Microsoft

Quantum impact:
Energy and utilities

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Few industries have as significant an impact on our daily lives as the energy and utilities sectors. Not long ago, our energy system was dominated by fossil fuels like coal, natural gas and petroleum. The mix of sources has begun to change, with renewables like solar, hydro, geothermal and wind growing in importance. But if we are to meet our global climate targets and avoid dangerous climate change, the world needs to accelerate this transition even faster. These changes pose complex challenges for suppliers and operators as new cost-effective energy sources and distribution processes are developed.

Where energy once came only from large-scale suppliers and the grid was unidirectional, end customers are now integrating with the smart grid with distributed energy sources like solar panels and batteries in their homes. With these less predictable renewable sources and decentralized supply permeating the grid, optimization of suppliers' production and distribution becomes exponentially complex.

In addition to solving complex optimization problems, quantum computers may be able to aid in chemistry and materials development far beyond the capacity of present-day supercomputers. Such simulations could lead to breakthroughs in materials science such as batteries with greater capacity and longer life spans, high temperature superconductors, and new catalysts for converting and optimizing alternative fuel sources.

The promise of quantum

Quantum computing utilizes the properties of quantum mechanics to process information. Often operating with nanoscale components at temperatures colder than deep space, quantum computers have the potential to address some of the world's toughest challenges. Where current computers would require billions of years to solve the world's most challenging problems, with the right algorithm, a scaled quantum computer could find a solution in weeks, days, or hours.

When designed to scale, quantum systems will have capabilities that exceed our most powerful supercomputers. As the global community of quantum researchers, scientists, engineers, and business leaders continue to collaborate to advance the quantum ecosystem, we expect to see quantum impact accelerate across every industry.

From bits to qubits

The quantum bit, or qubit, is the basic unit of quantum information. Whereas a classical bit holds a single binary value, 0 or 1, a qubit can be in a "superposition" of both values at the same time. This enables quantum mechanical effects such as interference, tunneling, and entanglement, which in turn empower quantum algorithms for faster searching, better optimization, and greater security. When multiple qubits are connected, these properties can deliver significantly more processing power than the same number of classical bits. For instance, four bits is enough for a classical computer to represent any number between 0 and 15. But four qubits is enough for a quantum computer to represent every number between 0 and 15 at the same time.

Quantum-inspired solutions

Emulating these quantum effects on classical computers has led to the development of new types of quantum solutions that run on classical hardware, also called quantum-inspired algorithms.[1] These algorithms allow us to exploit some of the advantages of quantum computing approaches today on classical hardware, providing a speedup over traditional approaches. Using quantum solutions on classical hardware also prepares us for the future of quantum optimization on actual quantum hardware.

Load balancing

For the lights to come on when customers flip a switch, electricity supply and demand must be perfectly in sync. Many electric grids still rely heavily on power generated by fossil fuels, but growing levels of renewables are coming online every year. Sometimes the sun doesn't shine and the wind doesn't blow, leading to significantly more erratic production curves. As the proportion of intermittent sources grows, there is a significant risk of the grid becoming harder to manage and even unstable.

From a consumption standpoint, there are certain patterns that can be predicted. If everyone goes to work around the same time in the morning and then comes home around the same time in the evening, turns on their heater and plugs in their electric vehicle, the load will be small during the day and much greater in the evening. But changes in social trends like remote work and flexible schedules have the potential to cause unanticipated and erratic spikes in demand.

Load balancing aims to schedule connected devices and appliances based on their need, ultimately optimizing the energy usage and to minimize the usage cost. This approach spreads the electrical load over a time horizon in order to appropriately schedule the requests, optimizing the usage cost in a real-time environment to coordinate the availability of resources at off-peak times, the use of stored power, and the fact that there are peak consumption times that may not line up with peak availability.

With a multi-directional smart grid, it will become increasingly important to manage load balancing in local nodes to avoid energy loss from sending power generated at the edge of the grid back to the high-level grid.

