Written evidence submitted by Professor George Constantinides (LEC0002)

House of Commons Science, Innovation and Technology Committee Low-energy Computing Inquiry

Submitted in a Personal Capacity

Dear Chair and Members of the Committee,

1. Thank you for the opportunity to contribute to the Committee's inquiry. I am Professor of Digital Computation in the Department of Electrical and Electronic Engineering at Imperial College London. My research concerns how computation is physically realised: how algorithms, arithmetic, memory, interconnect, hardware architecture and software tools can be designed together so that computers do useful work with less energy.

2. My central message is simple. The UK is already a leading light in low-energy computing, including brain-inspired and non-traditional computer architectures. But that lead is fragile. Other countries are moving quickly, and the UK will not capitalise on its strengths unless it funds the long-term research that connects algorithms, software and hardware, rather than treating them as separate problems.

3. Neuromorphic computing and silicon photonics can both help with the sustainability challenge created by AI. They should not, however, be seen as a single magic solution. The energy cost of modern AI comes not only from doing calculations, but also from repeatedly moving data between processors, memories, chips and data centres. Conventional computers are still largely built around a separation between memory and processing. Much of the opportunity lies in breaking down that separation, reducing unnecessary data movement, and designing computation around the shape of the task.

4. This is what I would describe as a broader non-von Neumann approach. Neuromorphic computing is one important part of that family of solutions, but not the only one. Digital spatial architectures, reconfigurable computing, near-memory computing, event-driven systems, new interconnects, photonic technologies, better arithmetic, and better compilers all matter. The associated software is just as important as the chip: a novel machine that cannot be programmed, verified, benchmarked and used by researchers or companies will not change the energy footprint of AI.

5. It is also important that policy and funders do not define "neuromorphic" too narrowly. The term is used in different but legitimate ways. It can mean brain-inspired algorithms at the software level; event-driven or sparse movement of data at the system level; many small processing elements with local memory at the architecture level; or new devices and materials that mimic aspects of neurons and synapses. All these meanings can be useful. A broad definition will allow the UK to support practical near-term digital work as well as longer-term materials, device and photonic research.

6. For silicon photonics, the same point applies. Photonics can be extremely valuable for moving information quickly and efficiently, and in some settings for carrying out computation using the physics of light. But photonic devices must still sit inside a system with electronics, memory, packaging, control software, algorithms and users. The biggest gains will come when those parts are designed together.

7. The most important policy lesson is therefore co-design. Energy improvements are unlikely to come from investing only in AI algorithms or only in new hardware. They will come from people who understand both sides working over many years on shared problems: changing the model, the numerical precision, the dataflow, the memory system, the chip architecture and the software toolchain together. The ARIA-funded AIxSIM grant, led by Dr Aaron Zhao at Imperial College is a good example of this kind of thinking. Its purpose is to understand the performance and energy consequences of changing AI models and computing systems together, rather than assuming today's hardware or today's AI models are fixed.

8. The UK has strong foundations on which to build. In my own area, Imperial College London hosts, in my view, one of the most significant digital non-von Neumann architecture research groupings in the world. This includes my own work and that of colleagues such as Wayne Luk, Peter Cheung, Christos Bouganis, John Wickerson, Aaron Zhao, Samuel Coward and others. The group spans reconfigurable and spatial computing, machine-learning systems, compilers, formal verification, arithmetic, approximation, and hardware/software co-design.

9. I was Principal Investigator and Centre Director of the EPSRC Centre-to-Centre award SpatialML, the Centre for Spatial Computational Learning. SpatialML brought together Imperial College London, the University of Southampton, the University of Toronto, UCLA and other academic and industrial partners to rethink deep learning for non-traditional architectures. Its lesson was that the most productive question is not simply "how do we accelerate a fixed AI model?", but "how should the AI model, the hardware and the software change together?"

10. This UK strength is not limited to universities. The UK has an important industrial and open-technology base relevant to low-energy computing, including Arm, Imagination Technologies, Fractile, lowRISC, Graphcore, Literal Labs and other companies or organisations in the wider ecosystem. The UK also has strengths in photonics, compound semiconductors, verification, design IP and specialist AI hardware. The policy challenge is to stop this expertise leaking away at the point where ideas need patient capital, access to prototyping, and sustained engineering support.

