

A graphic in the top right corner showing a grid of square microchips with gold-colored centers, arranged in a perspective view that recedes into the distance.

# 2D Materials Innovation & the future of semiconductor technologies

GSA International Semiconductor Conference | Semiconductor Innovation for Net Zero  
London, 13<sup>th</sup>-14<sup>th</sup> March 2024



# Our Challenge

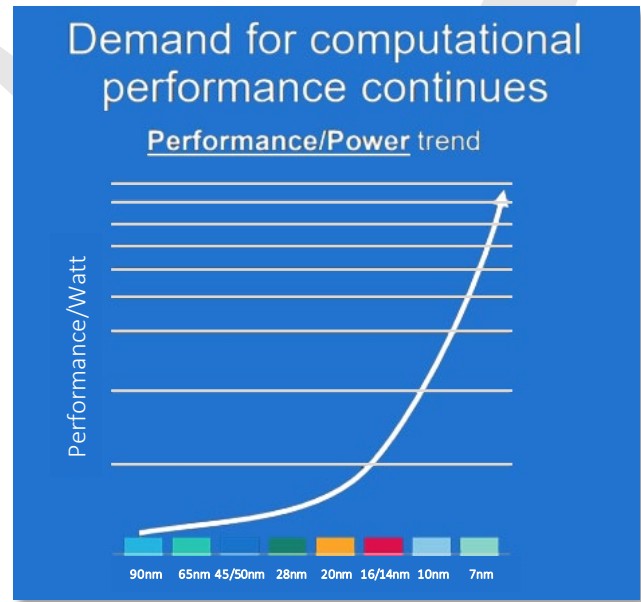
By 2030 it is conservatively estimated that more than **20% of the world's energy** will be consumed by computing

- In 2020 datacenters used **more energy than the whole of the UK**,
- cryptocurrency mining consumed **more energy than the population of Argentina** and
- AI's impact is yet to be fully understood, where a simple ChatGPT query uses over **5 times the energy** of a standard search engine

Sources: Frontier Group, IBM, IEA

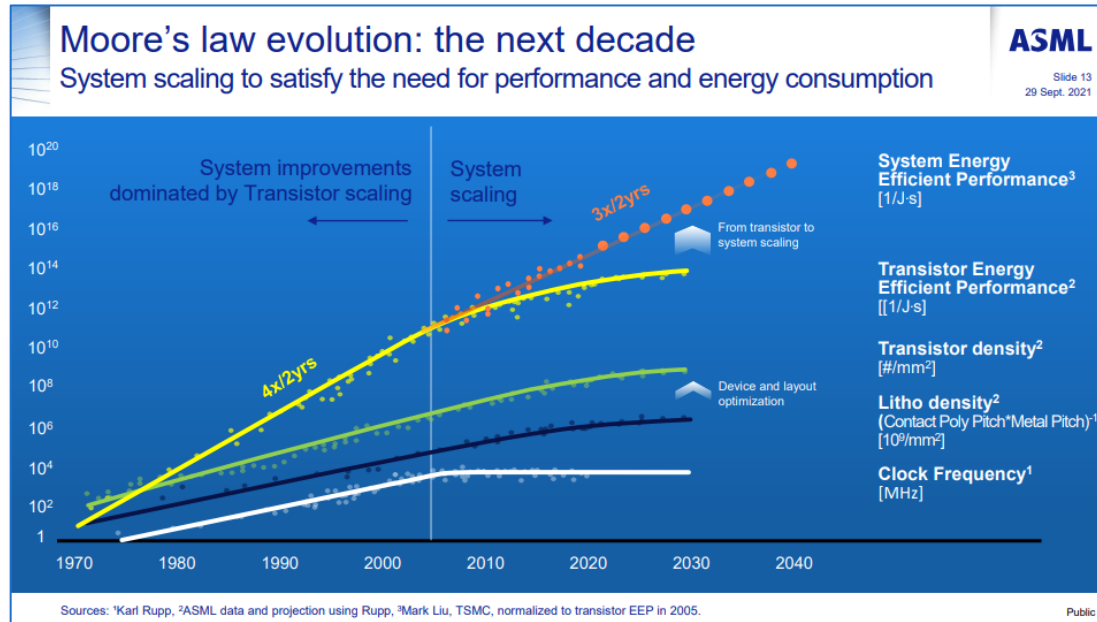
At the heart of all of this are Semiconductor Technologies...