This use case is a prime area of focus for quantum optimization: How can we efficiently determine the best schedule for resources and run these computations at a timescale that's most relevant to the problem? And longer term, how can we actually control those resources in a coordinated fashion, being responsive to variability in both demand and supply within the power grid?

As problems become more complex with new energy resources being introduced to the grid, and as appliances and consumption trends become more erratic, computation becomes substantially more difficult and time consuming to calculate.

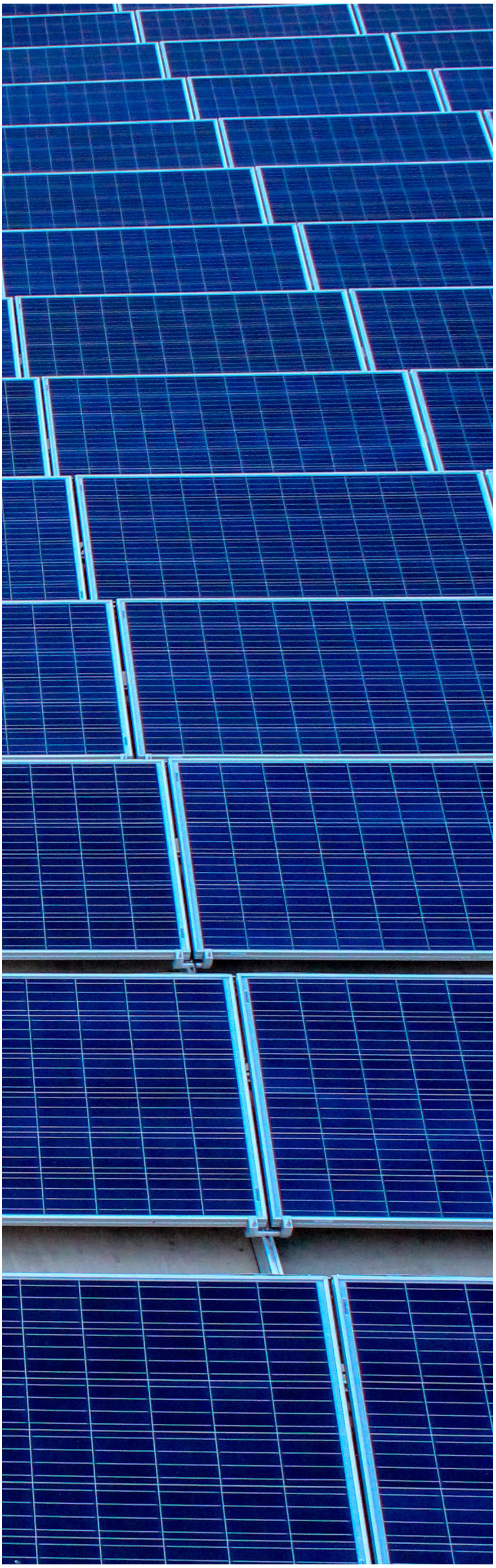
We have identified quantum-inspired optimization techniques that outperform conventional methods and are looking to replace these conventional solvers with quantum-inspired algorithms now and quantum algorithms in the future.

Unit commitment

Another application for quantum computing is power generation optimization. The challenges in this area focus on deciding which generating units to run based on the cost of the units, constraints on the grid, and constraints on the units. This remains one of the most significant problems in power system management. Unit commitment (UC) is compute-intensive, making these problems a prime area for quantum-inspired optimization.

Unit commitment seeks to identify the best generating resources to run, based upon forecasted loads, as well as power generation efficiencies and capacity limitations. The problem becomes complex because each thermal generating unit has an optimal operational setpoint based upon efficiency heat rate curves. Generating units may have steam generation using waste heat for further efficiency. Units may also produce water for a municipal water supply, further adding to the modeling and scheduling complexity.

Growing complexity from constraints including emission limits, market requirements and intermittent renewable sources make unit commitment a vital problem to solve with better efficiency. Microsoft has developed a powerful quantum-inspired optimization algorithm for UC that outperforms classical solvers.



