Energy and utilities

Tokamak Energy

World-leading innovative company uses Siemens Digital Industries Software technology in quest to create fusion power

Products

Solid Edge, Teamcenter

Business challenges

Design and manufacture a compact tokamak

Deliver an engineering solution to demonstrate breakthrough physics

Demonstrate energy gain from fusion

Keys to success

Use industry-leading design tools of Solid Edge

Accelerate decision making

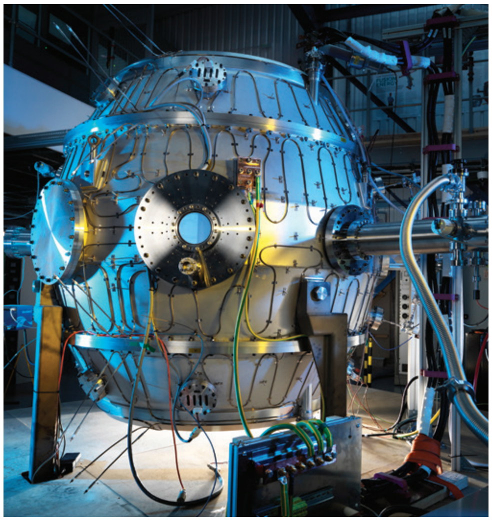
Use Solid Edge simulation to confirm structural performance

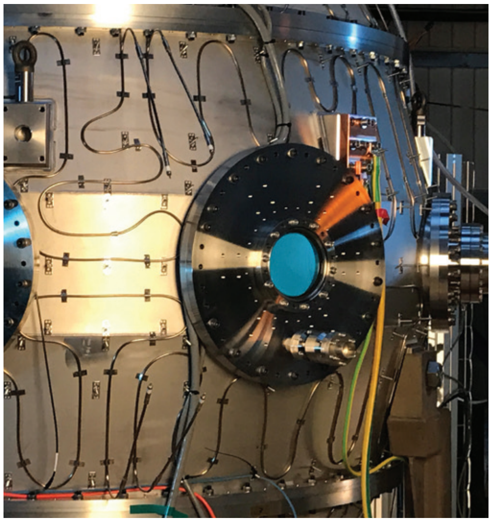
Tokamak Energy chooses Siemens Digital Industries Software solutions for tackling one of mankind's biggest engineering challenges

The search for a source of clean, unlimited power with no carbon emissions

There is a huge burst of energy when the nuclei of two light atoms fuse together to produce one heavier nucleus. Stars are created and maintained from such reactions, and our sun is powered by fusion as it continuously turns hydrogen nuclei into helium. For mankind, fusion is the key to an unlimited supply of low-carbon energy and, in contrast to fission, it does not create a chain reaction or produce long-lived toxic waste material.

The easiest way to achieve fusion on earth is by combining two hydrogen isotopes, deuterium and tritium. Fusion reaction takes place at extremely high temperatures and high pressures where gas turns into plasma. The best way to confine the plasma is through magnetic fields in a specialized container known as a tokamak (the word is a Russian language acronym for toroidal chamber magnetic coils). The best performing tokamak, the Joint European Torus (JET) device at Culham in Oxfordshire, once produced 16 megawatts (MW) of fusion power, but it has so far proved impossible to produce excess energy from fusion, because the energy required to keep the plasma hot enough for a reaction, and at the same time contain it, has exceeded the energy produced.





