Peak oil and the miracle of shale oil

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Introduction[1]

The global peak of "conventional" crude oil production was reached in the 2000s. However no crude oil peak was observed then, because the "miracle" of US shale oil took place. Anticipating limitations of conventional resources, the history of shale oil starts in the '60s-'70s with research on mass-scale hydraulic fracking and even nuclear fracking. To state that the shale oil "miracle" is a product of human genius is therefore partly true. It is less known that it is also a product of the "extraordinary" massive monetary policy.
In 2020, Covid-19 brought the oil market back to normalcy. Taken together, the level of maturity of hydrocarbon deposits - conventional or not - and the declining efficiency of oil-recovery techniques from geological reservoirs suggest that the global peak in crude oil production from November 2018 shall never again be equaled. The peak of conventional oil, the shale "miracle" and the return to "normalcy" will have consequences for the future of the world's macroeconomic (growth), financial (inflation) and environmental ("green" finance) future.

The start of the century saw an energy "miracle", with immensely far-reaching historical consequences on macroeconomics, finance, geopolitics, environment, even anthropology: the advent of "shale oil"[2].

[1] I warmly thank the members of ASPO (Association for the study of gas and oil peaks - especially J. Laherrère, D. Pillet and O. Rech), of THE SHIFT PROJECT, the services of the US BEA and the Archives of IFPEN (French Institute of Oil and Renewable Energies).

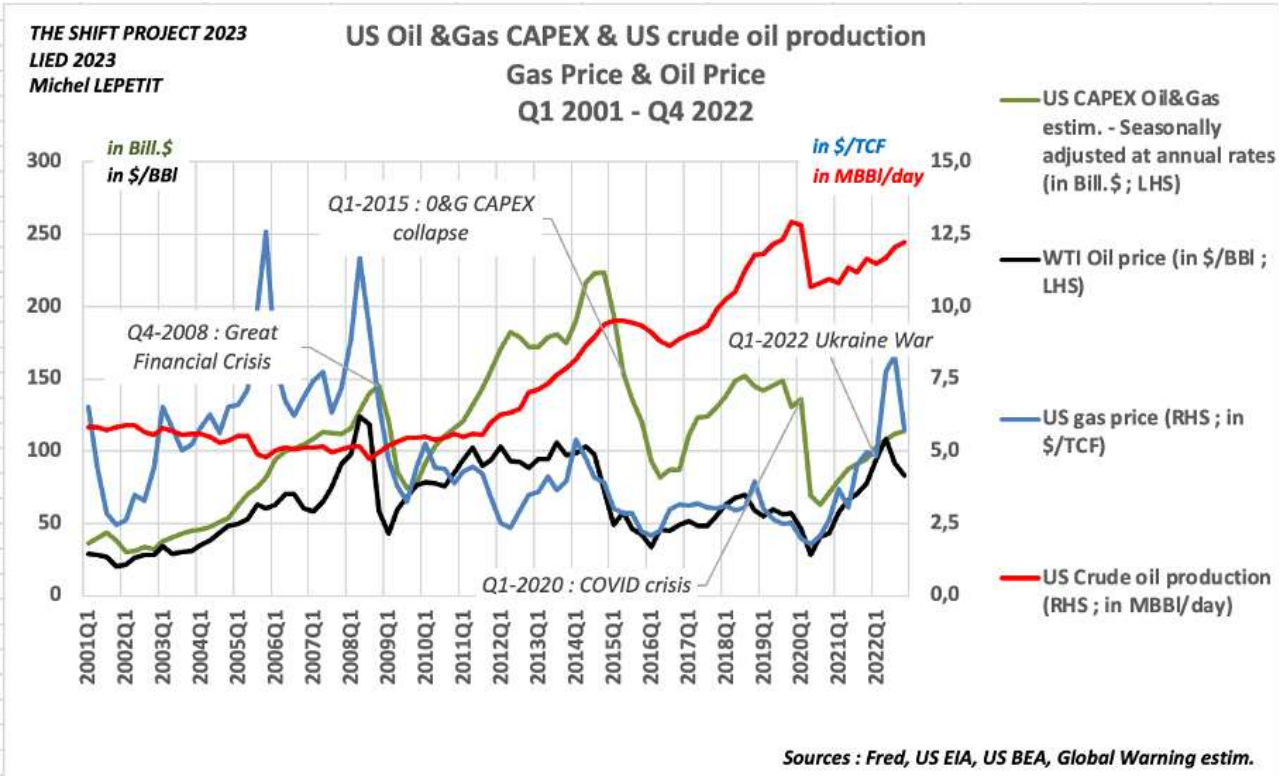
[2] Specialists refer to "shale oil" as "Light Tight Oil" (LTO) : bedrock oil or compact reservoir oil. Tight gas is also known as bedrock gas or compact reservoir gas.

Shale oil made the fear of peak oil vanish for a decade.
In the early 2000s, the world, thirsty for liquid hydrocarbons, suddenly faced its peak of production for the so-called "conventional" oil.

The approach of this peak led to a tenfold rise of oil prices, peaking in 2008 and triggering - through the loss of solvency of property borrowers - a systemic financial crisis known as the "subprime mortgage crisis". Then, to everyone's surprise, in the 2010s, a new source of world oil production growth providentially sprang up in the United States. This emergence of shale oil was at first indiscernible to then become spectacular.

The low spare oil production capacity in the Middle East - and Saudi Arabia in particular (Lepetit, 2023a)[3] - combined with buoyant Chinese demand, explain the price surge of the 2000s. China was waking up, and the world was quaking.

surprise to many, not least of all geologists: the more or less porous nature of the rocks containing these hydrocarbons meant the extraction from the subsoil was possible, but complex and, on the face of it, financially not profitable. In fact, and this is the real macroeconomic “miracle”, shale oil was never profitable throughout the 2010s.
Figure 1 shows that growth in US crude oil production in the 2020s is less robust than in the previous decade, owing to the lower level of investment in the sector. Figure 2 (see next page) shows recent monthly trends in crude oil prices and production in the United States, as well as some rather lackluster short-term outlooks.
On the basis of a systemic analysis of the "shale miracle", a historical prognosis can be put forward: the global peak in crude oil production, combining both conventional and unconventional[4], has probably passed already. Given the sharp natural decline in production from conventional oil fields and a much steeper natural decline in shale oil wells, and given the mediocrity of hydrocarbon reservoir



From 2010 onwards, the exuberance of "unconventional" American oil production took center stage. This atypical oil, “shale oil”, came as a

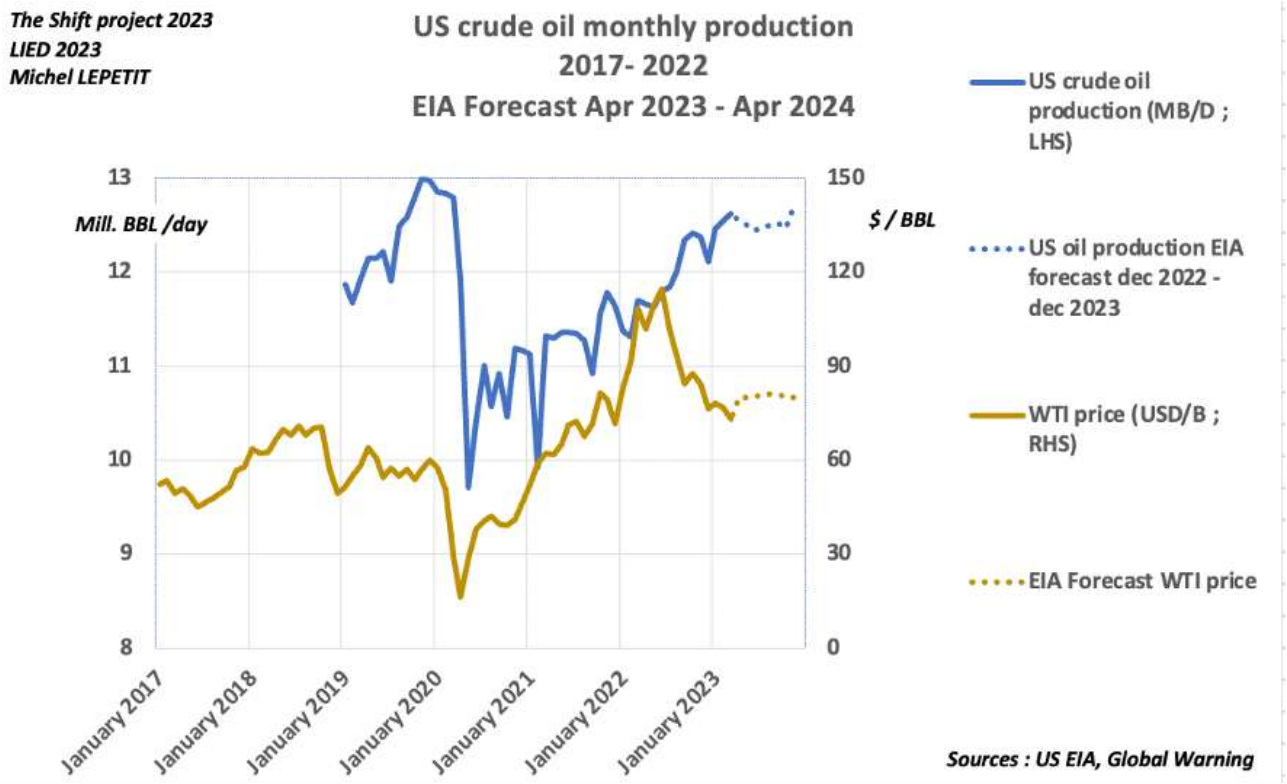
discoveries over the last twenty years - particularly for oil discoveries- (Blaizot, 2023)[5], one can safely bet that there will be no new source of global growth