# The Ever-Increasing Demands on Semiconductors



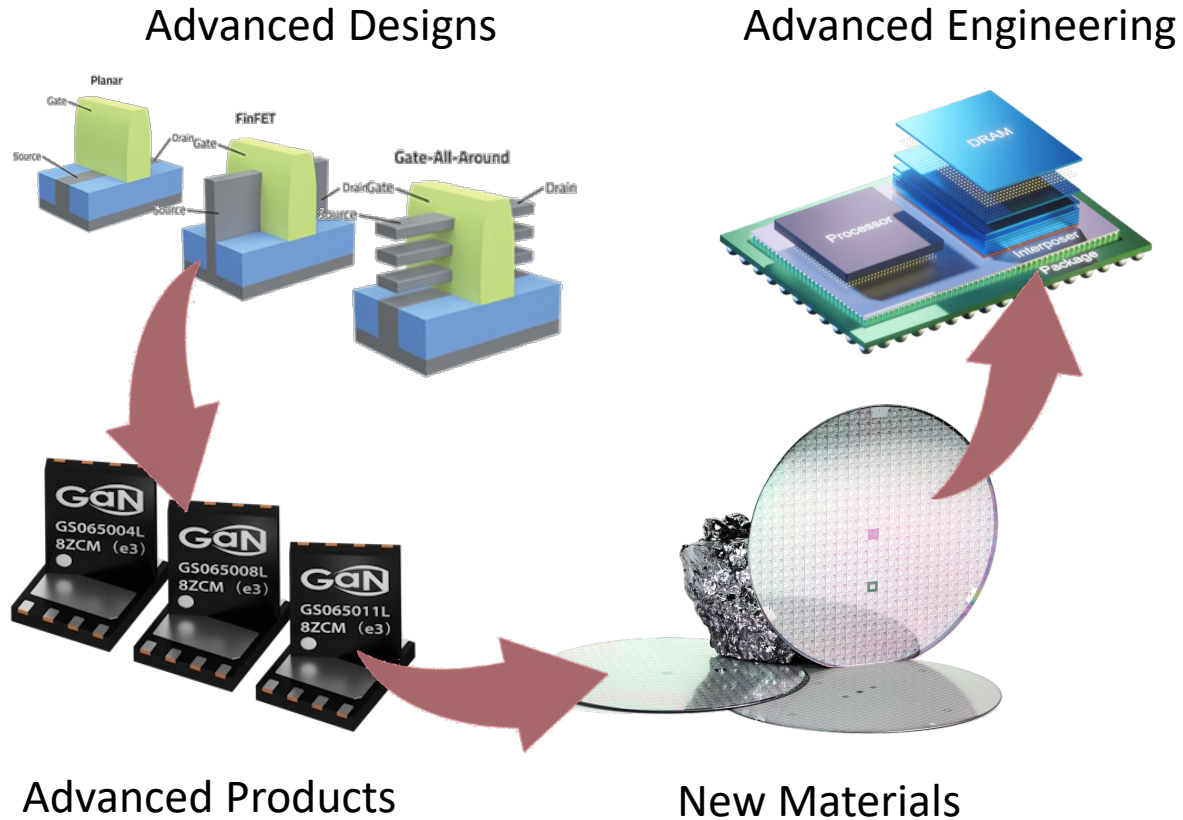
Source: International Business Strategies Inc.

# The Crux of the Situation

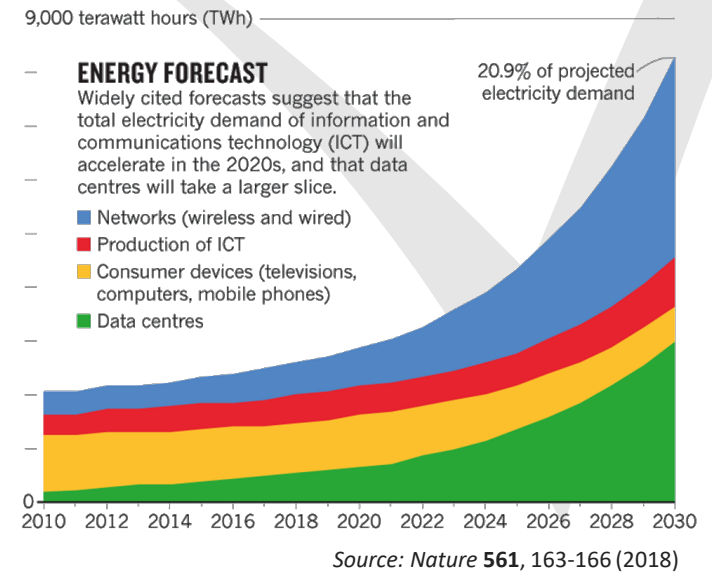


'The number of transistors on an integrated circuit will double every two years with minimal rise in cost'  
*Gordon Moore, 1965, 1975*