Results

Re-use of design data cuts development time

Precise geometry ensures designs are right first time

Effective team collaboration saves time

Design integrity confirmed through analysis

Potential problems identified early

Clear stakeholder communication

Rapid decision making – down from days to minutes

Fast design updates with easy assembly management

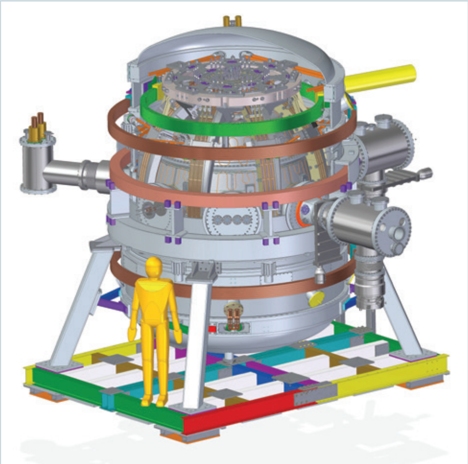
Product development agility

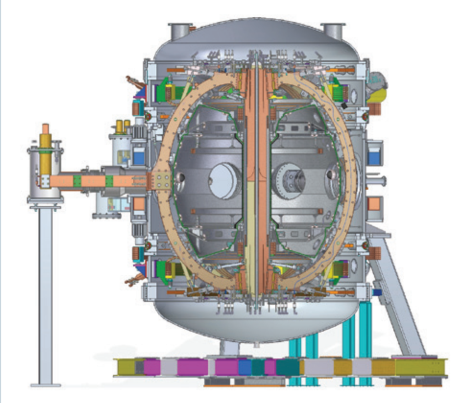
Creating and containing a star

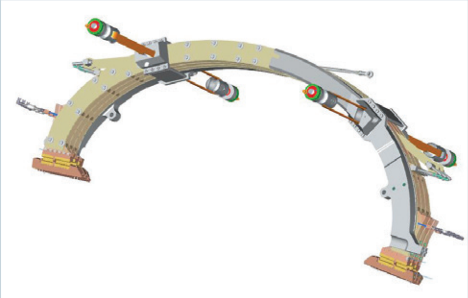
The conventional answer is to create bigger and bigger plasma containment vessels – one publicly funded tokamak currently under construction requires a building 20 stories high. Tokamak Energy is a private company with an innovative approach: to produce fusion energy within a compact device only a few meters wide. David Kingham, chief executive officer, explains: "Our aim is to be the first to commercialize fusion and the first to create a fusion device that produces an energy gain. We designed the world's first high-field spherical tokamak to take full advantage of this class of device."

Tokamak Energy has produced two laboratory prototypes, achieving a world first with the ST25 HTS, which demonstrated the use of high temperature superconductor (HTS) magnets. "Our latest design, ST40, uses copper magnets but is much more of an engineering challenge as we are aiming for exceptionally strong magnetic fields, up to three Tesla at the centre of the plasma," Kingham says. "We understand a lot about the physics, but the big question is how to contain and control the plasma at extremely high temperatures and pressures. We must make the magnetic field as strong as reasonably possible in such a compact device."

The early milestone of "first plasma" has already been reached. With copper magnets, the pulse length of maximum magnetic field has to be limited to about one second to prevent the copper from







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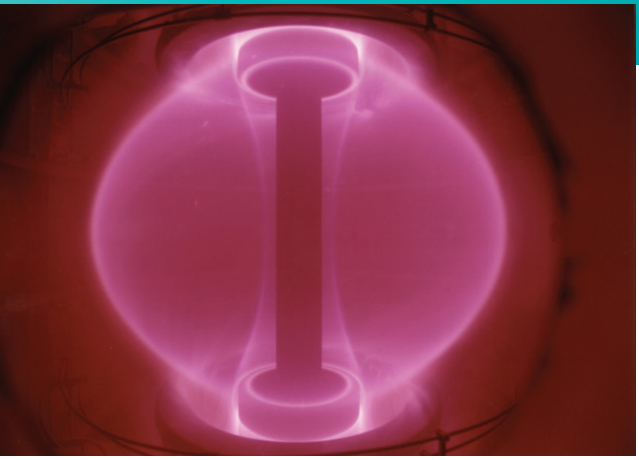
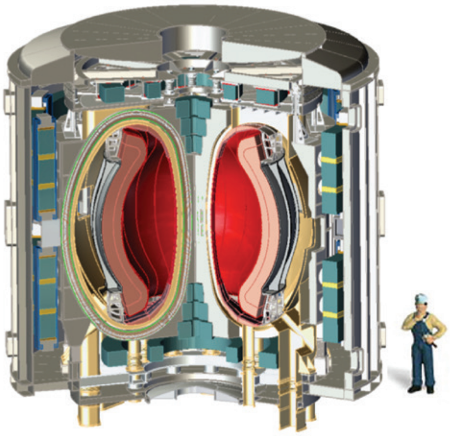


overheating. With no overheating issue, the high temperature superconductors to be used in future devices will be able to operate permanently, and Tokamak Energy has its sights set on a plasma temperature of 15 million degrees celsius (hotter than the center of the sun) and then on 100 million °C.