[3] Lepetit M. (2023a), “History of the limits of the production capacity of Saudi Arabia”, April 7th 2023, as seen on https://www.linkedin.com/pulse/le-pic-petrolier-mondial-est-advenuen-novembre-2018-michel-lepetit/?trackingId=C2KkZ1%2B5WDTxX74WspuP%2FA%3D%3D

[4] Other type of unconventional oil: oil produced from tar sands, mainly in Canada (3.3 M bpd in 2021 - see Alberta - Oil sands facts and statistics, seen on https://www.alberta.ca/oil-sands-facts-and-statistics.aspx).

[5] Blaizot M. (2023), "Two decades of conventional O&G discoveries - The main discoveries in 2022", ASPO, April 2023,

in crude oil (Rech, 2021)[6]: the era of oil miracles seems to have passed. Such a bold prognosis is risky as it had already wrongly been put forward at the beginning of this century, and requires to be based on a historical analysis of the situation of hydrocarbon extraction giants such as Russia (Lepetit, 2023b)[7] and Saudi Arabia (Lepetit, 2023a). Here we look at the world's third largest producer, its miraculous shale oil, with its root causes and limits.



The state of shale before 2008

US interest in shale gas reserves began in the late 1960s, even before the first oil crisis.

A now forgotten strategic issue for the US - and echoed in Europe's current concern of gas supply (Rech et al., 2022)[8] – the peak of US conventional gas production dates back to the early 1970s (US Senate, 1969)[9]. Access to new domestic resources was a crucial concern for natural gas, since importation by sea was even more limited than it is today. At the time, the liquefaction of natural gas was experimental and very expensive. Committees were set up in the United States to assess all exploitable hydrocarbon resources, including gas from coal gasification and kerogen exploitation in Colorado. Among the possible resources were deposits of gas trapped in compact, "unconventional" geological reservoirs, present in large quantities in the subsoil of vast regions of the United States. To release this gas, the rock first had to be fractured ("fracked"), unlike conventional reservoirs, which are only

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as seen on https://aspofrance.files.wordpress.com/2023/04/exploration-results-aspo-april-2023-mbl.pdf.

[6] Rech. O., Blaizot M. & Lehner A. (2021), "Approvisionnement pétrolier futur de l'Union européenne - Etat des réserves et perspectives de production des principaux pays fournisseurs", The Shift Project, May 2021, found at https://theshiftproject.org/ wp-content/uploads/2021/05/approvisionnement-petrolier-futurde-lUE_shift-project_mai-2021_rapport-complet.pdf (FR). This study focuses on oil suppliers of Europe, analyses amongst others Russia and Saudi Arabia.

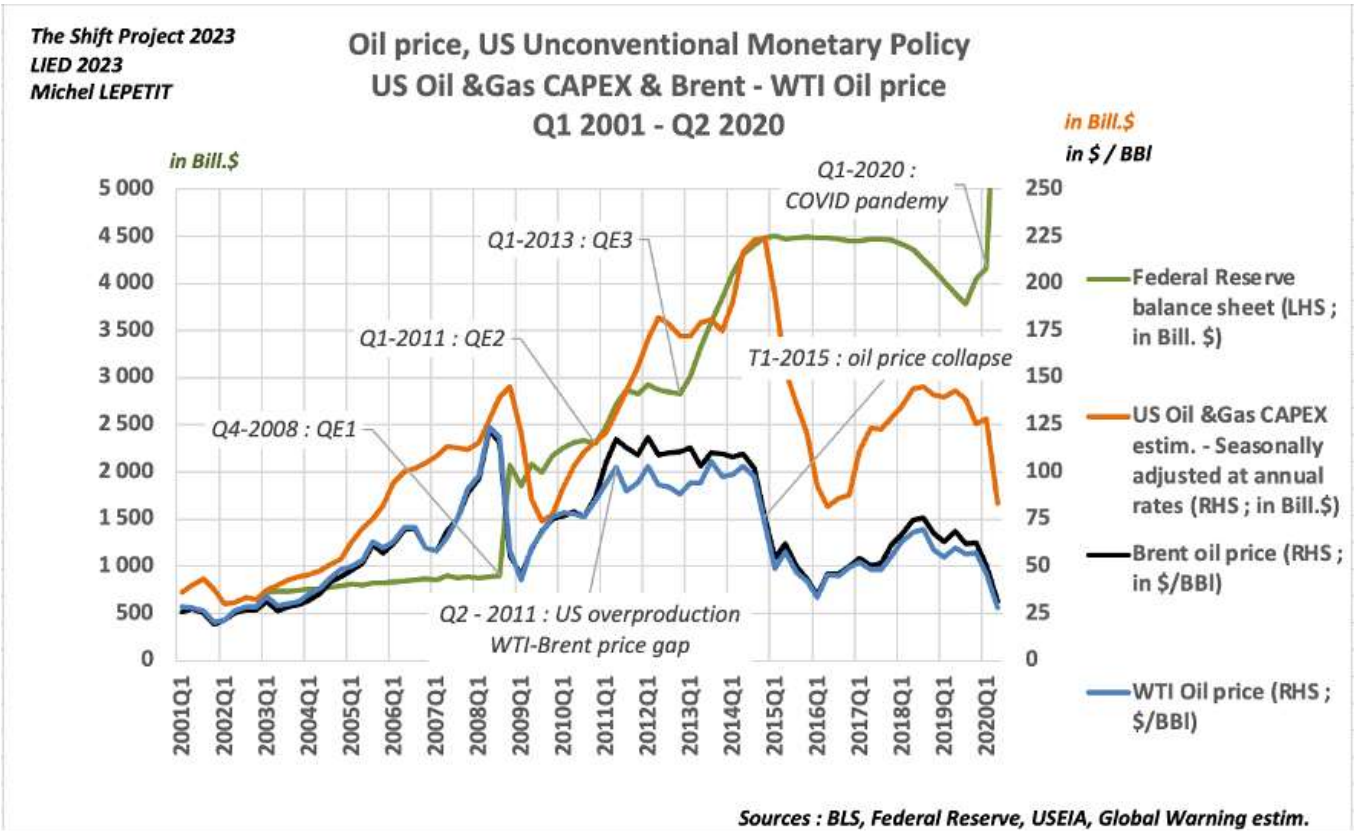
[7] Lepetit M. (2023b), "CIA 1977: the imminent Russian oil crisis and its global consequences", February 9th 2023, seen on https://www.linkedin.com/pulse/cia-1977-la-crise-imminente-du-petrole-russe-et-ses-michel-lepetit/?trackingId=SKOEWxSG3 YucybrGCB3i3Q%3D%3D (FR)

[8] Rech. O. et al (2022), "Natural gas: what risks for EU supply? 2025, 2030 and beyond", The Shift Project, December 6th 2022, found at https://theshiftproject.org/wp-content/uploads/2022/12/Gaz-naturel-risques-approvisionnement-UE-The-Shift-Project-pour-DGRIS-Synthese.pdf (FR)

[9] US Senate (1969), Hearings by the Committee on Interior and Insular Affairs, US Senate, Subcommittee on Minerals, Materials and Fuels - Natural Gas Supply Study, November 13 and 14th, 1969.

fractured - if at all - at a later stage, to improve the recovery rate.

