IMPERIAL

AI for Net Zero
Energy and Transport

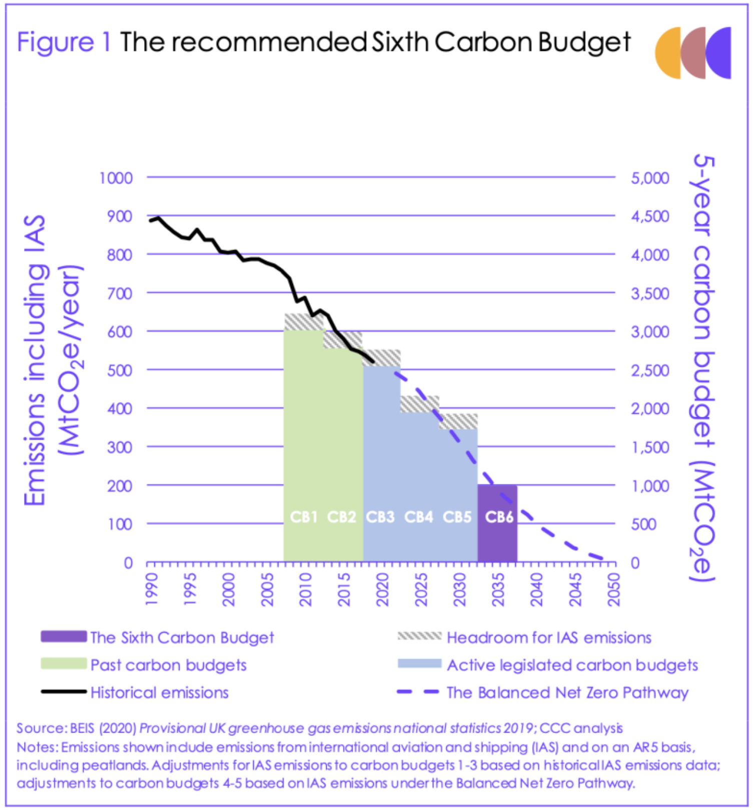
Case 1: Aerodynamics

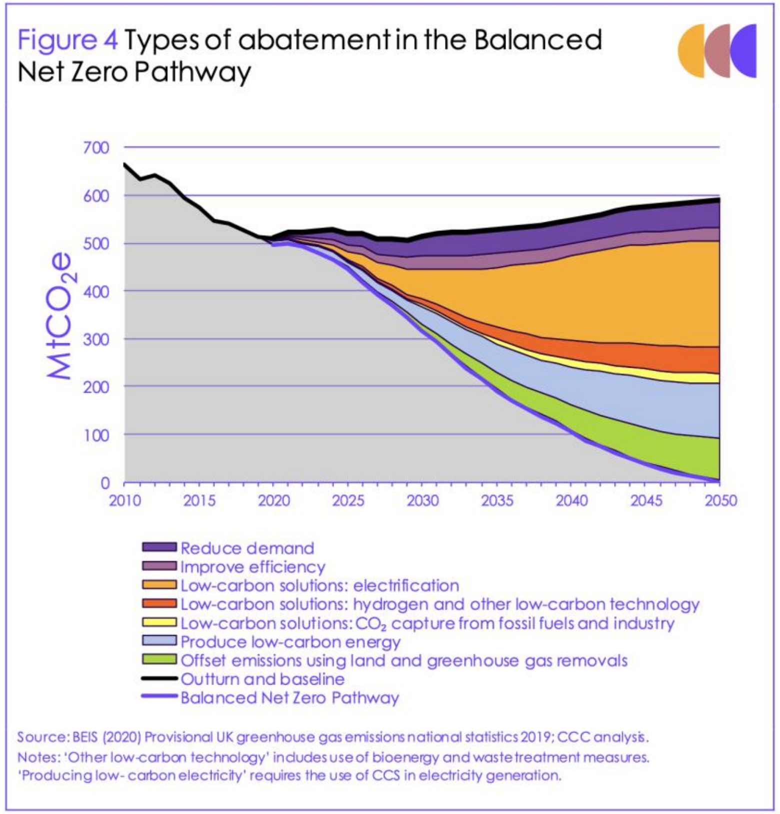
Case 2: Wind farms

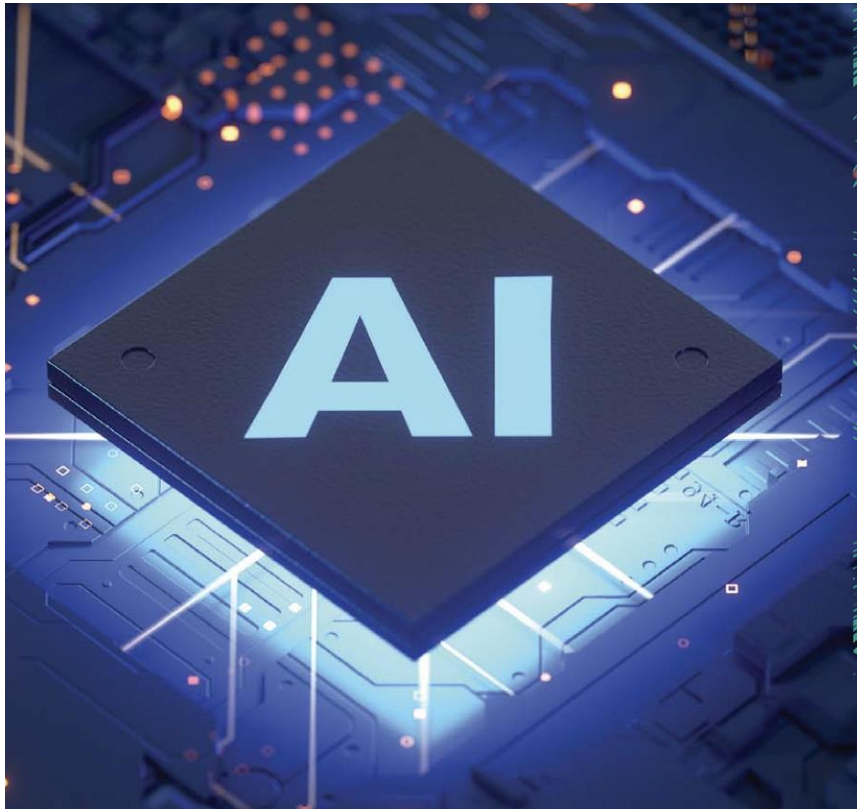
Sustainable Data-Centers for AI

Dr Georgios Rigas, Prof. Sylvain Laizet
20/05/2024

Achieving Net Zero







- Improve Efficiency
- Low Carbon Solutions (H_2, Electrification)
- Produce Low Carbon Energy