# The Continuing & Impressive Advancements



## However, the Biggest Challenge Persists



To effectively drive to **Net Zero** additional, new approaches are clearly required



# The Two-Dimensional Step Forward

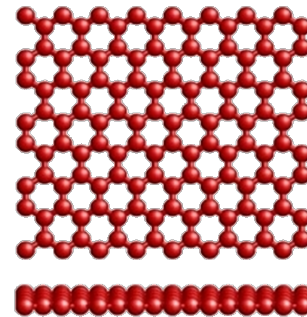
## Bulk 3D Semiconductor Materials



Elemental (Silicon)  
Binary (Gallium Nitride)  
Tertiary (Indium Gallium Arsenide)

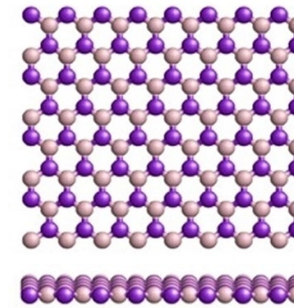
## Two-Dimensional Materials

### Elemental 2D



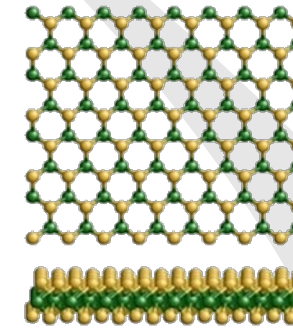
Graphene

### Binary 2D



Hexagonal  
Boron Nitride

### Multiplane 2D



Transition metal  
dichalcogenide  
(TMD)

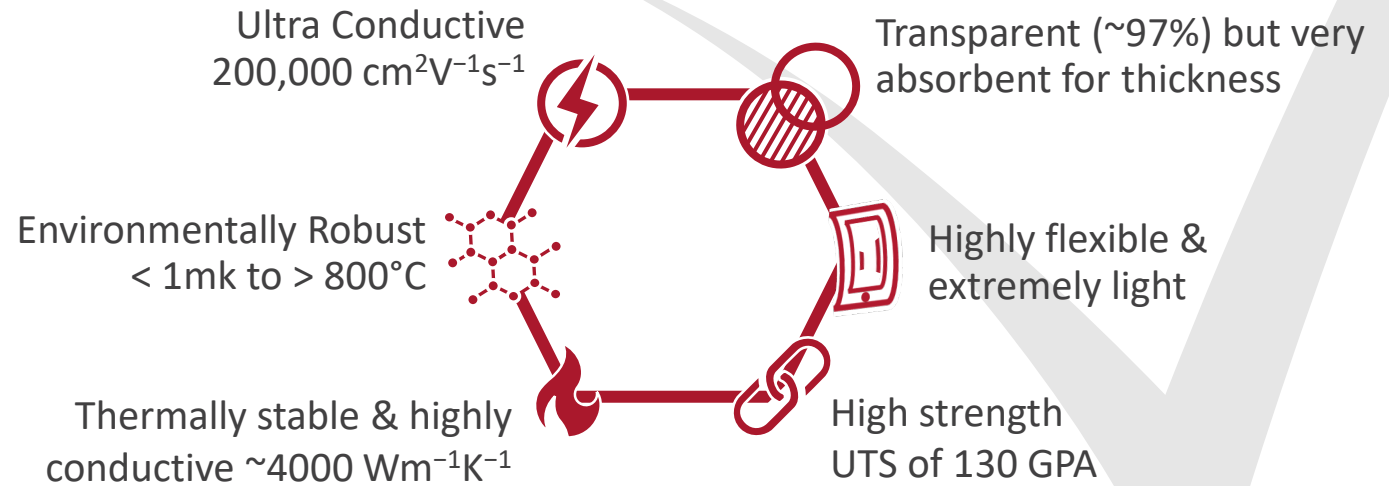
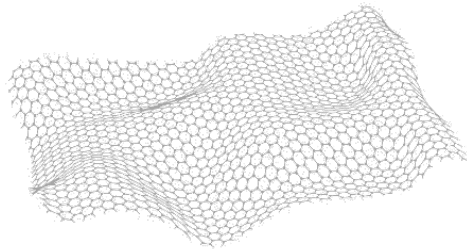
Confinement of a material to a single atomic layer brings extraordinary properties...