For this gas, difficult to extract from the rock in which it is trapped due to low permeability, the use of nuclear fracturing was envisaged as early as the 1960s. The 1973 crisis stimulated the creativity of American researchers, engineers, and economists (Oil & Gas Journal, 1974)[10]. The Federal Power Energy in conjunction with the oil industry as early as 1976 (DOE, 1995)[12] to extract these resources. Two main options were retained: nuclear fracturing and massive hydraulic fracturing. The first technical approach gave rise to in situ tests in 1967 followed by studies (Nixon, 1971)[13] but proved impossible to implement operationally. France itself became interested in the idea while proceeding with nuclear tests in the Sahara (Delort, 1970)[14].



Commission (FPC) was mobilized, as natural gas takes a major part in the country's electricity production (FPC, 1975)[11]. Prospective technical scenarios and their economic evaluation were meticulously studied by the US Department of The second route, massive hydraulic fracturing, appeared more promising, based on the well-mastered fracturing technology. It was already often used to improve the recovery rate on mature conventional hydrocarbon deposits in the United

[10] Oil & Gas Journal (1974), Energy pinch spurs research in Rockies, February 11, 1974, “Tristate conference hears plan to compare massive hydraulic fracturing with nuclear stimulation of tight gas sands in Piceance basin. (…)”

[11] FPC (1975), “The national gas survey - Federal Power Commission”, Voluminous and extraordinary report on natural gas resources in the United States. See : Vol. I - Chapter 9: "Future Domestic National Gas Supplies".

[12] DOE (1995), “DOE’s Unconventional Gas Research Programs 1976-1995”, US Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, 1995, found at https://geographic.org/unconventional_gas_research/eastern_gas.html

[13] Nixon (1971), "Address on Energy to Congress", June 1971, retrieved from https://www.presidency.ucsb.edu/documents/ special-message-the-congress-energy-resources *"(...) Progress in nuclear stimulation experiments which seek to produce natural gas from tight geologic formations which cannot presently be utilized in ways which are economically and environmentally acceptable. (...)".*

[14] Delort F. & Supiot F. (1970), "Productivité des gisements d'hydrocarbures stimulés avec des explosions nucléaires", Rapport CEA-R-3968, CEA, see on https://inis.iaea.org/collection/NCLCollectionStore/_Public/01/002/1002811.pdf

States. Research & Development enabled the adaptation of the technique to the nature of the bedrock that traps “shale gas”, and to perfect it. At the time, drilling was only vertical, although progress was made in the mid-1980s in mastering "directional" drilling. Federal government-supported works, studies, tests, and economic assessments followed one another from the mid-1970s onwards to extract these resources. The US gas crisis of the early 2000s (Darley, 2004)[15], the sharp rise in local prices brought with it (see Figure 1), and the advent of horizontal drilling over ever greater distances, finally made it possible to envisage economically rational access to shale gas.

Despite the technical progress, exploiting this resource remained barely profitable due to the depletion rate of wells, a major drawback known since the 1970s (estimated at 22% per year at the time; it is higher in 2023). This rate of decline is incommensurable with that of a "conventional" hydrocarbon - gas or oil - where it is around 3 to 5% per year. In 2023, the International Energy Forum estimates that shale oil production, which stood at 6 MB/pd in 2022, would naturally decline, in the absence of investment, to 2 MB/d in 2027 and 1 MB/d in 2030. That is -80% (IEF & S&P, 2023)[16].

Monetary policy and oil - from 2008 to 2020: thirst for dreams

The shale oil "miracle" had two main causes. The first was an undeniable technical progress, with massive hydraulic fracturing and horizontal drilling. This story, which received a great deal of media coverage, was widely mythologized, seducing many apologists of American entrepreneurship and its creative technical genius. The second cause was financial, explaining the exuberance of investment in this risky extractive activity. This is less well known, even though all industry experts and financial analysts noted month after month, year after year, the irrational nature of massive investment in "shale", without ever any return for investors (WSJ, 2014; Deloitte, 2020)[17]. Due to historically low rates driven by central banks, by the Federal Reserve particularly, investors' frenzied search for yield marked the 2010 decade. This proximity to the ZLB ("Zero Lower Bound": zero yields on the safest government bonds) led investors to take reckless risks. This policy has been "manufacturing" vulnerable asset classes for the following decade. One can think of the financing of commercial real estate and offices (EBA, 2022)[18] ; or the - though more modest - market for "catastrophe" bonds, particularly climate bonds, an asset class in crisis in 2023. The financing of shale hydrocarbons was just such an investment in the 2010s: misunderstood, seductive, and risky. The business model for exploiting these geologically complex deposits was unprecedented, and the promise of future technical progress made to investors was constantly renewed.

A simple economic model reveals the impact of successive waves of massive "quantitative easing" by the Federal Reserve in the 2010s (Lepetit, 2020)[19]. By lowering government bond yields to the so-called "risk-free" floor, the Fed pushed American investors into speculative investments such as shale oil and gas. A kind of "irrational exuberance" took hold of the financial markets, as shown in Figure 3: the amounts invested in the USA (CAPEX: CAPital EXpenditure) broke free from the historical trend

[15] Darley J. & Heinberg R. (2006), High Noon for Natural Gas: The New Energy Crisis, Chelsea Green Publishing Co, 2006.

[16] IEF & S&P (2023), "Upstream oil and gas investment outlook 2023", A report by the International Energy Forum and S&P Global Commodity Insights, Feb. 2023, found at https://www.ief.org/ focus/ief-reports/upstream-investment-report-2023

[17] WSJ (2014) – The New Winners and Losers in America's Shale Boom – 20/04/2014

“(…) While these newly public companies are spending more than they make, they say they offer investors fast growth and are spending necessary money to drill wells and lay pipes that will generate positive cash flow in the next few years. (…)”