AI for Net Zero: research landscape

https://gow.epsrc.ukri.org

Rank	Grant Reference	Principal Investigator	Holding Organisation	Grant Title	Value (£)
1.	EP/Y004450/1	Weiland, Professor M	University of Edinburgh	Real-time Digital Optimisation And Decision Making For Energy And Transport Systems	245,757
1.	EP/Y004841/1	Aston, Professor Sir JAD	University of Cambridge	Real-time digital optimisation and decision making for energy and transport systems	265,538
1.	EP/Y004930/1	Vogiatzaki, Dr K	University of Oxford	Real-time digital optimisation and decision making for energy and transport systems	265,915
1.	EP/Y005619/1	Rigas, Dr G	Imperial College London	Real-time digital optimisation and decision making for energy and transport systems	1,414,614
2.	EP/Y005732/1	Galindo, Professor A	Imperial College London	Enabling CO2 capture and storage using AI	789,045
2.	EP/Y006143/1	Elsheikh, Professor AH	Heriot-Watt University	Enabling CO2 capture and storage using AI	1,790,579
3.	EP/Y00597X/1	Balzter, Professor H	University of Leicester	Self-Learning Digital Twins for Sustainable Land Management	2,492,148
4.	EP/Y005376/1	SUN, Professor H	Durham, University of	Virtual Power Plant with Artificial Intelligence for Resilience and Decarbonisation (VPP-WARD)	1,845,327
5.	EP/Y005600/1	Short, Dr M	University of Surrey	Artificial Intelligence Enabling Future Optimal Flexible Biogas Production for Net-Zero	1,436,523
6.	EP/Y005597/1	Williamson, Professor D	University of Exeter	ADD-TREES: AI-elevated Decision-support via Digital Twins for Restoring and Enhancing Ecosystem Services	1,669,406
7.	EP/Y00504X/1	Pearson, Professor S	University of Lincoln	Plant selection and breeding for net zero	534,888
7.	EP/Y005430/1	Doonan, Professor JH	Aberystwyth University	Miscanthus AI- Plant selection and breeding for Net Zero	502,950
7.	EP/Y005694/1	Frey, Professor JG	University of Southampton	Plant selection and breeding for Net Zero	254,639

- UKRI grant awarded May 2023
- 7 successful projects (£13m) on Energy & Transport Systems, Carbon Capture, Land Management, Powerplants, Biogas, Plant selection
- 23-month duration (May 2023-March 2025)

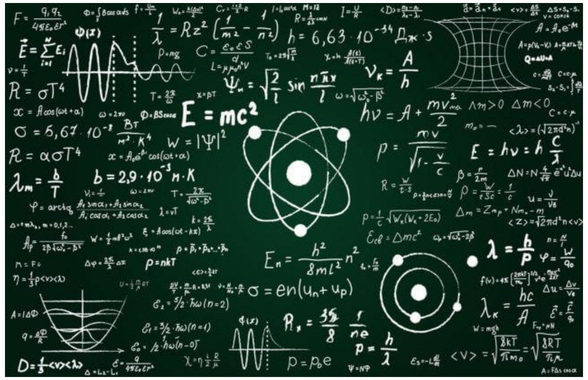
AI for Net Zero in Energy & Transport

https://www.imperial.ac.uk/ai-net-zero/

23-month duration (May 2023-March 2025)

