services.

Biophysical economics recognizes that energy does the work of producing wealth, and is essential for its distribution as well, whether that energy is derived from land, labor or capital-assisted fossil fuels. Ayres (e.g. Ayres and Warr, 2005), Kuemmel (e.g. in Hall et al., 2001) and Hall and Ko (2004) have shown that the production of wealth in industrial and developing societies has been a nearly linear function of the energy use in those societies, and that the correlation gets tighter when proper corrections are made for the quality of the energy used (e.g. coal vs. electricity) and for the amount of energy actually applied to the process (e.g. electric arc vs. Bessemer furnaces) and for imports and exports. Much, perhaps most, technology is ultimately about these things. It may seem obvious now that wealth is generated by the application of energy by human society to the exploitation of natural resources. Nature generates the raw materials with solar and geological energies, and human-directed "work processes" are used to bring those materials into the economy as goods and services. These processes have been made enormously more powerful over time through technologies and capital investments that are mostly ways to use more or higher quality energies to do the job. A human being would have to work for several years to do the physical work that a single barrel of oil is capable of. BioPhysical Economics also concerns itself with many other economic issues that are more usually considered from the perspective of the natural sciences, including changing grades of mineral ores, changes in water availability, degradation of soils and so on. Thus we view BPE as a supplement, or even an alternative, to DCF. As such it is logical, consistent with the laws of nature, explicit and repeatable. We think it has a great deal to offer to our understanding of economics and investment decisions by corporations and governments.

There are many ways that BPE can be used to understand, manage or make decisions about economic matters. Perhaps the most directly useful component is Energy Return on Investment (EROI, sometimes EROEI). It is a tool (or metric) and is simply the energy delivered from an energy extraction process divided by the energy required to get it:

$$1.\quad \mathrm{EROI}=\frac{\text{Energy delivered by an energy gathering process}}{\text{Energy used (or diverted from society) to get that energy}}$$

A lower EROI means that society must divert more of its total economic activity to get the energy to run the rest of the economy. The use of EROI avoids some of the problems with financial analysis while generating additional insight into the factors that influence present prices and future availabilities. EROI integrates the counteracting effects of depletion and technological improvements. The use of EROI has evolved over the past 40 years and yielded a broad set of analyses of the relative energy gain of various energy technologies ranging from different methods of oil extraction, to wind energy and photovoltaics (PVs) to corn-based ethanol. These studies yielded insights into a range of societal challenges, often predicting what people knew to be true but was not explicit. For example, it was found that corn-based ethanol has an EROI that approximates 1:1, i.e. it uses as much fossil energy as it produces as alcohol. Conventional oil extraction generally varies from about 30:1 to about 10:1 and has generally been decreasing (e.g. it was higher in the 1950s), whereas photovoltaic energy is generally considerably less than 10:1 unless some quality factor is applied to the electricity so produced (Prieto and Hall, 2012; Raugei et al., 2017). A modern society does not need just a positive EROI but a significant one, arguably at least 10:1 (Lambert et al., 2014).

The procedures for undertaking EROI were first stated explicitly in Hall 1972 (for migrating fish), for industrial processes in Cleveland et al. (1984) and Hall et al. (1986). They are outlined and reviewed in Murphy et al., (2011) and considered in relation to economic profitability in King and Hall (2011). The advantage of EROI relative to a pure economic assessment is that it refects the physical reality of obtaining a barrel of oil and is in principle more stable and more predictable than purely monetary considerations that are impacted by political and emotional considerations as well as temporary supply and demand imbalances. In our case we derived the numerator as barrels of oil from two publically available plans, which we then adjusted to per barrel costs at a rate of 6.1 GigaJoules per barrel (the mean energy value of a barrel of crude oil) and the denominator to energy units as follows: natural gas use was converted to energy values at 41 KiloJoules per cubic meter, and fertilizers using mean values for 20:20:20 NPK fertilizers (Murphy et al., 2011). Monetery items were converted to their energy units using mean energy intensities of their respective economies, 5 MJ/$ for Canada and 4 MJ/$ for the Netherlands. These values were entered into a new column on the spread sheets, summed as appropriate and the EROI derived from their ratio (Table 1).

Practical challenges with applying EROI include the difficulty of obtaining complete and consistent energy data, especially using appropriate boundaries. Developments in the field have facilitated its consistent application (see Hall et al., 2011; Murphy et al., 2011; Hall 2017), including aligning definitions to enable consistent comparison as well as the development of using proxies for the often hard-to-obtain exact energy data by using CO_2 (Celi et al. 2019) or money spent on fuel (Court and Fizaine, 2017). Interestingly, these three different approaches tend to generate similar EROI values when applied to the same boundaries. Another inherent limitation of EROI is that by focusing explicitly on the biophysical, it doesn't focus on the financials, hence ignores topics such as subsidies, taxes and other aspects of commercial arrangements. There are some EROI analyses that factor it in by making assumptions on where these taxes or commercial rents are spent, but these are assumptions, with the limitations that come with that. In general it is best to be as inclusive as possible with respect to the costs, which can be done relatively easily, if not precisely, by "following the money" (Prieto and Hall, 2012). We are aware of, and have published on, the sometimes controversy about divergent values for EROI but find that most of them are not large when properly calculated and understood, as detailed to some degree in Appendix 1 and the references therein.

To generate additional insight into the potential and limitations of EROI (and BioPhysical Economics more generally) we have applied the concept to an actual investment decision and the associated analysis as it would be taken at an energy company.

3. Introducing two investment cases: producing oil with steam versus micro organisms

The world currently produces some 95 million barrels of oil a day, representing a major source of energy and materials to society. Notwithstanding the various negative impacts, such as the CO_2 footprint in its end-usage, this oil has a range of applications that make our current society work, many of which currently don't have viable alternatives at scale. These include fueling agriculture, aviation, shipping and trucking, and also providing feedstocks for plastics, synthetic materials, coatings and paints, asphalt, etc. Oil wells, once drilled and hooked up, deplete continuously; meaning that to just maintain current production levels requires continuous investment in dollars and energy and therefore investment decisions such as the ones we explore here. Deciding upon the best investments constitutes one of the major activities of oil and gas companies. We next examine two "alternative" investment projects to get more oil from a DCF and an EROI perspective (Fig. 2 and 3).

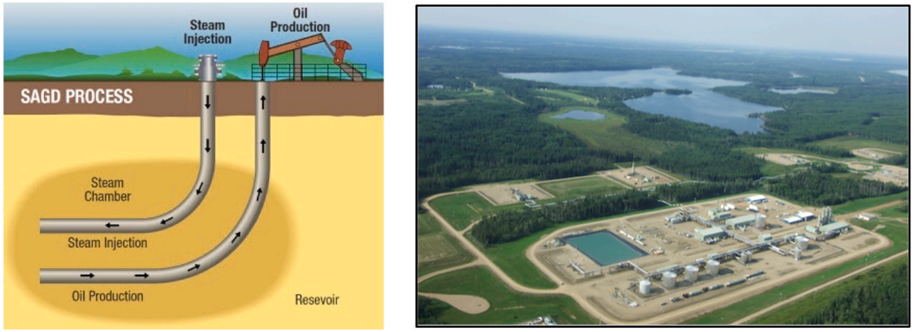


Fig. 2. Two diagrams of a SAGD project in the oil sands of Alberta. (Source: Alberta government).

Fig. 3. Schematic of traditional oil recovery from an oil field where water or natural gas is injected behind the oil to push it toward a collecting well.

