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An Overview of the Semiconductor Industry and a Framework for Creating a Semiconductor Strategy for the UK

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Introduction

1. Fortune estimated the global semiconductor market to be worth $426 billion in 2020, growing at a compound annual rate of 8.6% to $803 billion in 2028.[1] During COVID, the industry saw a significant increase in demand and experienced a global shortage that has adversely impacted a variety of industries, with automotive hit exceptionally hard. This shortage has created an interest by most countries in improving their *on-shore* and *near-shore* chip design and manufacturing capability. Indeed, semiconductors are so important that they have risen from being simply of economic interest, to some experts equating semiconductor sovereignty with national sovereignty.[2] Electropages[3] reported *"… modern society has become dependent on semiconductor technology to the point where it simply cannot function without placing it into essential products such as water and food"* and *"…a country that can become chip sovereign can withstand any external force that may affect [sic] the global semiconductor industry"*, implying of course that one that is not chip sovereign, cannot and will suffer. Semiconductors are frequently called *"the oil of the 21st century"* because they are increasingly a primary influence of geopolitics and the capital markets.

2. The EU and the US are pursuing various initiatives designed to ensure semiconductor sovereignty, investing tens of billions of dollars/euros of government funds in so-

[1] Fortune Business Insights, Report ID: FBI102365 (https://www.fortunebusinessinsights.com/semiconductor-market-102365)
[2] *Europe plans a Chips Act to boost semiconductor sovereignty*, Techcrunch, Natasha Lomas, September 15, 2021 (https://techcrunch.com/2021/09/15/europe-plans-a-chips-act-to-boost-semiconductor-sovereignty)
[3] *EU now working towards semiconductor sovereignty*, Electopages, Robin Mitchell, 17 September 2021 (https://www.electropages.com/blog/2021/09/eu-now-working-towards-semiconductor-sovereignty)

called *Chip Acts*. These initiatives are designed to boost semiconductor sovereignty and national security as part of a broader digital strategy and gained increased focus and public interest with the US-China trade war, the Russia-Ukraine war, as well as China's aggressive actions in Hong Kong, Tibet, Xinjiang (with the Uyghur's), skirmishes along its India border, and threats against and military sorties near Taiwan.

3. This paper is written for non-experts in semiconductor technology with the goal of providing a broad, albeit simplified, understanding of the semiconductor industry, its structure, value/supply chain, where the UK participates, its relative strengths and weaknesses, and considerations from a national and economic security standpoint. Some preliminary conclusions are presented, but the most important element is a strategic framework that can be evolved given the dynamic nature of the technology industry to create a strategic plan for the UK. Note that the industry typically uses the terms value chain and supply chain interchangeably even though supply chain is technically associated with moving physical assets whilst value chain is about relative competitive advantage within the chain.

<u>Semiconductors – What Are They?</u>

4. One can think of semiconductors as nothing more than tiny "switches" called **transistors** (invented in 1947) that are fabricated in specific types of materials that sometimes allow electric current (electrons) to flow, and sometimes not to – hence the word <u>semi</u>conductor.

5. There are many different materials that are semiconducting. The most famous and most used is Silicon (Si), but there are many others including Germanium (Ge), Graphene (C), and compounds such as Gallium-Arsenide (GaAs), Gallium Nitride (GaN), and Silicon Carbide (SiC), amongst others. Ironically, Silicon it is not the "best" semiconducting material, but the one that has the "best" overall properties for mass production, which is why it dominates high-volume mass production applications. The other materials are used for specific, frequently higher-performance, higher power, semiconductor applications including radio frequency (RF) and wireline

communications, power electronics, and sensors that are also extremely important and complement Silicon.

6. In 1958 the **integrated circuit** (IC) was invented which put multiple transistors on a single substrate. ICs are frequently called **chips**. Since their invention, the size of the transistors has decreased dramatically, and the complexity of the chips increased dramatically to create the unbelievable number of electronic devices which are so pervasive today.

7. In general, there are two types of circuits – **digital** and **analog**. Digital circuits are discrete, or binary "0s" and "1s", whilst analog circuits are continuous. The different types of circuits can be used to make two traditional types of chips – **logic** and **memory**. Memory chips store information, whilst logic chips process information. The most common logic chips are microprocessors often referred to as **CPUs** for central processing unit, and **GPUs** for graphics processing unit. Today such processor chips also have memory on them as well as circuits to communicate with adjacent memory chips (normally DRAM which stands for dynamic random-access memory used to store larger programs and data) and/or other logic chips. Other types of chips include analog and mixed signal, with the latter containing both analog and digital circuits (hence the word mixed). The important thing to note here is that there is a myriad of different types of chips.

8. The most advanced and complicated chips today are frequently called "system on chip", or **SoC** because they are complete systems in themselves, often comprised of multiple CPUs, GPUs, other digital circuitry for specific processing, memory, and interfaces to communicate with other chips and external memory. Simpler chips are often referred to as **Small or Medium Scale Integration (SSI/MSI),** and very basic semiconductor devices, such as individual transistors and diodes, as **discrete(s)**.

9. Digital chips like CPUs, GPUs, and memory "scale" and benefit from increasingly smaller transistors, whilst analog and mixed signal chips tend not to scale as well. Consequently, digital chips benefit from the newer, more advanced manufacturing processes, whilst analog and mixed signal chips tend not to and are optimally manufactured in older manufacturing processes. This is a very important distinction

because most electronic systems have all kinds of chips and therefore require all types of manufacturing technologies, old and new.

Semiconductor Industry Structure, Supply Chain, and Disaggregation

10. When the semiconductor industry was young most of the participants were **vertically integrated**, meaning that they did essentially everything to produce a chip. As the industry matured and the complexity of chips increased, however, the industry began **disaggregating**, meaning that specialist companies emerged to focus on and "take over" specific parts of the supply chain. Disaggregation is economically very efficient and beneficial for the industry, but it does complicate the supply chain and creates issues when the supply chain involves companies that are offshore, and even more complicated when these offshore companies are controlled or influenced by strategic adversaries. The important point to understand here is that if one loses any part of a disaggregated supply chain one cannot produce an end product. For instance, one can have the most advanced design capability on the planet, but if one cannot get all the design tools the product cannot be made. Or one can build a £20 billion fabrication plant (commonly called a fab), but if one does not have designs to run in the fab it is useless.

