For professional investors - August 2019

WELLS, WIRES, AND WHEELS...

EROCI AND THE TOUGH ROAD AHEAD FOR OIL

BNP PARIBAS
ASSET MANAGEMENT

The asset manager for a changing world

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INTRODUCTION

Oil needs long-term break-evens of $10-$20/bbl to remain competitive in mobility. In this report we introduce the concept of the Energy Return on Capital Invested (EROCI), focusing on the energy return on a $100bn outlay on oil and renewables where the energy is being used specifically to power cars and other light-duty vehicles (LDVs). For a given capital outlay on oil and renewables, how much useful energy at the wheels do we get? Our analysis indicates that for the same capital outlay today, new wind and solar-energy projects in tandem with battery electric vehicles (EVs)* will produce 6x-7x more useful energy at the wheels than will oil at $60/bbl for gasoline-powered LDVs, and 3x-4x more than will oil at $60/bbl for LDVs running on diesel. Accordingly, we calculate that the long-term break-even oil price for gasoline to remain competitive as a source of mobility is $9-$10/bbl, and for diesel $17-19/bbl.

Oil has a massive flow-rate advantage, but this is time limited. The oil industry is so massive that the amounts that can be purchased on the spot market can provide very large and effectively instantaneous flows of energy. By contrast, new wind and solar projects deliver their energy over a 25-year operating life. Nonetheless, we think the economics of renewables are impossible for oil to compete with when looked at over the cycle. We calculate that to get the same amount of mobility from gasoline as from new renewables in tandem with EVs over the next 25 years would cost 6.2x-7x more. Indeed, even if we add in the cost of building new network infrastructure to cope with all the new wind and/or solar capacity implied by replacing gasoline with renewables and EVs, the economics of renewables still crush those of oil. Extrapolating total expenditure on gasoline in 2018 for the next 25 years would see $25trn spent on mobility, whereas we estimate the cost of new renewables projects complete with the enhanced network infrastructure required to match the 2018 level of mobility provided by gasoline every year for the next 25 years at only $4.6-$5.2trn.

Economic and environmental benefits set to make renewables in tandem with EVs irresistible. The clear conclusion of our analysis is that if we were building out the global energy system from scratch today, economics alone would dictate that at a minimum the road-transportation infrastructure would be built up around EVs powered by wind- and solar-generated electricity. And that is before we factor in the other advantages of renewables and EVs over oil as a road-transportation fuel, namely the climate-change and clean-air benefits, the public-health benefits that flow from this, the fact that electricity is much easier to transport than oil, and the fact that the price of electricity generated from wind and solar is low and stable over the long term whereas the price of oil is notoriously volatile.

The death toll for petrol. With 36% of demand for crude oil today accounted for by LDVs and other vehicle categories susceptible to electrification, and a further 5% by power generation, the oil industry has never before in its history faced the kind of threat that renewable electricity in tandem with EVs poses to its business model: a competing energy source that (i) has a short-run marginal cost (SRMC) of zero, (ii) is much cleaner environmentally, (iii) is much easier to transport, and (iv) could readily replace up to 40% of global oil demand if it had the necessary scale. We conclude that the economics of oil for gasoline and diesel vehicles versus wind- and solar-powered EVs are now in relentless and irreversible decline, with far-reaching implications for both policymakers and the oil majors.

A warning from the European utility sector. If all of this sounds far-fetched, then the speed with which the competitive landscape of the European utility industry has been reshaped over the last decade by the rollout of wind and solar power – and the billions of euros of fossil-fuel generation assets that this has stranded – should be a flashing red light on the oil industry's dashboard.

* Throughout this report we refer to battery electric vehicles as EVs. In other words, we are talking about fully electric vehicles, not plug-in hybrids.

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1 EXECUTIVE SUMMARY

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EROCI IMPLIES LONG-TERM OIL BREAK-EVENS OF $10-$20/BBL TO REMAIN COMPETITIVE IN MOBILITY

In this report we introduce the concept of the Energy Return on Capital Invested (EROCI). EROCI is a metric that allows for the comparison of the energy yielded from a given level of investment in different energy sources and can be measured on both a gross and a net basis. In this report, we focus on the EROCI for a $100bn outlay on oil and renewables where the energy is being used specifically to power cars, other light-duty vehicles (LDVs), and other light and mid-heavy vehicles.[1]

We define gross energy as the amount of primary energy available before it is converted into useful energy in final consumption. We define net energy as the amount of energy that does useful work after taking in to account all energy-transportation and energy-conversion costs and losses.

What we are most interested in is how much a given capital outlay on oil and renewables translates into useful or propulsive energy at the wheels: in other words, for a given capital outlay, how much *mobility* can you buy?

More specifically, in our analysis throughout this report we define net energy to mean the useful energy provided at the wheels to LDVs powered by gasoline and diesel on the one hand, and to EVs powered by electricity from new onshore-wind, offshore-wind, and solar-photovoltaic (PV) projects on the other.

Accordingly, we use terawatt-hours (TWh) as the unit of energy to compare the EROCI of oil versus renewables, using a conversion ratio of 1 million barrels of oil equivalent (mboe) = 1.7TWh. As such, our concept of net EROCI throughout this report is effectively a variation on the notion of vehicle miles travelled (VMT), or vehicle kilometres travelled (VKT).

Given the sheer scale of the energy industry we have chosen to compare the EROCI of oil and renewables for a $100bn outlay, but the essential point to bear in mind throughout this report is that we are comparing the energy return on oil and renewables for the same capital outlay. In other words, whether we are looking at $1, $100, or $100bn of capital invested, what matters is the differential in the net energy yielded from oil on the one hand, and from wind and solar on the other, when the energy is consumed to provide mobility.

1.1.1 OUR EROCI ANALYSIS SHOWS THAT RENEWABLES IN TANDEM WITH EVS PROVIDE UP TO 7X MORE NET ENERGY FOR SAME OUTLAY

Our analysis leads to a very stark conclusion for the oil industry: for the same capital outlay today, wind and solar energy will already produce much more useful energy for EVs than will oil purchased on the spot market today at $60/bbl[2] and then used for gasoline- and diesel-powered LDVs.[3]

Indeed, and as shown in Figure 1, our model says that for the same capital outlay today, wind and solar energy would produce 6.2-7x more useful energy for EVs than would oil priced at $60/bbl for

1. Together these segments accounted for 36% of total oil demand in 2018, and if we add in power generation from oil – also vulnerable to competition from renewables – we get to 40% of current global oil demand at long-term risk of disintermediation from renewables according to our EROCI analysis in this report.
2. With the exception of our analysis of gasoline consumption in 2018 in Section 1.3 below (for which we use a price of $68/bbl derived from the average of WTI and Brent in 2018), throughout this report we take $60/bbl as our market reference price. This is because so far in 2019 the average of the Brent and WTI benchmarks has been very close to $60/bbl, and in the context of oil used as a road-transportation fuel the US WTI benchmark is particularly important (cross-checking the data from the US Government's Energy Information Administration at https://www.eia.gov/totalenergy/data/monthly/pdf/mer.pdf with the global breakdown shown in Figure 9 below, we estimate that the US accounts for ~40% of global gasoline demand and ~25% of global diesel demand).
3. We explain all of our modelling assumptions in detail below (see Section 2, *Methodology and Key Modelling Assumptions*).

LDVs running on a gasoline-powered internal-combustion engine (ICE), and 3.2x-3.6x more useful energy than oil at $60/bbl for LDVs running on diesel engines (Figure 2).[4]

With our analysis showing that wind and solar in tandem with EVs will yield significantly more useful energy for mobility than will oil for gasoline- and diesel-powered LDVs at $60/bbl, the real question is this: at what price would oil need to trade over the long term in order to remain competitive in the market for mobility?

The answer to this question will give a reference point for the break-even price levels oil companies should have in mind when thinking about which new projects to invest in. And on our calculations, the numbers are stark.

Figure 1: Net EROCI* from new renewables projects in tandem with EVs versus oil used for gasoline vehicles for a $100bn outlay (TWh)

ENERGY AND TECHNOLOGY SOURCES	GROSS POTENTIAL ENERGY[5]	GROSS ENERGY PURCHASED[6]	GROSS ENERGY AT PUMP OR CHARGER[7]	NET EROCI (MOBILITY)[8]	MULTIPLE OF EROCI OF OIL AT $60/BBL	IMPLIED OIL PRICE FOR SAME NET EROCI
Oil for gasoline LDVs	2,824TWh	1,497TWh	1,347TWh	337TWh	1x	$60/bbl
Onshore wind w/EVs	3,443TWh	2,583TWh	2,324TWh	1,673TWh	6.2x	$9.7/bbl
Offshore wind w/EVs	3,871TWh	2,903TWh	2,613TWh	1,881TWh	7x	$8.6/bbl
Solar-PV w/EVs	3,249TWh	2,437 Wh	2,315TWh	1,667TWh	6.2x	$9.7/bbl

Source: BNP Paribas Asset Management *In this report, net EROCI is the amount of mobility bought for a given capital outlay.

Figure 2: Net EROCI* from new renewables projects in tandem with EVs versus oil used for diesel vehicles for a $100bn outlay (TWh)

ENERGY AND TECHNOLOGY SOURCES	GROSS POTENTIAL ENERGY	GROSS ENERGY PURCHASED	GROSS ENERGY AT PUMP OR CHARGER	NET EROCI (MOBILITY)	MULTIPLE OF EROCI OF OIL AT $60/BBL	IMPLIED OIL PRICE FOR SAME NET EROCI
Oil for diesel vehicles	2,824TWh	1,497TWh	1,497TWh	524TWh	1x	$60/bbl
Onshore wind w/EVs	3,443TWh	2,583TWh	2,324TWh	1,673TWh	3.2x	$16.7/bbl
Offshore wind w/EVs	3,871TWh	2,903TWh	2,613TWh	1,881TWh	3.6x	$18.8/bbl
Solar-PV w/EVs	3,249TWh	2,437TWh	2,315TWh	1,667TWh	3.2x	$18.9/bbl

Source: BNP Paribas Asset Management *In this report, net EROCI is the amount of mobility bought for a given capital outlay.

For gasoline LDVs, we calculate the oil price required to yield as much net energy as would new renewables projects in tandem with EVs at $9-$10/bbl, and for diesel at $17-$19/bbl.

4. As explained in Section 2 below, for gasoline-ICE LDVs we assume a thermal efficiency of 20%, and for diesel-ICE engines we assume a thermal-efficiency rate of 35%.
5. We define gross potential energy as the amount of energy inherent in a given amount of expenditure on crude oil or new renewables projects before accounting for the real-world costs of getting the energy to the end consumer (in this case, the numbers are based on $100bn of expenditure). We explain this in more detail in section 2 below.
6. We define gross energy purchased as the amount of energy available from crude oil or new renewables projects after accounting for the costs of refining and transporting the energy, and any taxes payable (in the case of oil), and the costs of transporting the electricity (in the case of new renewables projects). Again, see Section 2 for more details.
7. We define gross energy at the pump as the amount of energy that reaches the end-consumer before it is used. As such it accounts for any energy losses in refining (for oil) or over the transmission and distribution grids (in the case of electricity from new renewables projects). Again, see Section 2 for more details.
8. We define net EROCI as the amount of useful energy, i.e. energy that actually provides mobility. As such, it is the amount of energy left available after combustion losses (in the case of gasoline and diesel engines) or after charging and conversion losses (in the case of renewable electricity used in EVs). Again, see Section 2 for more details.

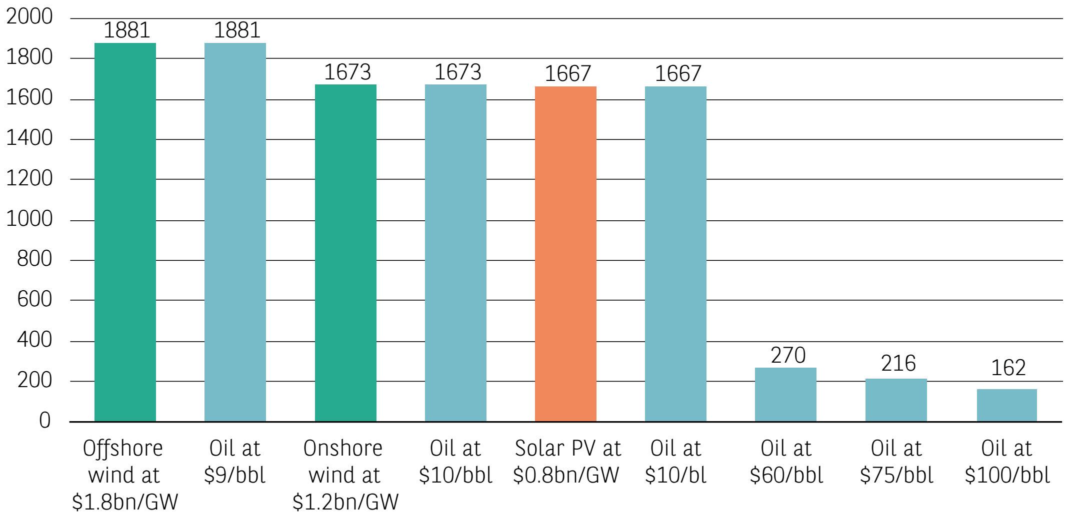
1.1.2 EROCI IMPLIES GASOLINE NEEDS OIL BREAK-EVENS OF $11-$12/BBL OVER LONG TERM

We calculate that for $100bn of total expenditure on new renewables projects assuming new-build costs of $60/MWh for onshore wind, $70/MWh for offshore wind, and $65/MWh for solar-PV, these technologies would generate 1,881TWh, 1,673TWh, and 1,667TWh respectively of useful energy for EVs over 25 years.

This compares with only 270TWh of useful energy provided for gasoline-powered LDVs with $100bn of crude oil purchased on the spot market today at $60/bbl.

Indeed, we calculate that for the same outlay on these different energy sources, oil would have to trade at $9/bbl to yield as much useful energy for gasoline-fuelled LDVs as offshore wind would yield in tandem with EVs, $10/bbl for as much useful energy as onshore wind in tandem with EVs, and $10/bbl for as much as useful energy as solar-PV in tandem with EVs (Figure 3).

