ENERGY TRANSITIONS – LESSONS FROM THE GREAT DEPRESSION

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Introduction

The massive change in energy systems required to significantly reduce global greenhouse gas emissions is equivalent to a transformation in what technology historian Thomas Hughes (1987) called a socio-technological regime. The low-carbon transition entails transformation of capital assets both for generating and for using energy, to overcome carbon lock-in (Dangerman & Schellnhuber, 2013; Kennedy & Corfee-Morlot, 2013; Kennedy, 2022; Kennedy, et al 2023; Rogelj et al 2015; Unruh, 2000; Williams et al 2012). The last time that the developed world undertook such a major energy system transformation was the 20th century transition from the *coal age* to the *oil age* – particularly for transportation. Although aggregate use of petroleum did not surpass coal in Europe and North America until after 1950 (Melsted & Pallua, 2018) – and coal is very much still used today – the transformation in ground transportation occurred much earlier. In the US, petroleum surpassed coal as the dominant transportation fuel in the early 1930s, with deep economic repercussions. Huber (2013) observes: "*In the United States, the last time the sociospatial organization of life – and energy consumption – was profoundly reorganized was during the 1930s*." Of course, the 1930s was the decade of the Great Depression, with severe levels of unemployment (Romer, 1993), the likes of which we would not wish to experience in the low-carbon transition.

Understanding the Great Depression has been called "*the Holy Grail of macroeconomics*" (Bernanke, 2000, p.6). Keynes (1936) developed his *General Theory of Employment, Interest and Money* during the early years of the Depression; and Robbins (2011) provided a neo-classical perspective in his 1934 book *The Great Depression*. Following Friedman & Schwartz (1963), several economists have interpreted the Depression from a monetarist perspective, including the impacts of tariffs on global trade (Hamilton 1987; Bernanke & James, 1991; Eichengreen, 1992; Temin, 1993; Crucini & Kahn, 1996; Bernanke, 2000; Eichengreen & Irwin, 2010). A variety of other economic interpretations of the Great Depression have been made (Temin 1976; Bernstein, 1987; White, 1990; Romer, 1990, 1993; Inklaar et al., 2011) – although all of these macroeconomic explanations are missing the critical role of energy.

In my recent work, I have demonstrated how the energy transition from a coal/railroad regime to a petroleum/automobile regime caused the Great Depression in the US (Kennedy, 2023). In short, the Depression entailed breaking the hegemonic control that the railroads held over the US economy. The railroads were essentially the country's main transportation system and its main energy supply system – and when the railroads declined due to competition from the automobile, the US energy supply was severely impacted. New biophysical economic methodology was applied in the study, building upon previous work on the modern US economy (Kennedy, 2022) and Great Britain during the Industrial Revolution (Kennedy 2020a,b, 2021).

At the macro-level, the methodology entailed mapping of energy use to capital stocks and investments in the economy. This was undertaken to quantify the key biophysical processes underlying growth and change in the economy, specifically: i) the energy used to build capital assets; ii) energy required to use capital assets; and iii) physical capital assets and energy itself used in the production, transformation and distribution of energy. These relationships can be seen in Figure 1, which divides the US economy into five categories of capital stock. A particularly important feature of Figure 1 is that it specifically shows the capital stock of railroads in the US economy of 1929. The value of the railroad assets was notably high at $42.3 billion. In practice though, railroads functionally overlapped – were part of – the capital stocks for: i) providing goods and services for consumption; ii) delivering energy; and iii) providing resource inputs for capital formation. This multi-functional characteristic of railroads underlay their essential role in prolonging the Great Depression.

A second aspect of the methodology entailed constructing a Sankey diagram showing the flows of various energy carriers (coal, oil, gas etc.) through the energy supply system. The energy flows were arranged around energy–supply capital stocks as shown in Figure 2. The Sankey diagram was useful for calculating the percentage of total primary energy supply carried by the railroads.