11. Also important to note is the fact that the US controls or essentially controls much of the semiconductor supply chain, which is exactly the reason for the US-China trade war and the Chinese government's interest in acquiring semiconductor assets globally, especially outside of the US, since it has largely been blocked by CFIUS (the Committee on Foreign Investment in the United States) – A case study on Imagination Technologies and Newport Wafer fab is presented below.

12. Figure 1 below depicts a simplified view of the disaggregated semiconductor supply chain today. The disaggregated elements are:

- **Electronic Design Automation (EDA)** tools, which are software used to design chips. EDA tools are critical because the most complex chip today has over two trillion transistors and advanced SoCs often have around 30-40 billion transistors, all clearly needing automation to design efficiently. Synopsys and Cadence are the most well-known EDA companies, followed by Siemens with its acquisition of Mentor Graphics.

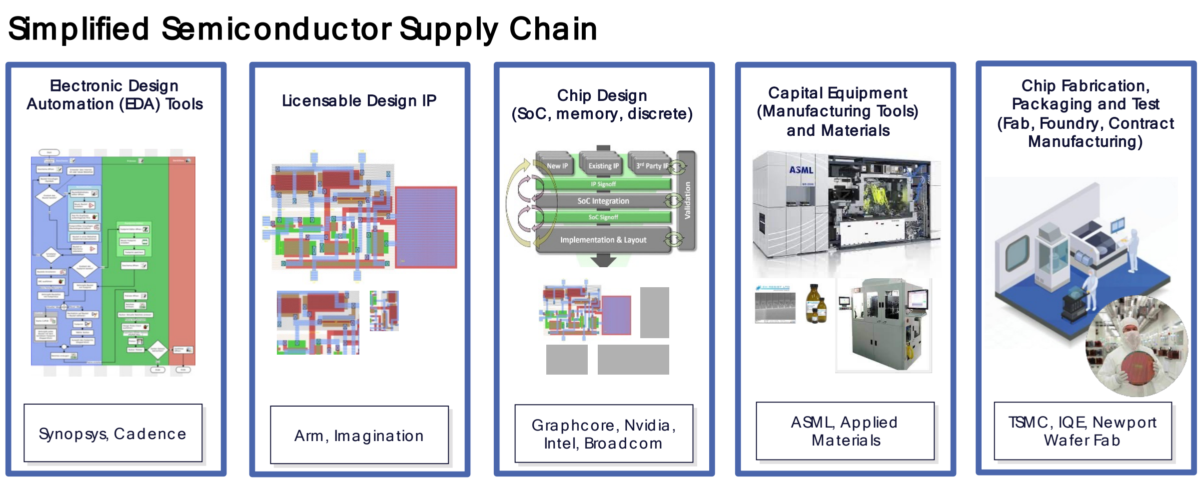
- **Licensable Design IP**, which are elements of an SoC that are designed by one company and licensed to others to integrate with EDA tools to complete an SoC. ARM is the most well-known pure Design IP company, along with Imagination Technologies. Synopsys and Cadence also have significant Design IP businesses.

- **Chip Design**, which are companies that use EDA tools and licensed Design IP to create and sell SoCs along with complementary software. Graphcore and Nvidia are examples of SoC Chip Design companies. Most Chip Design companies today are “fabless”, meaning that they do not have manufacturing capabilities themselves and consequently outsource manufacturing to “foundries” (contract manufacturers) such as TSMC.

- **Capital Equipment and Materials**, which are the machines and materials that are developed for manufacturing semiconductor chips. ASML is a well-known semiconductor Capital Equipment company that provides the most advanced lithography tools that enable the most advanced node manufacturing (so-called 7 nanometer (nm), 5nm, and eventually 3nm, 2nm, and 1nm).

- **Manufacturing**, which is typically broken down into chip fabrication and chip “packaging” and test, the latter two taking finished semiconductor wafers from a fab and putting them in electronic packages and testing to create a finished chip product that can be assembled on a printed circuit card and ultimately put in an electronic system. As noted above, most manufacturing is outsourced to companies like TSMC, which is the world leader in foundry and dominates the most advanced fabrication technologies (7nm and below). When manufacturing is captive to one supplier it is called an Integrated Device Manufacturer, or IDM. IQE and Newport Wafer Fab are two well-known UK semiconductor foundries, although with Newport Wafer Fab’s recent acquisition by Nexperia it is transitioning to an IDM serving only Nexperia and its parent company Wingtech in China.

Figure 1. Semiconductor supply chain showing disaggregation that has occurred over last 50 years.



Semiconductor Industry Growth and Cyclicality

13. The semiconductor industry historically has grown at approximately 8% CAGR and been rather cyclical, with boom-and-bust cycles every few years. Indeed, Malcolm Penn of Future Horizons believes that the market is heading towards recession today, after overheating during the COVID demand surge and supply shortage[4]. The worst of these cycles were historically associated with memory which had many competitors and went from dramatic over-capacity to under-capacity every few years, although memory cyclicality has decreased over the last decade because of substantial consolidation (competitors merged to reduce the overall number of competitors). Of course, cyclicality remains as it is impossible to precisely forecast supply and demand in an industry like semiconductors where the lead-time to bring on new capacity can take years. There are several reasons to believe that the industry overall will, however, continue its long-term growth despite cyclicality:

- Decoupling of the supply chain with China will require new suppliers or increased supply from current non-Chinese suppliers.
- Electrification of the automotive industry, advanced driver assistance (ADAS), and autonomous driving (AD) are increasing semiconductor content in automobiles.
- The industrial internet of things (IIoT), or "Industry 4.0", is driving internet connection to and smart, autonomous operation of, all sorts of industrial and medical equipment.
- New advanced technologies such as Artificial Intelligence (AI), Machine Learning (ML), and 5G require more data (memory) and more processing (CPUs, GPUs, and other advanced types of processors).
- Transition to the Cloud is driving demand for more data and more processing.
- COVID appears to have changed consumer purchasing trends with a shift in spending disposable income to electronics. Some businesses are also funding employees to create home offices.
- Continuing population growth, especially in developing countries, and their increasing disposable income.
- As will be discussed later in the paper, the end of Moore's Law means that semiconductor devices in the future will not have the same continuous improvement in transistor density as they have historically, which may mean that more devices will be required to increase system performance.