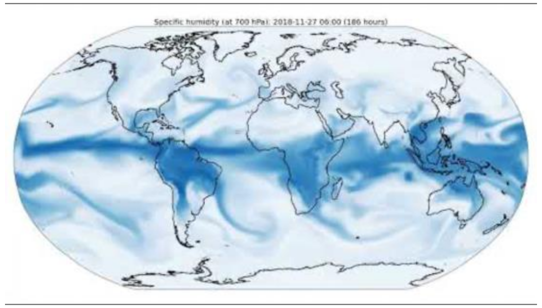
£2.5m, 7 Professors, 12+ Researchers

Physics Laws



Model – Predict – Control

Data - LLMs



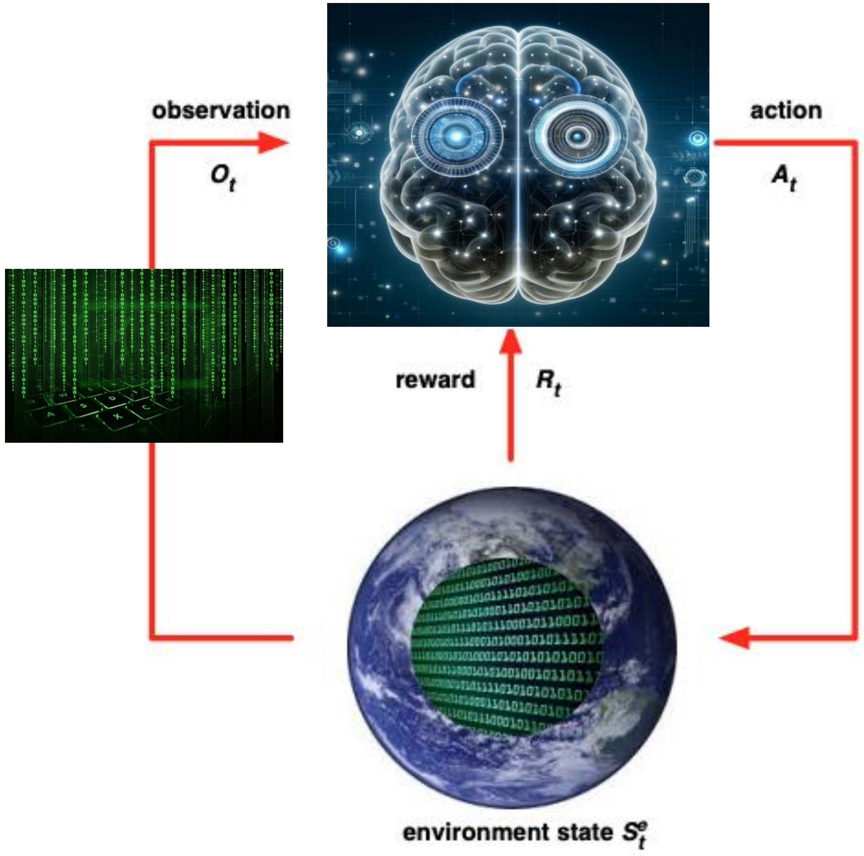
Weather

Self-driving

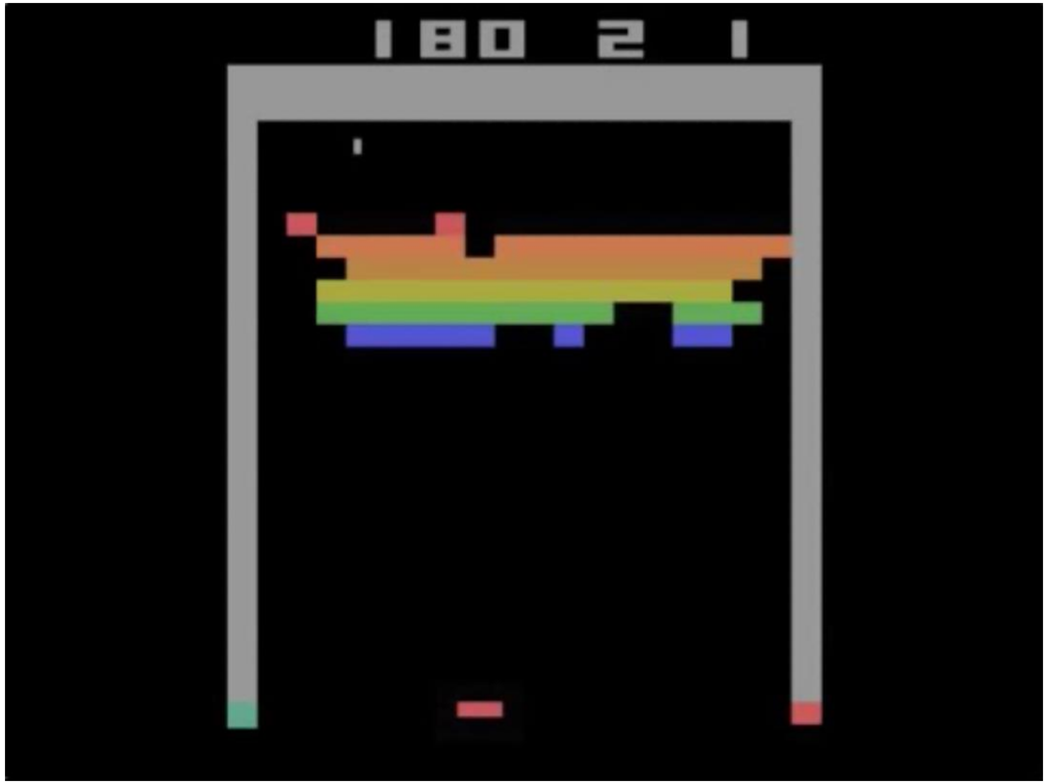
Robotics

From prediction to decision making
Reinforcement Learning

Perception - Action

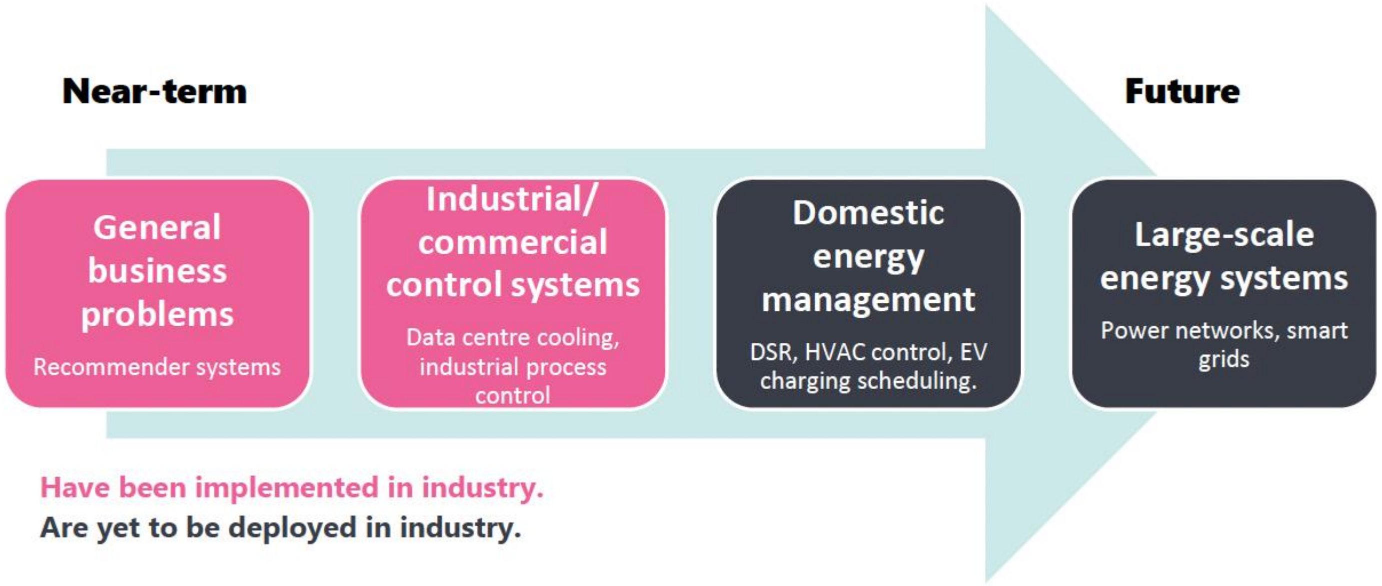


DeepMind (DQN 2015)



Where are we now

Catapult (Energy systems)

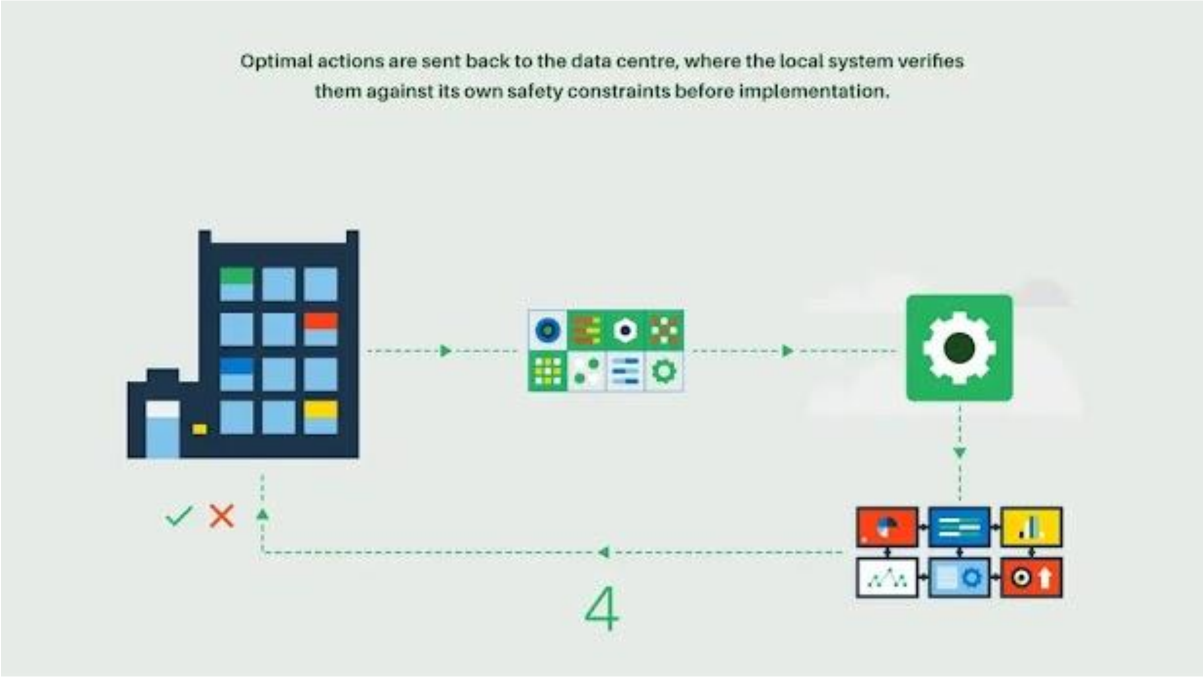


- Carbon Re are using RL to reduce carbon emissions in cement production.
- E.ON are using RL to determine the optimal placement of wind turbines in wind farms.
- digiLab are using RL to determine the optimal locations for solar panels on rooftops in local areas.
- **Microsoft:** Project Bonsai improved the energy efficiency of their HVAC systems and uncovered counterintuitive recommendations to what a human would assume using their RL solution.
- **digiLab** are using RL to optimise room temperature control for their 'TwinCity' solution.
- Debmalya Biswas published a report on their successful implementation of RL-based HVAC control in a factory in Switzerland.
- Google showed 40% improvement in energy efficiency of their data centres using their RL solution.
- Phaidra – a company founded by the people responsible for the improvement in Google's data centre cooling who focus on providing RL-based solutions for optimising industrial systems.