3.1. *Oil sands (SAGD) case*

Conventional oil seems to be more or less at or past a peak in production and alternatives are required if a flow of 95 m barrels of oil a day is to be maintained (Fig. 1). Oil sands, prevalent in Canada, represents some of the world's largest known oil reserves (165 billion barrels in Alberta, Canada, alone). Extracting the "oil" (or bitumen) from the sand is done by either mining with giant shovels and trucks or "in situ" production. Steam is required for the in situ "tar sands" production because the "oil" is about the consistency of asphalt and does not flow on its own.

This case looks at an in situ development project of a top quartile ("best") oil sands reservoir, with high permeability and relatively low viscosity. The oil will be extracted using a Steam Assisted Gravity Drainage (SAGD) development in Alberta, Canada. This implies injecting steam into the reservoir through a number of wells, making the oil flow and producing it through separate production wells.

The project is assumed to produce 50,000 barrels of oil per day for the coming 30 years (a total of 548 million barrels) and requires a central processing facility, boiler and infrastructure of $1bln, wells and drilling spending of $100m/annum and eventual abandonment cost at the end of the project. These assumptions are based on the public filings of similar projects (Alberta Energy Regulator, 2011, 2013). Natural Gas purchases are necessary for the steam production. Note that natural gas prices in Alberta are cheap as Alberta is a major natural gas production area, with local demand vastly outstripped by supply. On top of that, the project uses water from a nearby river. Heating the water for the steam by burning natural gas also emits significant CO_2. Alberta, Canada has currently a relatively low royalty regime and low CO_2 pricing.

3.2. *Biologically enhanced EOR case*

Our alternative investment project would be to extract more oil from existing, although faltering, wells:

Enhanced Oil Recovery (EOR), focuses on taking one or a set of actions to increase the recovery of an existing oil reservoir beyond its normal level of production through drilling, which typically limits recovery to ~30% of total reserves in place. Oil in the ground usually is not like oil in an oil can but more like an oil-soaked brick. Traditional (not enhanced) oil recovery usually means pumping water or natural gas behind the oil to pressurize the field and push it toward collecting wells. There are a variety of techniques including thermal, gas and chemical injection to get an extra ~10 to (rarely) 20% of recovery from the same field. The methods used have included injecting various substances (such as nitrogen, CO_2 or microbes) to either replace the oil or make the oil less viscous and ease its movement through the pores of the substrate.

There are studies that indicate that it is possible to increase the yield of small oil fields using a relatively cheap bacterial process, which reduces the size of the oil globules so that they can fit more easily through the pores of the substrate (i.e. reduce the viscosity to enhance migration). This technique is still relatively narrow in its application but is gathering momentum (Nikolova and Gutierrez, 2020). This case focused on using specialized microbial nutrient injection to enhance migration of oil to the well head at a "typical" mature onshore field in the Netherlands. This is done by analyzing the composition of the in-situ microbes to determine what nutrients are necessary to make them grow.

In this theoretical investment project, the assumption is that it is applied to a mature oil field in the Netherlands where it enhances ultimate reservoir recovery by 5%, representing 15,000 boe/day for 30 years. Since it extends the life of the field, the project would require continued operations staff and part of the cost of the project would be to pay for the technology/licensing cost. Also, since the field is in the Netherlands, it would be subject to Dutch tax, CO_2 pricing per European Carbon Trading System and government royalties on oil proceeds. As oil and gas companies generally regard this approach as more experimental, assumptions in this case include a slow (4 year) ramp-up profile and relatively modest incremental production. Most applications so far applying this technology have moved cautiously by going slowly well-by-well to ensure they understand the subsurface and reservoir dynamics well before involving the entire reservoir. Published results have generally been limited due to commercial confidentiality restrictions but a recent study from application at a range of fields in China provides some insights in its typical application and scale (She et al., 2019). Note that from a biophysical perspective, these nutrients, which are for our case assumed to be 20-20-20 NPK fertilizer, carry a significant energy cost. With an assumed cost of $5/bbl for the process, of which 85% relates to nutrients, this implies that at $500/ton for NPK, each barrel of oil produced requires 8.5 kg of NPK, which has an embodied energy of about 32 MJ per kg or 272 MJ per barrel extracted.

3.3. Overview of assumptions of the two cases

For purposes of calculating the EROI, see tables

2. $\mathrm{EROI}=\dfrac{\text{Energy delivered into the country's existing main crude oil pipelines}}{\text{Energy used over the lifecycle of the project to get that energy}}$

Note that for the energy cost of paychecks to labour involved in these projects, a general mix of the economy for each country is assumed (i.e. 5 MJ/$ in Canada, 4 MJ/$ per World Bank assumption). For steel, 34.4 GJ/t is assumed (Murphy and Hall, 2011). See for further assumptions Appendix 2.

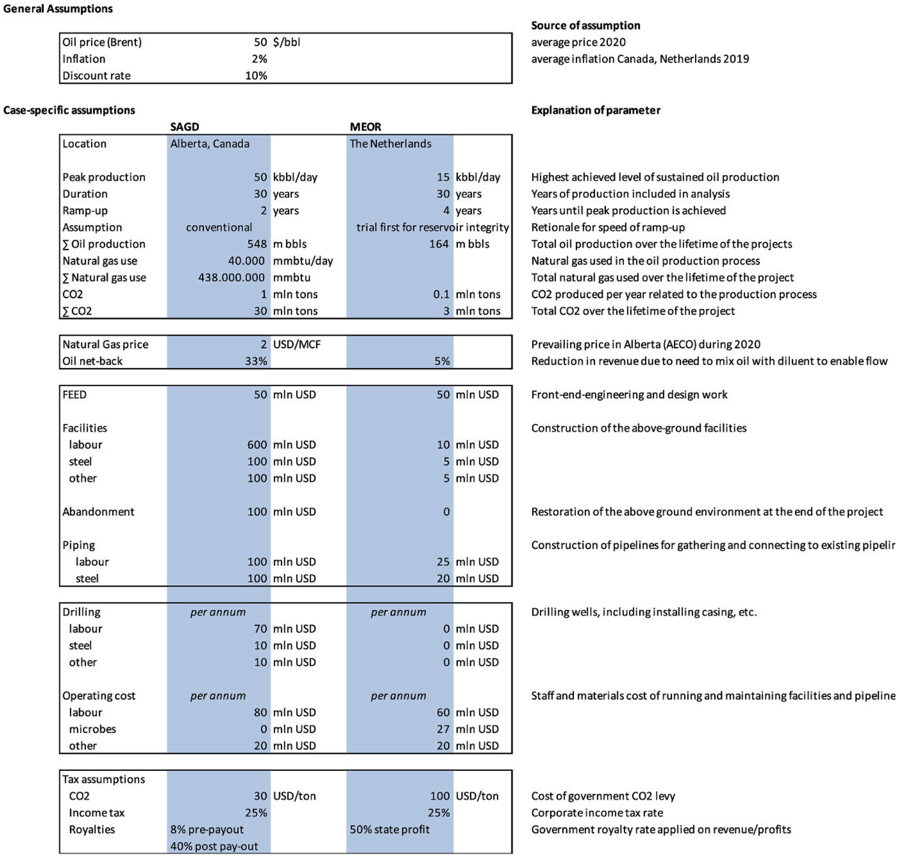
4. Results

The Oil Sands case has the higher internal Rate of Return (20% vs 19%) than the M-EOR case, indicating that from a pure DCF perspective it is the more attractive opportunity. Conversely, the outcomes of the EROI assessment strongly favors the M-EOR project which has an EROI of 17:6 as opposed to the SAGD project with 5.3:1 (Tables 1 and 2 and Fig. 4 and Table 2).

Overview of revenue (inflows) versus costs (outflows) and remaining free cash flow ($millions)

Table 1

Summary of key project assumptions.