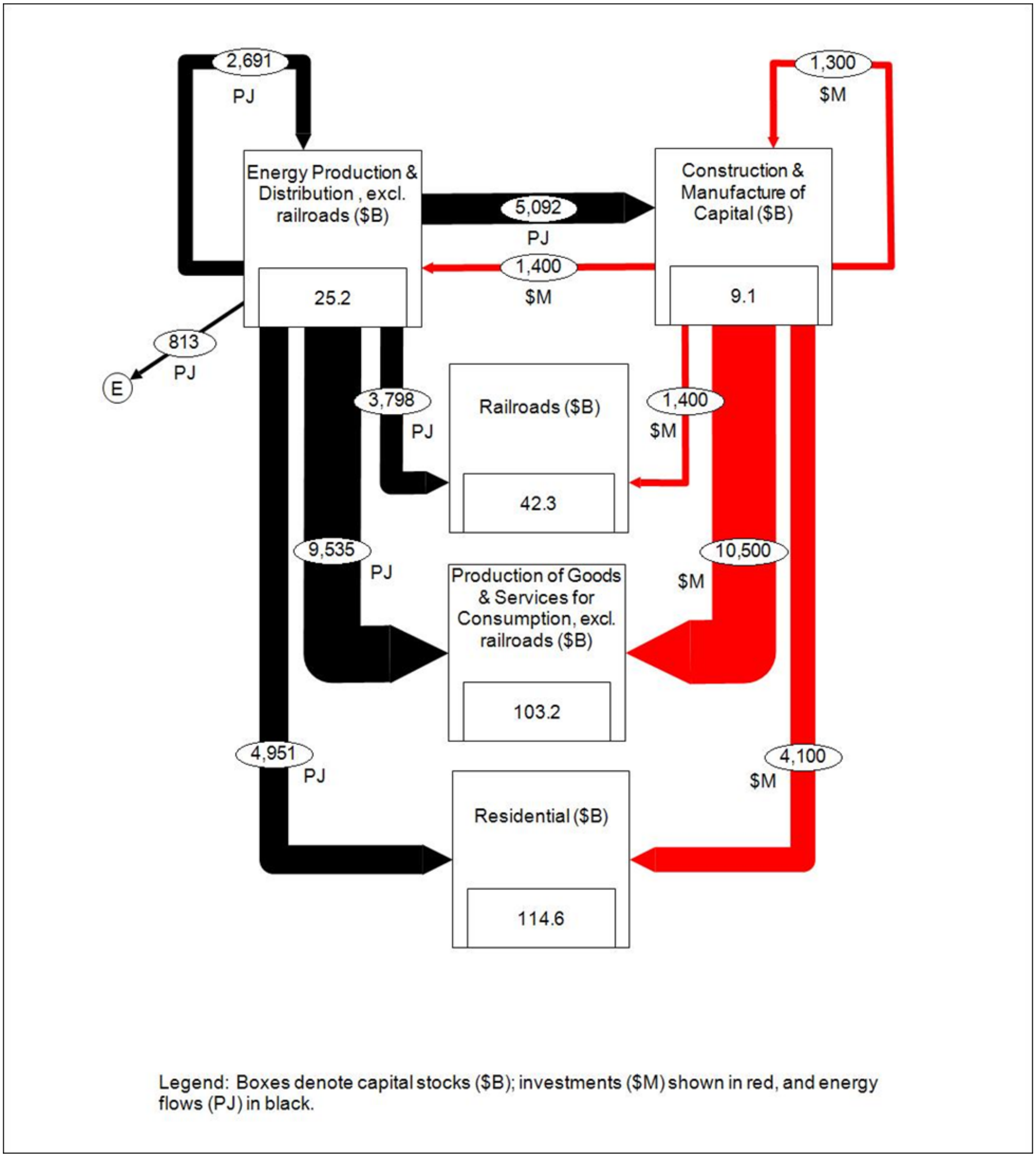

Figure 1. Energy flows (PJ) and capital investments ($ million, 1929) in the US economy for 1929. Five categories of capital stocks are shown: railroads; energy production and distribution (excluding railroads); production of goods and services for final consumption (excluding railroads); construction and manufacturing of capital assets; and residential. (Figure 4 from Kennedy, 2023)