[4] Future Horizons' Malcolm Penn Warns Chip Market Heading Toward Recession, John Walko, EE Times 26 Jan 2022.

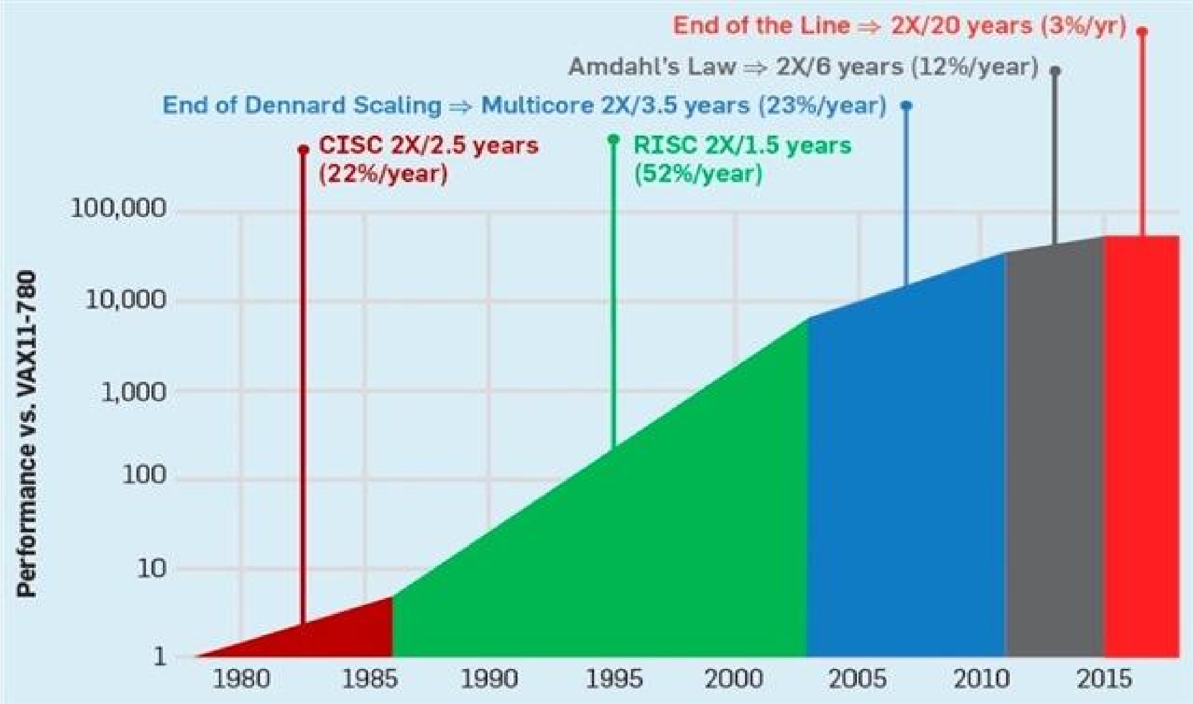
14. Consequently, as the industry continues to grow it is poised to be even more important economically and strategically in the future.

End of Moore's Law, Dennard Scaling, and Amdahl's Law

15. Semiconductor economics has been driven for over 50 years by **Moore's Law**, which states that the number of transistors per unit area of silicon will double every 12-24 months, **Dennard Power Scaling**, which states that despite the number of transistors increasing the power per unit area of silicon remains about the same because everything is shrinking, and **Amdahl's Law**, which defines limits of performance with multiple microprocessors. Unfortunately, these laws have been "failing", meaning that the same improvements in performance, power, and cost are no longer sustainable. **Figure 2** below shows a chart from a paper by John Hennessey and David Patterson[5], winners of the 2017 Turing Award. This chart shows a standard performance reference since the 1970s, noting the slowing of performance increase with the end of the various laws.

[5] A New Golden Age for Computer Architecture, Communications of the ACM, John L. Hennessy and David A. Patterson, February 2019, Vol. 62 No. 2, pp. 48-60 (https://cacm.acm.org/magazines/2019/2/234352-a-new-golden-age-for-computer-architecture/fulltext).

Figure 2. The end of Moore's Law showing a decrease in chip perfromance based on a standard reference.



Source: Hennessy and Patterson

16. The end of these various laws does not spell the end of semiconductors, only that the industry will need to change to new and novel design techniques, materials, so-called 3D structures, and other technologies to garner further significant improvements. Indeed, imec, a Belgium-headquartered R&D hub for nano and digital technologies has a roadmap that extends to 2036 with Angstrom-level (1Å = 0.1nm = 10^{-10} m) devices. Fortunately, the semiconductor industry is incredibly innovative, and many entrepreneurs see this situation as an opportunity, not a problem. It must, however, be considered strategically and means that just blindly building the next advanced node fab for £20+ billion may not be the best strategy.

Geopolitics and the British National Interest

17. In the Integrated Review[6], the UK identified a number of threats and opportunities

[6] The Integrated Review: Global Britain in a Competitive Age, the Integrated Review of Security, Defence, Development and Foreign Policy (https://www.gov.uk/government/collections/the-integrated-review-2021).

which have arisen as a result of changes in the global economy and the UK regaining full political sovereignty post-Brexit. The review is built on three key UK interests – sovereignty, security, and prosperity. It notes that Russia remains the "most acute threat in Europe" and "the most acute direct threat to the UK," and also comments on China's "increasing international assertiveness," as well as the "growing competition, including between states, and between democratic and authoritarian values and systems of government", positioning China and Russia as key sovereign powers that are both threats and opportunities to the UK. It goes on to point out that "adversaries and competitors are already acting in a more integrated way – fusing military and civilian technology and increasingly blurring the boundaries between war and peace, prosperity and security, trade and development, and domestic and foreign policy" and "the distinction between economic and national security is increasingly redundant".