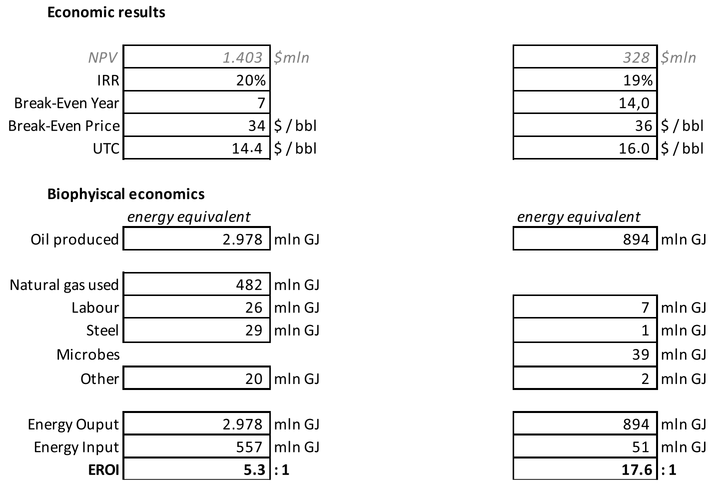
General Assumptions

			Source of assumption
Oil price (Brent)	50	$/bbl	average price 2020
Inflation	2%		average inflation Canada, Netherlands 2019
Discount rate	10%		

Case-specific assumptions

	SAGD		MEOR		Explanation of parameter
Location	Alberta, Canada		The Netherlands		
Peak production	50	kbbl/day	15	kbbl/day	Highest achieved level of sustained oil production
Duration	30	years	30	years	Years of production included in analysis
Ramp-up	2	years	4	years	Years until peak production is achieved
Assumption	conventional		trial first for reservoir integrity		Retionale for speed of ramp-up
∑ Oil production	548	m bbls	164	m bbls	Total oil production over the lifetime of the projects
Natural gas use	40.000	mmbtu/day			Natural gas used in the oil production process
∑ Natural gas use	438.000.000	mmbtu			Total natural gas used over the lifetime of the project
CO2	1	mln tons	0.1	mln tons	CO2 produced per year related to the production process
∑ CO2	30	mln tons	3	mln tons	Total CO2 over the lifetime of the project
Natural Gas price	2	USD/MCF			Prevailing price in Alberta (AECO) during 2020
Oil net-back	33%		5%		Reduction in revenue due to need to mix oil with diluent to enable flow
FEED	50	mln USD	50	mln USD	Front-end-engineering and design work
Facilities					Construction of the above-ground facilities
labour	600	mln USD	10	mln USD	
steel	100	mln USD	5	mln USD	
other	100	mln USD	5	mln USD	
Abandonment	100	mln USD	0		Restoration of the above ground environment at the end of the project
Piping					Construction of pipelines for gathering and connecting to existing pipelir
labour	100	mln USD	25	mln USD	
steel	100	mln USD	20	mln USD	
Drilling	*per annum*		*per annum*		Drilling wells, including installing casing, etc.
labour	70	mln USD	0	mln USD	
steel	10	mln USD	0	mln USD	
other	10	mln USD	0	mln USD	
Operating cost	*per annum*		*per annum*		Staff and materials cost of running and maintaining facilities and pipeline
labour	80	mln USD	60	mln USD	
microbes	0	mln USD	27	mln USD	
other	20	mln USD	20	mln USD	
Tax assumptions					
CO2	30	USD/ton	100	USD/ton	Cost of government CO2 levy
Income tax	25%		25%		Corporate income tax rate
Royalties	8% pre-payout 40% post pay-out		50% state profit		Government royalty rate applied on revenue/profits

Table 2
Comparison of key economic indicators based on detailed calculations of the two projects.



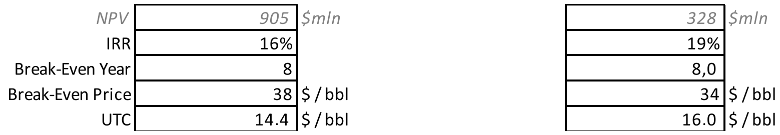
Economic results

NPV	*1.403*	*$mln*	*328*	*$mln*
IRR	20%		19%	
Break-Even Year	7		14,0	
Break-Even Price	34	$ / bbl	36	$ / bbl
UTC	14.4	$ / bbl	16.0	$ / bbl

Biophyiscal economics

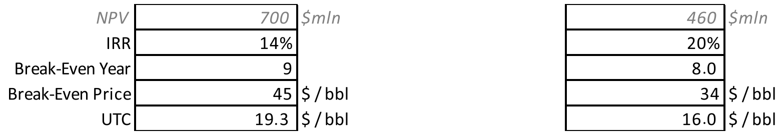
	energy equivalent		*energy equivalent*	
Oil produced	2.978	mln GJ	894	mln GJ
Natural gas used	482	mln GJ		
Labour	26	mln GJ	7	mln GJ
Steel	29	mln GJ	1	mln GJ
Microbes			39	mln GJ
Other	20	mln GJ	2	mln GJ
Energy Ouput	2.978	mln GJ	894	mln GJ
Energy Input	557	mln GJ	51	mln GJ
EROI	**5.3**	**: 1**	**17.6**	**: 1**

If a sensitivity is applied to both by using $100/ton for CO_2 the results look as follows:



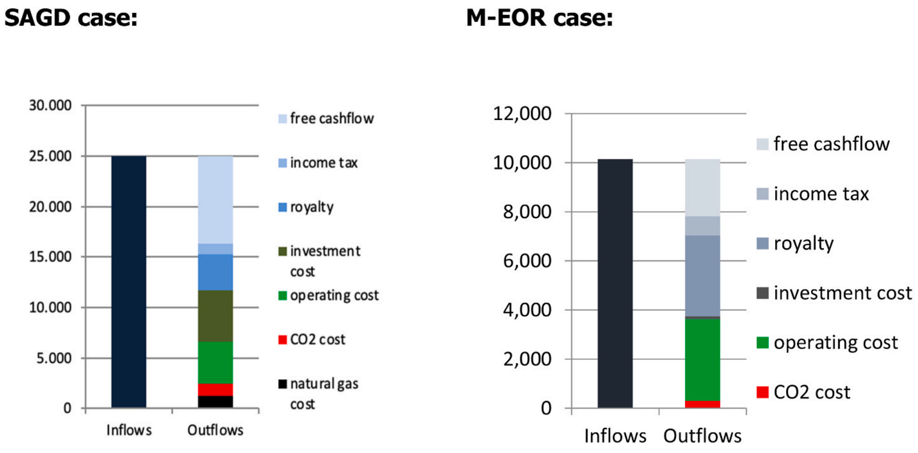
NPV	*905*	*$mln*	*328*	*$mln*
IRR	16%		19%	
Break-Even Year	8		8,0	
Break-Even Price	38	$ / bbl	34	$ / bbl
UTC	14.4	$ / bbl	16.0	$ / bbl

An alternative sensitivity removes taxes and applies the equivalent natural gas and CO2 prices from The Netherlands to both projects.



NPV	*700*	*$mln*	*460*	*$mln*
IRR	14%		20%	
Break-Even Year	9		8.0	
Break-Even Price	45	$ / bbl	34	$ / bbl
UTC	19.3	$ / bbl	16.0	$ / bbl

See appendix for detailed workings.



SAGD case:

M-EOR case:

Fig. 4. Comparison of the cash-in and cash-out over the life of the project.

5. Discussion

To be able to assess the usefulness of either type of analysis, it is necessary first to be clear on the goals of the company (vs society that might encourage it through regulation) that this investment aims to contribute to. At the most fundamental level, the primary "purpose" of a business is to maximize profits for its owners or stakeholders over time while maintaining corporate societal responsibility. For energy companies that typically engage in long term investment projects (i.e. 10-20+ years), the time dimension in conjunction with long term societal welfare through its supply of energy also becomes an important factor. This means that while they are not immune to pressures of short term results, they tend to have a longer and sometimes more comprehensive time horizon than most other companies.