Tackling the world's toughest engineering problem

ST40 weighs 50 tons. It is made of easy-to-machine special steel and copper alloys that are corrosion- and heat-resistant and provide low magnetic permeability, high conductivity and structural stability. The device is designed using Solid Edge® software, which Tokamak Energy implemented in 2014 with the assistance of Siemens Digital Industries Software solution partner OnePLM. Tokamak Energy is also implementing Teamcenter® software to manage and control the product development process.



"We knew that we had a series of design challenges to tackle so we were looking for an industry-standard tool with excellent parametric ability," says Bill Huang, senior tokamak engineer. "Solid Edge fulfilled both requirements."

"We have some original drawings all defined by the physics but some of our geometry is extremely complex," says Paul Tigwell, mechanical design consultant at Tokamak Energy. "For example, the 24 rods in the center column of ST40 each have a 15-degree twist so that together they form a helix shape. The toroidal field coil outer limbs are in the form of eight sets of three curved limbs bolted together with supports. When we first began working on ST40 it became clear that a 2D approach simply would not work. Solid Edge gives us the accuracy we need, and as a new user I found it very intuitive. It is easy to learn through trial and error."

Precision and structural integrity

To create a magnetic field of three Tesla at the 40-centimeter major radius of the plasma, 6 million amps must flow through the centre column of ST40. Up to 200 tons per square meter of pressure is applied to each of the 24 central wedges that form the toroidal field magnets in the middle of the doughnut-shaped vessel holding the plasma. Once the plasma current builds up inside the device, the whole tokamak tends to twist and it is critical that limbs do not move or windings short out.

"We need strength and a lot of precision components," Huang says. "For example,

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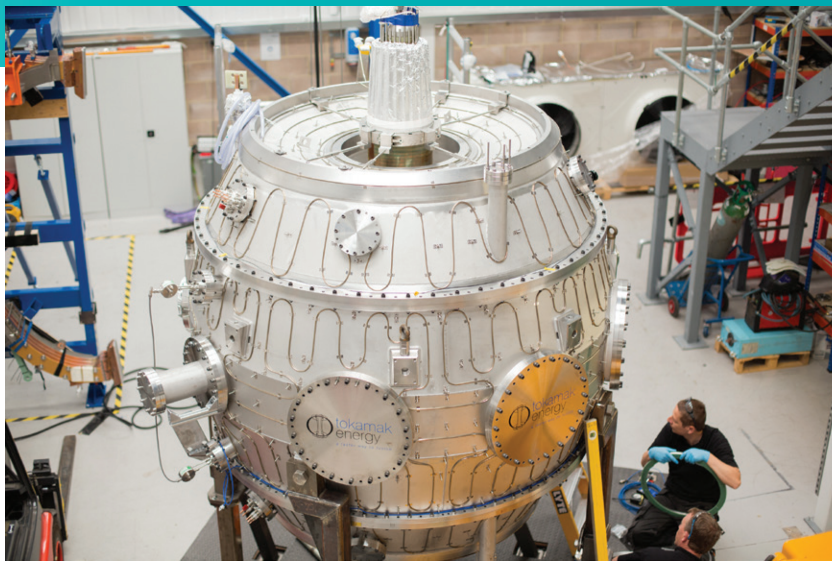

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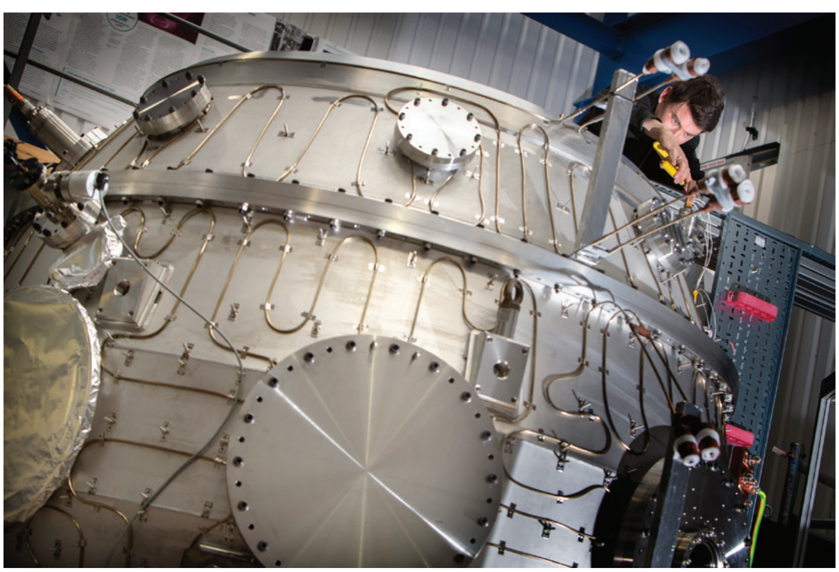