Independent system operators

Currently, Independent System Operators (ISOs) work on a 24-hour day-ahead schedule where energy suppliers bid their capacities into the market and the ISO matches generation to a forecasted load.

Sometimes when generation companies bid their proposed supply or capacity into the market, the market may take too long to "clear," and the generation company is forced to take a position on fuel (e.g. natural gas) before they know what commitment the ISO is buying.

In other words, the generation company may expect to generate a certain number of units of power and has purchased fuel with the intention of selling it to the ISO, but they may be preempted by a lower bid. At this point the generation company must resell their fuel position (potentially at a loss) or sell energy into the spot market (potentially at a huge discount). If the market could clear faster, the supply chain coupling could be better managed both for the generation company and the fuels suppliers.

The mix of energy sources continues to grow, and while adding one or two additional suppliers (e.g. wind or solar farms) may be fairly simple, adding hundreds of new energy sources to the market becomes substantially difficult, if not impossible.

Material science and chemistry

One of the first applications of quantum computers will be in the fields of materials science and chemistry. We see huge potential in areas leading to cleaner fuel, emission reduction and energy efficiency.

Better catalysts

An important area of research for the energy industry is to develop new methods for converting and optimizing alternative energy sources. Catalysis is a key technology in achieving this goal and impacts applications as varied as converting carbon dioxide into useable fuel sources or improving catalytic converters and smokestack scrubbers to help keep sulfur dioxide out of the atmosphere. Designing catalysts and predicting their reactions requires highly accurate calculations of energy differences of molecules. For many transition metal compounds, this is difficult, if not impossible, with today's classical computing, even running on the world's fastest supercomputer. Because quantum physics governs the interactions between atoms, quantum computing is uniquely suited to natively simulate and predict which materials will act as good catalysts for a chemical reaction.

High temperature superconductors

Power grids currently lose approximately 5-20% of their energy during transmission and distribution as electricity travels through the materials in the grid. That's a tremendous amount of wasted money and resources. Superconductors are materials that transport electric charge without resistance. Most of these materials require cooling to very low temperatures to function. More practical room-temperature superconductors could revolutionize the world's energy system but this class of superconductors is not yet fully understood at the microscopic level. Quantum computing is promising because of its potential to accurately and natively simulate the underlying physics of these complex systems and help scientists to design new materials with these desired properties.[2]

Case study:

Quantum computing and DEWA

Dubai Electricity and Water Authority (DEWA) is working with Microsoft[3] to develop new quantum solutions to address energy optimization and other challenges where classical computers have serious limitations.

As part of Dubai 10X, an initiative to use advances in technology to deliver new or existing services in radically different ways, DEWA wants to reimagine its role as a utility company by launching "Digital DEWA," the digital arm of Dubai Electricity and Water Authority, and is leveraging Microsoft Quantum to help accelerate its goals.

DEWA is working closely with Microsoft to develop a quantum strategy, including understanding where quantum optimization methods can be applied for greatest impact in Dubai, both on classical computers and in the future on Microsoft's quantum computer. Energy optimization, for example, requires far too much traditional computing power to identify the ideal balance of resources from different energy sources to meet ever-changing consumption needs in real time.

As the development of the quantum computer continues, select partners such as DEWA can access new quantum-inspired Azure services for the most complete, state-of-the-art, end-to-end quantum programming.

Working with Microsoft, the Quantum Development Kit toolset and Azure quantum-inspired services, DEWA will be able to program and test quantum algorithms, then apply those quantum solutions within the existing Azure platform to achieve real-world impacts even before the development of a general-purpose quantum computer. This work will also provide DEWA with a seamless migration to using Microsoft's quantum computer once it is available.

Real-time equipment operation

Ultimately, the goal is to move away from a 24-hour day-ahead schedule and transition to real-time operation of equipment. For example, to meet their goal of zero-emission energy sources by 2045, California needs very high-performing software assistance for the coordination of resources to deal with a high proportion of renewables.