Comparison of assessment outcomes.

- The Oil Sands case has the higher internal Rate of Return (20% vs 19%) than the M-EOR case, indicating that from a pure financial (DCF) perspective it is the more attractive opportunity, at least based on the assumptions used. The unit technical cost, defined as total capital and operating cost divided by total production, shows the SAGD case at $14.4/bbl and the M-EOR case at $16.0/bbl. Break-even price is $34/bbl for the SAGD case vs $36/bbl for the M-EOR case.
- On closer inspection the two royalty and tax regimes seem relatively similar in terms of tax and royalty rates. The Netherlands' rates are a bit higher, but a no-tax comparison of the two cases actually boosts the SAGD case's returns most. This is primarily due to the larger profit component of the SAGD case; i.e. the SAGD case is more profitable which means that the tax rates are applied to a (relatively and nominally) larger base.
- The primary difference between the two is the relatively low investment cost and high operating cost of the M-EOR case. The relatively high operational cost of the M-EOR project is driven by, on the one hand, the need to keep running (i.e. maintaining, monitoring, etc.) a mature oil field with its ageing facilities (originally designed for higher production and shorter life span). The SAGD case also carries operating cost, which includes pumping, operators to monitor and for maintenance, but those are for newer and more optimized facilities. Another factor is the cost of microbes/ingredients and associated royalties to the M-EOR service company. Depending on whether the facilities and other operational costs are shared with non-M-EOR wells, one could allocate less of that fixed operational cost to this project, which would further boost the economic attractiveness of the M-EOR case.
- The above conclusion is based on applying CO_2 pricing as currently prevalent in Alberta, Canada, with a market consensus view for the projected increase. Note that many oil & gas companies are applying higher CO_2 pricing than the forecast required for DCF with e.g. BP and Shell have used $40/ton of CO_2 for many years already for all projects even in places with no CO_2 pricing and have increased that further in recent years. Applying the artificial level of $100/ton worsens the attractiveness of the SAGD project. Depending on the CO_2 assumption taken, the EOR opportunity can come out to be more attractive in DCF terms. There is however no obvious basis for the level at which to set CO_2 price assumption.
- The outcomes of the EROI assessment strongly favors the M-EOR project which has an EROI of 17:1 as opposed to the SAGD project with 5.3:1. The underlying biophysical aspects driving that are evident on account of the high energy usage of the SAGD project, in terms of natural gas as well as additional construction required (including labor, steel, concrete, etc.). Our outcome in EROI terms of the SAGD case aligns well with earlier research on oil sands EROI (e.g. Poisson and Hall, 2013) based on analysis of the Canadian government on energy used, showing that extracting this oil takes about one quarter of the energy extracted. This 4:1 ratio of their overall sector is relatively close to the 5:1 ratio we find here for a top quartile reservoir.
- As a decision maker, looking at this set of contradictory results from the two methodologies should trigger a red flag and hence a desire to examine more closely the underlying issues here and perhaps become suspicious of using only the DCF method for making decisions that have a long time horizon. The highly adverse EROI rating in the case of the SAGD project indicates that from a biophysical perspective it is not preferred as a society and that the DCF analysis might in fact be misleading. Over time, which is a real consideration in a 20+ year project, societal pressures could very well result in aligning activities more with what makes sense from a biophysical perspective. This could mean, for example, increases in CO_2 and/or natural gas pricing, which this project would be impacted by. Alternatively it could result in curtailments or restrictions such as on water usage, which in this particular case is not analyzed by either method. Likewise, the M-EOR project, while still subject to regulatory pressures, is with its relatively high EROI rating a logical project to pursue from a biophysical perspective for a society that still needs oil. The strong results of the EROI analysis are a very red flag for us to examine the DCF (and the EROI) assessments much more carefully.
- The sensitivity analysis where taxes are removed, where CO_2 and natural gas prices are set at the same level as the Netherlands, indicates a much more aligned results between EROI and DCF analysis as the SAGD case is vastly inferior with both approaches.

5.1. Evaluation of the usage of the two approaches

Our original hypothesis is that a conjunction of the two approaches enables the user to navigate limitations and strengths inherent in each one, enabling a better assessment of the sustainability of the investments from a number of perspectives. These include reflecting the aspects of these cases to the material world and also long term potential for profitability and for supplying society with net energy. The outcome of these cases suggests that EROI effectively helps identify investments that are more robust in the long run in ways that DCF appears not to. DCF is typically based on the current outlook and regulatory environment where we believe that EROI identifies true value added to society from a biophysical perspective and as such is a better predictor of what will in the long run likely be taxed, constrained or valued. In this particular case we essentially see artificially low natural gas prices (due to supply/demand considerations at the time) and CO_2 pricing making a low EROI project more financially appealing than the competing higher EROI project.

EROI might do a decent job in predicting what particular activities might (over time) get taxed more if they are particularly energy intensive or trigger waste, but it doesn't help much with overall corporate tax differences or supply/demand dynamics in a country. Given that the stated aim of the company also includes maximizing profits, this is likely an aspect where DCF is more insightful. The same applies arguably to the cost of the proprietary M-EOR technology used, which depends on the provider of the technology and has likely less of a link with biophysical reality, albeit that presumably the price is set in a competitive environment influenced by that.

Note that the application of EROI in this particular case was done by using a shortcut approach for estimating some of the indirect costs. This made it easy and straightforward to apply by simply plugging in the assumptions typically available to the project team when doing an investment project (i.e. natural gas, other major categories of cost) and then translating those into their energy equivalents. The similarity of the outcome with earlier research (Poisson and Hall, 2013), which yielded a ratio of 4:1, based on Canadian government Input-Output data for Alberta oil sands, provides comfort that despite our use of far more aggregated data to derive energy costs in part from financial data, the results are likely to be sufficiently accurate for this example and probably many others.

Companies are unlikely to apply EROI analysis if the mechanics of adding EROI as an extra evaluation step is prohibitively onerous, making our rather aggregated approach especially useful. In fact, the EROI analysis could be built into existing typical industry DCF analysis for the economics analysis which already uses most of the data relevant to EROI analysis: oil output, direct energy inputs (e.g. natural gas), construction costs, financial costs, salaries and so on.

While it is not the explicit intent of this paper to include more comprehensive analyses of other elements of ESG beyond the direct and indirect impacts of EROI, our approach in principle could be extended to other issues, for example water use, which SAGD utilizes a great deal of and is subject to further constraints (currently also not considered in DCF). Our approach could be enhanced relatively easily with e.g. the work of Mulder et al., (2010).

There are alternative approaches for improving capital allocation for achieving the company's objectives that weren't explored here. This includes central directives constraining or blocking certain low EROI types of investments altogether (e.g. no more oil sands, which is essentially what Shell did). The primary counterargument to that is that it would be a rather blunt instrument that captures the most egregious cases but precludes the careful optimization over many projects that over time achieves significant improvement. For example, conventional oil investments cover a wide range of EROI outcomes, which has historically not been a decision consideration, except as EROI effects price (King and Hall, 2011). If EROI is considered as an additional factor in analysis to the point that it impacts decisions, more projects with a higher EROI could get selected, resulting in more robust investments with more energy for society as a whole, although perhaps at the expense of lower EROI in the future. Another alternative is to look at CO_2 explicitly as part of investment opportunities or look at the "CO_2 intensity" of a given investment opportunity. In terms of looking at CO_2 explicitly, it is unclear how exactly that helps in terms of comparing opportunities as it is a derived metric without a broader framework behind it and focuses on the important but singular issue of CO_2. It is clear that CO_2 is a relevant lens that would sit next to DCF but in our opinion doesn't yield the same depth of insights that EROI does.