Figure 3: Net EROCI* from new renewables projects in tandem with EVs versus oil used for gasoline vehicles for a $100bn outlay (TWh)

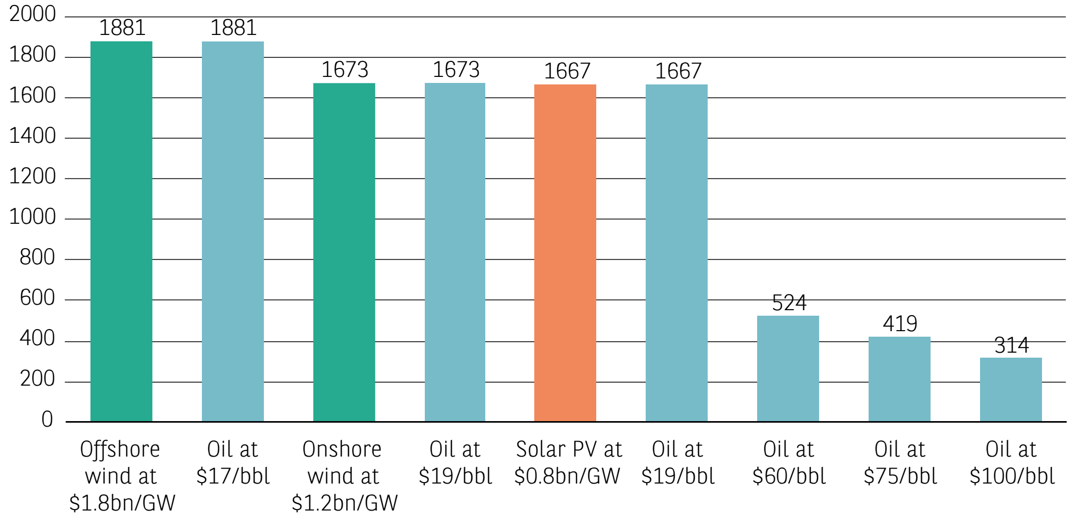


Source: BNP Paribas Asset Management estimates. *In this report, net EROCI is the amount of mobility bought for a given capital outlay.

1.1.3 EROCI IMPLIES DIESEL NEEDS OIL BREAK-EVENS OF $17-$19/BBL OVER LONG TERM

For diesel-powered engines, the numbers are only marginally better than those for gasoline. We calculate that for an outlay of $100bn, oil would have to trade at $17/bbl to yield as much useful energy for diesel-fuelled LDVs as new offshore-wind projects would for EVs, $19/bbl for as much useful energy as yielded by new onshore wind, and $19/bbl for as much as from new solar-PV projects (Figure 4).

Figure 4: Net EROCI* from new renewables projects in tandem with EVs oil used for diesel vehicles for a $100bn outlay (TWh)



Source: BNP Paribas Asset Management estimates. *In this report, net EROCI is the amount of mobility bought for a given capital outlay.

These are stunning numbers, and they suggest that the economics of renewables in tandem with EVs are set to become irresistible over the next decade.

Indeed, the clear conclusion of our analysis is that if the world were building out the global energy system from scratch today, then the economics alone would dictate that at a minimum the road-transportation infrastructure would be built up around EVs powered by wind- and solar-generated electricity rather than around oil, refineries, and gasoline and diesel vehicles.

But there is a catch, and it is a big one: oil has a massive incumbency advantage.

- 1.2 -

REALITY CHECK: OIL HAS A MASSIVE INCUMBENCY ADVANTAGE

The oil industry today enjoys a massive scale advantage over wind and solar of several orders of magnitude – oil supplied 33% of global energy in 2018 compared with only 3% from wind and solar[9] Moreover, EVs are currently more expensive than ICE and diesel vehicles on a sticker-price basis, and likely to remain so until 2023-25.[10]

This scale advantage over wind and solar gives oil the further advantages of speed and convenience: the oil industry is so massive that the amounts that can be purchased on the spot market can provide very large and effectively instantaneous flows of energy. By contrast, new wind and solar projects will only deliver their energy over a 25-year operating life. This underlines the point that the renewable-energy industry needs to scale up massively over the coming decades since on an absolute unadjusted basis wind and solar cannot deliver anything close to the energy that the global oil industry can deliver today as an instantaneous flow.

But then 100 years ago, before it had scaled up, the oil industry would not have been able to deliver the kind of instantaneous flow of energy it can deliver today either. The point here is that the oil industry has built up a giant global supply chain over many decades while wind and solar are at the beginning of that same journey.

9. See the BP Statistical Review of World Energy 2019, which gives total consumption of wind and solar power as 420 million tonnes of oil equivalent (mtoe) in 2018, out of total global primary energy consumption of 13,865mtoe. The BP Statistical Review is available at: https://www.bp.com/en/global/corporate/news-and-insights/press-releases/bp-statistical-review-of-world-energy-2019.html
10. We discuss projections for the cost trends for EVs in Section 1.4 below.

Moreover, individual oil projects do not deliver their output as an instantaneous flow, but typically over many years, taking time to build up to a peak level of production, then plateauing for a few years, and then entering into decline.[11] This means that reinvestment in new projects is needed every year to replace lost production, and this is where the price comparison with new wind and solar projects comes in: what really matters going forward is how competitive new oil projects will be with new wind and solar projects.

1.2.1 BUT INCUMBENCY'S ADVANTAGES ARE TIME-LIMITED

The advantages of speed and convenience enjoyed by the oil industry today are time-limited. This is because decline rates in the oil industry mean that every year it has to invest in new projects just to stand still. And the dilemma for the oil majors that arises out of this fact is that they have an average reserves-to-production (R/P) ratio of only 10 years, meaning that every year they need to replace ~10% of their reserves.[12]

This means that every year they bring new projects onstream to replace the reserves that are consumed, and every year they make final-investment decisions (FIDs) on future projects for production years down the line. It is these FIDs that will require ever greater scrutiny going forward, especially those with a break-even of >$20/bbl.

This is because by the time such projects sanctioned today actually start producing a growing portion of their output will be subject to fierce competition from a cheaper, cleaner fuel source. Of course, there remain big infrastructure challenges to be overcome – and paid for – if the potential of renewables in tandem with EVs is to be fulfilled over the next two decades but as the net-energy yield over the full life-cycle of renewables versus oil will only continue to improve over the next decade the competitive advantage is set to shift decisively in favour of EVs over oil-powered cars in the next five years. In our view, this is much sooner than the oil industry thinks.

For now, though, oil enjoys a significant energy-flow advantage over renewables. The question is, how big is this advantage, and how long will it last? One way of answering this question is to look at the energy-flow rate from oil used for gasoline in 2018 for a $100bn outlay, and compare this with the annual flow rates that can be achieved from a $100bn investment in new wind and solar projects.

- 1.3 -

NET EROCI OF OIL IN 2018: HOW MUCH MOBILITY DID GASOLINE PROVIDE AND AT WHAT COST?

How much useful energy – i.e. mobility – was provided by gasoline to cars and other LDVs in 2018, and how much did this mobility cost? The answer to this question will give us a reference point for how long oil will be able to live off its sunk infrastructure as a source of competitive advantage over new renewables projects.

11. The rise of US shale or light, tight oil (LTO) over the last decade is the exception to this pattern, as LTO projects typically deliver over 50% of their output in the first three years of their production. The flipside to this, however, is that in order to maintain existing levels of production LTO plays require constant re-investment in new drilling such that in aggregate the LTO industry is still cash-flow negative. For more on the cash-flow shortfall of the LTO business model see the recent FT article of 19 May, "US oil: Occidental's $56bn gamble on finding value in shale", available at: https://www.ft.com/content/d3d63bba-7653-11e9-be7d-6d846537acab

12. We derive this average R/P ratio from company reports cross-checked with sell-side equity analysts.

1.3.1 WE ESTIMATE TOTAL USEFUL ENERGY FROM GASOLINE IN 2018 AT 2,660TWH FROM A TOTAL OUTLAY OF $1.12 TRN

To derive numbers for the total amount of useful energy yielded by gasoline in 2018 and the outlay required to purchase this useful energy, we need to know three things: (i) the average cost of oil in 2018; (ii) the amount of oil used for gasoline in cars and other LDVs; (iii) any energy losses in converting oil into gasoline; and (iv) the average thermal efficiency of the global gasoline-fuelled vehicle fleet:

(i) For the average oil price in 2018 we add together the average 2018 prices of the two most important global benchmarks – the Brent price of $71/bbl and the WTI price of $65/bbl – and divide this number by two. This gives us an average 2018 oil price of $68/bbl.

(ii) For the amount of oil used for gasoline in cars and other LDVs we take the 2018 numbers for oil demand from the International Energy Agency[13] (IEA), and Wood Mackenzie's estimates for the share of this demand accounted for by gasoline in cars and other LDVs.[14]

(iii) Throughout this study we take the energy-density numbers provided by the US Government Energy Information Administration (EIA) for oil, gasoline, and diesel. On these numbers gasoline contains 10% less energy per barrel than crude oil.[15]

The IEA numbers show total oil demand of 99.2 million barrels per day (mbd) in 2018, which equates to 36.2 billion barrels of oil (bboe) over the whole year. Wood Mackenzie estimates the share of gasoline for cars and other LDVs in this total at 24%, which gives us 8.688bboe of gasoline demand for road-transportation purposes in 2018.

(iv) We assume an average efficiency rate for the internal combustion engine (ICE) in the global gasoline-fuelled vehicle fleet of 20%, although the true number is probably a little lower than this.

Putting all of this together, we calculate that in 2018

- Total expenditure on barrels of crude oil = $2.462 trillion (i.e. 36.2bboe*$68)
- Total amount of barrels of crude-oil demand for gasoline = 8.690bboe (i.e. 36.2bboe*24%)
- Total expenditure on barrels of crude oil intended for gasoline = $591bn (i.e. 8.690bboe*$68)
- Total amount of gross potential energy in crude oil intended for gasoline = 14,773TWh (i.e. 8.690bboe*1.7)
- Total amount of gross potential energy in gasoline at the pump = 13,296TWh (i.e. 14,773TWh*90%)
- Total amount of net energy – i.e. mobility – provided by gasoline = 2,660TWh (i.e. 13,296TWh*20%)

So, for $591bn of capital outlay just on the energy in the crude oil, consumers purchased total useful energy – i.e. mobility – of 2,660TWh. These numbers are summarized in Figure 5.

Figure 5: 2018 estimated total global expenditure on crude oil and on crude oil for gasoline, and useful energy yielded from gasoline

	MBD	MBY	PRICE	OUTLAY	GROSS ENERGY	USEFUL ENERGY
Total oil market	99.2	36,208	$68/bbl	$2,462bn	61,554TWh	n/a*
Oil for gasoline	23.8	8,690	$68/bbl	$591bn	13,296TWh	2,660TWh

Source: BNP Paribas Asset Management. *We do not attempt to calculate the useful energy from all of the crude oil consumed in 2018 as for our purposes here we are only interested in the useful energy from 2018 gasoline consumption.

However, the expenditure on the energy itself is only half the story, because for every dollar spent at the pump on gasoline, nearly half goes on refining, transporting, marketing, and taxing the energy itself.

13. See the IEA publication *Oil 2019: Analysis and Outlook to 2024* (Table 1.2, p. 17), available at: https://webstore.iea.org/download/getdownload/e5d579e3-b6cc-4e31-9590-36821f71f938?fileName=MRSoil2019.pdf.
14. See Section 1.5 below.
15. See Section 2.2 below.

As a consequence, we have to gross up the $591bn spent on the energy itself to derive the total amount of expenditure required for the 2,660TWh of useful energy provided by gasoline in cars and other LDVs in 2018. Taking again the EIA numbers used later in this report, we assume that only 53% of the total expenditure on gasoline is for the energy itself, with the rest required to cover all the other costs of getting the gasoline to the end-consumer at the pump: refining, transporting, marketing, and taxes.[16]

The EIA estimates that 53% of the total cost of gasoline at the pump goes on the energy in the crude oil, 15% on refining, 15% on transporting and marketing, and 17% on taxes, so this is the schema we have used to derive the total outlay (Figure 6).

Figure 6: Estimated total expenditure on oil used for gasoline in 2018, and useful energy yielded from gasoline for every $100bn

	ENERGY	REFINING	TRANSPORT/ MARKETING	TAXES	TOTAL	USEFUL ENERGY	MOBILITY /$100BN
Oil for gasoline	$591bn	$167bn	$167bn	$190bn	$1,115bn	2,660TWh	240TWh

Source: BNP Paribas Asset Management.

Putting all of this together, we calculate that in 2018:

- Total expenditure on crude oil intended for gasoline for cars and other LDVs = **$1.115trn** (i.e. $591bn/53%)
- Total net energy provided by gasoline = 2,660TWh
- Net EROCI of oil intended for gasoline = 2,660TWh/$1.115trn
- Net EROCI = 2.4TWh per $1bn

In 2018, therefore, we estimate the net EROCI of oil used for gasoline for an outlay of $100bn = 240TWh

By contrast, our estimates for the net EROCI for a $100bn outlay on new onshore-wind, offshore-wind, and solar-PV projects – assuming the output of these projects is then used for providing mobility to EVs – are those already shown above in Figures 1 and 3, namely:

- Onshore wind = **1,673TWh = 7x net EROCI of oil used for gasoline in 2018**
- Offshore wind = **1,881TWh = 7.8x net EROCI of oil used for gasoline in 2018**
- Solar-PV = **1,667TWh = 7x net EROCI of oil used for gasoline in 2018**

That said, because the $100bn spent on new renewables projects will only deliver its energy over an assumed operating life of 25 years, we also need to compare the annual flow rate of useful energy from our new renewables projects with the annual flow rate of useful energy from $100bn spent on oil on the spot market for gasoline.

1.3.2 $100BN ON SPOT OIL FOR GASOLINE YIELDS 3X-4X THE ANNUAL FLOW OF USEFUL ENERGY FROM NEW RENEWABLES PROJECTS

The sheer scale of the oil industry's sunk infrastructure will provide it with a significant advantage over renewables in terms of the flow of energy it can provide for the next 15-20 years: the 240TWh of net energy provided for every $100bn spent on oil for gasoline in 2018 is 3.9x, 3.4x, and 4.7x the annual flow rate of net energy that $100bn spent on new onshore-wind, offshore-wind, and new solar-PV projects respectively could deliver (Figure 7).

16. As explained in Section 2.2 below, these numbers are based on US costs, but with the US accounting for 40% of global gasoline consumption we think this is a reasonable proxy for global costs (although the tax element is typically higher in other parts of the world, especially Europe).

Figure 7: Useful energy (mobility): annual flow from $100bn spent on oil market for gasoline vehicles with oil at $60bn versus annual flow from $100bn spent on new renewables projects in tandem with EVs (TWh)

ENERGY AND TECHNOLOGY SOURCES FOR FUEL AND TRANSPORT	TOTAL NEW APACITY BUILT FOR $100BN	TOTAL NET ENERGY FLOW FOR $100BN	ANNUAL NET ENERGY FLOW FOR $100BN	ANNUAL FLOW: RENEWABLES AS FRACTION OF OIL	ANNUAL FLOW: OIL AS MULTIPLE OF RENEWABLES
Oil for gasoline LDVs	n/a	240TWh	240TWh	1x	1x
Onshore wind w/EVs	47GW	1,673TWh	67TWh	0.28x	3.6x
Offshore wind w/EVs	27GW	1,881TWh	75TWh	0.31x	3.2x
Solar-PV w/EVs	75GW	1,667TWh	67TWh	0.28x	3.6x

Source: BNP Paribas Asset Management

This is because in order to derive the annual flow rate of useful energy from new renewables projects we need to divide the total useful energy from a $100bn investment by 25 (our assumed operating life for new wind and solar projects). When we do this, we get the numbers shown in Figure 7: compared with the 240TWh of useful energy provided by $100bn spent on oil used for gasoline in 2018, our new onshore, offshore, and solar-PV projects would, for the same outlay, provide annual flows of only 67TWh, 75TWh, and 67TWh respectively.