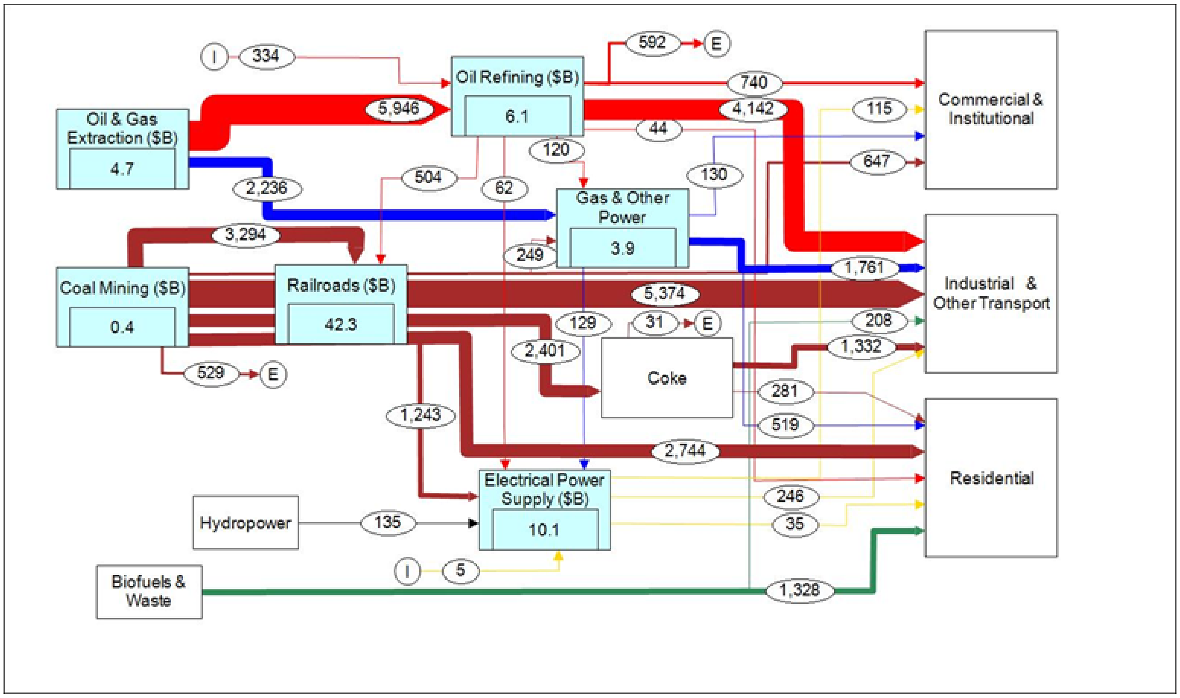

Figure 2. US Energy flows (PJ) and energy-supply capital stocks ($billion, current) for 1929. Note: useful heat, waste heat and some energy transfers are omitted; E=export; I=import; petroleum shown in red; natural gas and manufactured gas in dark blue; coal and coke in brown; fire wood, biomass & waste in green; electricity in yellow. (Figure 5 b from Kennedy, 2023)

The objective of the current paper is to assess what lessons from the Great Depression might apply to the modern day energy transition to a low-carbon economy. I will start by recapping the key findings from my previous study on the cause of the Depression – and expand upon content describing how discovery of massive oil fields in the US Southwest triggered the Great Crash of 1929. Lessons for the low-carbon transition will then be determined by examining five broad characteristics of the Great Depression, and further potential insights from biophysical economics on the broader field of macroeconomics will be discussed.

Understanding the Great Depression as an Energy Transition

The key findings from my previous paper (Kennedy, 2023) explaining how the Great Depression in the US was caused by an energy transition are summarized as follows:

1. There was a transition in US ground transportation from a coal/railroad regime to petroleum/automobiles in the late 1920s and 1930s. Petroleum surpassed coal as the predominant fuel for US ground transportation in 1931, during the early years of the Great Depression (Figure 3). A few trains in the Southwest had been powered by petroleum since the early 1900s. Energy use by motor-vehicles surpassed railroads in 1938.
2. In 1929, railroads – including urban systems – accounted for 24% of the stock of non-residential capital assets in the US economy (Figure 1). This was an exceptionally large proportion of the capital stock to be held by one industry. Moreover, railroads were part of the old established socio-technological regime; some of them became obsolete and went bankrupt in the 1930s.
3. Investment in railroads weakened in the 1920s and fell severely in the 1930s. The weakening of railroads investment in the 1920s was due to competition from automobiles for passenger transportation, aided by discovery of large oil reserves towards the end of the decade, and possibly the impacts of regulation by the Interstate Commerce Commission. By 1925, investments in motor vehicles, tractors and other internal combustion engines all exceeded those in steam locomotives. From 1929 to 1933, annual investments in railroads declined by 79%. They remained below the 1929-level for the rest of the 1930s.