One of the reviewers noted that in our general perspective we have previously found a positive correlation between EROI and financial return (e.g. King and Hall, 2011), which seems contradictory to our findings here where we find the two approaches yielding different results. However, this requires a "level playing field" where taxes, fuel costs and the like are the same. In our study we undertook "real world assessments" with the data of the real world, including taxation rates, fuel prices (lower in Alberta) and so on. If we get rid of taxes and equalize CO_2 and natural gas prices, then we find that our DCF and EROI analyses agree.

One area where biophysical economics and DCF are clearly at odds with each other is in the concept of discounting. DCF, derived off the Capital Asset Pricing Model (CAPM) and unburdened by physical or resource constraints, argues that getting income faster is preferable. BPE would argue that petroleum resources represent some of our planet's greatest assets that shouldn't be squandered by withdrawing them in an energy inefficient fashion -implying negative discount rates (Hall et al., 1986). In light of ongoing technological development, e.g. boosting efficiency in extraction, it may be preferable to leave resources in the ground longer rather than extract them quicker and presumably less efficiently. Day et al. (2022) argue that extracting oil from Louisiana marshes quickly in past decades, probably in response to a high discount rate, has lowered eventual yield of these major oil resources as well as generated much greater environmental damage than necessary.

Note that studies in the field of biophysical economics concluded that as an economy expands, energy prices go up and EROI decreases as increasingly lower EROI resources are used to meet demand (as first put forth with agricultural land by economist David Ricardo, e.g. Murphy et al., 2011; King and Hall, 2011). Applying that finding to the SAGD case suggests that this development should be done further into the future rather than now as opposed to the M-EOR one that is competitive now. By that time prices would be higher, perhaps technology more advanced and hence more efficient, making doing the SAGD project later in aggregate a better outcome or to leave these low grade resources in the ground altogether.

From a biophysical perspective, the purpose of an oil company is to provide economies with petroleum, perhaps their most valuable resource given its high energy density, and the use of which is correlated with human development, whether measured by GDP or the Human Development Index (Lambert et al., 2014). While there are many negative aspects associated with the production and use of oil, and these should be minimized, it is necessary to understand that there is a tradeoff between generating human development with oil and losing some wellbeing from its production and use. To what degree we might be able to replace oil with something less impactful is a discussion beyond this paper.

5.2. *Linking individual project evaluation to financial markets - the limitations of ESG*

As per the earlier discussion, ESG evaluations are relatively new and are still being developed, leaving their application still relatively ambiguous while blunt. The entire oil & gas sector is generally seen by investors as being weak in terms of its performance in ESG terms and is generally taken as not sustainable as a whole, as evidenced as ESG investors generally avoiding oil & gas. Within the sector, most of the interest of it seems to be focused on the E in ESG, which is in practice generally defined as exclusively CO_2. That creates a really narrow and often misleading brush for a wide variety of activities in terms of true underlying energy efficiency and sustainability. This limited perspective often causes the actions taken to not only not meet the objectives of reducing carbon but inflicting additional damage on a broad range of environmental, energy and social objectives. This lack of thorough investor scrutiny on these aspects also creates incentives for companies to engage in "green washing" where they would present the company in a greener light, finding ways to report less CO_2, etc. without necessary addressing underlying net CO_2 activities from a biophysical economics perspective (see e.g. Sekera and Lichtenberger, 2020).

Recent advances in non-financial reporting, including more companies signing up to the Global Reporting Initiative (GRI), has triggered increased disclosure with an expectation of further disclosure including on energy usage, CO_2, water usage, etc. This increased disclosure opens up the way for assessing energy companies truly as portfolios of projects with biophysical characteristics and assessing them accordingly. If equity research analysts and fund managers are increasingly able to assess the EROI of energy companies and their underlying portfolios, they are able to distinguish between those that have more robust portfolios from those that have weaker ones. In short, they can cut through the greenwashing and get a sharper lens on the underlying sustainability profile. Over time, as investors shift away from the weaker ones to the more robust ones, eliminating the current arbitrage opportunities, price differences will start to occur. As it becomes an area of interest to investors with direct share price implications, CFOs and then CEOs of companies will take note and the stronger ones will overhaul their investment decision making process to incorporate EROI, similar to how leading ones have incorporated CO_2 before. This in itself will trigger a greater interest in applying EROI to investment opportunities and pull for the necessary skills and information.

We are well aware that there are many other ESG questions and criteria beyond just the derivation/comparison of EROI but we believe that if a comprehensive EROI shows a negative or very marginal result, as is the case with U.S. corn ethanol (Murphy et al., 2011), this is a red flag. That EROI result by itself is likely to be (or should be) reason enough for dismissing any technology unless a very careful argument is made that acknowledges the low EROI but argues as to why it might be trumped by something else (in the above case conceivably subsidizing farmers). EROI does not incorporate or resolve all the myriad of other issues, such as many environmental issues, facing today's decision makers but can help by showing, for example, that if a project has a low EROI much of the environmental impact does not provide a net benefit to society. While EROI does not, and is not meant to, define "S" in ESG, it can also be a relevant component of understanding the social impacts of a given action. For example, if the net energy yield of a given project is marginal then the energy remaining to undertake social benefits will be lower (as identified in Lambert et al., 2014).

5.3. *Discussion of the broader impact for society and policy implications*

While our particular example that we give here is focused on corporate decision making the basic concept has much wider implications. Society faces extremely difficult and expensive investment decisions in the near future as we attempt to deal simultaneously with large pressures for decreasing CO_2 releases, rebuilding national economies and the depletion of our highest grade fuels. There is a large danger that poor decisions about energy will be made because they will be made based on expediency or emotion. Thus it is important that proposed plans are subject to the strictest standards of natural science to help ensure that they are feasible, accomplish their objectives and make the best use of all limited resources. This is just as true for NGO and governmental planning agencies as for individual companies.

To enable this science to work it is necessary that the information that enables investors and other analysts to make their determinations are accurate and actually available. This implies disclosing detailed energy data as part of companies' non-financial reporting at both the business segment and even project level. At the time of this writing there is a large proliferation of ESG-centric reporting "standards" that are anything but standard, and few of them include energy and other biophysical data in sufficient detail, let alone logically essential analyses such as EROI. As these standards inevitably converge, it is important that final standards include sufficiently detailed energy data to enable good EROI calculations which would allow investors and other analysts to evaluate the different energy sustainability profiles of companies and projects, and hence give them a useful risk measure. In addition there has been a degradation in some governmental data accounting that greatly hinders good evaluations (Guilford et al., 2011). There is a great need for objective and accurate data gathering and vetting at all levels.

Another necessary development would be to include biophysical economic considerations in determinations of whether or not a project is "sustainable". An example is the EU taxonomy which seeks to determine what activities and projects are sustainable and thus encourage more investment in those type of projects. Excluding EROI from that by focusing exclusively on metrics such as CO_2 intensity or non-carbon origin would create a real risk of steering investments towards projects that are actually not sustainable and ultimately wasteful for society in biophysical terms. The issues covered here lie at the heart of the requirements for achieving sound energy policy and successfully navigating the energy transition.

6. Conclusion and policy implications

The findings from exploring these two cases indicate that DCF alone does not provide the right answer for an energy company to achieve its objectives when comparing alternatives. Additionally, the standard DCF practice of basing its projections on current regulatory setup and rules may actually be misleading for a long-term project and underplay the likely changes in that regulatory setup. By disregarding the inherent limitations of the biophysical environment, DCF analysis is prone to underestimating the very predictable risks that those create to the company if and as the future pans out differently.