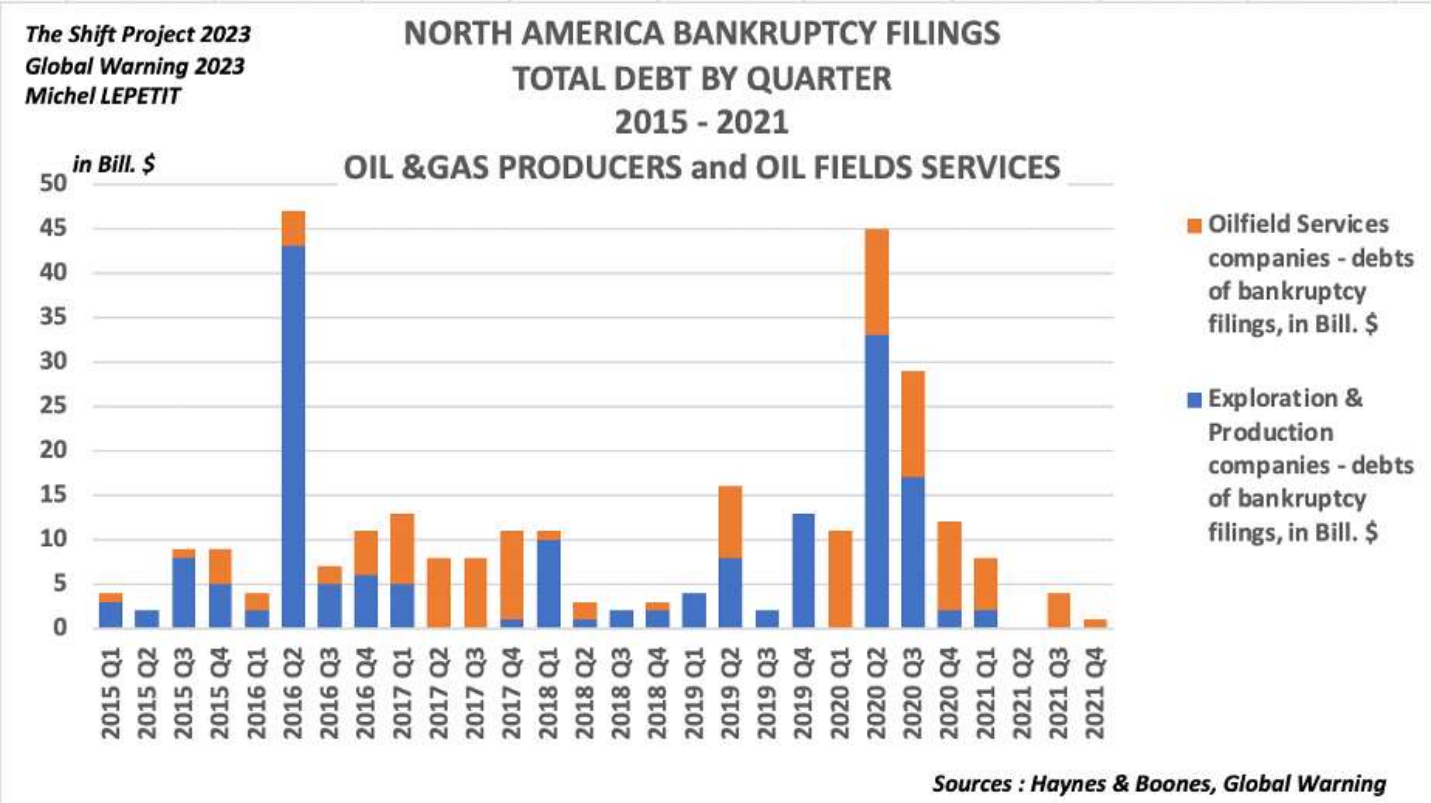
Deloitte (2020) – The Great Compression - Implications of COVID-19 for the US shale industry Navigating the great compression in shale oil production – Deloitte – 2020

“(…) The year 2020 marks the 1[0]-year anniversary of the US shale boom, which heralded an era of US energy independence and more than doubled tight oil production over the past five to six years. However, beneath this phenomenal growth, the reality is that the shale boom peaked without making money for the industry in aggregate. In fact, the US shale industry registered net negative free cash flows of $300 billion, impaired more than $450 billion of invested capital, and saw more than 190 bankruptcies since 2010 (…)”

[18] EBA (2022), "Banks exposed to downside risks as residential real estate markets get overheated - Residential real estate exposures of EU Banks: risks and mitigants", European Banking Authority report, 10 October 2022, seen on https://www.eba.europa.eu/banks-exposed-downside-risks-residential-real-estate-markets-get-overheated-eba-report-finds

[19] Lepetit M (2020), "Politique monétaire non conventionnelle et pétrole non conventionnel sont-ils liés", The Shift Project, report of 26/11/20, located at https://theshiftproject.org/article/ politique-monetaire-neutralite-carbone/

which had been due solely to oil prices[20]. This market "indiscipline" has had far-reaching consequences. Over the decade 2010-2019, nearly $900 billion has been invested in the risky American shale industry, with no financial return. This frenzied over-investment in the oil industry took many forms - capital, guarantee and debt[21] - and eventually led to an overproduction of oil. This overproduction, first localized in the United States in early 2011, soon put pressure on world prices (see Figure 3)[22]. It had a strongly disinflationary flavour, understood by only



few economists (Stroebel, 2020; Artus, 2021; Lepetit, 2022)[23]. The end of the shale "miracle" at the end of the 2010s thus contributed to the "mystery" of inflation return in the 2020s. This exuberant, inflation-free decade of the 2010s, and its monetary explanation, provides a useful insight into the inflationary crisis of the post-Covid 2020s and the general lack of understanding surrounding the current global resurgence of inflation.

The end of the fairy tale and a return to discipline after 2020

The market has regularly express doubts during the 2010s, but investors were still lured by this promise of future returns (WSJ, 2014; Domanski D. et al., 2015[24] ; Deloitte, 2020). The Covid-19 crisis

[20] See also the supplements to this article, posted online at https://www.linkedin.com/in/michel-lepetit/

[21] Listed equity market (notably via passive management); Bond market (including the high-yield market (notably via passive management)); Bank loans (notably reserve-based lending); Investment fund loans (notably distress funds); Venture capital and unlisted shares; Hedge funds; Mergers and acquisitions; Volumetric production payment; DrillCos ("Drilling joint ventures")…

[22] The historic discrepancy between the price of a barrel of Texas crude oil (WTI) and the price of a barrel of Brent crude oil (international market) reflected local overproduction and transportation bottlenecks.

[23] Stroebel F. et al. (2020), "A Structural investigation of quantitative easing", Deutsche Bundesbank Discussion Paper 2020, seen on: https://www.bundesbank.de/en/publications/research/discussion-papers/a-structural-investigation-of-quantitativeeasing-856942

Artus P. (2021), "Le retour à l'économie des années 1970", Les Echos du 08/04/2021, seen on: https://www.lesechos.fr/idees-debats/cercle/opinion-le-retour-a-leconomie-desannees-1970-1305380

Lepetit M. (2022), "Énergie et inflation",Institutions, AF2I newsletter n°67, October 2022, seen on: https://www.af2i.org/publications/

[24] Domanski D. et al. (2015), "Oil and debt", BIS Quarterly Review, March 2015, seen on https://www.bis.org/publ/qtrpdf/r_qt1503f.ht

and the momentary collapse in the world's need for mobility led to a sharp drop in global oil demand, and consequently in the price of a fuel that cannot be overstocked. On Monday, April 20, 2020, the price of WTI even turned negative, and a new wave of bankruptcies in the shale industry followed. It was the end of that dream. The post-Covid rise in interest rates made us forget - probably for a long time to come - the glorious times of capital abundance and investor recklessness of the 2010s (EIA, 2022)[25]. Early 2021, a return to strict investor “discipline” - the rational pursuit of profitability - virtually ended a decade of chronic bankruptcies in the shale industry. Law firm Haynes & Boone, experts in the sector, had developed a quarterly dashboard of shale industry bankruptcies, starting in early 2015. It published a final report in February 2022, explaining that it was no longer needed. In seven years, the US oil industry had seen $321 billion of debt restructured and often written off from 274 mostly Texas-based oil companies[26] (Haynes & Boone, 2022)[27].
Figure 4, reconstructed from the latest published reports, represents the quarterly volumes, between 2015 and 2021, of debts involved in these bankruptcies in $billions, for exploration and production companies, as well as for service companies. This chronicle firstly shows the wave of bankruptcies in the spring of 2016, which followed a sharp drop in prices, due in particular to overproduction by US oil companies; secondly, the wave of post-Covid bankruptcies and its subsequent drying-up.

World crude oil reached historic peak in 2018

The US oil market thus went back to a more "disciplined" mode from 2020 on. The global oil market, now back to " normal ", faces the same constraints as in the 2000s. The scarcity of unused and available surplus conventional oil production capacity, on the one hand, and the steady rate of decline of mature wells production, on the other, are likely to have serious consequences. To cope with the decline in active wells, IEF and other experts (IEF & S&P, 2023) believe that investment in hydrocarbon exploration and production will have to remain sustained if only to maintain production. Without investment, according to IEF, non-OPEC "conventional" production would decline by 5 MB/d by 2027, and 8 MB/d in 2030, compared with 2022. The monthly peak in global crude oil production (84.5 MB/d) reached in November 2018 will consequently be hard to match. According to US EIA figures, the drop in production between November 2018 and November 2022 would already have been in the order of 2.2 MB/d. Of course, even if crude oil production stagnates or even declines, production of liquid hydrocarbons - of which crude oil is a part - could continue to grow, and possibly exceed the volumes achieved at the end of 2018. However, just as gas is not a liquid, gas liquids (propane and butane) are not crude oil.[28] Saudi Arabia, and behind it the OPEC+ organization, i.e. Russia, do not seem inclined to make a substantial effort to stem the structural decline in world crude production (Lepetit, 2023a). Nor will a Russia at war (Lepetit, 2023b). The United States, the subject of this article, will not repeat their miracle. The recovered "discipline" of American shale oil is enabling major producers like Saudi Arabia to arbitrate production cuts. Aware of the strength of global demand, and with no fear of another player taking their place (such as the independent US producers during the exuberance of the 2010s), Saudi Arabia can orchestrate an OPEC+ production cut. The modest drop in export volumes is then more than offset by the significant rise in prices, which is the only phenomenon capable of wiping out the demand for oil corresponding to this drop. We are in the process of rediscovering the low

[25] EIA (2022), "US EIA - Annual Energy Outlook", EIA March 3, 2022, seen on: https://www.eia.gov/outlooks/aeo/production/ sub-topic-01.php *"(...)* ***Producers are more dependent on capital from cash flow.*** *The oil and gas industry was already moving towards a reliance on capital from cash flow rather than debt and equity. Covid-19 has accelerated this trend, making producers more dependent on internal sources of cash flow because external sources of financing are less available or require higher rates of return. (...)".*

[26] So called "Chapter 11". For shale companies, sometimes recidivists, one even spoke of "chapter 22".