AI for energy efficiency optimisation

From Atari games to energy efficient data centers

Recommendations every 5’



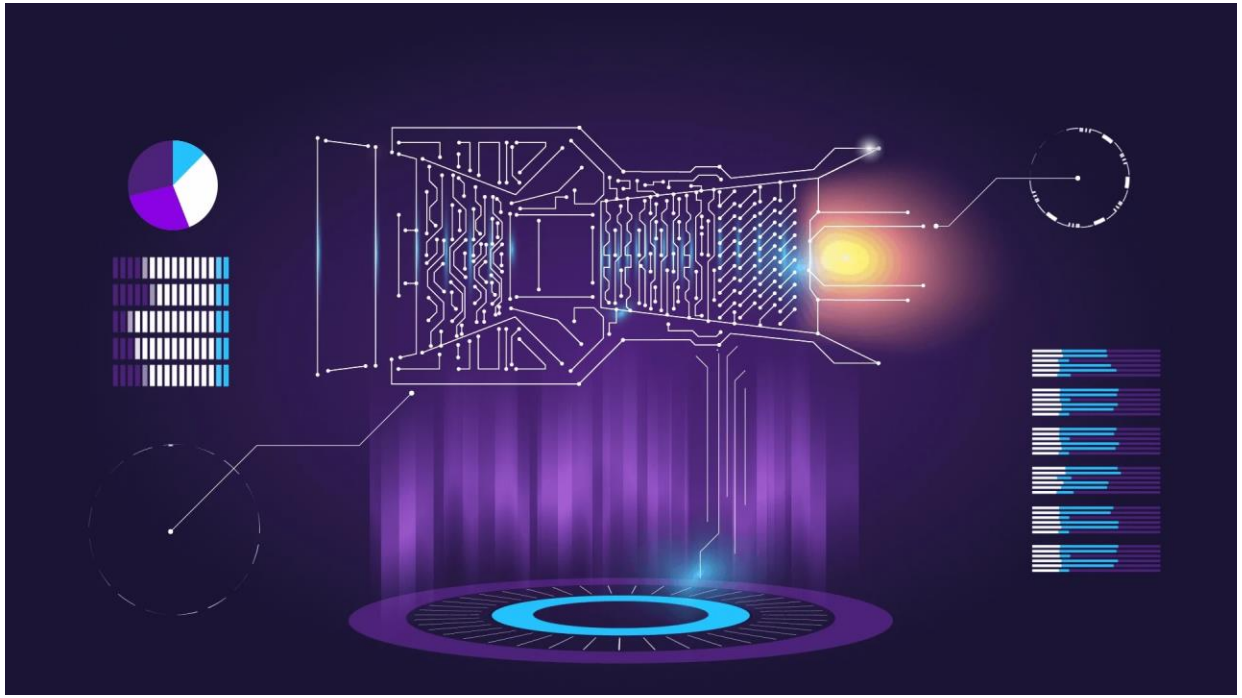
30% energy efficiency improvement

https://deepmind.google/discover/blog/safety-first-ai-for-autonomous-data-centre-cooling-and-industrial-control/

Gas Turbine AutoTuner (Siemens)

10% Lower NOx

GT Auto Tuner is an AI-based solution for gas turbines that uses a digital twin to optimize the turbine inlet temperature and emissions with the help of reinforcement learning.



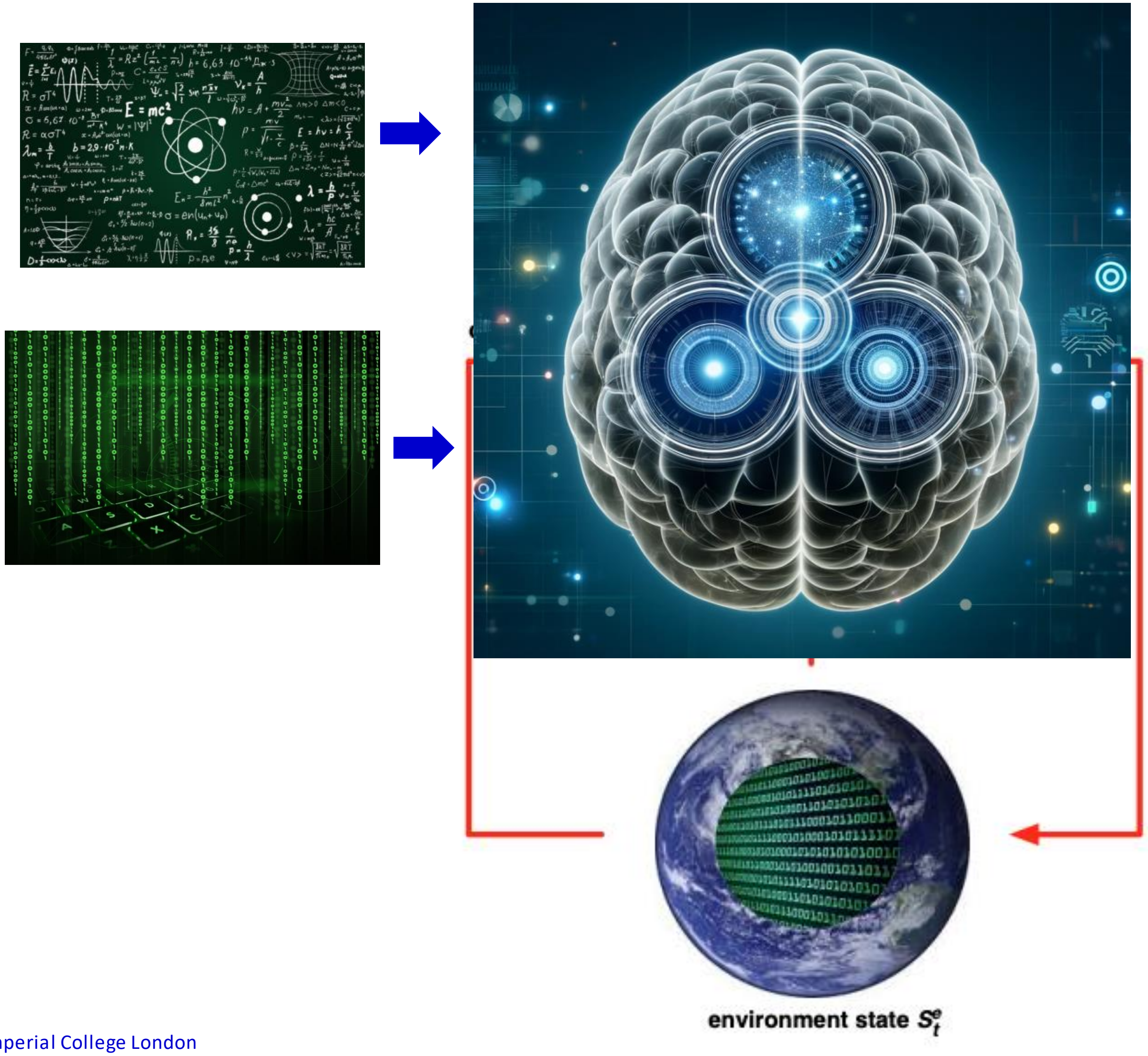
Physics Laws

Data - LLMs

– Predict – Control

Flow problems

Merging the digital and physical world



Can we model the environment and train policies to be able to directly take actions in the actual environment and also make long time horizon predictions?