From the difference in flow rates shown in Figure 7 it follows that in comparing the net EROCI of oil versus wind and solar throughout this report we should not compare these energy sources on a like-for-like basis. Rather, we need to take in to account the advantage that oil enjoys over renewables as a result of its existing scale and scope. Accordingly, our EROCI analysis for oil considers how much useful energy can be delivered from a $100bn outlay on the spot market today, whereas our EROCI analysis for wind and solar looks at how much energy can be delivered from $100bn spent on new projects.

Even allowing for this structural advantage enjoyed by oil in terms of flow rates, however, we think the economics of renewables are already impossible for oil to compete with when looked at over the cycle.

1.3.3 INFRASTRUCTURE BUILD-OUT KEY TO ADOPTION OF RENEWABLES AND EVS BUT ECONOMICS NOW IRRESISTIBLE

Figure 8 shows how much the mobility provided by gasoline in 2018 would cost over the next 25 years assuming a continuation of the current pattern of expenditure on gasoline on the one hand, and the cost of providing the same amount of annual mobility via new renewables projects in tandem with EVs on the other. In Figure 8 and Figure 9 we assume an oil price of $60/bbl, in keeping with the average global price so far in 2019 obtained from the average of the WTI and Brent benchmarks.

Figure 8: Total outlay required to purchase useful-energy flow (mobility) of 2,660TWh per year over 25 years, oil for gasoline vehicles versus new renewables projects in tandem with EVs (TWh)

ENERGY AND TECHNOLOGY SOURCES FOR FUEL AND TRANSPORT	TOTAL NET ENERGY FLOW FOR $100BN	ANNUAL NET ENERGY FLOW FOR $100BN	2018 DEMAND FOR NET ENERGY FROM GASOLINE	OUTLAY FOR ANNUAL NET ENERGY FLOW OF 2,660TWH	OUTLAY OVER 25 YEARS FOR NET ANNUAL ENERGY FLOW OF 2,660TWH	TOTAL OUTLAY ON OIL AS A MULTIPLE OF NEW RENEWABLES PROJECTS
Oil for gasoline for LDVs	270TWh	270TWh	2,660TWh	$984bn	$24.6trn	1x
Onshore wind w/EVs	1,675TWh	67TWh	2,660TWh	$3.97trn	$3.97trn	6.2x
Offshore wind w/EVs	1,881TWh	75TWh	2,660TWh	$3,55trn	$3,55trn	7x
Solar-PV w/EVs	1,667 Wh	67TWh	2,660TWh	$3.97trn	$3.97trn	6.2x

Source: BNP Paribas Asset Management.

As set out above, we estimate the total cost on oil for gasoline in 2018 to provide 2,660TWh of mobility at $1.115trn. Multiplying this by 25 gives us a total cost of $25trn over the next 25 years to provide 2,660TWh of annual useful-energy flow. By contrast, based on the annual flows of useful energy yielded on our calculations by new renewables projects in tandem with EVs for a $100bn outlay (Figure 7 above), we calculate that to scale up to the necessary level in order to be able to provide 2,660TWh per year over the next 25 years, the following levels of investment would be necessary:[17]

- For new onshore wind projects: **$3,970trn**

  We calculate this number by taking the annual net-energy flow from new onshore-wind projects from a $100bn outlay – 67TWh from 47GW of new capacity built for $100bn (per Figure 7) – and dividing this by 2,660TWh: 67/2,660 = 2.5%.

  We then take the $100bn outlay and divide this by 2.5%: $100bn/2.5%= **$3,970trn** from **1,873GW** of implied new capacity

- For new offshore wind projects using the same methodology = **$3,546trn** for **940GW** of implied new capacity

- For new solar-PV projects using the same methodology = **$3,970trn** for **2,985GW** of implied new capacity

In short, to get the same amount of mobility from gasoline as from new renewables in tandem with EVs over the next 25 years, it would cost 6.2x-7x more. Indeed, even if we add in on top of this the cost of building new network infrastructure – i.e. enhancements to the transmission and distribution networks to cope with the extra volumes of power generated from all the new wind and/or solar capacity implied by replacing gasoline with renewables and EVs – the economics of renewables still crush those of oil.

Figure 9 assumes an extra 30% of expenditure on top of the cost of building and operating the new generation capacity required to produce 2,660TWh of useful energy every year for the next 25 years. We take this 30% figure from the numbers in the New Energy Outlook 2019 (NEO 2019) published by Bloomberg New Energy Finance (BNEF) earlier this month.[18]

On this basis, and making the completely unrealistic assumption that no maintenance capex would be required for the upkeep of the global oil and gasoline infrastructure over the next 25 years, the total outlay on oil for gasoline over 25 years would still be 5.4x-6x higher than would be the outlay for new renewables projects. And that is before we even start to think about the cost of the externalities of burning oil.

17. Again, all these numbers are premised on our assumptions on the economics of renewables in tandem with EVs, as set out in detail in n Section 2 below.

18. The full report is only available to BNEF subscribers, but the summary findings are available at: https://about.bnef.com/new-energy-outlook/. The NEO 2019 projects a massive increase in renewable capacity out to 2050 (p. 88-89) that solar-PV capacity at utility scale could increase by 5,000GW by 2050, and wind capacity (onshore and offshore combined) by 3,800GW. However, the NEO 2019 also states (p. 175) that of the $10.3trn in capital expenditure on networks it projects out to 2050, only 30% is for incremental capacity associated with the very large projected build-out of new renewables capacity, the rest being for 'replacement and refurbishment of grid infrastructure that reaches the end of its lifetime'. We would also note that our assumptions regarding the cost of new build for wind and solar are more conservative than those of BNEF, as explained in Section 2 below.

Figure 9: **Total outlay required to purchase useful-energy flow (mobility) of 2,660TWh per year over 25 years, oil for gasoline LDVs versus new renewables projects in tandem with EVs (TWh)**

ENERGY AND TECHNOLOGY SOURCES FOR FUEL AND TRANSPORT	OUTLAY OVER 25 YEARS FOR NET ANNUAL ENERGY FLOW OF 2,660TWH	NETWORK UPGRADES REQUIRED FOR EXTRA RENEWABLES CAPACITY	TOTAL OUTLAY OVER 25 YEARS FOR NET ANNUAL ENERGY FLOW OF 2,660TWH	TOTAL OUTLAY ON OIL AS A MULTIPLE OF NEW RENEWABLES PROJECTS
Oil for gasoline for LDVs	$24.6trn	n/a	$24.6trn	1x
Onshore wind w/EVs	$3.97trn	$1,19trn	$5.16trn	4.8x
Offshore wind w/EVs	$3,55trn	$1,06trn	$4.61trn	5.3x
Solar-PV w/EVs	$3.97trn	$1,19trn	$5.16trn	4.8x

Source: BNP Paribas Asset Management.

In short, the economics of renewables in tandem with EVs as a competitor to oil as a road-transportation fuel are becoming irresistible. The implications for both policy-makers and the oil majors are very far-reaching.

- 1.4 -

IMPLICATIONS FOR POLICYMAKERS AND OIL COMPANIES

With the economics of road transportation already moving so dramatically in favour of renewables in tandem with EVs, once the other advantages of renewables and EVs over oil as a road-transportation fuel are factored in the case for accelerating the roll-out of renewables capacity becomes unanswerable. These other advantages are:

(i) the environmental benefits in terms of climate change and cleaner air
(ii) the public-health benefits that flow from this
(iii) the fact that electricity is much easier to transport than oil
(iv) the much greater price stability of wind- and solar-generated electricity compared with the price volatility of oil

We think that the implications of all this for both policy-makers and the oil majors are clear and compelling.

For policymakers, the economics of renewables are such now that there is a chance to accelerate the energy transition and the environmental and health benefits that come with it by providing targeted support to:

- EVs, via tax incentives (as has proven very successful in Norway, for example)
- Charging infrastructure for EVs (the lack of charging infrastructure is a big obstacle to the faster adoption of EVs)
- Energy-storage technologies (as renewables increase their share of overall power generation, storage capacity will be the key to enabling continuing increases in renewables capacity)

The point in all of this is that the annual expenditure on oil for gasoline – and for much of the mobility provided by diesel as well, as explained in Section 1.5 below – is an opportunity cost to society as a whole. On our numbers shown in Figure 8 the size of that opportunity cost is $24trn over the next 25 years on gasoline alone even before we take account of the cost of environmental externalities and the public-health costs.

For the oil majors, the challenge is on a scale that they have never faced before, and business-as-usual is simply not an option. With gasoline and diesel demand for vehicle segments at risk of competition from EVs accounting for 36% of global oil demand, and power generation for a further 5%, our analysis implies that investing in new oil projects with break-even costs of $20/bbl or higher will put up to 40% of future annual output from new projects sanctioned today at risk of stranding over the long term.

The risk of partial asset stranding on new projects sanctioned today arises from the long lead times between the FID and initial production (five to ten years), and the fact that projects then produce their oil over a number of years. It follows that the longer the projected production profile of a given new project sanctioned today, and the higher its break-even cost, the greater the risk that it will face having to sell an ever-increasing share of its annual output at prices below its full cost of production in the latter years of its producing lifetime.

- 1.5 -

EROCI PUTS 40% OF LONG-TERM OIL DEMAND AT RISK >$20/BBL

With gasoline demand for cars and other LDVs accounting for 24% of global oil demand, and diesel for cars and other LDVs for 3% (Figure 10), this poses a very serious strategic challenge to the oil-and-gas industry: 27% of global oil demand today is accounted for by uses that risk being rendered obsolete once wind and solar reach sufficient global scale, and EVs reach sufficient global penetration (the dark green segments in Figure 10).

But in fact it is even worse than that for oil. With light and mid-heavy road transportation also susceptible to electrification (9% of global oil demand), and with power generation from wind and solar already much cheaper than from oil (another 5%), this is a tremor portending an earthquake for the oil-and-gas industry: 40% of global oil demand today is accounted for by uses that will not make any economic sense once wind and solar reach sufficient global scale and cost-competitive batteries accelerate the penetration rate of EVs (Figure 11, the dark green segments).

Moreover, our analysis of the economics today does not capture the likely continuing and dramatic cost reductions in wind and solar and EV batteries over the next decade, meaning that the same analysis in a few years' time will likely bring the oil-price range required to be competitive with wind and solar as a fuel for LDVs into single figures, all else being equal.

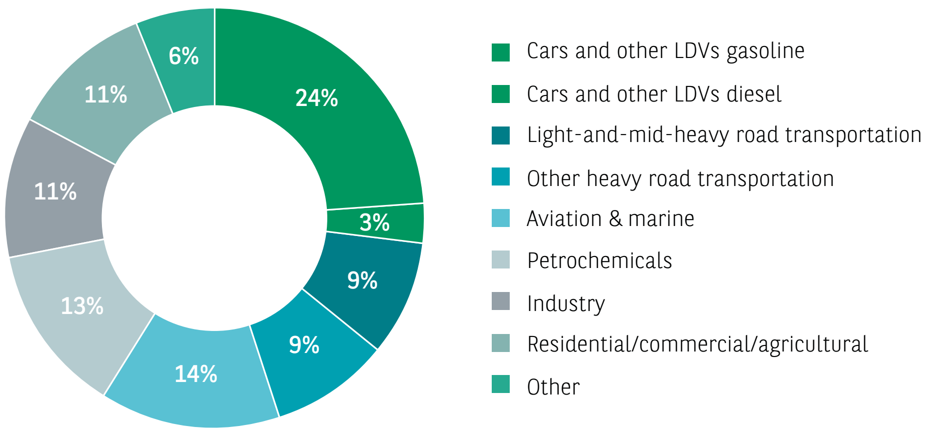
The energy-transition specialists BNEF and DNV GL (DNV) both expect EVs to reach a series of inflection points from 2022 onwards.

In its Electric Vehicle Outlook 2019 published in May 2019,[19] BNEF states (p. 15):

> *"As in our previous forecasts, we expect price parity between EVs and internal combustion vehicles by the mid-2020s in most segments,* ***though the first segment crosses by 2022*** *and there is a wide variation between geographies and vehicle segments. Until this is reached, policy support will be required in most markets."* (Our emphasis)

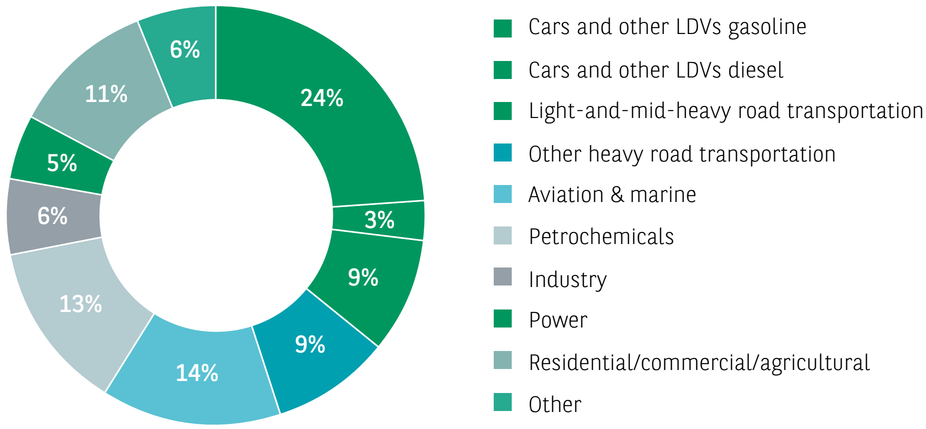
19. The full version of the BNEF Electric Vehicle Outlook 2019 is only available to subscribers, but a summary version of the report can be found at: https://about.bnef.com/electric-vehicle-outlook/#toc-viewreport.

Figure 10: Breakdown of global oil demand, 2018



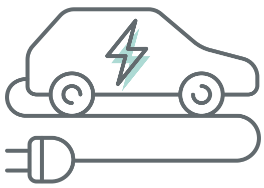
Source: Deutsche Bank, Wood MacKenzie.

Figure 11: Breakdown of global oil demand, 2018



Source: Deutsche Bank, Wood MacKenzie.