While we are well aware that there are many other ESG questions and criteria beyond just the derivation/comparison of EROI, we believe that if a comprehensive EROI shows a negative or very marginal result, as is the case with U.S. corn ethanol (Murphy et al., 2011). Any energy technology being evaluated should be assessed for EROI and if low should not be used unless a very careful argument is made that acknowledges the low EROI but argues as to why it might be trumped by something else (in the above ethanol case conceivably subsidizing farmers).

Thus EROI acts as an additional lens in this case, providing assurance in the case of the EOR opportunity and a red flag in the case of the SAGD one. This biophysical lens acts as an indicator of the sustainability of the project where a project that scores poorly in EROI terms effectively represents a case where the activities are not in synch with society's needs from a biophysical perspective. That, combined with a longer duration project, implies a higher likelihood that at some point society takes action to make an adjustment. Those adjustments could happen in terms of extra taxes, natural gas prices and restrictions that are arguably predictable by EROI analysis. It is however also clear that certain aspects are not addressed by EROI, including the relative financial attractiveness of the project on account of taxes, costs, etc. where these don't have a direct predictable biophysical component.

The degree to which the application of EROI is practical becomes a big factor in whether the analysis will actually be used. This particular case also provides credence to getting meaningful insights from estimating EROI by using a set of practical shortcuts on information typically easily available at companies when they do project decisions. It also illustrates the risk that proxies inevitably mean that some aspects are then left out, such as the example of water and potential restrictions on that. On balance, given the relevance of the aggregated approach as used here, it seems better to apply that and then use it for as many investment cases as possible to get some insights, rather than design a more perfect estimation of EROI and have companies decide that applying it is too onerous and not do it.

Overall, this paper presents a strong case for adding EROI (even through an imperfect assessment) as a complementary lens compared to sticking with only DCF (and CO_2). It provides a method of structurally differentiating investment opportunities that are robust in the long run versus those that are artificially attractive due to limitations of DCF analysis. By applying this consistently over time, a company can make its portfolio more robust to these risks while providing society with more useful energy. Where EROI results contradict other indicators -whether financial or sustainability (e.g. CO_2), the authors advocate that among decision makers this should trigger a discussion and closer look, thereby shining light on this key indicator of sustainability that could otherwise end up being a blind spot.

The same approach potentially also can be used for investments in "new energies" or other "CO_2 light" investments by companies. It is likely to be effective in differentiating cases that are fundamentally more sustainable from a biophysical perspective and thereby robust in the long run versus those that might look green/sustainable at first sight but are not.

This approach can also be used to identify projects that may be currently politically popular, hence subsidized and attractive in DCF terms, yet not sustainable in EROI terms. An EROI lens could pierce through that and separate the true sustainable projects from the "greenwashing" ones. Here it is important to undertake a comprehensive systems approach, such as is found in Sekera and Lichtenberger (2020). If projects don't make sense to society in EROI terms, any such subsidies would not be reflecting true net environmental gain and hence would be at higher risk of disappearing over time. There are a growing number of examples, including corn-based ethanol, which has an EROI of approximating 1:1 (Murphy et al., 2011), meaning it uses about as much energy to produce as it yields to society while meanwhile greatly increasing soil erosion, which is clearly not a sustainable activity for society even though ethanol was seen as "green". As society comes to terms with these issues, subsidies are likely to disappear. At a more aggregate level, the approach can also be used to assess the sustainability of companies as a whole in terms of energy provided to society and hence provide a measure of robustness to investments. That, in term, could displace current more qualitative ESG criteria and ultimately allocate capital more effectively.

6.1. Areas for future research

When considering areas of future research, it is noted that the literature has a sizeable number of high-quality studies that look in-depth at the EROI of individual projects (e.g. solar, wind, unconventional oil) as well as some excellent aggregate/macroeconomic analyses (e.g. Hall et al., 2014; Lambert et al., 2014). Some have argued that differences in results by different investigators make the predictions unreliable, although we think these issues mostly disappear when proper methods are used (e.g. Murphy et al., 2011; Hall et al., 2011; Hall 2017) or else provide additional insight into our options. There have been, however, few studies done that compare projects in a way that is practical to implement for companies in day-to-day decision making. While this may change in the future, companies are typically unable/unwilling to do a systems analysis of the entire life cycle for all energy use of every investment opportunity they have. Studies that test more practical applications of the concepts without a heavy burden of collecting detailed energy data and assess whether these still yield similar insights are critical to encourage practitioners to apply them to real life investment decisions. Another area that can benefit from further study is the application of these concepts in the market by identifying companies that have a superior portfolio from an EROI perspective and assessing whether their financial returns over time are superior. The above insights would predict that, given that they would be less likely to be impacted by some of the risks that companies with an inferior portfolio of projects in terms of EROI would be subject to.

CRediT authorship contribution statement

Jan-Pieter Oosterom: conceptualizing, writing and revising, DCF spread sheet analysis. **Charles A.S. Hall:** conceptualizing, writing and revising, EROI methodology.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. Both authors have financial holdings in various oil companies.

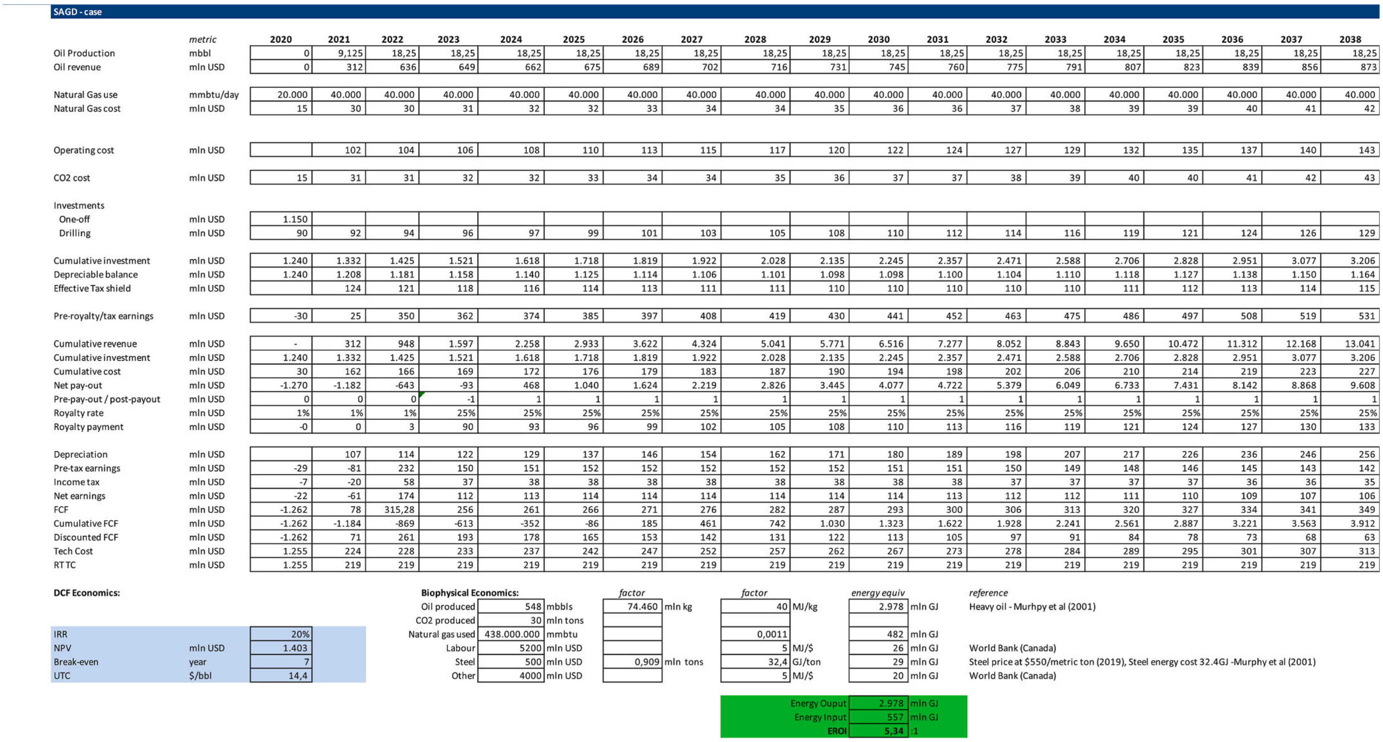
Appendix 1

There have been some criticisms of EROI that say although the concept is useful there is too much variability in the values obtained to trust specific values. The authors believes that the variability is not undue, and leaves us with (generally) tight enough values.