18. The Review was clear, however, that the UK should and would continue to have both political and economic relationships with both China and Russia (prior to the Ukraine war of course) and specifically calls-out the importance of sustaining strategic advantage through science and technology whilst urging a more strategic approach to relationships with such countries. It acknowledged that in some sensitive sectors and technologies the strategic rivalry was such that normal economic relationships would not be possible. Limits on the nature of the economic relationships would be necessary to protect national security. This insight lead, in part, to the National Investment and Security Act as well as a range of other actions relating to the involvement of Chinese controlled companies in infrastructure projects such as the roll out of 5G.

19. The Review, which has proven to be remarkably accurate so far, needs to be borne in mind by policy makers when considering the semiconductor industry, and the industries it supports.

<u>The Involvement of the Chinese Government in Business; a Reason for the Integrated Review and National Investment Security Act</u>

20. In 2019 the World Economic Forum reported[7] that while China is home to 109

corporates listed on the Fortune Global 500, only 15% of those are privately owned, and that "many would not have survived in our innovation-driven world without the perks [government financing] they enjoy". These companies, frequently called "State Owned Enterprises", or SOEs, may lack operational efficiency, but they certainly wield significant influence inside and outside of China. For instance, as will be discussed shortly, an SOE was the primary financer of the acquisition of the UK semiconductor company Imagination Technologies.

21. In June 2017 the Chinese government enacted a new National Intelligence Law[8] that placed rather open-ended new security obligations and risks to both Chinese nationals as well as foreigners doing business or studying in China. Of particular concern is the fact that these obligations are a shift from intelligence "defense" to "offense" by creating legal responsibilities to provide access, cooperation, or support for the Chinese government's intelligence-gathering activities. It was reported[9] that this law has already made its case for the US and its allies why there is a risk with Chinese companies: "…first with the party's systematic infiltration of private companies, and second with the introduction of a new national security law … that states 'any organization and citizen' shall 'support and cooperate in national intelligence work'". Consequently, any Chinese company, not just those owned by the Chinese government, is legally and definitively controlled by the Chinese government with respect to national intelligence work, which obviously can mean almost anything. It can be speculated that this law may have been the reason Jack Ma, one of China's richest entrepreneurs, disappeared for months after he addressed an assembly of high-profile figures with a controversial speech that criticized the Chinese financial system[10]. In the same referenced BBC documentary, Samantha Hoffman, a researcher at the Australian Strategic Policy Institute, commented "There are [Communist] party committees there to remind the companies…that the party ultimately has power, even over powerful individuals like Jack Ma."

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[7] World Economic Forum, The role of China's state-owned companies explained, Amir Guluzade, Chief Operating Officer, Private Wealth Institute, Ahmadoff & Co, 07 May 2019.
[8] Law Fare, Beijing's New National Intelligence Law: From Defense to Offense, Murray Scot Tanner, 20 July 2017.
[9] The Guardian, How the state runs business in China, 25 July 2019.
[10] BBC Radio Documentaries Unit, Why did Alibaba's Jack Ma disappear for three months?, Sam Peach 20 Mar 2021.

Security

22. Security is a very broad topic that we consider and address below in two parts – cybersecurity and economic security. Both are critical to national security and sovereignty.

Cybersecurity

23. Cybersecurity refers to protection against criminal or unauthorized use of electronic data. Cyberattacks have many names, including malware (plant something that is activated when a user “clicks”), phishing (fraudulent emails or messages to unsuspecting users to get a response), man-in-the-middle (intercept information), distributed denial of services (DDOS, that overloads networks or systems causing them to slow or go down), zero-day exploits (attack before a “patch” fixing a problem is implemented), etc. These attacks are designed to deny access to critical systems, obtain information, and/or disrupt systems for commercial gain, political manipulation (e.g., influencing elections), and/or military benefits (e.g., shutting down surveillance or communication systems). They use various techniques including viruses (infect programs), trojans (hide inside of a program), worms (propagate across computers), ransomware (threaten to delete or publish data unless a ransom is paid), and spyware (collect information about users, their systems, or habits).

24. Most cyberattacks exploit “bugs” (flaws) already in software and hardware, which is one reason why suppliers are frequently updating their systems. A more nefarious situation is when such “bugs” are purposely inserted into hardware or software for later exploitation – sorting through 30+ billion transistors in a chip to find an exploitable bug is clearly not easy. Avoiding such problems requires “control” of the entire semiconductor supply chain since a problem can be created with just one line of code (smallest part of a software program) and/or one transistor and possibly inserted at any point in the supply chain! “Control” here means knowing and trusting the supply chain companies, not necessarily physically owning or controlling them.

25. The good news is that most companies are increasingly monitoring their design,

development, and manufacturing processes to minimize the ability of a bad actor to create a problem. The bad news is that this is a difficult and expensive process. Any cybersecurity expert will tell you that it is impossible to guarantee protection, only that the appropriate protection can make attacks harder and ideally economically unviable. Any company or country wishing to protect against cyberthreats needs to have a clear policy and practice that minimizes the impact of known issues and ensures cyberattacks are economically unattractive. The best companies will have security architectures that are from "chip to cloud to crowd" and "zero-trust" meaning that access to networks requires strong authentication and permission each time. Only trusted suppliers should be used. And do not assume that small companies are "exempt" because they are too small and insignificant – these are exactly the companies I would use to weaponize electronics, especially if they provide some small product or service to larger companies.

26. So here is an obvious question – would you think it easier for a company owned or controlled by an adversary to create a cybersecurity issue, or one that was not owned or controlled by an adversary? Hint – it is not a trick question.