For its part, in its Energy Transition Outlook 2018 published in November 2018,[20] DNV states (p. 113):



"Supported by a multitude of sources, we expect EVs to reach cost parity with conventional light vehicles (based on full lifecycle costs, including fuel and maintenance) in 2024. Key questions at present concern the extent to which charging infrastructure can keep up, whether range restrictions of EVs influence buyer preferences as the average range improves, and what local and national policies will be applied to increase uptake in the short term. ***These initial factors will, however, rapidly pale into insignificance once EVs break through the cost-parity level.*** *The effect of cost reduction will be felt evenly across the world but charging infrastructure will be rolled out at varying speeds across world regions."* (Our emphasis)

20. The DNV study is available at: https://eto.dnvgl.com/2018/#Energy-Transition-Outlook-2018-.

In short, on the most generous reading the oil industry will, for the first time ever, have to cope with the concept of the price elasticity of demand for 40% of its production; on the most dramatic reading, it is only a matter of time before the economics of renewables and EVs overwhelm oil and displace up to 40% of its current demand.

This means that both the majors and the national oil companies (NOCS) are effectively in a race against time.

For the majors in particular, with an average reserves-to-production (R/P) ratio of 10 years, the risk is that the longer they continue investing to replace reserves on a barrel-for-barrel basis the greater the risk that they will end up with stranded assets for a portion of every dollar they invest in new projects.

Over the long term, up to 24% of future annual output from new projects sanctioned today with a break-even cost above $10/bbl will face long-term partial stranding risk (24% of current demand per barrel of oil sold globally is for gasoline), with a further 12% of future annual output from new projects sanctioned today at risk of partial long-term stranding above a break-even cost of $20/bbl (12% of current demand per barrel of oil sold globally is for diesel vehicles susceptible to competition from EVs).

There are two reasons for this:

- First, by the time those new projects start producing oil five to ten years from now the demand for up to 36% of each future barrel of production will be under much greater threat from ever more competitive wind-powered and solar-powered electricity in tandem with – by that time – price-competitive EVs.

  Of course, and as both BNEF and DNV emphasize, cost parity with ICE and diesel vehicles is not the only driver of EV adoption, and other factors – most importantly, the lack of sufficient charging infrastructure and the fact that the global vehicle fleet takes about 15 years to turn over – mean that in practice EVs will not fully displace ICE and diesel LDVs and light-heavy and mid-heavy vehicles for at least two decades.[21]

  As a result, for new oil projects on which the FIDs are taken today and for which production starts five to ten years down the line, we are not arguing that up to 40% of their output could be stranded as soon as they start producing.

  Rather, we are suggesting that by the late 2020s EV penetration rates will likely already have reached the point at which a fraction of each barrel produced by new projects sanctioned today might only be competitive at a price below their full cost of production, and that this portion will rise over the lifetime of these projects as the penetration rate of EVs increases.

- Second, the changing relative economics of oil versus renewables mean that the strategy of the NOCs – i.e. the companies that hold the largest reserves of the word's cheapest remaining oil – might also now start to change.

In other words, the oil majors could face a double competitive squeeze on their business model over the next decade:

1. on the demand side, up to 36% of the barrels they have traditionally produced will be at long-term risk of disintermediation from EVs;

2. on the supply side, and in direct response to this very same demand risk, NOCs might decide to ramp up production of cheap oil so as to remain competitive with the 36% of current demand that will be increasingly vulnerable to competition from wind- and solar-powered EVs over the longer term.

21. DNV's Energy Transition Outlook 2018 (p. 114) states that 'with an average vehicle lifetime of 10 to 18 years, depending on the region, it will take two or more decades to phase out combustion vehicles entirely'.

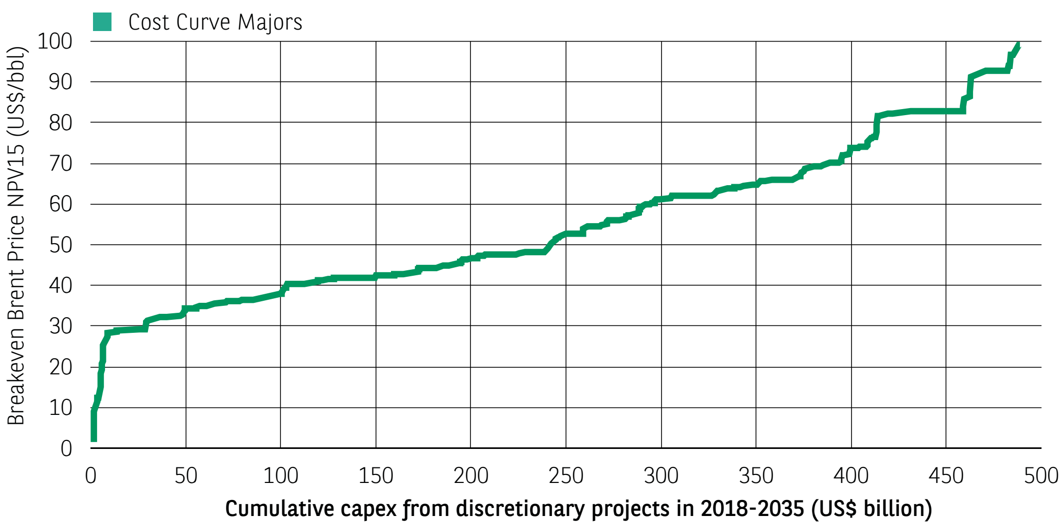
It follows that the longer the projected production profile of a given new project sanctioned today, and the higher its break-even cost, the greater the risk that it will face having to sell up to 36% of its output at prices below its full cost of production in the latter years of its producing lifetime. For a given new project sanctioned today that date could be 2035 or 2040 or later. The key point, though, is that whatever the risk a given new project sanctioned today faces of seeing up to 36% of its output stranded in its latter years, the economics of oil as a fuel for ICE and diesel vehicles versus wind- and solar-powered EVs are now in relentless and irreversible decline.

In short, with 36% of demand for crude oil today accounted for by LDVs, and a further 5% from power generation, the oil industry has never before in its history faced the kind of threat that renewable electricity in tandem with EVs poses to its business model: a competing fuel source that (i) has a short-run marginal cost (SRMC) of zero, (ii) is much cleaner environmentally, (iii) is much easier to transport, and (iv) could readily replace up to 40% of global oil demand if it had the necessary scale.

Or, to put it another way: if wind and solar already had the necessary scale and EVs were already cost-competitive with ICE and diesel vehicles, 40% of today's oil supply would have to be produced at the lower end of the industry cost curve – $20/bbl or less – in order to be competitive. Yet Wood MacKenzie estimates that collectively, the seven western oil majors – Exxon, Chevron, Shell, BP, Total, ENI, and Equinor – have very few opportunities for new projects at break-even levels of $20/bbl.

As shown in Figure 12, of the $500bn in discretionary capex – i.e. capex prior to FID – in Wood MacKenzie's database over 2018-35 for these companies, only $25bn (5%) is at break-evens of $30/bbl or less. Indeed, even at 40/bbl or less the majors' collective pre-FID opportunities amount to only $100bn of capex, with $400bn above this level, and $250bn requiring break-evens of $50/bbl or more.

Figure 12: Collective pre-FID capex break-evens for seven oil majors,* 2018-35



Source: Deutsche Bank, Wood MacKenzie. *Exxon, Chevron, Royal Dutch Shell, BP, Total, ENI, Equinor.

In our view, this should be an extremely alarming prospect for the oil majors. Accordingly, we think the oil majors should be accelerating the deployment of capital into renewable-energy and energy-storage technologies and/or reducing re-investment risk via higher dividend payouts to shareholders (especially the case for those with pre-FID projects at the upper end of the industry cost curve).

And if all of this sounds far-fetched, then the speed with which the competitive landscape of the European utility industry has been reshaped over the last decade by the rollout of wind and solar power – and the billions of euros of fossil-fuel generation assets that this has stranded – should be a flashing red light on the oil majors' dashboard.[22]

22. For more on what the oil-and-gas industry can learn from the experience of the European utility sector over the last decade, see the report by Carbon Tracker, *Lessons from European Electricity for Global Oil & Gas,* 20 December 2018, available at: https://www.carbontracker.org/reports/lessons-from-european-electricity-for-global-oil-gas/.

2 METHODOLOGY AND KEY MODELLING ASSUMPTIONS

Our approach to analyzing the EROCI of oil versus renewables on a full-cost basis goes through three stages and we make numerous assumptions at each stage of the analysis that are by their nature somewhat stylized. Below we set out our three-stage methodology and the key assumptions we make in our analysis.

- 2.1 -

METHODOLOGY: FROM GROSS POTENTIAL EROCI TO NET EROCI

We build out our EROCI analysis in three stages.

First, we look at the gross potential energy that a $100bn outlay on oil on the one hand, and new wind and solar projects on the other, would yield. By gross potential energy we mean how much energy $100bn would potentially yield if we did not have to worry about the cost of transporting it to the end consumer or the energy losses that occur along the way, either in the form of refining it (in the case of gasoline) or transporting it over high-voltage and low-voltage networks (in the case of renewables). Gross potential energy is therefore the amount of energy inherent in so many barrels of oil, or in so much power-generation capacity at a given assumed load factor.

Second, we then take in to account the costs and energy losses incurred in the conversion of crude oil into gasoline and diesel and its transportation to the pump and compare this with the costs and energy losses incurred in the transportation of wind- and solar-generated electricity to the charging point. On this basis we derive the gross energy yield at the pump or charging point.

Third, we then account for the energy losses in the vehicle itself. For all of the fuels we are looking at here – gasoline, diesel, and electricity from new onshore-wind, offshore-wind, and solar-PV projects – there are energy losses between the pump or charging point on the one hand, and the wheels on the other, but the losses are much greater for gasoline and diesel engines than they are for the batteries in EVs.

- 2.2 -

KEY ASSUMPTIONS FOR OIL AND FOR GASOLINE AND DIESEL ENGINES

How much useful energy our $100bn outlay on oil on the spot market will procure is a function of three things:

1. The assumed price of oil.

2. The breakdown of the expenditure on purchasing the oil itself, refining it, and then transporting it to the end consumer at the pump, while also taking account of the taxes incurred along the value chain.

3. The energy losses that occur along the way. For oil, the energy losses are of two main kinds: (i) energy losses at the refinery for gasoline (a barrel of gasoline contains ~10% less energy per barrel than crude oil, while diesel has almost exactly the same energy content as crude oil per barrel);[23] (ii) energy losses in gasoline and diesel engines.

23. We have taken our numbers for the energy content per barrel for crude oil, gasoline, and diesel from the website of the US Government's Energy Information Administration at: https://www.eia.gov/energyexplained/index.php?page=about_energy_units. The EIA gives the energy content of US produced crude oil as 5.719 million British thermal units (mBtu), and of imported crude oil as 6.063mBtu, which gives an average of 5.891mBtu per barrel of crude oil. For gasoline, the EIA number for energy content is 5.057mBtu, and for diesel 5.778mBtu.

For the price of oil, we take the average of the Brent and WTI benchmarks so far in 2019, which comes to $60/bbl. However, as we go through each stage of our EROCI analysis we look at a range of different oil prices, from $25/bbl all the way up to $100/bbl, before then deriving the prices at which we calculate crude oil would have to trade to yield the same amount of useful energy for gasoline and diesel for a $100bn outlay as would the same outlay on new wind and solar projects with the electricity used to power EVs.

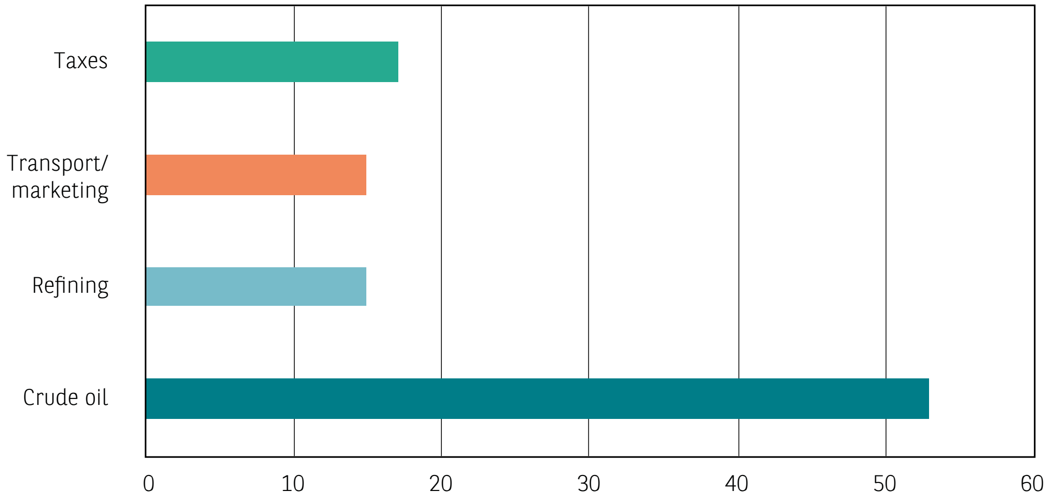
In terms of the breakdown of expenditure, we work backwards from the cost to the end-consumer at the pump. In other words, in order to deliver the gasoline or diesel to the pump, we ask how much of our notional $100bn we could spend on the crude oil itself, and how much would have to be spent to cover the costs of refining and transporting the oil to the end user, while also allowing for the taxes payable across the value chain. Looking again at the EIA's webpage on prices at the pump for gasoline and diesel, we derive the breakdown shown in Figure 13.[24]

In other words, we assume that of the $100bn outlay, only $53bn is spend on the crude oil itself, while the rest is accounted for by the various other costs that need to be covered to get the oil to the end-consumer as either gasoline or diesel.

In terms of the energy losses, we assume that gasoline has 10% less energy than crude oil, but that diesel has the same energy content as crude oil. This means that in terms of the gross energy at the pump, there is 10% less available for a gasoline engine than for a diesel engine.

Finally, we then have to account for the energy losses in the combustion process in gasoline-ICE and diesel engines. For gasoline engines, we assume a thermal-efficiency rate of 20%, while for diesel engines we assume a thermal-efficiency rate of 35%. Of course, these are stylized assumptions as in reality efficiency rates will vary between different engines, but we think these are reasonable estimates for the generic efficiency of the gasoline engine and diesel engines that comprise the world's existing vehicle fleet today.[25]

Figure 13: Breakdown of cost of gasoline and diesel at the pump



Source: US Energy Information Administration, BNP Paribas Asset Management estimates.

24. See the EIA website at https://www.eia.gov/petroleum/gasdiesel/. The most recent EIA data for May 2019 shows that for gasoline 54% of the end-user price for gasoline is accounted for by the crude oil, and for diesel 49%. We take 53% as an average of these two numbers given the greater weighting of gasoline in overall LDV consumption.