4. Railroads were still a critical part of the functioning of the economy – they were the backbone of industry. Railroads supplied about 70% to 75% of US energy needs, including ~70% of the energy required for capital formation (from calculations based upon Figure 2).
5. Looking in more detail, a decline in the number of rail freight cars was a constraint on the economy. Devine (1925) noted that shortage of rail cars put a limit on the supply of coal during periods of high demand. During WWII, Hultgren (1942, p. 334) went further, recognizing that "*car supply fixes a limit to the general expansion of industry*." Data from the US Census Bureau showed that the number of freight cars decreased from 2.414 million to 2.323 million between 1925 and 1929; and then declined approximately 20% further by 1935. "*In biophysical terms, the US economy's main energy delivery system – coal carried by railcars – was hamstrung.*" (Kennedy, 2023, p1).
6. The new petroleum / motor-vehicle regime was still partially dependent on the older coal / railroad regime. In 1929, almost half (46%) of refined petroleum products were transported by rail oil cars (Williamson et al., 1963); this shows the lock-in of railroads as the dominant socio-technological regime (Melstead & Palua, 2018; Hughes, 1987).
7. While the railroads – as with other economic sectors – suffered during the Great Depression, essentially the pain of the Depression was all about "*breaking the railroad's hegemony on the United States economy*" (Kennedy, 2023, p.12).

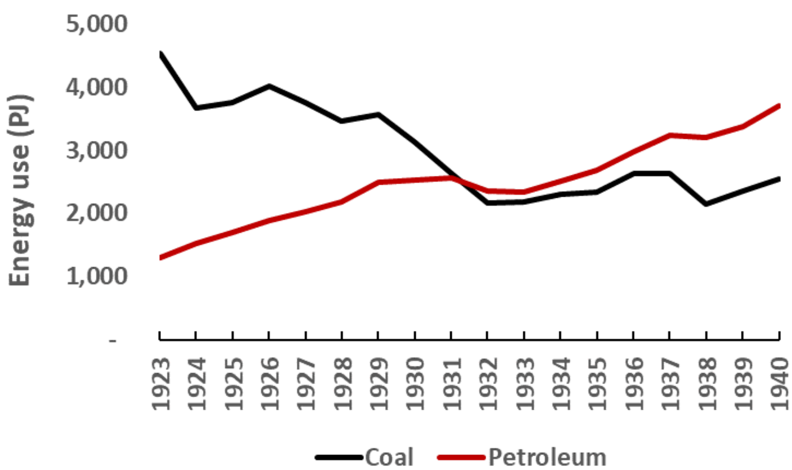

Figure 3. Use of petroleum for ground transportation in the United States surpassed coal in 1931 (adapted from Figure 1b in Kennedy, 2023)

The Trigger for the Great Crash

The transition from coal to oil in ground transportation can explain why the Great Depression was so long and protracted, but further evidence shows that the petroleum sector also seemingly had a key part in triggering the Great Crash of 1929. In short, discoveries of huge new oil fields in 1929 led to a major reduction in oil prices and announcement of oil supply certainty, which likely underlay the Great Crash. To understand the mechanism, it is necessary to first recap the history of US petroleum discovery in the 1920s.

For most of the 1920s, there was a concern that the US had a limited supply of petroleum reserves. A study by the US Geological Survey and American Association of Petroleum Geologists, published in January 1922, concluded that the US only had sufficient supplies to provide for another 18 to 20 years, at then rates of consumption (US Geological Survey, 1922; Dennis, 1985). In 1920, petroleum provided only 12% of the US primary energy consumption, whereas coal provided 73% (Schurr et al, 1960) – although this changed as motor-vehicle use grew over the decade. There was little increase in petroleum reserves during the early years of the decade; indeed, the quantity of known reserves declined in 1922 and 1924 (Figure 4). In 1925, Edward Devine, a member of the Federal Coal Commission concluded there was no possibility of oil replacing coal as the dominant form of energy supply for the US (Devine, 1925). The American Petroleum Institute was more optimistic; in 1925, they published a study suggesting that petroleum reserves were nearly inexhaustible (API, 1925; Dennis, 1985). The API study was not taken seriously, however; a survey of state geologists found that the API estimates ranged from 'absurd' to 'wholly inaccurate' – and the report failed to change the public discourse on oil uncertainty (Dennis, 1985; Olien & Olien, 1993). There was a modest increase in known petroleum reserves in 1925, with larger discoveries in 1927 (Figure 4) – possibly aided by advances in seismology. In 1928, a report by the Federal Oil Conservation Board (FOCB) – that President Coolidge had founded to address concerns over oil scarcity and waste – noted that records of oil production and consumption were being broken (US Department of the Interior, 1928). The 1928 FOCB report, nonetheless, primarily focussed on examining the potential of alternative oil sources, such as shale oil, oil derived from coal, and agricultural oil products, as well as energy efficiency measures. Summarizing the debate, Olien & Olien (1993, p.61) noted: "*Though the FOCB decided in 1928 that oil famine was not imminent, overall, conservationists continued to control public discourse on petroleum and to insist that America was running out of oil.*"