a) Perhaps the most common reason is the use of a "quality factor" for electricity of roughly 3. This is very common on photovoltaic (PV) studies. It is also sometimes called the "fossil fuel avoided" adjustment. This adjustment is perhaps appropriate in some (limited) uses if it is so labeled in methods and results, and non-adjusted values are also given. So EROI values of about 10:1 are often quoted in PV EROI reports, but this should be reported as: EROI = 3.3:1 (10:1 adjusted for quality of output).
b) Incomplete boundaries: One should include ALL the energy required to build and operate a facility. How to do this? "Follow the money". One can see how to do this explicitly in Prieto and Hall (2012). We included the energy required to support: on site engineering, roads, shipping, business services, professional meetings, flying the expert down from Finland to fix the whatever, taxes and so forth. These are all real expenses and should be included in energy costs. We found that the cost of the collectors and inverters, often the only costs covered by others, were but one third of total energy inputs.
c) Renewable energy is available only about one third of time: so one must include cost of storage/redundancy/wires etc. How much depend on % penetration. According to Graham Palmer storage may halve the EROI at high penetration. In whole system analyses EROI may drop even further during transition (Capellan Perez et al., 2019).
d) Time the output is estimated to last. For PVs both Prieto and Hopkirk found empirically that collectors lasted for 18 years vs the 25 years which is industry standard. A similar estimate may be the case for wind turbines.
e) Different assumptions/estimates for efficiency of modules etc. The theoretical efficiency has been increasing, but this is not so clearly the case for actual operations (which tend to be lower than theoretical efficiencies to start with. Bird droppings, dust, junction failure all reduce efficiency and have to be included.
f) Different estimates of energy cost of infrastructure: steel, fertilizer etc. This was examined in Hall et al. (2011). In general it was found in this case that the higher EROI case was less complete in including all costs (see c above)
g) including or not including co products (See Hall Dale Pimentel). If included must correct for actual vs theoretical usage.

When this corrections are made normally what appeared to be a large difference between values becomes much smaller, as in Hall et al. (2011).