Going back to the load balancing scenario, during the day, there is an greater supply of energy from solar and wind, meaning that less thermal units are running because the renewable sources are less expensive. Then at dark, demand goes up quickly at the same time that renewables decrease significantly. How do we backfill the loss of renewables? Thermal generating units can be started, but they won't ramp up fast enough to avoid the cliff. If demand forecasts are unpredictable it can be costly to maintain spinning reserve too far in advance.

An automated intelligent control system with demand response and controllable storage and coordination of resources is imperative, and this system must operate the grid in a highly penetrated renewables environment. We believe that in order to hit the necessary real-time processing speeds, classical compute techniques are not sufficient.

As we get new forms of energy, new participants and new business entities trying to solve for finer-grained optimization scenarios, it becomes both a scale and complexity problem with a need for parallelizable approaches.

Case study:

Harnessing the wind

We think of wind as being "free energy," but windmills actually disrupt airflow and if not properly placed and can move wind away from the area, leaving a windmill farm unable to harness the wind's maximum power. If one windmill is downwind from another, it will not operate very efficiently, but the notion of "downwind" changes regularly.

Microsoft Quantum Network Member Qubit Engineering is creating rotor models to simulate what turbulence looks like in the air in order to optimize windmill placement. A rotor model is a physics concept that has been used to approximate quantum mechanical systems. Envisioning an electron behaving like spinning top, one views the system as a mechanical engine of interacting rotors.

Azure Quantum has tools to solve these rotor models in order to find minimum and maximum energy configurations, and Qubit Engineering is applying these quantum theories to calculate the optimum placement of windmills within a space.

By understanding environmental factors and adding how each windmill might interact with each other, Qubit Engineering has created an abstract modeling scoring system to find optimal placement for maximum energy production under a variety of circumstances.

Azure Quantum

Quantum computing applies the properties of quantum physics to process information. Where current computers would require billions of years to solve some of the world's most challenging problems, a scaled quantum computer may find a solution in weeks, days, or hours. Azure Quantum is an open ecosystem of quantum partners and technologies. Building on decades of quantum research and scalable enterprise cloud offerings, it is a complete solution that gives you the freedom to create your own path to scalable quantum computing.

Azure Quantum is also your entry point to integrate quantum inspired optimization running on classical Azure hardware for immediate results. Through a familiar Azure environment, you'll have access to all the tools and resources you need to quickly ramp up on your journey to a quantum future and have an impact with quantum technology today.

An open ecosystem, enabling you to access diverse quantum software, hardware, and solutions from Microsoft and our partners.

A trusted, scalable, and secure platform that will continue to adapt to our rapidly evolving quantum future.

Quantum impact today, with pre-built solutions that run on classical and accelerated compute resources (also referred to as optimization solutions).

Get ready for your Azure Quantum experience with the Quantum Development Kit

The Quantum development kit is an open-source development kit to develop quantum applications and solve optimization problems. It includes the high-level quantum programming language Q#, a set of libraries, simulators, support for Q# in environments like Visual Studio Code and Jupyter Notebooks, and interoperability with Python or .NET languages.

As quantum systems evolve, your code endures.

Learn more at https://azure.com/quantum

Prepare your organization

Tackling the world's toughest challenges requires computational power that exceeds that of today's most powerful computers. Where classical computing may take a billion years to address some of these challenging problems, quantum computing has the power to solve these problems in weeks, days, or even hours.

1. Find relevant use cases for your business

See how organizations like yours are using quantum solutions. The Microsoft Quantum website has case studies that show how companies are using quantum technology for their businesses, today.