# Two-Dimensional Superpowers

## Graphene

An unprecedented material

The first 2D Material



These combined properties deliver the 'wonder' material  
and at >150x more conductive than Silicon a revolutionary electronic material

# The Potential of a 2D Future

**MIT Technology Review**      Featured   Topics   Newsletter

By Emerging Technology from the arXiv

## 427GHz Graphene transistors, just the beginning for the wonder material?

The writing is on the wall for the silicon chip. Transistors have been shrinking for the last half a century but they cannot get smaller forever. Most industry pundits think that the downscaling of silicon chip technology cannot extend much beyond 2026. The big question, of course, is what will replace it.

One possibility is graphene, which various teams around the world have used to make hugely fast transistors. Last year, one team clocked a graphene transistor at a cool 427 GHz. So you could be forgiven for thinking that graphene is the perfect silicon replacement.

## Graphene Flash Memory

Augustin J. Hong<sup>†\*</sup>, Emil B. Song<sup>§1\*</sup>, Hyung Suk Yu<sup>§</sup>, Matthew J. Allen<sup>§</sup>, Jiyoung Kim<sup>||</sup>, Richard B. Kaner<sup>§</sup>, Bruce H. Weiller<sup>‡</sup>, and Kang L. Wang<sup>§</sup>

View Author Information ▾

Cite this: *ACS Nano* 2011, 5, 10, 7812–7817  
Publication Date: August 22, 2011  
<https://doi.org/10.1021/nn201809k>  
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by Kayleigh Brewer  
09 November 2023

## Scalable graphene sensor array for real-time toxins monitoring in flowing water

[Arnab Maity](#), [Haihui Pu](#), [Xiaoyu Sui](#), [Jingbo Chang](#), [Kai J. Bottum](#), [Bing Jin](#), [Ganhua Lu](#) & [Junhong Chen](#) ✉

*Nature Communications* **14**, Article number: 4184 (2023) | [Cite this article](#)

## Broad applications of sensors based on graphene

[Kuen Yao Lau](#) & [Jianrong Qiu](#) ✉

*Light: Science & Applications* **12**, Article number: 168 (2023) | [Cite this article](#)

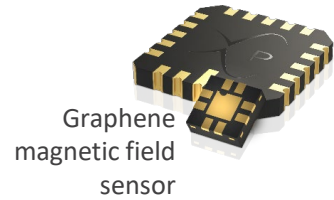
## High-responsivity graphene photodetectors integrated on silicon microring resonators

[S. Schuler](#), [J. E. Muench](#), [A. Ruocco](#), [O. Balci](#), [D. van Thourhout](#), [V. Soriano](#), [M. Romagnoli](#), [K. Watanabe](#), [T. Taniguchi](#), [I. Goykhman](#), [A. C. Ferrari](#) ✉ & [T. Mueller](#) ✉