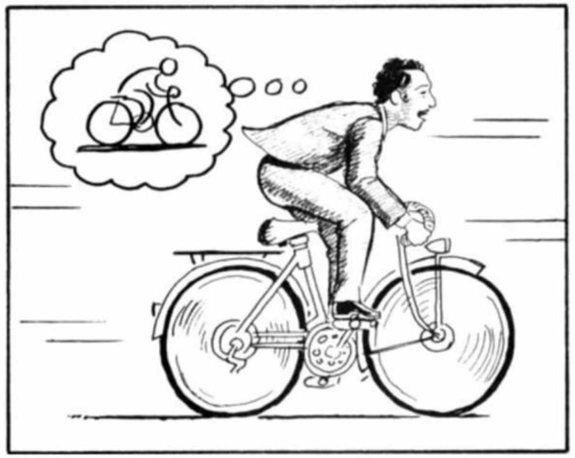


Figure 1. A World Model, from Scott McCloud's *Understanding Comics*. (McCloud, 1993; E, 2012)

The AI for Net Zero team

AI – Theoretical/Applied Eng – Policy Making

John Aston
Cambridge

Evidence Communication for Policymaking

Knowledge Exchange Activities

Michele Weiland
Edinburgh

Luca Magri
Imperial

AI for Digital Twins

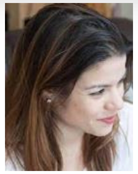
Efficient use of hardware for AI/HPC Workflows

Anastasia Borovykh
Imperial

Hydrogen

Wind Energy

Transport



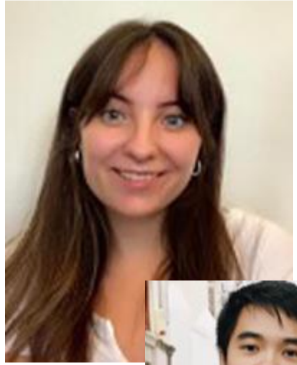
Konstantina Vogiatzaki
Oxford

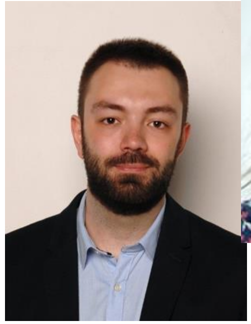
Sylvain Laizet
Imperial

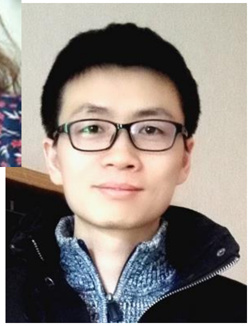
Georgios Rigas (PI)
Imperial

Postdoctoral Research Associates

Coordinator







RSE

Road Transport

Up to 70% of the energy is required to overcome aerodynamics

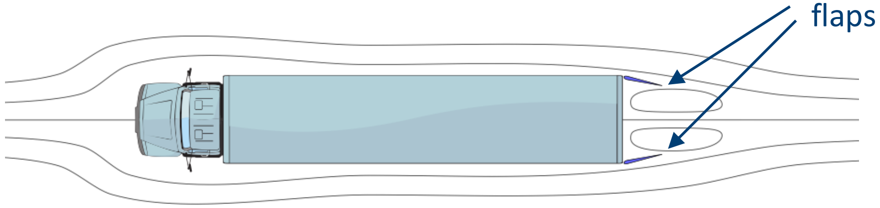
‘Trailers entering California are required to use EPA SmartWay-certified trailers or technologies,…, and must achieve a 4% or 5% improvement in fuel consumption.’ **(2016)**

0.7 million metric tons CO_2
$5.1 billion diesel fuel savings (2011-2020)

By reducing the Model S drag figure from 0.32 to 0.24, Tesla managed to increase the range of the car by about 50 miles.

2022: UK government changes legislation to permit the use of aerodynamic features and elongated cabs on lorries

Existing Solutions



STATIC aerodynamic flaps for trailers can reduce fuel up to 4%

WABCO OPTIFLOW implementation

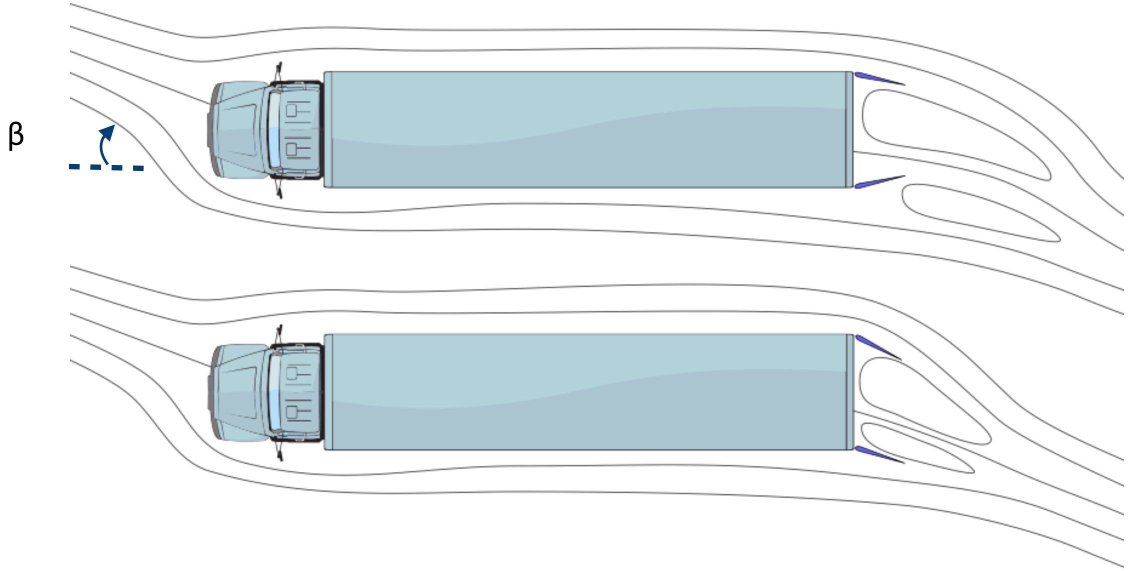
- Motorised/foldable tail flaps (doors open up to 260º for loading)
- Retrofit Option
- Adopted recently in the US market