25. We take these numbers from: https://rentar.com/efficient-engines-thermodynamics-combustion-efficiency/. The BNEF Electric Vehicle Outlook 2019 cited above estimates that the efficiency of gasoline engines has the potential for a 25% improvement by 2050, but since there is also scope for EV motors to improve their efficiency – and for the costs of both renewable electricity generation and EVs to fall further – we base our analysis on the numbers today. Moreover, the average efficiency of gasoline engines on the road today is probably below 20% given the number of old models still on the road.

What this means is that on our calculations 80% of the gross energy available at the pump as gasoline is lost in a gasoline engine and so does not provide useful or mechanical energy at the wheels, while for diesel on our numbers 65% of the gross energy at the pump is lost.

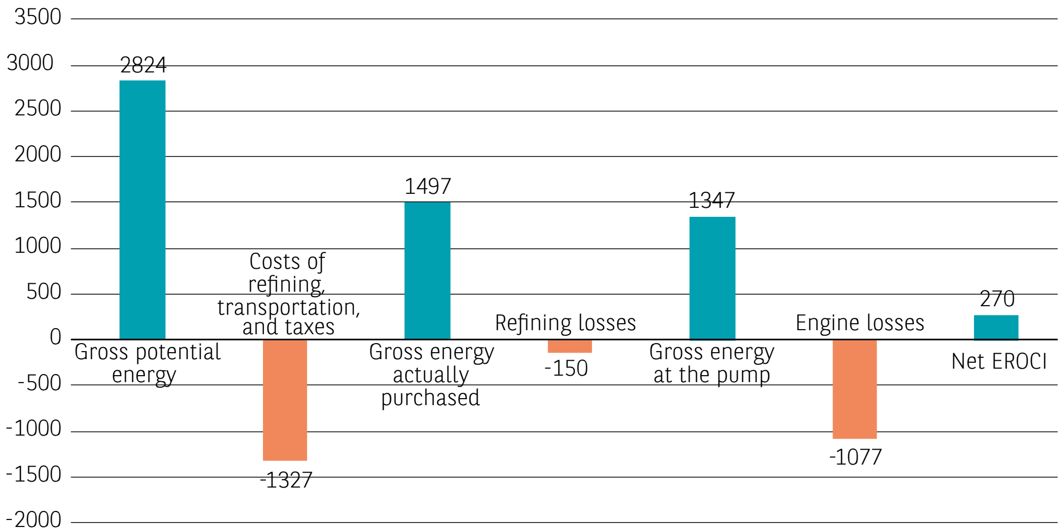
Figure 14 and Figure 15 then show the full three-step approach of our analysis for gasoline and diesel respectively that we use to derive our net-EROCI numbers. For gasoline, we start with the gross potential energy that we would get if we were able to spend the full $100bn on crude oil. At $60/bbl this would equate to 1.67bn barrels of oil, which equates to 2,824TWh.

However, we then have to factor in the costs of refining, transporting, and taxing the oil, and on our assumption that these costs will take up 47% of the total outlay, this leaves us with 53% of the gross potential energy as the gross energy actually purchased. This would equate to 883m barrels of oil, which in turn equates to 1,497TWh.

After accounting for the energy losses in refining gasoline, we have 1,347TWh of gross energy available at the pump, and then after taking in to account the energy losses in the gasoline-ICE, we end up with 270TWh of useful energy.

This means that the net energy available to do useful work at the wheels for an LDV with a gasoline-powered ICE is equivalent to only 10% of the gross potential energy inherent in $100bn worth of crude oil at $60/bbl.

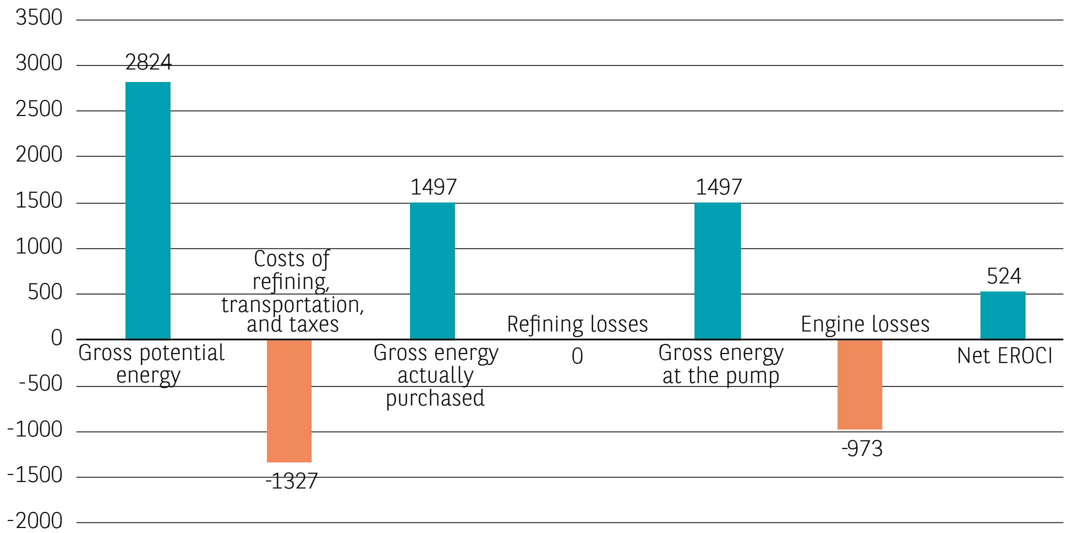
Figure 14: Derivation of net EROCI for $100bn spent on oil for gasoline at $60/bbl (TWh)



Source: US Energy Information Administration, BNP Paribas Asset Management estimates.

For diesel, we again start with the gross potential energy that we would get if we were able to spend the full $100bn on crude oil (2,824TWh), and with no energy losses at the refinery this gives us a gross energy at the pump for diesel after factoring in the costs of refining, transporting, and taxing the oil of 1,497TWh.

Figure 15: Derivation of net EROCI for $100bn spent on oil for diesel at $60/bbl (TWh)



Source: US Energy Information Administration, BNP Paribas Asset Management estimates.

After then taking in to account the energy losses in the diesel engine at our assumed thermal-efficiency rate of 35%, we finish with 524TWh of useful mechanical energy.

This means that the net energy available to do useful work at the wheels for a diesel-powered LDV is equivalent to only 19% of the gross potential energy inherent in $100bn worth of crude oil at $60/bbl.

- 2.3 -

KEY ASSUMPTIONS FOR NEW WIND AND SOLAR PROJECTS AND EVS

How much useful energy our $100bn outlay on new wind and solar projects will procure is a function of three things:

1. The assumed cost of building and operating new onshore-wind, offshore-wind, and solar-PV projects. This encompasses the upfront capital costs, the operating costs over the lifetime of the projects, the assumed cost of capital, assumed load factor, and assumed operating life.

2. The breakdown of the expenditure on building and operating these projects over their lifetime, and then transporting the electricity generated to the charging station.

3. The energy losses that occur along the way. The energy losses are of two main kinds: (i) energy losses as the power is transported across the networks; (ii) energy losses in charging the battery in an EV and converting it into chemical energy and then back into the electrical energy that provides the useful work at the wheels.

For the cost of building and running new wind and solar projects, we set out our key assumptions in Figure 16, while Figure 17 then shows the outputs from these assumptions after also factoring in transportation costs.

Figure 16: Key modelling assumptions for new wind and solar projects

TECHNOLOGY	ASSUMED COST TO BUILD	CAPITAL COSTS	OPERATING COSTS	ASSUMED LOAD FACTOR	ASSUMED COST OF CAPITAL	ASSUMED OPERATING LIFE
Onshore wind	$1.2bn/GW	80%	20%	25%	6%	25 years
Offshore wind	$1.8bn/GW	70%	30%	50%	10%	25 years
Solar-PV	$0.8bn/GW	85%	15%	15%	6%	25 years

Source: Exane BNP Paribas, Credit Suisse, BNP Paribas Asset Management.

As can be seen in Figure 16, the capital costs are by far the largest component for all three of our renewable energies, accounting for 80% of the total lifetime costs for new onshore-wind projects, 70% for new offshore-wind projects, and 85% for new solar-PV projects.

We assume a cost of capital of 6% for new onshore-wind and solar-PV projects, but a higher 10% for new offshore-wind projects as we regard these as riskier.

Figure 17: Key modelling assumptions for new wind and solar projects

TECHNOLOGY	AMOUNT OF CAPACITY BUILT WITH $100BN	GROSS LIFETIME OUTPUT*	NET LIFETIME EROCI**	BREAK-EVEN POWER PRICE
Onshore wind	47GW	2,583TWh	1,673TWh	$60/MWh
Offshore wind	27GW	2,903TWh	1,881TWh	$70/MWh
Solar-PV	75GW	2,437Wh	1,667Wh	$65/MWh

Source: Exane BNP Paribas, Credit Suisse, BNP Paribas Asset Management. *Gross lifetime output is the amount of power generated over 25 years before transportation and energy-conversion losses. Net lifetime EROCI is the total amount of useful energy provided at the wheels of EVs over 25 years.

On these assumptions we derive break-even costs for new onshore-wind, offshore-wind, and solar-PV projects of $60/MWh, $70/MWh, and $65/MWh respectively.[26] For the capacity factors, we assume 25% and 50% for onshore- and offshore-wind respectively, and 15% for solar-PV.[27] Finally, for the motor in EVs we assume an overall efficiency rate of ~70%, which breaks down as ~80% charging efficiency and ~90% electric-propulsion efficiency.[28]

Figures 18-20 then show how we derive the net-energy yield for $100 billion spent on new onshore- and offshore-wind and solar-PV projects from the starting point of the gross potential energy inherent in building new capacity with a $100bn outlay.

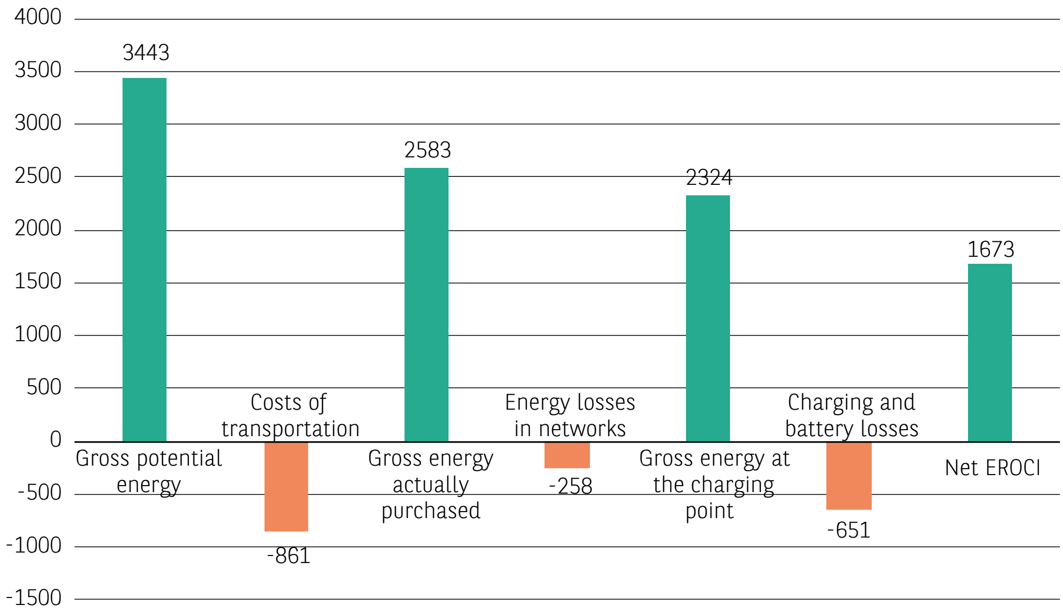
26. The latest study by Bloomberg New Energy Finance (BNEF) of the break-even costs for new onshore-wind, offshore-wind, and solar-PV projects – commonly referred to as the levelized cost of electricity (LCOE) – gives the following numbers: global average LCOE for onshore wind of $50/MWh, for offshore wind of $95/MWh, and for solar-PV of $57/MWh. The BNEF study was published in March 2019, with the full version only available to subscribers but the summary available at: https://about.bnef.com/blog/battery-powers-latest-plunge-costs-threatens-coal-gas/. In short, BNEF's average global new-build costs are already lower than the costs we are assuming for onshore wind and solar-PV, and while the BNEF number for offshore wind is higher than ours we would note that the latest costs in northern Europe are well below the $70/MWh that we are assuming: the most recently awarded offshore-wind project in Europe was the Dunkirk project won by a consortium for a long-term offtake price of "well below €50/MWh" (see the Reuters story of 14 June 2019: https://www.reuters.com/article/france-renewables-dunkirk/update-1-edf-consortium-wins-600-mw-dunkirk-offshore-wind-project-idUSL8N23L2MV).
27. We base our solar capacity factor of 15% on our estimate of the average global capacity factor for solar-PV in 2018. The *BP Statistical Review of World Energy 2019* cited above gives 2018 solar-PV output of 585TWh, while the IEA's *2019 A Snapshot of Global PV* (available at http://www.iea-pvps.org/index.php?id=266) shows that in 2018 global solar-PV capacity averaged 450GW.
28. This is based on the following source: https://insideevs.com/news/332584/efficiency-compared-battery-electric-73-hydrogen-22-ice-13/.

2.3.1 ONSHORE WIND: FROM GROSS POTENTIAL ENERGY TO NET EROCI

For new onshore wind (Figure 18), our starting point, as it was with oil, is the gross potential energy from a $100bn investment assuming no transportation costs or energy losses. On this basis, we would be able to spend $100bn on the capital and operating costs of the project, and as per Figure 16 above this would allow for $80bn to be spend on the new capacity itself – requiring a return of 6% – and $20bn on the lifetime operating costs.

At our assumed capital cost of $1.2bn/GW, this would give 63GW of new capacity – i.e. $80bn/($1.2bn*1.06) – and at our assumed load factor of 25% this would give 138TWh of annual output and 3,443TWh of lifetime output over 25 years.

Figure 18: Derivation of net EROCI for $100bn spent on new onshore-wind projects (TWh)



Source: Exane BNP Paribas, Credit Suisse, BNP Paribas Asset Management.

However, we then have to factor in the costs of transporting the energy to the end-consumer at the charging point, and we assume that this would account for 25% of the total outlay. This means we have to take $25bn off the $80bn we initially assumed as being available for investing in new projects, which means that we end up with 47GW of new capacity – i.e. ($75bn*0.8)/($1.2bn*1.06) – which on our assumed load factor of 25% gives us 2,583TWh of gross energy actually purchased.

After accounting for energy losses over the transmission and distribution networks of 10%, we have 2,324TWh of gross energy available at the charging point.

Finally, after taking in to account the energy losses in charging the battery and converting the energy in the motor (~30%), we end up with 1,673TWh of useful energy from our $100bn outlay.

This means that the net energy available to do useful work at the wheels for an EV powered by onshore wind is equivalent to 50% of the gross potential energy inherent in $100bn worth of new onshore-wind projects at a capital cost of $1.2bn/GW.