[27] Haynes & Boone (2022), “Oil patch Bankruptcy Monitor”, Final Report, January 31, 2022, seen on https://www.haynesboone.com/-/media/project/haynesboone/haynesboone/pdfs/energy_bankruptcy_reports/oil_patch_bankruptcy_monitor.pdf?rev=e57d3129b7504ea190df5d33dbacae44&hash=F461E4FE13446BE821B8AE9080C349E6

[28] This leads to a gap in value of these products - roughly 23% with crude oil in the US over the 2010s.
US EIA - Hydrocarbon gas liquids explained - Prices for hydrocarbon gas liquids, see on https://www.eia.gov/energyexplained/hydrocarbon-gas-liquids/prices-for-hydrocarbon-gas-liquids.php

elasticity of oil demand to its price, barring brutal economic recessions.

Shale oil production peak?

Since the beginning of 2020 and the final wave of bankruptcies that hit the shale oil industry, the dream has vanished. The waves of money creation that accompanied the COVID pandemic did not encourage investors' exuberance, at least in our sector of activity. In the absence of monetary boost, analysts and observers noticed the - though relative - (see figure 1) moderation of the investment effort in the shale oil industry. This financial discipline allowed the sector to get back to the fundamentals: geology and physics. Hydrocarbon extraction remains complex and the rate of decline for oil wells is still high. Worse, without the deceiving boost that characterized the 2010's, shale oil extraction showed the first signs of a slowdown with more mature and less productive reservoirs. Perspectives of such a decline may remind us of similar difficulties encountered by conventional oil a few years ago. Certainly, American technical ingenuity pushed the limits of horizontal drilling every year (from an average of 4,000 ft in 2007 to 9,000 ft in 2022), seemingly gaining in efficiency and productivity. Nonetheless, the best shale oil reservoirs were exploited first, especially during the exuberant decade of the 2010's. As early as March 2022, the American Energy Information Administration (EIA) warned about the uncertain future of shale oil, particularly about the actual size and producibility of American reservoirs, and – implicitly – the economic viability of the sector (EIA, 2022)[29].

In April 2022, the World Bank warned about the elevated costs associated with shale oil extraction in the USA, masked by the disturbance triggered by the Pandemic (World Bank, 2022)[30]. At the end of 2022, the Dallas Federal Reserve acknowledged this worrying trend in its trimester surveys. Indeed, among a group of oil companies that was surveyed during the last trimester of 2022 regarding the main factor slowing down the growth of their production: 27% of the 90 responding companies pointed out " Maturing [oil] asset base " (Fed, 2022a)[31]. In January 2023, a well-documented article of The Financial Times announced the end of the "shale boom" (FT, 2023a)[32]. In March 2023, influential individuals spoke up during a public conference in Texas to warn that the sunny days of shale oil were probably behind us (WSJ, 2023; FT, 2023)[33]. In March 2023, the Rystad Energy company acknowledged that several indices associated with shale oil activity were worrisome and that the peak of productivity in the famous Permian basin may have been reached mid-2021. This decline in productivity would probably remain moderate (Rystad, 2023; Figure 5 above)[34]. In March 2023, the Dallas Federal Reserve

[29] EIA (2022), "US EIA - Annual Energy Outlook", EIA March 3, 2022, seen on https://www.eia.gov/outlooks/aeo/production/subtopic-01.php *"(…) Tight oil is primarily driving the growth in the oil production outlook, followed by offshore resources. (…). However, estimates of technically recoverable tight or shale crude oil and natural gas resources are uncertain. (…)"*

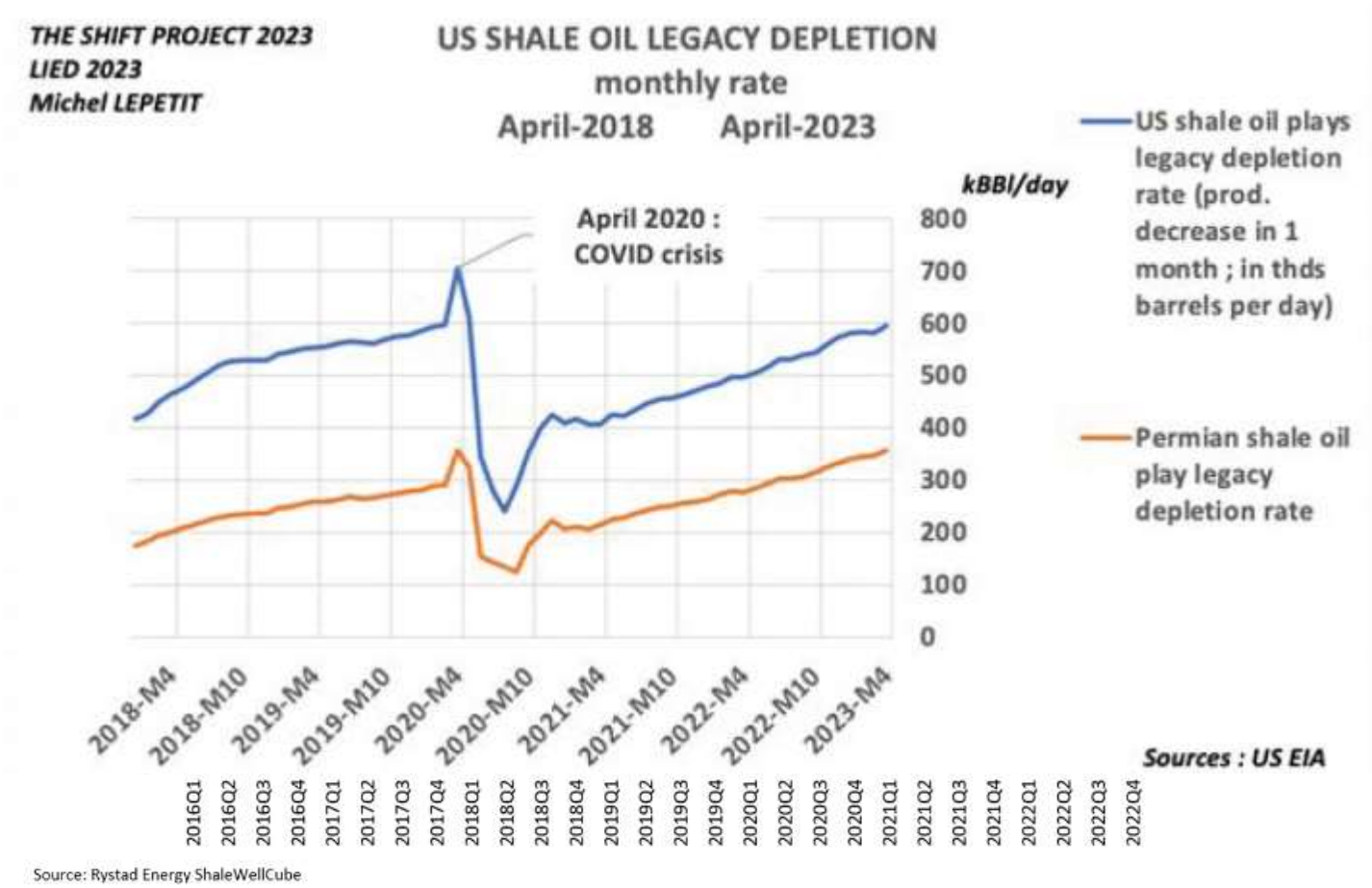
[30] World bank (2022) "Commodity Markets Outlook", World Bank, April 2022, seen on https://openknowledge.worldbank.org/bitstream/handle/10986/37223/CMO-April-2022.pdf - p40

[31] Fed (2022a), "Dallas Fed Energy Survey - Oil and gas expansion still solid; cost increases moderate, supply-chain delays persist", Federal Reserve Bank of Dallas. Dec. 12th 2022. Seen on https://www.dallasfed.org/research/surveys/des/2022/2204 For the first time, this potential answer was put up, behind "Cost inflation and/or supply-chain bottlenecks" (32%) and ahead of "Availability of capital" (16%). See also the answers to the question asked in the Dallas Fed Survey of Q2 2022 : " Which of the following is the primary reason driving uncertainty regarding your firm's outlook?"