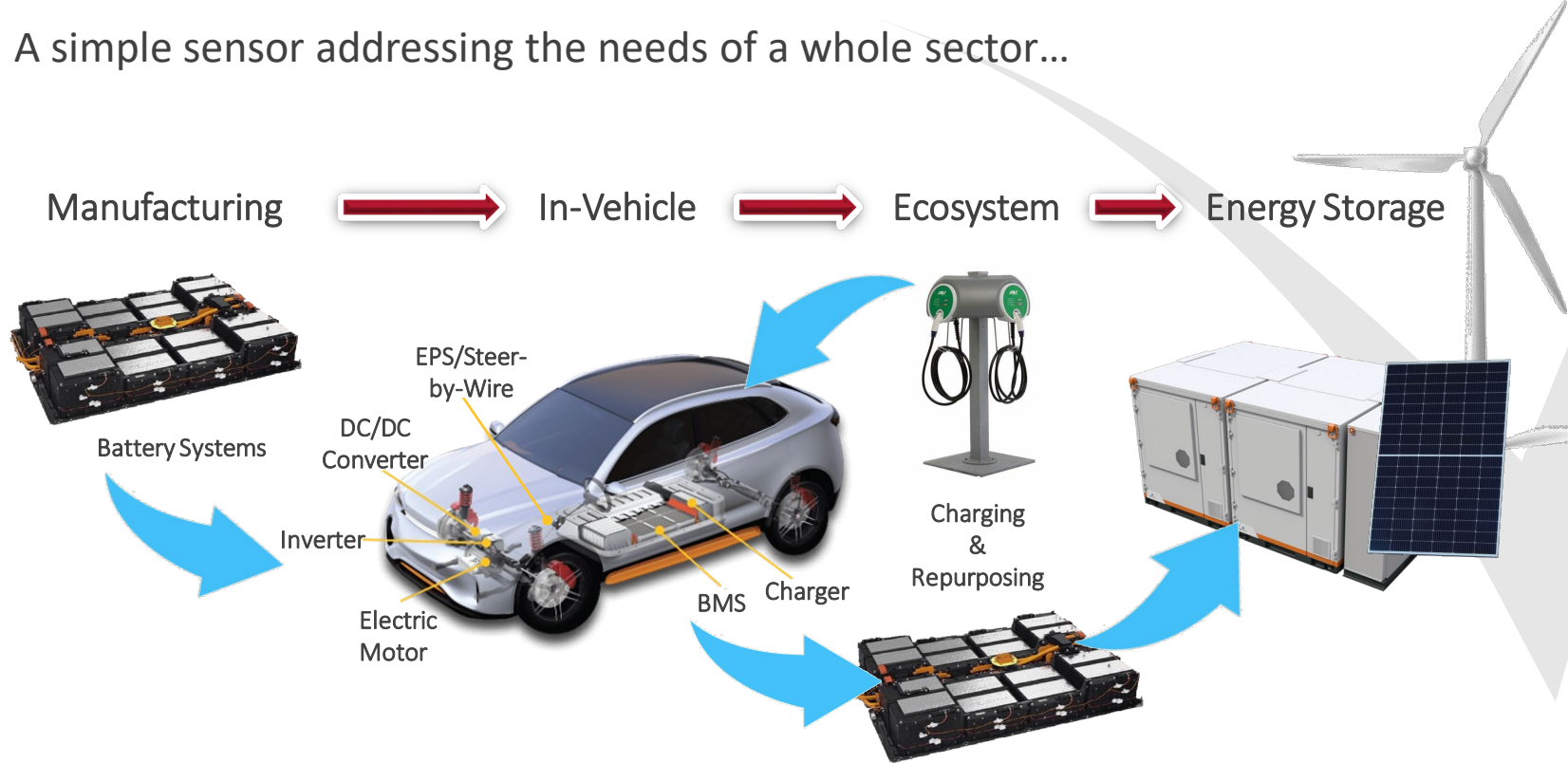
*Nature Communications* **12**, Article number: 3733 (2021) | [Cite this article](#)



# Graphene Electronics | Changing the State of Play

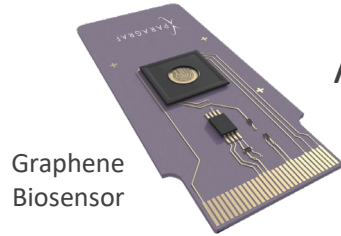


A simple sensor addressing the needs of a whole sector...



...driving energy efficiency, improved performance and waste reduction

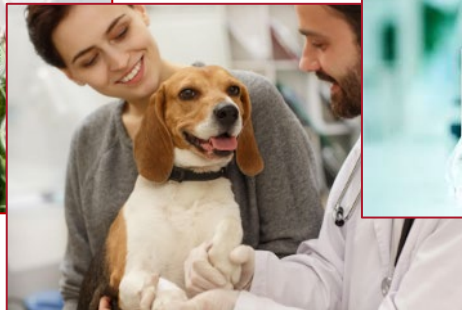
# Graphene Electronics | Changing the State of Play



A simple field effect transistor (gFET) transforming analysis...