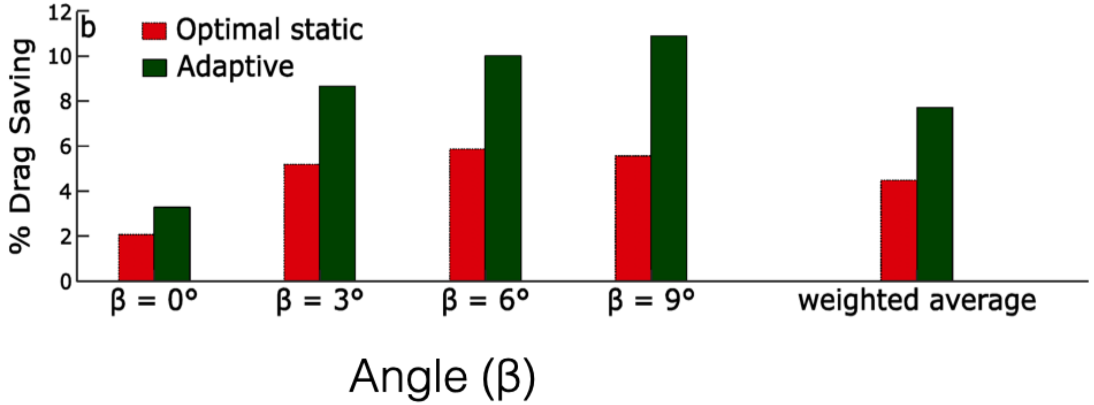
www.wabco-optiflow.com Youtube Link

Our solution

SmartFlap position adapts based on angle (β) of

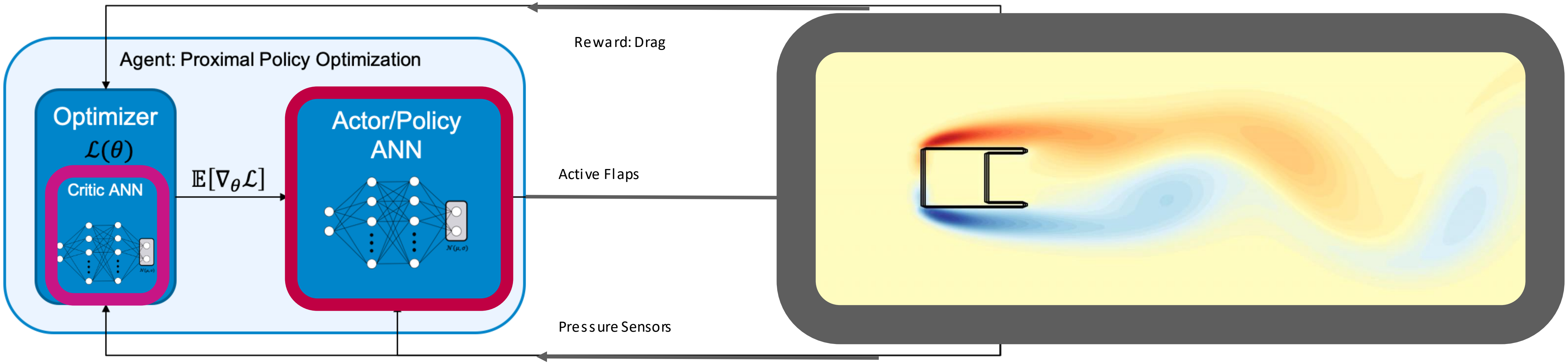
- Cross-wind direction
- Vehicle manoeuvre





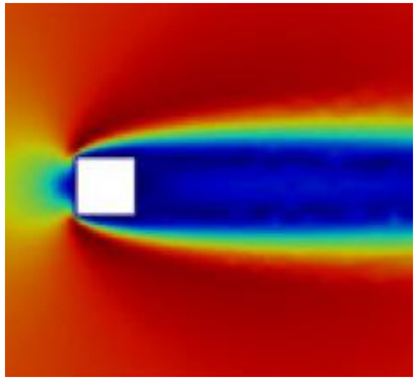
Patent PCT/GB2016/053364

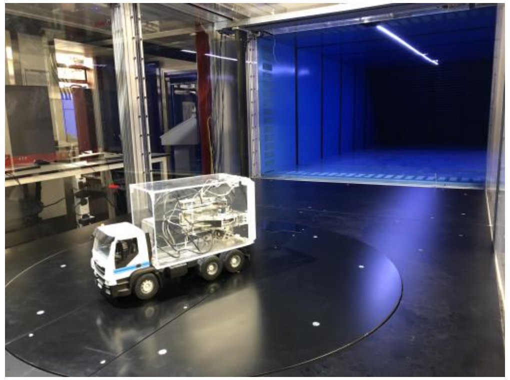
Reinforcement Learning of Aerodynamics
Digital twin

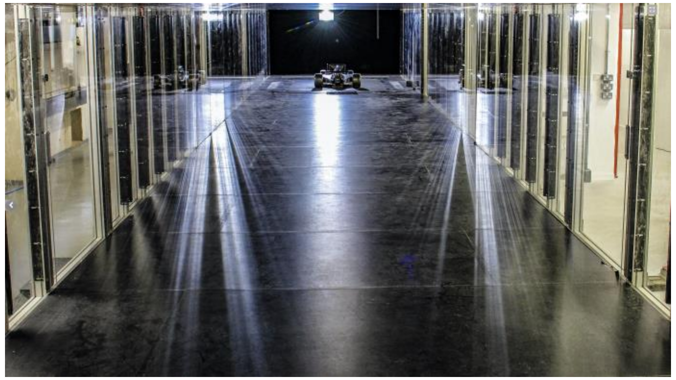


Proof of concept
Wind tunnel experiment

NOW (TRL 3)







I: Digital twin
(Laminar 2D)

II: Scale 1:10
(wind tunnel 5ft x 4ft)

III: Scale 1:2
(wind tunnel 10ft x 5ft)

IV: Scale 1:1
(real environment)

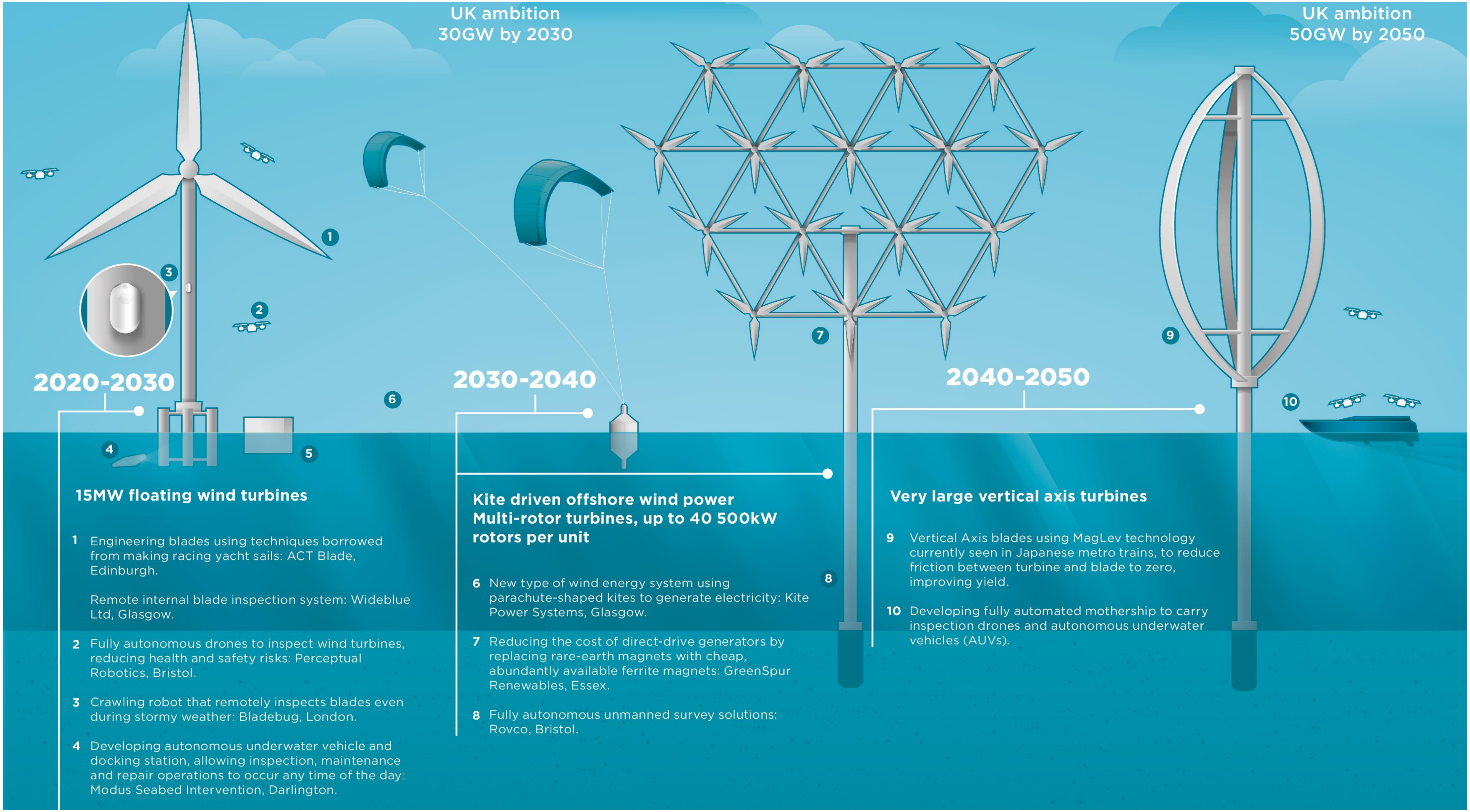
Wind farms: some numbers

2022 (offshore) 63 GW installed (over 30 years) (UK 15 GW)
Net Zero 2050 (offshore): 2,000 GW (200,000 turbines) (UK target 125 GW)