11. The 2021 eFutures report by Indiveri and Najjar on the UK landscape in AI and brain-inspired computing hardware made a similar strategic point: the UK has a real opportunity in brain-inspired computing, but only if the community is coordinated and the field is supported as a national capability. That conclusion remains right. Neuroware, the new Innovation and Knowledge Centre dedicated to neuromorphic hardware led by Prof Tony Kenyon at UCL, is a welcome step because it can bring together materials, devices, photonics, architectures, algorithms and measurement.

12. On international competition, the UK should be clear-eyed. The United States has hyperscalers, semiconductor companies and a powerful defence research ecosystem. China is investing at scale. The EU has strong semiconductor, photonic and research infrastructure, including centres such as imec and CEA-Leti. Taiwan, Korea and Japan have deep semiconductor manufacturing and packaging capability. Canada remains important in AI and neuromorphic research. The UK cannot outspend all of these countries, and should not try to copy their entire industrial structure. Its advantage is in design, software, systems, verification, scientific creativity, and focused academia-industry clusters.

13. That is also how I would define sovereign capability in this area. The UK does not currently have full sovereignty across leading-edge fabrication, electronic design automation, high-bandwidth memory, advanced packaging and the largest AI data-centre infrastructure. But sovereignty need not mean owning every part of the supply chain. In low-energy computing it should mean having the domestic capability to specify, design, simulate, verify, prototype, measure, program, secure and adapt critical computing systems, and to retain enough intellectual property and skilled people in the UK that we are not merely a source of ideas commercialised elsewhere.

14. Software and design tools should be treated as part of that sovereign capability. Dr Sam Coward's work on open and verifiable electronic-design automation, including e-graph-based optimisation and verification, and Dr John Wickerson's open-source and formal-methods contributions to hardware/software verification, illustrate why this matters. These are not peripheral activities: if the UK has trustworthy design tools, compiler infrastructure, open benchmarks and verification expertise, it can influence how future low-energy machines are built even when some fabrication takes place overseas.

15. The UK also needs better mechanisms for moving people between universities and companies without forcing them to choose one world or the other. Joint appointments, industrial secondments, Royal Academy of Engineering-style research chairs, flexible IP arrangements and promotion criteria that value deep industrial engagement would all help. This is especially important in computing hardware, where useful impact often requires academic staff and research teams to work closely with industry over several design cycles.

16. I would therefore urge the Committee to recommend five practical actions. First, Government and UKRI should fund a long-term low-energy computing programme that explicitly covers the full stack: algorithms, numerical methods, architecture, devices, interconnect, compilers, runtime software, verification, packaging and measurement. Secondly, digital non-von Neumann architectures should be funded alongside neuromorphic materials and silicon photonics, because most near-term energy gains will come from digital architecture and software, and almost all future gains will come as a result of co-designed software.

17. Thirdly, future IKCs and similar centres should be judged by system-level outcomes, not only by papers or impressive device demonstrations. Useful metrics include measured energy-to-quality on realistic workloads, usable software stacks, open benchmarks, integrated demonstrators, industry adoption, trained people retained in the UK, and UK-held intellectual property. Fourthly, researchers and companies need shared access to prototyping infrastructure: multi-project wafer runs, advanced packaging, test and measurement facilities, and modern design tools.

18. Fifthly, Government should use procurement, patient capital and targeted translation funding to help UK start-ups and scale-ups cross the gap between excellent research and commercially robust products. The UK already has the talent. The risk is not that the UK lacks ideas, but that those ideas mature elsewhere because other countries provide the infrastructure, engineering continuity and capital needed after the first discovery.

19. In conclusion, neuromorphic computing and silicon photonics are important parts of the answer to AI’s energy challenge, but the wider answer is a national capability in low-energy computing as a stack. The UK can lead in this field if it invests in the bridge between algorithms and hardware, supports the software that makes new hardware usable, and connects excellent university research to companies without losing ownership of the results. With timely support, low-energy computing can make AI capability, net-zero ambition and technological sovereignty mutually reinforcing.

Yours faithfully,

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The author acknowledges the use of GPT-5.5 and Gemini 3 in drafting and revising this evidence; the views, technical conclusions, and policy recommendations expressed herein are entirely those of the author.

26 April 2026