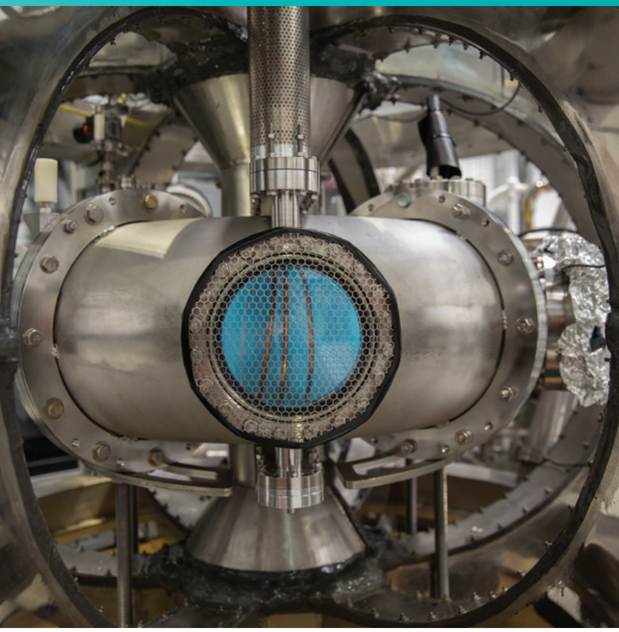
we must have contact pressure when the tokamak is in operation, so we have positioned sensors on joints. These sensors are very challenging to design because the current across each joint can be up to 250 kiloamps. We also had to design machine tools to improve the joint contact area using a lapping process.”

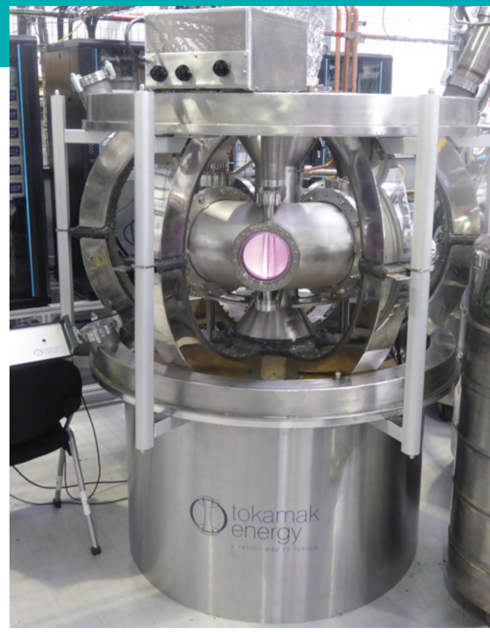
David Zakhar, engineering designer at Tokamak Energy, makes use of the finite element analysis capability within Solid Edge to simulate stress on components and assess forces and constraints. It is crucial to know about possible displacements and movements, especially since the ST40 incorporates electromagnetic frequencies. “The vacuum vessel has its own frequency and the frame has a frequency and we do not want them to be the same so I look at all the natural frequencies. Understanding vibration is critical,” Zakhar says.

Handling complexity with ease

Of the 24 center column wedges, 23 are identical and, according to Tigwell, the ability to repeat the design within Solid Edge has accelerated the overall development process. “It is really beneficial to have features such as section view and dynamic motion,” he says. “We can identify potential issues and machining tolerances. We need to achieve tight tolerances, for example accuracy to five microns on the joint sensors and no more than 0.01 degrees of difference between the parallels of the beam.”

There are more than 300 assemblies and 48,000 parts in ST40, including nearly 2,000 unique parts. One aim was to create flexibility so that the whole device could be built in stages and dismantled easily. Tigwell, who works on larger components and assemblies, is responsible for checking the main assembly and working out the build sequence. “Solid Edge includes helpful assembly management tools,” Tigwell says. “It is very useful to be able to switch off certain parts by type or size to focus on specific details, view the outer





"It is great to be able to work both on a flat surface or the final profile."