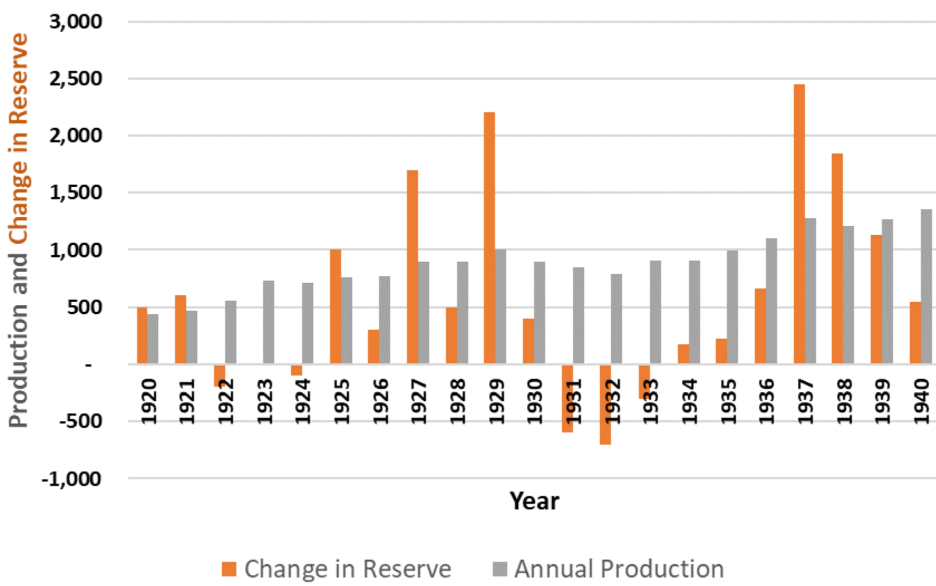

Figure 4. Changes in proven US crude petroleum reserves, and annual production, 1920 to 1940. Units: Millions of 42-gallon barrels (adapted from Figure 3 of Kennedy, 2023; based on data from US Census Bureau Historical Statistics).

In 1929, however, there was discovery of massive new oil fields in the US Southwest. Kemp (2015) remarked on the findings as follows:

"*In October 1929, U.S. commercial crude stocks peaked at a staggering 545 million barrels, following the discovery of a series of huge new oil fields in Oklahoma, Texas, the rest of the Southwest and California*."

In the above quote, Kemp refers to stocks of crude oil that peaked in October 1929. These were stocks of crude held by petroleum companies as a hedge against uncertainty in supply.

When the Great Crash occurred – between October 24 and 29, 1929 – the *New York Times* noted that the cause of the Crash was thought to be "*inward rather than outward*" (Topics on Wall Street, p.43, Oct. 24, 1929). In other words, there was no apparent external news that upset the market. With hindsight, though, we can now see that there was indeed other news reported in the *New York Times* that connects major changes in the petroleum industry to the Great Crash (Figure 5).

New York Times, Oct. 22, 1929

STANDARD OIL CUTS CALIFORNIA PRICES

Reduction of 50 to 75 Cents a Barrel Attributed to Big Overproduction.

OTHERS TO FALL IN LINE

Shell Company Announces It Will Meet New Rates—Union Oil Expected to Act Also.

New York Times, Oct. 29, 1929

STANDARD OIL CUTS BIG CRUDE STORAGE

New Jersey Company Announces Reduction of 20,000,000 Barrels, or 22%, in 2½ Years.

REVERSES PREVIOUS POLICY

Future Held No Longer Uncertain and Utilization of Stocks Financially Desirable.

Figure 5. Headlines from the *New York Times* pertaining to the petroleum industry at the time of the Great Crash. A large cut in California oil prices was reported on October 22 – two days before Black Thursday. An announcement that future supplies of oil were no longer uncertain – and thus a policy on storage could be reversed – was made on October 29 (Black Tuesday).

On October 22, 1929 – two days prior to Black Thursday – the *New York Times* reported that the Standard Oil Company of California had announced a "*drastic reduction in crude oil prices*" due to "*long-continued, unrestrained overproduction.*" The size of the oil price cut was reported for two different oil densities at three different locations, with the former prices expressed over a range of values. Using median values for former crude prices, I calculated that the price cuts ranged between 50% and 60%. Using the lowest and highest values of former crude prices, the range of price cuts was between 43% and 64%. Broadly speaking, the oil price cuts averaged more than fifty percent.