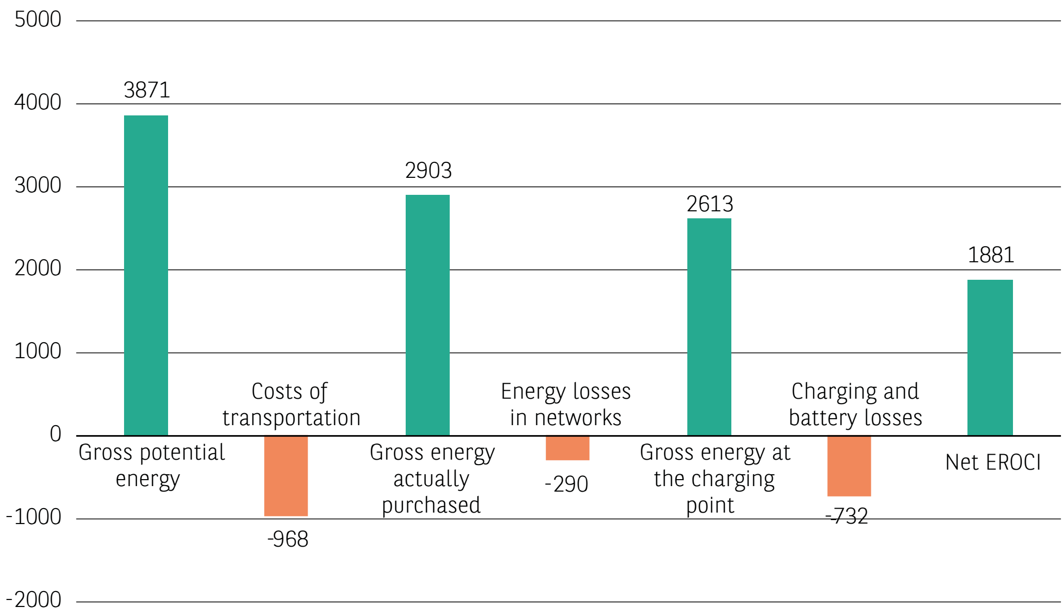
2.3.2 OFFSHORE WIND: FROM GROSS POTENTIAL ENERGY TO NET EROCI

For new offshore wind (Figure 19) our starting point again is the gross potential energy from a $100bn investment assuming no transportation costs or energy losses. On this basis, we would be able to spend $100bn on the capital and operating costs of the project, and as per Figure 10 this would allow for $70bn to be spend on the new capacity itself – requiring a return of 10% – and $30bn on the lifetime operating costs.

At our assumed capital cost of $1.8bn/GW, this would give 35GW of new capacity – i.e. $70bn/($1.8bn*1.10) – and at our assumed load factor of 50% this would give 155TWh of annual output and 3,871TWh of lifetime output over 25 years.

Again, though, we then have to factor in the costs of transporting the energy to the end-consumer at the charging point, and again we assume that this would account for 25% of the total outlay. This means we have to take $25bn off the $70bn we initially assumed as being available for the capital investment in new generation capacity, which means that we end up with 27GW of new capacity – i.e. ($75bn*0.7)/($1.8bn*1.10) – which on our assumed load factor of 50% gives us 2,903TWh of gross energy actually purchased.

Figure 19: **Derivation of net EROCI for $100bn spent on new offshore-wind projects (TWh)**



Source: Exane BNP Paribas, Credit Suisse, BNP Paribas Asset Management.

After accounting for energy losses over the transmission and distribution networks of 10%, we then have 2,613TWh of gross energy available at the charging point.

Finally, after taking in to account the energy losses in charging the battery and converting the energy in the motor (~30%), we end up with 1,881TWh of useful energy from our $100bn outlay.

This means that the net energy available to do useful work at the wheels for an EV powered by offshore wind – as with onshore wind –is equivalent to 50% of the gross potential energy inherent in $100bn worth of new offshore-wind projects at a capital cost of $1.8bn/GW.

2.3.3 SOLAR-PV: FROM GROSS POTENTIAL ENERGY TO NET EROCI

For new solar-PV (Figure 20), our starting point is again the gross potential energy from a $100bn investment assuming no transportation costs or energy losses. On this basis, we would be able to spend $100bn on the capital and operating costs of the project, and as per Figure 20 this would allow for 85bn to be spend on the new capacity itself – requiring a return of 6% – and $15bn on the lifetime operating costs.

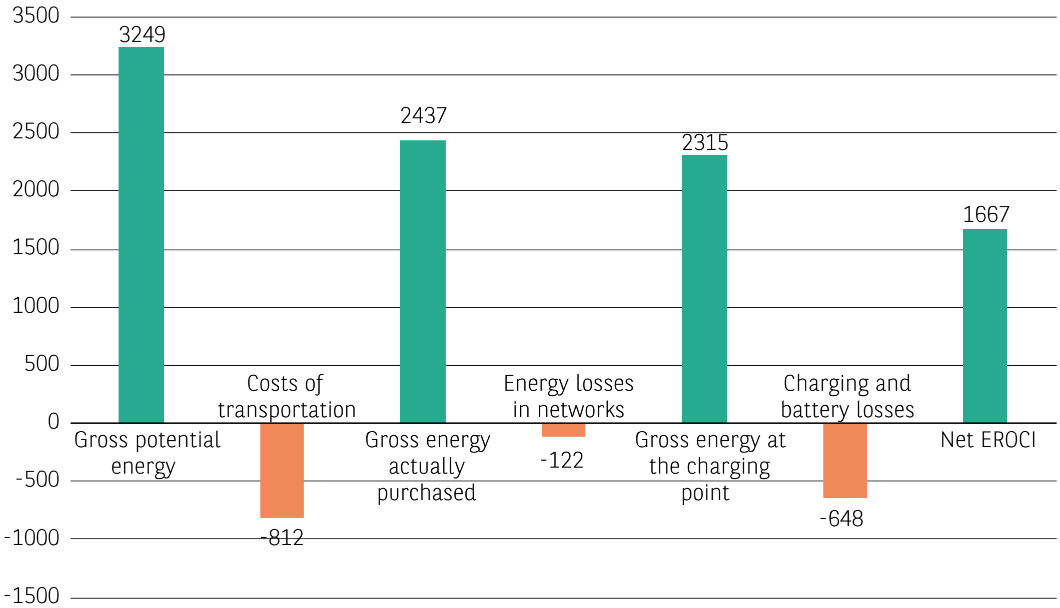
At our assumed capital cost of $0.8bn/GW, this would give 100GW of new capacity – i.e. $85bn/($0.8bn*1.06) – and at our assumed load factor of 15% this would give 103TWh of annual output and 3,249TWh of lifetime output over 25 years.

Again, though, in the real world we then have to factor in the costs of transporting the energy to the end-consumer at the charging point, and again we assume that this would account for 25% of the total outlay.

This means we have to take $25bn off the $85bn we initially assumed as being available for the capital investment in new generation capacity, which means that we end up with 75GW of new capacity – i.e. ($75bn*0.85)/($0.8bn*1.06) – which on our assumed load factor of 15% gives us 2,437TWh of gross energy actually purchased.

After accounting for energy losses over the transmission and distribution networks of a lower 5% (we think it reasonable to assume that more of the new solar capacity would be embedded capacity than would be the case for onshore and offshore wind), we then have 2,315TWh of gross energy available at the charging point.

Figure 20: Derivation of net EROCI for $100bn spent on new solar-PV projects (TWh)



Source: Exane BNP Paribas, Credit Suisse, BNP Paribas Asset Management.

Finally, after taking in to account the energy losses in charging the battery and converting the energy in the motor (~30%), we end up with 1,667TWh of useful mechanical energy from our $100bn outlay.

This means that the net energy available to do useful work at the wheels for a solar-powered EV is equivalent to 50% of the gross potential energy inherent in $100bn worth of new solar projects at a capital cost of $0.8bn/GW.

3 GROSS EROCI: OIL V RENEWABLES

In this section we show how much gross energy can be purchased with an outlay of $100bn on oil and on new wind and solar projects, and how much gross energy can then be delivered to the end consumer at the pump or charging point. Our calculations for oil assume that the $100bn is spent buying barrels of oil on the spot market, while for wind and solar we take into account the cost of building new projects, and the operating costs incurred in running those projects, over the course of their lifetimes. For all three of the renewables projects we look at here – onshore wind, offshore wind, and solar-PV – we assume an operating life of 25 years.

- 3.1 -

GROSS POTENTIAL EROCI VERSUS GROSS EROCI AT THE PUMP OR CHARGING POINT

We begin by looking at the gross potential energy that $100bn could buy if spent on oil or new wind and solar projects. This is the amount of energy that $100bn would purchase if we did not have to worry about the practical realities of transporting the energy to the end-consumer at the pump (for gasoline and diesel) or charging point (for EVs).

Even on a gross potential EROCI basis – i.e. before taking account of the costs and energy losses incurred in the transportation of energy to the pump or charging point – we find that oil priced at $60/bbl provides less energy for a $100bn outlay than does the same amount spent on new wind and solar projects. Indeed, even at $50/bbl oil yields less gross potential energy for a $100bn outlay than does the same sum spent on new onshore- and offshore-wind projects, while solar is close to competitive with oil at $50/bbl on this basis.

After then taking in to account the cost and energy losses incurred in the conversion of crude oil into gasoline and diesel and its transportation to the pump, and comparing this with the costs and energy losses incurred in the transportation of wind- and solar-generated electricity to the charging point, we find that our new renewables projects are even more competitive.

Compared with gasoline at the pump for the same $100bn outlay, electricity from new offshore-wind projects provide as much energy at the charging point as does gasoline at the pump with oil at $30/bbl, while new onshore-wind and solar power provide as much as gasoline with oil at $35/bbl. Versus diesel at the pump, new offshore-wind-powered electricity at the charging point is very competitive with oil at $35/bbl, while new onshore-wind and solar power provide more energy than oil at $40/bbl.

- 3.2 -

GROSS POTENTIAL EROCI: HOW MUCH GROSS POTENTIAL ENERGY DOES $100BN BUY?

If we did not have to worry about transporting oil to the refinery and converting it into gasoline or diesel and then transporting it again to the pump, how much gross potential energy would we get for a $100bn outlay at different oil prices?

Similarly, if we did not have to worry about transporting electricity from wind and solar farms to the charging point, how much gross potential energy would we get for a capital investment of $100bn?

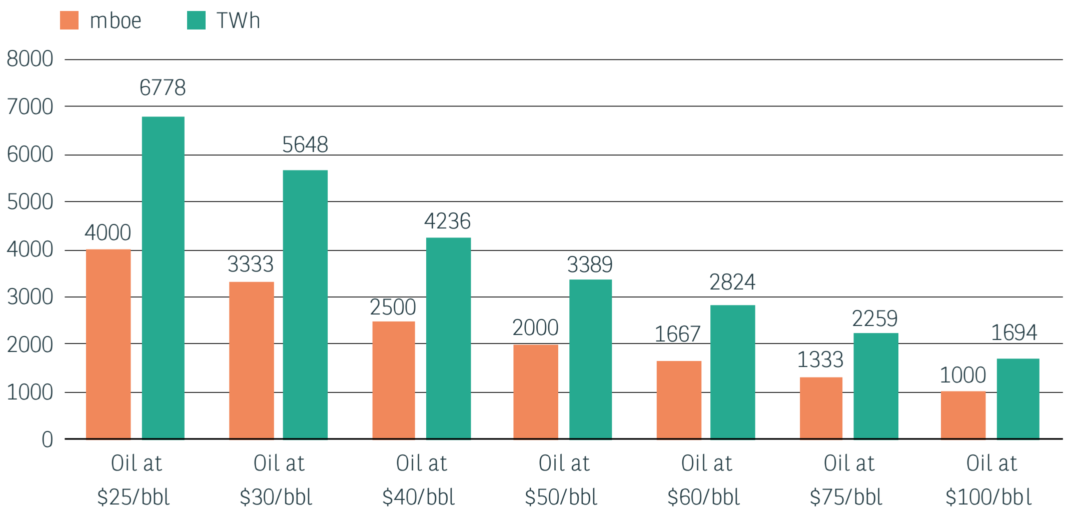
Let us look at each of our four energy sources in turn and see how they compare on this basis before then accounting for the practical matters of refining (for gasoline and diesel) and transporting these different energy sources.

3.2.1 OIL: HOW MUCH GROSS POTENTIAL ENERGY DOES $100BN BUY?

At the current Brent price of $60/bbl, a $100bn outlay would enable the purchase of 1.67bn barrels of oil. With one barrel of oil being equivalent in energy terms to 1.7MWh, this makes 1.67bn barrels of oil equivalent to 2,824TWh, and this is therefore the gross potential energy that a $100bn outlay on the spot market today would yield (Figure 21).

Figure 21 also shows the gross potential energy associated with a range of different oil prices. At $25/bbl, a $100bn outlay would purchase 4bn barrels of oil equating to 6,778TWh (oil prices last averaged $25/bbl for a whole year in 2002); at $100bbl, the same expenditure would yield 1bn barrels of oil, or 1,694TWh (Brent last averaged $100/bbl or more over the four years 2011-14).

Figure 21: Gross potential EROCI for oil at different prices



Source: BNP Paribas Asset Management estimates.

3.2.2 ONSHORE WIND: HOW MUCH GROSS POTENTIAL ENERGY FOR $100BN?

As explained in Section 2, we assume that for a new onshore-wind project with an expected operating life of 25 years, 80% of the total costs would consist of the upfront capital investment, and 20% of the operating and maintenance costs over the project's working life.

At our assumed new-build cost of $1.2bn/GW, and our assumed cost of capital for onshore wind of 6%, the $80bn available for the upfront capital investment would enable 63GW of new generation capacity to be built, i.e. $80bn/($1.2bn*1.06). At our assumed load factor of 25%, this would generate 138TWh a year – i.e. (63GW*24*365)*0.25 – and hence 3,443TWh of gross potential energy over our assumed operating life of 25 years.

3.2.3 OFFSHORE WIND: HOW MUCH GROSS POTENTIAL ENERGY FOR $100BN?

As explained in Section 2, we assume that for a new offshore-wind project with an expected operating life of 25 years, 70% of the total costs would consist of the upfront capital investment, and 30% of the operating and maintenance costs over the project's working life.

At our assumed new-build cost of $1.8bn/GW, and our assumed cost of capital for offshore wind of 10%, the $70bn available for the upfront capital investment would enable 35GW of new generation capacity to be built, i.e. $70bn/($1.8bn*1.1). At our assumed load factor of 50%, this would generate 155TWh a year – i.e. (35GW*24*365)*0.5 – and hence 3,871TWh of gross potential energy over our assumed operating life of 25 years.