We need 30 times more GW in 28 years (installation rate of 70–80 GW annually, 5,000 new turbines installed each year, 500,000 km^2 of ocean by 2050)

Where do we put all these extra offshore wind farms? maximise energy output / social benefits, minimum impact possible on the environment

3 options: new design, go big, optimise power output


UK ambition
30GW by 2030
UK ambition
50GW by 2050
2020-2030
2030-2040
2040-2050
1
2
3
4
5
6
7
8
9
10
15MW floating wind turbines
1 Engineering blades using techniques borrowed from making racing yacht sails: ACT Blade, Edinburgh.
Remote internal blade inspection system: Wideblue Ltd, Glasgow.
2 Fully autonomous drones to inspect wind turbines, reducing health and safety risks: Perceptual Robotics, Bristol.
3 Crawling robot that remotely inspects blades even during stormy weather: Bladebug, London.
4 Developing autonomous underwater vehicle and docking station, allowing inspection, maintenance and repair operations to occur any time of the day: Modus Seabed Intervention, Darlington.
Kite driven offshore wind power
Multi-rotor turbines, up to 40 500kW rotors per unit
6 New type of wind energy system using parachute-shaped kites to generate electricity: Kite Power Systems, Glasgow.
7 Reducing the cost of direct-drive generators by replacing rare-earth magnets with cheap, abundantly available ferrite magnets: GreenSpur Renewables, Essex.
8 Fully autonomous unmanned survey solutions: Rovco, Bristol.
Very large vertical axis turbines
9 Vertical Axis blades using MagLev technology currently seen in Japanese metro trains, to reduce friction between turbine and blade to zero, improving yield.
10 Developing fully automated mothership to carry inspection drones and autonomous underwater vehicles (AUVs).

Dogger Bank sits approximately 130km (80 miles) off the coast of Yorkshire and will occupy an area almost as large as Greater London and nearly twice the size of New York City. When fully complete, its 3.6 GW capacity will comprise 277 offshore turbines capable of producing enough energy to power the equivalent of six million British homes annually.

First power followed the installation of the first of GE Vernova's Haliade-X 13 MW turbines, one of the largest and most powerful globally, at the Dogger Bank site. This is the first time Haliade-X units have been energized offshore anywhere in the world. Each rotation of the 107m long blades can produce enough energy to power an average British home for two days.

Hornsea 2 Offshore Wind Farm

Powering over 1.4 million homes with green energy

Hornsea 2, located in the North Sea next to its sister project Hornsea 1, generates enough green energy to power over 1.4 million UK homes. As the world's largest offshore wind farm, it covers an area of 462 square kilometres (178 square miles).

1.32 GW
Total capacity

165
8 MW wind turbines

89 km
Distance from the Yorkshire coast

Mingyang presents 22-MW offshore wind turbine concept

Chinese wind turbine manufacturer Ming Yang Smart Energy Group Ltd (SHA:601615) has presented a 22-MW offshore wind turbine model, the MySE 22MW, said to be the world's most powerful offshore turbine unveiled so far.

MingYang wind turbine. Image by: Ming Yang Smart Energy Group @LinkedIn.

The model was presented at the China Wind Power 2023 last week and is "set for development between 2024 and 2025," according to a social media post by the company.

The giant turbine will have a rotor of over 310 metres and will be intended for high-wind regions. It will be suitable for both fixed-bottom and floating applications.

The news follows the presentation of the MySE 18.X-28X model in January.

The MySE 22MW was unveiled together with a large onshore wind turbine, the MySE 11-233, which is now in production at Mingyang's Inner Mongolia base. The company said this machine is tailored for the challenging conditions of desert and Gobi regions. With rotor diameters ranging from 233 to 243 meters and tower heights from 130 to 200 meters.

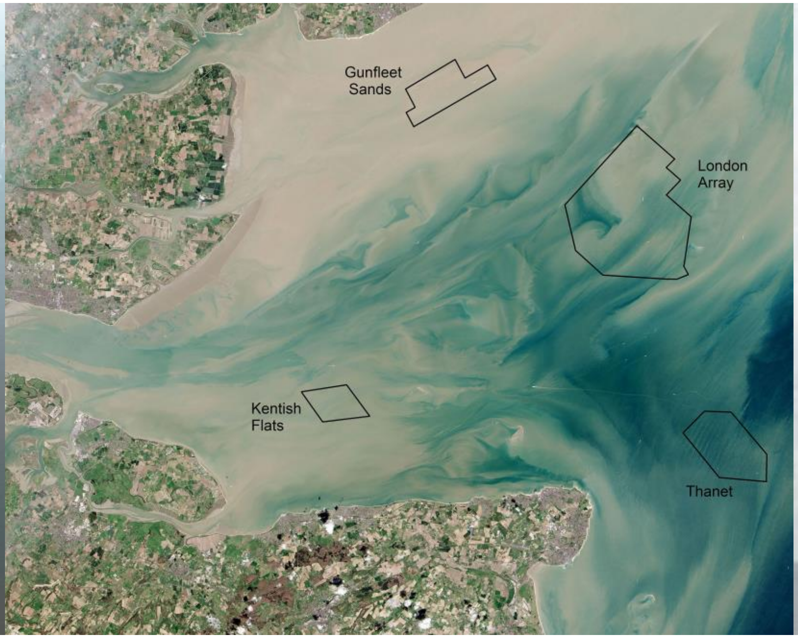
Optimisation Wind Farms

London Array: 175 wind turbines, 3.6 MW each, total 630 MW, can provide electricity for 500,000 homes [in theory]

Capacity factor (actual output divided by the theoretical capacity): ~45%

AI-based control can increase the capacity factor by ~20% **at no cost**

Increased capacity of 50 MW by AI-based solution→ 40,000 more homes



ICT: some numbers

What do you need to do AI? Information and Communication technologies (ICT)

By the end of the decade, ICT could consume up to 20% of the world's electricity (exponential growth)
E-waste is reported to be over 50 million metric tonnes, with less than 20% collected and recycled.

ICT create pollution in different ways. Storing and sending data, like streaming videos, cloud services, training AI models, use a lot of energy and contributes to pollution.

UK Research and Innovation (UKRI) wants to deliver a carbon neutral digital research infrastructure (DRI) by 2040 or earlier.

HOME › NEWS › THE INVESTMENT & MARKETS CHANNEL

AWS acquires Talen's nuclear data center campus in Pennsylvania

Cloud company pays $650 million – plans 960MW campus

First announced by *DCD* in July 2021, the 1,200-acre campus draws power from Talen Energy's neighboring 2.5GW nuclear power station in Luzerne County, the Susquehanna Steam Electric Station (SSES). The company broke ground in 2021 and completed the first 48MW, 300,000 square foot (28,870 sqm) hyperscale facility early last year, along with a separate cryptomine facility.