The price cuts only applied to California, but this was an important US market in two respects. First, from a production perspective, California became the largest oil producing state during the 1920s (Dennis, 1985). Second, California was also a major consumer of oil; in 1929 only New York state had more motor vehicle registrations than California – and only by about 14%.[1] As the *New York Times* headline noted, the Shell Oil Company immediately followed the price reductions made by Standard Oil – and there was a short article the next day, October 23, confirming that Union Oil of Texas had also followed suite. Such announcements of massive oil price cuts in a key US market, just one to two days before Black Thursday, are close enough that they could be considered the trigger for the Great Crash.

Moreover, there was a further article in the *New York Times*, which supports the overall hypothesis that oil price cuts, following discovery of huge new oil fields, caused the Great Crash. On Black Thursday, the New York Stock Exchange lost about $4 billion in paper value – with record declines in the last hour of trading, but then the major New York banks stepped in and attempted to resuscitate the market (Galbraith, 1954). This was temporarily successful,

[1] In 1929, California had 1,991,602 total vehicle registrations (automobiles, buses and trucks); New York State had 2,283,573. Source: https://www.fhwa.dot.gov/ohim/summary95/mv201.pdf accessed June 7, 2023

but the following Monday – October 28 – also witnessed a major loss of stock values, and then on October 29 – Black Tuesday – stocks lost a further $14 billion. Remarkably, on Black Tuesday, the *New York Times* printed another article "Standard Oil Cuts Big Crude Storage" which began:

"Holding that the future supply of crude oil was no longer an uncertainty, the Standard Oil Company of New Jersey yesterday announced a reversal of the long established policy of storage of crude oil against a possible shortage."

This article was essentially an announcement that America no longer needed to worry about running out of oil. Standard Oil of New Jersey – serving the other major US petroleum market – did more than just say we think there is plenty of oil now, they reversed their policy of storing crude oil as a hedge against future possible shortages.

Given the increase in known oil reserves in 1927 (Figure 4), it could be asked why clear recognition of oil supply certainty did not occur then. The October 29, 1929, *New York Times* article noted that Standard Oil of New Jersey had gradually been reducing its oil storage since 1927, but it seemingly did not make this public, nor formally reverse its policy of storing crude against uncertainty of supply. Moreover, the industry overall increased its crude stocks – and the public perception was that oil was still scarce (Olien & Olien, 1993). In summary, then, we can see that the Great Crash of 1929 was triggered by developments in the petroleum industry – and was essentially the tipping point from the *Coal Age* to the *Oil Age.*

Lessons for the Low-carbon Transition

We can draw lessons from the Great Depression by examining five broad characteristics of the energy transformation in the current context of the low-carbon transition. Specifically, the Great Depression entailed: i) a change of energy carrier; ii) change of transportation mode; iii) sudden discovery of new energy resources; iv) hegemonic control of the energy and transport system; v) and lock-in of socio-technological regime (Table 1).

Similar to the Great Depression, the low-carbon transition obviously entails a change of energy carrier – perhaps to several forms. The Great Depression primarily involved a change from coal to petroleum-based ground transportation, although there was an increase in natural gas use as well. The low-carbon transition has so far mainly entailed replacement of fossil fuels with electricity from renewable sources, although other energy carriers such as hydrogen and biofuels may have an increasing role too. While the Great Crash of 1929 was arguably a tipping point brought on by a large cut in Californian crude oil prices, changes in energy carriers are themselves gradual. This might possibly suggest that the change in energy carrier in itself may not cause a depression.

An important distinction of the Great Depression is that, beyond a change in energy carrier, it also entailed a change in the dominant transportation mode. The number of registered automobiles in the US increased by about a factor of four over the 1920s, which led to a decrease in demand for rail travel. Between 1925 and 1934, the number of passengers carried by railroads declined by 50%. Commercial air travel also began in the late 1920s, although passenger volumes were small at the time. With the low-carbon transition, it is uncertain whether major changes in transportation mode will occur. Replacement of gasoline and diesel-powered vehicles with electric vehicles does not entail a change in mode. A possible consideration, however, is that the sheer amount of energy required in electrifying transportation is too large – and so some degree of shift towards a less energy intensive mode, such as electric bicycles, might be necessary. The change in transportation mode stemming from the 1930s also involved changes in urban form – an evolution in the design of cities or change in the "*sociospatial organization of life*" as Huber (2013) noted.