Economic Security – Supply Chain, IP Theft

27. Besides the cyberattacks noted above, economic security depends upon the ability to protect one's intellectual property (IP), which for semiconductors means the designs, algorithms, processes, procedures, technologies, materials, etc. along the entire supply chain. IP theft has been a problem since at least the industrial revolution – the US garnered much IP in the 1800s from the UK and specifically Scotland regarding thermodynamics and steam-powered systems. Indeed, most countries tend to ignore IP theft up to the point that they have IP themselves and then they want to combat it. There is no doubt today that adversary states are continuously looking at ways, including criminal means, to access IP as evidenced, for example, by the high-profile university cases in the US[11] and the UK[12]. And globalization, whilst arguably

[11] Charles Lieber: Harvard professor guilty of hiding ties to Chinese programme (https://www.bbc.com/news/world-us-canada-59723343).
[12] Net closes in on Chinese 'spies' in UK universities where academics are suspected of passing pioneering British technology to Beijing (https://www.dailymail.co.uk/news/article-9608707/Chinese-spies-UK-universities-academics-suspected-passing-technology-face-arrests.html).

being in general a benefit to all participants, has fostered concern about commercial IP theft as evidenced by a need for the new UK National Security and Investment Act. This situation is examined next as a case study of two UK semiconductor companies that were recently acquired by companies with ties to the Chinese government.

Case Study: Imagination Technologies and Newport Wafer Fab

28. Both Imagination Technologies and Newport Wafer Fab are interesting examples that possibly highlight the cybersecurity and economic security risks of globalization and specifically the acquisition of British companies by a foreign adversary. The author has been involved somewhat in both cases and cannot provide some information because of non-disclosure agreements, but the publicly available information included here demonstrates the risks on its own.

29. Imagination Technologies is a UK Design IP licensing company most famous for its GPU technology that was used by marquee companies such as Apple and Intel. After decades of success and a listing on the LSE the company fell on hard times leading to its eventual acquisition by Canyon Bridge, an originally US-based private equity (PE) firm whose sole investor is a Chinese State-Owned Enterprises (SOE)[13].

30. Canyon Bridge initially attempted to acquire Lattice Semiconductor, a US company, but was blocked by CFIUS after it was noted in a letter to the US Treasury secretary from various members of congress that the "… transaction … appears to be directly affiliated with the government of the People's Republic of China (PRC), and further appears to be a legal construction intended to obfuscate the involvement of numerous PRC state-owned enterprises …"[14]. The same letter notes "… the PRC

[13] Footnote 2 from 5 May 2020 Foreign Affairs Committee Hearing on foreign asset stripping (full evidence in footnote 17 below): Imagination has written to the Committee to explain that their reference to China Reform's interest in the fund that acquired Imagination should have been 35%, and not 99%. The 99% figure refers to China Venture Capital Fund Corporation ("CVC"), a fund in which China Reform holds the largest interest, namely 35.29%. The other 64.71% of CVC is owned by China Pacific insurance (Group) Ltd, CCB Capital Management Company, CCB Trust Co. Ltd and Shenzhen Investment Holding Company Ltd. **CVC in turn holds a 100% interest in Yitai Capital Limited ("Yitai"), a Hong Kong company which was described in both Imagination's RNS announcement of 22 September 2017 and in the 9 October 2017 scheme documentation as a "Chinese state-owned enterprise." Yitai is the limited partner of the Canyon Bridge fund that owns Imagination holding 99% of the partnership interests in the fund, with Canyon Bridge Capital Partners LLC, the general partner of the fund, holding the remaining 1% partnership interest**.

[14] Letter from various members of congress to The Honorable Jack Lew, Secretary Department of Treasury (https://brooks.house.gov/sites/brooks.house.gov/files/Letter%20to%20CFIUS%20re%20Lattice%20Semiconductor%2012.6.16.pdf).

appears to have created an American venture capital firm [Canyon Bridge] to act as a conduit for Chinese government control over one of our largest semiconductor suppliers", with the obvious conclusion that the interests are not really motivated primarily by financial gain. The fact that Canyon Bridge is financed by a Chinese SOE and does not have several other (non-Chinese government related) investors as part of a syndicate of so-called "limited partners" (LPs), which is normally the case for such firms, is certainly consistent with its potential control or influence by the Chinese SOE and ultimately the Chinese government.

31. After failing to acquire Lattice Semiconductor, Canyon Bridge turned its focus to the UK which had less rigorous and strict acquisition rules than the US. In 2017 Canyon Bridge was successful in acquiring Imagination Technologies for a fraction of its peak LSE valuation. Imagination can be considered a significant prize for the Chinese government because essentially all processor companies (CPU and GPU) are in the US or have significant development in the US and therefore controlled by CFIUS. Moreover, as GPUs are used in Artificial Intelligence and Machine Learning, two of the Chinese government's primary areas of focus for global leadership, Imagination can be considered even more important. To acquire Imagination, Canyon Bridge had to attest that its financial sponsors (essentially the Chinese government through its SOE LP) were only "passive" investors, meaning that they had no control nor influence of Canyon Bridge as the "legal" acquirer of Imagination. The acquisition was approved under the previous UK laws, even though the Chinese SOE as the sole financier of Canyon Bridge obviously had to have some influence over Canyon Bridge because they were the sole investor in Canyon Bridge and therefore paid Canyon Bridge for its services.

32. In addition, unlike other Venture Capital and Private Equity firms, Canyon Bridge only had one primary and very large investment, Imagination, and a very small stake in a related processor company. This investment approach is counter to the normal practice of having a portfolio of investments that minimizes risk and maximizes profit. Indeed, "portfolio theory" is something that has been known and refined since its invention by the Nobel award winning economist Harry Markowitz in the 1950s[15].

[15] Portfolio Selection, The Journal of Finance, Vol. 7, No. 1, Mar 1952, pp. 77-91.

Having only one LP financer (the Chinese SOE) and one primary and very large investment (Imagination) is inconsistent with a philosophy to minimize risk, which is what any investor primarily interested in financial gain would do. So, what besides financial gain was of interest to Canyon Bridge and its sole LP, the Chinese SOE/government, with respect to Imagination?