[32] FT (2023a), "What the end of the US shale revolution would mean for the world - Fracking catapulted America to the top of the energy hierarchy, but low yields and a lack of reinvestment threaten that position", Financial Times, January 16, 2023, seen on https://www.ft.com/content/60747b3b-e6ea-47c0-938d-af515816d0f1 *"(…) But that transformative age is drawing to a close, say analysts, with unpredictable consequences. High costs and labor shortages now bedevil the shale patch. Wall Street wants profits paid back to investors, not reinvested in new rigs. Even with crude prices at $80 a barrel, a price far above the long-term average, shale producers still fear to splurge capital. To top it off, new wells are yielding less oil. (…)"*.

[33] WSJ (2023), "U.S. Shale Boom Shows Signs of Peaking as Big Oil Wells Disappear - America's biggest oil gushers are shrinking, evidence that companies have drilled through much of their best wells", The Wall Street Journal, March 8, 2023, seen on https://www.wsj.com/articles/u-s-shale-boom-shows-signs-of-peaking-as-big-oil-wells-disappear-2adef03f (2023b), "Oil executives warn of higher prices now that Opec is back 'in charge'", Financial Times, March 8, 2023, seen on https://www.ft.com/content/f1674a6e-39ae-4abb-ae2a-40fefb58d6b9

[34] Rystad (2023), "Evidence at odds with claims of dramatic shale productivity degradation - Talk of degradation



Source: Rystad Energy ShaleWellCube

entitled its first trimester survey: "Oil and gas expansion stalls amid surging costs and worsening outlooks" (Fed, 2023)[35]. The American EIA's monthly-published figures of extraction activity in the shale oil industry are a testimony of problems to come, while the decline in global production volumes accelerates[36] (cf. Figure 6, next page). If drilling ceases, the daily production of oil would drop by 600,000 b/d after one month, 1.2 million barrels after two months, and so on.

Consequences for investments with climatic impact

The myth of a voluntary decrease of oil demand at a global scale seems to be a thing of the past[37]. This myth participated in the collapse of the so-called "socially-responsible investment" (SRI), now possibly undermined for a long time. During the 2010's, the performance of a large part of SRI was fed by the artificially under-performing oil industry, penalized by the deflationary pressure of shale oil upon global oil prices. With the end of the "miracle" in the 2020's, the return to financial discipline, and therefore the return of the oil industry's financial profitability[38], spells the end of the over-performance of many SRI indices. The rise of interest rates possibly penalized speculative sectors such as the digital sector – of allegedly low-carbon intensity -, thereby inducing a chronic under-performance of its

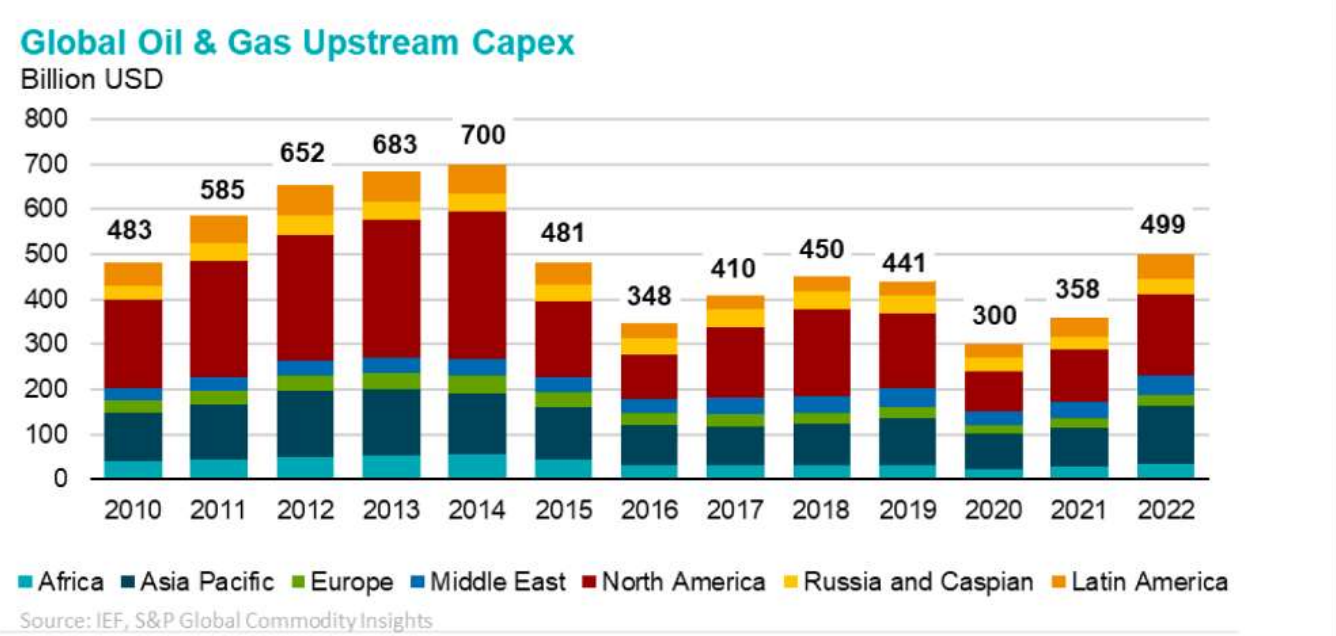
overblown, as ample top-tier locations remain untapped", Rystad Energy Shale Whitepaper, March 31, 2023, seen on https://sf-asset-manager.s3.amazonaws.com/97637/443/3677.pdf
March 2023 *"(…) Indeed, 2022 was the first year where there was some evidence of oil wells not being as productive as the year prior. There is a risk that 2021 was the year of peak productivity, but we are now entering a plateau, rather than observing precipitous declines that some fear could mark the beginning of the end of shale. (…)".*

[35] Fed (2023), "Dallas Fed Energy Survey - Oil and gas expansion stalls amid surging costs and worsening outlooks", Federal Reserve Bank of Dallas, March 29, 2023, seen on https://www.dallasfed.org/research/surveys/des/2023/2301

[36] US EIA - Drilling activity report

[37] See the EIA predictions on https://www.iea.org/reports/world-energy-outlook-2022/outlook-forenergy-demand

[38] Complementary data to this article, available on https://www.linkedin.com/in/michel-lepetit/



indices[39]. With an increasingly geologically constrained production, a growing number of reservoirs approaching maturity, and mediocre new discoveries, oil prices should increase on a long trend. The price of a barrel in 2022 triggered 499 billions of dollars of investments in hydrocarbons (IEF & S&P, 2023; graph 7)[40]. This figure was insufficient to send crude production back up, but it was adequate to stop a rapid decline in supply. However, this decline, if it was managed, would be necessary to face climate change: it is urgent in 2023 to reduce investments in hydrocarbons extraction if we want to preserve a livable planet. The mythical "peak oil demand" may remind us of the "oil consumption peak", concept that was developed by a few macroeconomists to explain the 1970's economical crisis, avoiding any reference to the energy crunch. Based on that concept, the 1973 crisis would have been triggered by the saturated level of home appliances in American households, which would have in turn slowed down their consumption. These two mythical oil demand peaks (1973; 21st century) illustrate the capacity of economical science to deny the actual pivotality of energy. Neither of these theories rely on any quantified analysis.