3.2.4 SOLAR-PV: HOW MUCH GROSS POTENTIAL ENERGY FOR $100BN?

As explained in Section 2, we assume that for a new solar-PV project with an expected operating life of 25 years, 85% of the total costs would consist of the upfront capital investment, and only 15% of the operating and maintenance costs over the project's working life.

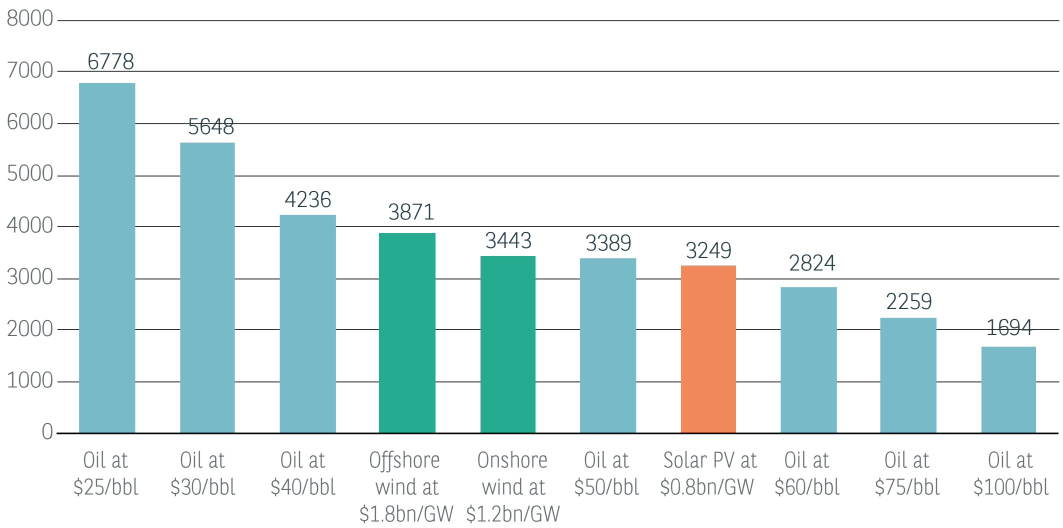
At our assumed new-build cost of $0.8bn/GW, and our assumed cost of capital for solar-PV of 6%, the $85bn available for the upfront capital investment would enable 100GW of new generation capacity to be built, i.e. $85bn/($0.8bn*1.06). At our assumed load factor of 15%, this would generate 130TWh a year – i.e. (100GW*24*365)*0.15 – and hence 3,249TWh of gross potential energy over our assumed operating life of 25 years.

3.2.5 OIL V RENEWABLES: HOW MUCH GROSS POTENTIAL ENERGY FOR $100BN?

Figure 22 shows how much gross potential energy a $100bn outlay would yield for a purchase of oil at a range of different prices, and for an investment in new wind and solar projects.

Both new offshore- and onshore-wind projects would yield more gross potential energy than oil priced at $50/bbl for an equivalent outlay of $100bn, while new solar projects would yield almost as much gross potential energy as oil priced at $50/bbl.

Figure 22: Gross potential EROCI from new renewables projects versus oil (TWh)



Source: BNP Paribas Asset Management estimates.

In reality, of course, the costs and energy losses incurred in getting oil and electricity to the end-consumer in a usable form do have to be taken into account. Accordingly, let us now account for these real-world costs and energy losses to see how this alters the amount of gross energy a $100bn outlay on our four energy sources delivers to the pump or charging point.

- 3.3 -

GROSS EROCI AT THE PUMP OR CHARGING POINT – HOW MUCH DOES $100BN BUY?

As explained in Section 2, on our assumptions for the breakdown of costs for gasoline sold at the pump (Figure 13 above),[29] only ~53% is paid for the actual energy contained in the crude oil initially.

The rest goes on refining costs (~15%), transportation (~15%), and excise taxes (~17%). Moreover, while diesel has almost exactly the same energy content per barrel as crude oil, gasoline contains 10% less energy per barrel than crude.

29. These numbers are based on end-user prices in the US and so give a more generous energy yield than would be the case in many other jurisdictions owing to the low level of US energy taxes (in the EU, for example, taxes would represent up to 75% of the end-user price at the pump).

Similarly, for electricity there is the cost of transporting the power to the end-consumer to be accounted for, and there are also energy losses incurred across the transmission and distribution networks. As explained in Section 2, we assume that transporting the electricity from new wind and solar projects to the end user will account for 25% of the total cost of getting the power to the end user.

On top of this, we assume that for solar power, 5% of the electricity generated will be lost in transportation to the end consumer, and for both onshore and offshore wind that 10% will be lost.

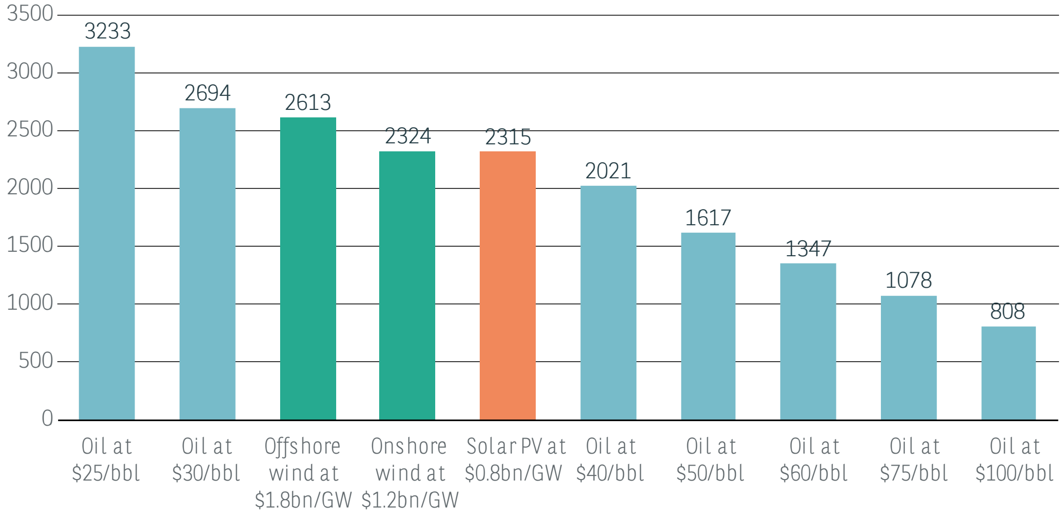
3.3.1 GASOLINE: WIND AND SOLAR COMPETITIVE WITH OIL AT $30-$35/BBL

Figure 23 shows the amount of gross energy delivered to the pump as gasoline for a $100bn outlay at different oil prices, and the amount of gross energy delivered to the charging point for a $100bn outlay on new onshore- and offshore-wind projects, and new solar-PV projects.

As can be seen, at $60/bbl, a $100bn outlay on oil would deliver 1,347TWh of gross energy to the pump.

This breaks down as $53bn of expenditure on the oil itself and the remaining 47% on refining, costs, transportation costs, and excise taxes. $53bn spent on oil at $60/bbl would purchase 883m barrels of oil, which equates to 1,497TWh.

Figure 23: Gross EROCI at the pump/charging point: gasoline versus new renewables projects (TWh)



Source: BNP Paribas Asset Management estimates.

However, after being refined into gasoline the energy content is reduced by 10%, such that for a $100bn outlay at $60/bbl covering the full costs of getting oil to the pump as gasoline the gross energy provided would be 1,347TWh.

For wind and solar, the cost of transportation and the energy losses incurred by transporting electrons across transmission and distribution networks also reduce the amount of gross energy available to the end-user at the charging point. For a $100bn outlay, we assume that $25bn will go towards transportation costs along transmission and distribution networks. This would leave $75bn for the new wind and solar projects themselves, with 80% of this sum available for capital investment in new onshore projects, 70% for new offshore projects, and 85% for new solar-PV projects.

For onshore wind, after the adjustment for transportation costs, this gives $60bn for new generation capacity (with the residual $15bn needed for lifetime O&M costs over 25 years), and at our assumed new-build cost of $1.2bn/GW with a 6% cost of capital this would result in 47GW of new capacity. At our assumed load factor of 25%, this would yield 103TWh per year before energy losses, and 93TWh per year after assuming 10% is lost in transportation.

Multiplying this by 25 gives a gross EROCI at the charging point for a $100bn outlay on new onshore-wind projects of 2,324TWh.

For offshore wind, after the adjustment for transportation costs, this gives $53bn for new generation capacity (with the residual $22bn needed for lifetime O&M costs over 25 years), and at our assumed new-build cost of $1.8bn/GW with a 10% cost of capital this would result in 27GW of new capacity. At our assumed load factor of 50%, this would yield 116TWh per year before energy losses, and 105TWh per year after assuming 10% is lost in transportation.

Multiplying this by 25 gives a gross EROCI at the charging point for a $100bn outlay on new offshore-wind projects of 2,613TWh.

For solar-PV, after the adjustment for transportation costs, this gives $64bn for new generation capacity (with the residual $11bn needed for lifetime O&M costs over 25 years), and at our assumed new-build cost of $0.8bn/GW with a 6% cost of capital this would result in 75GW of new capacity. At our assumed load factor of 15%, this would yield 97TWh per year before energy losses, and 93TWh per year after assuming 5% is lost in transportation.

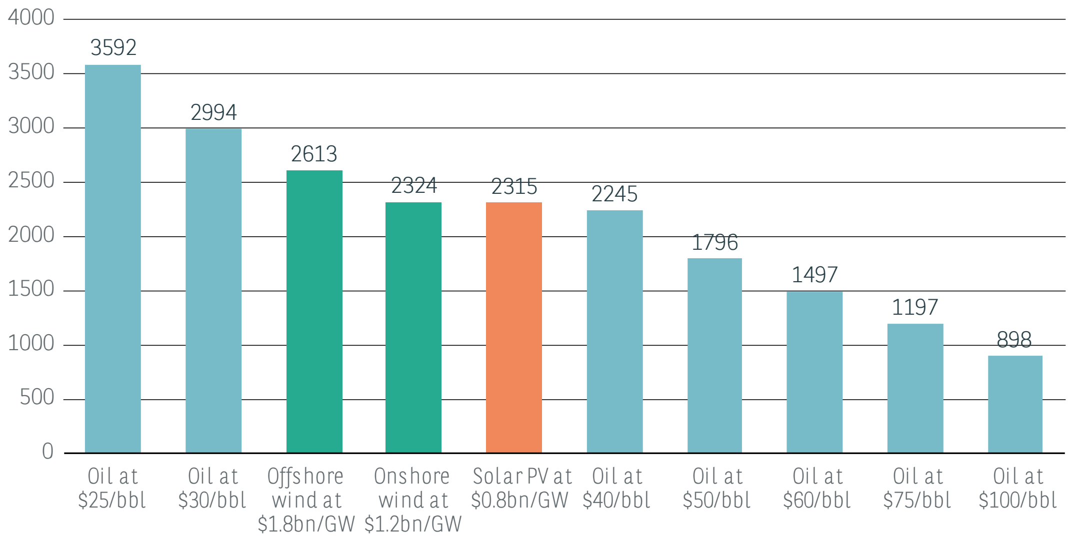
Multiplying this by 25 gives a gross EROCI at the charging point for a $100bn outlay on new solar-PV projects of 2,315TWh.

In short, for the same outlay on oil and renewables, new offshore-wind projects would provide as much gross energy at the charging point as gasoline would at the pump with oil priced at $30/bbl, while new onshore-wind and solar-PV projects would provide as much as gasoline with oil priced at $35/bbl.

3.3.2 DIESEL: WIND COMPETITIVE WITH OIL AT $35-$40/BBL, SOLAR AT $50/BBL

Figure 24 shows the amount of gross energy delivered to the pump as diesel for a $100bn outlay at different oil prices, and the amount of gross energy delivered to the charging point for a $100bn outlay on new onshore- and offshore-wind projects, and new solar-PV projects.

Figure 24: **Gross EROCI at the pump/charging point: diesel versus new renewables projects (TWh)**



Source: BNP Paribas Asset Management estimates.

The figures for our three renewable-energy sources are unchanged from Figure 17 above, while for diesel there is a greater gross-energy yield than for gasoline as it has the same energy content per barrel as crude oil. Accordingly, this raises the price level slightly at which oil can deliver the same amount of gross energy to the pump in the form of diesel as renewables can to the charging point.

This means that for the same outlay on oil and renewables, new offshore-wind projects would provide as much gross energy at the charging point as diesel would at the pump with oil priced at $35/bbl, while new onshore-wind and solar-PV projects would provide slightly more than diesel with oil priced at $40/bbl.

- 3.4 -

CONCLUSION ON GROSS EROCI: GASOLINE AND DIESEL NEED OIL AT $35-$50/BBL

Even before factoring in the respective energy losses incurred by the combustion of gasoline and diesel in gasoline and diesel engines on the one hand, and the charging and energy-conversion losses in an EV battery on the other, it is clear that oil is currently priced way above levels at which it would be competitive with power from new wind and solar projects on a full life-cycle basis.

Indeed, at just over $60/bbl Brent is currently trading at twice the level it would need to be for gasoline to provide the same gross energy at the pump as electricity from new offshore-wind projects at the charging point for an equivalent outlay, assuming there were a level playing field.

And these numbers look considerably worse for oil once we take in to account these energy losses in order to derive the net EROCI on a $100bn capital outlay on oil versus renewables.

4 NET EROCI: OIL V RENEWABLES

In this section we look at how much net energy can be purchased with an outlay of $100bn on oil and on new wind and solar projects. Our calculations build on the analysis laid out in Section 3, in that we begin with the gross energy delivered to the pump for gasoline and diesel on the one hand, and the gross energy delivered from new wind and solar projects to the charging point on the other.

The point of our analysis is to show how much useful or propulsive energy is provided – i.e. how much of the gross energy delivered to the pump or charging point translates into mobility – by a $100bn outlay. This means accounting for the fact that for all of the fuels we are looking at here – gasoline, diesel, and electricity from new onshore-wind, offshore-wind, and solar-PV projects – there are energy losses between the pump or charging point on the one hand, and the wheels on the other. As explained above, our assumptions on these energy-conversion losses are as follows:

1. For gasoline, we assume a thermal efficiency of 20% for a gasoline engine
2. For diesel, we assume a thermal efficiency of 35% for a diesel engine
3. For the motor in EVs we assume an overall efficiency rate of ~70% (this breaks down as ~80% charging efficiency and ~90% electric-propulsion efficiency).

Our analysis leads to a very stark conclusion for the oil industry: for the same capital outlay today, wind and solar energy will already produce significantly more useful energy for EVs than oil at $60/bbl will for cars and other LDVs. Indeed, our model says that with the technology already available today, and for the same capital outlay of $100bn with oil priced at $60/bbl, wind and solar energy would produce 6.2x-7x more useful energy for EVs than would oil for gasoline-powered LDVs, and 3.2x-3.6x more useful energy than would oil for diesel-powered LDVs.