33. Approximately one year after Imagination was acquired a new CEO (the author) was hired to turn the company's poor performance around. By all accounts the turn-around was going well, especially with a large deal with Apple, the launch and delivery of new high performance GPU products, and the addition of many new, experienced executives to the team. In April 2020, however, the CEO and other senior executives resigned from Imagination in protest at an attempt by the Chinese SOE to add four additional directors and taking formal control of the board of Imagination[16]. The resignations triggered an investigation by the UK government, the Foreign Affairs Committee, and ultimately testimony by two of the resigned executives at a 5 May 2020 select committee hearing.[17] The action by the executives and the UK government resulted in the proposed four additional directors related to the Chinese SOE sole investor in Canyon bridge not being appointed to the board of Imagination. What is unclear and unknown, of course, is if there are other risks from Chinese government (through its SOE and Canyon Bridge) involvement in Imagination, either from a cybersecurity or economic security standpoint.

34. Newport Wafer Fab, the largest semiconductor fab in the UK, is a very different business than Imagination as it is involved in manufacturing of specialized semiconductors. It is an older fab, having been previously owned by Infineon, a German company. Like Imagination, it had fallen on hard times and apparently missed contractual commitments to Nexperia, a Dutch company acquired by a Chinese firm called Wingtech that has ties to the Chinese government. The missed contractual commitments apparently allowed Nexperia/Wingtech to add directors to the Newport Wafer Fab board, which in turn triggered a rapid sale of Newport Wafer

[16] CEO and execs to resign if China takes control of Imagination (https://www.electronicsweekly.com/news/business/ceo-top-execs-resign-china-tries-take-control-imagination-2020-04/).

[17] The FCDO's role in blocking foreign asset stripping in the UK (https://committees.parliament.uk/event/910/).

Fab to Nexperia/Wingtech. This sale initially passed a UK security review but has been called in for further review again based on the new UK National Security and Investment Act. It is important to note that Newport Wafer Fab was originally a foundry business supporting many customers in the UK and globally, but post-acquisition is in the process of shifting all production only to Nexperia/Wingtech (i.e., transitioning to an IDM). Additionally, there are concerns that the technology may be transferred to a Chinese fab[18]. Newport Wafer Fab has "older" technology that can be used in sensors, RF devices, and power electronics, along with more advanced photonics technology that can be used in strategic military applications. These technologies were identified in China's 14th Five Year Plan (2021-2025) as critical and where China can take a global lead. Of course, ownership/control of the fab by Chinese government-controlled entities can theoretically create cybersecurity and economic security issues as discussed previously.

35. It is also interesting to note similarities in the Imagination and Newport Wafer Fab acquisitions:

- Both companies had financial difficulties which triggered their sale.
- Both companies were acquired by parties that were "technically separate" from the Chinese government yet had obvious and clear relationships with the Chinese government, including and especially financing.
- Both companies had technologies that were clearly of strategic importance to the Chinese government.
- There were attempted take-overs of both boards by the Chinese government or related entities through the addition of new directors, which was unsuccessful for Imagination only because executives resigned and the UK government became involved, but was successful for Newport Wafer Fab, although there is a review ongoing today that may reverse the takeover.

36. An old adage may apply here – whenever there are too many coincidences, there are no coincidences.

37. Given these two cases and their similarities one may conclude that the Chinese government has a strategic focus on acquiring UK semiconductor assets, and the

[18] Chinese firm could 'leak' UK advanced tech to Beijing after plant takeover, claims expert, EXPRESS 10 July 2021 (https://www.express.co.uk/news/uk/1460960/china-uk-news-chinese-company-semiconductor-plant-wales-uk-military-tech).

simple fact that they acquired Imagination and Newport Wafer Fab means that these firms must be important to it. In the case of Imagination, its GPU technology is essentially unavailable to the Chinese government elsewhere because such processor companies other than Imagination are controlled by the US from which China is blocked. China needs GPU technology for Artificial Intelligence and Machine Learning applications – very important technology areas that the Chinese government has publicly stated that they want to dominate. In the case of Newport Wafer Fab, the technology was considered strategic by the Chinese government in their most recent Five-Year plan and an area where they can possibly create a global leadership position. On its face, both Imagination and Newport Wafer Fab would, therefore, logically also be strategic for the UK and its allies, both from offensive and defensive standpoints. And, of course, both Imagination and Newport Wafer Fab may now be a cybersecurity and economic security risk.

Sourcing and Supply Chain: On-shore, Near-shore, and Off-shore

38. A simple conclusion, albeit what would prove it be an impractical one, is to require the entire semiconductor supply chain be in the UK. In theory this might be possible but not every company will want to have all operations in the UK and remember why the supply chain disaggregated in the first place – it was more economically efficient and technically superior for certain industry participants to focus on part of the supply chain and serve the others. So even if one could contain the entirety of the supply chain in the UK, it might be so inefficient as to not be worth it technically or economically.

39. A better approach is to have a supply chain managed through entities that are strategically positioned on-shore, near-shore, and off-shore (**Figure 3**) with careful consideration as to which parts are “allowed” to be adversary controlled or influenced.

40. This introductory, overview paper does not allow enough space to completely review the entire UK semiconductor ecosystem, but the above framework does provide a way of examining it, ideally for each industry segment (e.g., automotive, industrial,

consumer, etc.). It is recommended that the following be included in such an analysis:

- What the UK believes it does particularly well and where it can differentiate globally (below we will discuss Compound Semiconductors, Design IP, and SoC design in general as candidates) to create global bargaining power, meaning that allies and adversaries need the UK technology.
- What the UK global allies (e.g., the Five Eyes) do well and how that can complement the UK capabilities. Ideally allies plus UK-domiciled technology will complete most of the supply chain and have significant bargaining power over adversaries.
- What the UK global adversaries do well and how it can be used to adversely impact the UK and/or its allies. For these technologies the UK and its allies must have alternative sources, even if less than ideal and with poor economics.
- Various scenario analyses and game theory planning with different strategies by the UK, its allies, and its adversaries. This analysis should use the Russia-Ukraine war for lessons learned.

Figure 3. Supply chain distribution.