Damian Lockley
Mechanical Design Consultant
Tokamak Energy

"Solid Edge enables us to work out exactly how to manufacture and assemble the sphere before we actually do it."

Paul Tigwell
Mechanical Design Consultant
Tokamak Energy

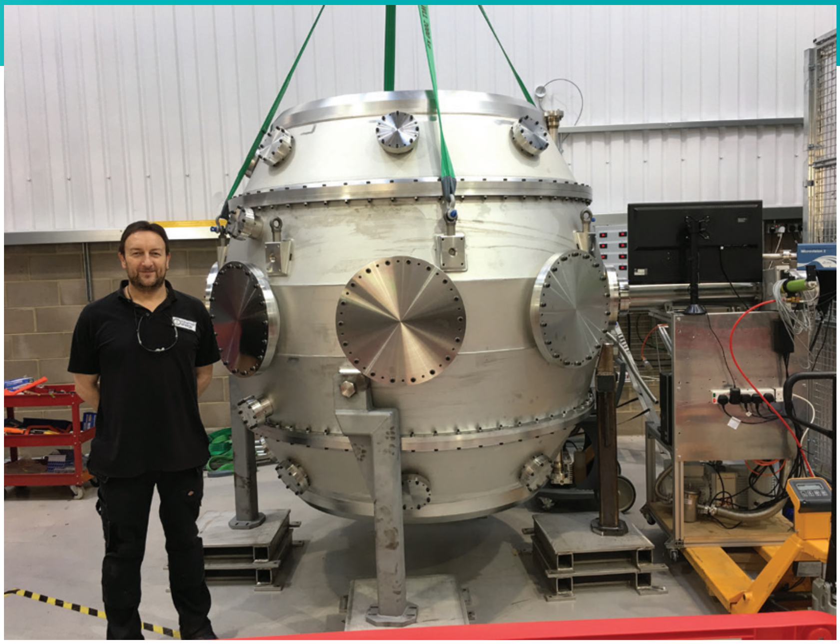
shape or confirm a space envelope. I can make a change then update and view the model quickly and easily."

Damian Lockley, mechanical design consultant, specializes in small-scale parts and assemblies. One of these is a two-meter-long tube with an array of tiny holes. "As the roll is made of seven sections, I drew all the markings for the water cutting jet to a tolerance to 0.1 of a millimeter in one section, then used the pattern feature to copy all the slots over to the other identical sections. I designed the tube first as a flat sheet so that it could easily go through the water cutting process at one supplier, ensuring that it could be rolled up and welded together by another supplier. It is great to be able to work both on a flat surface or the final profile as this makes sure that parts fit together perfectly first time."

Collaboration and speedy decision making

"We started out with no existing hardware and created everything in a virtual world," Lockley says. "With Solid Edge we can communicate on various levels, sharing geometry to design new parts. Our visualization capabilities support clear communication, particularly with colleagues and partners outside of the design office. As a result, a decision that might previously have taken a few days can now be made within a few minutes." Huang adds, "Solid Edge is brilliant, especially when multiple people are working on different aspects of development. It really supports collaboration."

For Tokamak Energy, Solid Edge is not just a design tool. "By highlighting potential issues and identifying essential equipment, Solid Edge enables us to work out exactly



how to manufacture and assemble the device before we actually do it," explains Tigwell. "We realized, for example, that certain removable parts of ST40 are out of reach of our crane and that the only way to build the device was to work from the bottom to the top."

Members of the design team send drawings and STEP files to suppliers and print hard copies straight from Solid Edge so that workshop colleagues can see the manufacturing and assembly steps. Plans for the workshop include access to 3D PDF files from Solid Edge so that technical operators can rotate models and zoom in to see specific details.