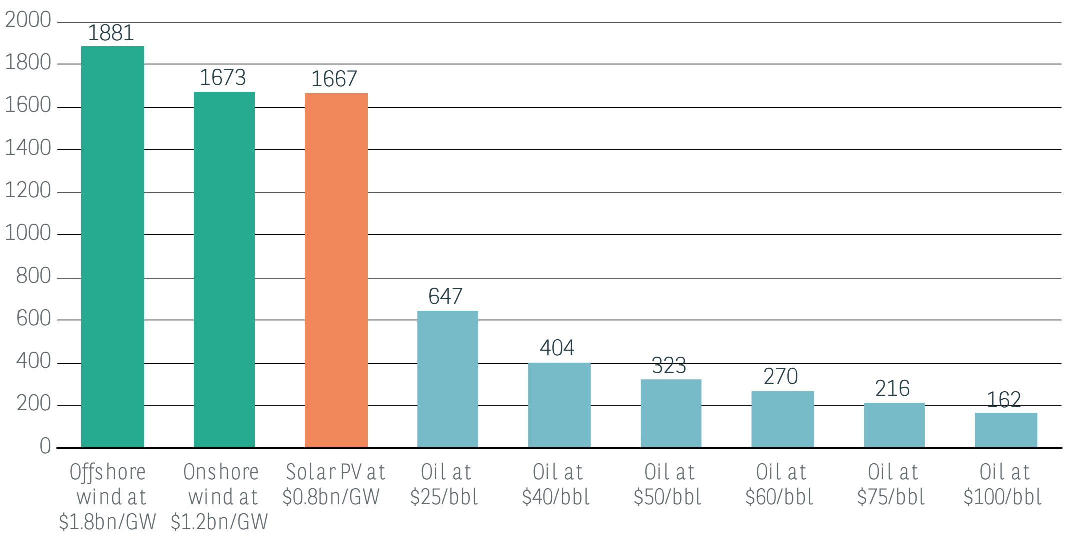
- 4.1 -

GASOLINE: HOW MUCH NET ENERGY DOES $100BN AT $60/BBL OIL BUY?

As we saw in Section 3.3.1 above, with oil priced at $60/bbl we calculate that $100bn of oil purchased on the spot market and then refined into gasoline would deliver 1,347TWh of gross energy at the pump (Figure 22 above). Accordingly, to derive the net EROCI on this outlay, we simply need to account for the energy losses incurred by the combustion process in a gasoline-ICE.

Accordingly, and as shown in Figure 25, taking our assumption of a 20%-efficient gasoline engine gives us a net energy yield for a $100bn investment with the oil price at $60/bbl of 270TWh (i.e.1,347TWh*0.2).

Figure 25: Net EROCI: gasoline versus new renewables projects in tandem with EVs at oil prices (TWh)



Source: BNP Paribas Asset Management estimates.

4.1.1 ONSHORE WIND: HOW MUCH USEFUL ENERGY FOR $100BN?

As explained in Section 3.3.1 above, we calculate that $100bn spent on new onshore-wind projects would deliver 2,324TWh of gross energy at the charging point (Figure 22 above). Adjusting for the energy losses incurred in the charging and energy-conversion processes on the basis of our assumed respective efficiency rates of ~80% and ~90% gives us an overall efficiency rate for EV motors of ~70%, such that our 2,324TWh of gross energy at the charging point becomes 1,673TWh of useful energy at the wheels.

This means that on our numbers the net EROCI of onshore wind is 6.2x higher than that of oil at $60/bbl with that oil used to produce gasoline (i.e. 1,673TWh versus 270TWh).

4.1.2 OFFSHORE WIND: HOW MUCH USEFUL ENERGY FOR $100BN?

Using the same methodology and EV-efficiency assumptions for offshore wind as for onshore, the 2,613TWh of gross energy at the charging point from a $100bn outlay on new projects shown in Figure 22 above becomes 1,881TWh of useful energy at the wheels (Figure 25).

This means that on our numbers the net EROCI of offshore wind is 7x higher than that of oil at $60/bbl with that oil used to produce gasoline (i.e. 1,881TWh versus 270TWh).

4.1.3 SOLAR: HOW MUCH USEFUL ENERGY FOR $100BN?

Again, on the same methodology and EV-efficiency assumptions for solar as for onshore wind, the 1,862TWh of gross energy at the pump from a $100bn outlay on new projects shown in Figure 23 above becomes 1,667TWh of propulsive energy at the wheels (Figure 25).

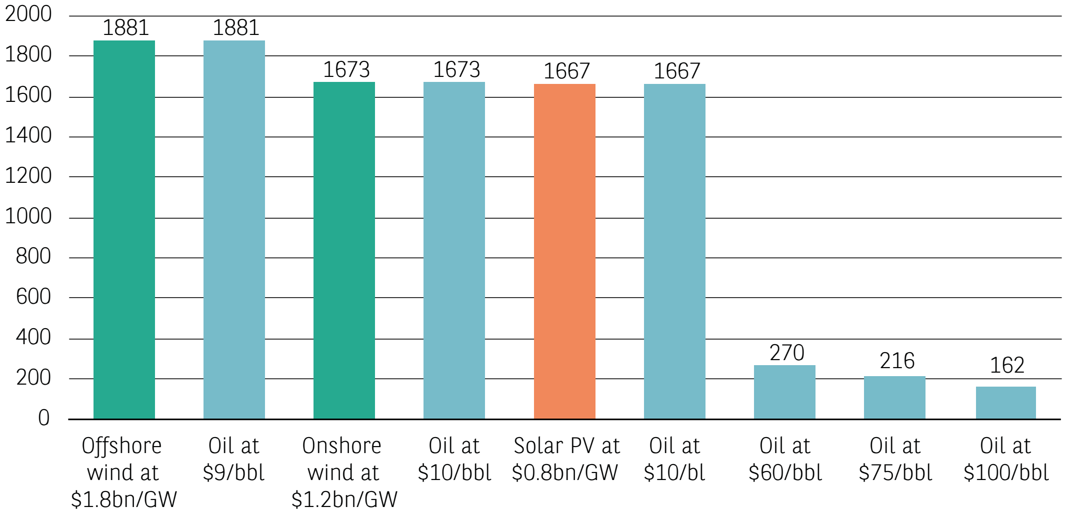
This means that on our numbers the net EROCI of solar-PV is 6.2x higher than that of oil at $60/bbl with that oil used to produce gasoline (i.e. 1,881TWh versus 270TWh).

- 4.2 -

EROCI IMPLIES GASOLINE NEEDS OIL BREAK-EVENS OF $9-10/BBL OVER LONG TERM

From all of our EROCI analysis above, we conclude that oil would have to trade at $9-10/bbl to yield as much useful energy for ICE LDVs running on gasoline as new wind and solar projects will generate for EVs over an assumed operating life of 25 years (Figure 26).

Figure 26: Net EROCI from new renewables projects in tandem with EVs versus oil used for gasoline vehicles (TWh)



Source: BNP Paribas Asset Management estimates.

For gasoline to yield as much useful energy as new onshore-wind projects for a $100bn outlay, we calculate that oil would have to trade at $10/bbl.

For gasoline to yield as much useful energy as new offshore-wind projects for a $100bn outlay, we calculate that oil would have to trade at $9/bbl.

For gasoline to yield as much useful energy as new solar-PV projects for a $100bn outlay, we calculate that oil would have to trade at $10/bbl.

In other words, for gasoline to be competitive as a fuel in LDVs over the long term based on the economics of renewables already today, oil would need to trade at 80-85% below the current market price.

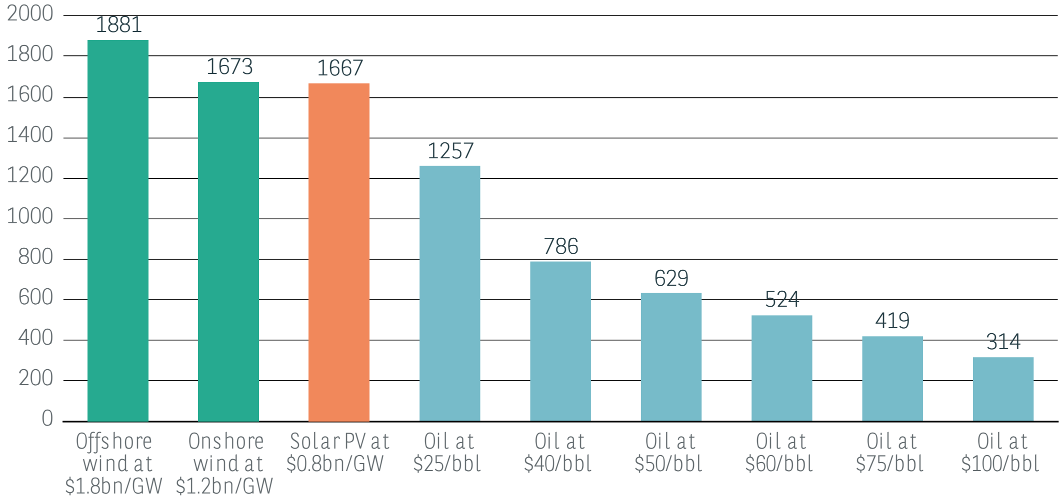
- 4.3 -

DIESEL: HOW MUCH NET ENERGY DOES $100BN AT $60/BBL OIL BUY?

As we saw in Section 3.3.2 above, with oil priced at $60/bbl, we calculate that $100bn of oil purchased on the spot market and then refined into diesel would deliver 1,497TWh of gross energy at the pump. Accordingly, to derive the net EROCI on this outlay, we simply need to account for the energy losses incurred by the combustion process in a diesel engine.

As shown in Figure 27, taking our assumption of a 35%-efficient diesel engine gives us a net energy yield for a $100bn investment with oil at $60/bbl of 524TWh (i.e.1,497TWh*0.35).

Figure 27: Net EROCI: diesel versus new renewables projects in tandem with EVs at different oil prices (TWh)



Source: BNP Paribas Asset Management estimates.

The figures for our three renewable-energy sources are unchanged from Figure 24 above. This means that while the net EROCI of oil converted into diesel is higher than that of gasoline, it is still well below that of new wind and solar projects.

For new onshore-wind projects, the net EROCI on our numbers is 3.2x higher than that of oil at the current Brent price of $60/bbl with that oil used to produce diesel (i.e. 1,673TWh versus 524TWh).

For new offshore-wind projects, the net EROCI on our numbers is 3.6x higher than that of oil at the current Brent price of $60/bbl with that oil used to produce diesel (i.e. 1,881TWh versus 524TWh).

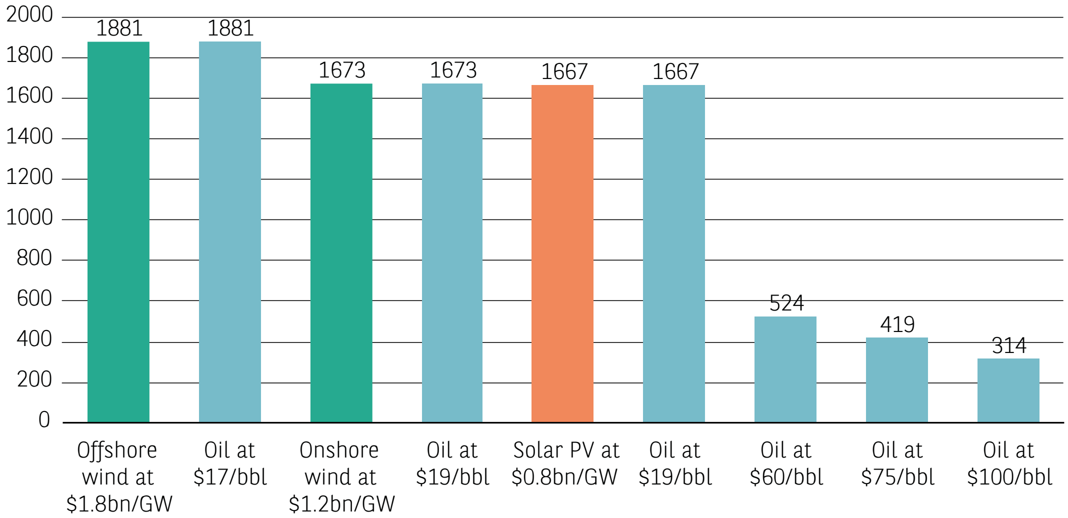
For new solar-PV projects, the net EROCI on our numbers is 3.2x higher than that of oil at the current Brent price of $60/bbl with that oil used to produce diesel (i.e. 1,667TWh versus 524TWh).

- 4.4 -

EROCI IMPLIES DIESEL NEEDS OIL BREAK-EVENS OF $17-$19/BBL OVER LONG TERM

From all of our EROCI analysis above, we conclude that oil would have to trade at $17-19/bbl to yield as much useful energy for diesel-fuelled LDVs as new wind and new solar projects will generate for EVs over an assumed operating life of 25 years (Figure 28).

Figure 28: Net EROCI from new renewables projects in tandem with EVs versus oil used for diesel LPVs (TWh)



Source: BNP Paribas Asset Management estimates.

For diesel to yield as much useful energy as new onshore-wind projects for a $100bn outlay, we calculate that oil would have to trade at $19/bbl.

For diesel to yield as much useful energy as new offshore-wind projects for a $100bn outlay, we calculate that oil would have to trade at $17bbl.

For diesel to yield as much useful energy as new solar-PV projects for a $100bn outlay, we calculate that oil would have to trade at $19/bbl.

In other words, for diesel to be competitive as a fuel for LDVs over the long term based on the economics of renewables already today, oil would need to trade at 70-72% below the current market price for Brent.

- 4.5 -

CONCLUSION: GASOLINE AND DIESEL ECONOMICALLY UNSUSTAINABLE AS LDV FUELS

Our EROCI analysis shows that after adjusting for all of the costs and all of the energy losses of delivering oil from the well to the wheels on the one hand, and renewable electricity from new wind and solar projects to the wheels of EVs on the other, new wind and solar projects combined with EVs would deliver 6.2x-7x more useful energy than gasoline with oil at $60/bbl, and 3.2x-3.6x more than diesel.

Moreover, this is on the basis of the costs and efficiency rates of the renewable-electricity technologies as they exist today. Yet over time, the costs of renewables will only continue to fall, while their efficiency rates will only continue to rise (thereby enabling higher load factors).

In particular, the scope for average solar-generation load factors to rise above the 11% we have assumed in this report is enormous given (i) the potential for further improvements in solar-PV efficiency rates, and (ii) the deployment of solar at much greater scale in sunnier parts of the world such as Africa, India, and the Middle East.

In short, whether in the form of gasoline or diesel, oil's days as a fuel for LDVs are clearly numbered because our EROCI analysis shows that the economics of new wind and solar projects combined with EVs are set to become irresistible.

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