A third key characteristic of the Great Depression was that it occurred following sudden discovery of new energy resources. In the late 1920s – and in particular 1929 – massive new oil fields were discovered in California, Oklahoma, Texas, and elsewhere in the US Southwest. Could discovery of large lithium, cadmium, or rare earth metal deposits have a similar impact today? It is hard to imagine that such a discovery could be as significant as the oil gushers of the late 1920s in transforming the transportation sector. Perhaps, however, rapid improvement in a technological process could dramatically decrease the cost of electric batteries or hydrogen production, for example, leading to similar impacts as discovery of new energy resources.

Characteristic of the Great Depression	Occurrence during the Great Depression	Possible Occurrence during the Low-carbon Transition
Change of energy carrier	Coal to oil (with natural gas following)	Replacement of fossil fuels with electricity from renewable sources; biofuels and hydrogen.
Change of transportation mode (accompanied by changes in urban form)	Rail to motor-vehicles (plus emergence of commercial airplanes)	Uncertain. Establishment of electric vehicles does not entail a change in mode, but the amount of energy required might require spatial reconfiguration.
Sudden discovery of new energy resources	Crude oil gushers in US Southwest	Uncertain. What would be the impact of a large discovery of lithium or cadmium, or a sudden technological breakthrough?
Hegemonic control of energy & transport system	Railroads owned 24% of non-residential capital stock; and controlled many coal mines.	Ownership is more dispersed today. The global oil & gas industry is powerful, but separate from the auto industry, trucking industry, utilities, airlines, roads & highways.
Lock-in of socio-technological regime	Exemplified by 46% of refined petroleum products being carried by railroads	Our economies are still heavily reliant on petroleum-based transportation; and fossil fuels for electricity generation, and heating, etc. Electric vehicles are carried to auto dealerships on diesel-powered trucks.

Table 1. Analysis of key characteristics of the Great Depression in the context of the low-carbon transition.

The level of hegemonic control over the energy and transportation systems that railroads held in the 1920s has no comparison today; so this fourth characteristic of the Great Depression is perhaps less strong for the low-carbon transition. By way of comparison, proportions of non-residential capital assets in the US economy for 2019, were 6% for the transportation and warehousing sector; 10% for highways and streets; and 8% for utilities (Kennedy, 2023). In 1929, the railroads were not only the dominant mode of land-based transportation, they also controlled 70 to 75% of the US energy supply system. In the modern economy, the ownership of assets for transportation and energy supply is more diverse with substantial capital stocks in oil & gas, the auto industry, trucking industry, utilities, airlines, and roads & highways. All of these industries or sectors existed in 1929 too, but they were dwarfed by the railroads.

The low-carbon transition, perhaps carries the risk of establishing an energy regime that is more hegemonic than currently – with electrical utilities becoming increasingly dominant. Increased electrification (with decarbonisation of electricity) is certainly an important strategy for deep decarbonisation (Williams et al. 2012; Stewart et al., 2018) and if electricity provides an increasingly higher percentage of end-use energy, then utilities could grow to become like railroads of the 1920s. This need not be the case, however, as utilities conversely may have to change business models under widespread adoption of building or community scale renewable energy generation (Kennedy et al. 2017).

Irrespective of the degree to which the low-carbon transition requires overcoming hegemonic control today, there is unquestionably lock-in to the current fossil fuel based socio-technological regime. This is similar to, though broader than, the notion of *carbon lock-in*, by which greenhouse gas emissions are strongly coupled with infrastructure systems, institutional design and consumer behaviour. (Unruh, 2000; Seto et al. 2016). Our economies are still heavily reliant on petroleum-based transportation; and fossil fuels for electricity generation, and heating, etc.

One aspect of lock-in of socio-technological regime is that a new, emerging regime is dependent upon the existing regime in order to grow. This was exemplified in 1929, by almost half of the refined petroleum products requiring transportation by railroads to get to market. A parallel example today is the delivery of electric vehicles to car dealership on board of large diesel-powered tractor-trailers. Adding to this example, is the challenge that use of electric vehicles in countries or jurisdictions with carbon-intensive electricity grids – above ~600 t CO_2e per GW.hr does not actually reduce emissions (Kennedy 2015).