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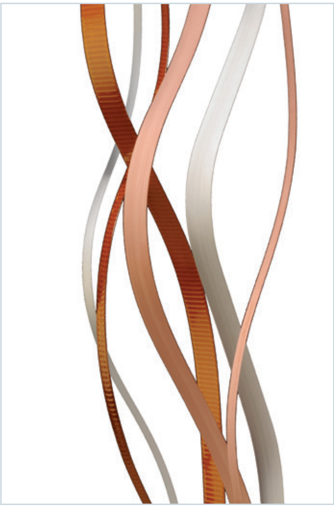
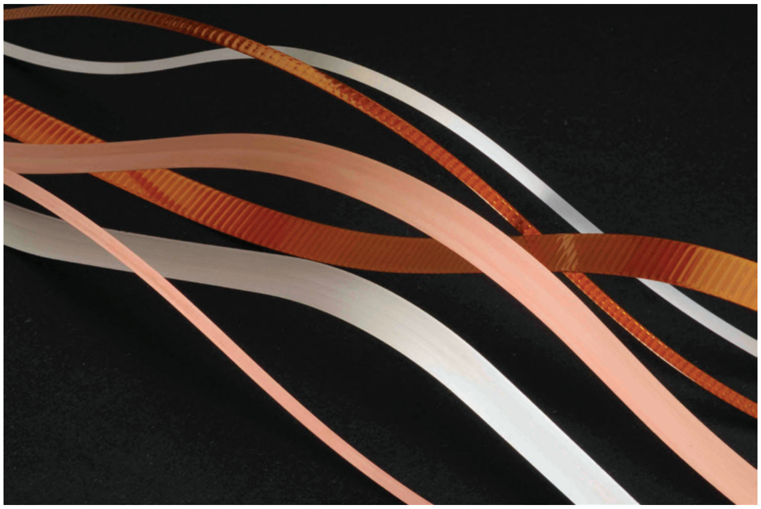




Solutions/Services

Solid Edge
solidedge.siemens.com

Teamcenter
siemens.com/teamcenter

Customer's primary business

Tokamak Energy aims to accelerate the development of fusion power based on compact spherical tokamaks with high-temperature superconducting magnets.

Customer location

Milton Park, Oxfordshire
United Kingdom

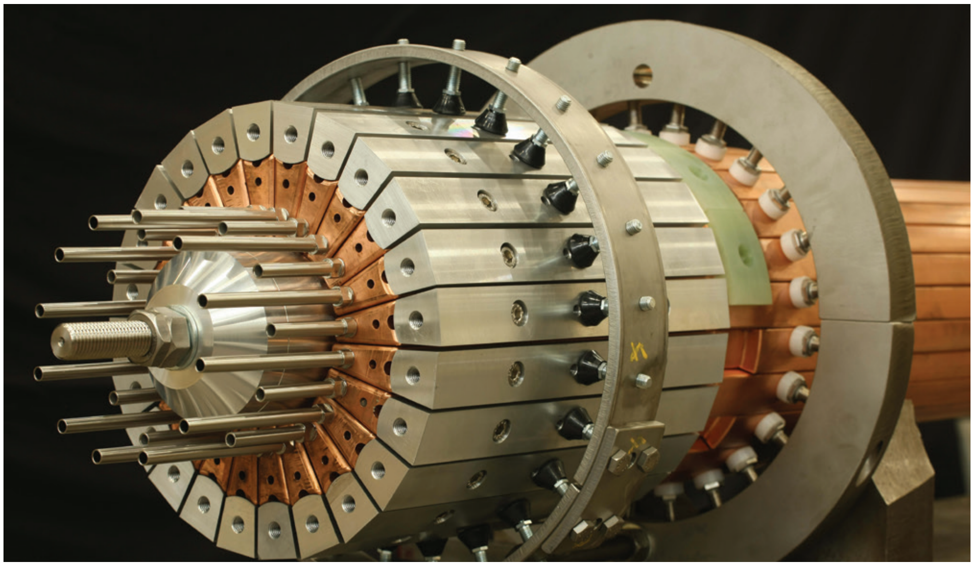
Solution Provider Partner

OnePLM
www.oneplm.com

Enterprising agility

"We believe that now is a great time to be involved in fusion as an innovative and fast-moving business," Kingham comments. "As we are investor-driven, the big question is always how quickly we can build and improve our prototypes. With Solid Edge, we can do very quick updates between different configurations and that gives us huge agility."

"We are tackling one of the very biggest challenges that mankind faces – the rapid provision of plentiful, cost-effective, clean, carbon-free energy," Kingman concludes. "To do this we have to be using the best-in-class materials and technologies, including the best design tools for the job – and that is where Solid Edge comes in."



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