Appendix 2



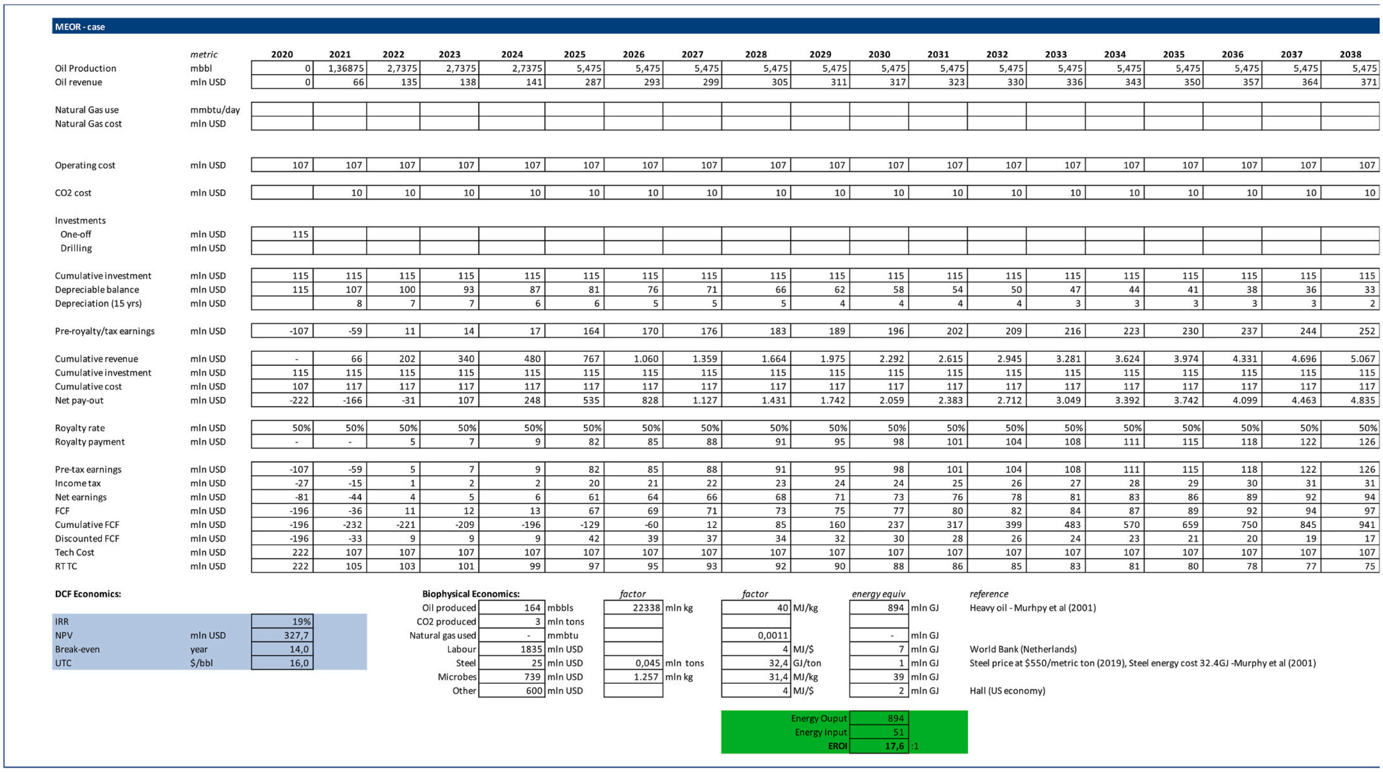
SAGD - case

	metric	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038
Oil Production	mbbl	0	9,125	18,25	18,25	18,25	18,25	18,25	18,25	18,25	18,25	18,25	18,25	18,25	18,25	18,25	18,25	18,25	18,25	18,25
Oil revenue	mln USD	0	312	636	649	662	675	689	702	716	731	745	760	775	791	807	823	839	856	873
Natural Gas use	mmbtu/day	20.000	40.000	40.000	40.000	40.000	40.000	40.000	40.000	40.000	40.000	40.000	40.000	40.000	40.000	40.000	40.000	40.000	40.000	40.000
Natural Gas cost	mln USD	15	30	30	31	32	32	33	34	34	35	36	36	37	38	39	39	40	41	42
Operating cost	mln USD		102	104	106	108	110	113	115	117	120	122	124	127	129	132	135	137	140	143
CO2 cost	mln USD	15	31	31	32	32	33	34	34	35	36	37	37	38	39	40	40	41	42	43
Investments																				
One-off	mln USD	1.150																		
Drilling	mln USD	90	92	94	96	97	99	101	103	105	108	110	112	114	116	119	121	124	126	129
Cumulative investment	mln USD	1.240	1.332	1.425	1.521	1.618	1.718	1.819	1.922	2.028	2.135	2.245	2.357	2.471	2.588	2.706	2.828	2.951	3.077	3.206
Depreciable balance	mln USD	1.240	1.208	1.181	1.158	1.140	1.125	1.114	1.106	1.101	1.098	1.098	1.100	1.104	1.110	1.118	1.127	1.138	1.150	1.164
Effective Tax shield	mln USD		124	121	118	116	114	113	111	111	110	110	110	110	110	111	112	113	114	115
Pre-royalty/tax earnings	mln USD	-30	25	350	362	374	385	397	408	419	430	441	452	463	475	486	497	508	519	531
Cumulative revenue	mln USD	-	312	948	1.597	2.258	2.933	3.622	4.324	5.041	5.771	6.516	7.277	8.052	8.843	9.650	10.472	11.312	12.168	13.041
Cumulative investment	mln USD	1.240	1.332	1.425	1.521	1.618	1.718	1.819	1.922	2.028	2.135	2.245	2.357	2.471	2.588	2.706	2.828	2.951	3.077	3.206
Cumulative cost	mln USD	30	162	166	169	172	176	179	183	187	190	194	198	202	206	210	214	219	223	227
Net pay-out	mln USD	-1.270	-1.182	-643	-93	468	1.040	1.624	2.219	2.826	3.445	4.077	4.722	5.379	6.049	6.733	7.431	8.142	8.868	9.608
Pre-pay-out / post-payout	mln USD	0	0	0	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Royalty rate	mln USD	1%	1%	1%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%
Royalty payment	mln USD	-0	0	3	90	93	96	99	102	105	108	110	113	116	119	121	124	127	130	133
Depreciation	mln USD		107	114	122	129	137	146	154	162	171	180	189	198	207	217	226	236	246	256
Pre-tax earnings	mln USD	-29	-81	232	150	151	152	152	152	152	152	151	151	150	149	148	146	145	143	142
Income tax	mln USD	-7	-20	58	37	38	38	38	38	38	38	38	38	37	37	37	37	36	36	35
Net earnings	mln USD	-22	-61	174	112	113	114	114	114	114	114	114	113	112	112	111	110	109	107	106
FCF	mln USD	-1.262	78	315,28	256	261	266	271	276	282	287	293	300	306	313	320	327	334	341	349
Cumulative FCF	mln USD	-1.262	-1.184	-869	-613	-352	-86	185	461	742	1.030	1.323	1.622	1.928	2.241	2.561	2.887	3.221	3.563	3.912
Discounted FCF	mln USD	-1.262	71	261	193	178	165	153	142	131	122	113	105	97	91	84	78	73	68	63
Tech Cost	mln USD	1.255	224	228	233	237	242	247	252	257	262	267	273	278	284	289	295	301	307	313
RT TC	mln USD	1.255	219	219	219	219	219	219	219	219	219	219	219	219	219	219	219	219	219	219

DCF Economics:		
IRR		20%
NPV	mln USD	1.403
Break-even	year	7
UTC	$/bbl	14,4

Biophysical Economics:			*factor*		*factor*		*energy equiv*		*reference*
Oil produced	548	mbbls	74.460	mln kg	40	MJ/kg	2.978	mln GJ	Heavy oil - Murhpy et al (2001)
CO2 produced	30	mln tons							
Natural gas used	438.000.000	mmbtu			0,0011		482	mln GJ	
Labour	5200	mln USD			5	MJ/$	26	mln GJ	World Bank (Canada)
Steel	500	mln USD	0,909	mln tons	32,4	GJ/ton	29	mln GJ	Steel price at $550/metric ton (2019), Steel energy cost 32.4GJ -Murphy et al (2001)
Other	4000	mln USD			5	MJ/$	20	mln GJ	World Bank (Canada)

Energy Ouput	2.978	mln GJ
Energy Input	557	mln GJ
EROI	**5,34**	:1



MEOR - case

	metric	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038
Oil Production	mbbl	0	1,36875	2,7375	2,7375	2,7375	5,475	5,475	5,475	5,475	5,475	5,475	5,475	5,475	5,475	5,475	5,475	5,475	5,475	5,475
Oil revenue	mln USD	0	66	135	138	141	287	293	299	305	311	317	323	330	336	343	350	357	364	371
Natural Gas use	mmbtu/day																			
Natural Gas cost	mln USD																			
Operating cost	mln USD	107	107	107	107	107	107	107	107	107	107	107	107	107	107	107	107	107	107	107
CO2 cost	mln USD		10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Investments																				
One-off	mln USD	115																		
Drilling	mln USD																			
Cumulative investment	mln USD	115	115	115	115	115	115	115	115	115	115	115	115	115	115	115	115	115	115	115
Depreciable balance	mln USD	115	107	100	93	87	81	76	71	66	62	58	54	50	47	44	41	38	36	33
Depreciation (15 yrs)	mln USD		8	7	7	6	6	5	5	5	4	4	4	4	3	3	3	3	3	2
Pre-royalty/tax earnings	mln USD	-107	-59	11	14	17	164	170	176	183	189	196	202	209	216	223	230	237	244	252
Cumulative revenue	mln USD	-	66	202	340	480	767	1.060	1.359	1.664	1.975	2.292	2.615	2.945	3.281	3.624	3.974	4.331	4.696	5.067
Cumulative investment	mln USD	115	115	115	115	115	115	115	115	115	115	115	115	115	115	115	115	115	115	115
Cumulative cost	mln USD	107	117	117	117	117	117	117	117	117	117	117	117	117	117	117	117	117	117	117
Net pay-out	mln USD	-222	-166	-31	107	248	535	828	1.127	1.431	1.742	2.059	2.383	2.712	3.049	3.392	3.742	4.099	4.463	4.835
Royalty rate	mln USD	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%
Royalty payment	mln USD	-	-	5	7	9	82	85	88	91	95	98	101	104	108	111	115	118	122	126
Pre-tax earnings	mln USD	-107	-59	5	7	9	82	85	88	91	95	98	101	104	108	111	115	118	122	126
Income tax	mln USD	-27	-15	1	2	2	20	21	22	23	24	24	25	26	27	28	29	30	31	31
Net earnings	mln USD	-81	-44	4	5	6	61	64	66	68	71	73	76	78	81	83	86	89	92	94
FCF	mln USD	-196	-36	11	12	13	67	69	71	73	75	77	80	82	84	87	89	92	94	97
Cumulative FCF	mln USD	-196	-232	-221	-209	-196	-129	-60	12	85	160	237	317	399	483	570	659	750	845	941
Discounted FCF	mln USD	-196	-33	9	9	9	42	39	37	34	32	30	28	26	24	23	21	20	19	17
Tech Cost	mln USD	222	107	107	107	107	107	107	107	107	107	107	107	107	107	107	107	107	107	107
RT TC	mln USD	222	105	103	101	99	97	95	93	92	90	88	86	85	83	81	80	78	77	75

DCF Economics:		
IRR		19%
NPV	mln USD	327,7
Break-even	year	14,0
UTC	$/bbl	16,0

Biophysical Economics:			*factor*		*factor*		*energy equiv*		*reference*
Oil produced	164	mbbls	22338	mln kg	40	MJ/kg	894	mln GJ	Heavy oil - Murhpy et al (2001)
CO2 produced	3	mln tons							
Natural gas used	-	mmbtu			0,0011		-	mln GJ	
Labour	1835	mln USD			4	MJ/$	7	mln GJ	World Bank (Netherlands)
Steel	25	mln USD	0,045	mln tons	32,4	GJ/ton	1	mln GJ	Steel price at $550/metric ton (2019), Steel energy cost 32.4GJ -Murphy et al (2001)
Microbes	739	mln USD	1.257	mln kg	31,4	MJ/kg	39	mln GJ	
Other	600	mln USD			4	MJ/$	2	mln GJ	Hall (US economy)

Energy Ouput	894	
Energy Input	51	
EROI	**17,6**	:1

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