2. Build a quantum workforce

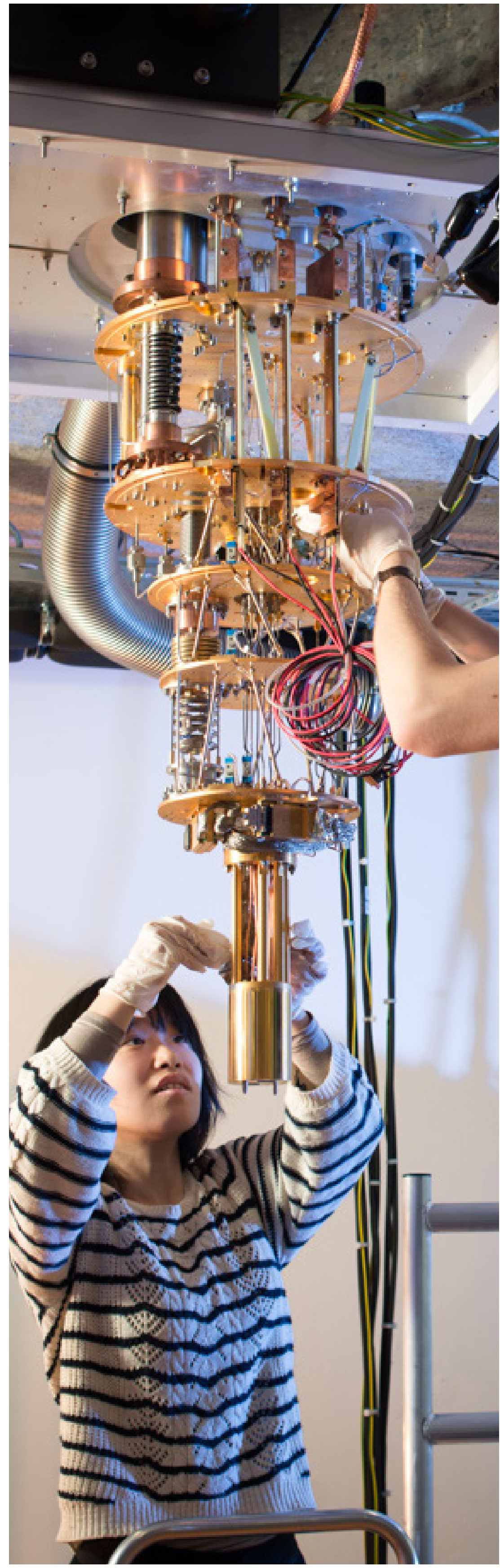
Ensure your organization is ready for quantum computing by assembling a quantum task force comprised of C-suite sponsors, business unit managers, and developers. Augment over time with quantum specialists and mathematicians that are familiar with applications and algorithms that are most relevant for your business.

3. Join the Microsoft Quantum Enterprise Acceleration Program

Microsoft offers the Enterprise Acceleration Program to develop high-value, custom quantum solutions alongside the world's best quantum talent. This is a paid offering for Microsoft's most advanced enterprise customers to accelerate quantum adoption through direct collaboration with the Quantum team. Contact us to get started.

4. Experience impact today through Azure Quantum

Microsoft is building a full-stack quantum ecosystem, delivered through the power and scale of Azure's global cloud services platform. Apply to become an early adopter for preview access to Azure Quantum.



Authors

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Larry Cochrane is responsible for defining and driving Azure's global Power and Utilities energy strategy and forging partnerships with customers and partners for Azure adoption. Cochrane's in-depth knowledge and passion have been pivotal in Microsoft Azure Energy Management building block services and establishing Microsoft Azure NERC CIPs compliancy. With more than 25 years' experience, Cochrane has held numerous senior level positions and played pivotal roles in real-time control system from Wind Turbines to very large-scale Energy Management and Markets Systems.

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Stephen Jordan works in Microsoft's Quantum Systems group, researching quantum algorithms, particularly for simulation and optimization. He is also interested in quantum complexity theory, quantum inspired classical optimization heuristics, and post-quantum cryptography; and is the author and maintainer of the Quantum Algorithm Zoo.

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Brad Lackey is a Quantum Solutions Architect, specializing in creating quantum computing and quantum-inspired algorithms to solve real-world industrial problems. He also does foundational research in quantum information theory, (post-)quantum cryptography, and quantum programming languages.

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