Type	Definition	Adversary Controlled/Influenced
On-shore	Located in UK	Typically not an issue because of eminent domain, but can be a cybersecurity concern
Near-shore	Located in Europe	May be an issue depending on country laws, and can be a cybersecurity concern
Off-shore	Located in another country, such as India, China, or the US, that are several time zones away	Not a problem with Five Eyes, certainly a concern in China or Russia, and may be a concern in other countries if controlled or heavily influenced by adversary (e.g., India with influence by Russia?) or pose a cybersecurity risk

Russia-Ukraine War and Lessons from It

41. The fall of communism, the subsequent break-up of the former Soviet Union, and the “end” of the Cold War over 30 years ago marked the inclusion of Russia formally into the global economy. It arguably benefited the Russian populace, and certainly the elite that became unprecedently wealthy oligarchs and a sort of capitalist ruling elite, albeit mostly through the exploitation of Russia’s abundance of natural resources and not necessarily innovating in such things as semiconductor technology. Underpinning

the logic of including Russia, and indeed similar logic for globalization overall and specifically China becoming the manufacturer for the world, was the assumption that through capitalism and economic benefit to any country's general populace, former adversaries would eventually become partners as economies inextricably became bound through trade and supply chains. A logical conclusion indeed if our value systems were the same because everyone collectively becomes better off. Unfortunately, that now seems to have been a flawed or even false assumption.

42. The recent Russia-Ukraine war now clearly seems to indicate that our value systems are not, and have not, been the same, at least to the extent that these value systems are "controlled" by the ruling elite and not the people. Arguably this is the case for China and Russia as both have shifted from emerging capitalist democracies to autocracy and most likely dictatorship today with both heads of state essentially in place for life.

43. Much has been said about NATO creating the angst that has triggered Russia's invasion of the Caucasus (Georgia) in 2008, its annexation of Crimea in 2014, its invasion of the Donbass in 2014, and its recent full invasion of Ukraine again this year, but even if that is so, the pattern is rather obvious to anyone that cared to look at the facts, so things were going in the "wrong" direction for a long time. So even if it was "NATO's fault", then this fault should have been recognized by any government willing to look at the facts, and the current war could have been predicted.

44. The Ukraine is important to Russia geographically, militarily, and economically and based on its past actions one can only conclude that it has always been intent on taking it over. To support this strategy, Russia has created economic dependence of the EU on its oil and natural gas that it is now being used not only as leverage with the EU but financing the war as well! Technology in general, and semiconductors specifically, can be used by an adversary in the same way.

45. Turning to semiconductors and the UK, a similar situation can be envisioned, and frankly an even worse one if the UK semiconductor chips ultimately "come back" to the UK in the form of missiles from an adversary. One would not want to be in the

government that authorized such a sale or transfer of technology – not just embarrassing but life threatening and potentially regime and freedom ending.

46. *Old Technology vs New Technology "Fallacy"*

47. One of the frequent comments made regarding Newport Wafer Fab is something to the effect *"it is old technology, so it really does not matter"*. The fact that it is old is true, but does that really matter? If it did and Newport Wafer Fab was a liability, why did the Chinese government buy it? Do they not have anything else to do with the money they have benefited from globalization? Or might it have to do with their evolving Five-Year strategy and their realization that the technology is indeed critical? I think the latter. As discussed previously, there are all sorts of chips and technologies in most systems, old and new, with all being required to ship the system.

48. It is logical to place more value on the most advanced, newest technology that costs £20+ billion to build a manufacturing facility, plus more to develop, but the true value is in the whole, not just the parts, which is why understanding the entire ecosystem and value/supply chain is so important and indeed a matter of national sovereignty and economic and national security. If one does not have supply of that "old chip" in a car or an NLAW or Stinger missile it will not work!

Adversaries or Economic Partners, Can They Be Both?

49. The author is a proponent of free trade and ironically believes that adversaries can indeed be economic partners – most important and despite the situation with Russia and China, it is true free trade makes us all better off. He also believes, however, that the relationship with adversaries must be managed intelligently and carefully with a focus on IP protection, economic and national security, possible unintended consequences, and loss of bargaining power and options. Unfortunately, this does not seem to have been the approach the EU took with regards to Russian oil and natural gas despite a plethora of indications that "things were not going well and there might be a problem" for nearly two decades.

50. One is reminded of US President Theodore Roosevelt's view on foreign policy – "speak/walk softly and carry a big stick". The UK with its substantial and valuable

technology industry (as evidenced by the Chinese government's interest in acquiring British companies) has sufficient assets to follow President Roosevelt's advice and have commercial relationships with adversaries, provided it thinks "three chess moves ahead" to protect itself and its allies. It should, however, have a strict policy to maintain control of semiconductor assets as strategic and critical unless proven not to be – the risk of not doing so is significant and asymmetric.

Economic Realities, What the UK Does Well, and Strengthening Research & Innovation

51. Given the size of the semiconductor industry and its complexity both from a technical and supply chain standpoint it is impossible for any one country to control it, although the US and its allies nearly do, with Taiwan having a preeminent position in manufacturing through TSMC, and the EU having a preeminent position in capital equipment through ASML and advanced manufacturing R&D through imec.

52. The UK has lost much of its position in semiconductor manufacturing and capital equipment and has sold off $42 billion of semiconductor-related assets since 2010[19], a fact for which some have been critical[20]. Nevertheless, the UK still retains significant semiconductor assets and related bargaining power in a few areas:

- **Design IP** as evidenced by ARM and Imagination, although ARM is currently owned by a Japanese company following its acquisition by Softbank and has much of its development in the US so is controlled by CFIUS, and Imagination is frequently considered to be a Chinese government-controlled company.

- **Compound Semiconductors**, **Analog and Mixed Signal Design, and Advanced Materials**, as evidenced by IQE, Newport Wafer Fab, and the bustling ecosystem built on related technologies, much of it in Wales.

- **Advanced SoCs design**, as evidenced by Graphcore and a myriad of other companies.

[19] UK Sold Off $42 billion of Semiconductor Firms Before Review (https://www.bloomberg.com/news/articles/2021-07-11/u-k-sold-off-42-billion-of-semiconductor-firms-before-review).

[20] The UK need to protect its semiconductor assets instead of selling them off (https://technosports.co.in/2021/07/11/the-u-k-need-to-protect-its-semiconductor-assets-instead-of-selling-them-off/).

- **Futuristic, innovative technologies, and products**, as evidenced by the strong UK universities and start-ups.