AGRI-TECH



VETERINARY



FOOD



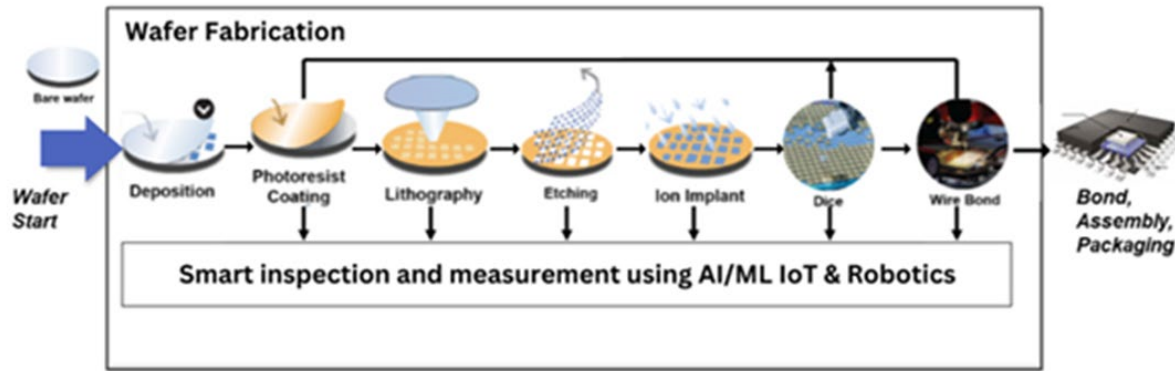
HEALTHCARE



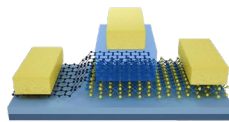
ENVIRONMENTAL

...delivering industry advancing, life changing, lifesaving diagnosis with reduced impact and footprint

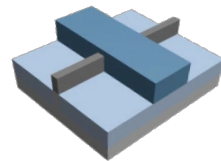
# 2D Materials | Reducing the Manufacturing Impact of Electronics



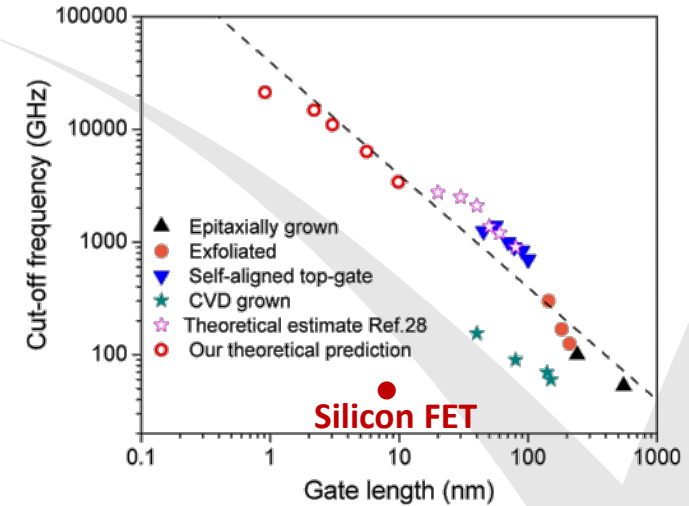
2D FET  
< 1nm high



Si FET  
> 30nm high



Minimizing material and processing requirements



Resetting & reducing device complexity

Driving semiconductor device production to a cleaner, less intensive, resource lighter and more cost-effective enabling the drive to Net Zero

# Achieving Net Zero Through Advanced Semiconductor Materials Innovations

By 2030 it is conservatively estimated that more than **20% of the world's energy** will be consumed by computing.

In 2020 datacenters used **more energy than the whole of the UK**, cryptocurrency mining consumed **more energy than the population of Argentina** and the impact of AI is yet to be fully understood, where a simple ChatGPT query uses over **5 times the energy** of a standard search engine.

Sources: Frontier Group, IBM, IEA,

Graphene > 50% Reduction

The healthcare sector is responsible for almost **5% of global greenhouse gas emissions** and has a carbon footprint equivalent to **514 coal-fired power plants**.

If the sector were a country, it would be the **fifth largest polluter** on Earth. Under a 'business as usual' scenario, emissions from **healthcare could triple between now and 2050**.

The two largest challenges are Overdiagnosis & Ecosystem Transportation (Patient, Samples, Laboratories)

Sources: The Lancet VOLUME 397, ISSUE 10269, P129-170, JANUARY 09, 2021, Health Care Without Harm, 2019, 2021, BMJ 2021

Graphene > 50% Reduction