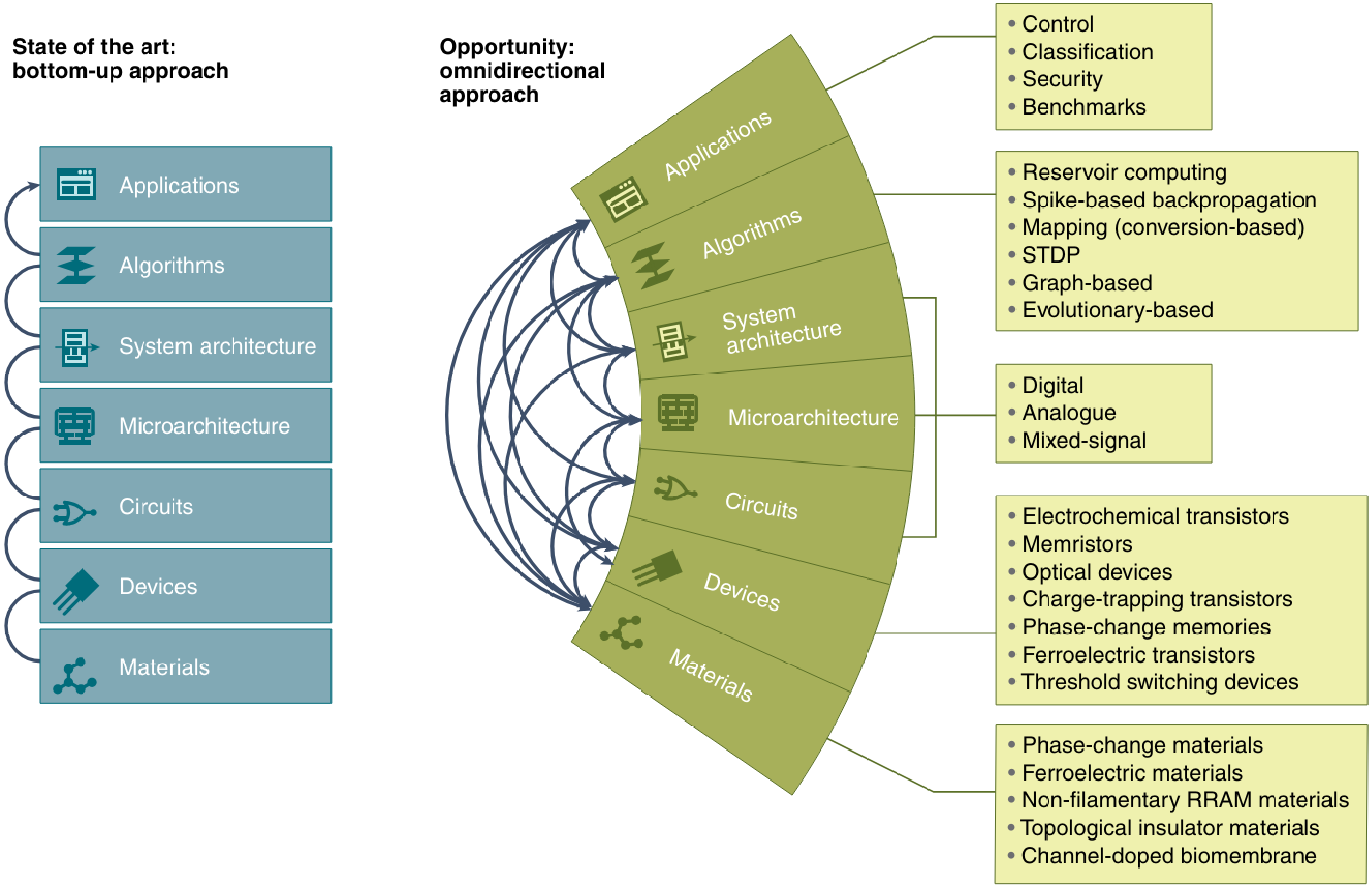
Talen said AWS aims to develop a 960MW data center campus. The cloud company has minimum contractual power commitments that ramp up in 120MW increments over several years; AWS has a one-time option to cap commitments at 480MW. The cloud provider also has two 10-year extension options, tied to nuclear license renewals

Scaling Compute – AI at 1/1000th the cost

See application timeline

co-design hardware-software

SW and HW are traditionally designed independently as SW programmers seldom need to think about which HW to run on, and HW is typically designed to support a wide range of SW.


State of the art:
bottom-up approach
Applications
Algorithms
System architecture
Microarchitecture
Circuits
Devices
Materials
Opportunity:
omnidirectional
approach
Applications
Algorithms
System
architecture
Microarchitecture
Circuits
Devices
Materials
• Control
• Classification
• Security
• Benchmarks
• Reservoir computing
• Spike-based backpropagation
• Mapping (conversion-based)
• STDP
• Graph-based
• Evolutionary-based
• Digital
• Analogue
• Mixed-signal
• Electrochemical transistors
• Memristors
• Optical devices
• Charge-trapping transistors
• Phase-change memories
• Ferroelectric transistors
• Threshold switching devices
• Phase-change materials
• Ferroelectric materials
• Non-filamentary RRAM materials
• Topological insulator materials
• Channel-doped biomembrane

IMPERIAL

Thank you

Case 1: Aerodynamics

Case 2: Wind farms

Sustainable Data-Centers for AI

AI for Net Zero
20/05/2024

References

[1] Weissenbacher, M., Borovykh, A. and Rigas, G., 2024. CHAROT: Robustly controlling chaotic PDEs with partial observations. In International Conference on Learning Representations (ICLR) 2024 Workshop on AI4DifferentialEquations In Science.
[2] Kelshaw, D., Rigas, G. and Magri, L., 2023. Physics-Informed CNNs for Super-Resolution of Sparse Observations on Dynamical Systems. Workshop at the 37th conference on Neural Information Processing Systems (NeurIPS).
[3] Xia, C., Zhang, J., Kerrigan, E.C. and Rigas, G., 2024. Active flow control for bluff body drag reduction using reinforcement learning with partial measurements. Journal of Fluid Mechanics, 981, p.A17.
[4] Bempedelis, N., Gori, F., Wynn, A., Laizet, S. and Magri, L., 2024. Data-driven optimisation of wind farm layout and wake steering with large-eddy simulations. Wind Energy Science.
[5] Danopoulos, E., Aston, J., Benson, L., Magri, L., Rigas, G., 2024. Development of a reporting guideline for Scientific Machine Learning based studies. Global Evidence Summit 2024. Accepted oral presentation.

[6] Charfeddine L, Umlai M. ICT sector, digitization and environmental sustainability: A systematic review of the literature from 2000 to 2022. Renewable and Sustainable Energy Reviews. 2023 Sep 1;184:113482.
[7] Malmodin J, Lövehagen N, Bergmark P, Lundén D. ICT sector electricity consumption and greenhouse gas emissions–2020 outcome. Telecommunications Policy. 2024 Jan 9:102701.

Web resources:

https://deepmind.google/discover/blog/graphcast-ai-model-for-faster-and-more-accurate-global-weather-forecasting/

https://es.catapult.org.uk/insight/reinforcement-learning-christopher-lee/

https://deepmind.google/discover/blog/deepmind-ai-reduces-google-data-centre-cooling-bill-by-40/

https://defradigital.blog.gov.uk/2023/02/23/why-sustainable-ict-is-vital/