The mythical impact of climate policy

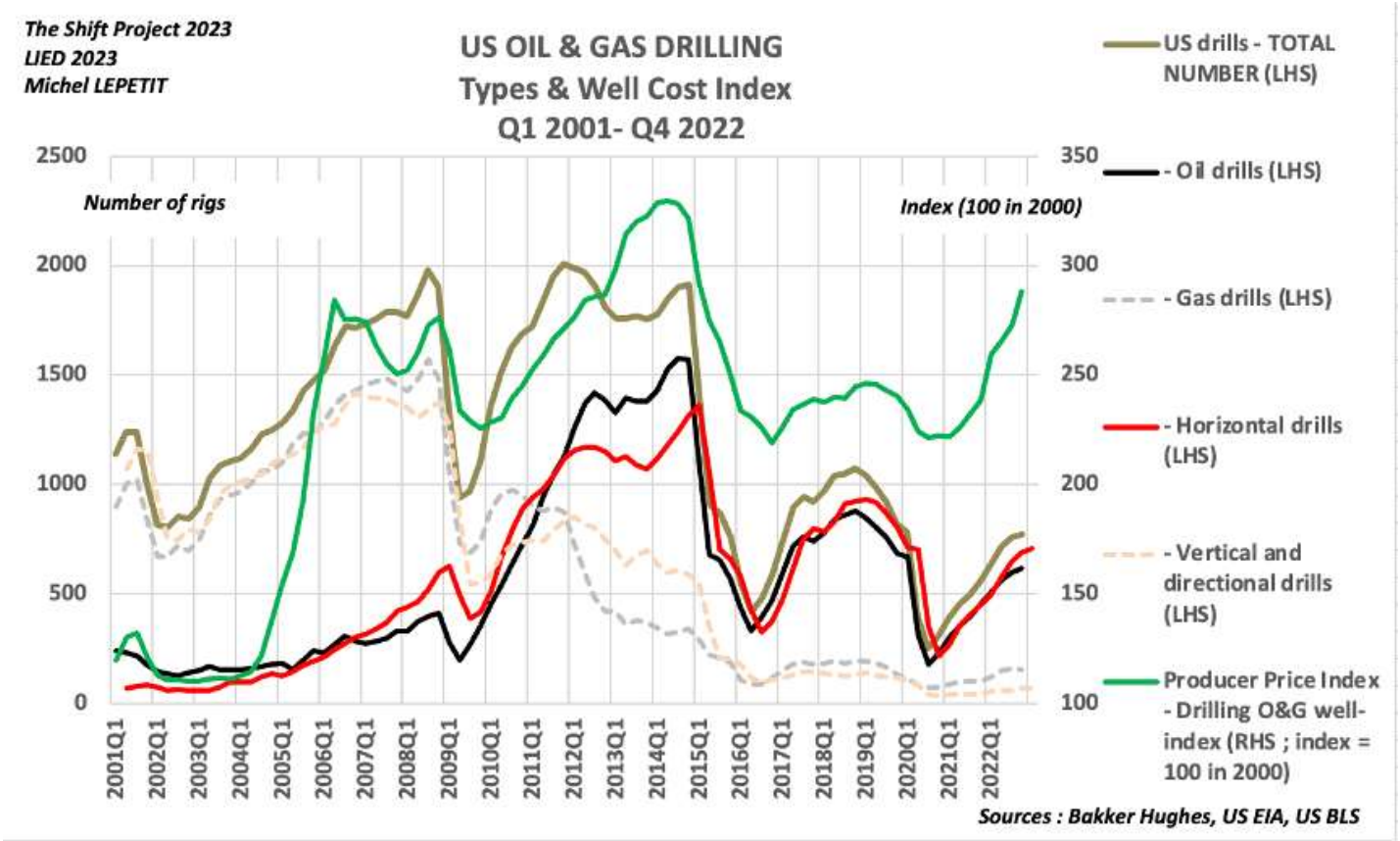
Falling short of demonstrating a decline in oil demand, some macroeconomists tried to demonstrate the influence of climate policy on oil supply. In April 2022, the International Monetary Fund (IMF, 2022)[41] ventured to do so, publishing an analysis of such an impact on oil and gas investments. They searched for an inflection point after 2015 – the year of COP 21 in Paris – between

[39] Complementary elements to this article, available on https://www.linkedin.com/in/michel-lepetit/

[40] IEF & S&P (2023), "Upstream oil and gas investment outlook 2023", A report by the International Energy Forum and S&P Global Commodity Insights, Feb. 2023, seen on https://www.ief.org/focus/ief-reports/upstream-investment-report-2023

[41] IMF (2022), "World Economic Outlook", IMF April 2022, seen at https://www.imf.org/en/Publications/WEO/Issues/2022/04/19/world-economic-outlook-april-2022, full text available at https://www.imf.org/-/media/Files/Publications/WEO/2022/April/English/text.ashx see: "Special Feature: Market Developments and the Pace of Fossil Fuel Divestment", p31

And p33 *"(…) Swings in capital expenditure are not unusual in the oil and gas industry, though. Using data from 1970 to 2019, an empirical analysis shows that oil and gas prices are the main drivers of capital expenditure (…) Fossil fuel investment followed a typical boom-bust cycle over the past decade. However, since oil and gas prices declined 50 percent between 2014 and 2016 and then recovered partially, the 40 percent decline in capital expenditure between 2014 and 2019 was deeper than the model's prediction, which suggests a 20 to 25 percent decline. While many factors could have been involved, the next section explores the role the clean energy transition may have played."*



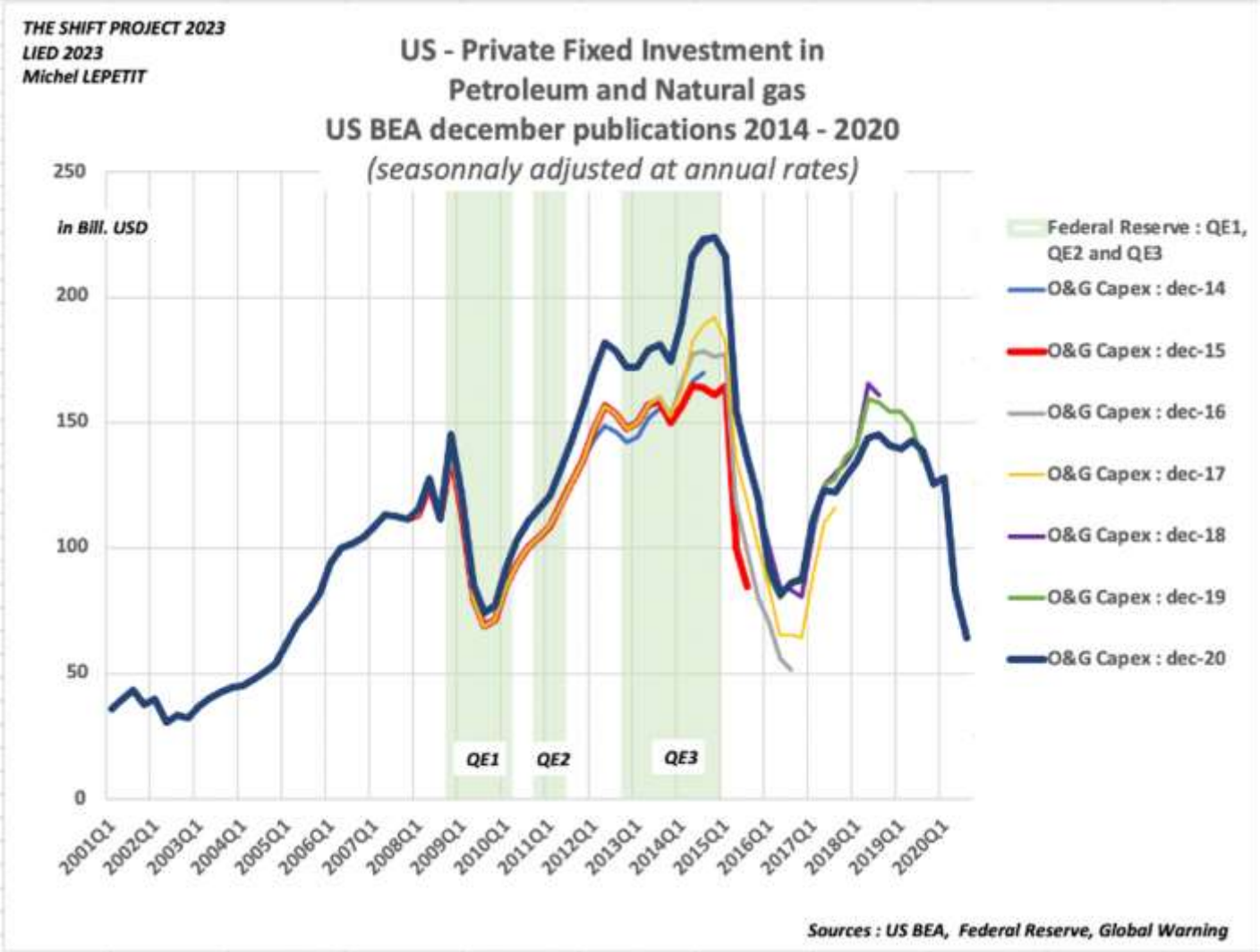
the price of oil and investments. This shows great confidence that social pressure would influence independent American oil companies (Fed, 2022b)[42] ; that oil industry "majors" would be able to commit to low-carbon investment plans; and would be able to honor such commitments, contrary to the outlook of anticipated petroleum investments for 2023 (IEF & S&P, 2023). Economists at the European Central Bank (ECB) (Schnabel, 2022)[43] and at the BRI (Karsten, 2022)[44] tried to explain the loosened link between the price of oil and hydrocarbons investments after 2000. Instead of focusing on the amounts of money invested in oil and gas exploration and production, they analyzed the number of active drilling sites. It is positive, and rare enough to be mentioned, that some macroeconomists relied on the real physical world to perform their analyses. Unfortunately, this approach was biased as it did not distinguish gas wells from oil wells; nor did it discriminate horizontal from vertical drilling. Lastly, the study did not take into account the strong inflation of production costs (see Figure 8 above). These macroeconomic attempts to attribute the relative lethargy of recent shale oil production to the link between "oil prices" and "level of investment", by looking for ruptures in either 2015 or 2020, seem tardy and unconvincing. The fact is that, until 2019, macroeconomists were lured by the data provided by the American administration. Indeed, the "irrational" behavior of shale oil investors, and