53. Of course, these are only areas and companies known to the author and there may be many more that can and should be developed. Individually and collectively, it is recommended that at least these areas be invested in and developed by the government to create a global leadership position. After all, isn't that what China was trying to do with Imagination and Newport Wafer Fab?

Defining a Strategy for the UK

Supporting and Maintaining the Current Capability

54. Given the criticality of semiconductor technology today for both economic security and national security there is a "Hippocratic oath" (do no harm) type of policy that is logically the most important base – assume that any semiconductor asset that exists today in the UK is critical and a risk if sold unless and until proven that it is not. The new UK National Security and Investment Act goes a long way to support this approach, but the recent situation with Newport Wafer Fab shows that the actual process of administering the law is complicated and very possibly insufficiently robust. And for the reader that is in government, please note that the pace of government is, let us say, just a bit slower than technology, and not acting with haste can have horrible unintended consequences – for example, blocking an action only to find that you have killed the company because customers and/or employees have already left. There is an important corollary here – the semiconductor industry is really about a combination of **physical assets** (fabs), **intellectual assets** (people), and **IP** (ideas put into practice). Any company or country can create a strategic position around any of these.

55. In the specific case of Newport Wafer Fab one has read in the papers that it is not critical or necessary because it is old technology. As described previously, the old part is true, but going back to the supply chain discussion, if one has all the new semiconductors for a car but none of the old ones, the car still cannot run or be sold

– and neither can a missile that uses the old parts! The travesty here is that the sound bite said over and over in the news sounds so logical, but in reality it has nothing to do with commerce and economic and national security. An even more obvious question to ask during a time when there are so many semiconductor supply constraints is why Newport Wafer Fab is so critical to China anyway if it is just old Technology? Oh, and to make things worse, military applications for all kinds of reasons tend to use older technology.

The UK Needs a Complete Analysis to Assess Its Critical Semiconductor Assets

56. The previous section lists some of the assets that the UK has that are unique and/or can be leveraged into global leadership. Of course, there likely may be more, which is an analysis that should be commissioned by the government and which the author will gladly help.

Defining the Core Capabilities of Adversaries and Partners

57. Just touching at a high level, the following can be concluded based on publicly available information:

- The US is particularly strong in all sorts of processors (CPU, GPU, etc.), memory, Design IP, SoC design in-general, EDA tools, and secondarily in advanced node manufacturing.
- Taiwan is particularly strong in advanced node manufacturing. TSMC's plans to build fabs in the US and Japan will extend its capabilities off-shore and to lower-risk geographies given the risk of a China-Taiwan conflict. Intel's plan to build advanced node fabs in Germany will do the same.
- The EU is particularly strong in capital equipment with ASML, advanced semiconductor R&D with imec**,** and SoC design in general with various companies. It will also eventually have advanced node manufacturing with Intel's commitments in Germany.
- Japan is particularly strong in materials and capital equipment, as well as SoC design. It will also eventually have advanced node manufacturing with TSMC's commitments.
- Korea is particularly strong in memory with Hynix and Samsung and secondarily in advanced node manufacturing.
- China is particularly strong in relatively low-end electronic assembly, SoC design, and older node manufacturing, but looking to add capabilities in everything semiconductor and especially advanced technologies.

58. Building a plan for the UK should leverage the capabilities of its allies and defend against its adversaries.

Building a UK Plan and Evolving the Strategy

59. The UK provides well intended governmental support to technology companies through various organizations such as Innovate UK, the Catapult Network, InvestUK, various government supported Venture Capital firms, and similar organizations supported by the devolved governments. One must wonder, however, how efficient these organizations are in building world-class UK companies? Venture Capital and Private Equity firms typically have management fees (costs) of 1%-2% of total assets under management – what is the equivalent for the UK government-backed organizations? Based on [off the record] discussions with various government organizations the key metrics seemed more around employment, followed-by positive press and not "failing" (publicly). Better metrics would be creating world-class British companies and "failing fast" (publicly) – ironically, failure is not a problem in technology, and if one is not failing periodically, one is normally not trying hard enough. And world-class companies normally do not initially have the most employees, but mediocre ones can limp along with more employees than they really need for decades, always ending in decline.

60. The UK National Security and Investment Act goes a long way to protect the UK from IP theft and various economic and military risks, but it is a new law and based on the Newport Wafer Fab case it is rather slow to be deployed and concluded, which is a real problem for the fast technology industry. Recommendations on how to automate an evaluation process and create a type of "security risk score" similar to a "credit score" for each technology company (and indeed companies in other segments as appropriate) has been proposed to various government and non-government entities but there seems to be little interest, with presumably a preference for the slow manual process that exists today. One of the problems that cannot be automated, however, is how to finally make decisions on specific situations. To be candid, it is unlikely that any government official will have the

experience and knowledge of the semiconductor industry to make such a decision. With the proposed automated process and a "technology review council" comprised of industry experts, academics, NCSC representatives, MOD representatives, and politicians it would be possible to not only make decisions rapidly, but guide evolution of the law. This is critical because the technology industry is not static, and what was not important previously, might be extremely important next year – closing the gate after the horse has bolted is not a good strategy.

Summary and Conclusion

61. Semiconductors have become ubiquitous to the point that they are associated with national sovereignty, a fact that is especially obvious with the supply shortages that have plagued the industry for the last couple of years. Unfortunately, the UK has lost or sold much of its semiconductor industry, but still retains key aspects and has a wealth of talent that can propel it to significant positions in areas such as Compound Semiconductor design and manufacturing, Design IP, and SoC design in general. Evidence of the value of the UK semiconductor capabilities is the Chinese government's interest in acquiring its assets and its involvement in the UK university system. In keeping with the Integrated Review, the UK should take steps to not only protect its current assets but grow its areas of unique competence and protect these against foreign acquisition, especially by adversaries. The current Russian-Ukraine war provides a cautionary tale of how technological and economic dependence can backfire, in that case with the EU not only being dependent on Russian oil and natural gas, but ironically financing the war for Russia with its purchase of Russian oil and natural gas! The UK should not make the same mistakes with semiconductor technology.