If carbon lock-in were to be rapidly overcome, then the potential economic challenge of creating stranded assets arises. Lock-in to the current fossil-fuel dominated regime is clearly problematic as it hinders progress in reducing greenhouse gas emissions. When lock-in is broken, however, we potentially face the economic challenge of creating stranded assets. Closing down of fossil-fuel related capital assets, such as oil refineries or gas pipelines, before the end of their useful life constitutes a loss of capital in the economy – and associated employment. Recent analysis for the US economy, however, shows that there is a low likelihood of major capital assets in the petroleum supply chain becoming stranded (Kennedy et al, 2023). This is because the annual depreciation rates for oil refineries and crude oil extraction assets are relatively high (~ 8 to 10%). Only for petroleum pipelines, with lower annual rates of depreciation (~2.5%), is the potential of creating stranded assets more likely. More broadly, the economically efficient rate of decarbonisation, with demand for fossil fuels declining at the same rate as their capital assets depreciate, is so rapid that it is hard for assets to become stranded (Kennedy et al, 2023).

Further Reflections

A final lesson from the Great Depression should perhaps be humility in our understanding of macroeconomic processes. In *The Great Slump of 1930*, written one year into the Depression, Keynes (1930, p. 126) observed:

"We have involved ourselves in a colossal muddle, having blundered in the control of a delicate machine, the workings of which we do not understand."

Keynes use of the metaphor that the economy was like a "delicate machine" is ironic, because machines require energy to function – and when Keynes developed his *General Theory of Employment, Interest and Money* during the Depression, the role of energy was given no consideration.

In Lionel Robbins' 1934 book *The Great Depression*, he displays a similar degree of humility, noting:

"*At this point it is necessary to proceed with great caution. Whatever be the ultimate truth with regard to the origin of this depression, one thing is certain, that no one explanation is capable of explaining all its different aspects. As we shall see in more detail in the next chapter, the fundamental causes, whatever they may be, have operated in a milieu more than usually disturbed by external changes and secondary oscillations, and their manifestations are thus inevitably complicated. It will take years of careful scrutiny of the available material before we can hope to be in a position to pronounce with complete confidence on these matters, and it is not certain that we shall ever reach this stage.*" (Robbins, p.44 of 2011 version)

In explaining changes in the production of capital goods during the 1920s, Robbins provided a theory anchored on monetary policy. Intriguingly, however, he briefly flirted with other possible causes including "*discovery of new natural resources*" (Robbins, p.42 of 2011 version), but unfortunately did not pursue that direction further.

Attempts to understand the Great Depression were important for development of the field of macroeconomics (Bernanke, 2000). Much progress in macroeconomics has, no doubt, been made over the past ninety years. Given, however, that we are only just beginning to understand the role of an energy transition in the Great Depression, this suggests that macroeconomics could learn more from biophysical economics (Cleveland, 1987; Georgescu-Roegen, 1971; Haberl, et al 2016; Hall & Klitgaard, 2018). Lying beyond mainstream economics, biophysical economics has developed several concepts that potentially might impact macroeconomics. These include work on: embodied energy (Hannon et al. 1983, 1985); energy-return on energy investment (Cleveland et al, 1984; Guilford et al., 2011); and material flows (Krausmann et al. 2008; Gierlinger & Krausmann, 2012); as well as studies of the role energy, or useful work, in economic growth more broadly (Ayres, et al, 2003; Ayres & Voudouris, 2014).

Conclusions

The Great Depression was caused by an energy transition, but it does not necessarily follow that all energy transitions involve an economic depression. Of the five characteristics of the Great Depression reviewed here (Table 1) only two – change of energy carrier and lock-in of socio-technological regime – clearly apply to the low-carbon transition. There is no hegemonic industry controlling the energy and transportation systems comparable to railroads in 1929, and a major change of transportation mode does not appear imminent, at least at the current time. The nature of the low-carbon transition – requiring construction of capital assets to produce and exploit renewable energy sources – also makes sudden discovery of a new energy source seem less likely, or relevant, than the discovery of oil gushers in 1929. There is, however, the possibility that a rapid technological breakthrough might have similar impacts. Moreover, the whole point about such discoveries is that they are a surprise – and so are obviously hard to predict. Overall, without sudden access to new energy supplies – which caused the Great Crash – nor a hegemonic industry controlling the economy – which prolonged the Great Depression – it seems unlikely that the low-carbon transition will be as economically painful as the Great Depression. Nonetheless, it would be foolish to assume that breaking out of the current socio-technological regime can be done without societal disruption, especially if some form of tipping point is experienced.

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