[42] Fed (2022b), Oil and gas expansion still solid; cost increases moderate, supply-chain delays persist, Dallas Fed Energy Survey, first quarter of 2022, seen on https://www.dallasfed.org/research/surveys/des/2022/2201#tab-questions Question : "Which of the following is the primary reason that publicly traded oil producers are restraining growth despite high oil prices?" Response : ["investor pressure to maintain capital discipline"]: 60% ; ["Environmental, social and governance issues]: 10%).

[43] Schnabel I. (2022), "Looking through higher energy prices ? Monetary policy and the green transition", European central bank, January 8th 2022, seen on https://www.ecb.europa.eu/press/key/date/2022/html/ecb.sp220108~0425a24eb7.en.html See Slide 4 : "Oil production is responding more slowly to rising prices". "(…) Last year's strong economic expansion, for example, was characterized by an atypically slow response of US shale oil production to rising oil prices, as such investments may no longer prove profitable to investors over the medium term – at least not to the same extent as they have done in the past, or as returns may become even more volatile (…)".

[44] Karsten A. (2022), "The return of inflation, BIS Geneve", April 5, 2022, seen at https://www.bis.org/speeches/sp220405.pdf See Graph 7 : "Energy supply has been slow to respond".

therefore their sensitivity to the US monetary policies, were hidden for a long time in the statistical data provided by the American administration. Figure 9 (next page) reconstitutes the history of investments in the oil industry, based on quarterly data from the Bureau of Economic Analysis (BEA). We see how, in December 2015, the temporal series



may have looked tightly correlated with the price of oil (The Economist, 2016)[45], just as it had been in the past. Besides, it is likely that BEA's internal econometric models favored this error of more than 500 billion dollars! Data were finally corrected at the end of 2018, showing the actual progression in investments, extraordinary both in terms of the amounts involved and their bursts.

Consequences of a global crude oil production peak

As mentioned in the introduction, the world peak production of crude oil associated with the history of shale oil will have consequence on macroeconomic, financial (Lepetit, 2022), geopolitical (FT, 2023)[46], macroprudential, environmental, and possibly even anthropological levels. From a macroeconomic viewpoint, in the hydrocarbon industry, a post-peak world may see an abnormal boost in the sector's profitability. First scenario: the strong profitability of industrial actors may decrease the need to resort to

[45] The Economist (2016), "The oil conundrum - Plunging prices have neither halted oil production nor stimulated a surge in global growth", Jan 23, 2016, seen at https://www.economist.com/briefing/2016/01/23/the-oil-conundrum See Graph 3 : "Energy sapping : US private fixed investment in energy". Also see the complements to this article uploaded on https://www.linkedin.com/in/michel-lepetit

[46] World Bank (2023), Falling long-term growth prospects: Trends, expectations, and policies", World Bank, March 2023, seen on https://openknowledge.worldbank.org/entities/publication/5c24beac-0ebb-4732-8078-d6252fca4a08

financial debt. Investors may then exhibit a "low-carbon" trajectory with no real effort but without truly impacting carbon emissions at a global scale. Second scenario: the oil sector becoming effectively a "rentier" sector and having lost its social purpose of searching for hydrocarbons, the pressure exerted by public opinion might induce its nationalization.

From a macroeconomic viewpoint, the unwanted decline in crude oil demand between 2018 and 2023 occurred within a long-term process initiated at the beginning of the 1970's, with an inevitable trend of worldwide productivity slow-down. In face of increasingly difficult access to oil – which is an energy with no substitute – Mankind has seen its economic productivity slowing down for half of a century. The shale oil "miracle", this new source of energy with much lower efficiency than conventional oil, did not reverse that trend. On the long term, global economic growth is slowing down ineluctably (World Bank, 2023[47]; IMF, 2023[48]).

The decline in oil demand which will accompany this peak oil will thus be of macroeconomic scale and, short of major changes, unvoluntary. Consequently, the decline will likely be chaotic, bringing with it regional and/or continental economic recessions, and/or local conflicts. It is urgent to voluntarily organize and plan a decrease in oil demand (The Shift Project, 2022)[49]. Short of the infamous individual carbon tax – stigmatized in France by the "yellow jackets'" protests – and its deliberate price signal, regulation and constraint will probably become necessary, along the lines of a "war economy" concept. For instance, planning a significant decrease of the speed limit on the roads would constitute an interesting idea in managing oil consumption, in France and in Europe as a start.

The Energy Return On energy Invested (EROI) is an attractive concept to physically explain the decreasing trend in global productivity. The EROI has been present throughout this article, for instance and specifically in association with nuclear fracking or gas production infrastructures… However, the EROI does not explain everything. If the EROI of shale oil hydrocarbons is low in comparison with that of OPEC conventional ones, the index ignores the favorable legal environment of private property rights belowground in the USA; or the pre-existence of oil and gas infrastructures in Texas before 2010; or the vibrancy of men and women of the industry. But most importantly, the EROI cannot possibly reflect the financial cause that explains the macroeconomic miracle of shale oil.

[47] World Bank (2023), Falling long-term growth prospects: Trends, expectations, and policies", World Bank, March 2023, seen on https://openknowledge.worldbank.org/entities/publication/5c24beac-0ebb-4732-8078-d6252fca4a08

[48] IMF (2013-2023), "IMF World Economic Outlook 2023", April 11 2023, seen on https://www.imf.org/en/Publications/WEO/Issues/2023/04/11/world-economic-outlook-april-2023

[49] The Shift Project (2022), FETP ; France Economic Transformation Plan ("PTEF : Plan de transformation de l'économie française"), 2022. See the PTEF reports that state the first proposals for the reduction of speed (1) on long range mobility (110 km/h on highway); and (2) on freight transport (80 km/h).